THE COMPOSITION AND ORIGIN OF WISCONSINAN TILL IN MAINLAND NOVA SCOTIA

by

ERIK NIELSEN

Submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at Dalhousie University, Halifax, Nova Scotia, June, 1976.

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

The last page of the thesis is a map showing Nova Scotian place names mentioned in the text.

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

Field mapping, till fabric analysis at 21 sites, grain size analysis, pebble counting, and heavy mineral analysis of 324 samples were used to determine the source, direction of transport, and method of erosion, transport and deposition of Nova Scotian till.

Only one major till sheet, in places showing distinct basal, englacial, and ablation phases can be distinguished in the field. It is of "classical" Wisconsinan age. Five mineral suites have been distinguished by R-mode factor analysis. The mineral suites are: 1) a detrital suite derived from post-Devonian sediments, 2) an augite suite from the North Mountain basalt, 3) an amphibole-epidote suite from the Cobequid Mountains, 4) a metamorphic suite from the southwestern and northeastern parts of the Meguma Group, and 5) an apatite-andalusite suite from the Devonian batholiths.

The mineral, pebble, and grain size distribution in the till sheet indicates generally south southeastward ice flow across mainland Nova Scotia. Generally the composition of the tills reflect that of the immediately underlying bedrock except for the red clay drumlin till deposited along the Atlantic coast which has a higher content of amphibole, augite, and mud than the surrounding till sheet. The source of the red drumlin till is the Carboniferous lowlands and the Cobequid Mountains. The red clay till was transported englacially and subsequently deposited along the Atlantic shore

as melt-out till after crossing a "skip zone", an area of little or no red mud till between its source in the northwest and the drumlin fields of the east coast. The "skip zone" coincides with the drainage divide which runs down the length of Nova Scotia. Topographic high areas such as North Mountain, the Cobequid Mountains, the Antigonish Highlands, and the "skip zone", including South Mountain, were major areas of erosion.

Till fabric analysis indicates that basal ice flow conformed to the underlying bedrock topography whereas the orientation of indicator fans suggests that the regional ice flow was almost unidirectional from a source in the north northwest. Radiating dispersal fans from South Mountain and the Cobequid Mountains attest to the presence of late active Wisconsinan ice caps.

ACKNOWLEDGEMENTS

I am indebted to my supervisor, Dr. H. B. S. Cooke, for giving me the opportunity to do this study, for his encouragement and for long discussions of the many problems encountered throughout the work. I should also like to thank Drs. G. K. Muecke, D. J. W. Piper, M. J. Keen, D. R. Grant and V. K. Prest for helpful discussions and suggestions, and for critical comments on the manuscript.

Dr. C. A. Field and Dr. L. Weldon of the Dalhousie University Mathematics Department were most helpful with the factor analysis in the planning stages. Mr. R. Barkhouse from the Dalhousie Computer Centre assisted with the computing. Dr. D. B. Clarke and Mr. B. MacKay provided valuable help with the mineral identification. Dr. V. K. Prest and Dr. D. R. Grant of the Geological Survey of Canada supplied the ^{14}C date on the Nictaux Falls sample.

I am indebted to Dr. G. K. Muecke for allowing me to use unpublished work on the regional metamorphism of the Meguma Group.

The project was financed by a National Research Council Postgraduate Scholarship.

Special thanks are due to Heather Cross and Dianne Crouse for typing the manuscript.

CHAPTER 1

INTRODUCTION

The Glacial Sequence in Nova Scotia

Nova Scotia was undoubtedly covered by ice sheets before the Wisconsinan stage as evidenced by the Bridgewater conglomerate, an older drift represented by isolated outcrops in the province. The evidence for glacial origin of the Bridgewater conglomerate is that it rests unconformably on underlying striated bedrock surfaces and that it contains numerous striated pebbles from foreign sources lying to the north and northwest. The highly weathered state of the conglomerate also testifies to its pre-Wisconsinan age although no definite age can be assigned to it. The conglomerate is characterized by brown limonite cement which renders it unique among the glacial deposits in Nova Scotia. Nevertheless, other pre-Wisconsinan tills have been described in Nova Scotia, especially in Cape Breton (Mott and Prest, 1967) and southwestern Nova Scotia (Clarke _et al._ 1972). In both these areas, as well as in other scattered localities, buried organic deposits have been found; however, their ages are unknown since they are beyond the range of the ^{14}C dating method. Later ice invasions have largely eradicated the drift of these earlier episodes, leaving mainly till of Late Wisconsinan age.

The main glacial till sheet varies greatly from one area to another. The variations usually result from the composition of the bedrock over which the glacier moved, the mode of deposition, the distance of transport and the amount of weathering since deposition.

Till is the most widespread of all the surficial materials and covers most of the province (MacNeill, 1960). On the uplands the till is generally thin and bedrock is widely exposed. Thick till deposits are more common over the lowlands and in the valleys. The only topographic features of consequence formed by the till are the drumlins, of which there are several thousand in the province (Wilson, 1938). Only three end moraines are known to exist on the mainland, in the Joggins[1], Parrsboro Gap and Comeauville areas. This, of course, makes the identification of ice margins most difficult. It also complicates the problems of recognizing multiple till sheets since the detritus carried and deposited by an ice invasion may have few characteristics that were not shared by the preceeding invasion. A moraine system occurs offshore, roughly parallel to the coastline and some 30-40 km from it (King, 1969).

Nova Scotia tills including that of the red drumlins are best designated as ground moraine deposited by basal accumulation from moving ice or dropped from melting ice during recession.

Purpose and Scope of the Study

In the last few years there has been an increasing demand for information concerning the surficial deposits of Nova Scotia. Although the general pattern of ice movement is known, more specific detail is required

---

(1) The location of places mentioned in the text is shown on a map in the back of the thesis.

and the present study seems to be a logical step in the collection of information about the last glaciation of the province.

Specifically, this study had several objectives:

(a) Systematic Pleistocene survey

The only previous regional studies of the surficial deposits were carried out by Grant (1963) and Nolan (1963). Grant worked on the indicator pebbles of samples collected along the south and eastern shores of the province and Nolan examined the heavy minerals of the Nova Scotian beach sands. The present study is intended to investigate any possible relationship between Nolan's heavy mineral provinces and Grant's pebble provinces and to extend their work to cover the entire mainland area of the province.

(b) Mineral Provenance

The use of mineral provenance to delineate ice flow has not been attempted in Nova Scotia till deposits. It is hoped that this study will demonstrate the potentialities of the method. It is also hoped that useful indicator minerals may be identified and through construction of a mineral facies map of the till sheet make future work easier.

(c) Ice Current Theory

Grant (1963) proposed hypothetical ice currents across the province. Mineralogical, sedimentological and geomorphological investigations of the present study were initiated to substantiate, modify or refute Grant's inferences.

(d) Till Fabric Analysis

Mapping of ice movement direction by the use of till fabric analysis has been avoided in this province. Hopefully the usefulness of this tool in Nova Scotia will be demonstrated although much more needs to be done. This method was tested in the area around Minas Basin, where directional indicators are scarce, in order to delineate ice movement direction there.

(e) Bedrock Control of Till

Elson (1961) states that the granulometric composition of till is governed by (1) bedrock lithology, (2) method of transport, and (3) method of deposition. The importance of each of these criteria as it pertains to Nova Scotian tills will be considered.

(f) Delineate Mappable Till Units

In addition to the construction of a mineral facies map of the till sheet one objective of this study is to construct a facies map showing grain size distribution.

(g) Heavy Minerals as a Tool for Correlation

Dreimanis and Reavely (1953) tried to differentiate multiple sections of tills in Ontario using heavy minerals but were only marginally successful. This same method was tried in Nova Scotia with the hope that it might be more successful here.

Location and Sampling Programme

The area of investigation comprises the whole of mainland Nova Scotia, excluding Cape Breton Island and the northeastern part of the mainland near the Strait of Canso. The latter two areas were excluded from the study because the Geological Survey of Canada is working on the glaciation of those regions. It also excludes large parts of the Cobequid Mountains and the interior of the eastern Atlantic upland where there was no access by road.

Samples were collected along 3,000 km of roads and along sea cliffs during the summers of 1971, 1972, and 1973. Road cuts and sea cliffs were sampled almost exclusively because they provided good fresh exposures in depth and good control on stratigraphy. Ready access also speeded the collection of the samples and thus made wider coverage possible in the time available. Generally samples were collected every 5 to 10 km but additional samples were collected in regions where the till was highly variable (Figure 1).

Each sample was collected from a depth of at least 1 to 1.5 m to ensure that it was below the zone of frost action and weathering. Before taking the sample, the surface was cleaned thoroughly to remove any altered or weathered material. Approximately 8 to 12 kg of till was collected at each location either by channelling or by scraping it off the large, clean, freshly exposed surface. Large samples were collected for two reasons: 1) at least 2 kg of pebbles in the 5 to 22 mm range is needed for pebble counting, and 2) to minimize the effects of possible inhomogeneities in the till matrix.

A total of 324 till samples were collected and 21 till fabric analyses were carried out. Preliminary investigation of the prepared samples during the winter indicated that samples were also needed from southern New Brunswick. Nine samples were collected there.

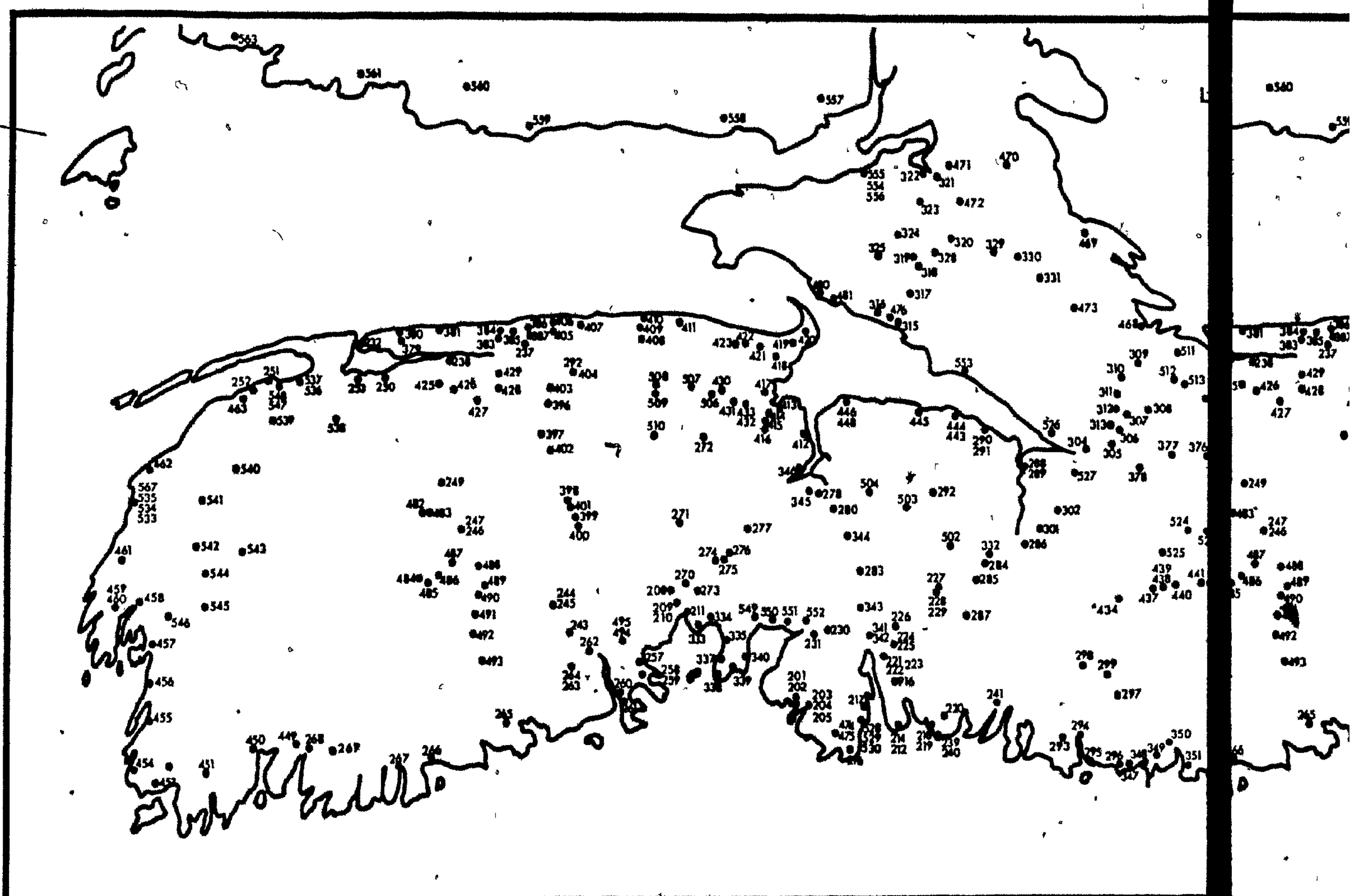
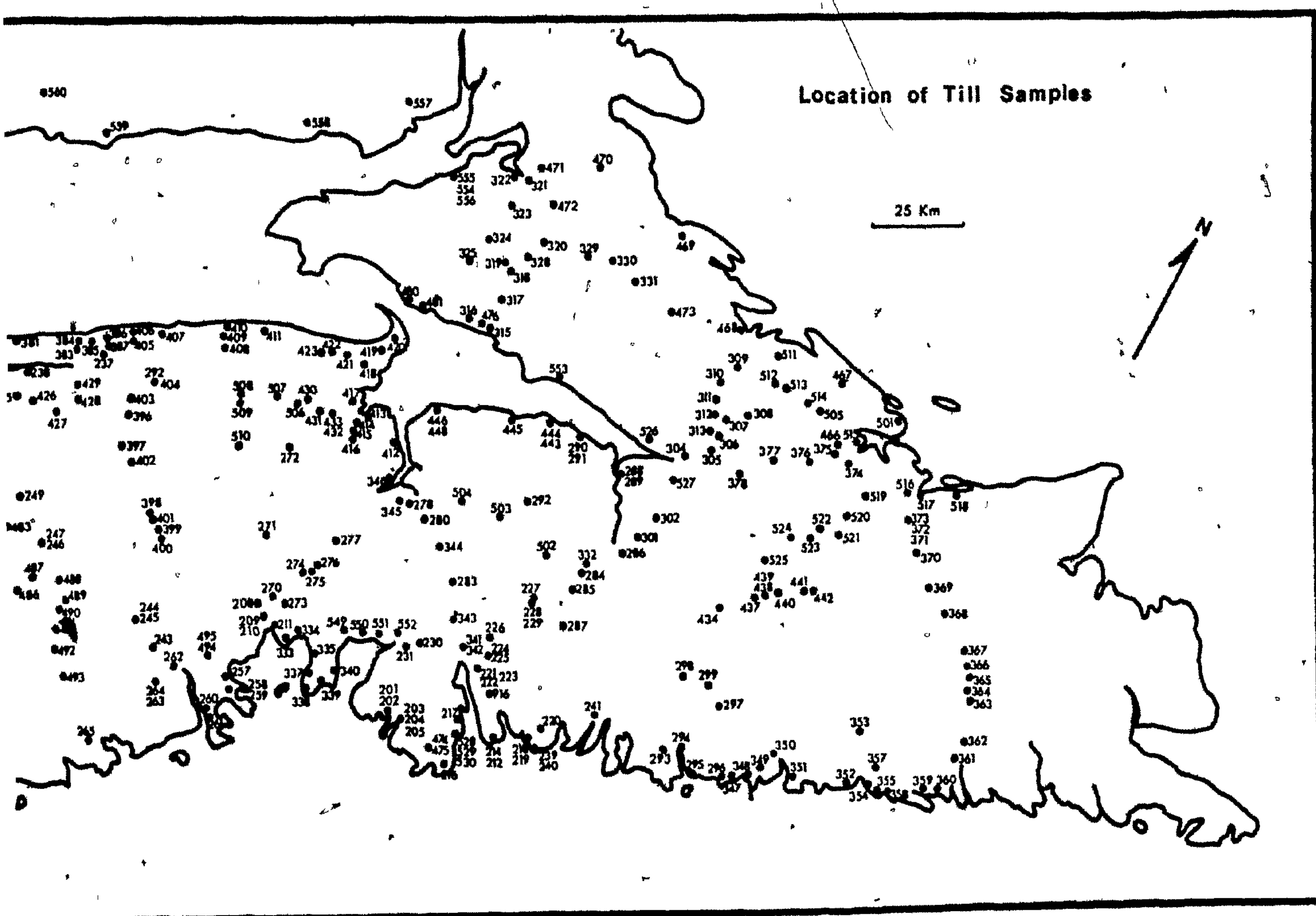


Figure 1. Location of till samples.

e 1. Lo

1 OF



e 1. Location of till samples.

2 of 2

CHAPTER 2

PHYSIOGRAPHY AND GEOLOGY

Physiography

The upland surface of Nova Scotia is part of the remnant of a broad Cretaceous peneplain (Goldthwait, 1924). The peneplain in Nova Scotia is highest in the northwest and slopes gently towards the south-southeast. In Cape Breton (outside the study area) the peneplain reaches a maximum elevation of over 500 m. In mainland Nova Scotia the upland surface rises from the Atlantic coast to an elevation of 200 to 230 m in the Cobequid Mountains. Three major physiographic regions can be distinguished (Figure 2).

1. The lowlands are gently undulating plains ranging in elevation from sea level to 130 m and occasionally to 200 m where they merge with the uplands.

The lowlands along the Northumberland Strait and the area around Minas Basin are composed of soft sandstone, shale, siltstone, limestone, conglomerate and gypsum.

2. The highland region of mainland Nova Scotia can be divided into three main areas:

a. The Cobequid Mountains extend east-west across the northern part of the mainland. They are approximately 150 km long and 16 km wide. This resistant ridge is made up of granite, diorite, syenite, assorted varieties of acid volcanic rocks, minor amounts of basalt and andesite and some sedimentary

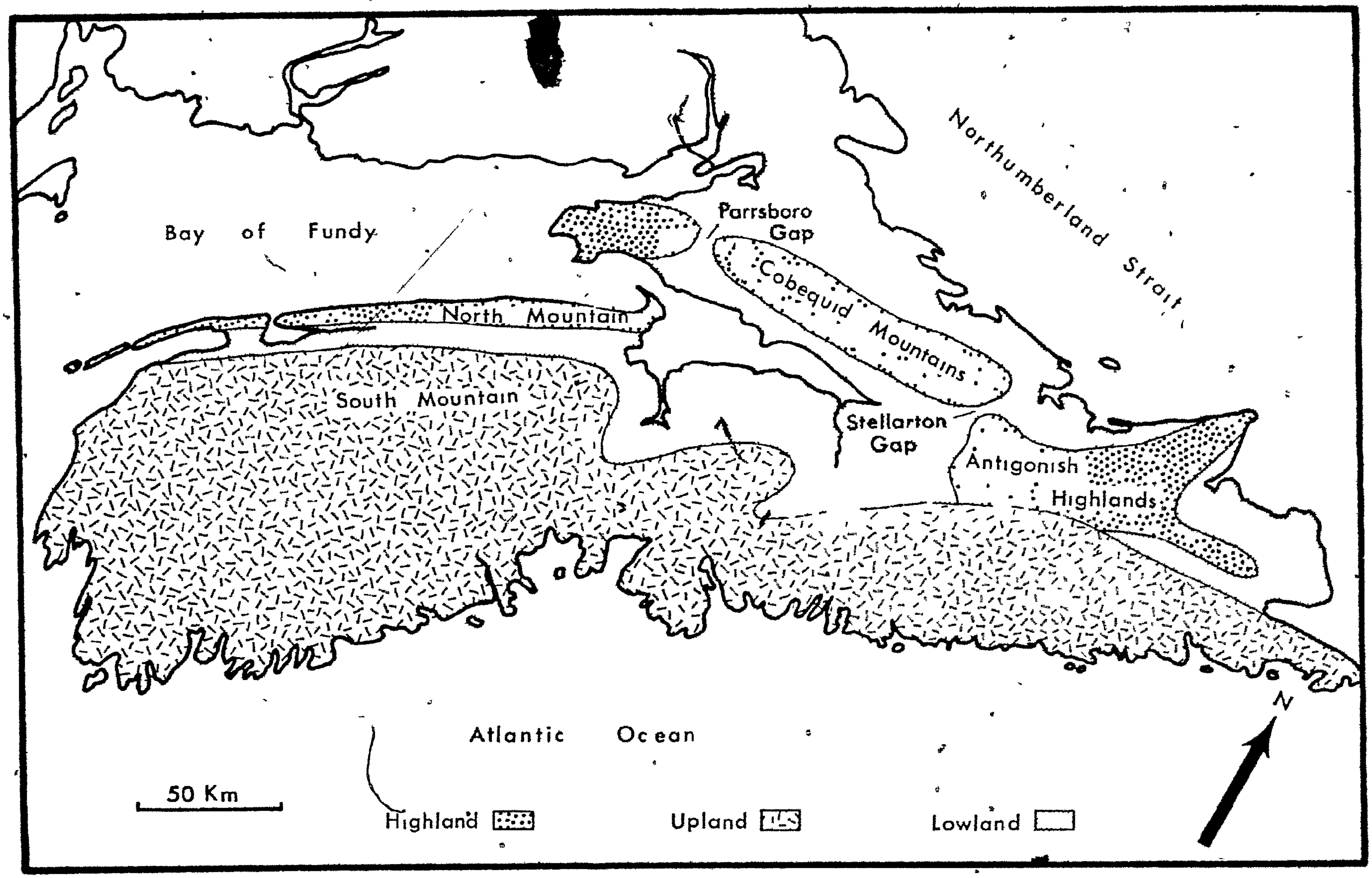


Figure 2. Generalized physiographic divisions of Nova Scotia.

rocks. The only significant break in the ridge are the Parrsboro and the Wentworth Gaps.

b. The antigonish Highlands extend south and east of the Cobequid Mountains for about 100 km and range in width from 17 to 40 km, overlapping the Cobequids for about 16 km. This highland area is composed of sandstones, shales, conglomerates, minor amounts of basalt, diorite, gabbro and granite. Between the Cobequids and the Antigonish Highlands is the Stellarton Gap.

c. The North Mountain extends for about 200 km in an east-west direction along the south shore of the Bay of Fundy. This ridge consists of basalt and varies from 2 to 6 km in width.

3. The upland region occupies a broad belt along the Atlantic shore and is about 150 km wide in the southwest and 45 km wide in the northeast. The area is underlain by Devonian granite and by slate and metaquartzite of the Meguma Group.

Drainage Divides

The divides which separate the rivers draining into the Atlantic Ocean, Northumberland Strait and the Bay of Fundy are shown in Figure 3. As the peneplain surface generally slopes to the south, undulations of the drainage divide to the north indicate that the land is higher in that direction. Similarly, undulations of the drainage divide to the south indicate a general lowering of the divide in that direction. For example, the drainage divide north of St. Margaret's and Mahone Bays is low compared to the drainage divide at the headwaters of the LaHave River.

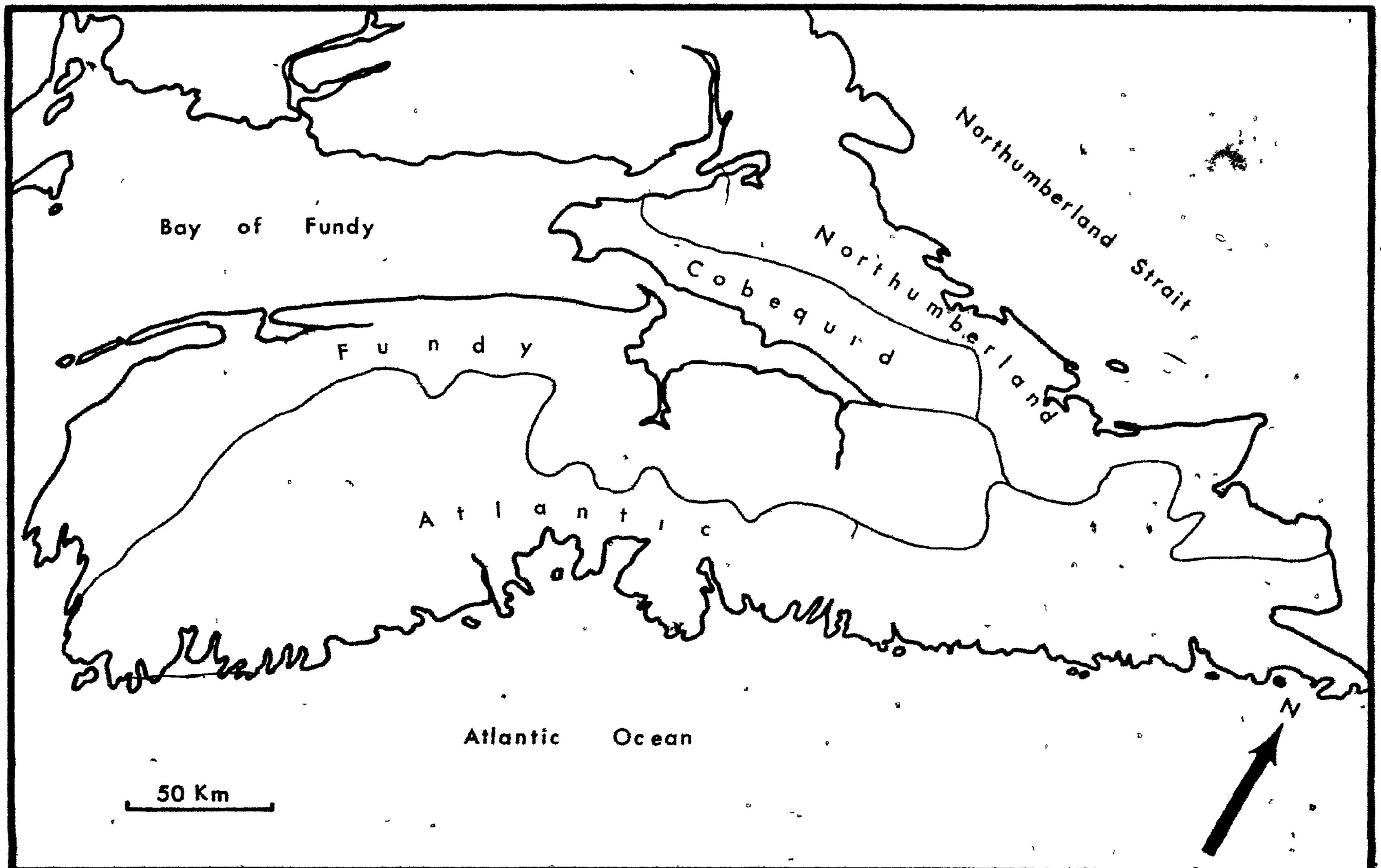


Figure 3. Major drainage divides in Nova Scotia.

The drainage divides shown in Figure 3 separate mainland Nova Scotia into four regions based on the attitude of the regional slope. The Atlantic Coast and Cobequid regions slope to the south, the Northumberland and Fundy regions to the north. The streams of the Cobequid and Fundy regions discharge into the Minas Basin and the Bay of Fundy.

Previous Work

Early Studies

Honeyman (1878, 1882, 1886, 1890) was the earliest geologist to recognize and delineate the boulder train of basaltic pebbles from North Mountain. His map of the boulder train showed that the eastern limit was a line running from Cape Split to Chezzetcook. Other basaltic pebbles to the east of Chezzetcook were interpreted as originating at Five Islands and Bass River. Honeyman also recognized that distantly travelled pebbles were associated with red tills or "red heads". He misinterpreted these "red heads", which are known today to be drumlins, as a terminal moraine.

Dawson (1893) was the first to express the opinion that, since granites of southern provenance are found on top of North Mountain, northward moving ice must at some time have flowed off the Southern Upland.

Goldthwait (1924) summarized all the known data about the physiography and history of ice movement and drew maps showing the dispersion of erratics, and the distribution of drumlins. He disagreed with Dawson's interpretation of the granite erratics on North Mountain and instead believed that there must be a granite source similar to that on the Southern Upland somewhere in the Cobequid Mountains or Bay of Fundy and at the southwestern end of the Annapolis Valley and maybe near Kentville.

In 1941 Wickenden reported the occurrence of end moraines in Cumberland County. He interpreted the Joggins-Amherst moraine as a lateral moraine of one or two ice lobes, one which he believed to have moved down from the north and the other from the northeast (he probably means northwest). From the kames and moraines he mapped on the Cobequid Mountains he concluded that the ice probably abutted on the north side of the Mountains for a considerable period of time. The three till types at Joggins were thought by him to indicate three ages of glaciation or advances of the ice from different directions in view of their different lithologies.

MacNeill and Purdy (1951) returned to the concept of South Mountain active ice flowing northward.

Hughes (1957) suggested that the Shubenacadie area had been glaciated by a single ice movement from the northwest to the southeast, and that the two tills at Eagles Nest Point recorded a fluctuation in the ice margin when it stood in the Hants-Colchester Lowland.

Hickox (1962) established, by means of detailed pebble counting, the decrease in the concentration of granite pebbles from the Southern Upland across the Annapolis Valley. The controversy of the South Mountain ice cap and the northward flow of ice into the Bay of Fundy was considered to have been resolved and is now regarded by many people as an established fact.

Studies by Grant (1963)

Grant (1963), in the only substantial investigation of Nova Scotian tills hitherto undertaken, analysed the pebble fraction of 176 till samples. As this work is essentially unpublished, it is necessary to summarize it at some length.

Grant's samples were collected within approximately 40 km of the Atlantic coast between Yarmouth and Ecum Secum. The underlying bedrocks in these areas are granite, slate and metaquartzite. Grant was able to divide the till in this into four main groups: 1) granite tills (more than 60% granite pebbles), 2) metaquartzite tills (more than 60% metaquartzite pebbles), 3) slate tills (more than 60% slate pebbles), and 4) hybrid tills where the local components do not exceed 60%.

The granite till is centered over the granite batholith, and little dispersion occurs outside the source areas.

Grant recognized four types of metaquartzite tills: metaquartzite tills rich in metaquartzite, metaquartzite till rich in granite pebbles (found close to the granite batholiths), and two types of metaquartzite tills with an abnormally high concentration of foreign pebbles, found in and around the drumlin fields. Much of the metaquartzite till was moved southward over the slate. The slate till was also found to be richer in foreign pebbles in the drumlin areas.

Grant divided the hybrid tills into four groups depending on the admixture of granite, slate, quartzite and foreign pebbles. Type A hybrid till is dominated by granite pebbles and was found in the Sambro-St. Margaret's Bay area. Types B and C hybrid tills are characterized by the presence of metaquartzite and slate and an abundance of foreign pebbles. These till types are found around LaHave River, Cow Bay to Chezzetcook, Owl's Head, Ecum Secum, Moose River, Musquodoboit and Windsor. Grant attributed the pebble composition of these tills to their proximity to or position within drumlin fields. Type D hybrid till, with approximately equal percentages of granite and metaquartzite pebbles, is found mainly in the Yarmouth, Shelburne and Musquodoboit Harbour areas. Grant believed the controlling factor to be dilution by overlap from the surrounding bedrock.

Grant concluded that 1) hybrid tills are the result of simple mixing by overlap, and 2) hybrid tills very rich in foreign pebbles are located in and around drumlin fields. He then separated the local and foreign components and plotted the distribution of foreign pebbles (Figure 4). He further separated the North Mountain, Cobequid and Minas Basin components and found that the North Mountain and Cobequid pebbles were restricted to the drumlin fields, and the Minas Basin pebbles to the areas between the drumlin fields.

These initial results led Grant to make a more thorough study of the nature of the pebble distribution in the red clay drumlins within the study area. The important features of the red clay drumlins as inferred by Grant (1963) are listed below:

Morphological Features

1. The drumlins occur in well-defined groups or fields.
2. The drumlin fields are oval; their long axes strike parallel to the direction of ice travel, and to the drumlins within them.
3. The spacing (concentration) of drumlins in the group is characteristic for this area (one drumlin/1.6-2.0 sq. miles).

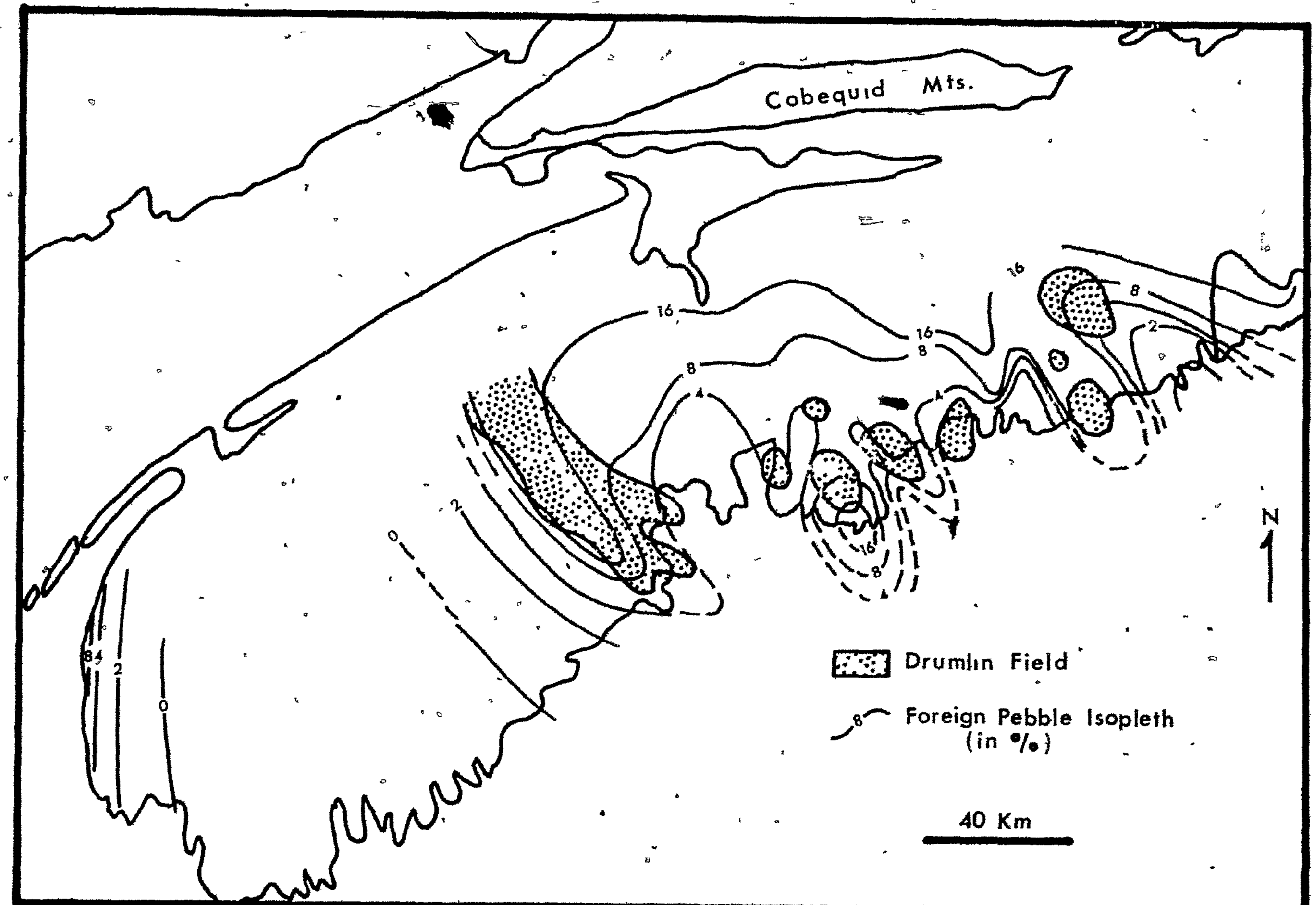


Figure 4. Drumlin fields and foreign pebble lobes according to Grant (1963).

4. The drumlins in any field have parallel trends.
5. The trends in nine of the fields is southeasterly (130°-150°). The two exceptions are southerly trends (172°).
6. Most of the drumlins in the area have similar dimensions:

   Length: 3000-4000 feet   Width: 1000-1300 feet

   Height: 75- 150 feet   Length/width ratio = 3:1

Stratigraphy

1. The drumlins are surrounded by the loose-textured, light coloured till sheet and rest on a firm, dark, underlying till, the lithology of which strongly reflects the underlying bedrock.
2. The contact of drumlin and underlying compact till is very sharp, and is marked by large metaquartzite boulders.
3. In drumlin areas, the underlying till is unusually compact and stands vertically on erosional slopes, compared to the distinctly lesser slope maintained by the overlying drumlin till and the associated loose-textured till sheet.
4. There are signs, in a few localities, of a third member underlying the compact till.
5. Similarly, in a few localities the drumlins are mantled with a member of local till.

Pebble Lithology

1. Each drumlin field has a distinctive pebble association.
2. All fields, except that at Chezzetcook, have 10%-20% Cobequid pebbles.

3. The lithologic differences between fields are created by variations in the ratio of 'Minas' to 'local' pebbles.
4. The average quantity of 'Minas' pebbles in the till of a drumlin field varies inversely, and linearly, with the distance of the field away from the Minas Basin area. The decrease in transport is due to the differential destruction of these softer species.
5. The Lunenburg and Chezzetcook fields are characterized by their much greater contents of North Mountain and Cobequid pebbles respectively.
6. As a drumlin field migrates from a northerly source area onto a southerly source area the drumlin till is progressively enriched in pebbles from the southerly source, according to a linear function.
7. Similarly, there is a progressive increase in local pebbles towards the fringes of the field.
8. In the Lunenburg field, the red clay/drumlins and a red stony till sheet are related to a red sandy drumlin phase with an intermediate composition.
9. The data strongly suggest that the red drumlin till is transitional to (or has been derived from) a similar red till derived from the intertidal and estuarine mud of the Minas Basin area.

Grant believed that the ice flow and pebble distribution in a drumlin field were the result of a velocity gradient similar to that found in present day valley glaciers. What exactly caused the ice currents to form is uncertain since the valleys which cross the province are very small. For this reason he called his "ice current" model "Hypothetical" (Figure 5).

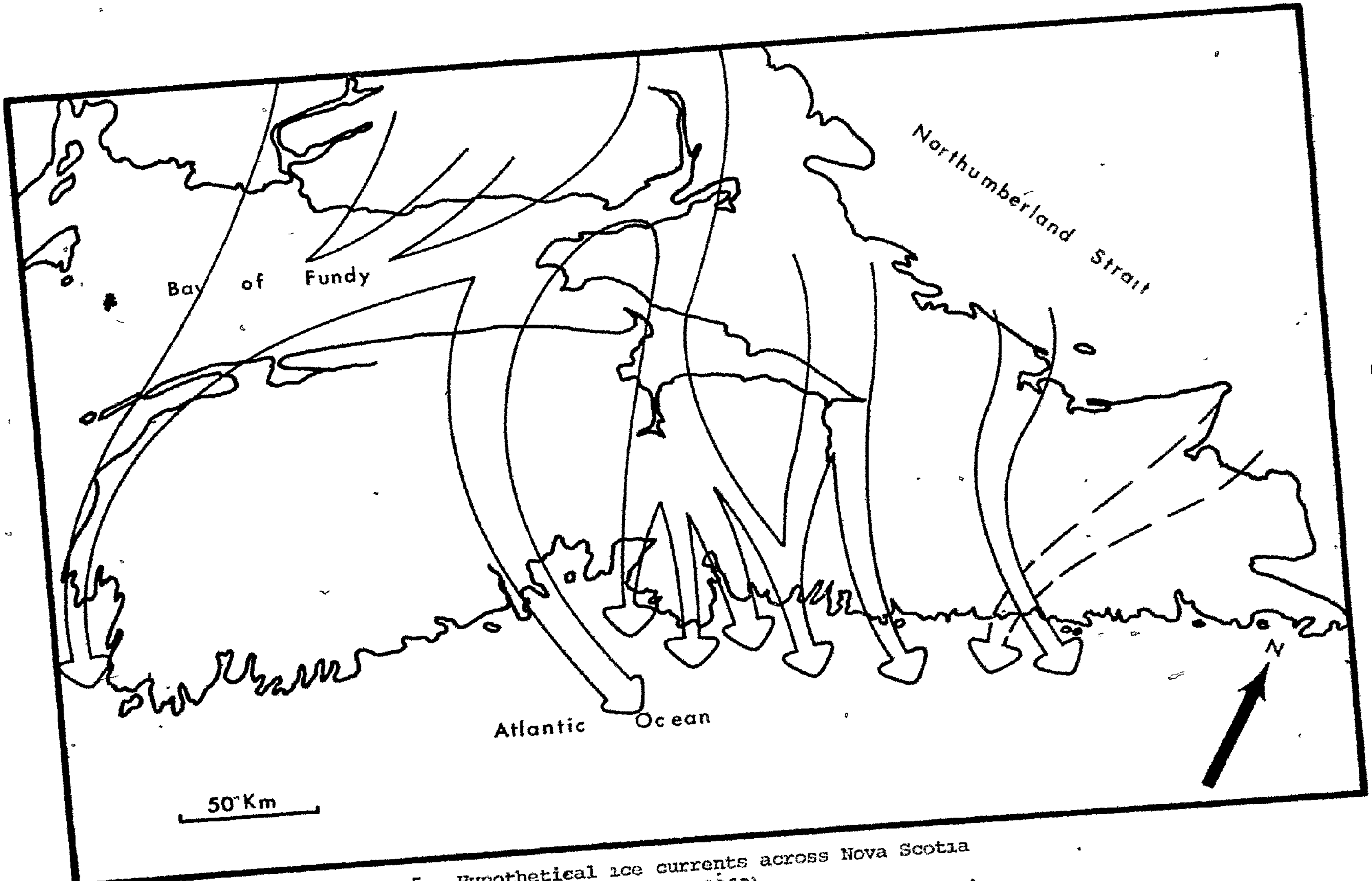
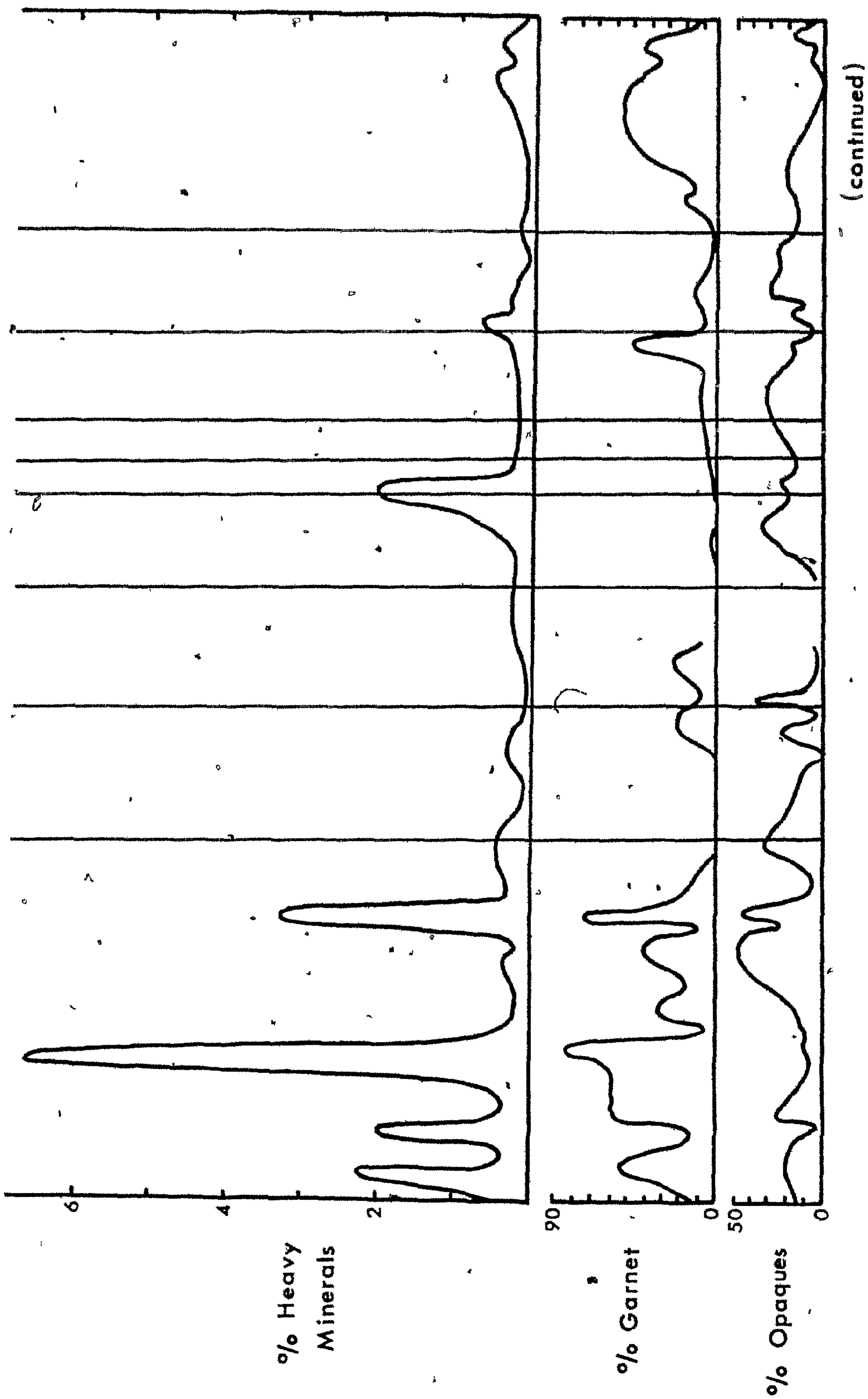


Figure 5. Hypothetical ice currents across Nova Scotia (redrawn from Grant, 1963).

Heavy mineral studies by Nolan (1963)

Nolan (1963) mapped the distribution of heavy minerals in 130 beach samples from Nova Scotia. This work is largely unpublished. He concluded that augite was the only indicator derived from a distantly travelled till. Nolan's raw data for 11 of his major minerals from the Strait of Canso to Yarmouth have been plotted in Figure 6. The concentration of augite between Sheet Harbour and Liscomb Point was believed by him to have been derived from till whose souce lay in the Pictou-Antigonish Highland region to the north and north-northwest. Between Owl's Head and Sheet Harbour augite is conspicuously absent; he concluded that the till adjacent to the coast was either of local derivation or from some distant source other than the Pictou-Antigonish Highlands. The Owl's Head area is the northern most coastal area containing augite derived from North Mountain basalt. Also a very high concentration of augite is found between St. Margaret's Bay and the mouth of the LaHave River, and another high between Shelburne and Liverpool.

Nolan attributed the distribution of all the other minerals to local bedrock sources. Two pronounced hornblende anomalies are present east of Halifax: the first anomaly is centered on the Cow Bay, Chezzetcook and Owl's Head drumlin fields; the second is centered on the Liscomb and Ecum Secum drumlin fields. Subsequent to Nolan's work, soil mapping by the Nova Scotia Soil Survey in Guysborough, Halifax, Lunenburg, Queens, Shelburne, Yarmouth, Annapolis and Kings Counties at a 1 inch to 1 mile scale has delineated the distribution of drumlins in these counties. The data from these soils maps have been compiled in Figure 7 to show the distribution of drumlin fields in


(continued)
% Heavy Minerals
6
4
2
% Garnet
90
0
% Opaques
50
0

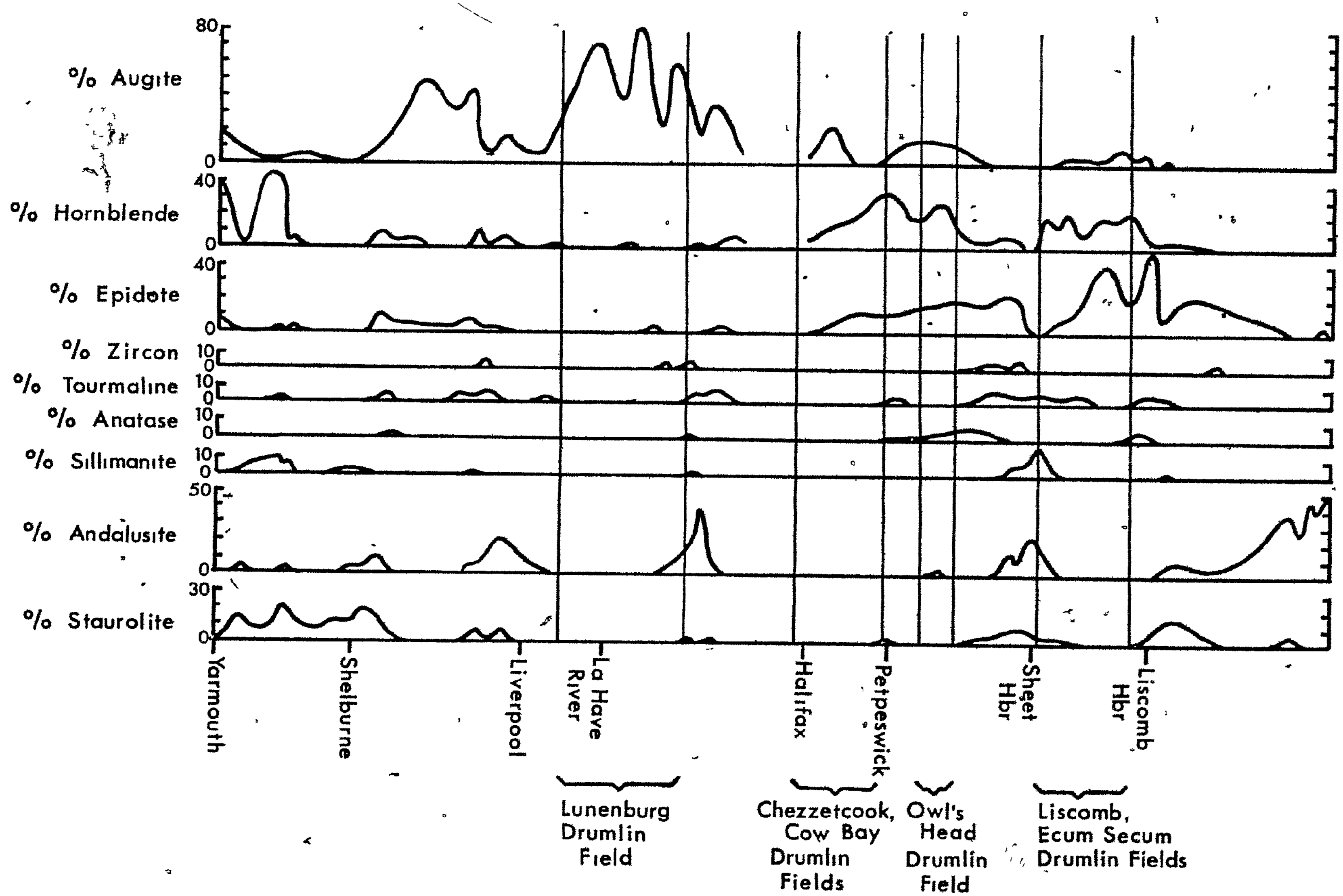


Figure 6. Distribution of selected heavy minerals in Nova Scotian beach sands between Strait of Canso and Yarmouth. Drawn from Nolan's (1963) data.

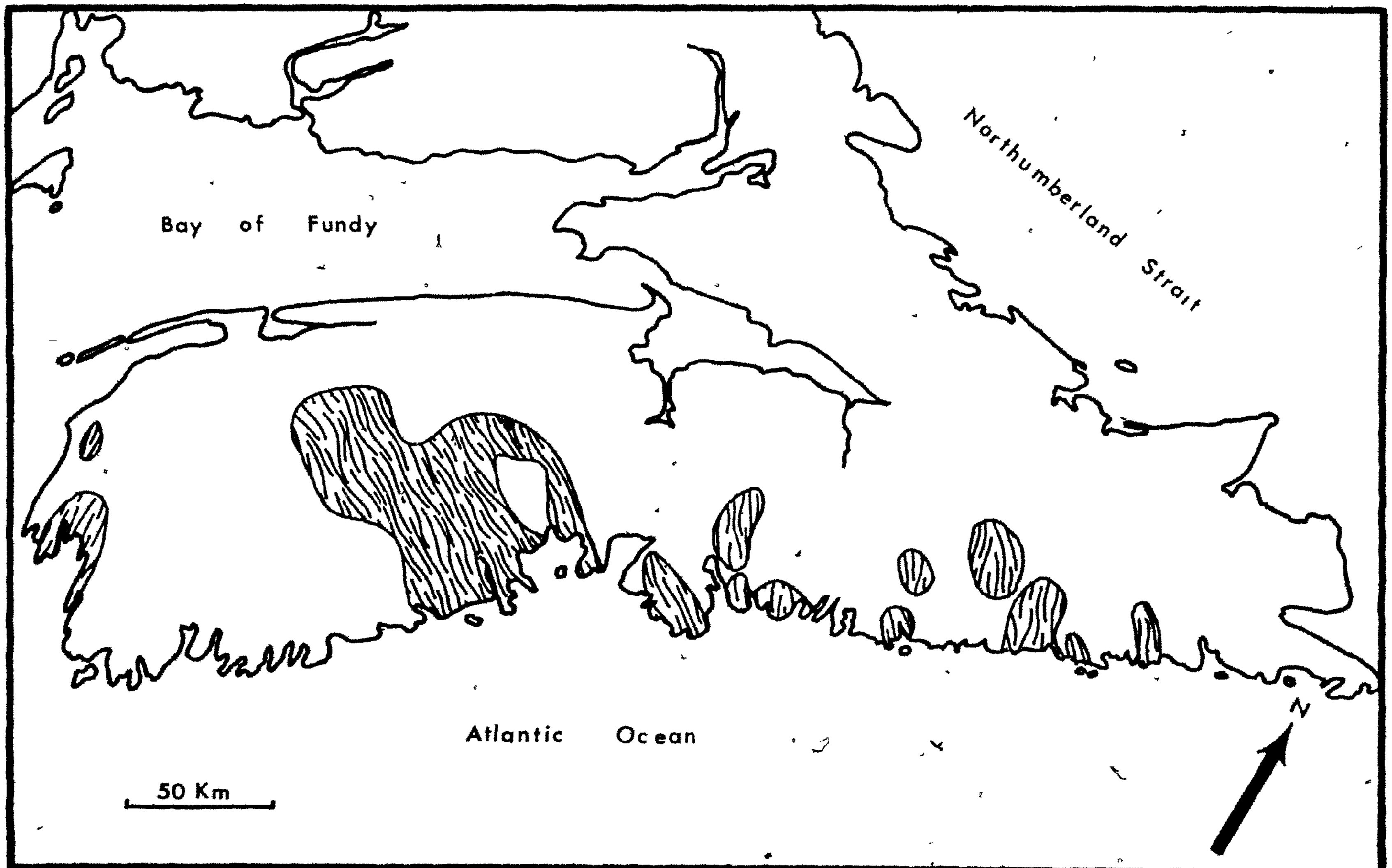


Figure 7. Nova Scotian drumlin fields. Compiled from the Nova Scotia Soil Survey reports.

Nova Scotia. The approximate positions of the drumlin fields have also been plotted on Figure 6. With the exception of the anomaly between Shelburne and Liverpool, the augite anomalies are roughly centered on the drumlin fields although there are some exceptions. For example, augite occurs outside the drumlin fields in St. Margaret's Bay, around Petpeswick, north of Owl's Head and in the Liscomb Harbour area. There are several possible reasons for the poor correlation between augite distribution in beach sand and in drumlins. The augite could have been redistributed by longshore currents or transported shoreward from sources on the Scotian Shelf by the Holocene transgression. Alternatively, the augite may not be restricted solely to the drumlin till or there could be more drumlins immediately offshore or onshore which have not been mapped.

Recent Studies

King (1969, 1972) reported a lobate submarine end-moraine complex 30 to 40 km off the southeastern shore of Nova Scotia. It has not yet been determined whether this is a terminal or recessional moraine. Glacial till has been found out to the edge of the shelf and represents the farthest advance of any continental ice sheet. The age of this advance is unknown.

Prest and Grant (1969), from analyses of striae and other glacial lineations, concluded that the development of local ice in some parts of the region was sufficiently early and extensive to have barred Laurentide ice from parts of Nova Scotia (Figure 8). They also concluded that the Laurentian Channel diverted Laurentide ice from Prince Edward Island, Cape

Breton Island, and also from the Magdalen Islands which remained unglaciated.

Grant (1971c) on the evidence of striae and other rock-inscribed features, drumlin shape and esker orientation proposed that; 1) the earliest ice flow across the province was in a easterly and southeasterly direction, 2) during the maximum Wisconsinan the ice moved southward, 3) during recession there was radial outflow from an ice cap centered around Kejimkujik Lake. He also proposed a center of northward flow located on the continental shelf south of Cape Breton. Gravenor (1974) proposes a similar ice center on the continental shelf south of Yarmouth. His conclusions are based on the shape of drumlins and on till fabrics.

Since 1958, the Nova Scotia Soil Survey has systematically remapped Lunenburg, Queens, Yarmouth, Shelburne, Digby, Halifax, Guysborough, Kings, Annapolis and Cumberland Counties at a scale of 1 inch to 1 mile. The soil types often reflect strongly the nature of the parent material. Grant (1963) used this observation to delineate the red clay drumlins in the southeast part of the province. The soil maps and reports contain the most complete and detailed account of Nova Scotian tills from a physical but not from a petrographic view point. Nevertheless they are the closest thing to a unified surficial geology map of the province yet available.

Four reports with accompanying surficial deposit maps have been produced by the Groundwater Section of the Nova Scotia Department of Mines since 1968, covering the Annapolis Valley, Truro and Musquodoboit Valley areas (Trescott, 1968; Hennigar, 1972, Pinder, 1968 and Lin, 1970).

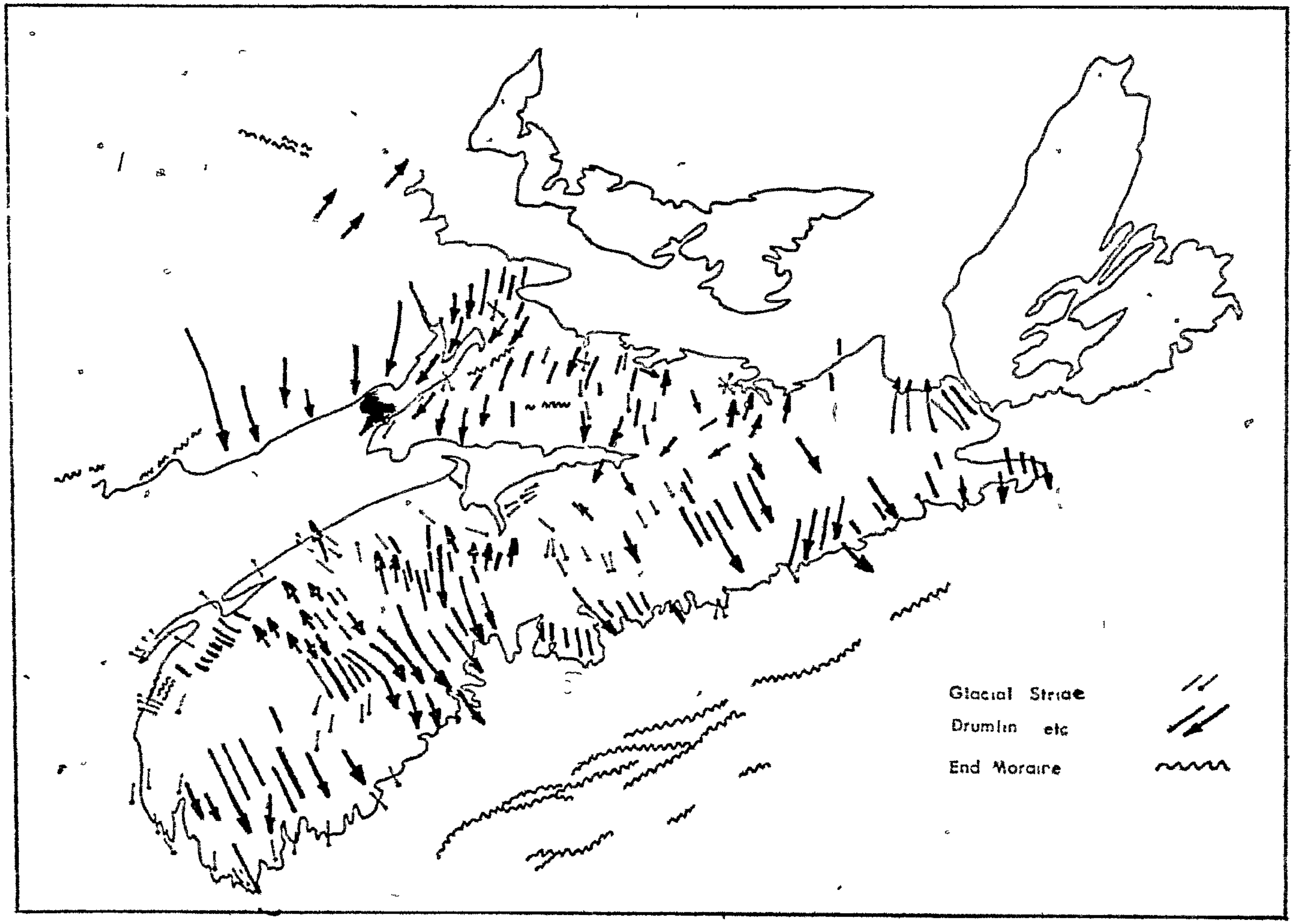


Figure 8. Glacial features indicative of ice flow (redrawn from Prest and Grant, 1969).

CHAPTER 3

PLEISTOCENE CONCEPTS

Till

The classification of tills by Flint (1957) into ablation and lodgement tills has since been modified by several authors. Dreimanis (1969) proposed a classification system based on the mode of deposition which Mörner (1973) suggested be also adopted in Europe. Other classifications proposed are the morphological systems of Nichol and Bjorklund (1973) and the mode of deposition system of Boulton (1971, 1972) (Table 1). The schemes of Dreimanis and Boulton do not differ markedly, but Boulton's classification is preferred and is used in this study with the modification that supraglacial till is divided into ablation till and flow till.

Boulton (1972) defines till as "an aggregate whose components are brought together and deposited by the direct agency of glacier ice, which, though it may suffer post-depositional deformation by flow, does not undergo subsequent disaggregation and deposition". He has shown that, using the supraglacial-englacial criterion, there are 3 types of till : (1) flow till, which is released supraglacially and undergoes deformation as a result of flow; (2) melt-out till, which is released supraglacially or subglacially from stagnant ice; and (3) lodgement till, which is deposited beneath actively moving ice and has undergone shear deformation. Boulton (1972) relates the erosion, transportation and deposition of tills to the temperature regime of of the ice.

TABLE 1

Till classification after Boulton (1972)

Proposed classification		Old Scheme
Supraglacial tills	Flow till Melt-out till	Ablation till
Subglacial tills	Melt-out till Lodgement till	Lodgement till

Glacial Erosion

Erosion of bedrock surfaces under glacier ice has been observed by several authors in the last 100 years (Chamberlin, 1888; Price, 1973; Boulton, 1972).

Bedrock surfaces are eroded by particles already entrained in the ice and consequent polishing and scratching by these same particles. Boulton (1972) argues that in order for crushing and abrasion to take place, water must be present at the ice-bedrock contact. The thicker the ice the higher the basal water pressure needed to maintain erosion. If the substrate is highly permeable a water layer will not form and crushing and polishing will be reduced. In subglacial areas where water freezes to the base of the ice, the processes of crushing and polishing will not be as important as they are in areas of basal melting. Meltwater from adjoining areas of basal melting will flow into this region and freeze to the bottom of the ice, thus trapping debris.

In the case where the glacier sole is frozen to the substrate basal sliding will not occur. Movement does, however, occur in the ice some distance above the sole. This flow increases in the higher levels of the ice profile and approximates to the general shape of the underlying topography. The tops of topographic highs will come into contact with moving ice and may be eroded.

The other method of erosion under basally frozen ice is by incorporation of large erratic blocks. Planes of weakness in the substrate may be present if the permafrost is shallow or if there is high pore pressure. Large slabs of frozen sediment or large blocks of bedrock may be transported long distances by this method if the path is not obstructed. Large volumes of material could be eroded and incorporated by this mechanism.

In temperate glacier regimes the products of erosion are incorporated into the basal ice by the freezing of water derived from pressure melting on the up-glacier side of obstructions. The regelation layer formed in the lee of one obstruction is destroyed by pressure melting on the next obstruction. If, however, the glacier temperature regime changes downstream to one of freezing of water to the sole, or to one where the sole is frozen to the substrate, debris can be incorporated englacially. If the water freezes to the sole a debris layer will move higher up in the ice as it moves along and it will consequently not be destroyed on the next obstructions but will override them. If the debris band moves basally toward an area where the sole of the glacier is frozen to the substratum, i.e. a zone of compression

(Nye, 1952), it will be sheared up to higher levels in the glacier.

The acquisition of debris by regelation is a process whereby only a limited amount of material becomes incorporated englacially because the rate of pressure melting is controlled by the rate at which heat flows through the obstacle. Unless the obstacles are sufficiently small (several centimeters), sufficiently large heat flows are not possible (Boulton, 1972).

Where ice flows from an area of appreciable relief to an area of low relief, rock debris is removed from the stoss side and from the tops of the hills to be incorporated englacially by thrusting (Moran, 1971; Elson, 1961; Shilts, 1973). These obstructions are in the order of magnitude of the Caledonian Highlands in New Brunswick and the Cobequid Highlands in Nova Scotia, and are not to be confused with the smaller obstructions inducing basal melting and regelation, as mentioned earlier.

Glacial Deposition

Till may be deposited supraglacially either as ablation till, by melting out of stagnant masses of buried ice, or by deposition subglacially from active ice basal till. Ablation till derived from debris falling onto the glacier surface is insignificant in ice caps and ice sheets as most of the material is derived subglacially.

The type of deposit forming will depend on the position of the debris in the ice. If most of the debris is carried near the base of the ice, lodgement till will predominate. On the other hand, if the englacial component is high, ablation till and melt-out tills will be abundant. Only if there is very considerable basal melting can englacial debris, carried high in the ice, be deposited by lodgement.

Boulton (1972) argues that lodgement till forms in areas of basal melting when the friction drag on particles of debris being moved over the bed equals the tractional forces exerted on it by the ice. On a rough surface or where the substratum is permable, thus increasing the frictional drag, lodgement till will be thickest. Also there will be more meltwater, due to pressure melting, where the ice is thickest. Thin ice therefore favours the deposition of lodgement till as compared with thick ice. Deposition will initially be against obstructions, but will slowly fill depressions while protuberances will be eroded.

In areas where there is a balance between freezing and melting the rate of deposition of lodgement till will be greater if no meltwater comes into the region. In the portion of a glacier where the temperature is such that water freezes to the sole of the ice, or the ice is frozen to the bed, there is generally no deposition of lodgement till. The debris is largely englacial and the majority of till is supraglacial till. This till may slide down the snout of the glacier as flow till and then be overridden.

Debris carried in an englacial position such as at the periphery of ice caps and ice sheets and in polar type valley glaciers accumulates on the glacier surface as the ice melts away, forming a cover of supraglacial till. Fluvial activity produces stratified deposits and water-saturated till flows by gravity down slopes to form flow till.

Debris-laden stagnant ice melts out from beneath overburden either at the top surface or at the bottom surface. The resultant melt-out till retains much of it's englacial structure (Boulton 1971).

Characteristics of Till

Lodgement till

This is commonly recognized as having:

- a high proportion of silt and clay relative to ablation till in the same area
- a fissile structure where clayey
- rounded and striated clasts
- a high degree of compaction
- clasts generally oriented with the long axes parallel to the direction of ice movement
- boulders are not common but cobbles occur in great numbers
- a local origin
- foliation may be present
- narrow lens-shaped layers of stratified sand may be present (Flint, 1971, p. 172 and Gillberg, 1955, p. 520).

Ablation Till

Ablation till had been described as having the following characteristic as compared to lodgement till

- looser and coarser grained than basal till

- boulders and cobbles are common (Gillberg, 1955)
- clasts are commonly angular or subangular with no striations
- the proporition of sand and gravel is high while the amount of clay is low
- pebbles have an almost random orientation (Elson, 1961)
- because of its loose texture it oxidizes quickly and is usually brown or yellowish-brown in colour (Elson, 1961)

These characteristics are the result of down-wasting of the surface of the ice, which results in the accumulation there of the englacial debris. Elson (1961) and Boulton (1972) have divided the ablation till into two units, melt-out till and flow till.

Melt-out till

Melt-out tills are formed by the melting of ice masses from the top downwards, and tend to be produced above a melting ice surface and below a confining overburden. This type of melt-out till can alternatively be called ablation till. Melt-out tills can also form under stationary ice which is melting basally. Melt-out tills are characteristically not as compact as lodgement till nor is the fabric as well defined as in lodgement till (Boulton 1970, 1971).

The a/b planes of melt-out till clasts tend to be in the horiztonal plane. In some instances it has also been noted that the grain size of englacial debris becomes finer upward in the ice, presumably because the higher debris has travelled farther than the debris carried lower down in the ice and has undergone more mechanical breakdown during transport. This would result in a melt-out till with an upward decrease in grain size, as well as a lateral decrease in grain size, at any level in the direction of ice movement (Boulton, 1970).

Flow till

Flow till has been described by Boulton (1968), Marcussen (1973) and others. Englacial debris is concentrated on the surface of the ice by downwasting. If the till simply remained there it would accumulate to a thickness no greater than the depth of summer melting. Not until the climate changes will the depth of melting change. If this melt-out till should slide downslope under the force of gravity it is termed flow till. The factors controlling the formation of flow till are grain size of the material, water content, topography and whether or not the ice/ablation till interface is frozen.

Layering resulting from flow into fluviatile or lacustrine environments is a common feature of this type of till. Successive layers of till alternating with fine, well sorted sand, silt or clay laminae, and the fabric characteristics, serve to distinguish flow till from melt-out till or lodgement till.

The characteristic properties of supraglacial till as described by Boulton (1970, 1971, 1972) and Marcussen (1973) are markedly different from those characteristics of ablation till described by Elson (1961), Gillberg (1955) and Flint (1971). The supraglacial tills described by Boulton were primarily derived from the englacial debris load and from polar glaciers. On the other hand, if debris falls onto a glacier surface from surrounding nunataks it will have more of the characteristics outlined by Gillberg, Flint and Elson.

Frost heaving of the coarser fraction of the upper few meters of a till section can also give it the appearance of the ablation tills described by Gillberg, Flint and Elson.

CHAPTER 4

STRATIGRAPHY

Introduction

Detailed examination of all till exposures was made at all sampling stations in the area. Till sections vary greatly from massive deposits to deposits rich in structures and textures. The number of tills, the nature of the contacts, the angle of repose, the compaction and the colour of all till deposits were observed. The relationship between till and meltwater deposits was noted and all areas were examined for ice disintegration features such as kettle holes. Deformation structures and evidence of shearing was also recorded. All exposures were closely examined for the presence of wood, peat, shells or other material suitable for ^{14}C dating.

The writer has concluded that the multiple till sections in Nova Scotia fall into two main categories: 1) those till sections in which the multiple tills apparently represent multiple glaciation; and 2) those till sections with multiple till phases which are the result of only one glacial ice cover.

Older Till Deposits
Predating the Last Glacial Substage

The precise interpretation of a multiple till section can be very difficult (Flint, 1961; Gilbert, 1965; Howard, 1965; Pessl, 1971; Drake, 1971;

Stewart and MacClintock, 1971). Only in a few instances is the evidence beyond reproach, such as where tills are separated by a paleosol or where the tills can be accurately dated. In mainland Nova Scotia there are only two ^{14}C dates which are related to the ages of the till. MacNeill (1969) reports a date of 33,200 ± 2000 years B.P. on wood beneath 70 feet of red till at Miller Creek, Hants County. The other date of 38,600 ± 1300 years B.P. (GSC-1440) is by Grant (1968) on shells from marine sand separating two tills at Salmon River near Yarmouth.

Salmon River and Vicinity

The till sequence at Salmon River is typical of a number of exposures located between Yarmouth and Digby in southwestern Nova Scotia. At Salmon River a lower hard, red till is overlain by marine sand dated by ^{14}C at 38,600 ± 1300 years B.P. (GSC-1440) (Grant, 1968) and by U/Th at 44,000 years B.P. (Grant, 1975). The marine sand is therefore now assigned to a "Mid"-Wisconsinan interstadial and not the Sangamonian interglacial as originally proposed by Clarke et al. (1972) and the underlying red till is therefore presumed to be early Wisconsinan.

A grey and a red lodgement till and an ablation till were deposited subsequent to the deposition of the marine beds. The colour differences in the two lodgement tills is possibly the result of fluctuations in the direction of ice movement during deposition of the till. The two lodgement tills and the ablation till overlying the marine sand are believed to have been laid down during the "classical" Wisconsinan. The general stratigraphic sequence of the Salmon River section is shown in Figure 20.

The lowest till at Salmon River is the only sample of "pre-classical" Wisconsinan till collected for analysis. It is numbered 533.

Milford Gypsum Quarry

The only other previously reported "pre-classical" Wisconsinan till in the study area (besides the Bridgewater conglomerate) is at the Milford Gyspum Quarry. At various times during the quarrying operation at Milford one till and possibly two tills have been identified overlying a layer of organic debris containing logs, leaves and other macro-fossils. Under the organic debris another possible till has been identified (Prest, 1972). Organic material from the Milford Gypsum Quarry has been dated by ^{14}C at 50,000 years B.P. (GSC-1642). Till samples were not collected.

Lunenburg Drumlin Field

During the present study a grey till of the consistency of concrete was found at three localities in the Lunenburg drumlin field. Each till outcrop is mantled by a grey slaty drumlin till. This hard grey till is tentatively correlated with the lowest till exposed at Salmon River.

Younger Multiple Till Deposits

Hartlen Point

The till section at Hartlen Point is well exposed in a sea cliff at the southeastern extremity of a 60 square km drumlinoid sheet and forms a good

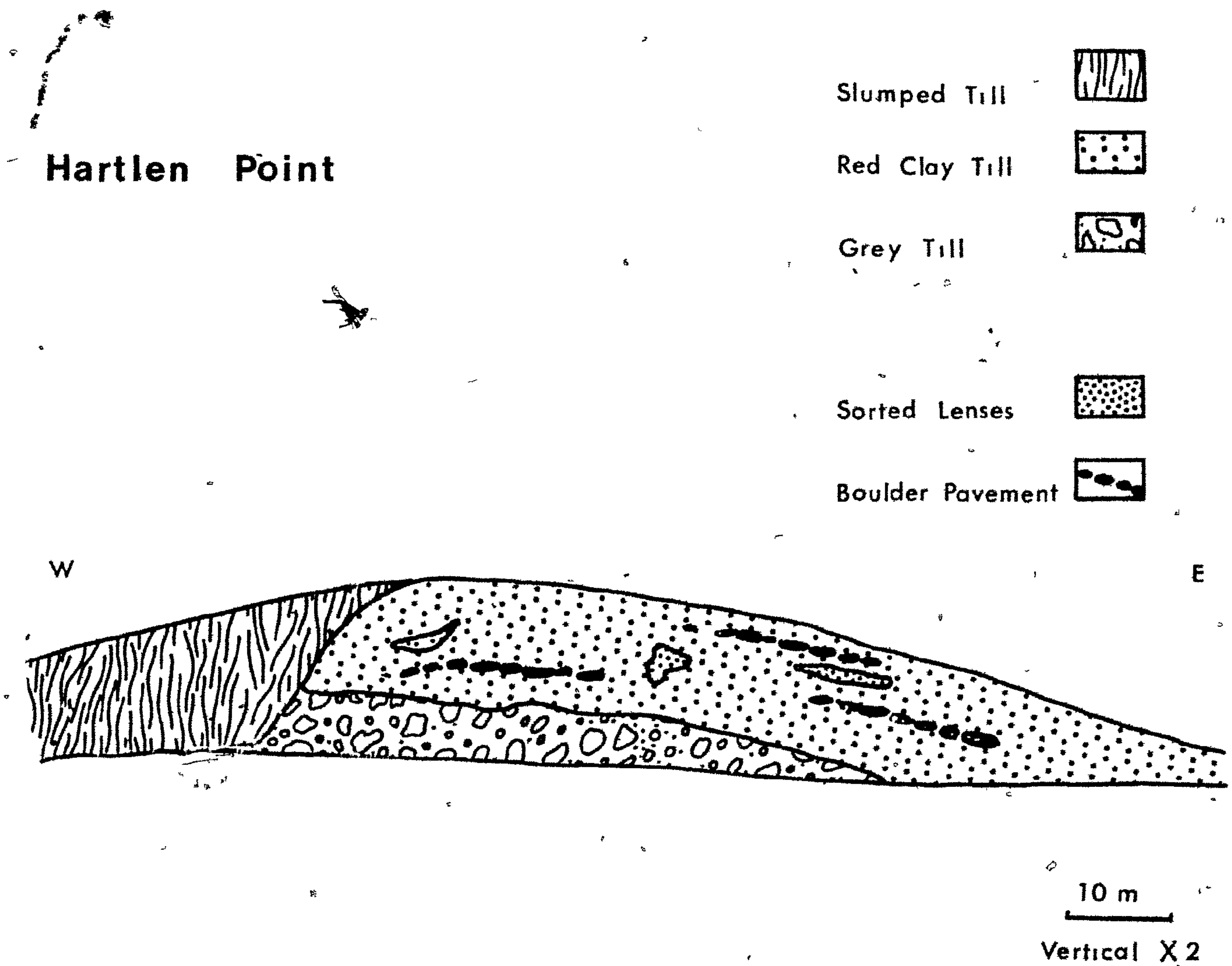


Figure 9. Cross section through drumlinoid sheet at Hartlen Point.

"standard" comparison. The maximum height of the exposure is 9.2 m. The section exposes two tills. The upper till is a 'red' clayey till, 7.6 m thick and is typical of the drumlin till. The lower till is grey and is 1.6 m thick, but the bedrock is not exposed. Metaquartzite and slate underlie the lower till at a depth of about 2 to 3 m (Figure 9).

The exposure of lower till is about 75 m long and it outcrops in the core of the Hartlen Point drumlin. The matrix is homogeneous and structureless, grey in colour, clayey, and more compact than in the upper till.

The matrix of the upper till (the drumlinoid till sheet) is red, clayey and compact. Three types of well sorted lenses of sand, silt, and clay are found throughout the exposure. Type 1 inclusions are pods, generally a couple of metres long and a few tens of centimeters thick and completely irregular in shape. Characteristically the inclusions are homgeneous and deformed with shear planes cutting them. The boundary with the enclosing till is often gradiational and poorly defined (Figure 10).

Type 2 inclusions are clayey and fissile. They are undulating wisps a couple of centimeters thick and 1 to 2 m long. The contact between the clayey inclusion and the surrounding till is sharp. Internally the inclusions have a fissile structure parallel to the enclosing boundaries (Figure 11).

Type 3 inclusions are exposed on the flank of the drumlin under about 3 m of red upper till. The lower till is not exposed there and as the sand body extends below the base of the exposure it is not known if it is an inclusion. The sand body is 10 to 20 m long and 1 to 2 m high. The exact boundaries are diffuse and ill-defined. The lens is composed of well sorted,

Figure 10 Irregular shaped (Type I) inclusion of sorted matrix in the red clay till at Hartlen Point.

Figure 11 Long thin (Type II) inclusion of clay accumulated along shear planes in the upper red clay till at Hartlen Point.

structureless sand grading into till (Figure 12).

Lenses of well sorted sand, silt and clay in the upper till bear witness to the action of running water. Type 1 inclusions indicate that some water was present before the deposition of the till, as the inclusions are massive, irregular shapes showing deformation. Type 2 inclusions formed along shear planes in the till by the action of groundwater at some time after deposition of the till. Type 3 inclusions are similar to type 1 in that it formed before or during the deposition of the upper till.

Several layers of boulders are found in the upper till. They consist of a layer of boulders, one boulder thick, lying end to end and extending across the whole or part of the outcrop. A metre or two above this layer there is another boulder layer and sometimes a third and a fourth. The individual boulders are striated parallel to their long axes, which in turn are parallel to the long direction of the drumlin.

Grant (1963) called such a layer a carpedolith, which is an erosional surface formed as a result of sheet wash runoff. They have also been called boulder pavements (Flint, 1971). Holmes (1941) attributes such boulder layers to shearing. In view of their great number, lack of areal extent, fabric, and striae they are interpreted here as being deposited by shearing.

The pebble fraction of both tills is dominated by metaquartzite and slate. Both tills have a variety of foreign pebbles but the upper till is slightly richer in the foreign component. The fabrics of both tills are very strong (See Chapter 5).

Figure 12 Horizontally deposited (Type III) inclusion and gradational contact with the surrounding red clay till at Hartlen Point.

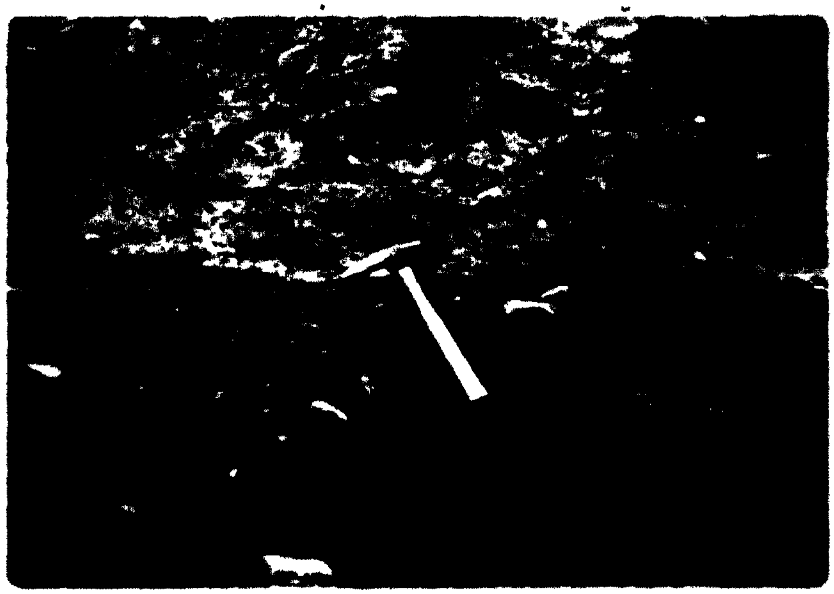


Figure 13 Knife sharp contact between red clay till and lower compact grey till at Hartlen Point.

The contact between the two tills is knife-sharp (Figure 13). There is no evidence of erosion at the contact.

Cole Harbour

The approximately 15 m thick till section exposed in the sea cliff on the eastern side of the entrance to Cole Harbour is similar to the Hartlen Point exposure located 6 km to the west. The section consists of a compact grey lower till 3 m thick overlain by a thick red clay till 12 m thick.

A large kettle hole is exposed in part of the section, occupying a substantial part of the red till. The kettle is floored with red till about 1 m thick, below which the lower grey till is exposed (Figure 14). The kettle hole indicates that a large block of ice was buried in the red till while the ice was still actively flowing, as is indicated by the fabric. The ice block, which later melted to form the kettle hole, was probably separated from the overlying ice by shearing. The ice block may even have formed an obstruction around which the rest of the red drumlin till was plastered.

Sandwich Point

Three tills are exposed at Sandwich Point, on the western side of the entrance to Halifax Harbour. The maximum height of the exposure is about 7 m and the length about 35 m.

The bottom unit is a compact grey clayey till, clearly the lateral equivalent of the lower till at Hartlen Point and Cole Harbour (Figure 15).

The middle red clay till is the lateral equivalent of the upper till at

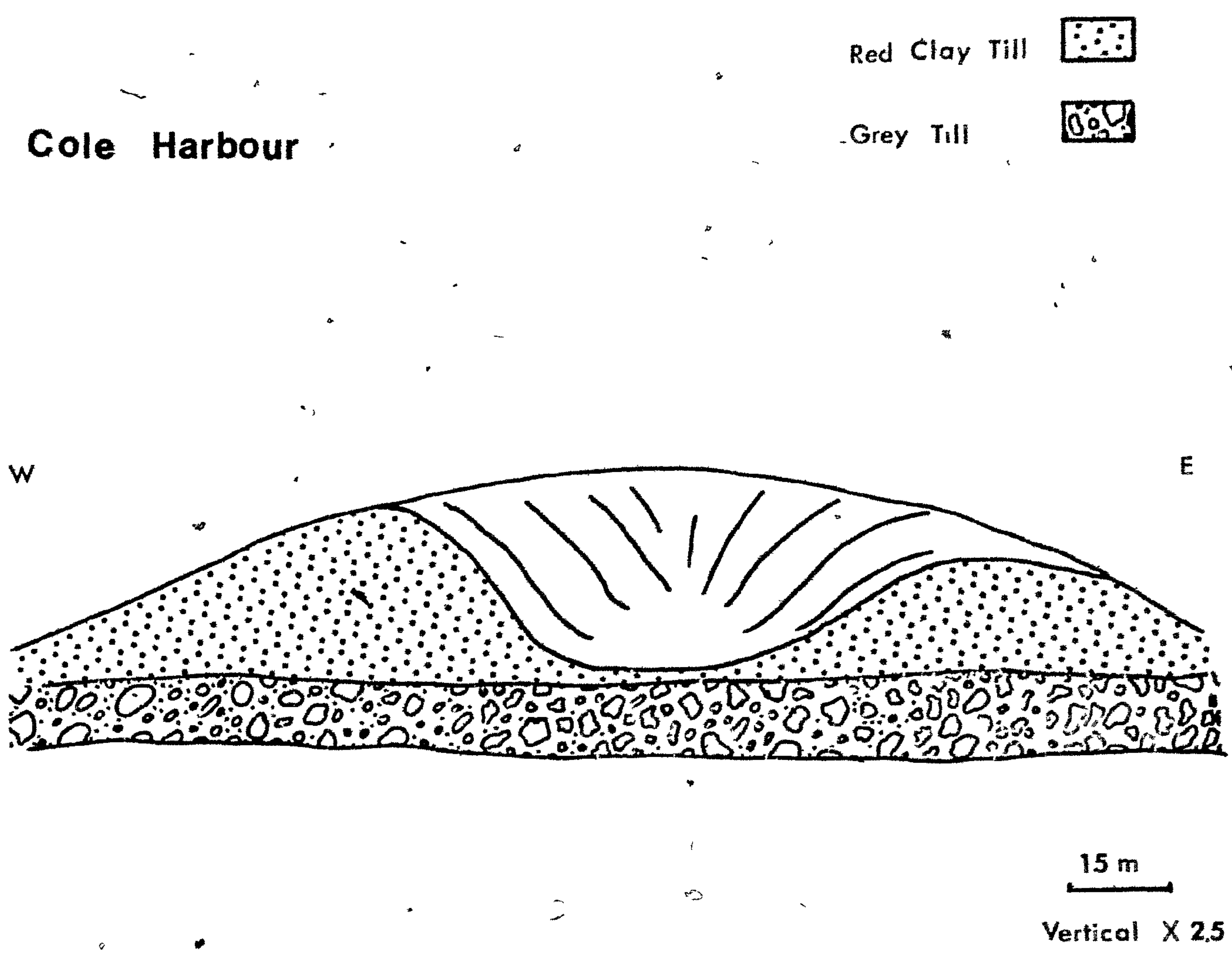


Figure 14. Cross section of till exposure at Cole Harbour.

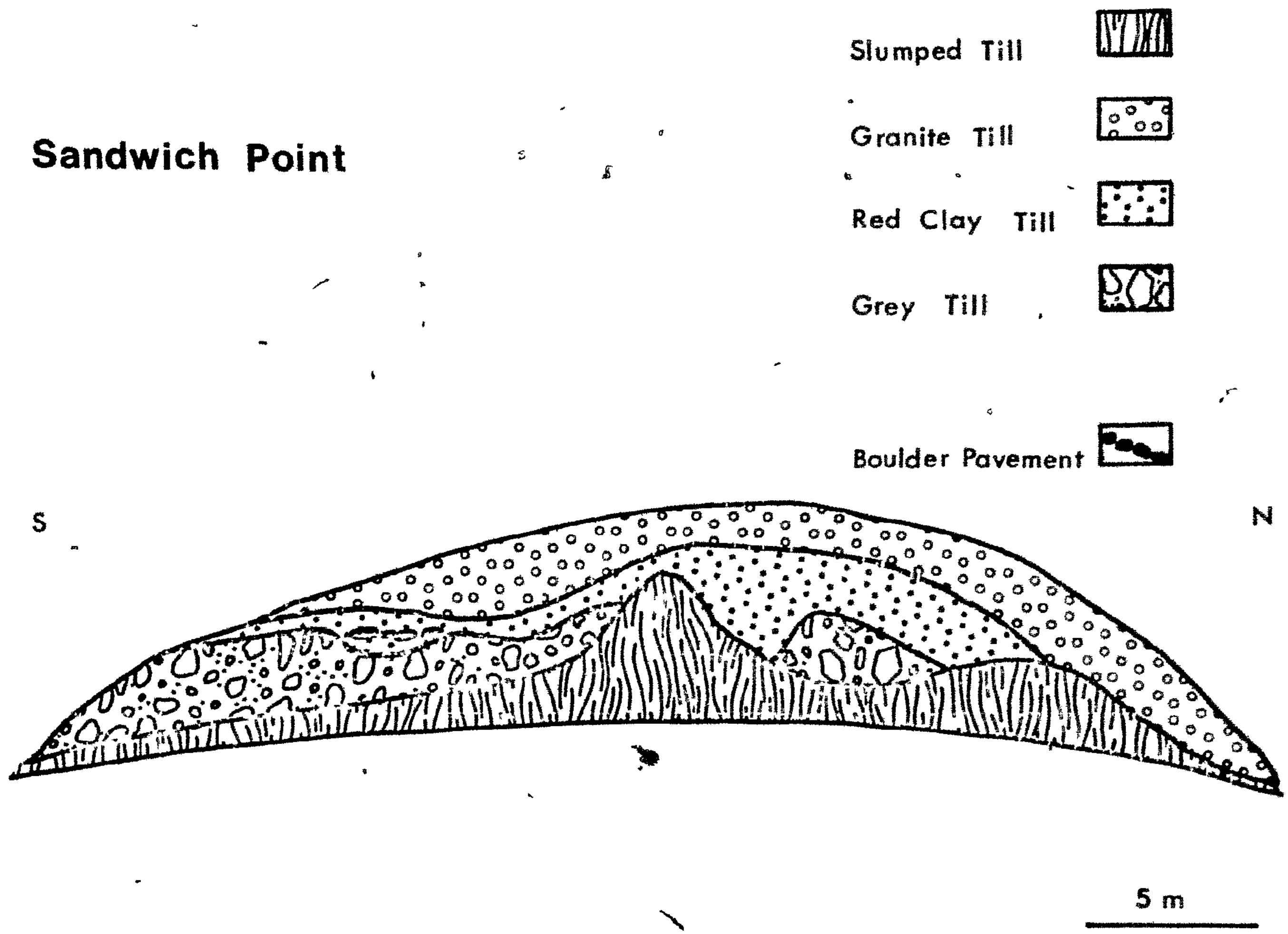


Figure 15. Cross section through till exposure at Sandwich Point.

Hartlen Point and Cole Harbour. The contact between the lower and middle till is gradual and ill-defined, unlike the sharp boundary observed between the two tills at Hartlen Point or Cole Harbour.

Overlying the red clay till is a coarse, sandy, granitic till. The pebbles and boulders are large and numerous and consist predominantly of granite. The till is structureless with no apparent fabric. The sandy matrix makes this till very prone to slumping and consequently it obscures a great deal of the exposure. Grant (1963) termed this till a granite hybrid till as it is a mixture of red clay till and granite till. It is believed that this hybrid till is the equivalent of the thin ground moraine which covers most of the granite, slate and quartzite bedrocks outside the drumlin areas.

Whites Lake

Exposed in the gravel pit behind the baseball field at Whites Lake is a 15 m thick till section, consisting of a lower red clayey till and an upper thick sandy till. The upper till is similar to the top till at Sandwich Point. The lower till is similar to the red clay till widely exposed in the drumlins in the region.

Two parallel sandy dykes, 30 cm wide and more than 3 m long originate in the upper till and intrude into the lower red clay till. The dykes dip towards the south-southeast at about 45° (Figure 16).

Considerable controversy exists over the interpretation of till wedges. (Mörner, 1972, 1973 and Worsley, 1973, 1974, 1975). It is generally agreed

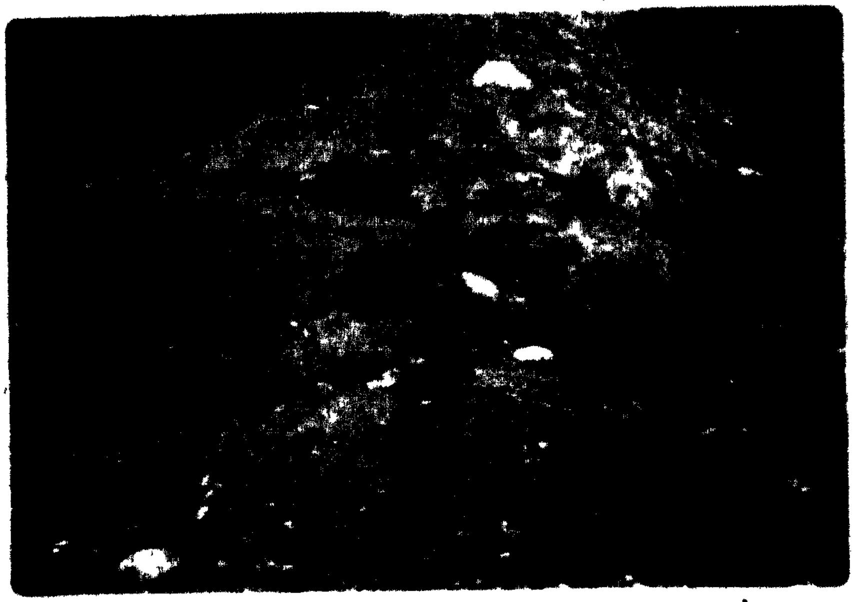


Figure 16   Red clay till overlain by granitic till and injected by coarse sandy till wedges at Whites Lake. The sandy granitic till is darker in colour.

however, that till wedges are formed by moving ice. The till wedges at Whites Lake indicate that the hybrid till was deposited by moving ice and not simply as the result of ablation. The underlying till was probably frozen at the time.

The Parrsboro Gap

A small moraine is situated in the Parrsboro gap just north of Parrsboro. The moraine is composed of outwash and red flow till (Figure 17). When the ice abutted against this moraine the red till flowed out over the moraine from the upper surface of the ice. The red till was possibly brought to the

Figure 17 Flow till in a small moraine in the Parrsboro Gap.

Figure 18 Large block of red clay till in ice contact stratified drift near St. Croix.

ice surface by shearing. Alternatively it may have occupied an englacial position and was brought to the ice surface by ablation.

St. Croix

A large body of ice contact stratified drift (possibly an esker) is situated in the central part of the St. Croix river valley near St. Croix. A block of red clay till is situated near the top of one exposure (Figure 18).

The numerous faults found throughout indicate that the drift was in contact with the ice at the time of formation. The location of the deposit in the middle of the valley indicates the till block slid into its present position from above. The till occupied an englacial or supraglacial position before final deposition.

The Highlands and Uplands

Most of the till on the upland and highlands has been formed by partial influence of the bedrock morphology. Much of the bedrock is covered with till but bedrock outcrops are also numerous. The hills are irregular in shape and without apparent orientation. The surface of the till is often rich in large, sometimes enormous boulders, which lie loose on top of many hills.

The interior of the till is more heterogeneous than that of the red or grey clay tills. The boulder content is generally high near the surface, due to the action of either ablation or frost heaving. The matrix is loose and sandy.

Genetic classification of till developed from the granite bedrock is difficult. The ground moraine which has developed over the metaquartzites and slates sometimes shows distinct basal and ablation till phases.

Although Hickox (1962) demonstrated northward movement of ice from South Mountain during deglaciation, no till sheet directly attributable to only this event has been recognized. The till over North Mountain and in the Annapolis Valley consists of a homogeneous mixture of material derived from the north and from the south. The radiating late glacial ice cap over South Mountain reorganized the preexisting till deposits and added a small amount of local components. The possibility that the hybrid till in the Halifax-St. Margaret's Bay area was deposited by this radiating ice cap cannot be discounted.

The Lowlands

The till sheet in the lowland region is more continuous and generally thicker than on the uplands and highlands. The till developed in the lowlands is difficult to classify genetically. At Joggins, for example, the thick till sequence is apparently composed of three basal tills (Figure 19).

The tills along Northumberland Strait and around Minas Basin are characteristically red or reddish brown in colour whereas the tills derived from the highlands and uplands are grey and rarely brown in colour.

Interpretation

Although most of the ubiquitous till sheet is ascribed to the "classical" Wisconsinan, there is some evidence of multiple glaciation and interstadial conditions at isolated localities such as Salmon River, Milford Gypsum Quarry, and as occasional residual patches throughout the Lunenburg drumlin field. Ice advanced across the proglacial deposits and early till, eroding and incorporating these sediments into the new till. Only isolated remnants of the older till are found today and the till which blankets the province is the product of only the most recent ice advance. Locally this hseet may show ablation till, englacial melt-out till, and basal lodgement till phases.

The compact grey clay till exposed at Hartlen Point is tentatively believed to be the basal lodgement till representing the earliest phase of glacial depostion during Wisconsinan time. This timm may have been more widespread initially, but a change to englacial incorporation of vast amounts of red clay sediment in the Carboniferous Lowland and a change in the mode of deposition may have been accompanied by erosion of the tills deposited earlier on the uplands. The occurrence of balls of red clay till in kame and esker deposits around Minas Basin and the presence of red clay flow till in the Parrsboro Gap moraine indicates that the red clay till occupied an englacial position during transport.

On the uplands the englacial till was deposited as drumlins by basal melting. The incorporation and transport of englacial debris in the form of red clay till was controlled by geomorphology and ice dynamics, and in the areas where there was no drumlin formation ground moraine was deposited. This ground moraine can sometimes be divided into basal and ablation till but at times it is not clear which phase is represented. As melt-out till

Figure 19. Three tills exposed at Joggins.

deposition declined, fluctuations occurred in some places. In the area between Halifax and St. Margaret's Bay, for example, a gradual change in deposition took place, passing from red clay till to locally derived sandy granitic till with some foreign pebbles; this is the so-called hybrid till. There is no evidence for a withdrawal of the ice from the beginning of deposition of the compact grey clayey lodgement till until after the upper granite till was deposited at the close of Wisconsinan time. The entire "classical" Wisconsinan glacial sequence is preserved only at Sandwich Point. The general stratigraphic sequence is shown in Figure 20.

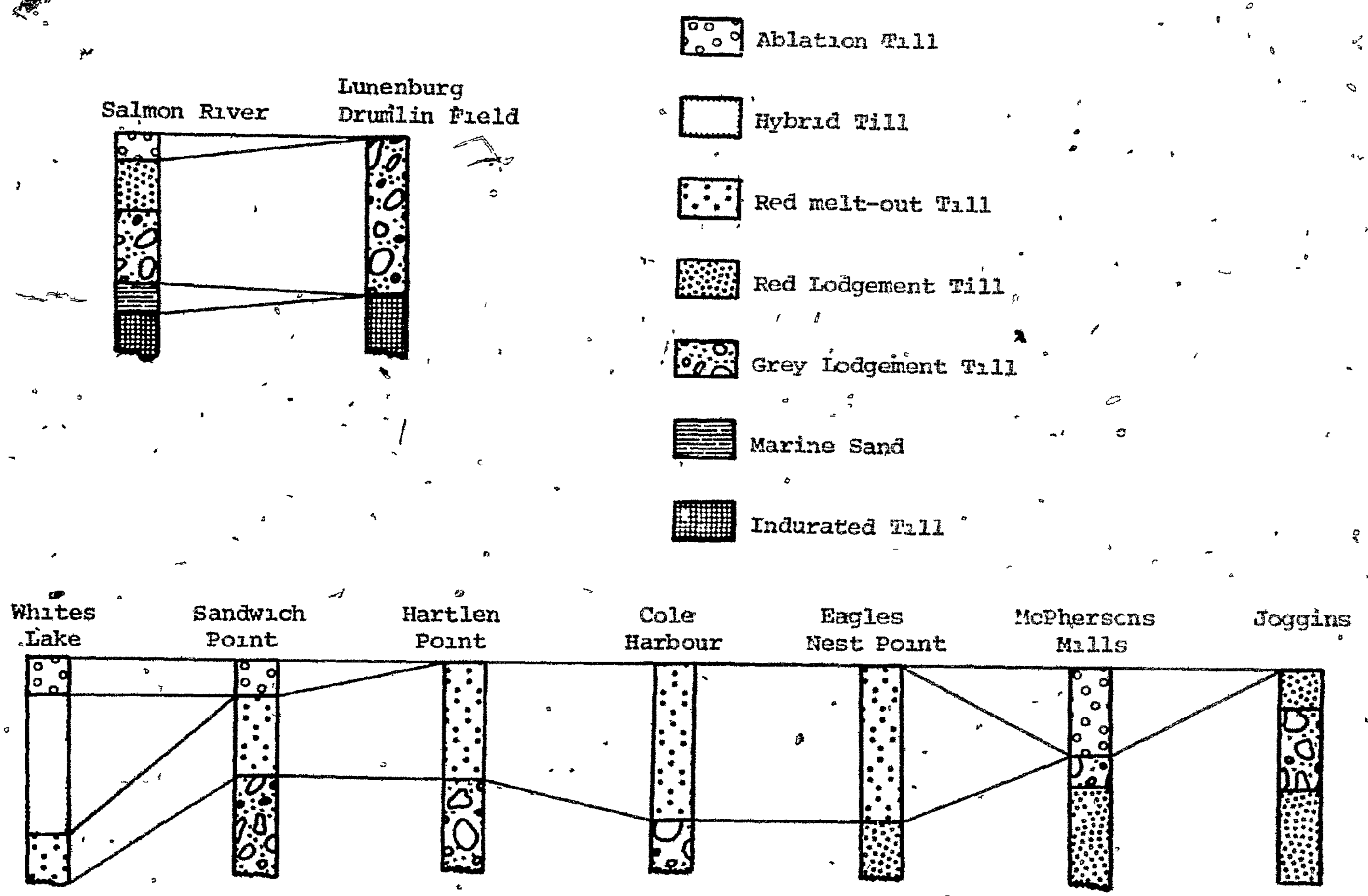


Figure 20. Correlation of major Nova Scotian till deposits. The scale is schematic.

Conclusions

1. With few exceptions, all till deposited before the "classical" Wisconsinan was removed by the ice that deposited the regional till sheet.
2. A few isolated and protected pockets of older till are found scattered through the area, notably at Milford and along the shore north of Yarmouth.
3. Grey lodgement till was deposited over parts of the Meguma during early "classical" Wisconsinan time.
4. With few exceptions the grey lodgement till was eroded prior to the deposition of red clay till.
5. The primary mode of transport of the red clay till was englacial.
6. Spreading and thinning of the ice sheet along the margin caused downward movement and basal deposition of red clay englacial debris as melt-out till.
7. At the time of deposition of the red clay till shearing of the ice was prevalent.
8. Where the red clay till was deposited over the Meguma Group drumlins formed.
9. In the Halifax-St. Margaret's Bay area the red clay till is overlain by a local granitic hybrid till, possibly ablation till.
10. Late "classical" Wisconsinan ice flow from local ice caps resulted in homogenization of preexisting till deposits and only minor addition of local components.

CHAPTER 5

TILL FABRIC ANALYSIS

Introduction

Considerable literature has accumulated on till fabric analysis during the last hundred years. Such studies are generally concerned with (1) determination of regional ice movement, and/or (2) problems connected with the formation of the fabric and the deposition of till. Graphic representation and statistical analysis of data play an important part in the analysis of till fabrics.

Regional Ice Movement

Till fabric studies conducted to determine regional ice movement are numerous. Such studies usually entail the measurement of the azimuth and dip of the long axis of rod-shaped pebbles at suitable intervals throughout a region. One hundred pebbles are usually measured at each site. The site location is often governed by the availability of suitable exposures. The data can be plotted on a rose diagram, a stereographic projection, or a contoured equal area net. The fabric diagrams are then transferred to a map and a visual interpretation of the regional ice-flow directions is made. This method is based on the theory that the long axes of rod-shaped pebbles lie parallel to the ice-flow direction and the pebbles dip upstream (Harrison, 1957). Till fabric analysis is a useful tool in areas where other directional indicators such as striae, crag-and-tail and drumlins are absent.

Origin of Till Fabric

Holmes (1941) completed the first extensive work on the origin of till fabrics and till deposition. He was concerned with clast shape and its control on fabric. Holmes found that there are two basic types of fabric generated: 1) rods are aligned ... e long axis parallel to the ice flow direction, and 2) blades and discs (a defined by Zingg, 1935) tend to be aligned transverse to the ice flow.

Considerable controversy now exists over whether clast shape affects the fabric (Andrews and Smith, 1970; Lindsay, 1970; Andrews, 1971; Drake, 1974) and where and how a fabric is generated (Holmes, 1941; Glen et al. 1957; Harrison, 1957; Andrews and Smith, 1970; Lindsay, 1970). There is general agreement that the fabric is formed in response to some real directional stress and that parallel fabrics are more common than transverse fabrics. Most authors agree that the long axes of pebbles lying parallel to the ice flow direction dip upstream. Mark (1974) however showed that only 8 out of 28 fabrics measured in southwestern British Columbia had a-axis planes which dipped significantly.

Local and Regional Variability in Till Fabric

Andrews and Smith (1970) made a detailed statistical study on till fabrics and discovered that there is little or no lateral variation, but the vertical variation can be quite large within short distances. They argue against the existence of a well-defined contact between basal till and the ice and propose that the fabric is formed immediately after deposition of the till. The till is almost fluid at this time as a result of water produced by pressure melting at the base of the ice sheet. The pressure of the overlying ice then causes the till to flow. If the pressure gradient is across a slope, the resultant fabric would be the resultant between the pressure flow and the gravity force on the slope. MacClintock and Dreimanis (1964) and Ramsden and Westgate (1971) explained vertical variation in till fabrics as the result of plastic deformation during readvance of glacier ice from a new direction. On the other hand, Harrison (1957) explained the vertical variation as the result of gradual change in flow direction as the till accumulated. It has been suggested that regardless of the cause the problem of within-site variability in till fabrics can be overcome by measuring fewer pebbles at more localities; for example, instead of measuring 100 pebble orientations within 1 sq. m, measure 10 pebbles at 10 substations spaced at 10 or 20 m intervals and at a constant height above the base of the exposure, the bedrock, or some other datum (Andrews and Smith, 1970).

Although there is considerable controversy about the origin of till fabrics, especially transverse fabrics, as well as the usefulness of the dip direction, the variations in till fabrics contribute valuable information about ice-flow directions and till depositional processes in both time and space.

Nova Scotian Till Fabric Analysis

The primary aim of making till fabric analyses in Nova Scotia was to gain information concerning regional ice movement in areas where other directional indicators are lacking. Although many glacial striae have been measured in Nova Scotia (Prest and Grant, 1969) several objections to their use are apparent: 1) striae are ephemeral, and hence only useful if they are recorded in great numbers on a regional basis; 2) striae are formed as a result of glacial erosion, whereas till is the produce of glacial deposition, the two processes being separated in time; and 3) the sense of direction is difficult to determine from striae.

Method

Fabric was measured at 21 localities (Figure 24). All measurements were made at depths thought to be below the maximum depth of frost penetration to ensure that the pebbles were undisturbed.

Fabric stations were selected mainly in the Carboniferous lowlands, where other directional data are lacking; where the till is clayey and cohesive; and where the length to width ratio of pebbles in the 5 to 22 mm range is 3:2 or better in order to facilitate accurate measurement.

Andrews and Smith (1970) calculated that for a general study the main characteristics of the sample distribution are present after N (number of measurements) = 25. Increasing N to 100, for example, does not reduce or increase the spread of the data. Increasing N will result in a smaller standard error. For a regional study relatively large standard errors can be tolerated but for detailed work the standard error of the mean (95% cone of confidence) should be on the order of 5 - 10°. In this study ten substations were selected at one location, 5 substations at one location, 4 substations at one location, 3 at two locations, 2 at six locations and 1 at ten locations. Two stations consisting of 1 substation each have 41 and 59 measurements. Each group of 25 measurements was made within an area of approximately one square meter and at a constant distance above a geological datum or below the top of the section.

Pebbles to be measured were loosened and removed from the till. A brass rod 0.5 cm in diameter and 30 cm long was inserted into the till so that it was parallel to the azimuth and dip of the long axis of the pebble. The azimuth of the brass rod was measured with a Brunton compass and the dip measured with a clinometer. The measurements are considered accurate within ± 5°.

A computer program developed by Mark (1971) was used to calculate the mean vector (M), the dip of the mean vector (D), the vector strength (R), the percent of the vector strength of the total sample (R%), the 95% cone of confidence around the mean vector, i.e. the standard error, (Θ), and the homogeneity of variance (K), for each substation.

If K=3, the Kmax/Kmin for the substation has been tested for homogeneity of variance as outlined by Hartley (1950). Where the Kmax/Kmin ratio exceeds the upper 5% point, heterogeneity is indicated and the substations cannot be combined. If homogeneity is indicated the substations have been combined and the F-test is used to ascertain if sample orientations belong to the same parent population.

Within-site (w) and between-site (B) precision parameters can be determined from the results and a suitable sampling program can be determined as outlined by Watson and Irving (1957).

The direction and plunge of the long axis of each pebble at each station is plotted on the lower hemisphere of an equal area projection (Appendix 1).

Note that the computer program uses a series of planes of reference other than the horizontal and calculates the length of the mean vector relative to each plane. The rotation producing the maximum mean vector length is considered to be the best solution and is used to determine the azimuth and dip of the mean vector and the associated statistics. For this reason the direction of dip shown on the equal area projections does not always agree with the calculated direction of dip, i.e. it is 180° out of phase.

At McPhersons Mills where three tills outcrop , the fabric of the bottom till was measured by the method described above. The fabric of the middle till was measured in the laboratory. A large oriented block of till measuring 0.5 m on the side was transported to the laboratory. Horizontal slabs of till measuring 2 x 15 x 20 cm were removed and x-rayed. The directions of the long axes of the horizontal projections of the pebbles and granules were measured on the negatives and plotted on polar coordinate paper. When the trend of the pebbles and granules was known, vertical slabs were cut parallel to that direction. The x-ray negatives of these slabs gave the direction of plunge of the clasts. Radiographs are an effective new method for fabric analysis of tills with small pebbles.

Hartlen Point

Six substations in the lower till and four in the upper till at Hartlen Point were selected for detailed fabric analysis in order to check small scale variations in the fabric and as a check on the chosen sample size of 25 pebble measurements.

In the upper till 25 pebble measurements were made at each of the four substations. The results are plotted in Figure 21 and the relevant statistics are given in Table 2. The azimuths and inclinations are plotted as points on an equal area net. The mean azimuth is shown by a line external to the edge of the plot and an arrow shows the preferred dip orientation. On either side of the mean short lines indicate the 95% cone of confidence about the mean (the standard error of the mean). It is clear that the four substations from the upper till are not all sampled from the same population. Subsample 1 is clearly different from the other samples. Subsample 1 is located on the eastern flank of the drumlin near the surface and may well have been modified by contour deflection or by solifluction.

In the lower till 25 pebble measurements were made at each of five substations, but only 15 were measured at Station 6. The results are given in Table 2 and are plotted on Figure 22. It is clear that the six subsamples from the lower till all belong to the same population.

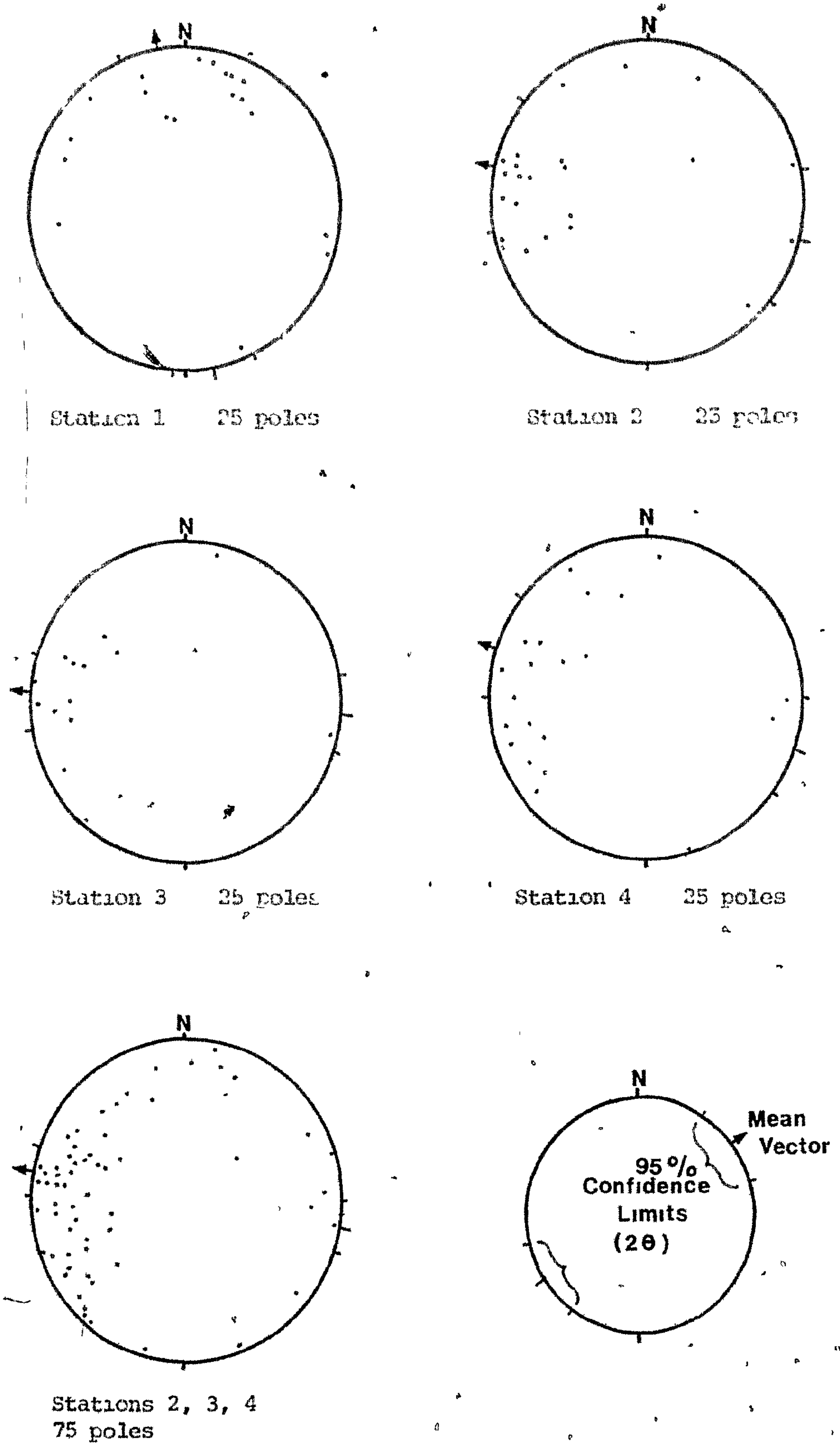


Figure 21. Till fabric measurements from the upper till at Hartlen Point.

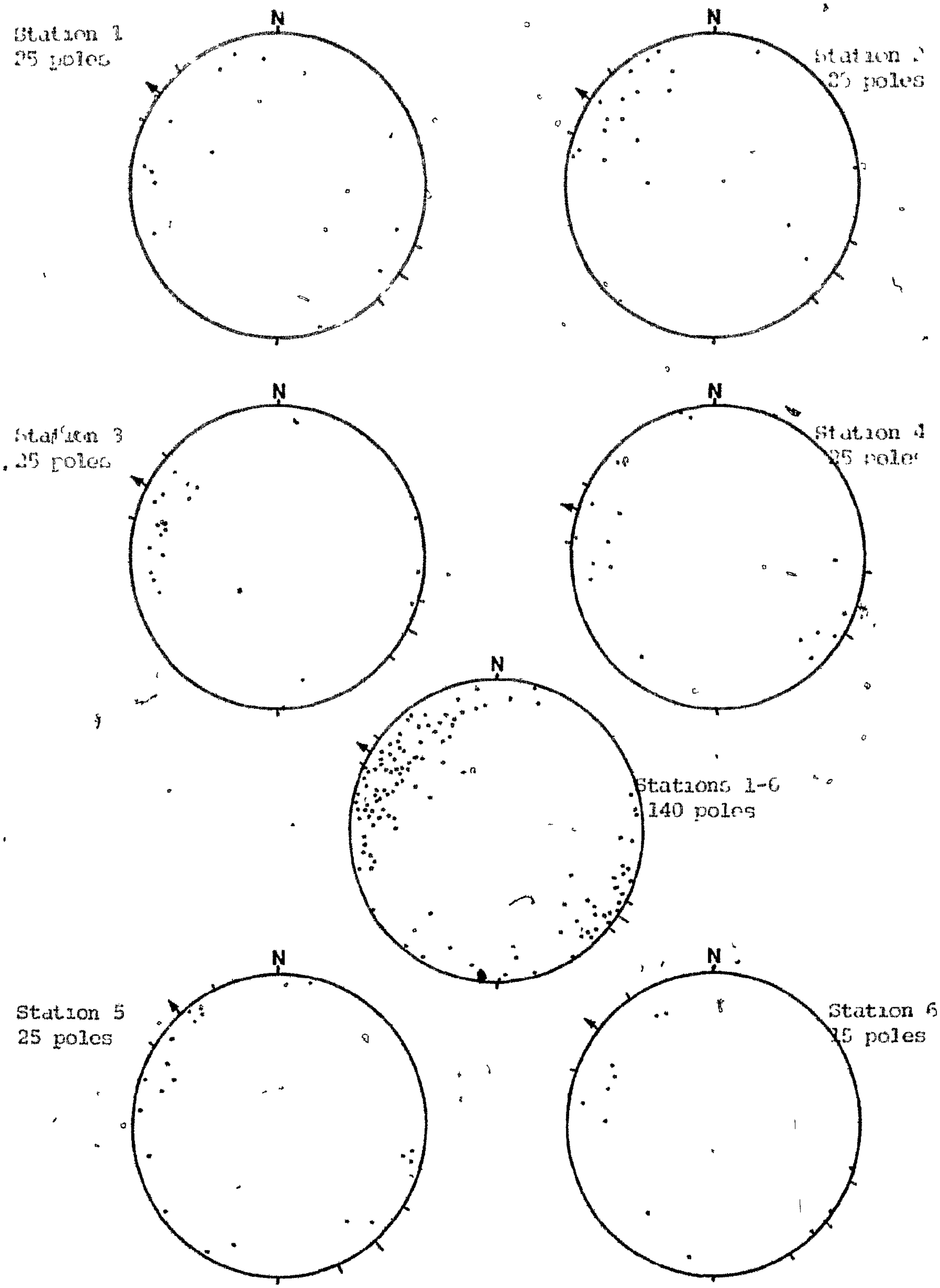


Figure 22. Till fabric measurements from the lower till at Hartlen Point (lower hemisphere equal area projections).

Figure 23 shows the mean vector and the standard error for each sub-station from east (the bottom of the diagram) to west (the top of the diagram) across the outcrop at Hartlen Point. In both the upper and lower tills the mean vectors move from the south towards the east and back towards the south along the east-west transect. The fabrics at Hartlen Point appear to vary regularly over horizontal distances as short as a few metres. Nevertheless the principal features of the fabric are delineated after measuring as few as 15 pebbles. If care is used in selecting the sampling site 25 pebble orientations are deemed sufficient to determine the general ice flow direction. Local variations in the till fabric make it desirable to select more than one substation at each locality.

Regional Ice Flow

The results of the statistical analysis of the till fabric data are listed in Table 2. The F-values indicate that the fabric of the till at Chaplin, Tatamagouche, Eagles Nest Point (Lower Till), Whites Lake, Cornwallis, Salmon River (oldest till) and Hartlen Point (Upper Till) are all composed of more than one population.

The various fabric populations are shown in Appendix 1. Variation in fabric orientation within short distances may be due to variation in the attitude of the surface of till accumulation, deformation by subsequent glacier movement, frost heaving, or solifluction.

	M	D	R	R (%)	N	O	K	F
McPherson's Mills								
Lower Till								
Stations 1, 2	43	-12	40.7	81.4	50	9.7	5.2	.5
Station 1	47	-14	19.5	78.0	25	15.7	4.3	
Station 2	40	-10	21.3	85.3	25	12.2	6.5	
Mount Thom								
Stations 1, 2	27	- 6	40.4	80.9	50	9.8	5.1	1.1
Station 1	33	- 3	18.8	75.3	25	16.9	3.9	
Station 2	22	- 8	21.8	87.3	25	11.2	7.6	
Riversdale	31	4	30.9	75.5	41	12.8	3.9	
Lorne								
Stations 1, 2	24	7	41.5	83.0	50	9.2	5.7	2.7
Station 1	33	16	21.4	85.7	25	12.0	6.7	
Station 2	28	2	20.5	82.1	25	13.8	5.3	
Chaplin								
Stations 1, 2	131	7	33.5	67.0	50	14.3	3.0	3.9
Station 1	109	10	16.8	67.3	25	20.0	3.0	
Station 2	326	0	17.9	74.6	25	17.6	3.7	
Plainfield	133	-25	20.3	81.3	25	14.1	5.1	
Tatamagouche								
Stations 1, 2	139	2	33.1	69.0	48	13.9	3.1	15.5
Station 1	342	- 6	18.9	79.0	24	15.6	4.5	
Station 2	100	- 2	17.9	74.8	24	17.6	3.8	
Debert	32	16	40.7	69.0	59	12.5	3.1	
Lower Selma								
Stations 1, 2	11	- 7	36.5	73.1	50	12.3	3.6	
Station 1	12	- 6	17.1	68.5	25	20.1	3.0	
Station 2	10	- 8	19.4	77.7	25	15.6	4.3	
Eagles Nest Point Upper Till	143	- 6	17.5	70.0	25	19.4	3.2	
Eagles Nest Point								
Lower Till								
Stations 1, 2	6	4	32.7	65.4	50	14.8	2.8	26.4
Station 1	339	6	19.5	78.2	25	15.6	4.4	
Station 2	64	1	19.3	77.2	25	16.1	4.2	
Mutton Cove	330	- 6	19.0	76.0	25	16.6	4.0	
St. Croix	13	16	18.8	75.3	25	16.9	3.9	
Windsor	124	8	19.7	79.0	25	15.2	4.5	
Avonport	115	- 3	18.0	72.3	25	18.3	3.4	
Wolfville	352	- 4	22.3	89.4	25	10.1	9.0	
New Minas	33	8	23.1	12.7	25	8.2	13.2	
Hartlen Point								
Upper Till								
Stations 1,2, 3,4	334	24	71	71.0	100	9.0	3.4	12.4
Stations 2,3,4	100	-18	58.5	78.0	75	8.7	4.4	1.1
Station 1	350	20	20.0	80.2	25	14.7	4.8	
Station 2	103	-13	19.7	79.8	25	25.3	4.5	
Station 3	94	-21	21.0	81.3	25	12.7	6.1	
Station 4	118	-20	18.2	72.9	25	18.0	3.5	

	M	D	R	R (%)	N	Θ	K	F
Hartlen Point								
Lower Till								
Stations 1,2,3,4,5,6	123	- 9	113.9	81.0	140	5.6	5.5	1.8
Station 1	306	12	21.2	85.0	25	12.4	6.4	
Station 2	124	- 9	20.8	83.2	25	13.2	5.7	
Station 3	119	-13	20.8	83.5	25	13.1	5.8	
Station 4	113	- 5	21.4	85.9	25	11.9	6.8	
Station 5	139	- 4	18.7	74.8	25	17.1	3.8	
Station 6	130	-15	12.4	82.8	15	18.0	5.4	
Whites Lake								
Lower Till								
Stations 1,2,3,4	140	8	71.9	72.6	99	8.7	3.6	5.4
Stations 1,3,4	146	8	53.9	73.9	73	9.9	3.7	1.0
Station 1	146	17	17.7	77.1	23	16.8	4.1	
Station 2	34	3	21.4	82.3	26	13.4	5.4	
Station 3	118	- 1	18.1	72.4	25	18.3	3.4	
Station 4	324	- 9	18.6	74.7	25	17.2	3.8	
Cornwallis								
Stations 1,2,3	234	- 5	54.2	71.3	75	10.3	3.4	4.3
Stations 2,3	110	3	38.6	77.3	50	11.0	4.3	1.2
Station 1	50	21	17.4	69.9	25	19.4	3.1	
Station 2	104	3	20.6	82.6	25	13.5	5.5	
Station 3	117	4	18.3	73.2	25	17.9	3.5	
Perry Brook	77	18	19.4	77.7	25	15.8	4.3	
Salmon River								
Till C	136	0	19.8	79.2	25	15.1	4.6	
Salmon River								
Till B								
Stations 1, 2	151	2	35.6	71.2	50	12.0	3.4	.8
Station 1	146	1	19.1	76.5	25	16.4	4.1	
Station 2	342	- 2	16.7	66.8	25	20.9	3.0	
Salmon River								
Till A								
Stations 1, 2	66	10	35.4	70.8	50	13.0	3.3	17.3
Station 1	47	14	20.8	83.2	25	13.2	5.7	
Station 2	123	- 7	18.4	73.9	25	17.6	3.6	

Table 2. Mean vector M, dip of the mean vector D, vector strength R, per cent vector strength (R(%), number of measurements N, standard error of the mean Θ, homogeneity of variance K and the F-value for till fabric data.

p. 117

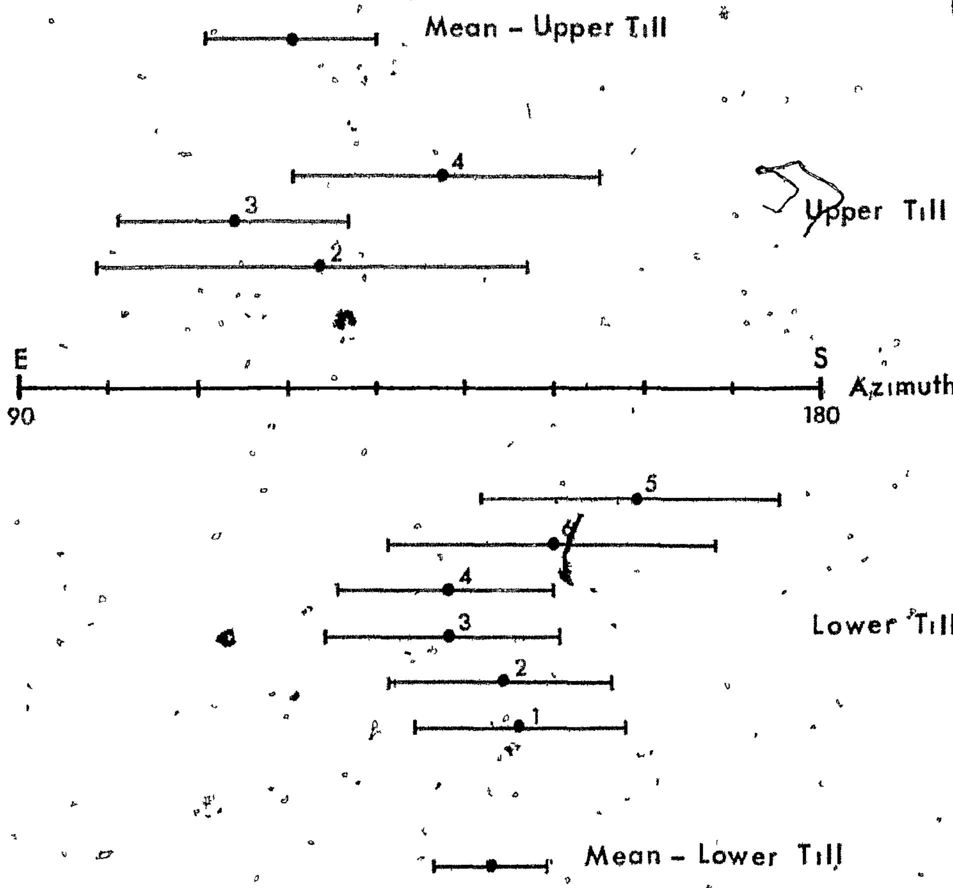


Figure 23. Plot of the variation in the direction of the mean vectors and of the 95% confidence limits from east (bottom of the diagram) to west (top of the diagram) in the upper and lower tills exposed at Hartlen Point.

The direction of ice movement as indicated by the orientation and dip of the mean vectors at each location is shown in Figure 24. The data for Tatamagouche, Chaplin, and Eagles Nest Point have not been included because of the difference between the directions of the mean vectors of the subsamples. The fabric from the upper till at Eagles Nest Point has been omitted because it has undergone post depositional alteration.

Figure 24 clearly reveals little or no consistancy to the direction of dip of the pebbles. This may be a consequence of assuming the surface of deposition to be horizontal and plotting the points on a horizontal plane. Addition of some estimate of the attitude of the depositional surface to the measured values would possibly result in a more consistent trend in the direction of dip. How such estimates could be made is difficult to see. Reorientation by late glacial ice remnants in a manner similar to that described by MacClintock and Dreimanis (1964) from other areas seems unlikely as successively higher fabric stations in each of two different tills at Salmon River and McPhersons Mills indicate that the fabrics have not been reoriented.

The till fabrics are generally oriented parallel to major topographic lineations. The fabric at Plainfield is parallel to the north side of the Cobequid Mountains. The Cornwallis and Perry Brook fabrics parallel the Annapolis Valley. The New Minas, Wolfville, Avonport, Windsor, St. Croix, and Mutton Cove fabrics follow the Avon River Valley. The Debert, and Lower Selma fabrics parallel the Wentworth and Shubenacadie Valleys. The Whites Lake and Hartlen Point fabrics parallel Halifax Harbour, Bedford Basin and Sackville River Valley. The fabrics at Riversdale, Mt. Thom, Lorne,

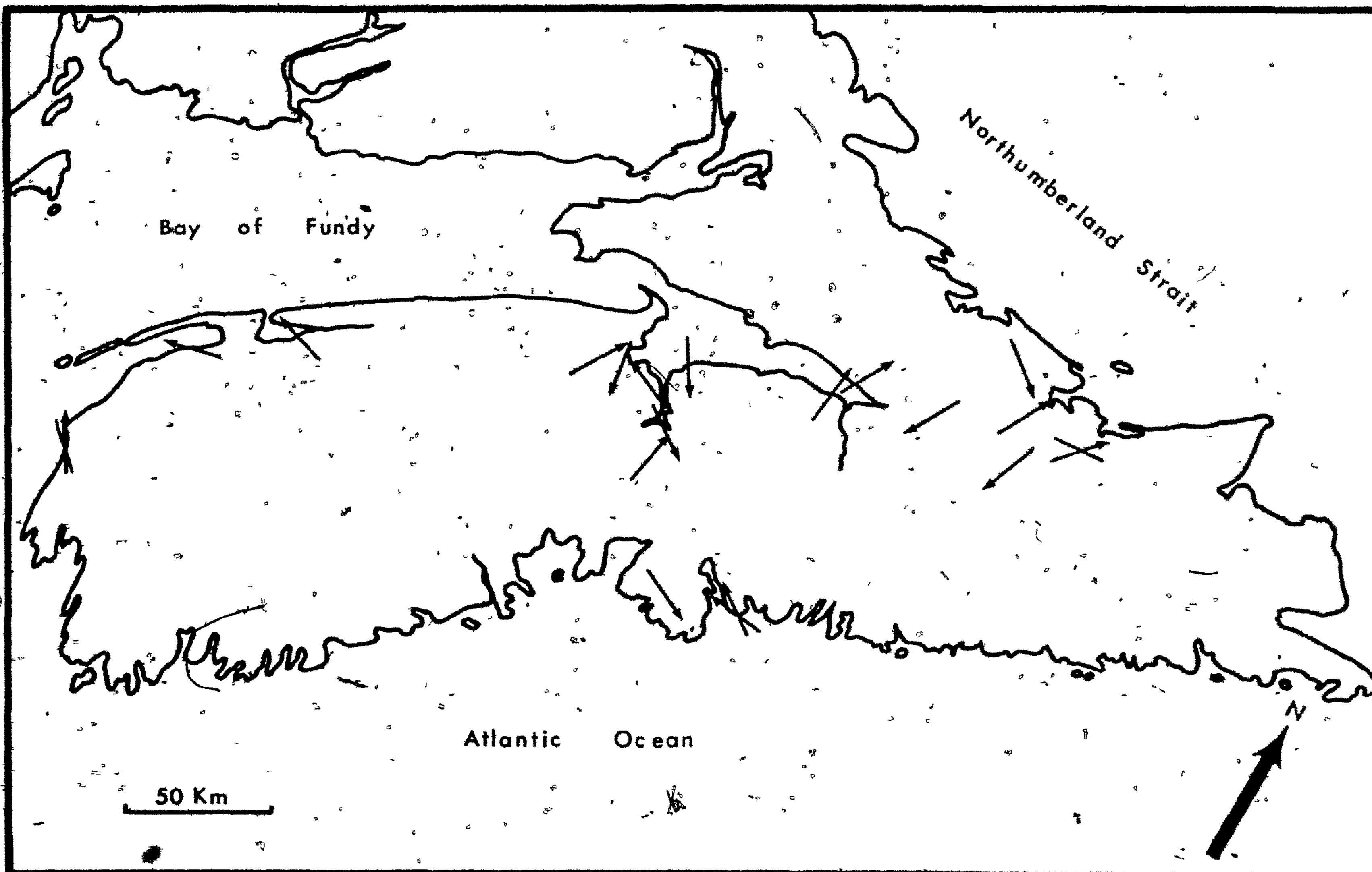


Figure 24. Direction and dip of the mean vectors of fabric data listed in Table 2.

and McPhersons Mills are oriented parallel to the Stellarton Gap.

Conclusions

Till fabric analysis suggests strongly that the basal ice movement and till deposition in Nova Scotia was controlled by the attitude of the surface of accumulation, i.e. the topography. The basal ice flowed parallel to the valleys and highlands. Only when the valleys were full of ice did the upper part of the ice sheet flow over the drainage divides independent of the underlying topography; however, the basal ice continued to follow the topography.

Due to the imprint resulting from topographic control, till fabric analysis is not regarded here as a particularly useful method for determining the general source of the ice which flowed across the province. Perhaps striation directions are also somewhat affected by local topography and local basal ice flow and represent late stages of glacial movement.

CHAPTER 6

TEXTURE

Laboratory Analysis

In the laboratory, the entire till sample was dried, weighed, and gently crushed with a hammer, without fracturing the component grains, until all the matrix had passed through a 2 mm sieve. The residual gravel fraction (> 2 mm) was washed, dried and weighed. The percent >2 mm was calculated and the percent <2 mm was calculated by subtraction from 100%. The <2 mm fraction was sampled by coning and quartering. Sand, silt and clay analyses were carried out using standard laboratory techniques (Folk, 1968). The proportions of sand, silt and clay were calculated so that when combined with the percent of gravel they totalled 100% of the "raw" till sample.

The sand fraction was sieved through a 500μ screen and the 63 to 500μ fraction was weighed and saved for heavy mineral separation.

Most authors plot, on a ternary diagram, the sand, silt and clay, recalculated to 100%, or the percent gravel + sand, silt and clay, [for example, see Krumbein (1933), Shepps (1953), and Dreimanis and Reavely (1953)]. In this study the percent gravel, sand and mud (i.e. silt + clay) was plotted on a ternary diagram because the gravel component makes a sizeable contribution to till derived from crystalline bedrock.

Results

Figure 25 is a plot of the percent gravel (10 cm to 2 mm), sand (2 mm to 63 microns), and mud (finer than 63 microns) of 324 Nova Scotian till samples. Although there are no very obvious groupings, the distribution in the lower half of the scatter suggests some degree of separation along an almost vertical line starting from the 50% gravel - 50% mud point. Two areas, labelled A and B have been distinguished on Figure 25.

In an effort to differentiate possible clusters in Figure 25 the percentages of gravel, sand, and mud for each sample were plotted on a four-end-member tetrahedron, with the percent mud subdivided on the ratio of silt to clay. Separate ternary diagrams of the percent gravel, sand, and mud were plotted for planes with silt/clay ratios respectively of 0/1, 1/1, 2/1, 3/1, 4/1, 5/1, 6/1, and 7/1. If two planes had a similar distribution of samples and were in consecutive order they were combined. This was the case for the planes 0/1 and 1/1, for 2/1, 3/1 and 4/1, and for the planes greater than 4/1. Accordingly there are finally only three separate ternary diagrams (Figure 26). In all cases the samples are plotted on the plane with the highest silt/clay ratio for that group, i.e., samples with silt/clay ratios lower than 2/1 are plotted on the plane with a 2/1 silt/clay ratio, and samples with silt/clay ratios from 2/1 to 4/1 are plotted on the 4/1 silt/clay ratio plane, and samples with silt/clay ratios higher than 4/1 are plotted on the 100% gravel-100% sand-100% silt plane.

The four-end-member tetrahedron (Figure 26) indicates that: 1) all

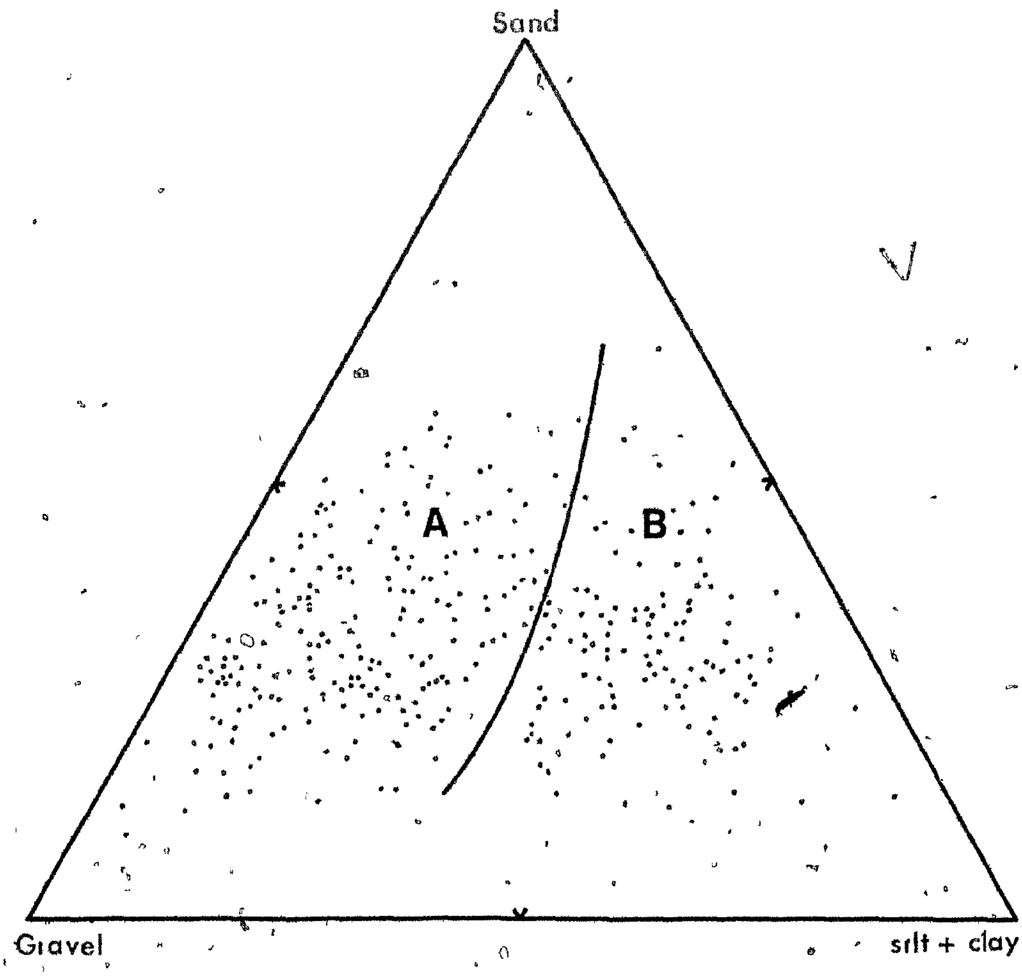


Figure 25. Gravel, sand, and silt + clay composition of till samples.

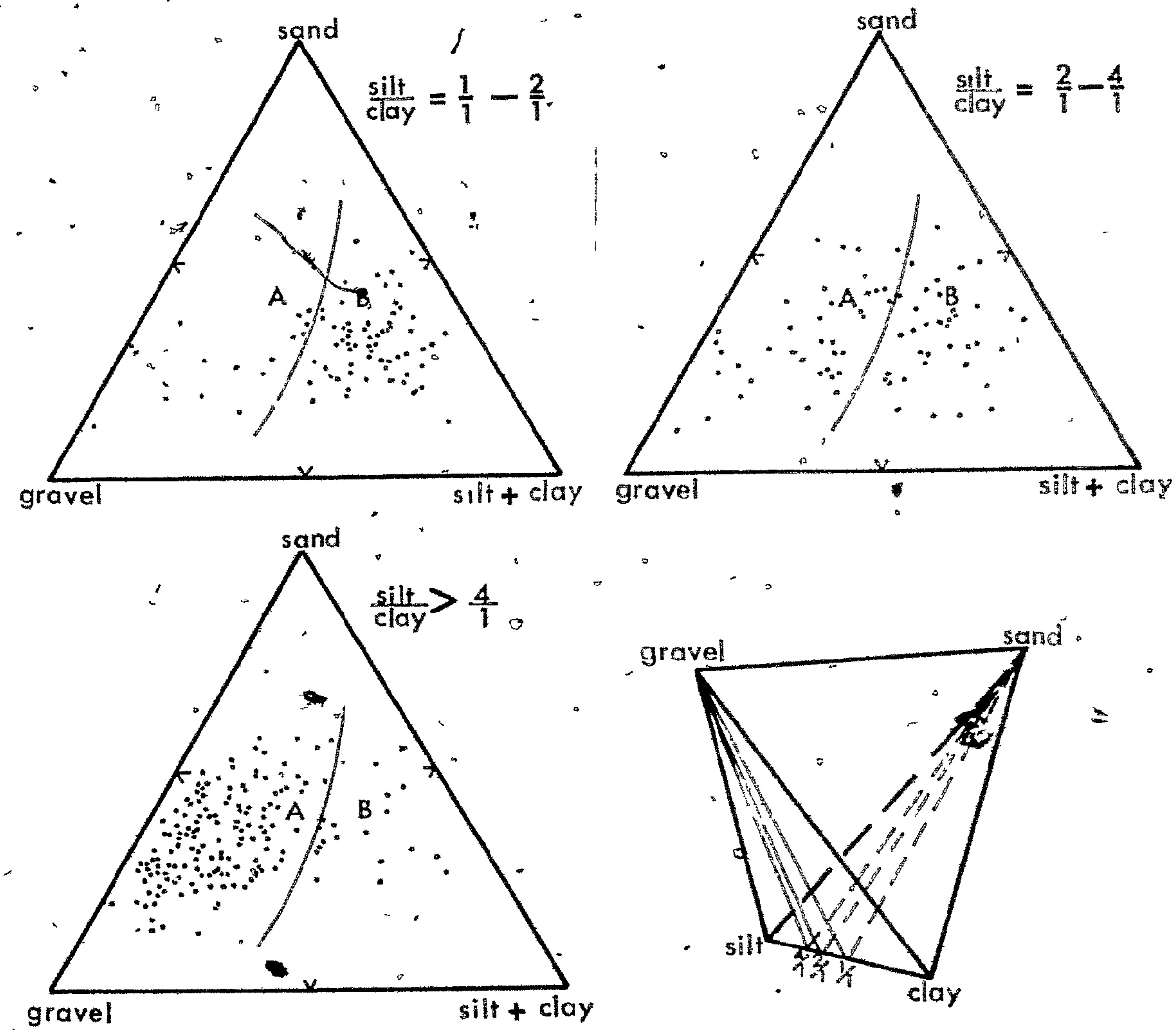


Figure 26. Variation in gravel, sand, silt and clay composition of Nova Scotia till. The lower right diagram shows the planes for the individual ternary diagrams.

the samples have silt/clay ratios greater than 1 (except for samples 404, 419 and 556, which are relatively close to 1 ; 2) samples with silt/clay ratios from 1/1 to 2/1 are rich in the fraction less than 63μ, that is silt and clay; 3) as the silt/clay ratio increases from 2/1 to 4/1 there is an increase in the gravel component at the expense of the silt and clay; 4) the samples with silt/clay ratios greater than 4/1 are rich in gravel and relatively poor in silt and clay; 5) the amount of sand is less than about 60% and in most cases less than 50%; 6) the percent sand is relatively constant in the three diagrams and 7) there is a weak but natural division between the gravel-rich tills and the silt and clay-rich tills. This twofold division is shown by a dashed line on Figures 25 and 26.

A lithofacies map (Figure 27) has been constructed which shows the distribution of the silt and clay-rich tills delineated as field B in Figure 25. Slight variations in drawing the upper part of the division between A and B zones on the ternary diagrams would affect very few samples and would not alter significantly the pattern shown in the lithofacies map. The map indicates that the till on the north side of the Cobequid Mountains along the Northumberland Strait is rich in silt and clay. Another tract of silt and clay-rich till 50 to 60 km wide stretches northeast-southwest between New Glasgow and Windsor. Small patches of muddy till are also found in the eastern and central parts of the Annapolis Valley and over North Mountain, in the area between Sambro and St. Margaret's Bay, and in the Cow Bay region east of Halifax. Minor scattered occurrences of muddy till are found throughout the rest of the region. The distribution of silt and clay-rich tills shows several noticeable features. Firstly, the large areas north and

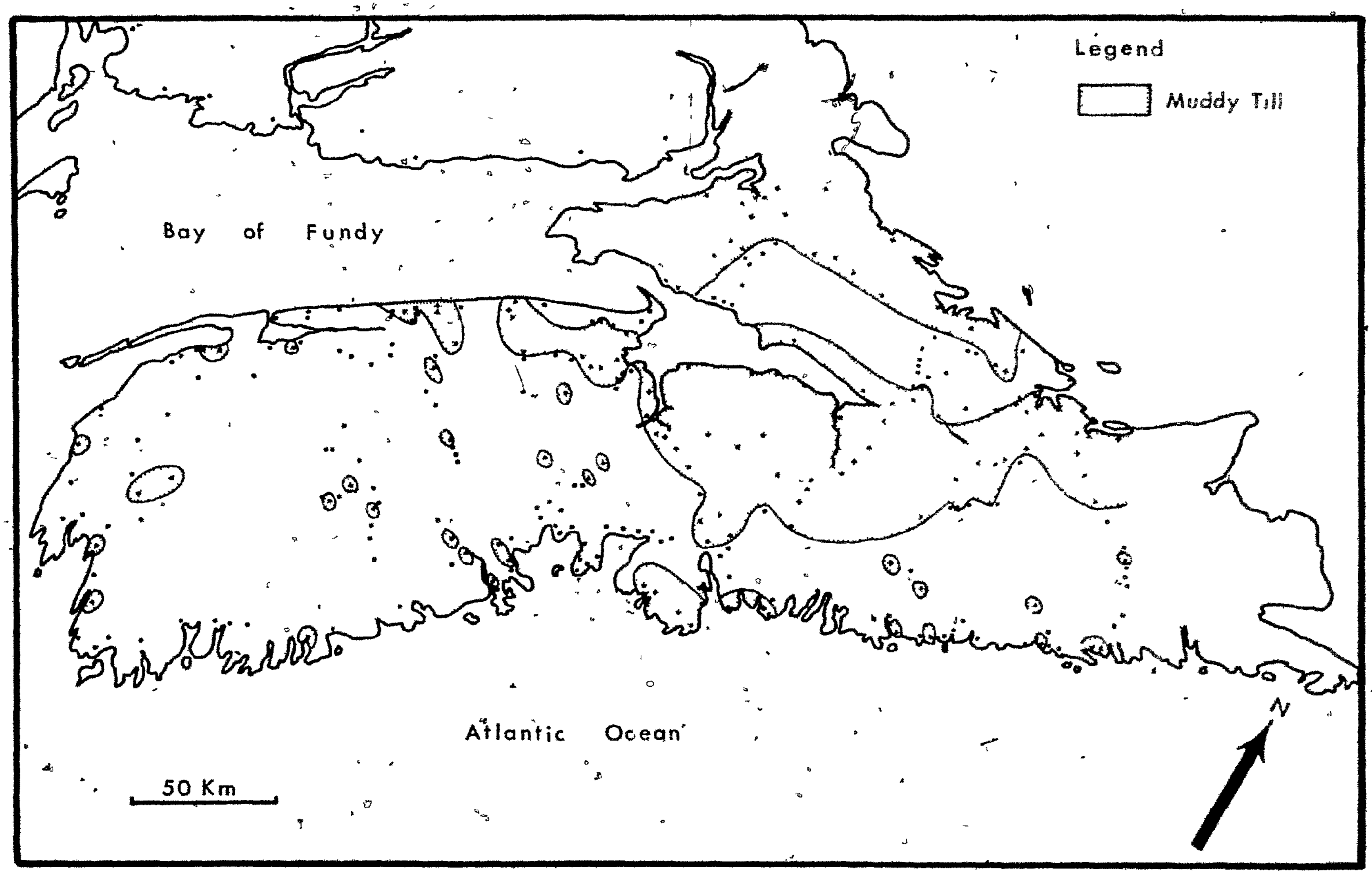


Figure 27. Lithofacies map showing the distribution of muddy till.

south of the Cobequid Mountains are centred on the Carboniferous Lowlands. The underlying bedrock in these areas is mainly shale and sandstone, as is also the case with the two patches in the Annapolis Valley. Secondly, in the belt of Carboniferous Lowland south of the Minas Basin and Antigonish highlands, the southern boundary of the silt and clay-rich tills extends southwards for some distance over the slates and metaquartzites of the Meguma Group; this is especially apparent in the area north of Halifax. Thirdly, some of the isolated patches of silt and clay-rich tills scattered over the Meguma Group and Devonian granite are centered on the drumlin fields, although others are not.

Figures 28 and 29 have been constructed to investigate further the relationship between gravel and mud content of drumlin till and the surrounding till sheet. The drumlin samples from the Eastern Shore are richer in clay and poorer in gravel as compared to the till sheet (Figure 28). There is only a little overlap. The drumlin samples from the Lunenburg drumlin field are also generally more muddy than the surrounding till sheet but there is considerably more overlap. There is no apparent difference in the gravel and mud content of the red clay drumlin and the slate drumlins in the Lunenburg drumlin field (Figure 29).

The occurrence of silt and clay-rich tills over texturally similar bedrock in the Carboniferous Lowland and the Annapolis Valley as well as in drumlin fields to the south provides strong evidence that the drumlin till originated in these regions. Grant (1963) postulated that the origin of the material for the red clay drumlins lay in the Minas Basin region. His

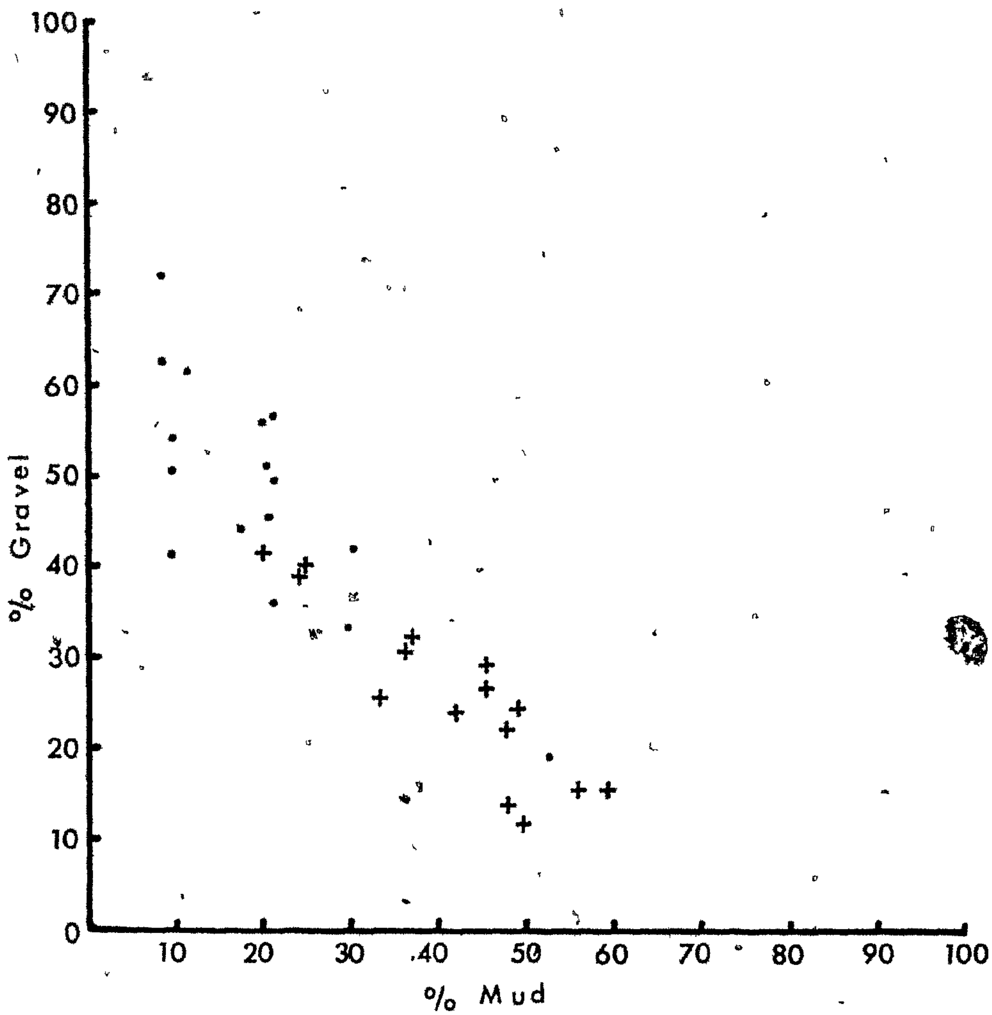


Figure 28. Variation in the gravel and mud content of drumlin samples (+) and non-drumlin (.) samples overlying Meguma bedrock northeast of Halifax.

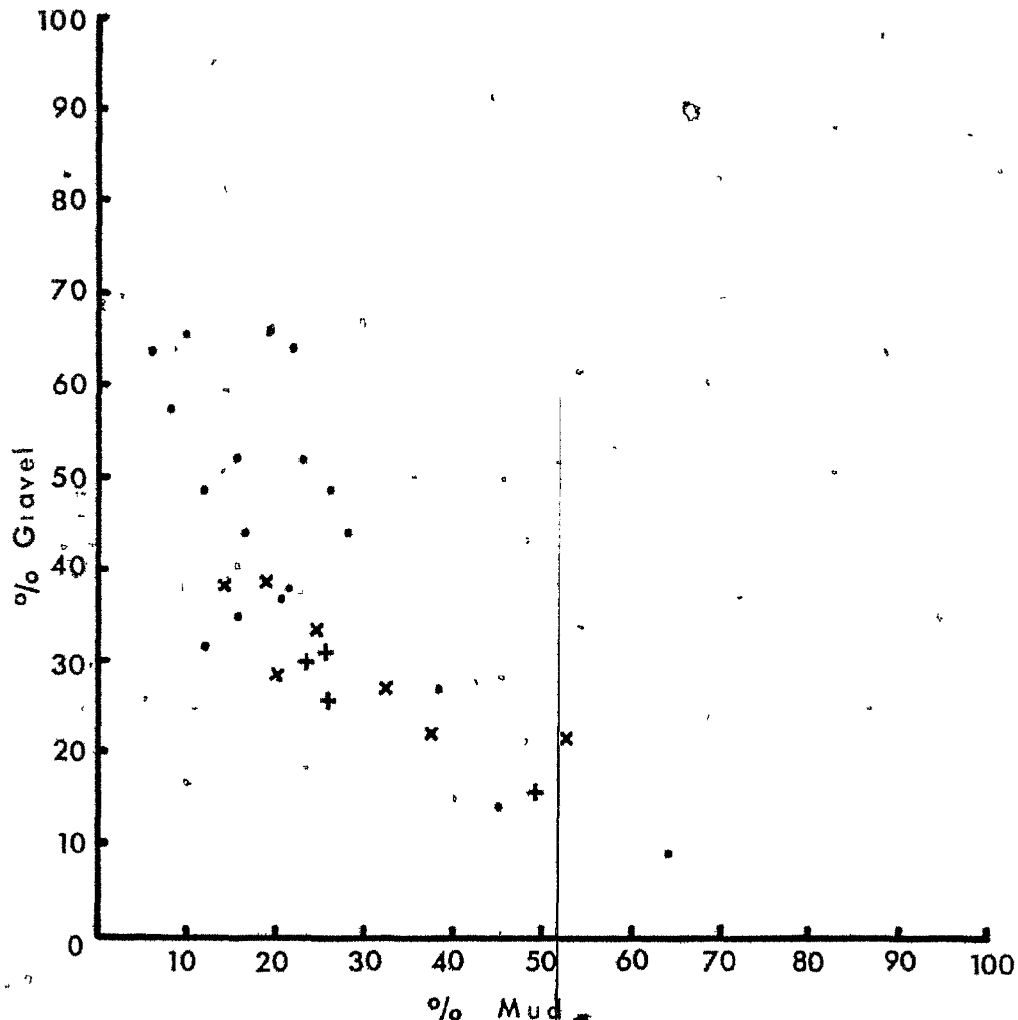


Figure 29. Variation in the gravel and mud content of slate drumlins (x), red clay drumlines (+), and non-drumlin (.) samples overlying Meguma bedrock in the region of the Lunenburg drumlin field.

conclusion was based on the texture of the drumlin matrix compared with the present inter-tidal mud in Minas Basin. Neither source can be considered exclusive for two reasons: 1) red inter-tidal silt and clay presumably were abundant in pre-glacial Minas Basin, and Northumberland Strait; 2) the breakdown of Triassic and Carboniferous rocks would produce grades of material similar to inter-tidal sediment in the area.

Examination of Figures 27, 28 and 29 shows that there are tills outside the drumlin fields which are texturally similar to that of the red drumlins and the Carboniferous Lowlands for examply the grey slaty drumlin till west of the LaHave River. However, there are also tills in the drumlin fields themselves which are texturally different from the red silt and clay-rich drumlin till, as measured by the parameters in this study.

As till at any one locality is a mixture of locally- and distantly-derived pebbles (Grant 1963), and of local and foreign heavy minerals (see later section), it is presumed that texturally the till matrix has both a local and a foreign component. The amount of "Minas Basin" material admixed with local material varies greatly, as shown by Grant (1963). He concluded that the "Minas Basin" material is found both in and between drumlins, and that where the greatest concentrations occur, the till is red. The till between the drumlins is richer in components of local origin, despite the fact that it occurs inside the limits of the drumlin field.

Till that is texturally similar to that of tbe Carboniferous Lowlands occurs over granite, slate and metaquartzite in the Uplands. This till is presumed to have formed primarily from local fine-grained rock or to have an abnormally high content of Carboniferous and Triassic material.

These conclusions are contrary to those of Boulton (1974, 1975) who found that large particles (>-7Ø) and very small particles (<-3Ø) both have relatively small velocities over the glacier bed, while particles of intermediate grain size move relatively more rapidly. Boulton found that the clast mode of a till from Breidamerkurjokull in Iceland coincides with the relatively high values of particle velocity. In the present study, this would mean that the gravel fraction moved quickly and the combined sand-silt-clay fraction moved more slowly. Hence the fine tills without a large gravel fraction would be most easily deposited by lodgement whereas the coarse gravelly tills (mode <-7Ø to >-3Ø) should be transported further. In Nova Scotia the basal tills are richer in the <-7Ø to >-3Ø fraction, which is an apparent contradiction of Boulton's findings. The inconsistencies between these two studies are possibly the result of: 1) Transport of large amounts of post-Devonian sediment in the <-7Ø to >-3Ø size fraction, followed by its breakdown in the area to the south and southeast of the source, at which time it would be deposited almost immediately. This alternative seems unlikely as the source rock is very soft and would break down rapidly; 2) The sediment was not carried in the basal part of the ice but rather in an englacial position. This seems more likely since no variations in flow rate would cause deposition as the sediment was not in contact with the substrate.

Conclusions

1. Two types of till are found in the study area; one is rich in gravel and the other is rich in silt and clay.

2. These two modes are the product of mixing resistant rocks, such as granite, slate, metaquartzite and basalt, with less resistant rocks, such as sandstone, siltstone and shale.
3. The hard rocks are found mainly in the Cobequid Mountains and in the uplands of the province (Devonian batholith, Meguma slate and metaquartzite).
4. The silt and clay-rich till is centered over the Carboniferous Lowlands north of the Cobequid Mountains and in the Minas Basin region.
5. The occurrence of muddy till outside the Carboniferous Lowlands can be attributed to two things. Firstly, most of the samples are from silt and clay-rich drumlins containing material derived from the Carboniferous Lowland. Secondly, a few silt and clay-rich samples from outside the known drumlin fields are either dislocated till sheet fragments transported from the Carboniferous Lowlands or in some cases the product of comminution of local fine grained bedrock.
6. The grey slate drumlin till found west of the LaHave River in the Lunenburg drumlin field is texturally similar to the red clay drumlin till found on the east side of the river.
7. The per cent gravel (or the gravel/mud ratio) can be used as a general indication of whether a till sample has local or foreign affinities. Local till over 'hard rock' is rich in the gravel fraction, but over Carboniferous and Triassic sediments the local till is rich in silt and clay.
8. The sand content of any till sample appears to be rather unpredictable.
9. The long distance transport of muddy till, which according to Boulton

resists transport in favour of coarser material in the -3Ø to -7Ø range, is believed to be due to englacial transport.

CHAPTER 7

PEBBLE EQUIFREQUENCIES

Introduction

Indicator boulders have been used extensively during the past one hundred years, especially in Scandinavia. Historically they have been used to determine the direction of glacier movement and for finding ore deposits (Jones 1973, Shilts 1973, Nichol and Björkelund 1973, Andersen 1945, V. Milthers 1913, K. Milthers 1945).

Indicator boulders afford the best and most reliable method for determining the direction of glacier movement. The ideal source of a good indicator is a point source, i.e. an outcrop of rock which has a small areal extent and a unique and easily identifiable lithology. As the glacier moves over the outcrop the indicator is incorporated into the ice, dispersed and deposited in a fan downstream from the outcrop. The length of the fan is a function of the resistance to breakage of the rock as well as of the rate of flow of the ice and the method of transport and deposition of the till. Gillberg (1965) has shown that the topography of the depositional surface, the kind of debris, and the presence or absence of another material, have strong influence on the distribution of indicator boulders. These factors will affect the indicator fan only to a minor degree. Mapping the occurrence of the indicator downstream from the source will show an areal variation which is the result of all the ice movements of different ages that have affected the area (Gillberg, 1965). If the fan is the result of one glaciation with the ice moving in only one direction, it will be a train with almost parallel sides. If the area was glaciated several times from slightly different directions or if the directions of basal movement changed during the life of the glacier, the fan may spread out by as much as 80° or more (Andersen 1945, Rankama 1965, Jones 1973, Gillberg 1965, 1967, 1968). Float mapping, i.e. mapping indicator boulders of unknown origin, is a powerful prospecting tool in glaciated areas (Dreimanis 1958, Grip 1953, Shilts 1971, Jones 1973). This technique is based on the observation that the source is usually located relatively close to the apex of the indicator fan.

The size of fans varies greatly. For example, indicators from Finland have been found in Denmark and northern Germany, over a thousand kilometres away (Andersen 1945). In other instances the fans are only a fraction of a kilometre long (Dreimanis 1958, Jones 1973). Grip (1953) describes an outcrop with no indicator fan at all. Gillberg (1965) has shown that blocks are comminuted exponentially downstream. If this is the case then how did the indicators from Finland survive transport to Denmark and north Germany? Even the largest and hardest rock would disappear after a few hundred kilmetres of ice transport according to Gillberg's model. Englacial or supraglacial transport must have been the primary modes of movement of this material.

Indicators are not exclusively boulders but can be any size material transported downstream from its source by an overriding glacier. The gravel size fraction is commonly used in indicator studies because it is easy to identify. Lundquist (1935) and Flint (1947) used the 20 cm size fraction; Slatt (1971) used the 4-2 mm fraction; and still others have used the fine sand fraction (Gwyn and Sutterlin, 1971). Grant (1963) used the 5 to 22 mm fraction whereas Nolan (1963) used the 63μ to 500μ fraction in their respective studies in Nova Scotia.

In the present study two sizes of indicators have been used: the 5 to 22 mm fraction and the 63μ to 500μ fraction.

Method

Grant (1963) traced 50 rock species to 7 source regions in Nova Scotia. He was, however, mostly concerned about the origins of the exotic pebbles in the drumlin fields along the South and Eastern Shores. The distribution of easily identifiable lithologies was thought to be adequate for the present study. Consequently, pebble counts were made of coarse grained, leucocratic igneous rocks consisting primarily of diorite, granodiorite, granite and syenite, which will henceforth be termed granitic erratics. Pebble counts were also made of fine grained melanocratic rocks consisting primarily of basalt although diabase and andesite may be represented in small amounts. The second type will henceforth be termed basaltic erratics, because of their relatively limited distribution and distinctive lithologies.

The percentages of coarse grained granite rocks and fine grained basalts were determined for the 5 to 22 mm fraction of all the samples. At least 300 pebbles were counted per sample.

Figures 30 and 31 show the equifrequency distribution of basaltic erratics and granitic erratics. The potential sources in Nova Scotia are shaded. Interpretation is based on the assumption that the indicators should be more numerous near the origin than at some distance from the source. Grant (1963) has shown that this is not always the case, as Cobequid indicators are concentrated in till between Halifax and St. Margaret's Bay and decrease in a northerly direction before they increase again. Chapman and Putnam (1966) also note that Shield rocks increase away from the source in the Peterborough drumlin field in southern Ontario. Gillberg (1965) describes situations in Sweden where a large indicator block has been transported some distance downstream from the source before it was crushed. The crushing would add a large number of smaller indicators to the till at that point and it would show up as an anomaly on the equifrequency map. As the anomalous occurence of Cobequid indicators described by Grant occurs over granite, which is in this case a source region, the possibility that the indicator might increase away from the source is thought to be minimal. It is also felt that some of the "granitic" Cobequid indicators used by Grant may have been derived from the Devonian granite batholith which has been shown by MacKenzie (1974) to be composed of at least five different types of granite. Red granites, previously thought to occur only in the Cobequid Mountains, have been identified in the Devonian batholiths (Marc Charest, personal communication 1976). Grant's anomaly between Halifax and St. Margaret's Bay may in fact not be real.

Distribution of Basaltic Erratics

Figure 30 shows the equifrequency distribution of basaltic pebbles in Nova Scotian till. The map shows that basically three separate indicator fans were formed:

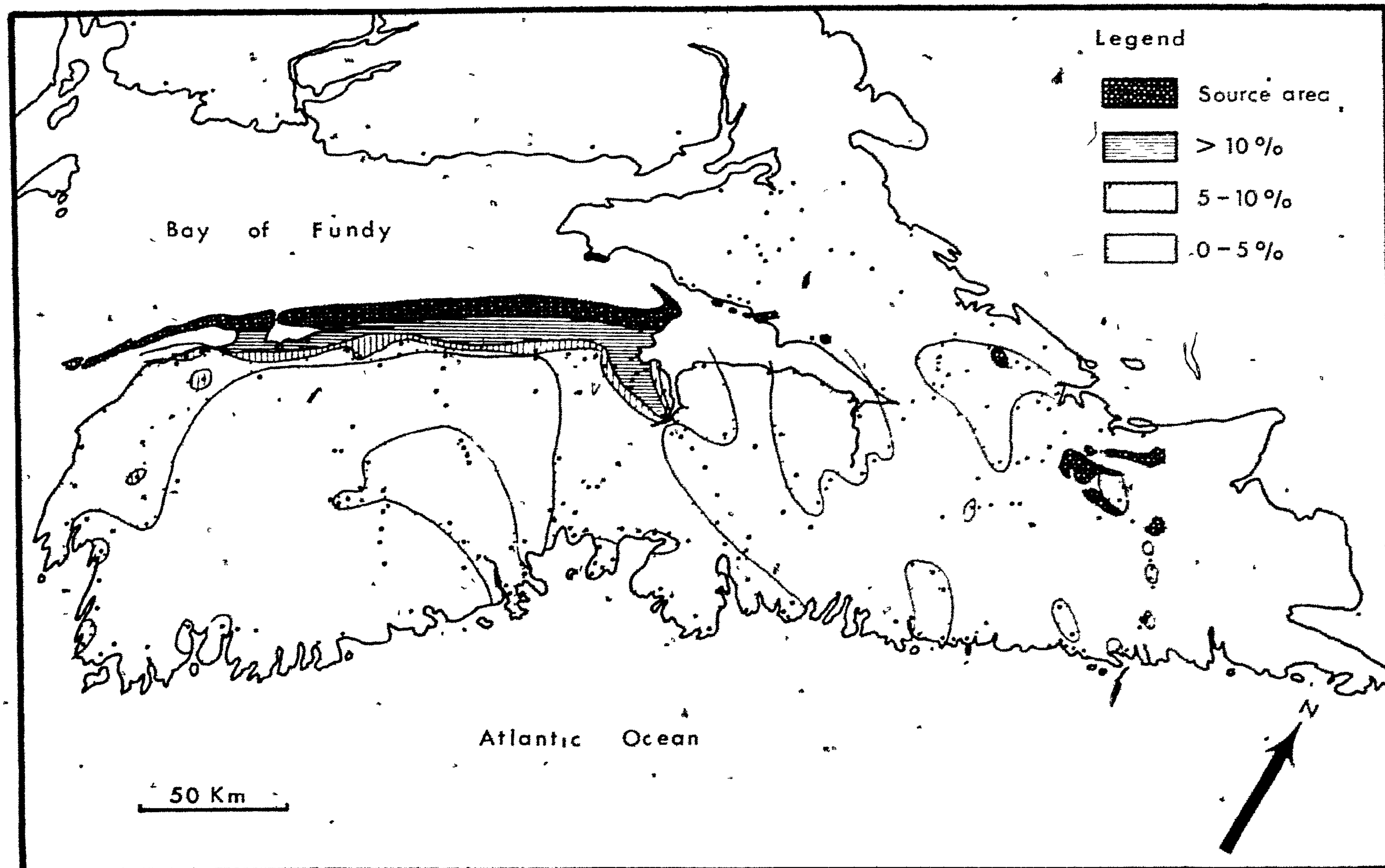


Figure 30. Distribution of basaltic erratics.

1) southeast of North Mountain
2) southeast of the Traissic outliers on the north side of the Minas Basin; and
3) south and southeast of the River John Group in the eastern end of the Cobequid Mountains.

The largest exposure of basalt is the North Mountain basalt which extends for about 200 km along the south shore of the Bay of Fundy. Smaller outliers of the same Triassic basalt are found at Cape D'Or, Clarke Head, Five Islands and Bass River to the east. The Triassic basalt is the youngest bedrock in Nova Scotia with the exception of a few isolated pockets of Cretaceous sediment in the Shubenacadie Valley. The Triassic basalt has therefore not been recycled into younger sandstones and conglomerates in Nova Scotia. This well-defined exposure of basalt is thus an excellent indicator.

Gillis (1964) reports 1,100 feet of basalt intercalated with shales, sandstones, limestone and oil shale in the River John Group in the eastern end of the Cobequid Mountains. He also reports the presence of volcanic rock fragments to a minor degree in the Millville Conglomerate of the Pictou Group. The River John Group is considered a point source but the Millville Conglomerate and Pictou Group have almost insignificant amounts of basaltic fragments (Gillis, 1964).

The North Mountain Basaltic Erratics

The concentration of basaltic pebbles in the till falls off very rapidly southeast of the source exposure. Well defined indicator fans are however, to be found in the east southeast of Kentville and in the west southwest of Annapolis Basin.

The lobate nature of the distribution of basaltic pebbles follows the northern boundary of the Devonian granite batholith. The batholith also forms a high obstruction to glacier flow. The sandy till which has formed over the granite is very permeable, which could have resulted in the weathering out of the basaltic pebbles after deposition of the till. Also the texture of the granite till could have resulted in the destruction of the basaltic pebbles or dilution to such an extent that large amounts of material would have to be examined to find basaltic pebbles. The occurrence of basaltic pebbles over parts of the granite batholith in the Halifax, Mahone Bay and Kentville area, and the decrease in the basaltic pebbles before reaching the granite indicates that the distribution is primarily controlled by topography. Ice moving upslope from the Bay of Fundy would have been in a state of compression; movement would have been slow and friction high. Material eroded from North Mountain would have been deposited on the proximal slope of South Mountain very shortly after its incorporation into the ice. Indicators would, however, be carried away by the more actively moving ice in the low areas surrounding the granite batholith. As the ice slowly moved up the proximal slope the upper ice probably sheared over the basal ice and moved rapidly over the batholith. On descending the lee slope the ice spread out and flowed, easily distributing the few indicators, which would have been sheared up into the higher ice. Basaltic pebbles were scattered from Yarmouth to Chezzetcook Inlet on the leeward side of the topographic divide which runs down the axis of the peninsula.

The concentrations of basaltic erratics in the Lunenburg drumlin field and the area around Halifax, and Mahone and St. Margaret's Bay are associated with the positions of the river valleys which transect the province at these two locations. The Avon River on the northwest and Mahone Bay, St. Margaret's Bay, and Bedford Basin-Halifax Harbour on the southeast form a corridor which allowed relatively easy passage of ice across the province. The Margaretsville Gap in North Mountain and the LaHave River Valley formed a similar corridor and also facilitated the passage of ice across the peninsula. These corridors are the site of Grant's "ice currents".

The Clarke Head, Five Islands, Bass River Basaltic Erratics

The basaltic pebbles from Clarke Head, Five Islands and Bass River are distributed in a fan southeast of the source. The fan is short and restricted mostly to the Shubenacadie River Valley and the adjacent lowland. Sporadic occurrences of basaltic pebbles are also found on the leeward side of the divide separating the Shubenacadie River Valley from the rivers draining into the Atlantic Ocean. The basalt in the till around Ship Harbour is believed to have been derived from the fan centered on the Shubenacadie River Valley. It is difficult to conclude that the length, shape and position of the train is strictly controlled by the topography. The limited lateral extent and scarcity of outcrop of the source resulted in only a little basalt being added to the overriding ice. The train does indicate that the ice flowed southeast over Minas Basin and up the Shubenacadie River Valley where most of the basaltic indicators were deposited.

The River John Basaltic Erratics

This is the least well defined basaltic indicator train in mainland Nova Scotia. The incorporation of basaltic rock fragments into sediments overlying the River John Group, namely the Pictou Formation and Millville Conglomerate, may mean that the source is somewhat larger than that shown on the map. The dispersal pattern shows that the ice moved in a southeasterly direction and that the concentration decreased to zero but picked up again around Ecum Secum, after crossing the "skip zone" centered on the drainage divide between the source area and the Eastern Shore.

The occurrence of basaltic pebbles at Hardwood Hill near the mouth of West River indicates that ice flowed in an easterly direction at one time.

Distribution of Granitic Erratics

The known sources of intrusives are shown in Figure 31. Gillis (1964), also reports the presence of Cobequid intrusive clasts as much as a meter in diameter in the River John, Riversdale and Pictou Groups in the area west of Pictou. Stevenson (1958) notes the presence of many granitic pebbles in the Annapolis Group, Pictou Group and Horton Formation around Truro. Benson (1967) reports granite pebbles in the conglomerates of the Horton Formation and the Pennsylvanian in the Hopewell area. Weeks (1948) records

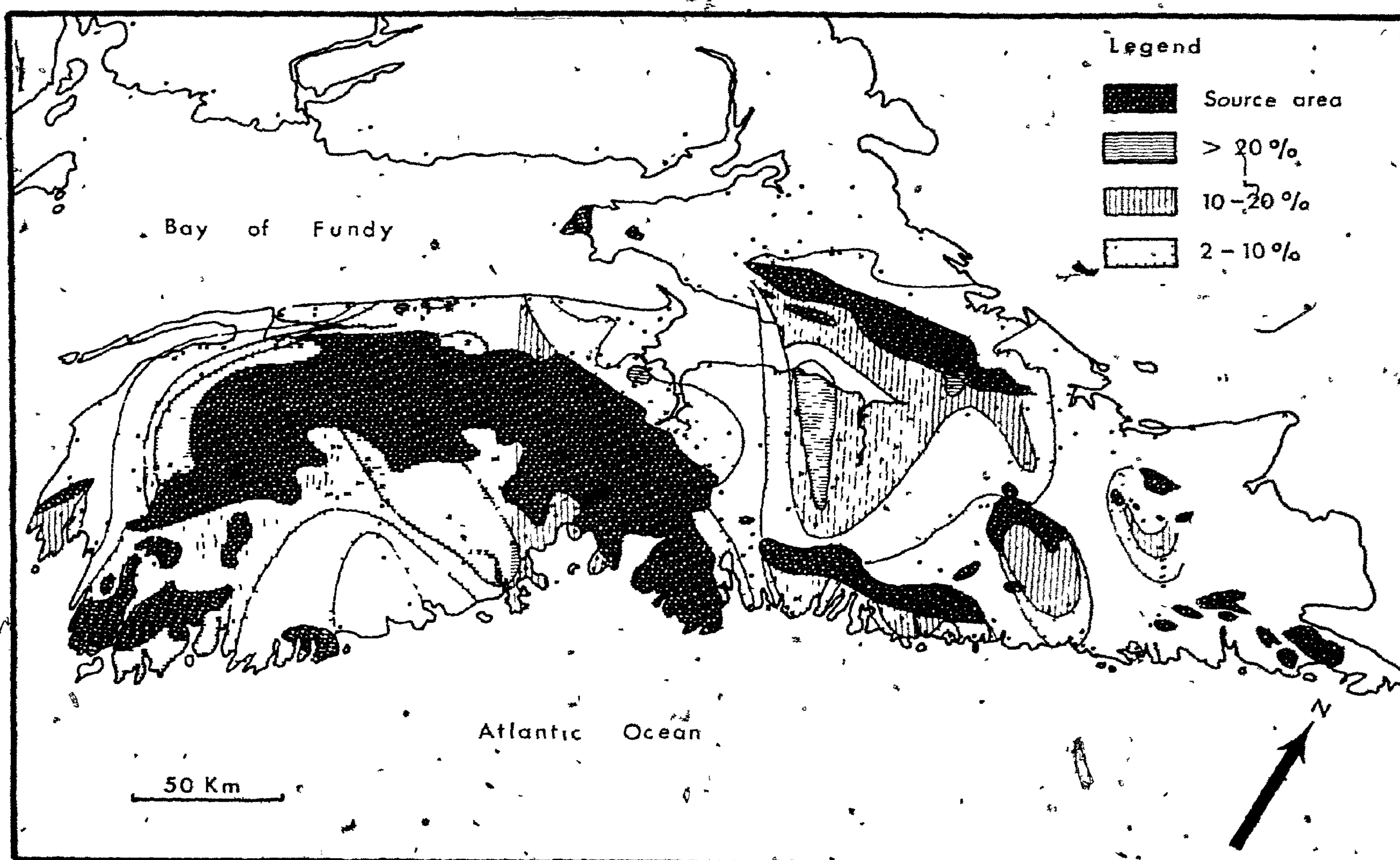


Figure 31. Distribution of granitic erratics.

granite pebbles in the basal Pennsylvanian in the Londonderry and Bass River areas. Stevenson (1959) reports granite clasts in the Horton in the Shubenacadie and Kennetcook areas. Taylor (1969) observes conglomerates in the Annapolis Group in the western end of the Annapolis Valley; these congomerates probably contain granite clasts. Freeman (1972) reports in his work on the Cheverie Formation south of Minas Basin that "In the alluvial fan arkosic pebble conglomerates are so similar to the granites compositionally that at first glance they might be mistaken for one another". Also, Frankel (1966) described conglomerate beds in southeastern Prince Edward Island with clasts of gneiss, granite, granodiorite and basalt. Poole <u>et al.</u> (1972, p. 294) report conglomerates in the Cumberland Group derived from the western end of the Cobequid Mountains. The igneous plutons in Nova Scotia have obviously contributed large quantities of pebbles to the conglomerates in the immediate neighbourhood and these "second hand" sources may have added considerably to the tills. It is, however, impossible to determine accurately the proportion of the conglomerates which represents pebbles of intrusive origin, to what extent these conglomerates were exposed to glacial erosion, and what percentages of these pebbles were incorporated into the resultant till. It is assumed that they may constitute several percent of the pebble fraction in the overlying till of those areas.

The intrusive rocks in mainland Nova Scotia can be divided into three groups: the South Mountain batholiths, the Eastern Shore batholiths, and the Cobequid intrusives.

South Mountain Indicator Train

The concentration of granitic indicator pebbles decreases in all directions from the South Mountain batholith.

1.) To the northwest of the batholith, more than 20% granitic pebbles are to be found in the till at Nictaux Falls and at a number of localities on the North Mountain basalt. The origin of the South Mountain granites on North Mountain has been the subject of controversy for almost a hundred years (Dawson 1893, Goldthwait 1924, Hickox 1958, and others). Hickox (1958) established that the granites were of South Mountain origin and not derived from Cobequid or New Brunswick sources as suggested by Goldthwait (1924). The granite equifrequency lines on Figure 31 support Hickox's view that ice flowed from South Mountain northward into the Bay of Fundy. Prest and Grant (1969) argue that the northward flow over North Mountain was caused by drawdown resulting from incursion of the sea into the Bay of Fundy during the late Wisconsinan. Marcussen (1974) points out that sediment is transported only when an ice sheet is advancing - similar to bulldozing. He bases this opinion on the observation that the basal ice at Camp Century, 100 km from the margin of the Greenland ice sheet, is 100,000 years old. If this is the case, granite pebbles could not have been transported over North Mountain if the movement was only in response to drawdown. The indicators would have been transported northward only if there was active flow in a northward direction. This flow could have been the result of actively flowing ice moving outwards from the South Mountain highland or from active flow from the northeast down the long axis of the peninsula. In either case the Bay of

Fundy would have acted as a chute discharging large quantities of ice into the Atlantic Ocean (Shepard, 1930; Prest and Grant, 1969).

ii.) Along the north side of the batholith a limited area around Windsor and Kentville yields granite-type pebbles that constitute 2% of the pebble fraction. This percentage decreases towards the north and east, and the material may have been transported by radial outflow from a late Wisconsinan ice cap centered over South Mountain, as proposed by Hickox (1958) and others. Although it may be argued that the pebbles and boulders in the till to the north and northeast of their source were derived from conglomerates around Minas Basin or even by deflection of the ice to the east by South Mountain itself this is unlikely because of the large size (up to a metre) of some of the erratics and because of the obvious indication of radial outflow near Middleton. The distribution of granite erratics in the Windsor-Kentville area is taken as further corroborating evidence of radial outflow of ice from South Mountain.

iii.) The decrease in granite indicators westward from the batholith suggests active flow from the centre of the peninsula. Alternatively, the main ice moving southeastward may have been deflected to the west by the batholith itself.

iv.) The main ice flow from the north-northwest cannot be separated from the later radial flow simply on the basis of the distribution of granite indicators in the area south of the granite batholith. In this area the two directions would be parallel.

v.) The equifrequency lines in the Yarmouth to Shelburne region indicates that the flow was generally towards the south. In the Yarmouth area flow was towards the south-southwest, whereas near Shelburne flow was more southerly.

vi.) Ice-flow in the LaHave River Valley was in a southeasterly direction. This indicator train is well defined, rich in granite pebbles, and coincides with the Lunenburg drumlin field. The long axis of the indicator train also matches the direction of the long axes of the drumlins (Cann and Hilchey, 1958).

The granite pebble indicator fan coincides with the basalt pebble indicator fan in the Lunenburg drumlin field. This large, well-defined fan is the result of very active excavation of both basalt and granite between Margaretsville on the Bay of Fundy and New Germany in the center of the peninsula. Grant (1963) calculated the volume of the basalt deposited in the Lunenburg drumlin field and found that it compared will with the volume of material missing in the gap in the North Mountain basalt north of Nictaux Falls. The reason for the active erosion in this area is probably rapid ice flow down the LaHave River valley. Once the ice had filled the Minas Basin and Bay of Fundy it piled up against the North Mountain and South Mountain divides and finally crossed it first in the east and west and then in the middle, as the divide is highest south of the area between Middleton and Bridgetown. A considerable "head" would have to be built up to the north before the ice front would cross. Once the ice crossed the topographic divide it flowed very rapidly down the lee slope toward the southeast. The rapid flow of ice caused increased erosion in the high areas of North Mountain basalt and the South Mountain batholith.

The anomalously high concentrations of granite pebbles in the till around Halifax Harbour and Bedford Basin is the result of ice flowing into Bedford Basin and Halifax Harbour off the higher pluton to the west.

The Eastern Shore Indicator Trains

Small but well-defined granite indicator trains are located south and southeast of three plutons on the Eastern Shore and in the Antigonish Highlands. These fans were formed by ice moving towards the southeast. This is the same direction as is indicated by the River John, Clarke Head, Five Islands, and Bass River basaltic indicator trains.

The Cobequid Mountains Indicator Trains

The source of granitic rocks in the Cobequid Mountains extends on a broad front almost east-west perpendicular to the direction of the last ice movement (Grant, 1963). Consequently a very broad fan of granitic erratics has formed to the south of the intrusives. Interestingly the area of spread narrows southward, possibly as a result of destruction of the granitic pebble components. An exceptionally high concentration of indicators (20%) is found to the west of and parallel to the Shubenacadie River. The position of this high concentration of indicators and the position of the fan is governed by the shape and position of the source of the erratics. The equifrequency lines on the southwestern side of the fan, however, are very close together. This may be the result of several factors. The ice flow may have been channelled by the Shubenacadie River Valley. Ice flow may have been perpendicular to the axis of the Cobequid Mountains but it could have been deflected to the east by ice moving from Kentville and Windsor towards Halifax. The southeastern end of the fan appears to have been influenced by the topography but nothing more positive can be said about this fan until the precise sources in the Cobequid Mountains are investigated more thoroughly.

The origin of the undulation in the equifrequency lines at the southeastern end of the Cobequid Mountains is an enigma. The lobe at this locality may possibly have some unknown control in the source area. On the other hand, ice flow on the north side of the Cobequid Mountains may have been diverted towards the east and would not have been able to breach the Cobequid Mountains until it reached the Stellarton Gap. At this point south southeasterly flow was again possible. The low concentration of pebbles to the south of the eastern end of the Cobequids could be the result of diversion of the ice, creating a "lee". The asymmetry of the equifrequency lines south of the Cobequids may also be a result of this "lee" effect, or 'late' ice in this area.

The dispersal of granitic indicators on the north side of the Cobequid Mountains, as indicated by the equifrequency line, is probably not due to northward ice flow. The pebble concentrations are considered too low and the sample localities too few to conclude that the distribution of pebbles is the result of ice movement and not merely the result of the presence of granite pebbles in the underlying conglomerates.

Conclusions

Equifrequency maps showing basaltic and granitic erratic distributions indicate that:

1. The ice moved in a generally southeaterly direction across most of the province.
2. In the southwestern part of the province the ice moved in a more southerly direction.
3. Basal ice was deflected to the east and to the west around the highland formed by South Mountain and North Mountain.
4. The regional variation in the topography played an important role in determining the distribution of indicators in the Windsor area.
5. At a late stage, ice probably flowed actively northward from the South Mountain batholith across the North Mountain basalt.
6. There is not sufficient evidence as yet to corroborate the existence of an ice cap with radial outflow in the eastern end of the Cobequid Mountains.
7. Early ice probably flowed eastward parallel to the north side of the Cobequid Mountains.
8. Cobequid erratics decrease in a southerly direction away from the source.
9. Outcrop size, shape, orientation and position as well as the topography were the controlling factors governing the position and shape of indicator fans.

CHAPTER 8

HEAVY MINERALS

Introduction

Although heavy mineral analysis is regarded as a standard analytical technique in the study of glacial till, the number of rigorous studies is small. In most of the studies the samples are few and, although the analyses are quantitative, statistical treatment of any kind has been ignored.

Kruger (1937) made one of the earliest studies on the mineralogy of tills in Minnesota. He was primarily concerned with detecting differences in drift of various ages. He analysed 52 samples of Kansan, Illinoian, Iowan, Wisconsin Red and Wisconsin Grey till and 5 samples of unknown origin. He concluded that the great complexity was due to the admixtures and reworking of earlier soils and tills as well as the great variety of rock types over which the glaciers had passed. In spite of this, he felt that there were diagnostic differences between these tills of various ages.

Arneman and Wright (1959) analysed the heavy mineral fraction of 14 till samples, also from Minnesota. They felt that the presence of most of the minerals could be accounted for, but concluded that heavy mineral analysis of tills as a method of identifying and characterizing tills is not as effective as stone counts, mainly because of the difficulty of assigning particular minerals to particular rock types.

By far the largest contribution to heavy mineral analysis of tills has been made by A. Dreimanis and his students at the University of Western Ontario in London, Ontario. The first study (Dreimanis and Reavely, 1953) was aimed at differentiating the upper and lower tills on the north shore of Lake Erie. Heavy mineral analysis was carried out on 33 samples, 15 from the lower till and 18 from the upper. Garnet was the only mineral showing a significant percentage difference between the two units. The upper till contained more purple garnet than red garnet, the lower till a larger percentage of red garnet. Although this was considered to be the distinguishing feature there was overlap in some of the samples. There were other noticeable differences in the mineralogy of the two tills, but they felt that more sampling was needed to clarify the relationships.

The second study, by Dreimanis et al. (1957), was aimed at differentiating the upper and lower tills of the Lake Huron and Erie Lobes and also at finding the source of the till units in question. The Superior and Grenville Provinces of the Canadian Shield were identified as sources of the heavy minerals. The four tills were differentiated on the ratio of purple to red garnet as in the previous study, and on the ratio of tremolite and actinolite to chlorite and serpentine. Again, there was considerable overlap in the mineral ratios of the four units. One noteworthy point in this study and in the study by Sitler (1963) in northeastern Ohio and northwestern Pennsylvania is that the underlying bedrock was not considered to have contributed anything to the heavy mineral fraction except perhaps sulfides. The Canadian Shield was thought to be the source.

Gwyn and Sutterlin (1972) analysed 132 till samples collected in southern Ontario in a straight line along the southern edge of the Canadian Shield. They were able to differentiate sources of heavy minerals on the Canadian Shield by using R-mode factor analysis and discriminant analysis. Using a few samples collected in a line perpendicular to the ice flow direction, outside the source area, and using multivariate analysis, they reproduced the results previously attained by Dreimanis and Reavely (1953) and Dreimanis et al. (1957).

Vincent (1974) characterized 52 till samples from the north of England using Q-mode factor analysis, and assigned them to three different source areas.

The studies by Gwyn and Sutterlin (1972) and by Vincent (1974) have clearly shown the usefulness of multivariate analysis in the interpretation of heavy mineral data. Though neither of them had a large number of samples, they point out the usefulness of multivariate analysis in large regional studies with many samples.

Besides the regional studies of tills in the area surrounding the Great Lakes, heavy mineral analysis has been used in other areas in more specific studies. For example, Shilts (1974) mapped the dispersal of distinctive sand-sized garnet on the 'down-glacier' side of an altered syenite intrusion in Keewatin. Clague (1975) mapped the distribution of amphibole and garnet in the Southern Rocky Mountain Trench.

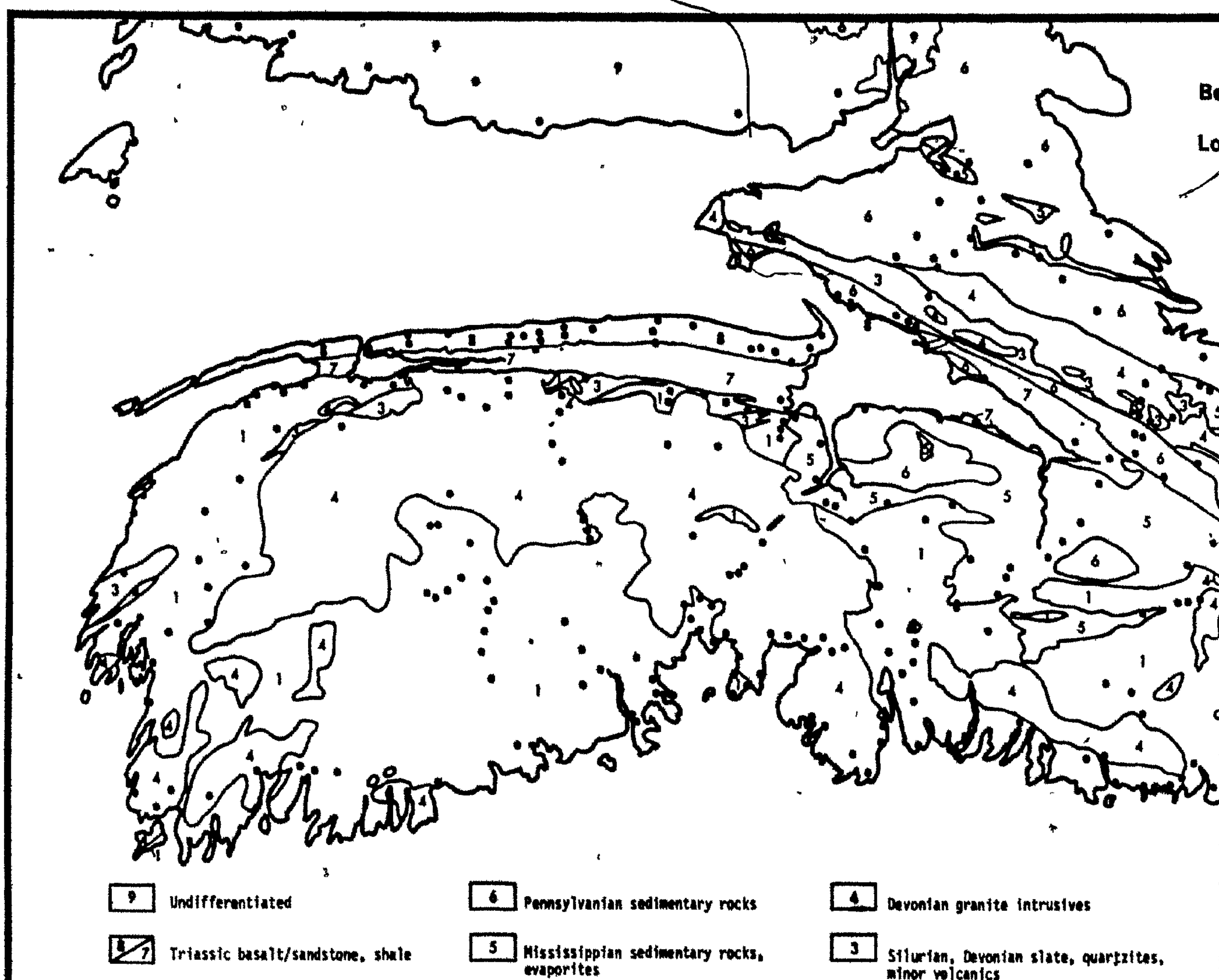
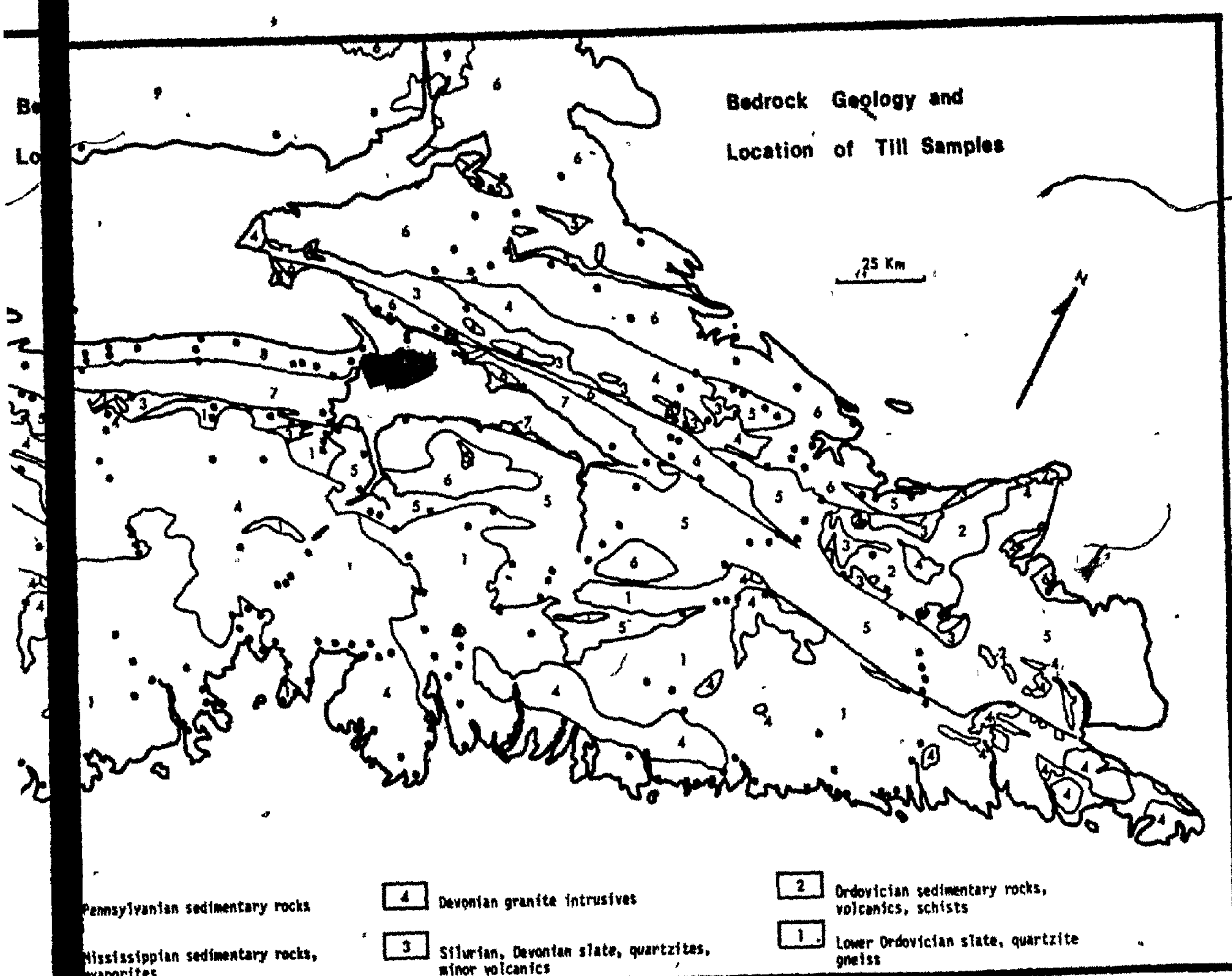


Figure 32. Nova Scotian bedrock and location of till samples.

1 OF



l location of till samples.

2 of 2

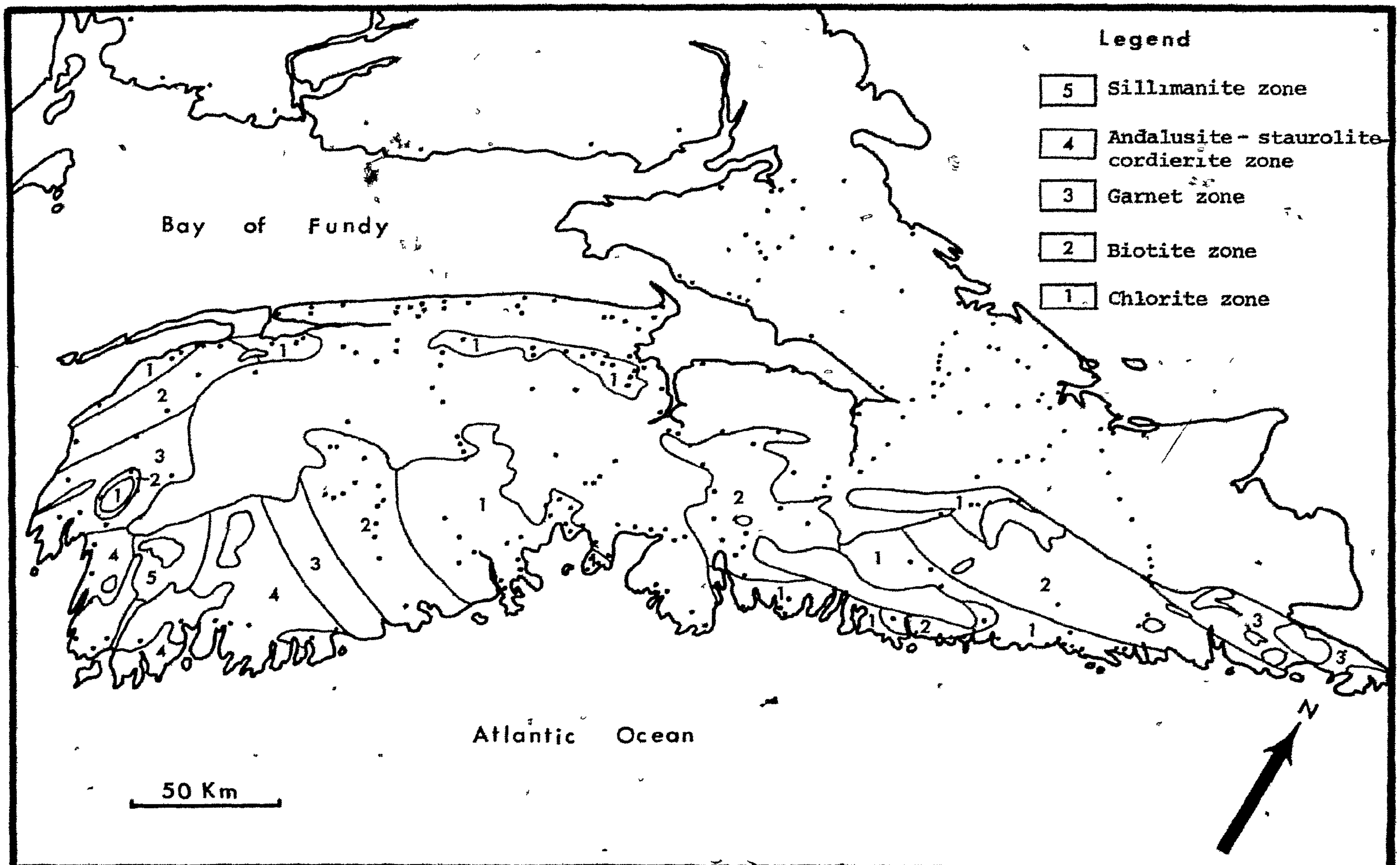


Figure 33. Regional metamorphic zones of the Meguma Group and location of till samples (from unpublished work by G. K. Muecke).

The present study is far more extensive than any of those mentioned above, covering three times the area (44,000 sq. km) of Grant's pebble investigation (15,000 sp. km) and involving detailed analysis of 324 samples. Previous heavy mineral studies have generally been concerned with sources outside the study area, whereas the present investigation deals with sources scattered throughout the region covered by the sampling programme.

Mainland Nova Scotia is an area of complex bedrock geology, characterized by Lower Paleozoic slates and metaquartzites of varied metamorphic grade, complex Devonian intrusives of differing composition, Carboniferous sandstones, shales and evaporites initially derived from Nova Scotia and southern New Brunswick, and volcanics varying in composition from rhyolite to basalt and in age from Paleozoic to Triassic. An attempt is made here to relate the heavy mineral suites with the bedrock geology. Figure 32 shows the sample locations and the bedrock geology of Nova Scotia and Figure 33 shows the sample locations and the regional metamorphic zones of the Meguma Group (from unpublished work by G. K. Muecke). A new element here is the application of R-mode factor analysis in an endeavour to identify indicator mineral associations as an aid in delineating ice flow directions.

Methods

Heavy Mineral Separation

From each till sample approximately 15 gm of fine sand (500 to 63μ) was taken and added to a separating tube containing a mixture of tetrabromoethane and carbon tetrachloride with a specific gravity of 2.808. This liquid was prepared by adding 12.5 ml of carbon tetrachloride to 87.5 ml of tetrabromoethane. Previous workers in Nova Scotia (Nolan, 1963 and Lyall, 1969) have used this liquid instead of bromoform (S. G. 2.89). This substitution is advantageous because of the difference in cost of the liquids. After 3 hours of settling, with occasional stirring, the heavy fraction was drained off in the manner outlined by Carver (1971).

Preliminary information showed that the heavy mineral grains were coated with a reddish material believed to be iron oxide, and as such were not completely translucent. An iron oxide removal procedure modified from Mehra and Jackson (1958) was used to remove the stains. The heavy mineral fraction was placed in a 100 ml beaker to which 40 ml of 0.3 M Na-citrate solution and 5 ml of 1.0 M $NaHCO_3$ solution was added. The temperature was brought to near boiling and 1 gm of solid sodium dithionite ($Na_2S_2O_6 \cdot 2H_2O$) was added. The sample was stirred for 15 minutes, filtered, dried and weighed. This procedure removed the coating. This method is preferred to the more classical treatments with concentrated acids as the latter destroys heavy mineral grains, notably apatite. Also, the dithionite methods is fast and safe.

The heavy mineral fraction was expressed as a percentage of the total weight of the 500 to 63μ fraction from the till sample.

The light and heavy mineral fractions were stored in glass vials.

Preparation and Counting of Slides

Prior to mounting, the minerals were homogenized in the vials, using a spatula, in case mineral stratification had taken place during handling and storage. The grains were mounted carefully in Canada Balsam and sealed with a cover glass.

Before point counting was started, a standard slide collection of 41 commonly known heavy minerals was prepared from samples in the Dalhousie Geology Department Museum collection. These were studied in order to facilitate identification of the minerals in the unknown slides. Sixteen unknown heavy mineral species were microprobed semiquantitatively and identified early in the study.

Point counting was done using a mechanical stage mounted on a binocular petrographic microscope. The ribbon method of counting was used whereby all the minerals in the field of view along each traverse were identified, i.e. the number percent of each mineral was measured. Approximately 300 mineral grains were identified on each slide.

As a control, duplicates were made of the 7 samples and each slide was counted separately and the results compared. Duplicate grain counts are listed in appendix 4. Also, the first 75 slides counted were counted again at the end of the study to confirm the correctness of the mineral identification. Both procedures confirmed the reliability of the results.

The minerals identified in the study are opaques, zircon, rutile, sphene, tourmaline, anatase, almandine, spessartine, staurolite, andalusite, sillimanite, augite, amphibole, epidote and apatite. In a few samples other minerals were also identified, but they were not included in the final tabulation because of their low numbers and limited distributions. Calcite or dolomite was observed in four samples from the Halifax area. Zoisite was observed in a few samples near Bridgewater and Lunenburg. Fluorite was observed in a few samples from New Ross and St. Margaret's Bay. No attempt was made to subdivide the pyroxene or amphibole groups. A few orthopyroxene grains, mainly hypersthene, were observed in a couple of samples. More than one type of clinoamphibole is thought to be derived from the Cobequid Mountains, but these were not subdivided.

Mica, chlorite, rock fragments and altered minerals were initially included in the point counting. They were later excluded because it was felt that the peculiar settling properties of mica and chlorite and the varied specific gravities of the rock fragments led to differential settling depending on the size and amount of these constituents. The results from one sample would therefore not be necessarily representative of that locality and it could not be compared to other samples. However, these minerals are included in the total percentage of heavy minerals.

When approximately 300 grains had been counted the percent opaque minerals was calculated. The percentage of each of the other 14 minerals was then calculated as a percent of the total non-opaque fraction. This technique is similar to that used by Nolan (1963), James (1966), and Cok (1970). The results of the point counting are tabulated in appendix 4.

Correlation

To test possible correlations between tills 15 samples were collected from three till sections exposed in the Halifax area, namely Hartlen Point, Cole Harbour 6 km to the east, and Sandwich Point 9 km to the west. In each case, the tills are stratigraphically distinct units comprising a lower, compact grey till overlain by a red clayey till. The analysis is intended to serve as a test of whether the mineralogical affinities are greater in a lateral or a vertical direction and as a test of the point counting and sample spacing. Nine of the samples are red clay till - five from Hartlen Point, three from Cole Harbour, and one from Sandwich Point. Six samples are of the lower grey till - three from Hartlen Point, two from Cole Harbour, and one from Sandwich Point. Spearman rank correlation coefficients were calculated and the results plotted as a dendrogram (Figure 34).

The dendrogram shows a strong correlation between all of the samples of red clay till and between it and the underlying compact grey till. A test of significance (see Appendix 3) indicates no meaningful mineralogical variations between the red and grey tills exposed in the Halifax area even when multiple till samples are collected.

The important implications of the results of this small study are fourfold. Firstly, one can be reasonably certain of obtaining a representative sample by sampling any apparently homogeneous portion of a till outcrop. Secondly, till sheets which are stratigraphically continuous vary little over quite long distances. This makes a sample spacing of 5 to 10 km fairly representative. Thirdly, it is difficult to determine the provenance of tills in a multiple till section, and necessitates the use of other parameters such as colour, till fabric, pebble lithologies, stratigraphic continuity, and degree of oxidation. Fourthly, there is no mineralogic difference between the matrix of the Cow Bay drumlin field, the Chezzetcook drumlin field and the eastern part of the Sambro drumlin field tills.

To test further the hypothesis that the mineralogy of the tills in Nova Scotia varies little either laterally or vertically and that there are essentially no differences between the different products of glaciation at any one locality, samples from multiple till sections were compared to the immediately surrounding samples by Spearman rank correlations. The following groups of samples were analysed and the significance of the correlation calculated (Appendix 3). Samples separated by a horizontal line are multiple till samples from the same location.

1. 201/202, 203/204/205, 474/475, 216

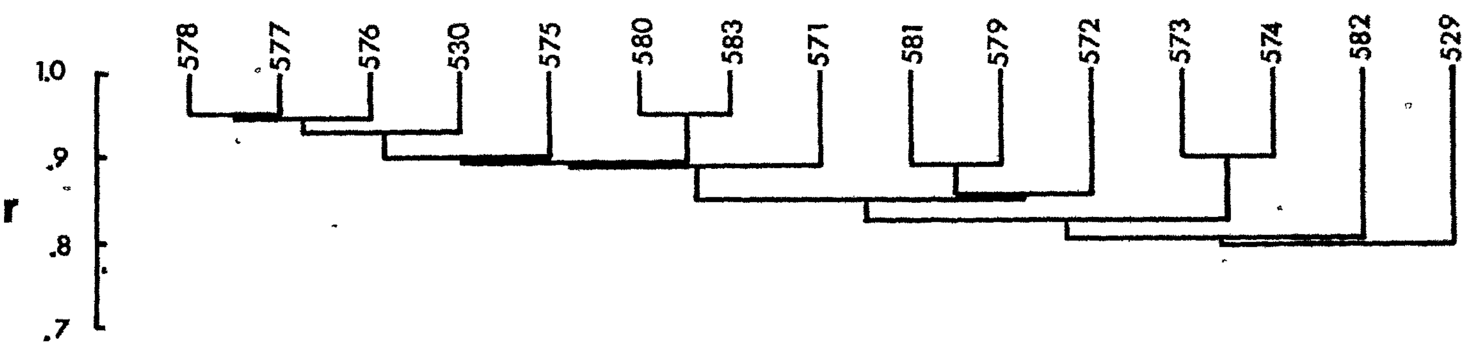
2. 567/535/534/533, 462, 459, 463, 461, 541, 458

3. 438/439, 441, 437, 525, 440

4. 290/291, 288/289, 527, 526, 302

5. 495/494, 260, 262, 257

6. 555/554/556, 323, 321, 322, 324



	Hartlen Point	Cole Harbour	Sandwich Point
Red clay till	571, 572, 573 574, 575	579, 580, 581	529
Grey till	576, 577, 578	582, 583	530

Figure 34. Dendogram showing the result of cluster analysis on red clay till and grey clay till from the Halifax area.
The correlation matrix which forms the basis for the dendrogram is listed in Table III-9 in Appendix 3.

7. 221, 222/223, 224, 227, 228/229, 226, 342, 287, 343

8. 373/372/371, 519, 370, 516, 517

The r values of samples 440, 324, 343, and 517 in groups 3, 6, 7, and 8, respectively are below the 95% level of significance indicating no significant correlation with the other members of the group. Samples collected from multiple till phases correlate highly with each other and most of the immediately surrounding samples.

These analyses corroborate the hypothesis that the mineralogy varies little within an area no matter what the physical nature of the sample.

Heavy Mineral Distribution

Percent Heavy Minerals

The equifrequency distribution map (Figure 35) shows the variation in the percent heavy minerals in the 1 to 4 Ø range of the sand fraction.

Anomalously high concentrations of heavy minerals in the tills are found in five regions of the study area. Of all the samples, the eastern and western parts of North Mountain and the Cobequie Mountains produced the till richest in heavy minerals. Other concentrations are found north and northeast of Yarmouth, and around Liverpool. The eastern Cobequid fan is wide, indicating that several directions of ice flow were responsible for its formation. The minerals concentrated in this fan are primarily amphibole

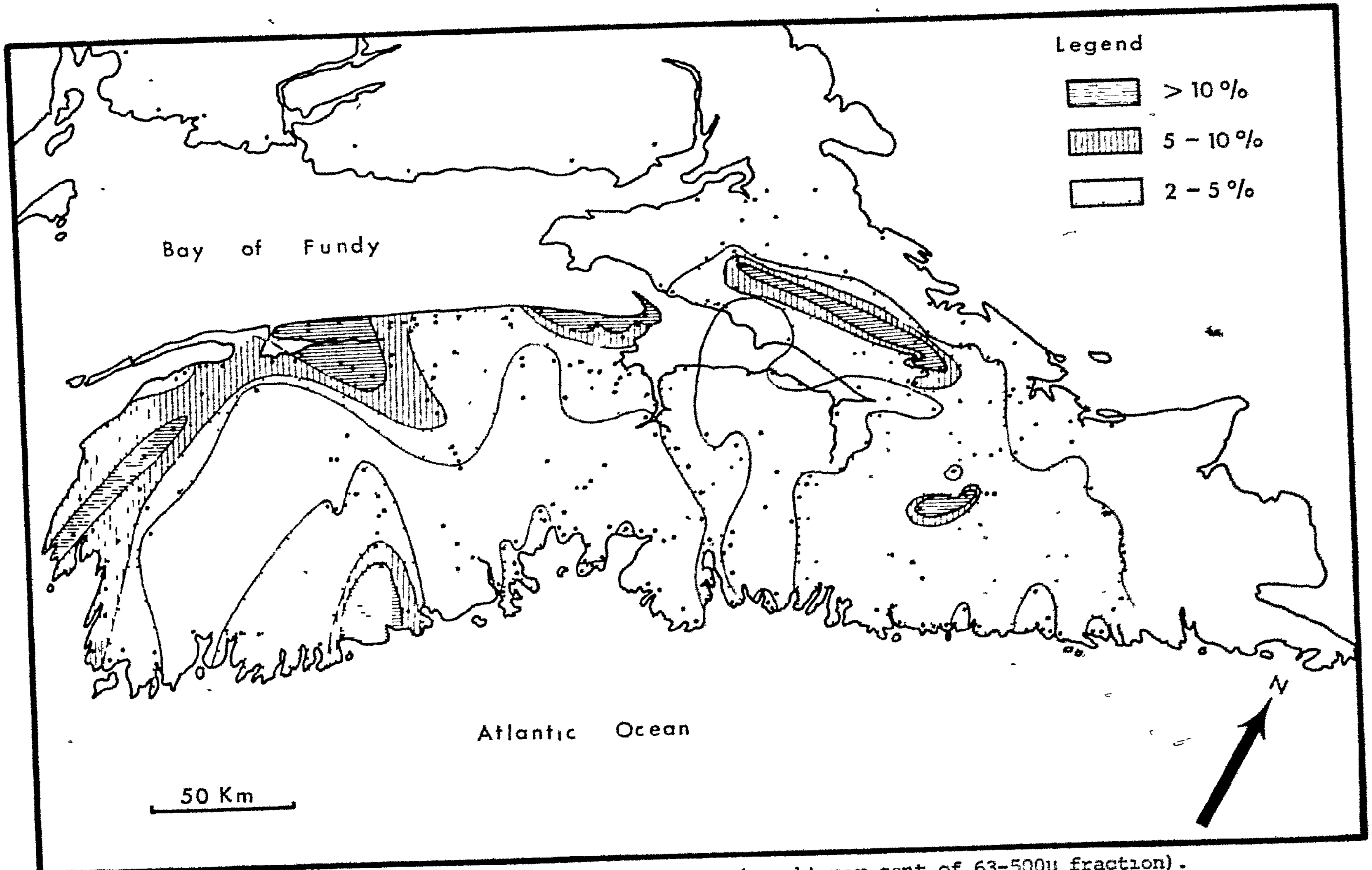


Figure 35. Distribution of heavy minerals (weight per cent of 63-500μ fraction).

and epidote derived from the intrusive rocks of the Cobequid Mountains. The distribution of heavy minerals from the eastern and western ends of the Cobequid Mountains indicates that erosion was greater there than over the central part of the mountains. Heavy minerals are relatively poor in the area south of Minas Basin to the Atlantic Coast because of the high content of Carboniferous sedimentary rocks (especially evaporites). The lack of heavy minerals in this region is a good indicator of southerly ice movement. The two North Mountain fans composed mainly of pyroxene, indicate that ice traversed the basalt and distributed the heavy minerals over South Mountain. An area with virtually no heavy minerals extends northwest from the Devonian batholith into the Bay of Fundy over the central part of North Mountain.

The heavy mineral distribution in the remainder of the study area is related to the local bedrock.

Amphibole

The distribution of amphibole in Nova Scotia, (Figure 36), is generally high to the east of a line from Halifax to Windsor as well as in the Digby-Yarmouth region but scarce or absent over the main Devonian batholith and the adjoining areas to the north and south.

In the west, between Digby and Yarmouth a large anomalous concentration of amphibole is found. The belt is approximately centered on the White Rock Formation and the principal source is most probably the metavolcanics of this formation. Hornblende-rich granite intrusives also occur in the south.

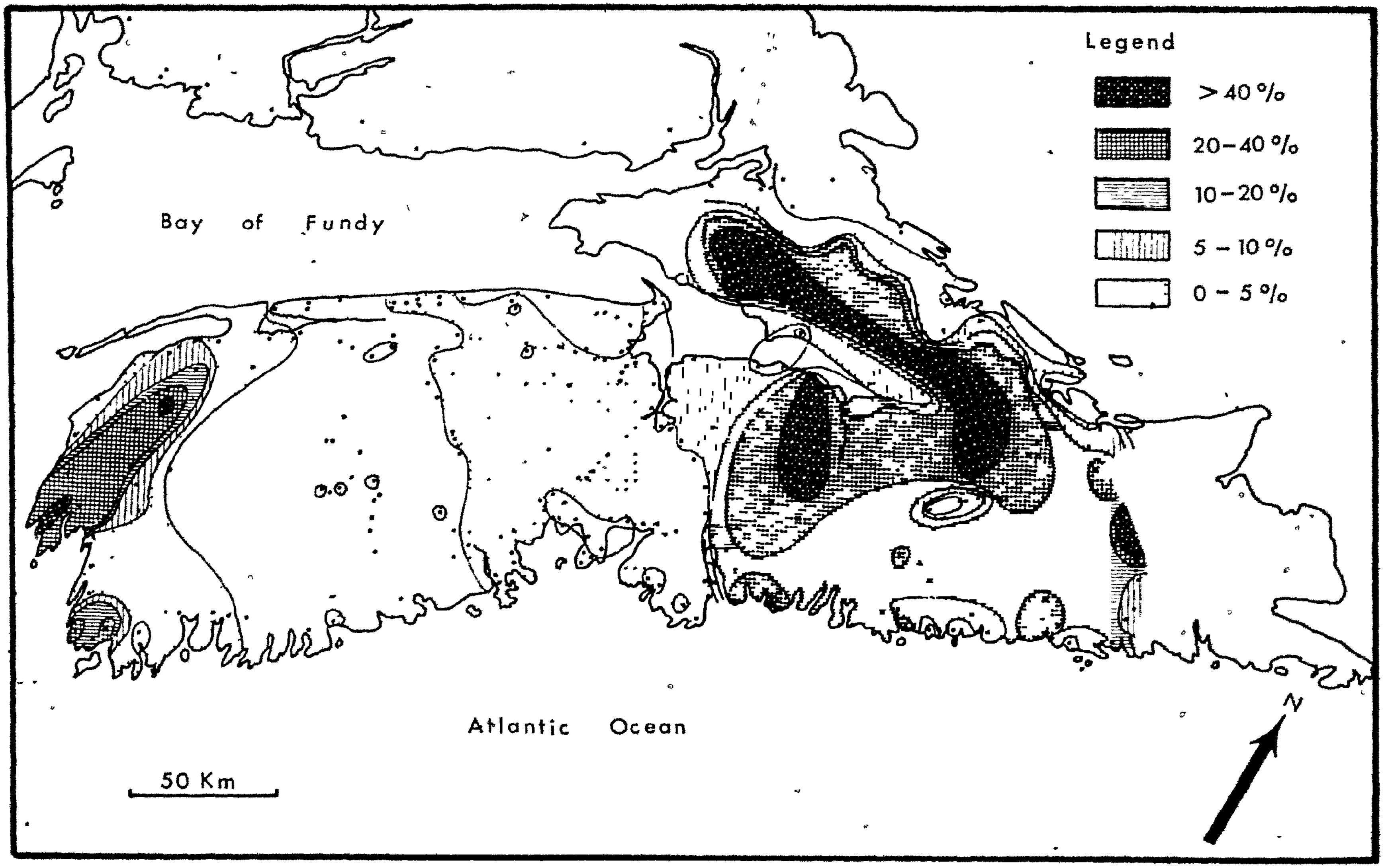


Figure 36. Distribution of amphibole.

The distribution in the till seems to be directly related to the immediately underlying bedrock.

The amphibole over the eastern half of the main Devonian granite pluton as far west as the LaHave River was derived from patches of volcanics of Lower Paleozoic age scattered between Kentville and Middleton. The absence of amphibole over the eastern end of North Mountain excludes the Cobequids as the source.

The small amounts of amphibole found over North Mountain northwest of Middleton were derived from volcanics around Nictaux, or from an unknown source in New Brunswick. Amphibole is not present in the till over North Mountain except in the central region and the Cape Split region in the east.

Amphibole is a scanty component of the till overlying the whole of the main Devonian granite batholith west of a line from Windsor to Halifax, and is completely absent in the Chester-Hubbards area. This is consistent with a lack of potential sources in the bedrock.

The distribution of amphibole in the eastern part of the study area clearly shows ice movement in an almost due southerly direction from the source areas in the Cobequid and Antigonish Highlands.

Amphibole is a common constituent of the intrusive rocks in the Cobequid Mountains and in Browns Mountains (Weeks, 1948; Benson, 1974). From the Cobequid belt, the concentration of amphibole falls off in an irregular fashion towards the south. Conspicuously high concentrations are found along the Atlantic shore, noticeably in the Sambro, Cow Bay, Chezzetcook, Owls Head and Liscomb drumlin fields. There is also a patch of notably low concentration near the head of the Musquodoboit River and a belt of low value near the coast between Ship Harbour and Sheet Harbour, similar to that found by Nolan (1963) in the coastal sands.

The low percentage of amphibole to the east of the Musquodoboit River Valley is a result of the samples being collected from a very prominent topographic high area with elevations over 200 metres. Consequently, this area was a major obstacle to ice movement and one of considerable erosion. The till is generally very thin and mostly locally derived. The amphibole in the Liscomb drumlin field has its source to the north-northwest, as do the Owls Head and Moose River fields. The Cow Bay and Chezzetcook drumlin fields, which are indistinguishable from one another, are a dislocated continuation of the fan which extends south from Minas Basin west of the Shubenacadie River Valley.

The concentration of amphibole in the Sambro drumlin field was apparently derived from the east of the granite-Meguma contact between Halifax and Windsor. The exact source is not determinable.

Figure 37 shows the variation in the percent amphibole and the percent mud for drumlin and non-drumlin samples situated on Meguma bedrock northeast of Halifax. The drumlin and non-drumlin samples are listed in Appendix 4. Clearly there are two distinct till types in this area - a muddy till rich in amphibole and a less muddy till with low concentrations of amphibole.

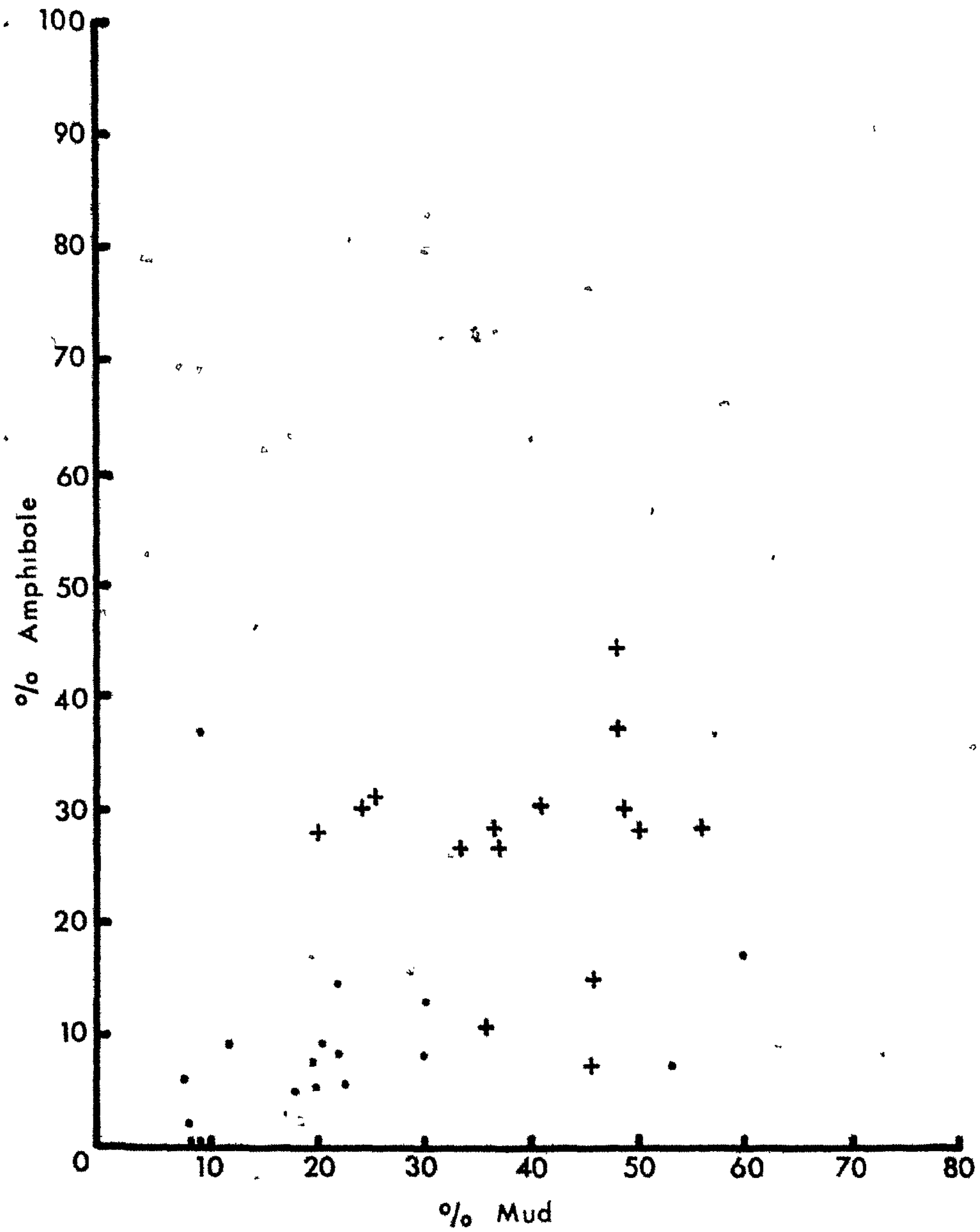


Figure 37. Variation in the amphibole and mud content of drumlin (+) and non-drumlin (•) samples overlying Meguma bedrock northeast of Halifax.

The drumlin till was derived from the post Devonian sediments to the north and from the intrusives north of the Cobequid-Chedabucto fault. There is no clear separation between drumlin and non-drumlin samples but rather the compositional change is gradational, indicating mixing with local components to varying degrees.

Although there is a marked break in distribution of points at 20 percent amphibole this might be the result of a limited number of samples. Further analysis of the anomalous drumlin samples below the 20 percent amphibole might elucidate this question.

The almost complete absence of amphibole in the Minas Basin area is believed to be due to one of two factors: 1) Minas Basin was a major area of glacial erosion, or 2) the Cobequid Mountains formed a 'lee' area to the south in which no till deposition took place in the main stage of glaciation. The distribution of staurolite, sphene, anatase, apatite and andalusite (believed to be derived from the Minas Basin area) and the close correlation between the distribution of these minerals and the lithofacies map (Figure 27) indicates that the first alternative is more likely to be correct. This is further substantiated by the lack of any clear relationship between the distribution of staurolite and amphibole in Minas Basin. However, to the south (towards Halifax) and west from Windsor to Middleton there is a strong positive relationship between staurolite and amphibole. Thus it is concluded that amphibole and staurolite come from two separate sources in or near the Cobequid Mountains. The distribution of amphibole east of the eastern limit of staurolite suggests that the amphibole source continues in that direction whereas the staurolite source stops near Truro.

The distribution of amphibole east northeast from the Cobequid Mountains toward Pictou Island indicates ice movement in that direction. This confirms the observation by Prest et al. (1971) of Cobequid erratics in this region. Similarly, the distribution of amphibole north of the Cobequid Mountains might be the result of northerly ice flow. However, little is known of the distribution of amphibole in the Carboniferous sediments in that area and it seems very possible that the amphibole may be secondarily derived from the ancient sediments.

Epidote

The equifrequency map (Figure 38) shows a large concentration of epidote extending south and southeast from the eastern end of the Cobequid Mountains. This fan extends to the Atlantic shore with a decrease east of the Musquodoboit River Valley. Epidote is a common constituent of most till samples but is absent over most of North Mountain and the western half of South Mountain which is underlain by granite.

Epidote is found extensively in the bedrock throughout the province. It is reported in the granodiorites of the Cobequid Mountains (Gillis, 1964) and throughout the low grade metamorphic rocks of Lower Paleozoic age (Taylor, 1967, 1969). The presence of epidote in the biotite and garnet zones of the Goldenville metaquartzites (G. K. Muecke, personal communication) makes it of limited use as an indicator in large areas of the province.

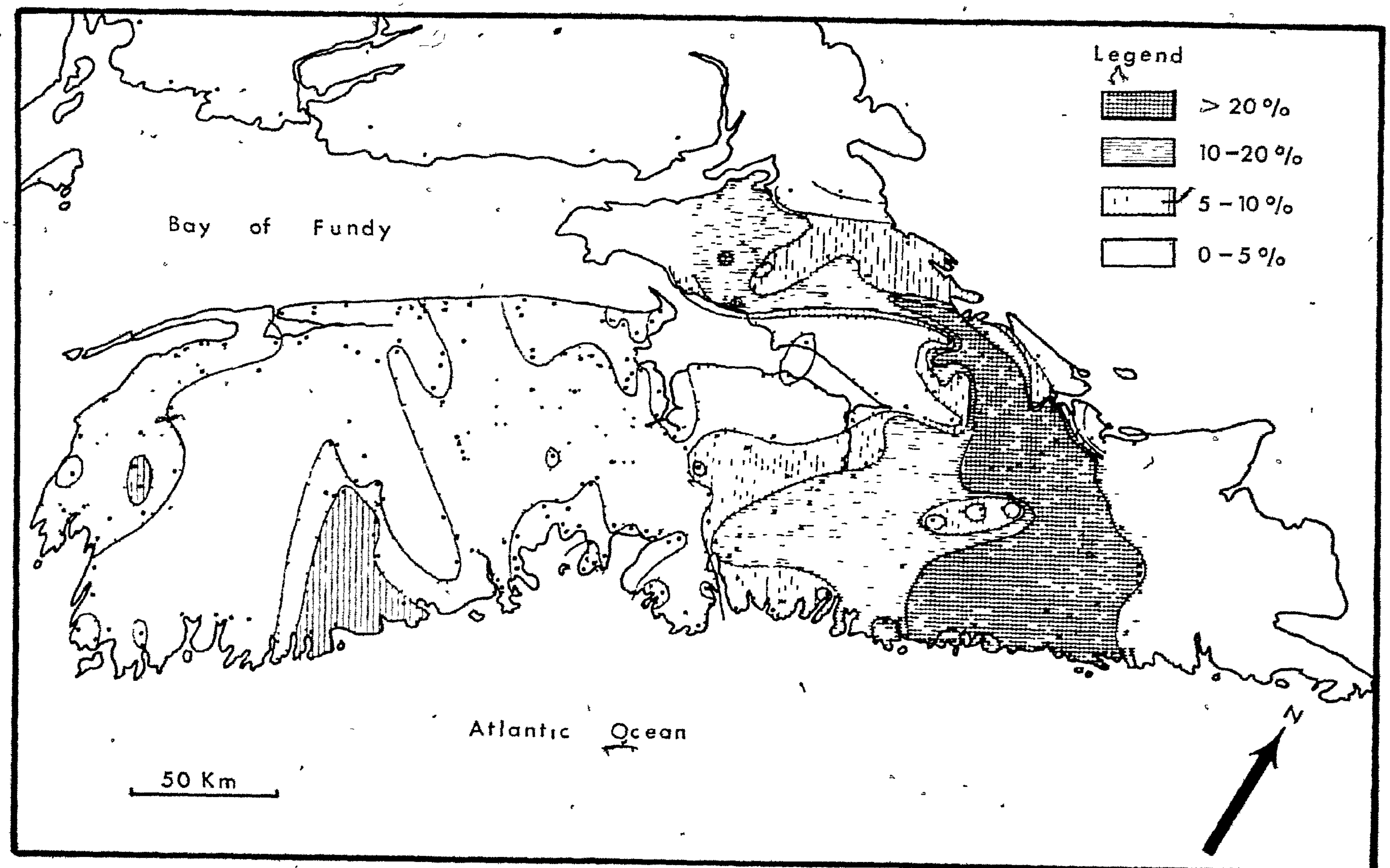


Figure 38. Distribution of epidote.

The Cobequid Mountains and Antigonish Highlands were big sources of epidote which was distributed south and southeastward across the Meguma to the Atlantic shore. Some of the epidote in the eastern part of the study area was derived from the underlying Meguma bedrock. The eastern Cobequid fan shows a very similar distribution to amphibole in the region. However, unlike amphibole, there appears to be no preferential concentration of epidote in the drumlin till (Figure 39). There is a low concentration of epidote around Sheet Harbour which indicates that the till there is from a different source than that of the surrounding area. This is similar to the findings of Nolan (1963) (Figure 6).

The till in Minas Basin and on the highlands east of the Musquodoboit Valley are very low in epidote content. This distribution is similar to that of amphibole.

West of a line joining Halifax and Windsor the epidote content is low, indicating little or no Cobequid influence. The trace amounts of epidote present in the till over the eastern half of the main Devonian granite pluton and the central part of North Mountain were derived from the Paleozoic rocks between Middleton and Wolfville and distributed southward and later northward.

It is noteworthy that epidote is only present in small amounts in the Lunenburg drumlin field. This fact precludes the possibility that the glacier flowed southwest across the Cobequid Mountains and the eastern half of the main batholith as postulated by Grant (1963). This fact is corroborated by the distribution of amphibole in this area.

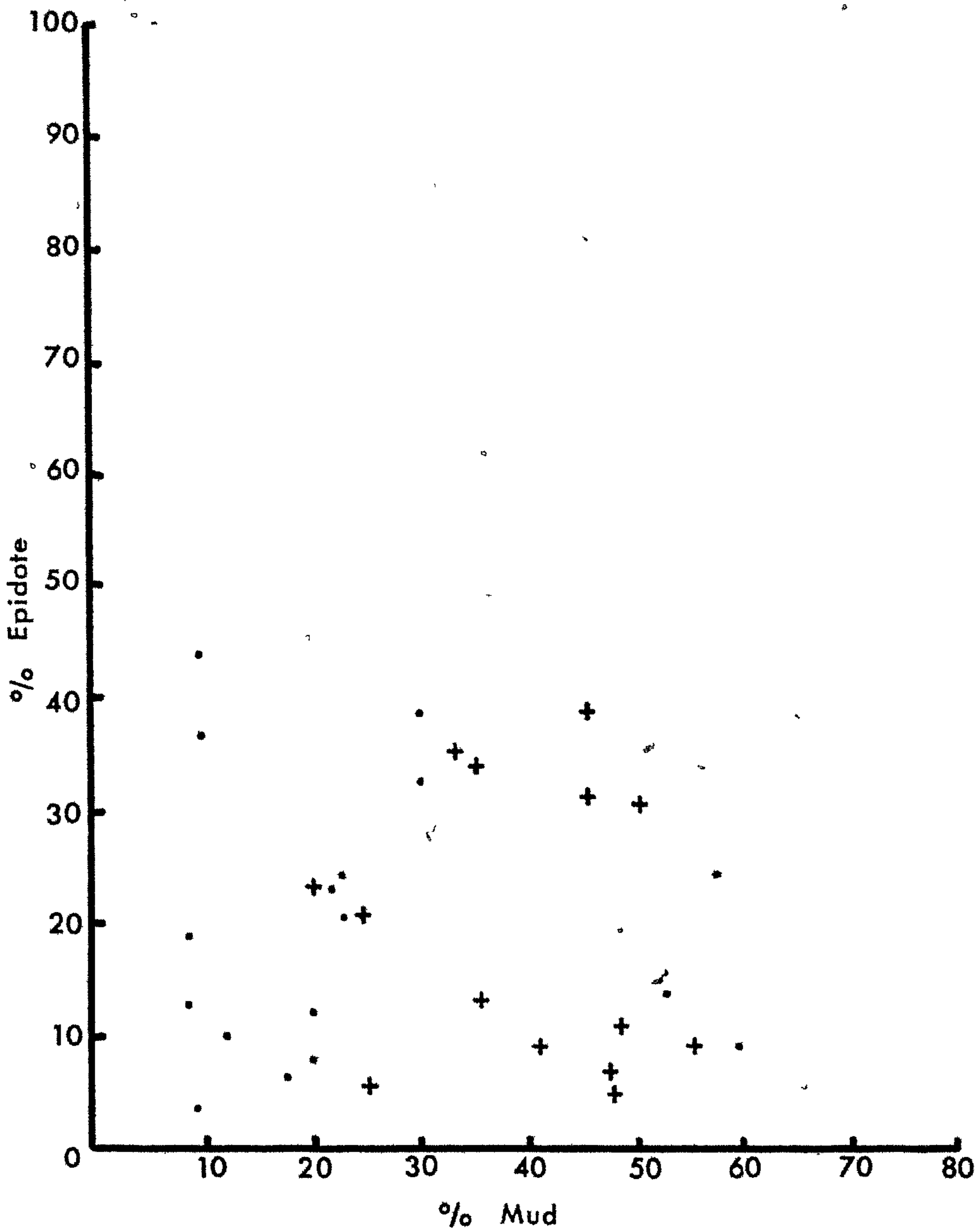


Figure 39. Variation in the epidote and mud content of drumlin (+) and non-drumlin (·) samples overlying Meguma bedrock northeast of Halifax.

The variation in epidote content in the rest of the area is governed by its distribution in the local bedrock.

Augite

The equifrequency map (Figure 40) shows a large augite fan south of North Mountain with its main axis through the Lunenburg drumlin field and the Devonian batholith. The fan is lobate in nature and extends from Halifax in the east to beyond Yarmouth in the west. Other areas of high percentages of augite are found southeast and east of the Cobequid Mountains and southeast of Minas Basin. Augite is absent north of the Cobequid Mountains. The Triassic basalt of North Mountain is the primary source of pyroxene in the large fan through the Lunenburg and Sambro drumlin fields. Within the Lunenburg drumlin field there is a strong correlation between the presence of basaltic pebbles in the till and high values of augite. Over the granite batholith, augite percentages are slightly lower than over the Meguma to the south, as is also the case with the distribution of basaltic pebbles.

Figure 41 shows the variation in augite with changes in till texture. The lack of any meaningful trend indicates that the distribution is controlled not by the grain size variation of the local till but by the outcrop pattern and the size of the source area. The figure also indicates that over North Mountain the till low in mud is richer in augite than the mud-rich till. This is the result of the presence of foreign heavy minerals derived from north or south of the area. The samples from the central part of North Mountain

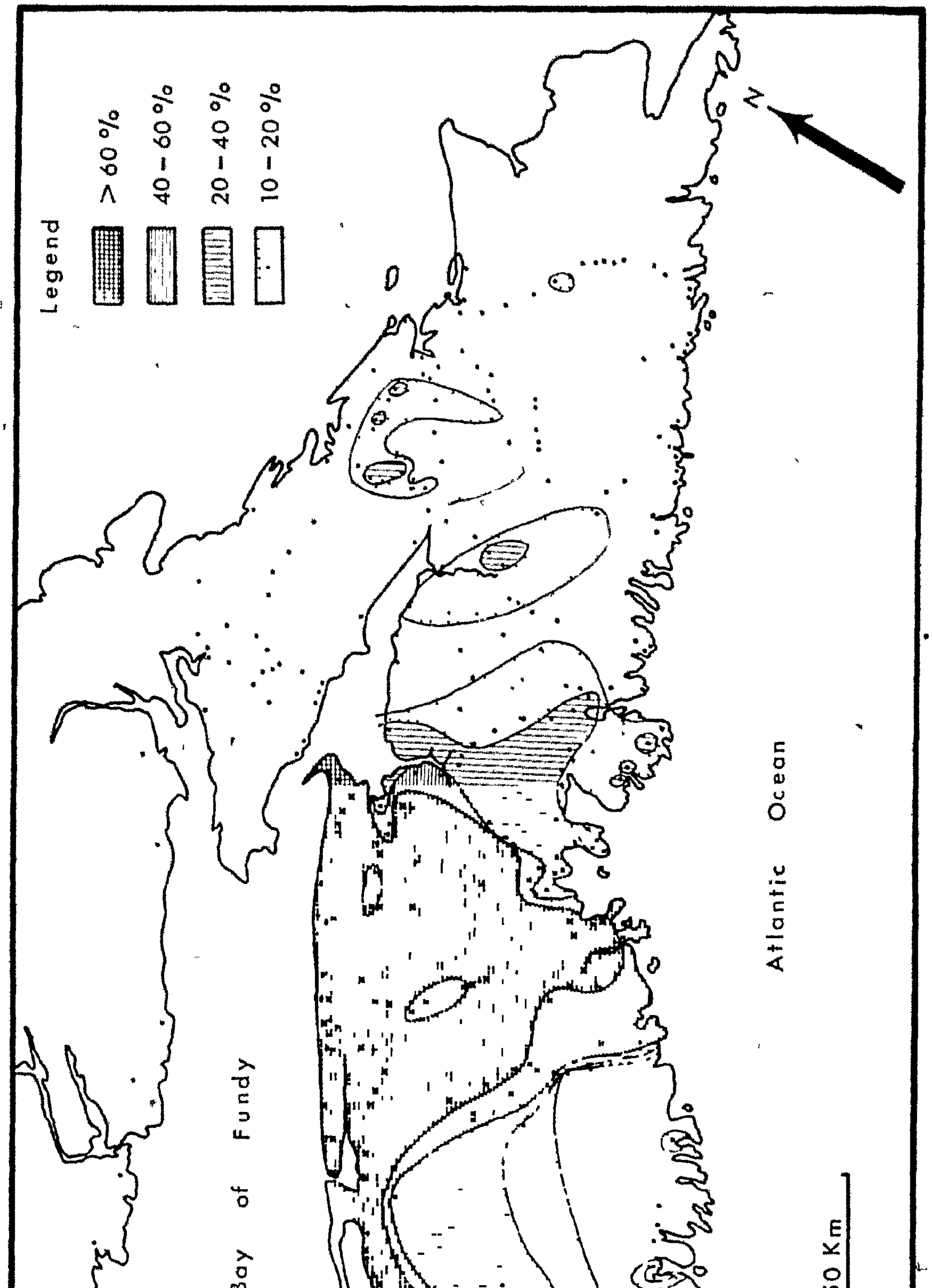


Figure 40. Distribution of augite.

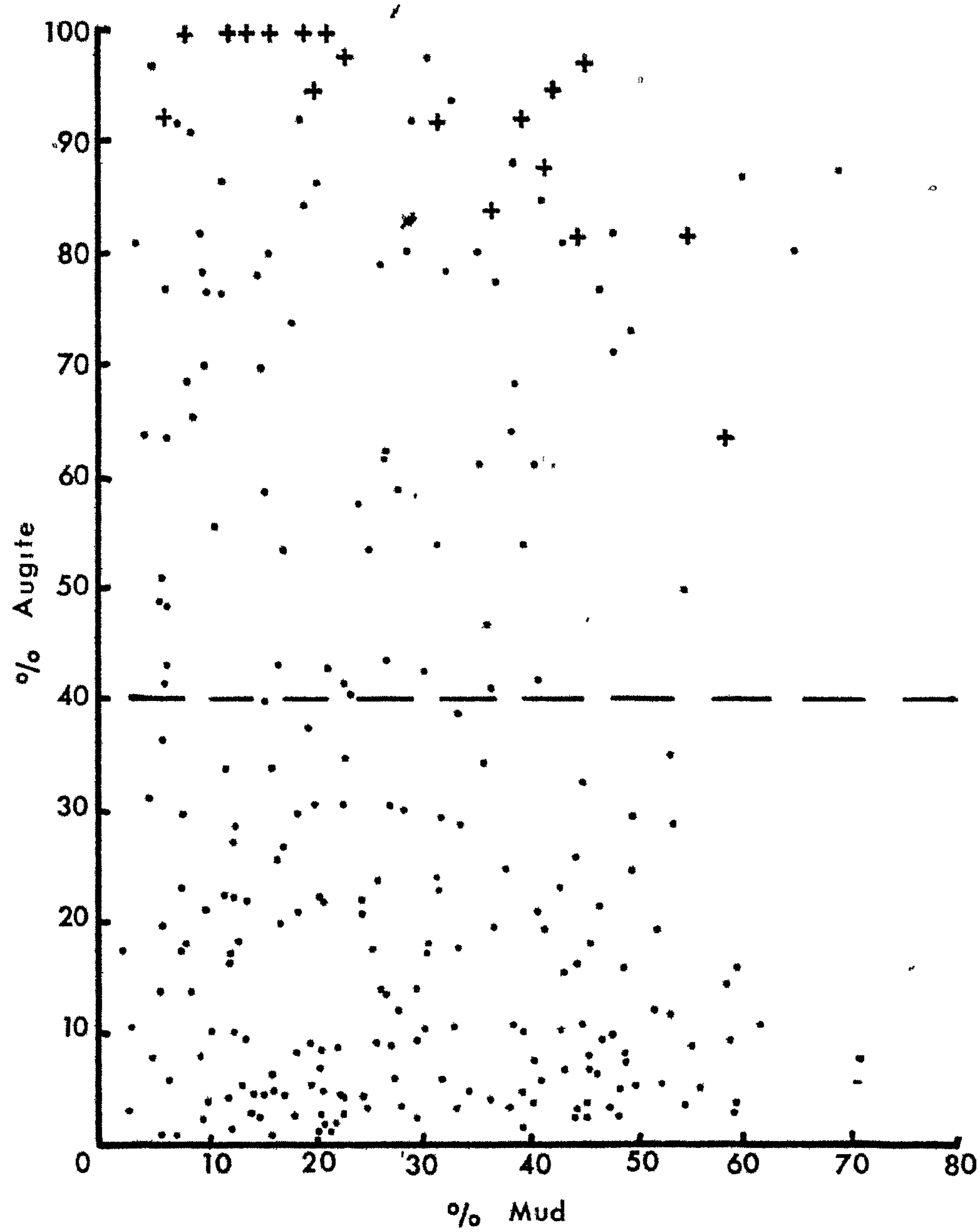


Figure 41. Variation in the augite and mud content of all Nova Scotian till samples. (+) indicates samples overlying North Mountain.

have been shown to be rich in silt and clay and they are correspondingly lower in augite content. This is clearly seen by comparing the lithofacies map (Figure 27) and the augite frequency distribution map (Figure 40).

Figure 42 shows the relationship between augite and the percent mud for samples from the Lunenburg drumlin field only. Drumlin samples are richer in augite but there is considerable overlap with the non-drumlin samples. Also, the percent mud in the samples does not serve as a criterion for distinguishing drumlin and non-drumlin samples.

Augite distribution south of North Mountain indicates a strong south-easterly ice flow, especially in the Lunenburg drumlin field.

The basaltic outliers at Clarke Head, Five Islands and Bass River have produced a large indicator fan which extends southeast of Minas Basin almost to Taylors Head. The Carboniferous basalts of the River John Group and Millsville Conglomerate appear to be the sources of the augite fans in the eastern Cobequid Mountains. The orientation of these fans indicates ice flow directions towards the south and southeast.

The distribution of augite on the Eastern Shore is similar to that found by Nolan (1963, Figure 6). However, it is difficult to determine the exact sources of augite in this part of the study area because of the low percentages, relatively wide sample spacing and also because the North Mountain, Minas Basin, eastern Cobequid and Antigonish Highland fans all point towards this region and some of them may in fact overlap.

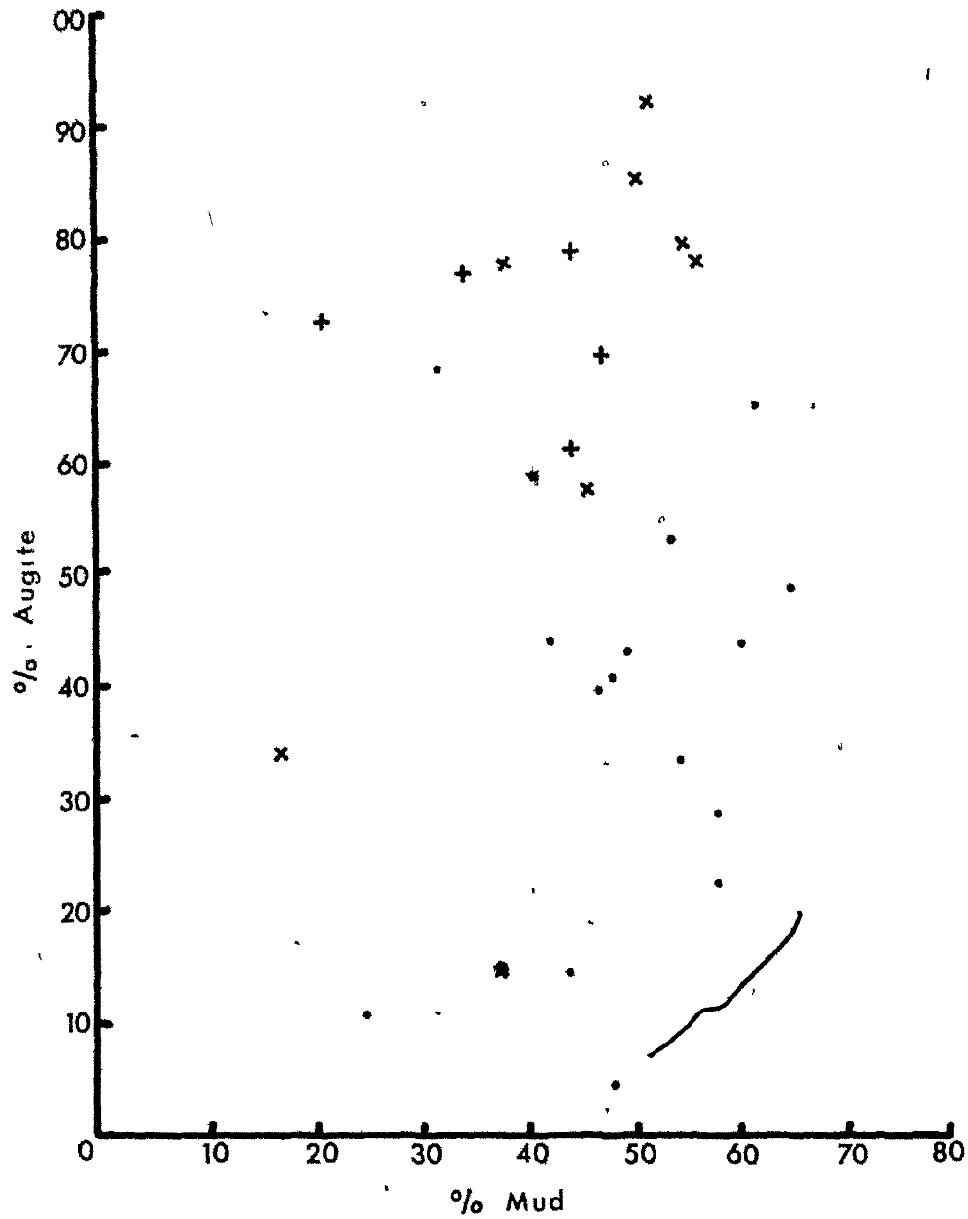


Figure 42. Variation in the augite and mud content of slate drumlin (X), red clay drumlin (+), and non-drumlin (•) samples overlying Meguma bedrock in the area of the Lunenburg drumlin field.

Sphene

Figure 43 shows the distribution of sphene in Nova Scotian tills. Although the distribution is somewhat scattered and the percentages low there are several areas of meaningful concentrations. The Springhill-Amherst, Pugwash-Tatamagouche and Pictou-Trafalgar regions are all areas of relatively abundant sphene. The areas north and west of St. Margaret's Bay, between Weymouth and Yarmouth and southeast of Minas Basin also have significant representation of sphene in the till. Sphene is also present in isolated samples from the Eastern Shore, Kejimkujik Lake area and the eastern end of the Annapolis Valley.

Sphene is an accessory mineral in many igneous and metamorphic rocks. The only known occurrence in the bedrock in Nova Scotia is in metavolcanics of the White Rock Formation north of Yarmouth. It is a relatively resistant mineral and may be a common constituent of many sandstones.

Sphene is believed to be locally derived, except for the areas immediately west of the Shubenacadie River and on the eastern end of the Cobequid Mountains.

The source of the large fan at the eastern end of the Cobequid Mountains is uncertain. The shape of the fan indicates a southeasterly movement of ice through this region. The presence of more than 5% sphene in the Tatamagouche area but not to the immediate south may indicate ice flow parallel to the north side of the Cobequid Mountains and not perpendicular to them. It is possible that the sphene in the till south of the eastern end of Minas Basin

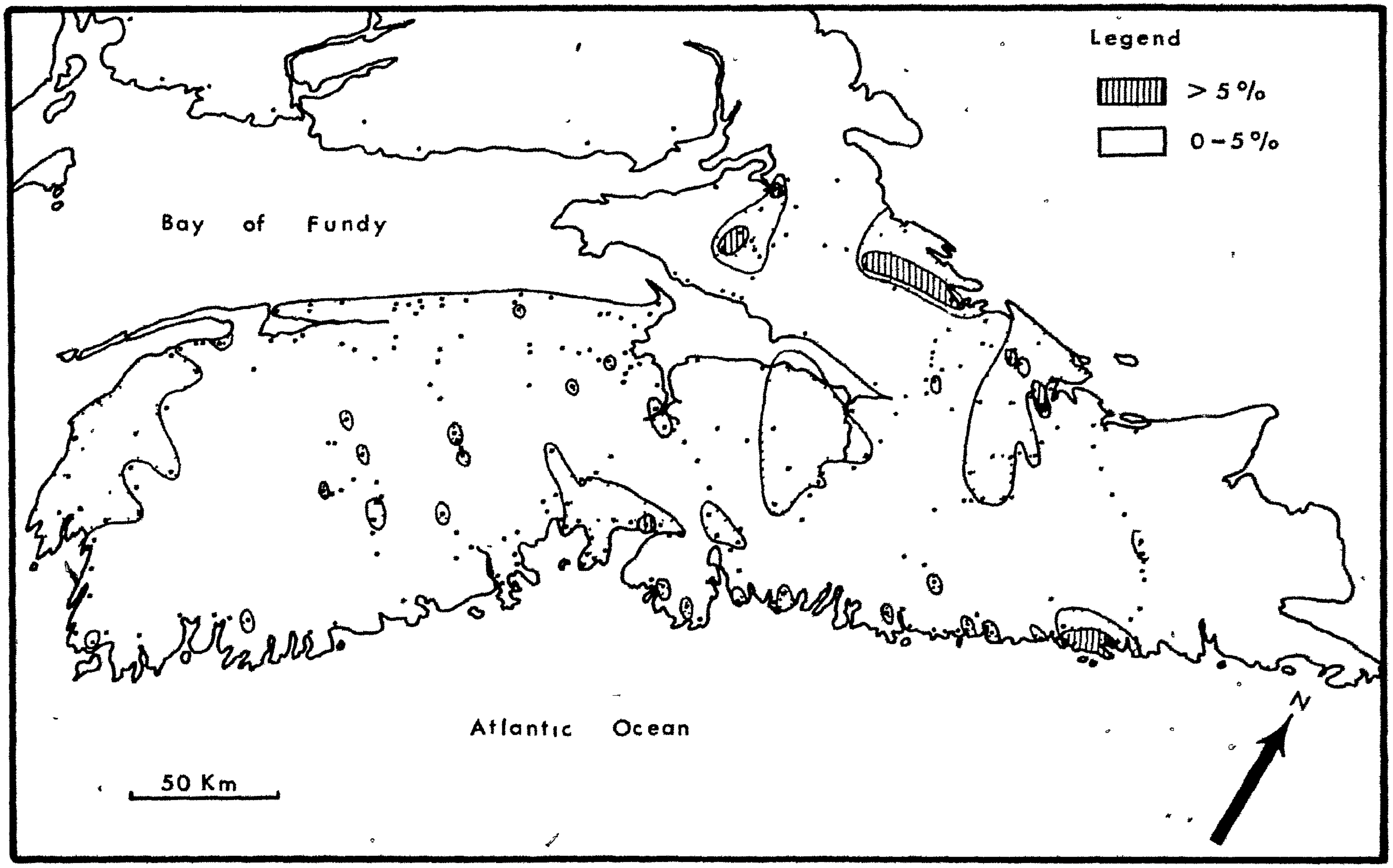


Figure 43. Distribution of sphene.

had its source along the Northumberland Strait. The distribution of amphibole and staurolite is similar to the distribution of sphene west of the Shubenacadie River. Both amphibole and staurolite are derived from sources to the north of the fan. Wherever the sphene source is, it lines up with the two anomalies on either side of the Cobequids.

Apatite

The equifrequency map (Figure 44) shows concentrations of apatite in six regions of the study area. The Amherst area and the belt from Pugwash to New Glasgow are rich in apatite. The till over the western end of the Devonian batholith and the area around St. Margaret's Bay have anomalously high percentages of apatite. The till to the south, and especially to the southeast, of Minas Basin is rich in apatite. Minor concentrations of apatite are found at Ship Harbour and Sheet Harbour on the Eastern Shore, at Barrington Bay and Shelburne in the southern part of the province and over the central part of North Mountain in the northwest.

Taylor (1967, 1969) reports the occurrence of apatite in the Goldenville and Halifax Formations as well as in the Devonian granite. Thus apatite should be present in most of the post-Devonian sediments surrounding the Meguma and Devonian rocks. Worth (1969) found apatite in the Horton Bluff Formation, and it was observed in Triassic sandstone during the present study. Weeks (1948) reports apatite in the granitic rocks of the Cobequid complex. Loring and Nota (1969) report 9% apatite in the Paleozoic sandstone and 7% in the beach sand from the New Brunswick coast between Cape Tormentine and

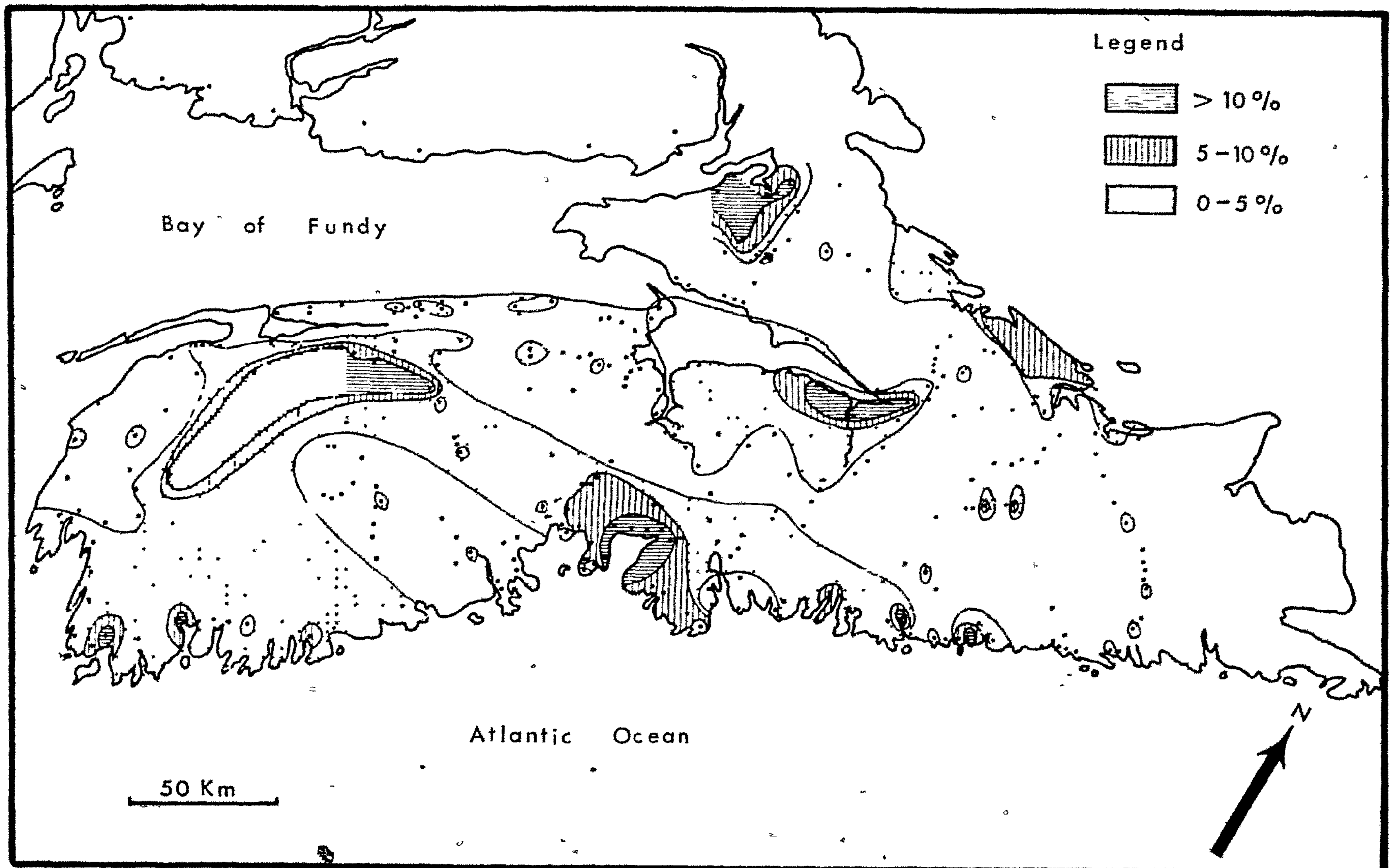


Figure 44. Distribution of apatite.

Miramichi Bay.

Since apatite occurs only in trace amounts, its usefulness as an indicator is questionable. In most instances its distribution is directly related to the immediately underlying bedrock. For example, the Barrington Bay, Shelburne, western Devonian granite, St. Margaret's Bay and Eastern Shore occurrences are directly related to the underlying granite sources. Similarly, the occurrences over Minas Basin and north of the Cobequid Mountains are related to the underlying sediments in which apatite is a detrital component. Only the presence of apatite over North Mountain is unequivocally the result of ice movement, although it is not possible to determine from it the direction of ice flow.

The near absence of apatite in the drumlin fields of Lunenburg, Cow Bay-Chezzetcook, Moose River, Owls Head, Liscomb and Ecum Secum as well as over the northeastern part of the main Devonian granite batholith is believed to be the result of dilution by high percentages of other minerals derived from outside these areas.

<u>Rutile</u>

Relatively high percentages of rutile are found in till in several parts of the study area (Figure 45). The highest values are in the area between Five Islands and Joggins - in sample 316, rutile comprises 59% of the non opaque fraction. Abundant rutile also occurs between Windsor and Halifax along a line which follows close to the eastern edge of the main Devonian

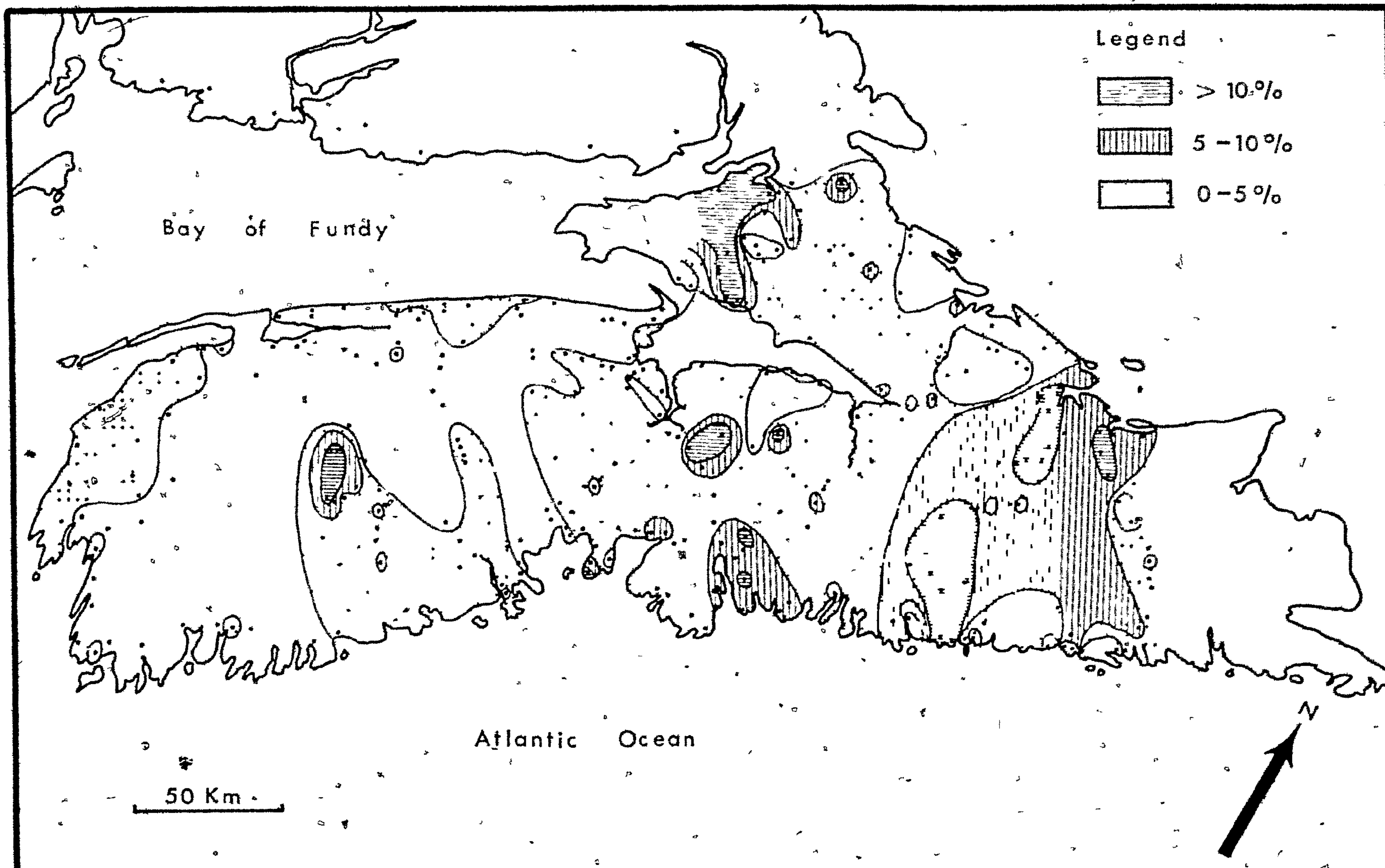


Figure 45. Distribution of rutile.

batholith. Rutile is concentrated in two fans extending southwards from the Pictou region towards Ship Harbour and Sherbrooke. Along the E[illegible]n Shore rutile percentages vary greatly over short distances, whereas in the southern part of the province it occurs either as a trace component or not at all except in the Kejimkujik Lake area. Over North Mountain rutile is found in trace amounts in the central part, but is otherwise absent.

Rutile, like zircon and tourmaline, is an ultrastable mineral originating in granitic intrusives and slates. Reference to rutile in Nova Scotia bedrock has been made by Worth (1969) who observed it in the Horton Bluff Formation near Wolfville. Nolan (1963) and Cok (1970) observed rutile in beach and shelf sediments around Nova Scotia. Miller, Graves, and Zentilli (1976) observed rutile in the quartz veins in the Meguma. Rutile is probably present in the various granitic intrusives in small quantities as well. These two rock types were the sources of the rutile deposited in the post-Devonian detrital sediments in central and northern mainland Nova Scotia.

The distribution of rutile in the till is in most cases related to the underlying bedrock with three possible exceptions: 1) rutile in the till overlying the North Mountain basalt was derived from either the northwestern or southwestern side of the mountain; 2) the rutile in the till overlying the eastern end of South Mountain batholith may have been derived from the underlying granite but more likely originated from the slates and detrital sediments to the north and east; and 3) the two fans originating near Pictou and New Glasgow indicate a southerly and southeasterly ice flow direction. These two fans may extend to the Atlantic shore but due to the presence of substantial quantities of rutile in the Meguma slate it is difficult to determine the locally derived component in that area.

The wide distribution of rutile in post-Devonian sediments as well as the generally low percentages makes it a poor indicator mineral.

Zircon

Figure 46 shows the equifrequency distribution of zircon in Nova Scotian till. The distribution is patchy, complex and difficult to interpret. In the northern and eastern parts of the province, in the areas underlain by sediments, there is a noticeably higher concentration of zircon. The areas underlain by Devonian granite and Meguma rocks are on the whole low in zircon, although there are local unexplainable variations.

The eastern end of the Cobequid Highlands is characterized by great variation in the zircon content of the till. A high percentage is found in the Pictou region, extending southeast across volcanic rocks of the Arisaig Group. The source of this fan is the post Devonian sediments found north of the Cobequid Mountains and Antigonish Highlands.

The other noticeable zircon fan extends southeast from the Rawdon Hills. The source for this fan is in the post Devonian sediments around Minas Basin or possibly the Cobequid Mountains.

Zircon is conspicuously absent from the eastern and western parts of North Mountain and most of the region between Digby and Yarmouth that is underlain by the Meguma and the White Rock Formations.

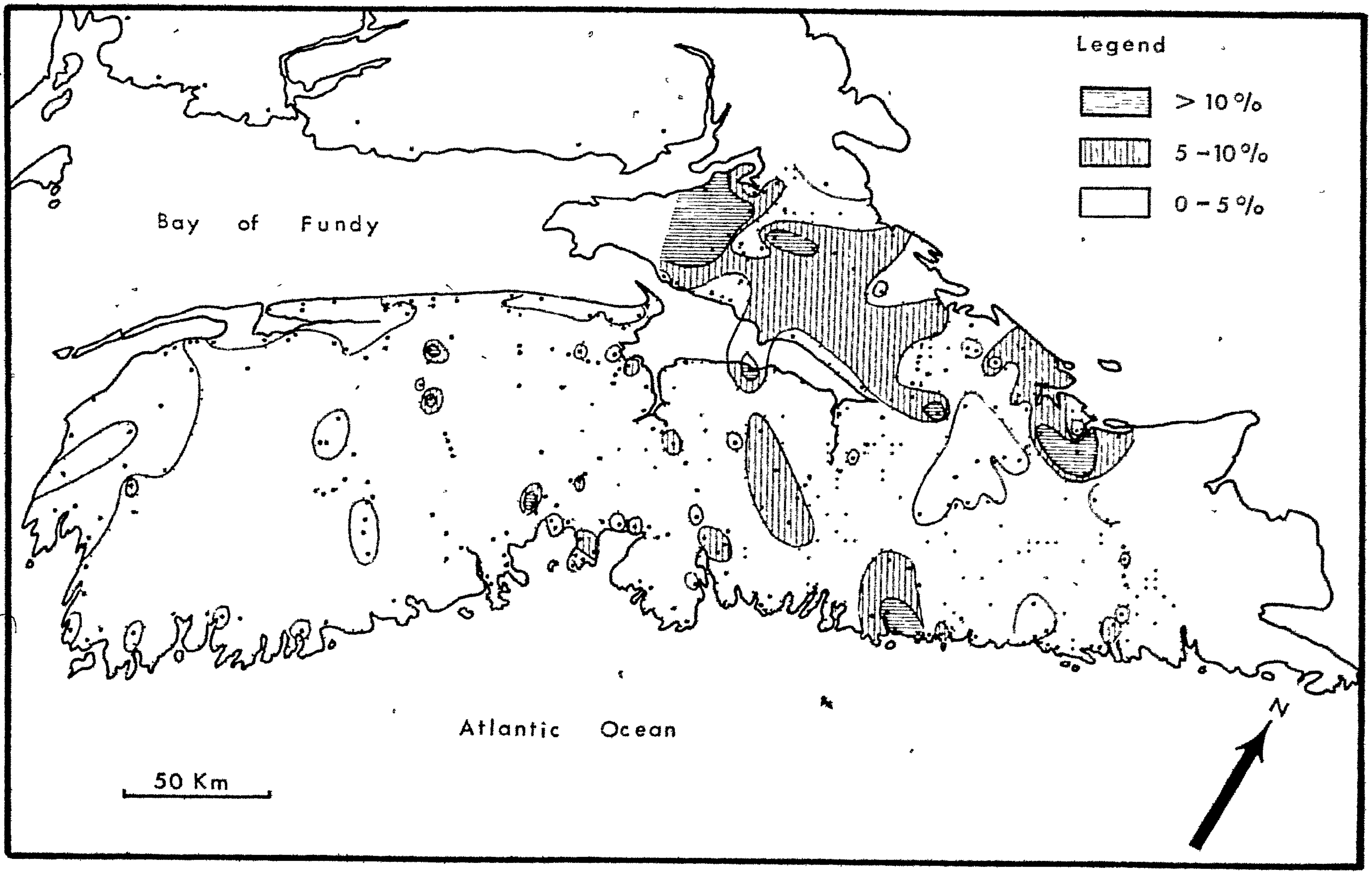


Figure 46. Distribution of zircon.

The usefulness of zircon as an indicator mineral is questionable because it is widely distributed in small quantities, as are the other ultrastable minerals.

The presence of zircon on the North Mountain basalt is evidence that the basalt was overridden by ice carrying debris from either the Triassic sediments on the north or south of the Mountain, or from the Devonian batholith to the south.

Staurolite

Figure 47 shows the distribution of staurolite in Nova Scotian tills. The distribution is characterized by four pronounced and several minor occurrences. The greatest concentrations of staurolite are in the Liverpool to Yarmouth area and the area east of Taylors Head along the Eastern Shore. The largest area extends approximately from Truro to Middleton to Halifax. North of the Cobequid Mountains staurolite is found between Tatamagouche and Amherst. More scattered occurrences are found in the Halifax to St. Margaret's Bay area, Chezzetcook area, Lunenburg area and northwest of Lunenburg and between Weymouth and Yarmouth.

The distribution of staurolite on the Eastern Shore, east of Taylors Head, and on the South Shore, between Liverpool and Weymouth, is directly related to the underlying bedrock (Taylor and Schiller 1966).

The Carboniferous and Triassic rocks north of the Cobequid Mountains and in Minas Basin are the main source of staurolite outside the Meguma Group. Figure 48 is a plot of the percent staurolite against the percent silt plus clay for all the samples in the area excluding those samples which overlie

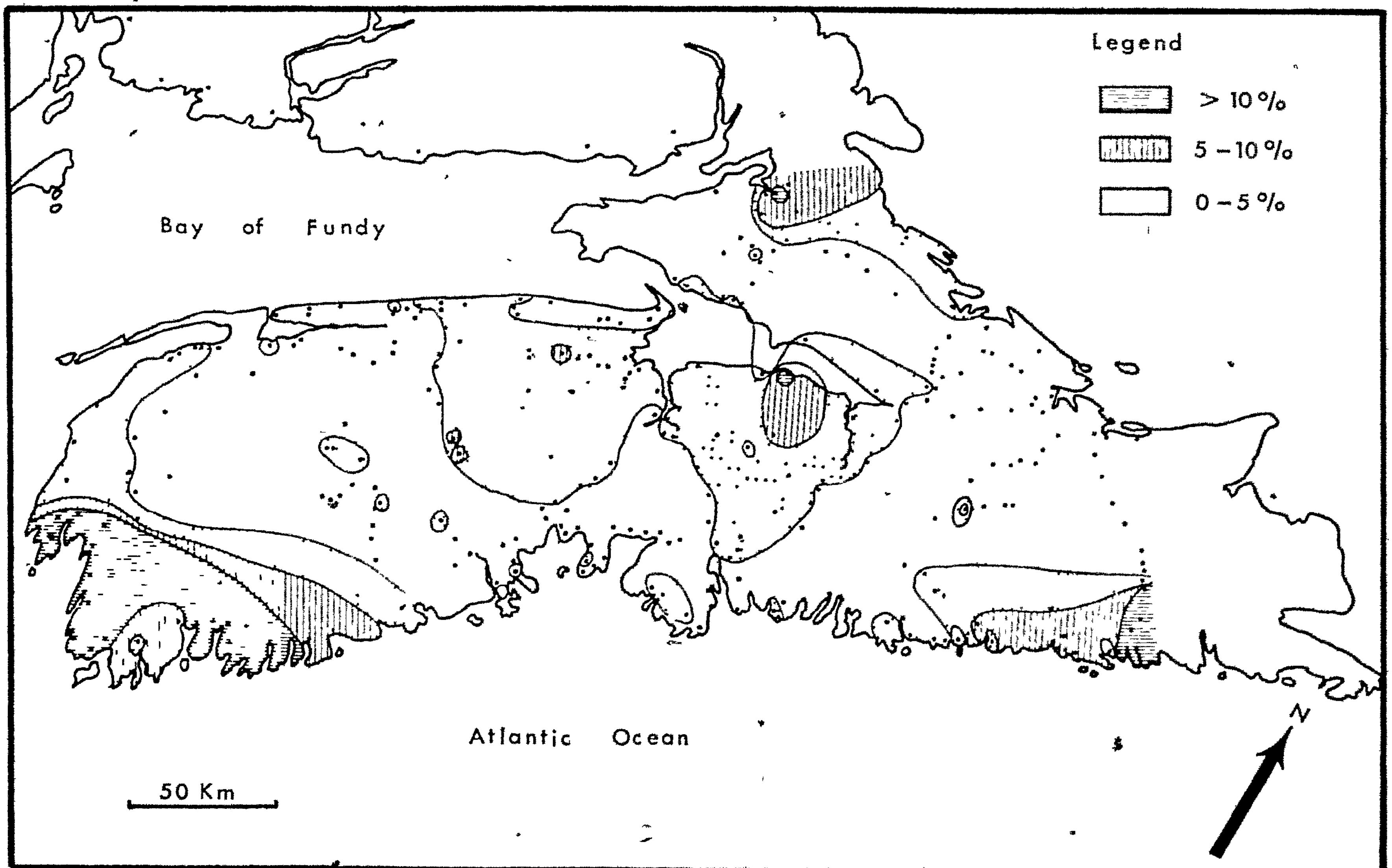


Figure 47. Distribution of staurolite.

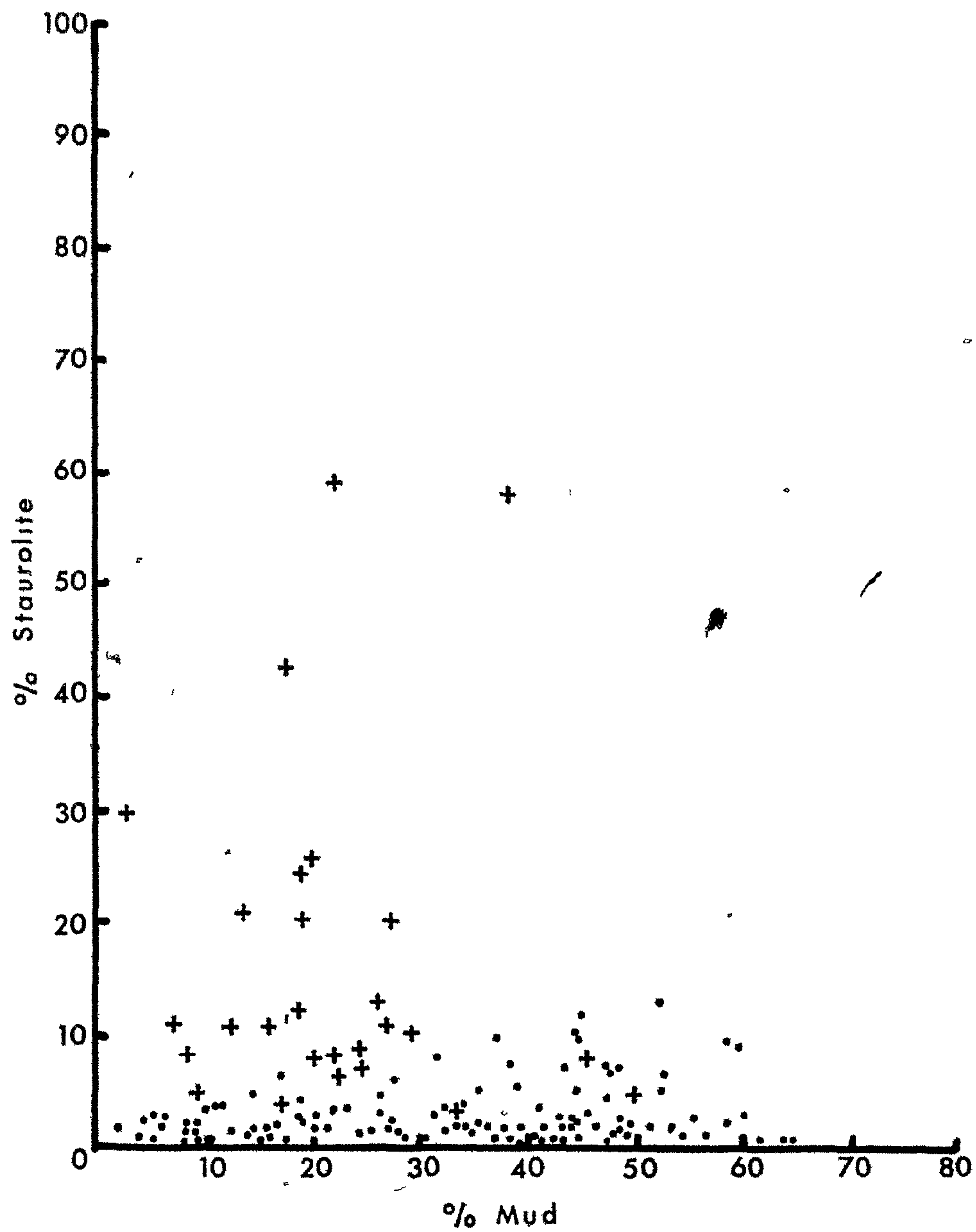


Figure 48. Variation in the staurolite and mud content of till samples from the whole study area excluding samples overlying the staurolite zone of metamorphism (see Fig. 33) and samples with no staurolite present. (+) indicates drumlin samples, (•) non-drumlin samples.

rocks of the Meguma group that contain staurolite. The diagram indicates that there is muddy till rich in staurolite and muddy till poor in staurolite. Therefore it is concluded that the muddy till is derived from more than one source. Figure 48 clearly shows two staurolite source areas as well as a positive correlation between the mud and staurolite content of till from the Carboniferous Lowlands. This relationship is also obvious when the staurolite isofrequency map (Figure 47) is compared to the lithofacies map (Figure 27).

Staurolite in the belt from central North Mountain and Wolfville to the Chester area was derived from an unknown source. Possible source areas include: 1) Triassic sediments in the Annapolis Valley, or 2) Triassic and Carboniferous sediments in Chignecto Bay. The close resemblance between the distribution of staurolite and grossularite as well as amphibole and epidote indicates that the Paleozoic sediments in the Middleton to Wolfville area are the sources of the staurolite on North and South Mountains.

The staurolite in the till north of Halifax and in the Sambro area is the result of ice moving due south from the eastern end of Minas Basin. The Chezzetcook drumlins contain staurolite which is presumed to come from a northwesterly direction. Interestingly enough, there is no staurolite in the sample from the Cow Bay drumlin field, which grades into the Chezzetcook drumlin field to the west.

Andalusite

Andalusite distribution in Nova Scotian tills is shown in Figure 49. It is found in three major areas - over the South Mountain batholith, around

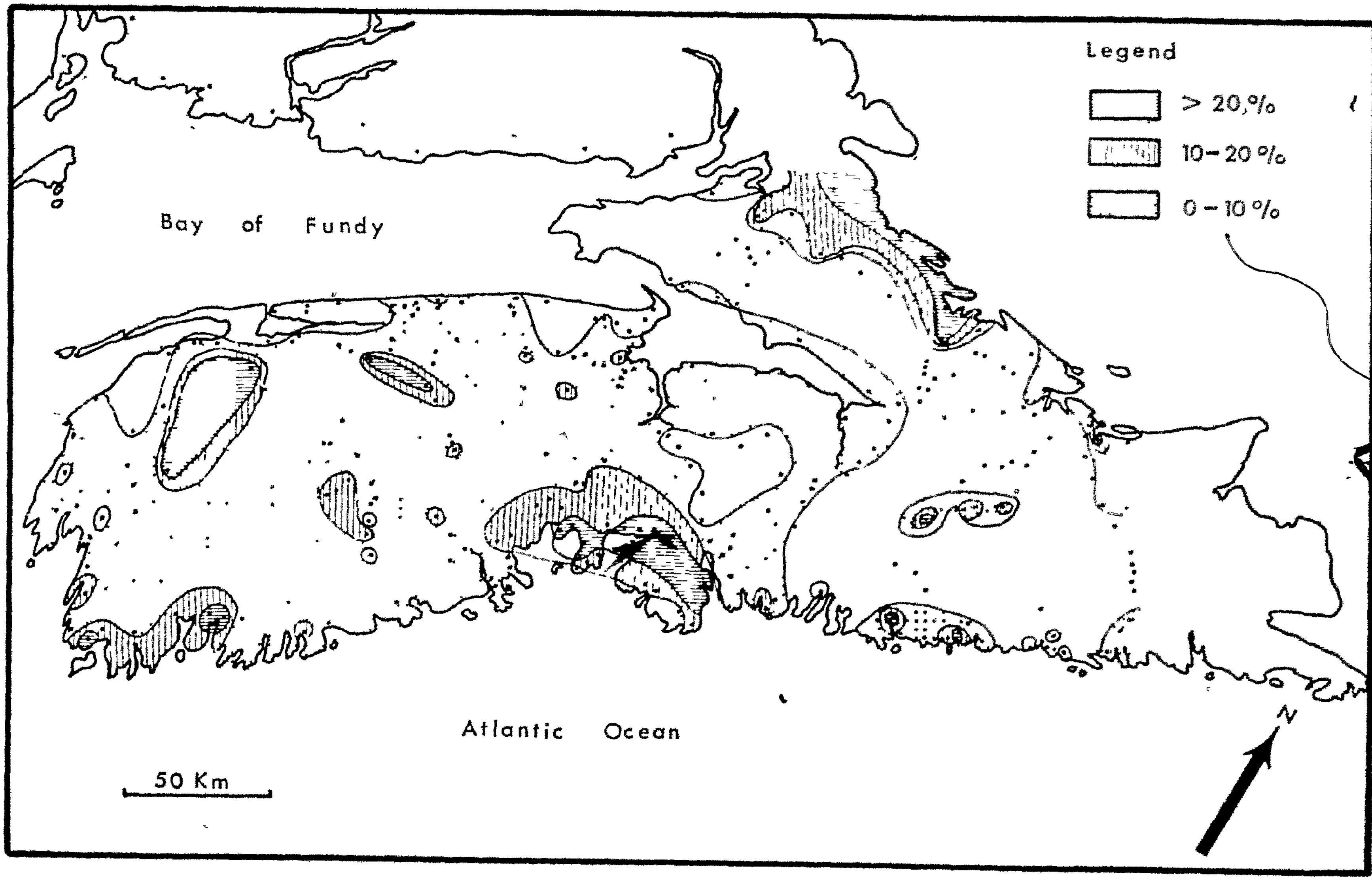


Figure 49. Distribution of andalusite.

Barrington Bay, and in the Ship Harbour-Sheet Harbour area. A surprisingly high percentage of andalusite is found in the till between Amherst and Tatamagouche and also around New Glasgow. It is also found in the till over the central part of North Mountain. The Cobequid Mountains, the western part of the Antigonish Highlands, the Rawdon area, and a large east-west tract parallelling the Eastern Shore (but inland from the sea) are areas with no andalusite in the till.

Andalusite is an accessory mineral in the adamellite phase of the Devonian granites in the area south of the Cobequid fault (Mackenzie, 1974). It is also found throughout most of the Meguma Group as a product of regional and contact metamorphism (Taylor, 1967, 1969). Although it has not been reported as a detrital mineral, it is believed to be present in the post-Devonian sediments surrounding the Meguma platform.

Andalusite distribution is directly related to the immediately underlying bedrock, except over the central part of the North Mountain basalt. The presence of andalusite in the latter region testifies only to the fact that ice moved over the area and gives no information about the direction of ice movement.

The apparent absence of andalusite in the southeastern area is probably due to masking by heavy concentrations of amphibole and epidote.

Sillimanite

Sillimanite is found in six small areas scattered throughout the province: 1) the Sissiboo River area south of St. Mary's Bay, 2) east of

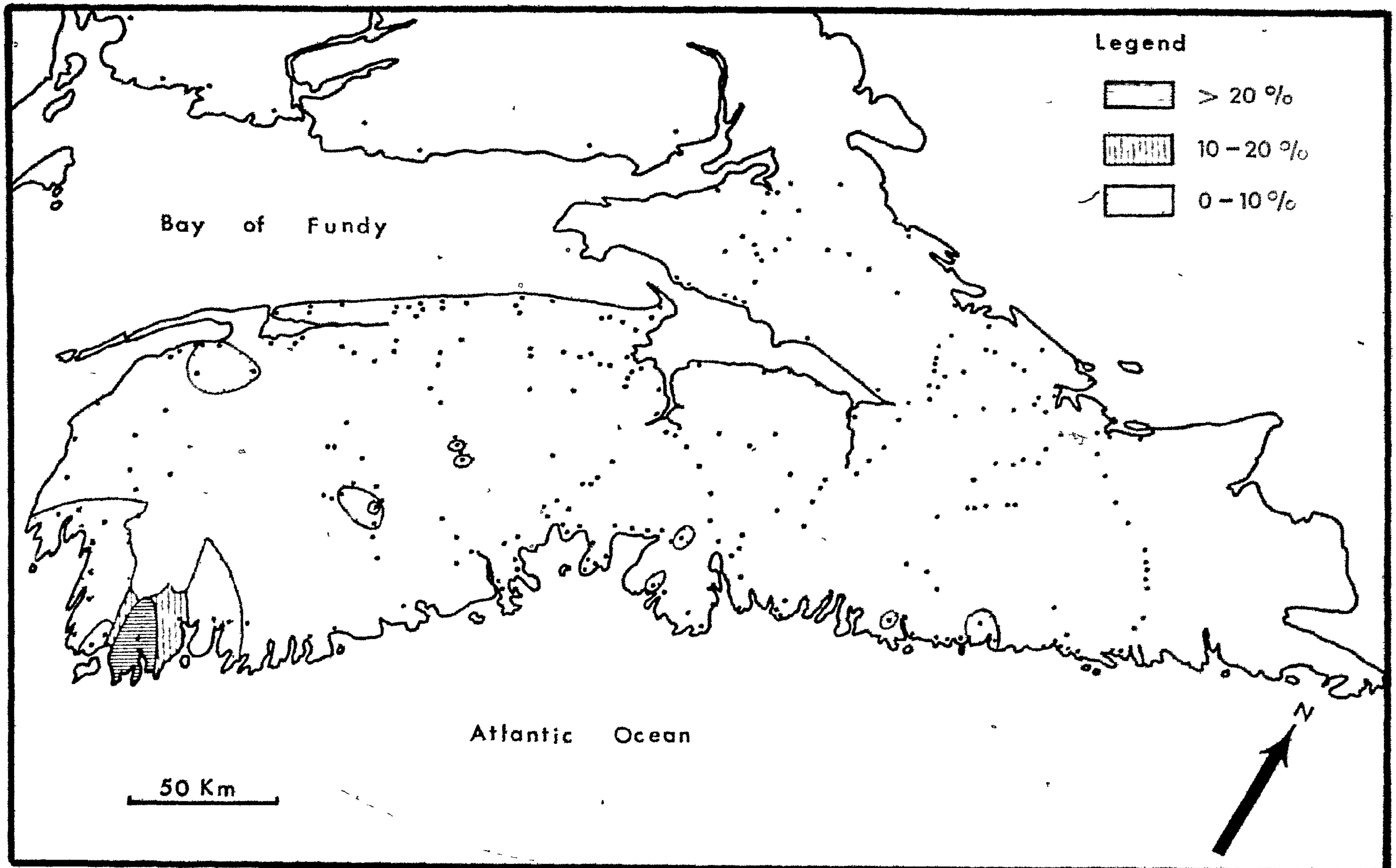


Figure 50. Distribution of sillimanite.

Lake Rossignol, 3) the Cherryfield area between Bridgewater and Middleton, 4) along the eastern side of St. Margaret's Bay, 5) Ship Harbour, and 6) Sheet Harbour. The particular sources are probably local but are not known. A large sillimanite indicator fan occurs between Yarmouth and Jordon Falls in southern Nova Scotia (Figure 50) and is bounded by two lines that are approximately at right angles. The greatest sillimanite concentrations occur between Shelburne and the head of Barrington Bay. Muecke (unpublished data) has delineated the sillimanite zone of metamorphism in the Great Pubnico, Bloody, Big Gull and Quinan Lakes areas, 30 km west and northwest of Shelburne (Figure 33). This is clearly the source of the sillimanite in the large fan in the southwestern part of the province.

The orientation of this fan indicates ice movement directly southwards. Compared to the western side, the eastern side of the fan is especially well formed. The occurrence of sillimanite as far west as Yarmouth is interpreted as mineral derivation from underlying bedrock and not as the result of northwesterly ice flow.

The limited distribution of sillimanite in the bedrock makes this one of the best indicator minerals and the resultant fan a sensitive directional marker.

Tourmaline

Figure 51 shows the equifrequency distribution of tourmaline in Nova Scotian till deposits. Relatively high percentages are found in the Carboniferous Lowlands to the north of the Cobequid Mountains and the area

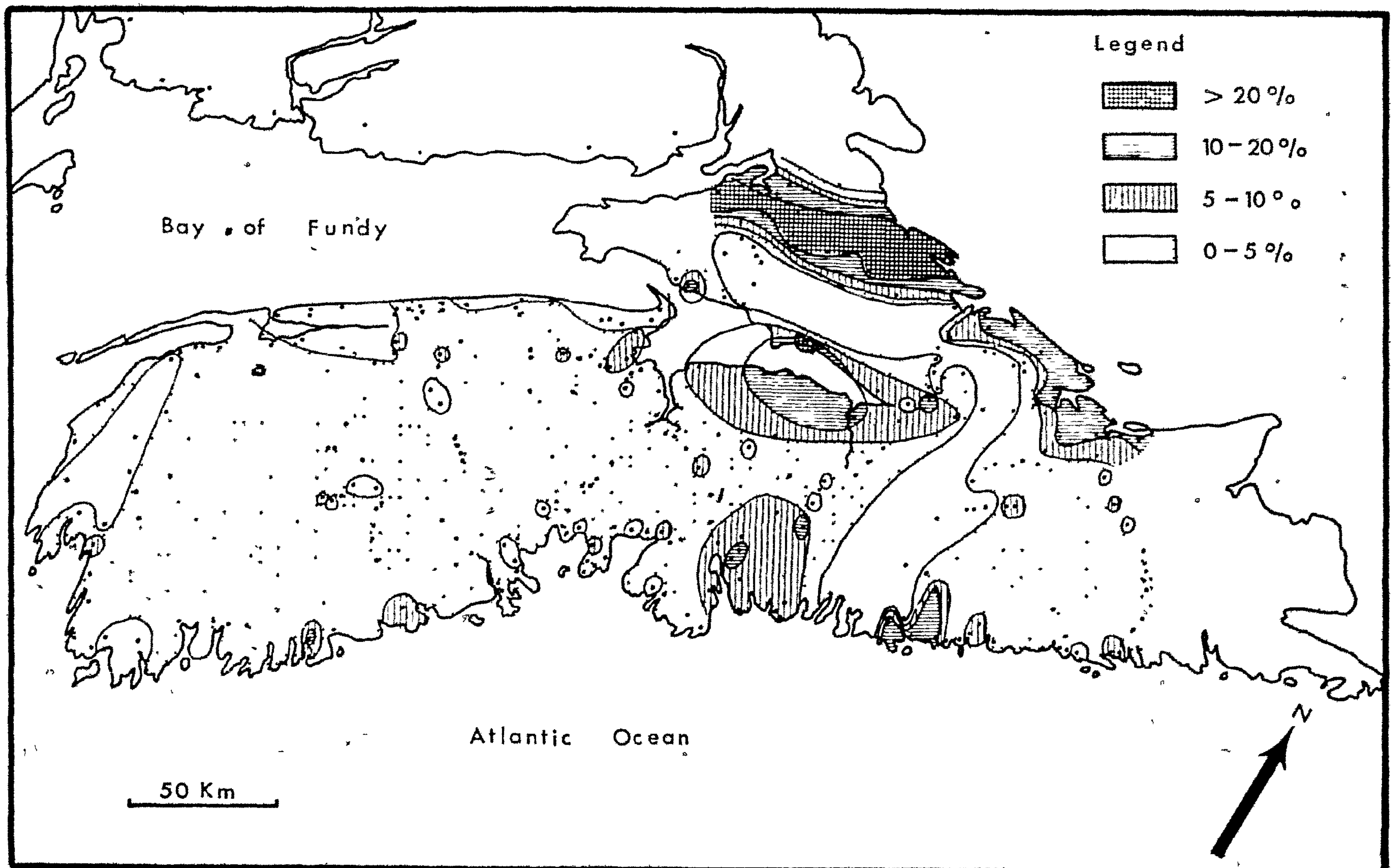


Figure 51. Distribution of tourmaline.

surrounding the eastern end of the Minas Basin. A high concentration is also found around Halifax, Ship Harbour, Liscomb and Moose River. Tourmaline is conspicuously absent in the Cobequid Mountains and in a long belt extending from the eastern end of the Mountains to Sheet Harbour on the Atlantic coast. It is present over the central portion of North Mountain in the Middleton area. Otherwise, tourmaline is not present over the basalt.

Tourmaline is a widely distributed mineral, occurring in the Meguma Group, the Devonian granite and in all the post-Devonian sediments on which information is available. Notable exceptions are the volcanics of North Mountain, the Cobequid Mountains, the Antigonish Highlands and the evaporites of the Windsor Group.

Due to the wide distribution of tourmaline in the bedrock in Nova Scotia and its occurrence in small quantities, its usefulness as an indicator is somewhat limited. The post-Devonian sediments are richest in tourmaline and they may be the cause of the anomalous concentration found south of those regions. The only area where tourmaline distribution can confidently be interpreted as being the result of ice movement is over the North Mountain basalt. The presence of tourmaline in Triassic sediments on both sides of the basalt makes it impossible to determine the ice flow direction; it only indicates that the central part of the mountain was overridden by ice resulting in an area of deposition of till with some foreign components.

Spessartine

A small, clear, colourless, euhedral garnet, identified as spessartine,

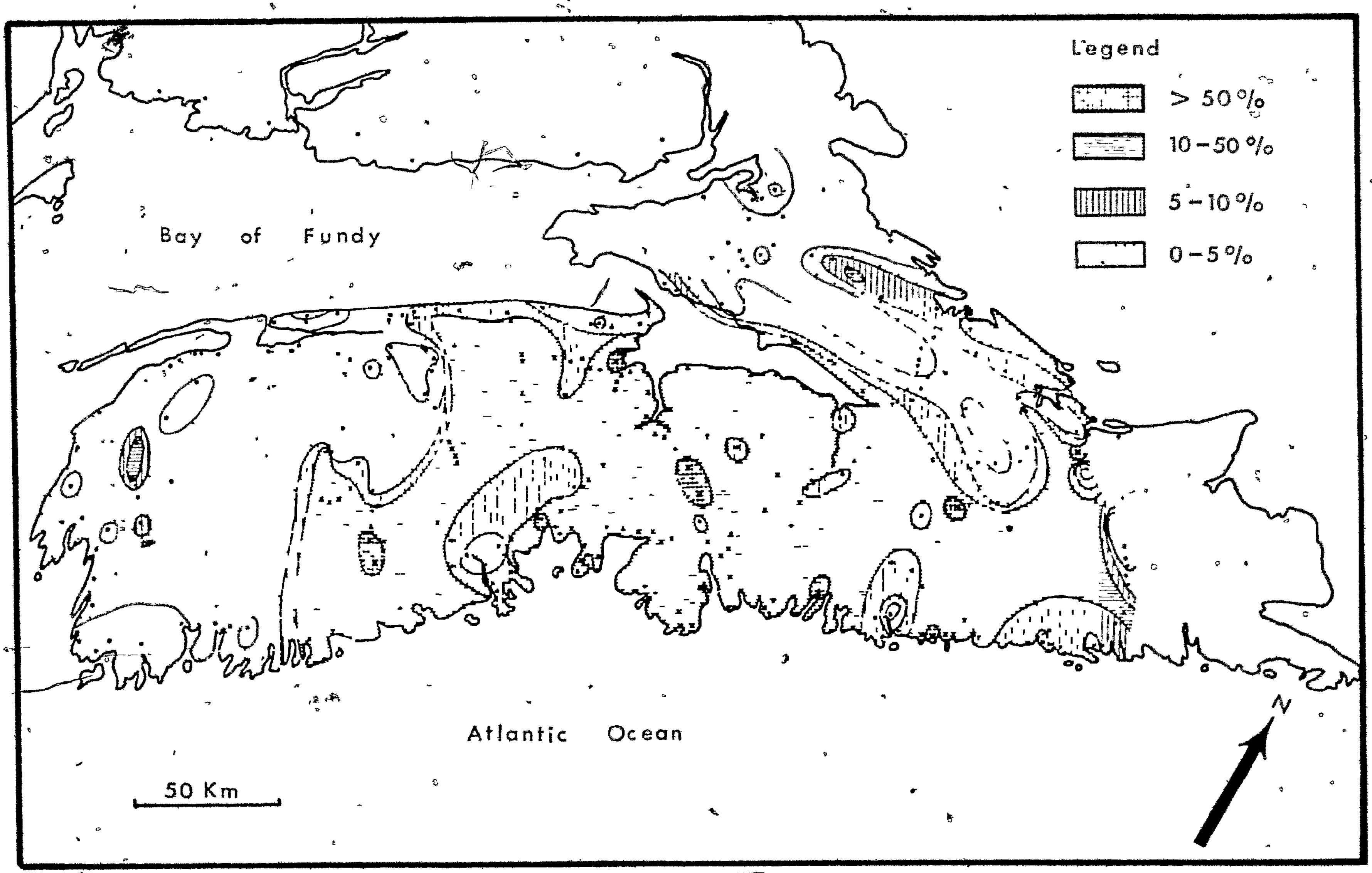


Figure 52. Distribution of spessartine.

is present in most of the till samples. It is almost absent in the Shelburne to Yarmouth area and between Joggins and Five Islands. Spessartine is abundant in the area from Kejimkujik Lake to the eastern end of the study area south of the Cobequid Mountains and Antigonish Highlands. In the eastern Cobequid Mountains spessartine percentages are very low and two lobes with minor amounts of spessartine extend southeastward into the very abundant spessartine region to the south (Figure 52).

The low percentages at the eastern end of the Cobequid Mountains is believed to be the result of masking by large amounts of Cobequid material, notably amphibole and epidote, the presence of which in high percentages causes a corresponding decrease in the percentages of other minerals. The absence of spessartine between Chaplin and Pictou is an indication of southeasterly ice flow in the region.

North and south of the Paleozoic sediments in the eastern half of the Annapolis Valley the percentages are relatively high compared to the values over the western half of the North and South Mountains. As the Scots Bay Formation floors the Bay of Fundy it cannot be the source of the spessartine, because if it were so the entire area south and southeast of the Bay would have approximately equal amounts of spessartine. Spessartine has been recognized by Thompson (1974) as a detrital component of the Scots Bay Formation, where it comprises from 5 to 20% of the heavy mineral fraction. The low spessartine percentages in the samples from west of the 5% iso-line (running from Lawrencetown in the Annapolis Valley to Sable River on the Atlantic coast) are the result of ice moving across the Bay of Fundy. The relatively small amounts of spessartine from the Scots Bay Formation can be considered as 'background noise'. The high percentages on North Mountain north of Middleton must have been derived primarily from the Paleozoic sediments bordering the Annapolis Valley between Middleton and Windsor. Therefore it can be conclusively stated that the distribution of spessartine in this region indicates a local northward flow of ice.

Almandine Garnet

High percentages of almandine garnet are found in the till in the Carboniferous Lowland north of the Cobequid Mountains, between Yarmouth and Liverpool, and east of Ship Harbour. Most of the samples contain some almandine garnet except those from the eastern and western ends of North Mountain, the Cobequid Mountains and the Browns Mountains.

Almandine garnet was originally restricted in its distribution to three areas of the Meguma: 1) the Canso area, 2) the triangle from Yarmouth to Liverpool and north to the Devonian granite contact (Figure 33), 3) the granite Meguma contact zone. The high percentages of almandine garnet in the till in the Yarmouth-Liverpool and Ship Harbour-Sherbrooke areas is related to the underlying bedrock.

Loring and Nota (1969) report 30% garnet in beach samples from both the north shore of Prince Edward Island and the Magdalen Islands, and 3% and 7%, respectively, from the bedrock in these areas. The bedrock and surficial sediments of the pre-Wisconsinan Gulf of St. Lawrence and the Carboniferous

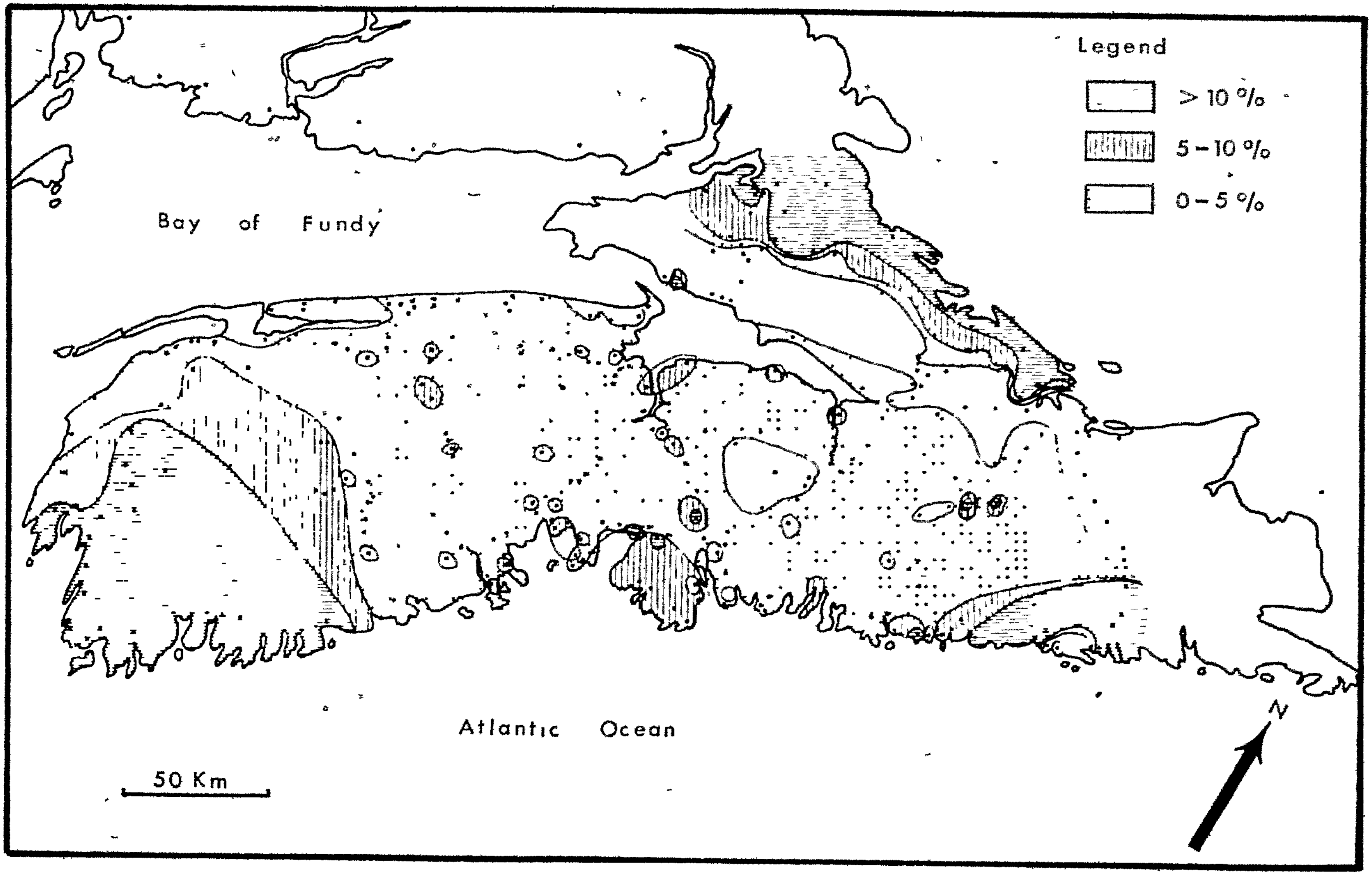


Figure 53. Distribution of almandine garnet.

rock north of the Cobequid Mountains must have been the main source of the low and widely distributed quantities of almandine in the till.

The complete absence of almandine garnet in the till over the Cobequid and Browns Mountains suggests that almandine is not found in the bedrock in those areas and that these areas were not the sites of deposition of till derived from the surrounding lowlands.

The presence of almandine over the central part of North Mountain indicates that the area was overridden by ice flowing either out of or into the Bay of Fundy. The distribution over the rest of the province is patchy and difficult to interpret. The post-Devonian sediments undoubtedly contributed small quantities of almandine to the till derived from those areas.

Anatase

There are two types of anatase in the tills of Nova Scotia. The most easily recognized type is a deep blue, tetragonal form. Nolan (1963) mistakenly identified this type of anatase as kyanite, which has not been identified in this study in any samples from mainland Nova Scotia. The second type of anatase is turbid brown in colour and the form is usually less well-developed. The latter type may include rutile mistakenly identified as anatase. However, it is included with anatase because it is distinctly different from the typical blood-red rutile.

The distribution map (Figure 54) shows a high percentage of anatase in the Carboniferous Lowlands north and south of the Cobequid Mountains. Anomalously high percentages are found around Amherst, Tatamagouche, New

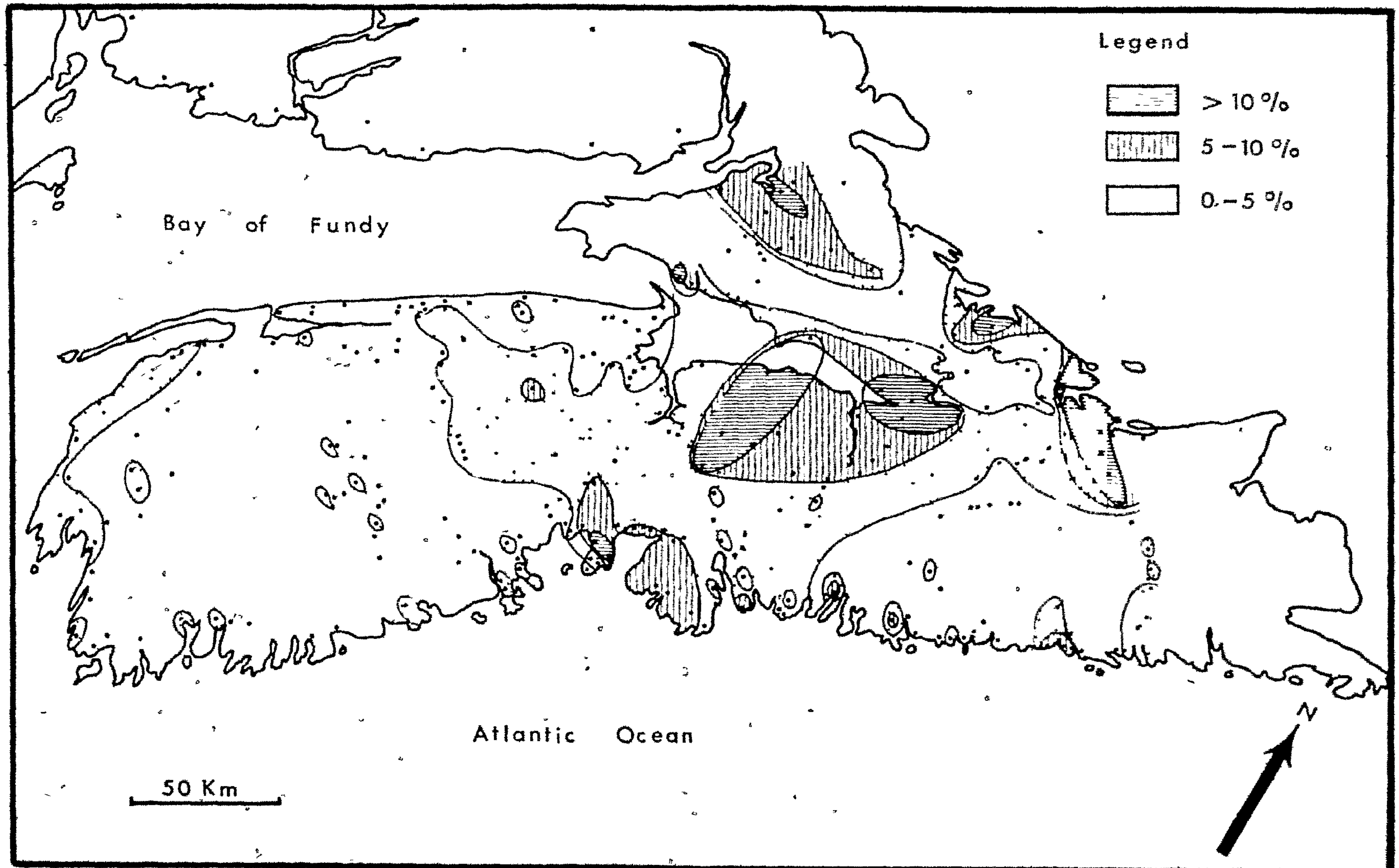


Figure 54. Distribution of anatase.

Glasgow and south of Minas Basin. The area around St. Margaret's Bay is rich in anatase, as are isolated localities along the Atlantic coast east of Halifax. West of a line joining LaHave River and Middleton, anatase occurs only sporadically. The Cobequid Mountain till is devoid of anatase as is the till on North Mountain except for sample 405 north of Middleton.

The distribution of anatase over the eastern half of the main Devonian granite pluton and southeast of Kejimkujik Lake, as well as its absence over the Cobequid Mountains, indicates that the source is the slate between Middleton and Wolfville and around Kejimkujik Lake or south of the Annapolis Basin. The high percentages of anatase around Minas Basin and north of the Cobequid Mountains indicates that the bedrock in these areas was a source. Comparison of the lithofacies map (Figure 27) and Figure 54 and Figure 55 shows a weak positive correlation between the occurrence of muddy till and anatase. Anatase distribution is similar to that of staurolite except in the Pictou-New Glasgow area. In the latter area there is a distinctive anatase indicator fan, the source and lateral extent of which is unknown. It appears to originate in the Northumberland Strait and extend southeastward over the Antigonish Highlands. Loring and Nota (1969) report 19% anatase in bedrock samples on the north shore of Prince Edward Island and 10% in bedrock samples from the Magdalen Islands.

Detrital anatase from the Minas Basin and the Carboniferous rocks north of the Cobequid Mountains was also deposited in the till of the Sambro, Cow Bay, Chezzetcook, Owls Head, Moose River, Liscomb , Ecum Secum and Indian River drumlin fields.

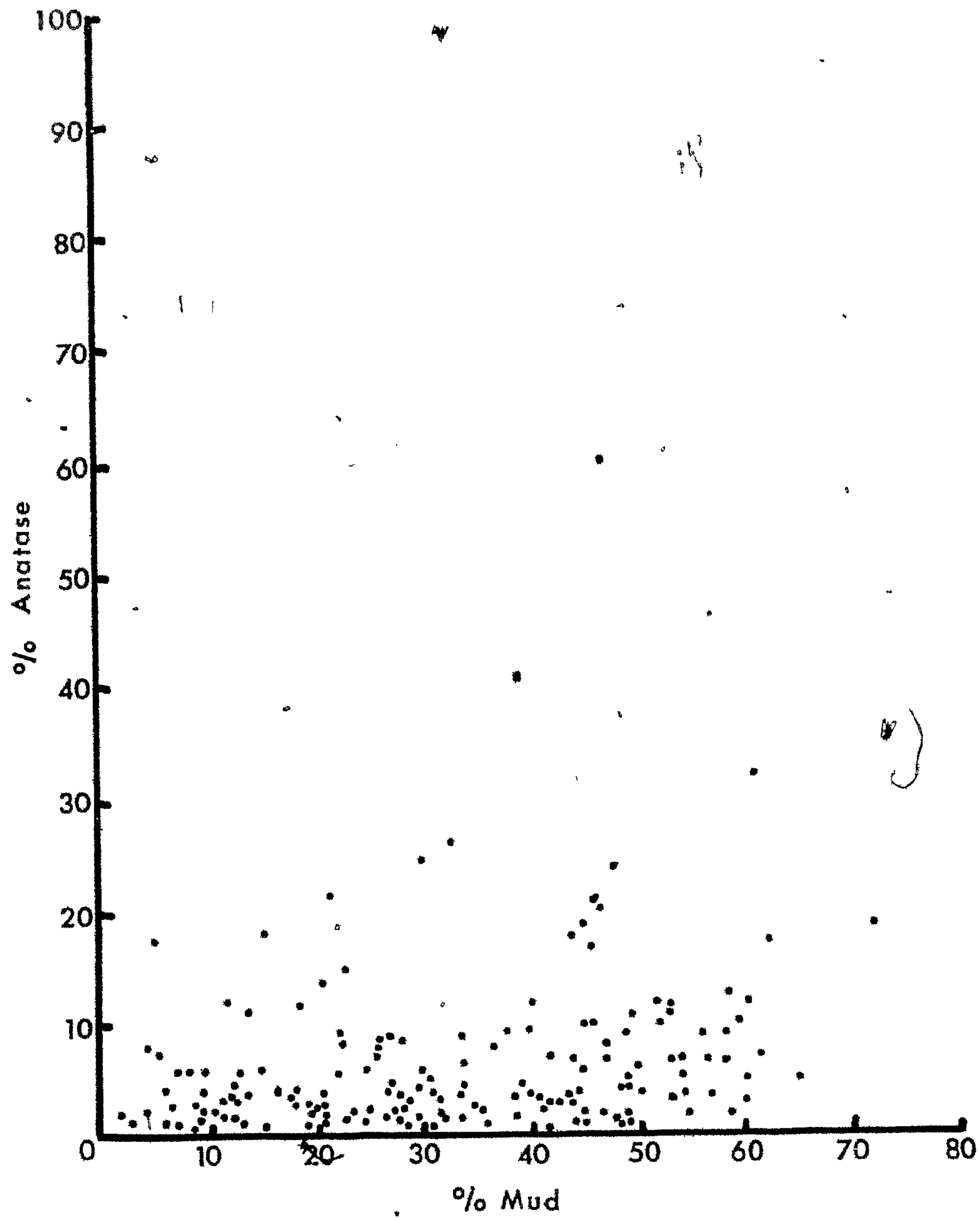


Figure 55. Variation in the anatase and mud content of Nova Scotian till samples.

The absence of anatase or its occurrence in trace amounts over the Meguma in the eastern and southwestern regions outside the drumlin fields suggests that the tills in these areas are locally derived and that the heavy mineral composition is close to the underlying bedrock, or else dominated by a completely foreign suite in which anatase is absent.

Opaque Minerals

An equifrequency plot of the distribution of opaque minerals in Nova Scotian tills shows a high concentration in the Carboniferous Lowlands and the area to the southwest towards Halifax and Middleton. Notably high concentrations lie within the area between New Glasgow and Tatamagouche, around Amherst, and in the Cheverie-Rawdon area south of Minas Basin. High concentrations of opaque minerals are also found over Meguma bedrock in a belt between Digby and Barrington Bay and in the area bounded by Liverpool, Bridgewater and Kejimkujik Lake. Scattered, isolated high concentrations are found along the Atlantic shore between St. Margaret's Bay and Sherbrooke (Figure 56).

Opaque minerals over the eastern section of the main granite pluton were derived from the Minas Basin area and spread south and southwest. Figure 57 shows that there are two distinguishable sources of opaque minerals related to the mud content of the till. Group A clearly shows a direct relationship between opaque mineral content and mud content. This group is believed to have some Minas Basin and Carboniferous sediment content. Group B is relatively poor in opaque minerals but still rich in silt and clay, and is found either over North Mountain basalt or has more than 70% augite

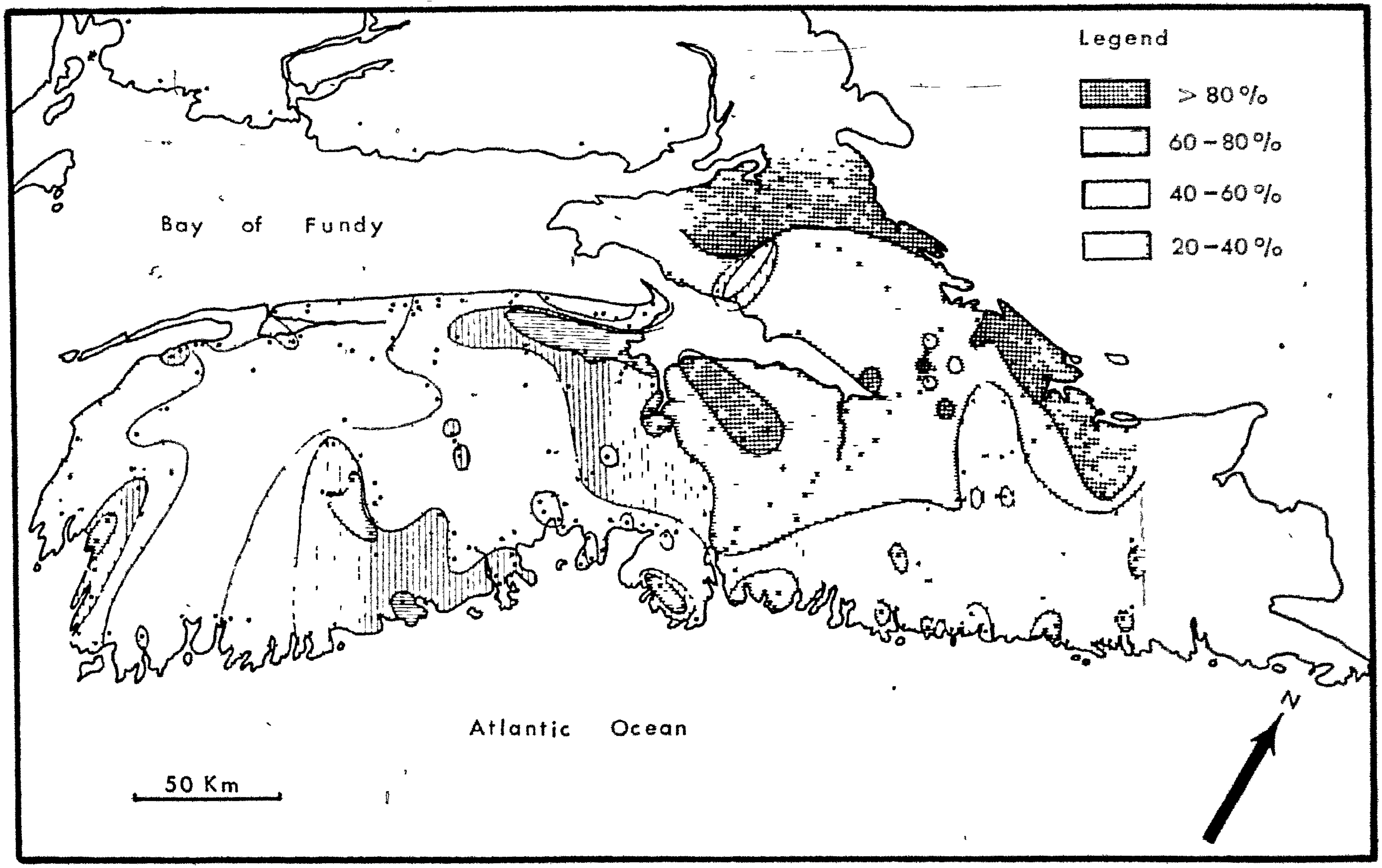


Figure 56. Distribution of opaque minerals.

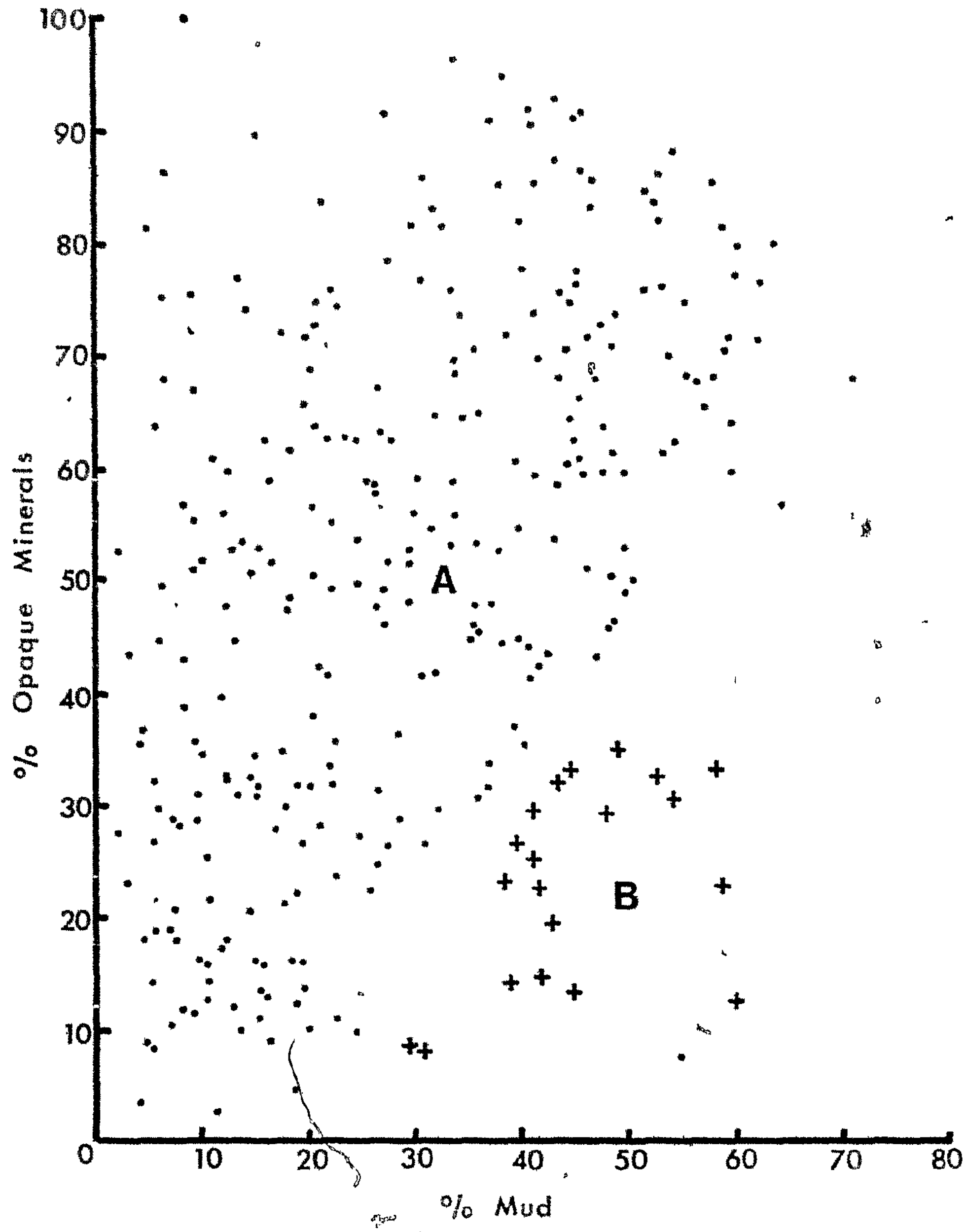


Figure 57. Variation in opaque mineral and mud content of Nova Scotian till samples. Samples with >70% augite are indicated by (+).

in the nonopaque fraction and is thus primarily derived from North Mountain basalt.

The high percentages of opaque minerals in the Amherst and New Glasgow-Pictou region is reminiscent of the anatase distribution. The drumlin fields on the Eastern Shore have slightly higher percentages of opaques than the surrounding samples as a result of southerly ice flow from the Carboniferous Lowlands where opaque minerals where concentrated as placer deposits.

Opaque minerals are a minor constituent of the mineral assemblage on North Mountain, but there is a somewhat higher concentration over the central part of the mountain north of Middleton.

The distribution of opaques over North Mountain is probably due to radial ice flow from South Mountain as the distribution is similar to that of other minerals (staurolite, anatase, almandine, zircon, rutile, grossularite, andalusite and tourmaline). The variation in content of opaques in the southwestern part of the province underlain by Meguma and granite bedrocks is controlled by the distribution in the underlying bedrock.

Discussion

Table 3 summarizes the location of the dispersal fans of the major indicator minerals in the study area, and shows the mean direction of ice flow inferred from them. These mean directions are plotted in Figure 58B.

It is concluded that ice flow was dominantly from a north-northwesterly direction and that the ice flowed directly across the province to terminal

Table 3: Major ice flow directions as deduced by indicator fan orientation.

MINERAL	LOCATION OF INDICATOR FAN	ICE FLOW DIRECTION
Amphibole	Most of the province	155°
	Pictou area	65°
Sphene	Rawdon Hills	165°
	Eastern Cobequid Mountains	165°
Staurolite	South of Minas Basin	170°
Tourmaline	Minas Basin	160°
	Pictou	170°
Spessartine	North Mountain	Northward
Rutile	Windsor area	160°
	NNW of Halifax	140°
	Pictou area	170°
Zircon	New Glasgow	145°
	Eastern Shore	140°
	Enfield-Rawdon Hills	140°
Augite	Western half of Nova Scotia	135°
	Shubenacadie	125°
	Eastern Cobequid Mountains	155°
	"	65°
	"	120°
	"	165°
Epidote	Eastern South Mountain	150°
	North of Halifax	145°
	Eastern area of province	155-140°
Anatase	New Glasgow	130°
	Dartmouth	150°
Sillimanite	Barrington Bay	160°
Opaques	Antigonish Highlands	130°
	Rawdon Hills-Dartmouth	145-150°
	Windsor	155°
% Heavy Minerals	Shubenacadie-Eastern Shore	140°
	Antigonish Highlands	135°

positions on the Scotian Shelf.

Grant (1963) concluded that the main ice flow across the province trended approximately 145° (Figure 58A). Indicator fans throughout the area confirm that the major ice flow was towards 140-145° (Figure 58B). However, the augite fan in the Shubenacadie area shows an ice movement towards 125°, and the augite fan in the eastern Cobequid Mountains shows ice flow towards 120°. Because of the quality of the augite date the direction of these fans must be taken as real. Two major ice flow directions are proposed to have occurred - one south-southeasterly towards 145°, and the other east-southeasterly towards 120°. Staurolite and almandine garnet north of the Cobequids appears to move almost directly southwards (170°) and this direction is closely matched by staurolite south of the Minas Basin.

The Lunenburg drumlin field can be divided into an amphibole and a non-amphibole phase. The former is composed of red clay till, the latter of slate and metaquartzite till. The Lunenburg drumlins can be distinguished from the drumlins along the Eastern Shore by the percent augite, the former being very rich in augite, the latter very poor. The differentiation between the three types of drumlins in the area is a function of outcrop pattern in the source areas. Grant (1963) concluded that the variability in the pebble fraction was a function of distance of transport from the Minas Basin. He believed the lithologic differences to be a function of variations in the Minas Basin component but to be independent of the Cobequid component.

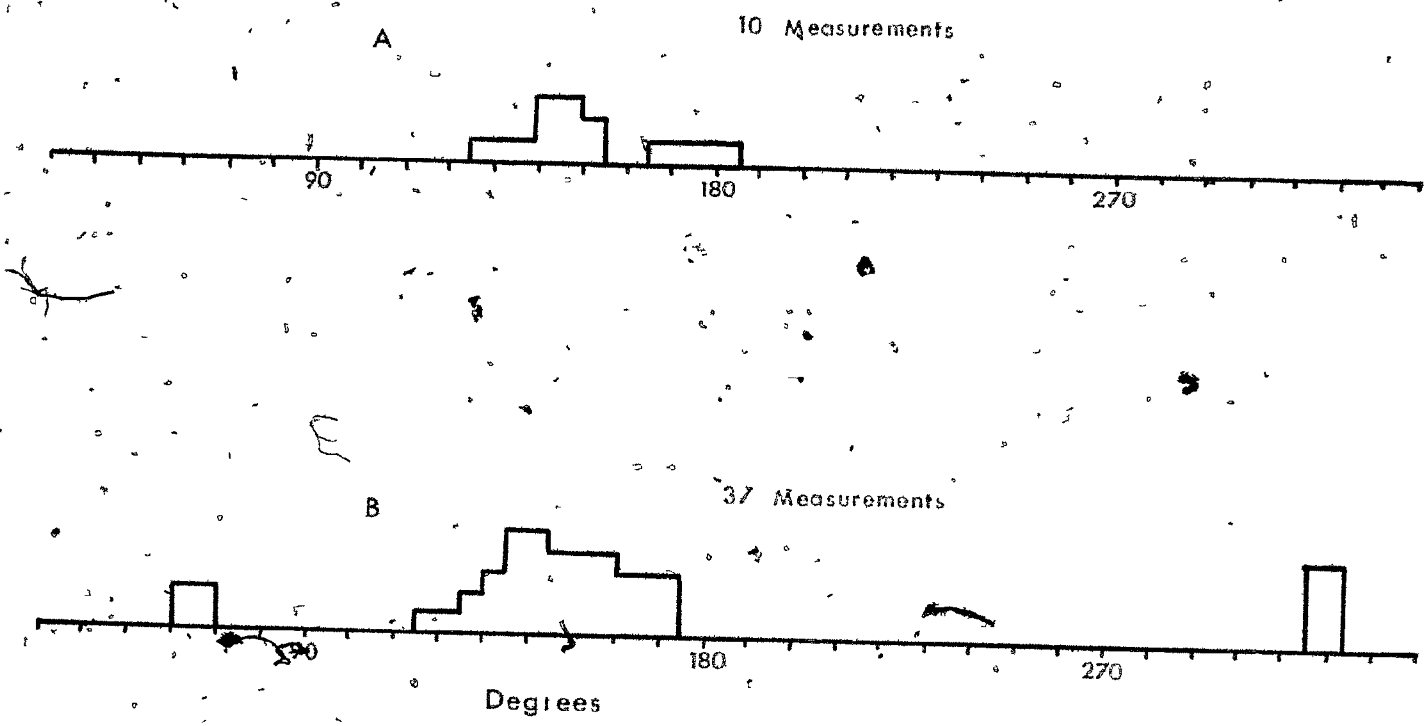


Figure 59. Histogram of drumlin orientations (A) compiled from data by Grant (1963) and the mean direction of ice flow inferred from dispersal fans (B).

The drumlin till along the Eastern Shore can easily be distinguished from the local till by the amount of mud and amphibole.

Several minerals, notably, anatase, andalusite, staurolite and spessartine indicate northerly ice flow from South Mountain over North Mountain and into the Bay of Fundy.

In the Pictou area the amphibole distribution indicates easterly ice flow. Radial outflow from the highlands is attributed to active flow from late "classical" Wisconsinan residual ice caps as described by Hickox (1962), Prest and Grant (1969).

Conclusions

1. There are no detectable sources outside the province.
2. The lobate distribution pattern is largely a function of the size of the source area, that is, it does not necessarily indicate ice currents or lobes.
3. There were two different directions of ice flow across the province, as well as localized northward flow over North Mountain and eastward flow near Pictou.
4. Amphibole and augite are the best indicators of distant sources.
5. Sillimanite and other minerals are good indicators on a local basis.
6. In the area east of Halifax, drumlin samples are richer in amphibole than non-drumlin samples, with only slight overlap.

7. Amphibole anomalies on the Eastern Shore are centered in the areas where the till is classed as muddy. Two tills are distinguished in this region, indicating two sources - one local, one foreign.

8. Amphibole is found in trace amounts in red clayey till samples east of the LaHave River; its origin is at present unexplained.

9. Correlation between muddy till and distribution of staurolite is found around Minas Basin.

10. No distinct drumlin phase is present over the eastern half of the main granite batholith. Till composition is gradational between local till and foreign red clay till.

11. Over North Mountain there is an inverse relation between the percent mud and the percent augite in the till.

12. Mineral distributions outlined by Nolan (1963) for Nova Scotian beaches correspond to the mineral distributions found in the till in the adjacent area, implying that beach sand is derived largely from erosion of local till.

13. Augite is distributed equally throughout the red clay drumlins and the slate drumlins in the Lunenburg drumlin field. The non-drumlin samples are generally less muddy and poorer in augite than the drumlin samples.

CHAPTER [illegible]

FACTOR ANALYSIS

Introduction

Factor analysis was developed early in the twentieth century for psychometric research, and has been used extensively by geologists in the last 20 years [see for example Manson and Imbrie (1964), Cameron (1967), Klovan (1966), Imbrie and Purdy (1962), Imbrie and Van Andel (1964), Vincent (1974), Knebel and Creager (1974), and Gwyn and Sutterlin (1972)].

A detailed explanation of the theory of factor analysis can be found in Imbrie and Van Andel (1964) or Harbaugh and Merriam (1968). It is sufficent to say that the principal objective of factor analysis is to obtain a concise description of the observed data. This is accomplished by explaining as much of the variance of each variable (R-mode factor analysis) and of the total variance using the minimum number of factors.

Basically there are two different types of factor analysis. R-mode analysis studies the relationship between variables and Q-mode analysis the relationship between samples. The latter type is preferred by geologists because factor loadings can then be plotted directly on a map and contoured. Instant objective facies maps [illegible] by this method. The disadvantage of the Q-mode method is that most computer programs are not designed to hardle more than 100 samples. As more than 300 samples were used in this study another technique had to be chosen.

Computer Technique

R-mode factor analysis was used to detect which of the heavy minerals are indicators. The most suitable program is the Statistical Package for the Social Sciences (SPSS) factor analysis program which is available at the Dalhousie University Computer Library. The principal factoring with iteration method and varimax rotation was used because it is the more widely used technique in geological applications (op. cit.).

The data for the 15 heavy minerals are entered as percent. The sixteenth variable is the percent heavy minerals in the 500 to 63μ fraction of each sample. Figure 59 shows the relationship between the number of factors and the percent of variance accounted for by each of the factors. The figure indicates that the first four factors account for 50.6% of the total variance. The change in slope of the line indicates that these first four factors describe that part of the mineralogy that the samples have in common (50.6%). The rest of the variation is random. The low percentage of the total variance accounted for is the result of the great variability in mineralogy of the source rocks.

The communality refers to the goodness of fit of the factor analysis. The communality is 1.00 where an individual variable is perfectly represented by an ensemble of factors and less than 1.00 if the sample is not totally reconstituted by that group of factors. Table 4 lists the communalities for the present study. The values are on the whole relatively low; Gwyn and Sutterlin (1972) indicate that the values should be above 0.8 although they

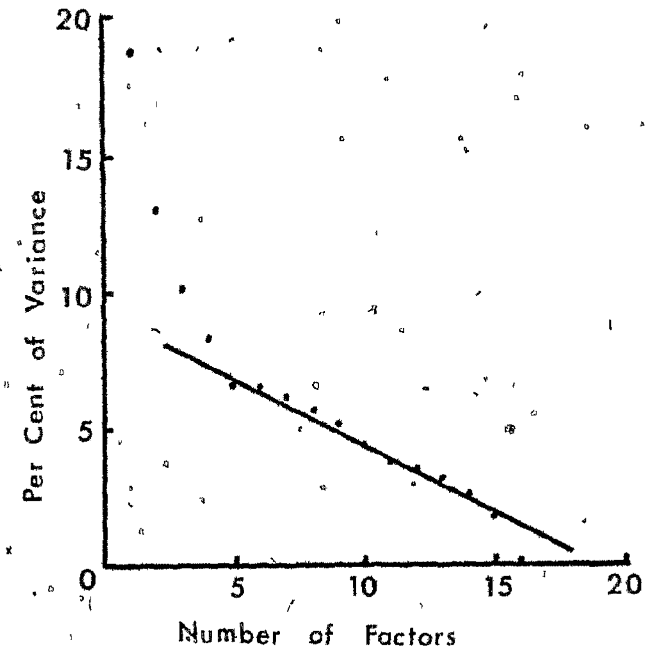


Figure 59. Relationship between the number of factors and the variance. The points on the straight line represent random variation.

Table 4. Communalities, variance and factor loadings from R-mode factor analysis on heavy mineral data.

VARIABLE	ESTIMATED COMMUNALITY	FACTOR	EIGENVALUE	PERCENT OF VARIANCE	CUMULATIVE PER CENT
Opaque	.613	1	3.020	18.9	18.9
Zircon	.545	2	2.079	12.9	31.8
Rutile	.684	3	1.657	10.4	42.2
Sphene	.329	4	1.349	8.4	50.6
Tourmaline	.657	5	1.137	7.1	57.7
Anatase	.604	6	1.050	6.6	64.3
Almandine	.740	7	.947	5.9	70.2
Spessartine	.903	8	.909	5.7	75.9
Staurolite	.626	9	.822	5.1	81.0
Andalusite	.776	10	.668	4.2	85.2
Sillimanite	.310	11	.625	3.9	89.1
Augite	.973	12	.503	3.1	92.3
Amphibole	.925	13	.491	3.1	95.3
Epidote	.856	14	.434	2.7	98.1
Apatite	.593	15	.297	1.9	99.9
% Heavy Minerals	.240	16	.012	.1	100.0

Factor Matrix Using Principal Factor with Iterations

VARIABLE	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
Opaque	.794	-.090	-.154	-.032
Zircon	.458	.127	-.113	.338
Rutile	.320	-.081	-.053	.251
Sphene	.246	.016	.078	.224
Tourmaline	.481	.196	-.191	.124
Anatase	.408	.082	-.234	-.026
Almandine	.091	.486	.474	-.245
Spessartine	.226	.096	-.569	-.583
Staurolite	.029	.254	.396	-.330
Andalusite	-.019	.668	.104	.212
Sillimanite	-.073	.124	.173	-.114
Augite	-.893	-.100	-.327	.187
Amphibole	.189	-.578	.475	-.065
Epidote	.398	-.452	.258	.103
Apatite	-.000	.526	.101	.214
% Heavy Minerals	-.428	-.129	.086	.036

VARIABLE	ESTIMATED COMMUNALITY	FACTOR	EIGENVALUE	PERCENT OF VARIANCE	CUMULATIVE PER CENT
Opaque	.696	1	2.645	40.4	40.4
Zircon	.427	2	1.693	25.8	66.2
Rutile	.624	3	1.303	19.8	86.0
Sphene	.171	4	.910	14.0	100.0
Tourmaline	.357				
Anatase	.234				
Almandine	.643				
Spessartine	.794				
Staurolite	.389				
Andalusite	.645				
Sillimanite	.072				
Augite	1.041				
Amphibole	.711				
Epidote	.443				
Apatite	.471				
% Heavy Minerals	.219				

Varimax Rotated Factor Matrix

After Rotation with Kaiser Normalization

VARIABLE	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
Opaque	.760	.222	-.021	-.196
Zircon	.587	-.030	-.109	.077
Rutile	.146	.055	-.087	-.028
Sphene	.293	.111	-.042	.065
Tourmaline	.566	-.105	.008	.031
Anatase	.449	-.010	-.075	.001
Almandine	.116	-.064	.774	.131
Spessartine	.222	-.109	-.132	-.031
Staurolite	-.010	.033	.622	-.007
Andalusite	.009	-.150	.117	.774
Sillimanite	-.076	-.024	.254	.023
Augite	-.597	-.661	-.261	-.256
Amphibole	.147	.810	-.064	-.141
Epidote	.193	.557	-.089	-.218
Apatite	.058	-.062	.034	.669
% Heavy Minerals	-.449	-.059	-.034	-.051

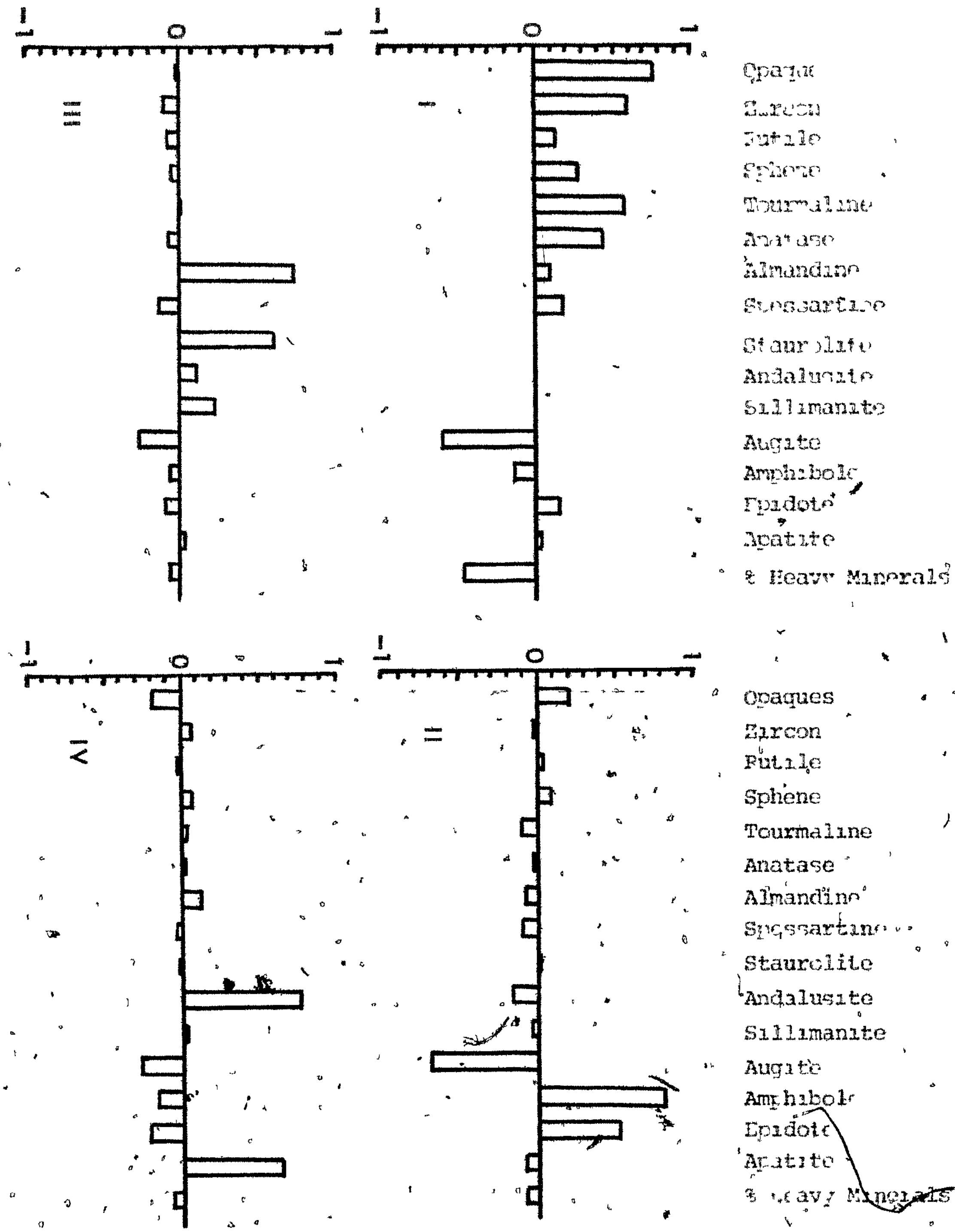


Figure 60. Graphic representation of the factor loadings for factor I II III and IV.

have some values below that initially. It is, however, to be expected in view of the variability of the source rock and the frequency distribution of the individual minerals.

Figure 60 shows graphically the result of R-mode factor analysis of the 16 variables. The scree diagram (Figure 59) indicates that there are four separate factors or mineral suites. Maps showing the distribution of each suite have been constructed by totalling the components of each suite.

The distribution of the minerals in suite I has been plotted in Figures 61 and 62. The suite is composed of opaque minerals, zircon, tourmaline, anatase, augite and percent heavy minerals. The latter two react inversely with the other members of all the groups and hence are considered as a distinct suite (IB) and plotted separately (Figure 62). This suite has four main sources in Nova Scotia. The augite and "percent heavy minerals" originate in the eastern Cobequid Mountains and North Mountain. It may be termed the <u>augite suite</u>. The opaques, zircon, tourmaline and anatase constitute suite IA and are derived primarily from the Carboniferous and Triassic Lowlands north and south of the Cobequid Mountains. Henceforth this association will be referred to as the <u>detrital suite</u>.

Figure 63 shows the distribution of suite II minerals. This suite is composed of amphibole, epidote and augite. The latter is usually absent when amphibole and epidote are present and they react reciprocally to one another. The distribution of suite II has been plotted both with and without augite because augite with amphibole and epidote combined are a good indicator of the affinities of Nova Scotia till matrix (Figure 64).

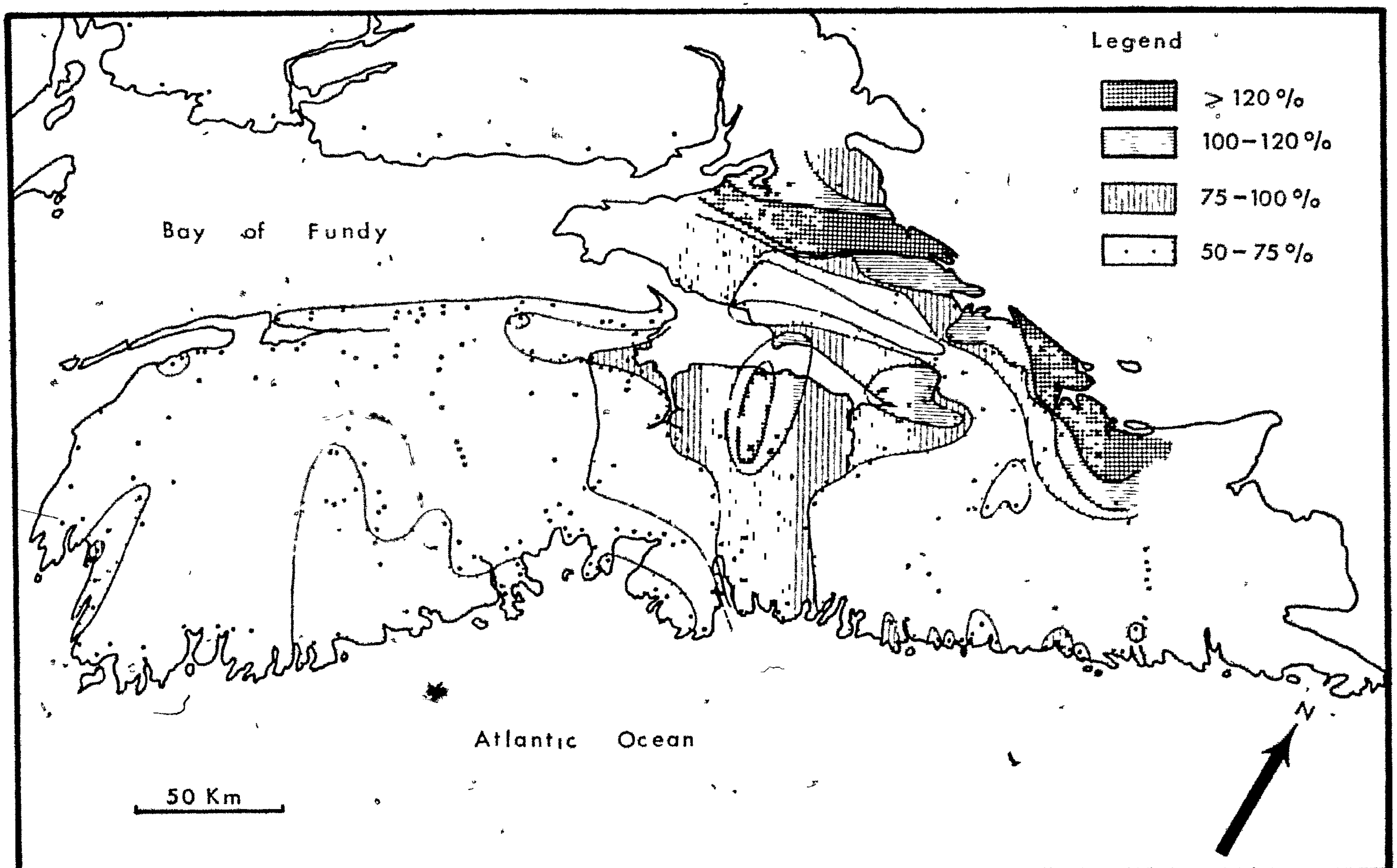


Figure 61. Distribution of the detrital suite (suite IA).

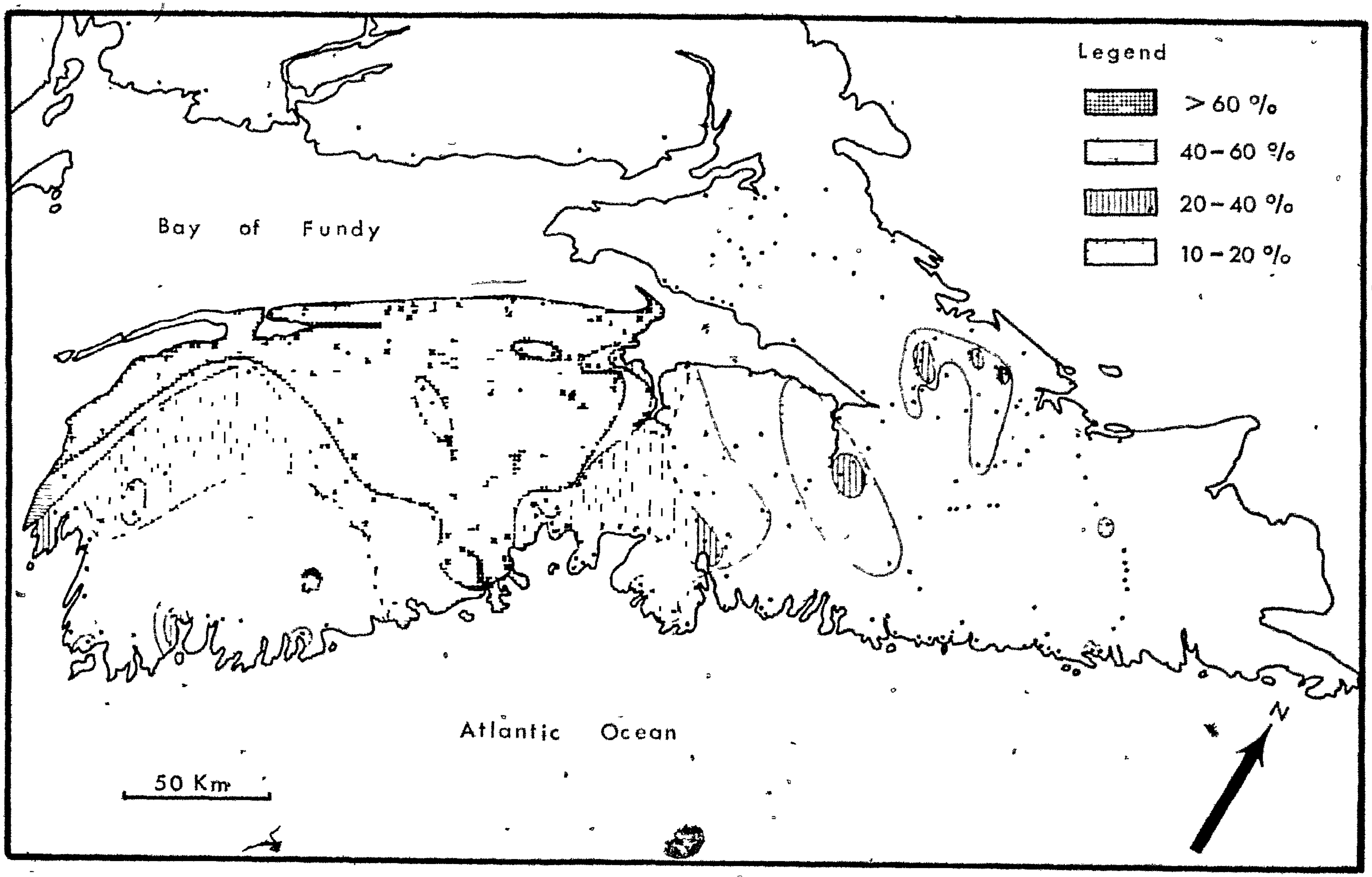


Figure 62. Distribution of the augite suite (suite IB).

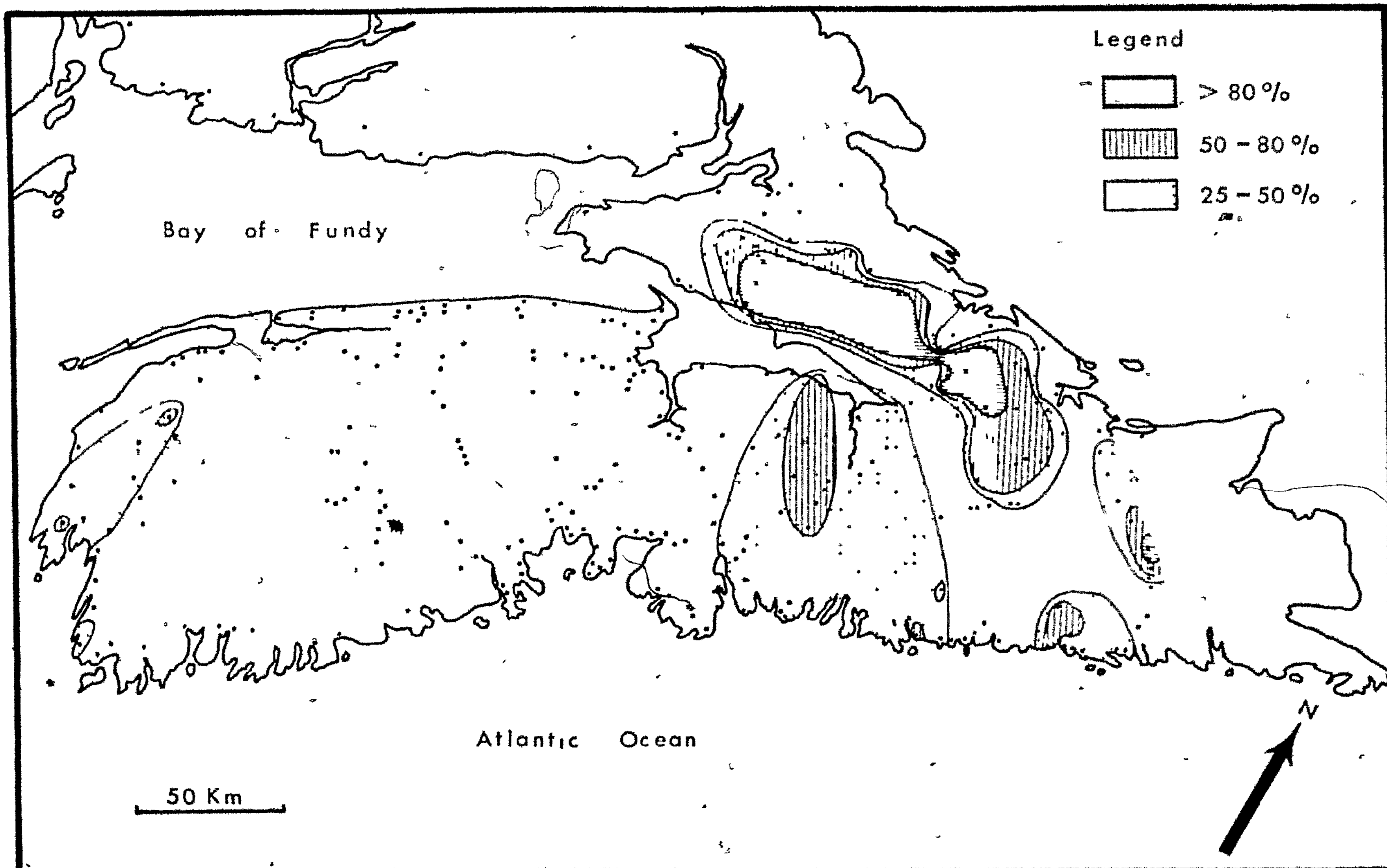


Figure 63. Distribution of the Cobequid suite (suite II).

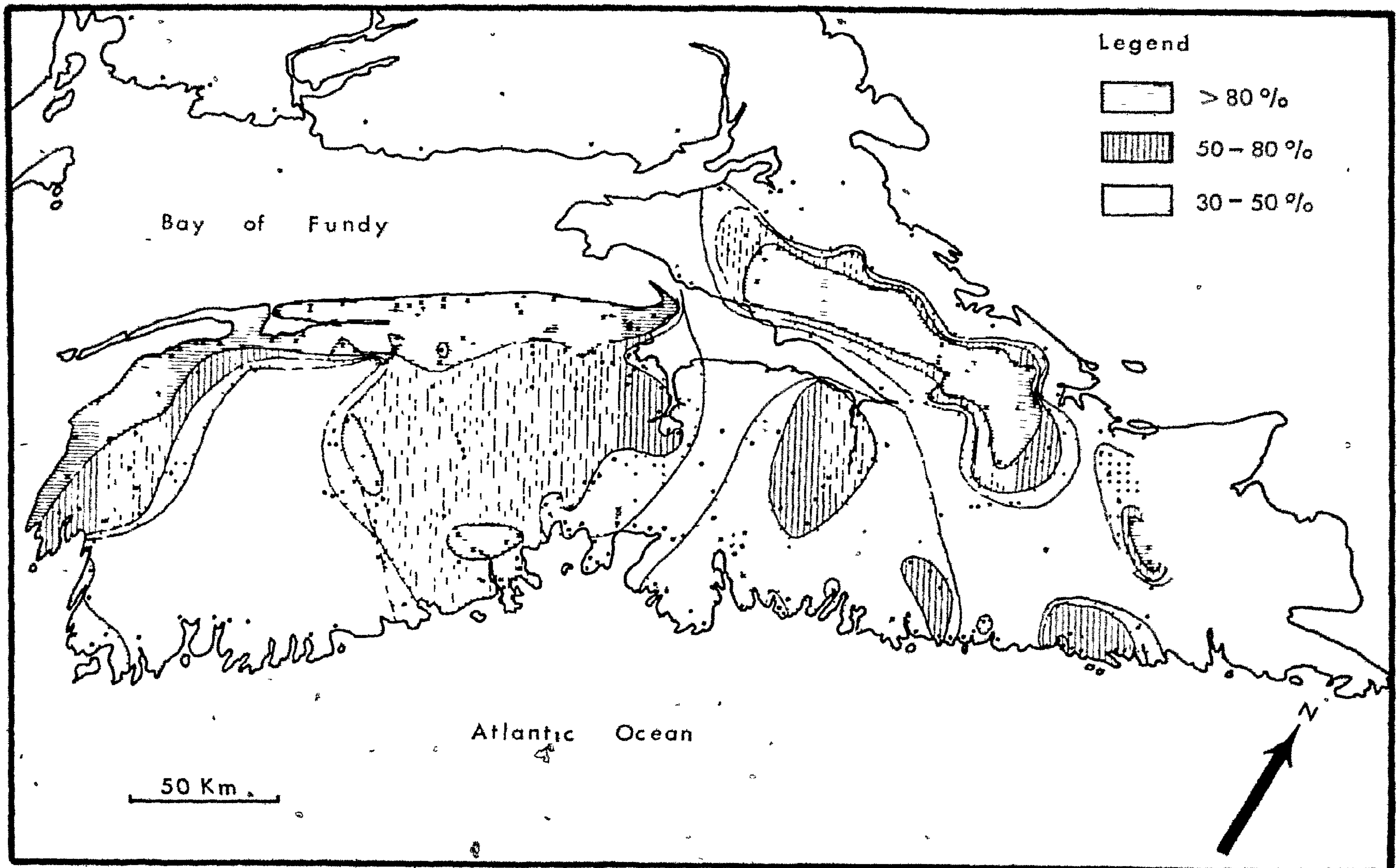


Figure 64. Distribution of the Cobequid and augite suites (suites II and IB).

Amphibole and epidote have a very limited source - primarily the Cobequid Mountains and parts of the White Rock Formation - hence this is termed the Cobequid suite.

Figure 65 shows the distribution of suite III, consisting of almandine garnet, staurolite and sillimanite. This suite, termed the metamorphic suite, originates primarily from four areas of the province. It is a common constituent of till overlying the medium grade metamorphic rocks of the Meguma Group in Guysborough, Yarmouth, Queens and Shelburne Counties and of the Carboniferous rocks north and south of the Cobequid Mountains.

Figure 66 shows the distribution of suite IV, consisting of apatite and andalusite. The main source for this suite is the Devonian granite, with minor sources in the Meguma Group and the post-Devonian sediments, especially north of the Cobequid Mountains. It may be termed the apatite-andalustie suite.

Results

R-mode factor analysis, followed by addition of the mineral percentages of the constituents of each factor group and direct plotting of these values on a map, has shown to be an effective technique in representing heavy mineral distributions in till deposits. Equifrequency maps show the detailed distribution of individual minerals and often well-defined indicator fans are delineated (for example, augite, amphibole, and sillimanite); however, these patterns are often complex and hard to interpret. The complexity can

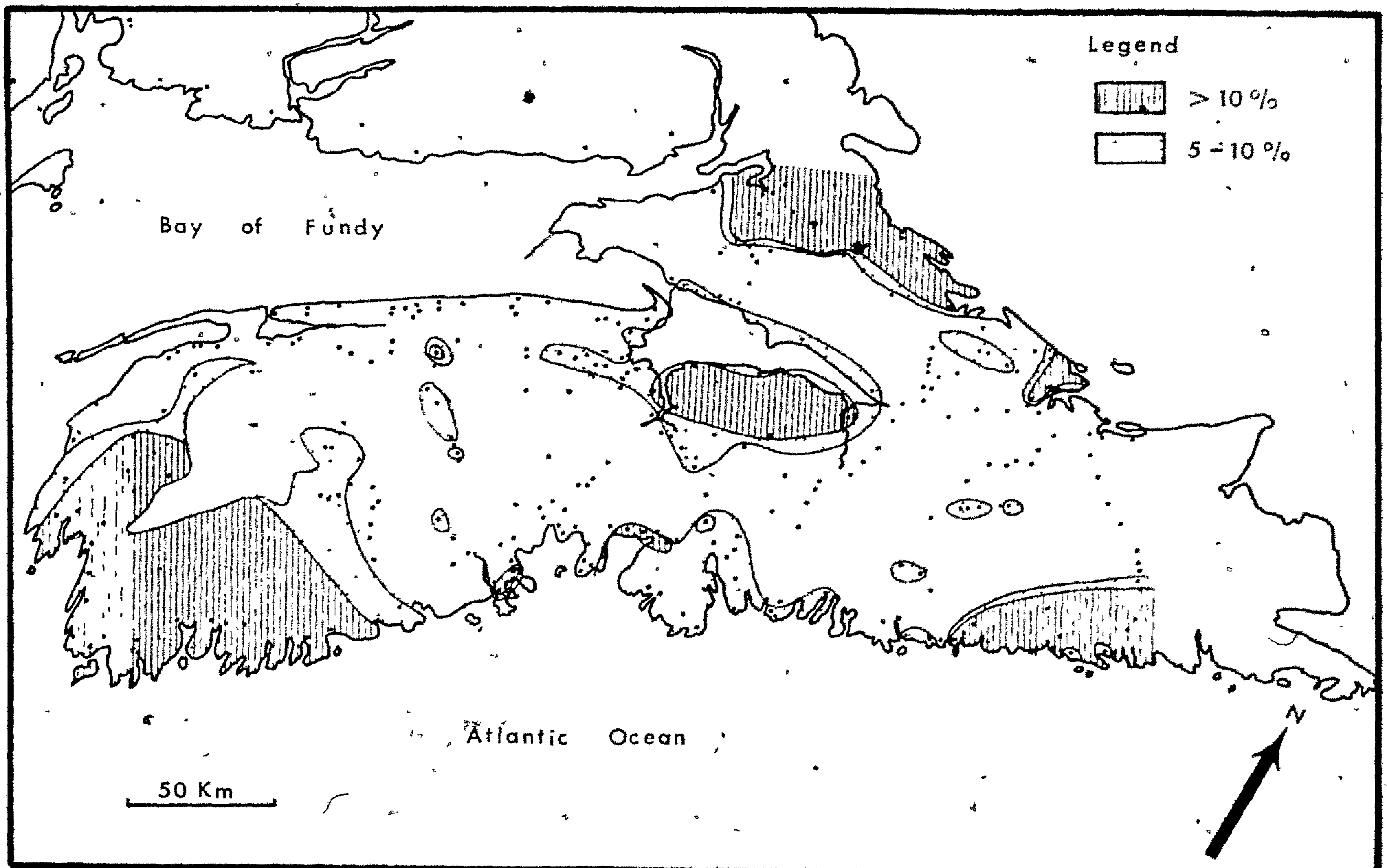


Figure 65. Distribution of the metamorphic suite (suite III).

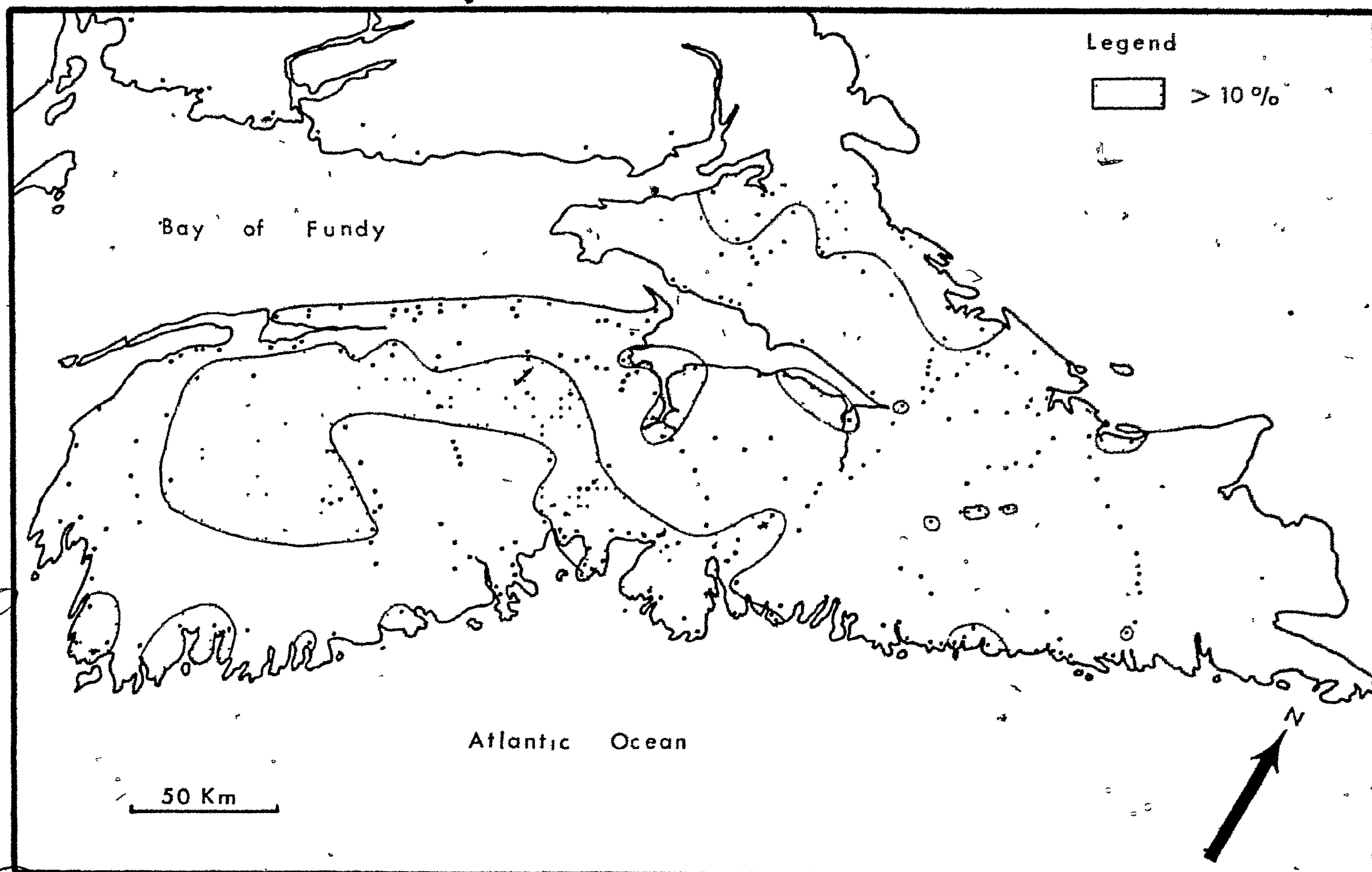


Figure 66. Distribution of the apatite-andalusite suite (suite IV).

be due to such variables as: 1) sampling of weathered till in which minerals have been differnetially dissolved, 2) variation of the distribution of heavy minerals within a single lithologic bedrock unit, 3) too wide a sample spacing, 4) misidentification of heavy minerals, 5) insufficient point counts, and 6) insufficient care in the preparation of heavy mineral slides. By using R-mode factor analysis a concise description of the available non-random data is achieved. However, details of small indicator fans where the mineral is restricted to a few samples (such as sillimanite) are lost. The techniques of factor analysis and equifrequency maps must be used together to obtain the maximum information from the available data.

The five mineral suite maps constructed from the results of the R-mode factor analysis indicate a strong affinity for the immediately underlying bedrock. The mineral suites also extend beyond the source regions and define composite mineral fans related to ice movement.

The detrital suite extends from Minas Basin almost due south to the Atlantic shore east of Halifax. A similar fan trending in the same direction is also found around New Glasgow. Scattered occurrences associated with drumlin fields are found along the Eastern Shore. The close relation between the distribution of the detrital mineral suite and the mud content (Figure 27) is shown in Figure 67.

The Cobequid Mountain suite (amphibole and epidote) has two well-defined fans extending almost due south from the source area. One fan originates in the eastern end of the Cobequid Mountains, the other at the eastern end of the Minas Basin. An isolated occurrence of the Cobequid suite is found on

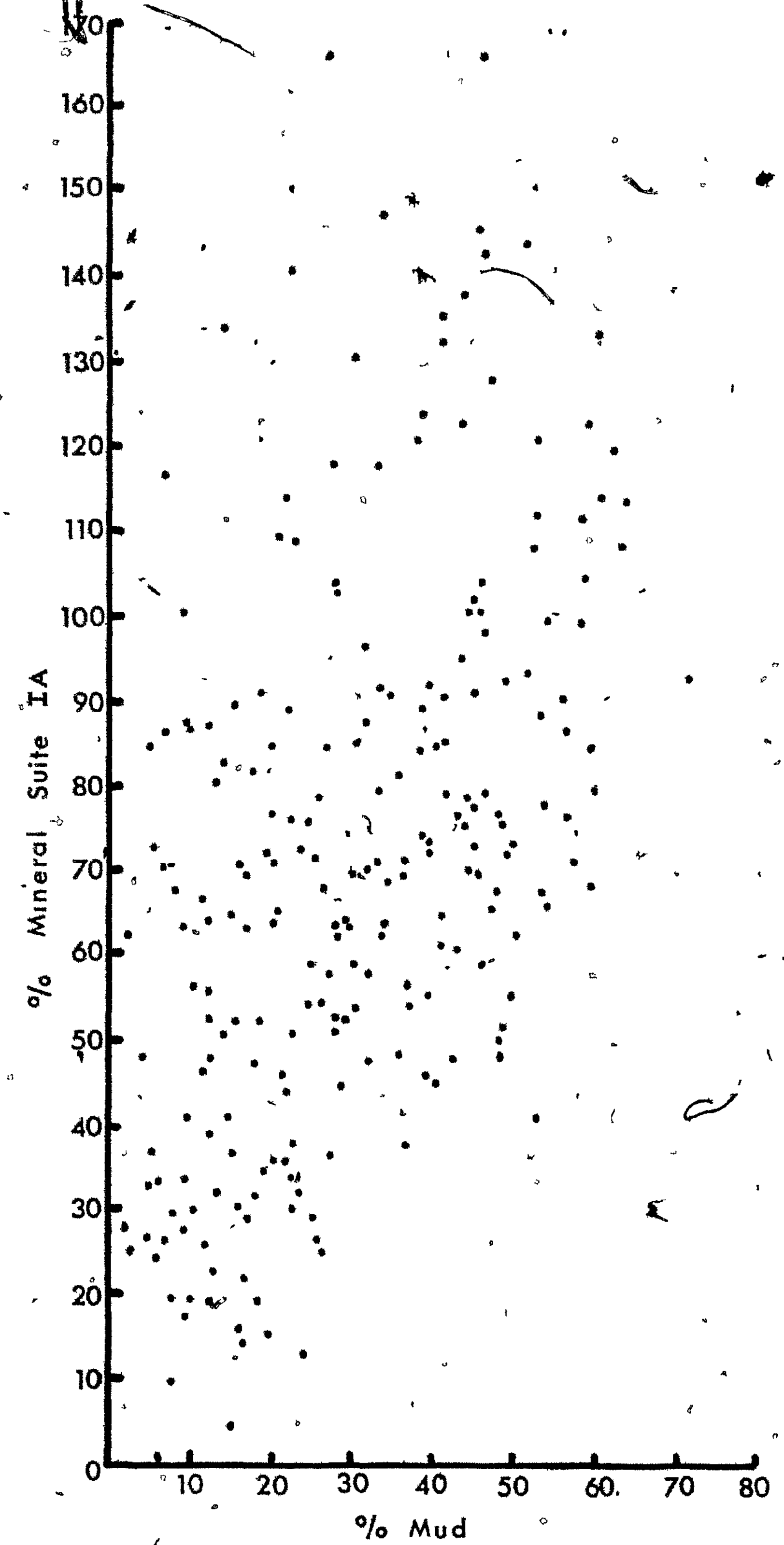


Figure 67. Variation in the detrital mineral and mud content of till samples with less than 60% augite.

the Eastern Shore which originated in the eastern Cobequid Mountains. Amphibole and epidote are also present in the till overlying the White Rock Formation in the Yarmouth area.

The distribution of the metamorphic suite is mostly related to the underlying bedrock. The anomaly in the Halifax area originated in the Minas Basin.

The distribution of the apatite-andalusite suite is related primarily to the immediately underlying bedrocks. Isolated occurrences may have upstream sources but these are indeterminable because of the patchy distribution.

Mineral suite IB is composed wholly of augite. Its origin and distribution have been discussed above. Although augite is designated as suite IB it is probably the most important indicator mineral. The mineral suites decrease in importance as indicators from I to IV. Augite primarily belongs in suites I and II but is a negative factor and is better separated and designated IB because of its importance.

Discussion

Mineralogically, it is impossible to subdivide the drumlins into distinct fields as was done by Grant (1963) using pebble lithologies.

To investigate the relationship between minerals derived from the Cobequid Mountains and the adjacent Minas Basin in the drumlin and non-

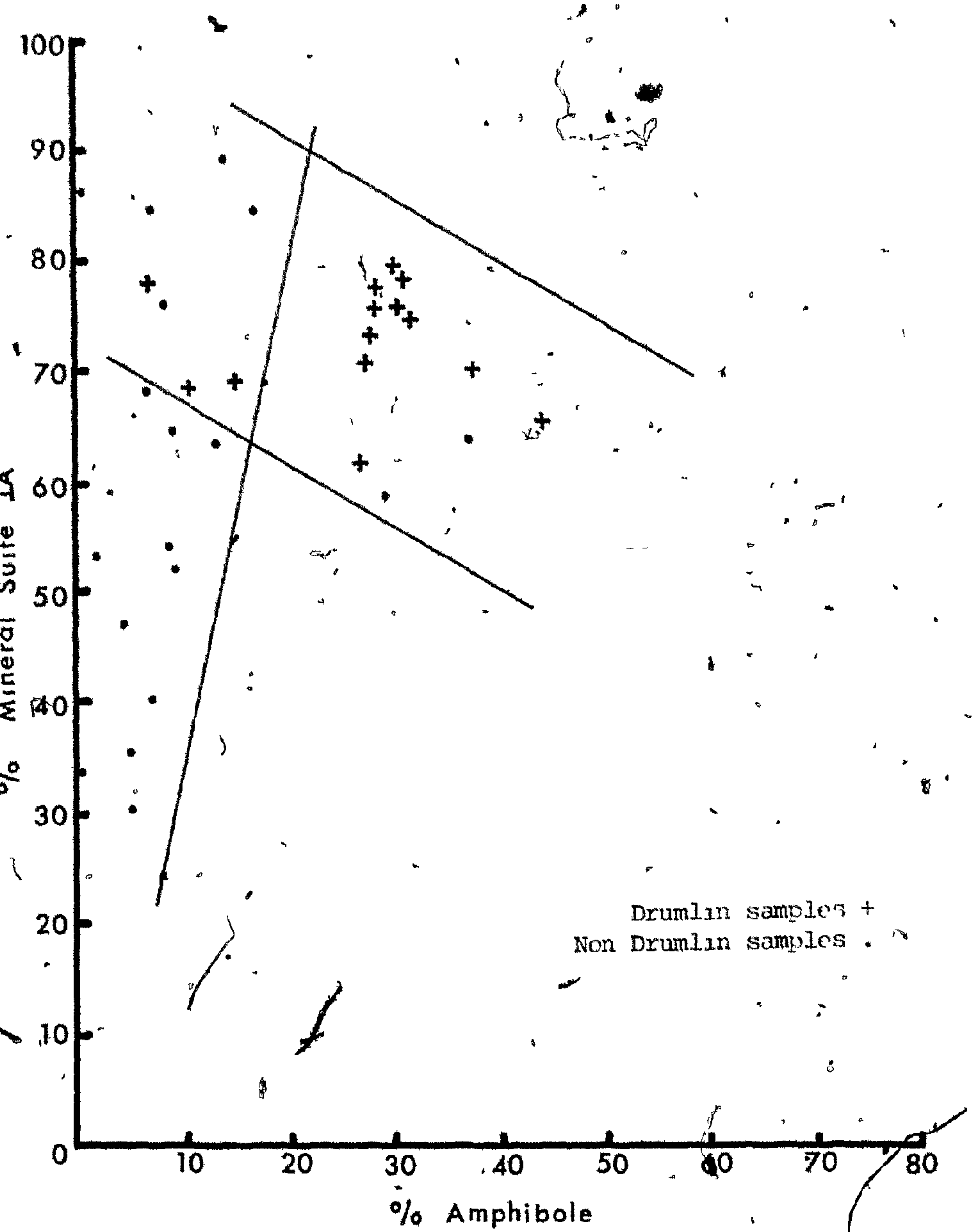


Figure 68. Variation in the detrital mineral and amphibole content of drumlin (+) and non-drumlin (.) till samples overlying Meguma bedrock east of Halifax.

drumlin samples from the Eastern Shore, Figure 68 was constructed. Figure 68 indicates that as amphibole increases so do the minerals of the detrital suite in the non-drumlin samples; however, as amphibole increases the detrital component decreases in the drumlin samples. This leads to four conclusions: 1) in the non-drumlin samples, the local component decreases as amphibole and mineral suite IA components increase; 2) in the drumlin samples, which are essentially foreign in composition, the negative relationship is a function of the addition of the two components in their source areas, that is, if the local component is constant, any fluctuation in the amount of one of the two foreign components will cause a similar but opposite response in the other foreign component; 3) there is one main source of the foreign components in the drumlins along the Eastern Shore; and 4) the inability to subdivide the drumlin samples as to their specific origin and the inverse relationship between the foreign components indicates that they came from approximately the same region.

Conclusions

1. Using R-mode factor analysis, five mineral suites can be distinguished.
2. Each suite is derived primarily from the underlying bedrock.
3. All the suites show some displacement towards the south-southeast.
4. Three types of till can be distinguished along the Eastern Shore: 1) Drumlin samples rich in amphibole 2) Drumlin samples poor in amphibole and 3) Ground moraine poor in amphibole.

5. Augite (suite 1B) from North Mountain and amphibole and epidote (suite II) from the eastern end of the Cobequid Mountains are good "indicators" in the area to the south of the sources. The concentration of these three minerals in samples south of North Mountain and the Cobequid fault is an indication of whether a till sample is of local or distant origin.

CHAPTER 10

DISCUSSION AND CONCLUSIONS

Chronology and Origin of Nova Scotian Till Deposits

Prior to 1975 there had been no attempt to organize the Quaternary sedimentary formations in Nova Scotia into a generalized stratigraphic sequence based on carbon 14 dating of the deposits. In 1975, Grant proposed a stratigraphic classification of the glacial deposits based on the available ^{14}C dates and field measurements. As there are relatively few dates on Nova Scotian tills and related deposits it is felt that Grant's correlation chart is unjustifiably complex. A simpler chronology is proposed here, based on till fabric analysis, grain size analysis, field relations, pebble counting and heavy mineral analysis as well as on the available ^{14}C dates. These dates have been assembled from various sources and are listed in Table 5, and shown graphically in Figure 69.

In spite of the limited number of dates, it is apparent that they fall into four main groups. Group 1 consists of a series of "infinite" dates, the youngest of which is >34,000 years B.P. These dates and their stratigraphic position record a series of ice advances and retreats in the early Wisconsinan. These deposits are of limited areal extend and are mostly restricted to hollows where preservation against removal by later ice advances is more likely.

TABLE 5

Carbon 14 Dates for Nova Scotia

and southwestern New Brunswick

Date in years B.P.	Remarks	References
GROUP I		
>34,000	Marine shells in till, Janvrin Is., Richmond Co., C.B.	Prest *et al.*, 1972
>38,270	Wood between two tills, Bay St. Lawrence, Victoria Co., C.B.	Mott and Prest, 1967
>39,000	Wood under till, River Inhabitants, Inverness Co., C.B.	Grant, 1971a
>39,000	Shells from till, Gilbert Cove, Digby Co.	Grant, 1975
>39,000	Shells from till, Cape St. Mary, Digby Co.	Prest *et al.*, 1972
>42,000	Peat under till, Addington Forsk, Antigonish Co.	Prest *et al.*, 1972
>44,000	Wood between tills, Whycocomagh, C.B.	Mott and Prest, 1967
>50,000	Organic beds under till, Milford, Halifax Co.	Prest *et al.*, 1972
>51,000	Wood between tills, Hillsborough, Inverness Co., C.B.	Mott and Prest, 1967
>52,000	Sandy peat under till, Castle Bay, Cape Breton Co., C.B.	Grant, 1975
GROUP II		
32,000 ± 630	Mastodon femur, Middle River, C.B.	Byers, 1975
32,100 ± 900	Shells from esker, River Inhabitants, Richmond Co., C.B.	Grant, 1971a
33,200 ± 2000	Wood under 70 ft. of till, Millers Creek, Hants Co.	MacNeill, 1969
38,600 ± 1300	Marine shells under till, Salmon River, Digby Co.	Clark *et al.*, 1972

(Table 5 - continued)

GROUP III		
8,770 ± 150	Bottom of Salmon River Lake Core, C.B.	Livingston, 1968
9,650 ± 150	Bottom of Silver Lake core, Halifax Co.	Livingston, 1968
10,160 ± 160	Bottom of Gillis Lake core, Richmond Co., C.B.	Schofield and Robinson, 1970
10,250 ± 240	Peat under slumped till, Port Hood Is., Inverness Co., C.B.	Hickox, 1962
11,200 ±	Average of 13 dates from palaeo-indian site, Debert, Colchester Co.	MacDonald, 1968
10,764 ± 101	Bottom of Folly Bog core, Colchester Co.	Livingstone, 1968
10,900 ± 160	Sandy peat from drill hole, Sable Is.	Terasmae and Mott, 1971
11,000 ± 170	Peat under slumped till, Port Hood Is., Inverness Co., C.B.	Terasmae, 1974
11,200 ± 100	Organic bed in alluvium, Nictaux Falls, Annapolis Co.	
11,700 ± 160	Bottom of Conoran Lake core, Lunenburg Co.	Railton, 1972
14,100 ± 200	Seaweed in marine clay, Gilberts Cove, Digby Co.	Grant, 1971c
18,800	Peat from Scotian Shelf moraine	King, 1969
13,000	Six dates on shells from Bay of Fundy, New Brunswick	Gadd, 1973
16,500 ± 370	Bottom of kettle hole, southwestern N. B.	Gadd, 1973
13,600 ± 200	Mastodon bone, Hillsborough, N. B.	Prest *et al.*, 1972
GROUP IV		
10,300 ± 150	Subtill peat, Bras D'Or Lake, C.B.	Grant, 1971a
11,670 ± 170	Wood between two tills, Benacadie Point, C. B.	MacNeill, 1969

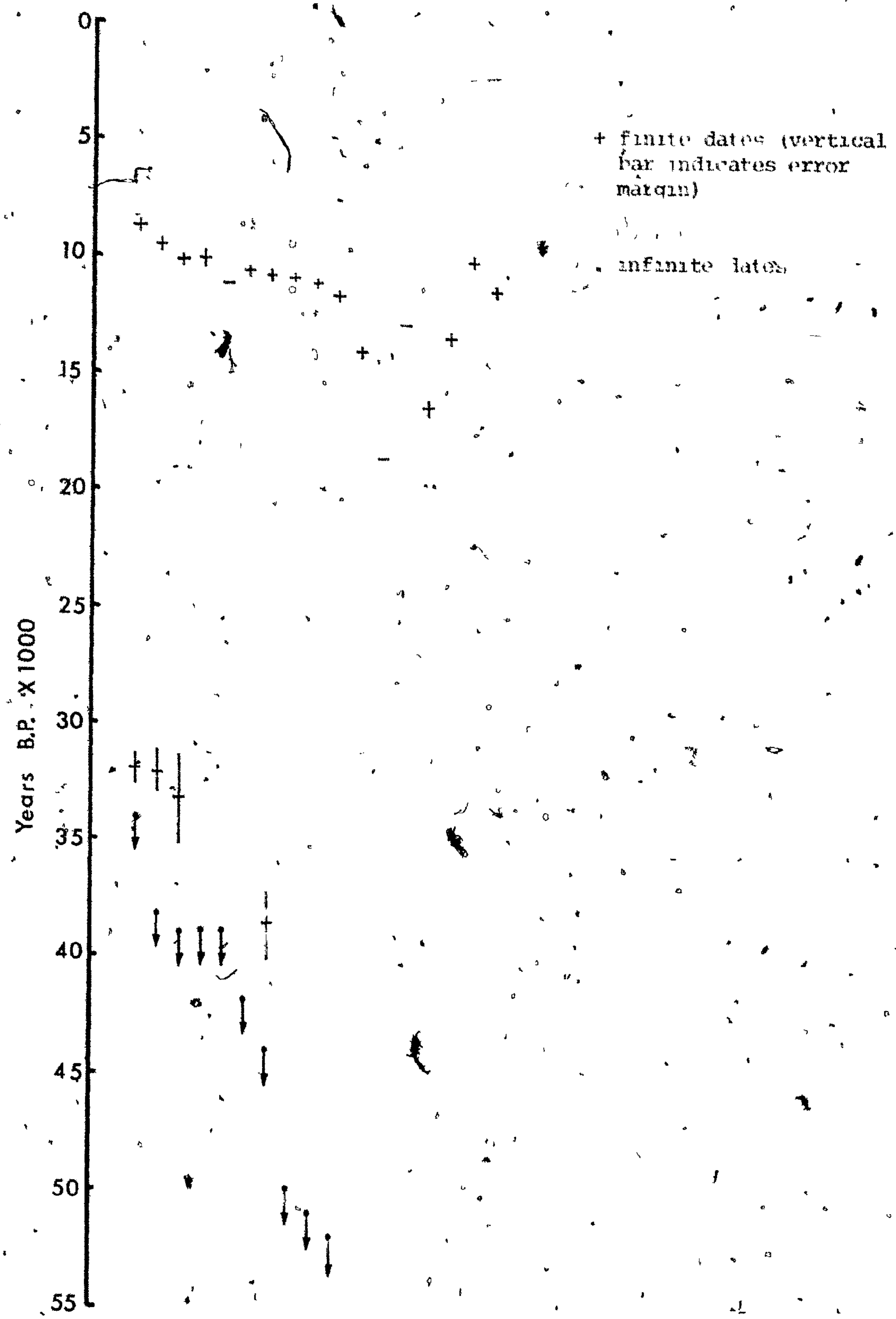


Figure 69. ^{14}C dates for Nova Scotia and the Scotian Shelf.

Group II consists of four finite dates between approximately 32,000 years B.P. and 39,000 years B.P. Two of these samples are overlain by till, which indicates that during this interval Nova Scotia was at least partly free from ice, followed by an extensive period of ice cover starting about 32,000 years B.P. The complete absence of ^{14}C dates between 32,000 and 14,000 years B.P. suggests that the area was under ice cover.

Group III consists of a great number of dates ranging from 18,800 years B.P. to around 9,000 years B.P. These dates mark the minimum age for deglaciation, the oldest being on the Scotian Shelf and the younger ones on shore. Dating of marine deposits in association with moraines in New Brunswick around the Bay of Fundy indicates that the shoreline became ice free about 14,000 years B.P. and that the ice calved into the ocean (Gadd, 1973). The presence of the Sable Island sand and gravel, which has gone through the transgressive zone, indicates that calving did not take place on the Atlantic side of the province. There is no sediment in the Bay of Fundy equivalent to the Sable Island sand and gravel of the Scotian Shelf (Gordon Fader, Bedford Institute of Oceanography, personal communication, 1974).

Group IV consists of two dates between 12,000 and 10,000 years B.P. on material underlying till. These two dates are from Cape Breton and record advances of local glaciers in that area during late glacial times.

When Was the Main Till Forming Event?

The period between approximately 32,000 and 14,000 years B.P., the "classical" Wisconsinan in east-central Canada, is characterized in Nova

Scotia by its complete absence of ^{14}C dates. The main glacial erosional and till forming events in Nova Scotia are therefore assigned to this period.

The four dates between 32,000 and 38,600 years B.P. mark the start of the main Late Wisconsinan glaciation in Nova Scotia. The presence of amphibole (presumably from the White Rock Formation) in sample 534 which overlies the marine sand at Salmon River (dated at 38,600 ± 1,300 years B.P.) could be interpreted as indicating that this till might be the product of the expansion of a local ice cap as suggested by Grant (1975). However, it seems more likely that the amphibole was brought from a source in New Brunswick as it is clear from the high percentage of augite in the Salmon River till that ice must have crossed the North Mountain basalt moving in a southward direction.

The only other known locality where information can be obtained about the early onset of the "classical" Wisconsinan ice is Milford. However, the deposits there are so complex and poorly exposed that a satisfactory interpretation is not yet feasible.

The exact timing of the deposition of the main till sheet is difficult to estimate. At 18,800 years B.P. the main ice sheet terminated in a series of submarine moraines now situated 30-40 km offshore (King, 1969). As the Sable Island sand and gravel between the present Atlantic Coast the offshore moraines indicates transgression of the sea over subaerially exposed glacial deposits the ice must have melted back before the rise of sea level. By 14,100 ± 200 years B.P. the sea was abutting against the ice front at Gilbert Cove near the head of St. Mary's Bay. Using a modified sea level curve based on the work of Flint (1972) and Mörner (1971), for worldwide sea level fluctuations and ^{14}C dates from the Scotian Shelf (James, 1966 and Grant, 1970), it can be estimated that at 14,100 years B.P. sea level on the Scotian Shelf must have been at about -60 m. As the - 60 m contour lies about 2 km offshore, on the landward side of the moraine system on the shelf, the ice front must have been less than that distance from our present Atlantic shoreline. Two ^{14}C dates indicate that the Nova Scotia mainland was deglaciated by about 12,000 years B.P.: one by Railton (1972) on the bottom of a core from Conoran Lake in Lunenburg County of 11,700 ± 160 (GSC-1486), and one by the present author on organics from alluvial sediments in the Annapolis Valley of 11,200 ± 100 (GSC-2062), as well as other dates from Port Hood Island and Prince Edward Island. The small residual ice cap which remained active over South Mountain probably existed after the Gilbert's Cove sediments were deposited 14,100 ± 200 years B.P. This conclusion is based on the observation by Hickox (1962) that near Margaretsville on the Fundy Shore there is a proglacial delta with a superposed kame. The rising of the sea on the Atlantic shore to the -60 m level and its incursion into the Bay of Fundy 13,500 years ago (Gadd, 1973) would have limited a late glacial ice cap over South Mountain to a maximum diameter of 125 km. Using the equations of Nye (1952) for calculating the thickness of an ice cap of known radius gives a maximum height of 1.2 km at the centre if the underlying surface is flat. Since the underlying South Mountain reaches a maximum elevation of 282 m above sea level it is estimated that the South Mountain ice cap had a maximum thickness of 1 km at 13,500 years B.P. This is comparable with the modern Barnes ice cap in central Baffin Island which measures 150 km by 62 km and rises to a maximum thickness of 1128 m. An ice cap of such magnitude would have remained active and perpetuated radial flow of ice and rock debris for some time. The ^{14}C dates at Nictaux Falls and Conoran Lake (Table 5) require that the ice cap be gone by 12,000 years B.P., which would give it a maximum life span of 1,500 years. However, the ice front along the Atlantic shore may have been located further inland and consequently the ice cap could have been smaller initially.

The almost complete absence of recessional moraines and the abundance of kame terraces indicate that the ice stagnated and melted down from the top. Kame terraces are notable in the Annapolis-Cornwallis Valley, the Parrsboro Valley and along the north side of the Cobequid Mountains. Hughes (1957) also concluded that this deglaciation process operated in the area south of the Cobequid Mountains. He concluded that stagnation was caused by rapid thinning of the ice over the Cobequid Mountains, causing the ice to the south to be stranded. A late ice cap in the eastern Cobequid Mountains (Prest and Grant, 1969) and an ice tongue abutting against the emergent delta at Parrsboro and the small moraine in the Parrsboro Gap all testify to the presence of active ice north of the Cobequid Mountains during a time when much of the rest of the study area was covered only by stagnant ice. Gadd (1973) estimates that marine subemergence in the Bay of Fundy reached its maximum at about 13,500 years B.P. but that parts of southwestern New Brunswick may have been ice free as early as 16,500. The Parrsboro delta can hence be indirectly dated at 13,000 to 14,000 years B.P. The older of these dates is the more likely since western Prince Edward Island and Shippengan, N.B. were ice free by about 12,500 years B.P. (Kranck, 1972 and Thomas et al., 1973). Active ice abutting against the north side of the Cobequid Mountains would have to originate to the north.

Incursion of the sea into the Gulf of St. Lawrence 15,000 - 14,500 years B.P. (Prest, 1972), and subsequently into the Northumberland Strait, indicates that the residual ice cap over the eastern Cobequid Mountains and Antigonish Highlands came into being at approximately the same time as the South Mountain ice cap. Carbon 14 dates at Folly Bog and the Debert paleo-indian site (Table 5) indicate that the area to the north and south of the Cobequid ice cap was ice free at 11,251 - 10,338 years B.P. It is noteworthy that the bottom of the Folly Bog core has the same date as the occupation site at Debert. However, the core lacks an L pollen zone, that is, there is no record of tundra vegetation but rather evidence of park tundra verging on open woodland (Byers, 1975). The Folly Bog core was taken in a kettle hole similar to the kettle hole near Cherryfield, Maine, where there was a 2,000 year lag in organic production after deglaciation. If it took 2,000 years for the ice to melt out of Folly Bog the area would have been free of ice at 12,500 years B.P. Therefore it seems likely that any residual ice cap in the eastern Cobequid Mountains was shortlived.

The available ^{14}C dates and the method of deglaciation indicates that the ice on the Scotian Shelf and in the area south of the Cobequid Mountains had started to deglaciate at least by 18,800 years ago and that by 14,000 years B.P. the sea had invaded the Bay of Fundy. On the Atlantic shore, the ice did not reach as far as 20 km east from the present shore and may in fact have been gone from the area. The method of deglaciation was by stagnation and downwasting on the Atlantic side and by calving into the Bay of Fundy. Active ice remained in the eastern Cobequid Mountains for a short while longer but was gone before 11,000 years B.P.

There, it is most likely that the main till forming event had ended by 14,000 years B.P. over most of the area and by 11,000 years B.P. in the eastern Cobequid Mountains, over South Mountain, and in Cape Breton.

How long was the till forming process active?

It is important to note that the till cover in the province is generally from a few metres to a few tens of metres thick and is rather homogeneous in composition. While the till forming events (s) could have occurred at any or perhaps several times between 32,000 years B.P. and deglaciation at 14,000 years B.P., the till sheet which is preserved over most of the area is believed to have formed towards the close of the interval. Goldthwait (1974) calculated that basal till accretes at rates of about 1 to 5 cm/year, which means that only 1,000 to 5,000 years are required for 50 m of till to accumulate. This rate does not take into account the rapid rate of infilling of small topographic irregularities. Since few till sections reach thicknesses of 50 m, 5,000 years is considered a maximum time for the deposition of the till in the province. Obviously the rate of deposition varies greatly from place to place; nevertheless, the above data gives some indication of the time involved. If the till forming event lasted less than 5,000 years and was over by 14,000 years B.P., it must have started at a maximum of 19,000 years B.P. Till deposited prior to this time had a high probability of being eroded again by the active ice.

Distribution of Nova Scotian Till Types

In the present study, two main till types have been recognized. One group is composed primarily of local components, the other of distantly travelled foreign components. The local tills can be further divided into five suites based on their heavy mineral content. Granulometrically only two tills have been recognized - those derived primarily from granite, slate, metaquartzite and basalt, and those derived from sandstones, shales and siltstones. The foreign till was deposited as drumlins scattered along the Eastern and South Shores of the province. The foreign affinities of this till are marked by its red colour, muddy composition and high content of augite, amphibole, and detrital minerals. The source for this till was the Cobequid Mountains, North Mountain, and the Carboniferous Lowlands in the northwestern part of the province. The very small percentage of pebbles in the Lunenburg drumlin field which are obviously not of Nova Scotian origins are presumed to be from New Brunswick. Other than in this field, there is no indication that long distance transport (in the order of hundreds of kilometres) added significantly to the composition of the till.

The distribution of pebbles and heavy minerals in the till indicates that the ice moved across the southwestern part of the province from the north-northwest. In the northern part of the province the ice came from the northwest as there was slight basal deflection by the Cobequid Mountains. The ice movement as shown by indicator fans everywhere parallels the long axes of the drumlins. The very strong southeasterly ice flow indicated by the distribution of augite southeast of the Minas Basin may possibly be due to early ice advancing out of the Bay of Fundy eastward into Minas Basin toward the Eastern Shore. Early ice advancing from New Brunswick would have been channelled through the valleys and filled the Bay of Fundy. By the time the ice from the northwest was thick enough to override the Cobequid Mountains, Minas Basin was already overflowing with ice from the west. During this time, ice north of the Cobequid Mountains flowed eastward through the Northumberland Strait towards Cape Breton.

Till fabric analysis indicates that movement of basal ice during the lodgement process was controlled primarily by the underlying topography as the trend of the fabrics parallel that of the hills. However, directional indicators on the Cobequid Mountains and South Mountain indicate that ice flowed in a direction parallel to those recorded on the upland, that is, uniformly southeastwards across the province. The upper ice thus flowed in response to a hydraulic gradient while the lower ice followed the topography. Shearing would have occurred widely in the ice at this time. It is difficult to say whether or not this differential flow pattern existed when the ice was at its maximum thickness. Certainly, this would have been the dominant process during the buildup and the retreat.

The size, shape, orientation and position of the bedrock outcrops were also the controlling factors responsible for the trends of the indicator fans. The fans are relatively straight and narrow and appear to transect the province more or less independently of topography. However, this may be the result of the relatively long distance between samples compared to the geomorphic features which controlled basal ice flow.

Glacial Processes

Erosion

Bridgewater conglomerate is preserved in many of the major river valleys along the Eastern and South Shores of the province, such as in the LaHave and Musquodoboit River valleys. This suggests that glacial erosion of the bedrock may not have been as intense as would be expected from evidence on hilltops, for example in the Halifax area. The valleys in the area have the typical glaciated U-shaped cross sections but they are not particularly straight or deep. The orientations of valleys and fjords along the Atlantic coast are basically controlled by bedrock structure and have been modified only slightly by the numerous ice advances of the Pleistocene.

On the other hand, the hilltops show evidence of severe glacial scouring. Highly polished glaciated pavements and roches moutonnées adorned with striae, crag and tail, lunate fractures and crescentic gouges are common features on the hills of resistant granite, slate and metaquartzite bedrock. The hills and mountains obviously presented a considerable obstacle to ice flow and were the major areas of bedrock erosion. Hilltop erosion accounts for the profusion of distantly travelled components along the Atlantic coast; these components originated in the Cobequid Mountains, Antigonish Highlands, North Mountain, South Mountain and even the Caledonian Highlands of southern New Brunswick.

Glacial erosion in the Carboniferous Lowlands north and south of the Cobequid Mountains and in the Bay of Fundy was similar to that in the areas of more resistant bedrock. However, erosion was much easier in the lowlands, and hence erosion was greater. The area is characterized by an absence of steep hills and low elevations. Thick accumulations of muddy till are common. The nature of the bedrock precludes the ready preservation of directional indicators such as striae and crag and tail.

Transport

Glacial erosion of hilltops and upward shearing caused by erosion on upstream dipping surfaces are two of the main methods of incorporating debris into the ice at various levels above the base. Englacial debris may also be produced if one glacial lobe flows over another. Englacial debris is believed to have been incorporated by all these methods into glacier ice moving southeastward across the Carboniferous Lowlands and the Cobequid Mountains, Antigonish Highlands, North Mountain, South Mountain and the Caledonian Highlands. The degree of contribution of each of the three methods of incorporation is difficult to evaluate. Evidence of shearing is abundant in the red, muddy, englacially-transported till along the Atlantic shore. This may be related to conditions prevalent in that region at the time of deposition but may also reflect the nature of the debris-carrying ice over the whole region. This question remains to be answered.

Most of the till in the area is locally derived basal till. Transport has usually been short, as can be seen by the rapid change in composition of the till across bedrock geologic boundaries. The till was transported at the base or in the lower few meters of the ice. The mixing of local material with distantly transported material is indicated by the grain size variations and the lithologic composition of the tills. The zones of basal and englacial transport were not two distinct layers in the ice.

The occurrence of locally derived ablation till over the basal till and foreign till in some parts of the province prompted Grant (1963, 1975) to assign this distinctive till phase to a separate ice advance - the South Mountain ice cap advance. The rather widespread but patchy occurrence of this till, as well as its composition and texture, indicates that it is ablation till which formed after the deposition of the melt-out till. Mineralogically, the ablation till cannot be distinguished from the underlying melt-out till. The main difference between the ablation and underlying till is the lower percentage of silt and clay and the high percentage of local gravel in the ablation till.

The ablation till was formed by washing and sorting of basal and englacial material brought to the ice surface by shearing and downmelting. This debris was mixed with material derived locally by frost shattering and quarrying of nunataks during the late "classical" Wisconsinan when the ice was thin.

Changes in flow direction of the ice can be recognized from the upward changes in the composition of the till in several places. In the Annapolis Valley and over North Mountain the change from southerly ice flow to northerly flow during the late Wisconsinan did not result in the formation of two distinctly different till units. Only one till is present, but it contains indicators from both the north and south as a result of reworking of the earlier material. Hickox (1962) observed a vertical increase in the content of South Mountain granite in the till of the Annapolis Valley. This suggests that the ice cover remained present throughout but the basal flow changed as the surrounding area was deglaciated.

Two distinct till units have been identified in the New Glasgow area at McPherson's Mills. The till composition and directional indicators in the [redacted] Cobequid Mountains also testify to the presence of late glacial ice flowing eastward from this region. This ice cap was very short lived as shown previously.

<u>Deposition</u>

If the till in the study area is classified as to the mode of deposition, it falls into two main types - basal and ablation till.

The ablation till is widespread over much of the province. It is easily recognized when associated with basal till because it is uncompacted, sandy and rich in gravel. It was transported only a short distance and was not deposited until the ice finally melted away. The fine silt and clay were washed out of the till by meltwater on the surface of the ice. It was further sorted and disaggregated when it slumped off steeply inclined ablating ice remnants.

The basal till can be divided into two different types: 1) Lodgement till; materials that were transported at the base of and in the lowest part of the ice and deposited by being plastered onto the bedrock; and 2) Melt-out till; englacial materials that were transported within the ice. The foreign englacial materials were deposited by being plastered on the bedrock surface or on basal till. It was brought down from its englacial position primarily by basal melting due to friction and geothermal heat, and also by spreading and thinning of the ice as it moved south-southeast down the gentle gradient of the Atlantic watershed towards the ice margin of the Scotian Shelf.

The basally deposited melt-out till was deposited in the form of drumlins along the South and Eastern Shores of the province. Grant (1963) suggested that the drumlin fields were located along hypothetical rapid flow lines in the ice. Work by King et al. (1972) indicates that the ice terminus was a floating ice shelf which was located over parts of deep inner basins of the Scotian Shelf, seaward of the main moraine system. Calving of the ice front into the sea could possibly be the driving mechanism for Grant's hypothetical ice streams, if they really existed.

Summary of Salient Conclusions

This study has established the following major conclusions relevant to the glacial geology of mainland Nova Scotia.

1. With few exceptions, all till deposited before the "classical" Wisconsinan was removed by the ice that deposited the regional till.
2. A few isolated and protected pockets of older till are found scattered through the area, notably at Milford and along the shore north of Yarmouth.
3. Grey lodgement till was deposited over parts of the Meguma during early "classical" Wisconsinan time.
4. With few exceptions the grey lodgement till was eroded prior to the deposition of red clay till.
5. Using R-mode factor analysis, five mineral suites can be distinguished:
   1) a detrital suite
   2) an augite suite
   3) a Cobequid Mountain suite
   4) a metamorphic suite
   5) an apatite-andalusite suite
6. There are no detectable sources outside the province.
7. All the suites show some displacement towards the south-southeast.
8. Each suite is derived primarily from the underlying bedrock.
9. Amphibole and augite are the best indicators of distant sources.
10. Granulometrically two types of till are found in the study area; one is rich in gravel and the other is rich in silt and clay.

11. These two modes are the product of mixing resistant rocks, such as granite, slate, metaquartzite and basalt, with less resistant rocks such as sandstone, siltstone and shale.

12. The hard rocks are found mainly in the Cobequid Mountains and in the uplands of the province (Devonian batholith, Meguma slate and metaquartzite).

13. The silt and clay-rich till is centered over the Carboniferous Lowlands north of the Cobequid Mountains and in the Minas Basin region.

14. The percent gravel (or the gravel/mud ratio) can be used as a general indication of whether a till sample has local or foreign affinities. Local till over 'hard rock' is rich in the gravel fraction, but over Carboniferous and Triassic sediments the local till is rich in silt and clay.

15. In most of the areas where the red clay till was deposited over the Meguma Group drumlins formed.

16. The occurrence of muddy till outside the Carboniferous Lowlands can be attributed to two things. Firstly, most of the samples are from silt and clay-rich drumlins containing material derived from the Carboniferous Lowland. Secondly, a few silt and clay-rich samples from outside the known drumlin fields are either dislocated till sheet fragments transported from the Carboniferous Lowlands or in some cases the product of comminution of local fine grained bedrock.

17. In the area east of Halifax, drumlin samples are richer in amphibole than non-drumlin samples, with only slight overlap.

18. No distinct drumlin phase is present over the eastern half of the main granite batholith. Till composition is gradational between local till and foreign red clay till.

19. Three types of till can be distinguished along the Eastern Shore: 1) Drumlin samples rich in amphibole 2) Drumlin samples poor in amphibole and 3) Ground moraine poor in amphibole.

20. Amphibole is found in trace amounts in red clayey till samples east of the LaHave River; its origin is at present unexplained.

21. The grey slate drumlin till found west of the LaHave River in the Lunenburg drumlin field is texturally similar to the red clay drumlin till found on the east side of the river.

22. Augite is distributed equally throughout the red clay drumlins and the slate drumlins in the Lunenburg drumlin field. The non-drumlin samples are generally less muddy and poorer in augite than the drumlin samples.

23. In the Halifax-St. Margaret's Bay area the red clay till is overlain by a local granitic hybrid till, possibly ablation till.

24. Over North Mountain there is an inverse relation between the percent mud and the percent augite in the till.

25. The primary mode of transport of the red clay till was englacial.

26. Spreading and thinning of the ice sheet along the margin caused downward movement and basal deposition of red clay englacial debris as melt-out till.

27. At the time of deposition of the red clay till shearing of the ice was prevalent.

28. The ice moved in a generally southeasterly direction across most of the province.

29. In the southwestern part of the province the ice moved in a more southerly direction.

30. Basal ice was deflected to the east and to the west around the highland formed by South and North Mountains.

31. The regional variation in the topography played an important role in determining the distribution of indicators in the Windsor area.

32. Till fabric analysis suggests strongly that the basal ice movement and till deposition in Nova Scotia was controlled by the attitude of the surface of accumulation, i.e. the topography. The basal ice flowed parallel to the valleys and highlands. Only when the valleys were full of ice did the upper part of the ice sheet flow over the drainage divides independent of the underlying topography; however, the basal ice continued to follow the topography.

33. Outcrop size, shape, orientation and position as well as the topography were the controlling factors governing the trends of the indicator fans.

34. Early ice probably flowed eastward parallel to the north side of the Cobequid Mountains.

35. The lobate distribution pattern is largely a function of the size of the source area, that is, it does not necessarily indicate ice currents or lobes.

36. The long generally straight and almost unidirectional indicator fans indicate that Nova Scotia was glaciated by ice advancing from the north-northwest. The direction of ice flow across Nova Scotia is almost perpendicular to the main topographic obstacles in the province. The

source of the ice clearly lay northwest of Nova Scotia, most likely in New Brunswick.

37. The radial distribution of erratics to the east, north, and west around South Mountain from Windsor to Yarmouth, as well as northward and eastward trending indicator fans from the Cobequid Mountains indicates active radial outflow from highland areas. Hickox (1962) showed that a late "classical" Wisconsinan ice cap was situated over South Mountain.

38. Late "classical" Wisconsinan ice flow from local ice caps resulted in homogenization of preexisting till deposits and only minor addition of local components.

REFERENCES

Andrews, J. T. and Shimizu, K., 1966. Three-dimensional vector technique for analyzing till fabrics: Discussion and fortran program. Geog. Bull., 8, (2), p. 151-165.

Andrews, J. T. and Smith, D. I., 1970. Statistical analysis of till fabric: methodology, local and regional variability. Q. J. Geol. Soc. Lond., 125, p. 503-542.

Andrews, J. T., 1971. Methods in the analysis of till fabrics. In Goldthwait, R. P. (ed.), Till, a Symposium, The Ohio State Univ. Press, p. 321-327.

Andersen, S. A., 1945. Isströmmenes retringer over Danmark i den siste Istid, belyst ved Ledeblokundersögelser. Med. Dansk Geol. For., 10 (5), p. 594-615.

Arneman, H. F., and Wright, H. E. Jr., 1959. Petrography of some Minnesota tills. J. Sediment. Petr., 29 (4), p. 540-554.

Bayley, L. W, 1896. Report on the geology of southwestern Nova Scotia. Geol. Surv. Can., Ann. Rept. IX, pt. M, p. 30-60.

Beaumont, P., 1971. Break of slope in particle-size curves of glacial till. Sediment., 16, p. 125-128.

Benson, D. G., 1974. Geology of the Antigonish Highlands, Nova Scotia. Geol. Surv. Can., Mem. 376.

Benson, D. G., 1967. Geology of Hopewell map-area, Nova Scotia. Geol. Surv. Can., Mem. 343.

Berthelsen, A., 1973. Weichselian ice advances and drift successions in Denmark. Bull. Geol. Inst. Univ. Uppsala, New Series, 5, p. 21-29.

Bishop, B. C, 1957. Shear moraines in the Thule area, northwest Greenland. U. S. Army Snow Ice and Permafrost Research Establishment Corps of Engineers Research Report 17.

Blatt, H., Middleton, G. and Murray, R., 1972. Origin of sedimentary rocks. Prentice-Hall, Inc., New Jersey, 634 p.

Boulton, G. S., 1971. Till genesis and fabric in Svalbard Spitsbergen. In Goldthwait, R. P. (ed.), Till, a Symposium; The Ohio State Univ. Press, p. 41-72.

Boulton, G. S., 1968. Flow tills and related deposits on some Vestspitsbergen glaciers. J. Glaciol., 7, (51), p. 391-412.

Boulton, G. S., 1970. On the origin and transport of englacial debris in Svalbard glaciers. J. Glaciol., 9, (56), p. 213-229.

Boulton, G. S., 1970. On the deposition of subglacial and melt-out tills at the margins of certain Svalbard glaciers. J. Glaciol., 9, (56), p. 231-245.

Boulton, G. S., 1972. Modern Arctic glaciers as depositional models for former ice sheets. J. Geol. Soc. Lond., 128, p. 361-393.

Byers, D. S., 1975. Environment and subsistence. In Ogden, J. G. III, (ed.) Environmental change in the Maritimes. N. S. Inst. Sci., 27, Supplement 3, p. 3-16.

Cameron, E. M., 1967. A computer program for factor analysis of geochemical and other data. Geol. Surv. Can. Paper 67-34.

Cann, D. B. and Hilchey, J. D., 1954. Soil survey of Antigonish County, Nova Scotia. N. S. Soil Survey, Rept. No. 6, 54 p.

Cann, D. B. and Hilchey, J. D., 1958. Soil survey of Lunenburg County, Nova Scotia. N. S. Soil Survey, Rept. No. 7, 48 p.

Cann, D. B. and Hilchey, J. D., 1959. Soil survey of Queen's County, Nova Scotia. N. S. Soil Survey, Rept. No. 8, 48 p.

Cann, D. B., Hilchey, J. D. and Smith, G. R., 1954. Soil survey of Hants County, Nova Scotia. N. S. Soil Survey, Rept. No. 5, 65 p.

Cann, D. B. and MacDougall, J. I., 1965. Soil survey of Kings County, Nova Scotia. N. S. Soil Survey, Rept. No. 15, 97 p.

Cann, D. B. and Wicklund, R. E., 1950. Soil survey of Pictou County, Nova Scotia. N. S. Soil Survey, Rept. No. 4, 66 p.

Carruthers, R. G. 1947-48. The secret of glacial drifts. Proc. York. Geol. Soc., 27, p. 43-57 and 129-172.

Carver, R. E. (ed.), 1971. Procedures in sedimentary petrology. Wiley-Interscience, Toronto, 653 p.

Chapman, L. J. and Putnam, D. F., 1966. The physiography of southern Ontario. Univ. of Toronto Press, Toronto.

Clague, J. J., 1975. Glacier-flow patterns and the origin of late Wisconsinan till in the southern Rocky Mountain trench, British Columbia. Geol. Soc. Am. Bull., 86, p. 721-731.

Clarke, 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. Can. J. Earth Sci., 9 (8), p. 1030-1038.

Clifton, H. E., 1963. The Pembroke breccia (Mississippian of Nova Scotia). Ph.D. John Hopkins Univ.

Cok, A. E., 1970. Morphology and surficial sediments of the eastern half of the Nova Scotia shelf. Ph.D. thesis, Dalhousie University.

Crosby, D. G., 1962. Wolfville map-area Nova Scotia. Geol. Surv. Can., Mem. 325.

Crowl, G. H. and Frankel, L., 1970. Surficial geology of Rustico map-area, Prince Edward Island. Geol. Surv. Can., Paper 70-39.

Dawson, J. W., 1893. The Canadian ice age, being notes on the Pleistocene geology of Canada, with special reference to the life of the period and its climatic conditions. Priv. Publ., Montreal, 301 p.

Deer, W. A., Howie, R. A. and Zussman, J., 1970. An introduction to the rock-forming minerals. 6th impression, Longman, London, 528p.

Drake, L. D., 1971. Evidence for ablation and basal till in east-central New Hampshire. In Goldthwait, R. P. (ed.), Till, a Symposium; The Ohio State Univ. Press, p. 73-91.

Drake, L. D., 1974. Till fabric control by clast shape. Geol. Soc. Am. Bull., 85, p. 247-250.

Dreimanis, A., Reavely, G. H., Cook, R. J. B., Knox, K. S., and Moretti, F. J., 1957. Heavy mineral studies in tills of Ontario and adjacent areas. J. Sediment. Pet., 27 p. 148-161.

Dreimanis, A., and Reavely, G. H., 1953. Differentiation of the lower and the upper till along the north shore of Lake Erie. Jour. Sediment. Petrol., 23, p. 238-259.

Dreimanis, A., 1958. Tracing ore boulders as a prospecting method in Canada. Trans. Can. Inst. Min. Met., LXI, p. 49-56.

Dreimanis, A., 1969. Selection of genetically significant parameters for investigation of tills. Zesz. Nauk. Univ. A. Mickkwicza, Poznan, Poland, Geografia 8, p. 15-29.

Elson, J. A., 1961. The geology of tills. Proceed. 14th Can. Soil Mech. Confer., Nat. Res. Counc. Can. Assoc. Com. Soil and Snow Mech. Techn. Mem., No. 69, p. 5-36.

Fisher, R. A., 1958. Statistical methods for research workers. 13th ed. Hafner Publishing Co. Inc., New York.

Flint, R. F., 1961. Two tills in southern Connecticut. Geol. Soc. Am. Bull., 72, p. 1687-1692.

Flint, R. F., 1947. Glacial geology and the Pleistocene epoch. New York-London.

Flint, R. F., 1971. Glacial and Quaternary geology. John Wiley and Sons, Inc., New York. 892 p.

Folk, R. L., 1968. Petrology of sedimentary rocks. Hemphill's, University of Texas, Austin, Texas, 170 p.

Frankel, L., 1966. Geology of southeastern Prince Edward Island. Geol. Surv. Can. Bull. 145.

Freeman, G. W., 1972. [illegible]atigraphy of the Cheverie Formation, Minas Sub-basin, Nova Scotia. M.Sc. Thesis, Acadia University.

Gadd, N. R., 1973. Quaternary geology of southwest New Brunswick with particular reference to Fredericton area. Geol. Surv. Can., Paper 71-34, 31 p.

Gillberg, G., 1955. Den glaciala utvecklingen inom Sydsvenska höglandets västra randzon. I Glacialerosion och moränackumulation; Geol. Fören. Stockholm Forh., 77, (4).

Gillberg, G., 1970. Glacial geology of Kinnekulle, W. Sweden. Geol. Fören Stockholm Förh., 92, pt. 3, p. 347-381.

Gillberg, G., 1969. A great till section on Kinnekulle, W. Sweden. Geol. Fören. Stockholm Förh., 91, p. 313-342.

Gillberg, G., 1967. Further discussion of the lithological homogeneity of till. Geol. Fören. Stockholm Förh., 89, p. 29-49.

Gillberg, G., 1968. Distribution of different limestone material in till. Geol. Fören. Stockholm Förh., 89, p. 401-409.

Gillberg, G., 1965. Till distribution and ice movements on the northern slopes of the South Swedish Highlands. Geol. Fören. Stockholm Förh., 86, p. 433-484.

Gillis, J. W., 1964. Geology of northwestern Pictou County, Nova Scotia, Canada. Ph.D. thesis, Penn. State University.

Glen, J. W., Donner, J. J. and West, R. G., 1957. On the mechanism by which stones in till become oriented. Am. J. Sci., 255, p. 194-205.

Goldthwait, J. W., 1924. Physiography of Nova Scotia. Geol. Surv. Canada, Mem. 140.

Goldthwait, R. P., 1960. Study of an ice cliff in Munatarassuaq, Greenland. U. S. Army, Snow Ice Permafrost Research Istb., Tech. Rept. 39, 108 p.

Goldthwait, R. P., 1974. Rates of formation of glacial features in Glacier Bay, Alaska. In Coates, D. R. (ed.), Glacial Geomorphology. Publications in Geomorphology, State Univ. of New York Binghamton, New York.

Grant, D. R., 1963. Pebble lithology of the tills of southwest Nova Scotia. M.Sc. thesis, Dalhousie University, Halifax.

Grant, D. R., 1970. Recent coastal submergence of the Maritime Provinces, Canada. Can. J. Earth Sci., 7, (2), p. 676-689.

Grant, D. R., 1971a. Surficial geology, southwest Cape Breton Island, Nova Scotia. Geol. Surv. Can., Paper 71-1, Pt. A, p. 161-164.

Grant, D. R., 1971b. Glaciation of Cape Breton Island, Nova Scotia. Geol. Surv. Can., Rept. Activities, Part B, p. 118-120.

Grant, D. R., 1971c. Glacial deposits, sea level changes and Pre-Wisconsin deposits in southwestern Nova Scotia. Geol. Surv. Can., Rept. of Act. 1971, pt. B, p. 110-113.

Grant, D. R., 1975. Glacial style and the Quaternary Stratigraphic record in the Atlantic Provinces, Canada. Geol. Surv. Can., Paper 75-1, pt. B, p. 109-110.

Gravenor, C. P., 1974. The Yarmouth drumlin field, Nova Scotia, Canada. J. Glaciol., 13, (67), p. 45-54.

Grip, E., 1953. Tracing of glacial boulders as an aid to ore prospecting in Sweden. J. Econ. Geol., 48, p. 715-725.

Harbough, J. W. and Merriam, D. F., 1968. Computer applications in stratigraphic analysis. John Wiley & Sons, New York, 282 p.

Hartley, H. O., 1950. The maximum F-ratio as a shortcut test for heterogeneity of variance. Biometrika, 37, p. 308-312.

Harris, I. M., 1970. The geology of the Goldenville Formation, Taylor Head, Nova Scotia. Ph.D. thesis, Univ. Edinburgh, Scotland.

Harrison, P. W., 1957. A clay-till fabric: Its character and origin. J. Geol., 65, p. 275-308.

Hennigar, T. W., 1972. Hydrogeology of the Truro area, Nova Scotia. N. S. Dept. Mines, Groundwater Sect. Rept. 72-1.

Hickox, C. F. Jr., 1958. Geology of the central Annapolis Valley, Nova Scotia. Ph.D. thesis, Yale Univ.

Hickox, C. F. Jr., 1962. Pleistocene geology of the central Annapolis Valley, Nova Scotia. Nova Scotia Dept. Mines, Mem. 5.

Hilchey, J. D., Cann, D. B. and MacDougall, J. I., 1960. Soil survey of Yarmouth County, Nova Scotia. N. S. Soil Survey, Rept. No. 9, 47 p.

Hilchey, J. D., Cann, D. B. and MacDougall, J. I., 1962. Soil survey of Digby County, Nova Scotia. N. S. Soil Survey Rept. No. 11, 58 p.

Hilchey, J. D., Cann, D. B. and MacDougall, J. I., 1964. Soil survey of Guysborough County, Nova Scotia. N. S. Soil Survey, Rept. No. 14, 55 p.

Holmes, C. D., 1941. Till fabric. Geol. Soc. Am. Bull., 52, p. 1299-1354.

Honeyman, D., 1877. Nova Scotian Geology. Superficial. Proc. Trans. N. S. Inst. Nat. Sci., 4, p. 109-122.

Honeyman, D., 1882. Nova Scotia Geology. Superficial. Proc. Trans. N. S. Inst. Nat. Sci., 5, p. 319-331.

Honeyman, D., 1886. Additional notes on glacial action in Halifax Harbour, Northwest Arm, and Bedford Basin. Proc. Trans. N. S. Inst. Nat. Sci., 6, p. 251-260.

Honeyman, D., 1888. Glacial geology of Nova Scotia. Proc. Trans. N. S. Inst. Nat. Sci., 7, p. 73-85.

Howard, A. D., 1965. Pseudo superglacial till. Science, 148, p. 1461-1462.

Hughes, O. L., 1957. Surficial geology of Shubenacadie map-area, Nova Scotia. Geol. Surv. Can., Paper 56-3.

Imbrie, J. and Purdy, E. G., 1962. Classification of modern Bahamian carbonate sediments. In Ham, W. E., (ed.), Classification of carbonate rocks; a symposium. Am. Assoc. Petroleum Geologists, Mem. 1, p. 253-272.

Imbrie, J. and Van Andel, T. H., 1964. Vector analysis of heavy mineral data. Geol. Soc. Am. Bull., 75, p. 1131-1156.

Jeffery, G. B., 1922. The motion of ellipsoidal particles immersed in a viscous fluid. Roy. Soc. Lond. Proc., Ser. A., 102, (715), p. 161-179.

James, N. P., 1966. Sediment distribution and dispersal patterns on Sable Island and Sable Island Bank. Ph.D. thesis, Dalhousie University.

Jones, M. J. (ed.), 1973. Prospecting in areas of glacial terrain. Inst. Min. Met.

King, L. H., 1969. Submarine end moraines and associated deposits on the Scotian Shelf. Geol. Soc. Am. Bull., 80, p. 83-96.

King, L. H., MacLean, B. and Drapeau, G., 1972. The Scotian Shelf submarine end-moraine complex. 24th I.G.C., Sec. 8, p. 237-249.

Kirby, R. P., 1969. Till fabric analysis from the Lothians, central Scotland. Geog. Ann., 51A, p. 48-59.

Kirby, R. P., 1969. Variation in glacial deposition in a subglacial environment: an example from Midlothian. Scott. J. Geol., 5, p. 49-53.

Klovan, J. E., 1966. The use of factor analysis in determining depositional environments from grain-szie distributions. J. Sediment. Pet., 36, (1), p. 115-125.

Knebel, H. J. and Creager, J. S., 1974. Heavy minerals of the east-central Vering Sea continental shelf. J. Sediment. Pet., 44, (2), p. 553-561.

Kranck, K., 1972. Geomorphological development and post-Pleistocene sea level changes, Northumberland Strait, Maritime Provinces. Can. J. Earth Sci., 9, (7), p. 835-844.

Kruger, F. C., 1937. A sedimentary and petrographic study of certain glacial drifts of Minnesota. Am. J. Sci., 34, p. 345-363.

Krumbein, W. C., 1933. Textural and lithologic variations in Glacial till. J. Geol., 41, p. 382-408.

Larsen, G., 1970. Hovedtraek af tungmineralanalysens resultater i Danmark. Dansk Geol. For. Aarskrift for 1969 (1970), p. 36-47.

Lin, C. L., 1970. Hydrogeology of the Musquodoboit River Valley, Nova Scotia. N. S. Dept. Mines Groundwater Sect. Rept. 70-3.

Lindsay, J. F., 1970. Clastic fabric of till and its development. J. Sediment. Pet., 40, No. 2, p. 629-641.

Livingstone, D. A., 1968. Some interstadial and post glacial pollen diagrams from eastern Canada. Ecol. Mon., 38, p. 87-125.

Loring, D. H., and Nota, D. J. G., 1969. Mineral dispersal patterns in the Gulf of St. Lawrence. Rev. Geogr. Montr., XXIII, No. 3, p. 289-305.

Lundqvist, G., 1935. Blockundersökningar. Historik och metodik. Sveriges Geologiska Undersökning, C 390.

Lyall, A., 1969. A study of offshore sediment movement and differentiation of beach and dune sands in the Cape Sable Island area, Nova Scotia. Ph.D. Thesis, Dalhousie University.

MacClintock, P. and Dreimanis, A., 1964. Reorientation of till fabric by overriding glacier in the St. Lawrence Valley. Am. J. Sci., 262, p. 133-142.

MacDonald, G. F., 1968. Debert: A palaeo-indian site in central Nova Scotia. Anthropology Papers, Natural Museum of Canada, No. 16, 207 p.

MacDonald, J., 1973. Stratigraphy of the upper member of the Horton Bluff Formation in the area of the type section near Hantsport, Nova Scotia. M.Sc. Thesis, Acadia University.

MacDougall, J. I., Nowland, J. L., and Hilchey, J.D., 1969. Soil Survey of Annapolis County, Nova Scotia. N. S. Soil Survey, Rept. No. 16, 84 p.

MacDougall, J. I., Cann, D. B. and Hilchey, J. D., 1961. Soil survey of Shelburne County, Nova Scotia. N. S. Soil Survey, Rept. No. 10, 38 p.

MacDougall, J. I., Cann. D. B. and Hilchey, J. D., 1963. Soil survey of Halifax County, Nova Scotia. N. S. Soil Survey, Rept. No. 13, 53 p.

MacKenzie, C. B., 1974. Petrology of the South Mountain batholith western Nova Scotia. M. Sc. Thesis, Dalhousie University.

MacNeill, R. H., 1969. Some dates relating to the dating of the last major ice sheet in Nova Scotia. Mar. Sediments, 5, No. 1, p. 3.

Manson, V. and Imbrie, J., 1964. Fortran program for factor and vector analysis of geological data using an I.B.M. 7090 or 7094/1401 computer system. Kans. Geol. Survey Computer Contr., No. 13, 47 p.

Marcussen, I., 1974. Stones in Danish tills as a stratigraphic tool, A review. Bull. Geol. Inst. Univ. Uppsala, New Series, 5, p. 177-181.

Marcussen, I., 1973. Studies on flow till in Denmark. Boreas, 2, No. 4, p. 213-231.

Mark, D. M., 1971. Rotational vector procedure for the analysis of till fabrics. Geol. Soc. Am. Bull., 82, p. 2661-2666.

Mark, D. M., 1973. Analysis of axial orientation data, including till fabrics. Geol. Soc. Am. Bull., 84, p. 1369-1374.

Mark, D. M., 1974. On the interpretation of till fabrics. Geol., 2, No. 2, p. 101-104.

Mehra, O. P., and Jackson, M. L., 1958. Iron oxide removal from soil and clays by a dithionite citrate system buffered with sodium bicarbonate, p. 317-327, In A. Swineford (Ed.) Proc. VII Natl. Conf. Clays and Clay Miner.

Mickelson, D. M., and Borns, H. W., 1972. Chronology of a kettle-hole peat bog, Cherryfield, Maine. Geol. Soc. Am. Bull., 83, p. 827-832.

Miller, C. K., Graves, M. C., and Zentilli, M., 1976. Scheelite mineralization of southeastern Nova Scotia. Geol. Surv. Can., Paper 76-1A, p. 331-332.

Milthers, V., 1913. Ledeblokke i de skandinaviske Nedisningers sydvestlige Granseegne og deres Bidrag til Kundskaben om Isströmretningernes Skiften og Aldersfölge. Dan. Geol. For., 4, No. 2, p. 115-182.

Milthers, K., 1942. Ledeblokke og landskabsformer i Danmark. Dan. Geol. Und., II Rk, No. 69.

Moran, S. R., 1971. Glaciotectonic structures in drift, In Goldthwait, R. P. (Ed.), Till, a Symposium. The Ohio State Univ. Press, p. 127-148.

Mörner, N.-A., 1971. Late Quaternary isostatic, eustatic and climatic changes. Quaternaria, 14, p. 65-83.

Mörner, N.-A., 1972. The first report on till wedges in Europe and Late Weichselian ice flows in Southern Sweden. Geol. Fören. Stockholm Förh., 94, p. 581-587.

Mörner, N.-A., 1973. A new find of till wedges in Nova Scotia, Canada. Geol. Fören. Stockholm Förh., 95, p. 272-273.

Mörner, N.-A., 1973. Till stratigraphy in North America and Northern Europe. Bull. Geol. Inst. Univ. Uppsala, New Series, 5, p. 199-207.

Mott, R. J., and Prest, V. K., 1967. Stratigraphy and palynology of buried organic deposits from Cape Breton Island, Nova Scotia. Can. Jour. Earth Sci., 4, p. 709-723.

Muller, E. H., 1974. Origins of drumlins, in Coates, D. R. (Ed.), Glacial geomorphology. Pub. in Geomorph., State Univ. of New York, Binghamton, New York, p. 187-204.

Neale, E. R. W., 1963. Geology, Pleasant Bay, Cape Breton Island. Geol. Surv. Can., Map 1119A, Scale 1:63,360.

Nichol, I. and Bjorklund, A., 1973. Glacial Geology as a key to geochemical exploration in areas of glacial overburden. J. Geochem. Expl., 2, No. 2, p. 133-170.

Nie, N., Bent, D. H., and Hubb, C. H., 1970. Statistical package for the social sciences. McGraw-Hill Co.

Nolan, F. J., 1963. Heavy mineral analysis of the beach sands of Nova Scotia. M.Sc. Thesis, Dalhousie University, Halifax.

Nowland, J. L. and MacDougall, J. I., 1973. Soils of Cumberland County Nova Scotia. N. S. Soil Survey, Rept. No. 17, 133p.

Nye, J. F., 1952. The mechanics of glacier flow. J. Glaciol., 2, p. 81-93.

Pessl, F. Jr., 1971. Till fabrics and till stratigraphy in western Connecticut, In Goldthwait, R. P. (Ed.), Till, a Symposium. The Ohio State Univ. Press, p. 92-105.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1972. Sand and sandstone. Springer-Verlag, New York, 618 p.

Phinney, W. C., 1963. Phase equilibria in the metamorphic rocks of St. Paul Island and Cape North, N. S. J. Pet., 4, No. 1, p. 90-130.

Pinder, G. F., 1968. Hydrogeology of the lower Musquodoboit River Valley, Nova Scotia. N. S. Dept. Mines, Groundwater Sect. Rept. 68-2.

Poole, W. H., Sanford, B. V., Williams, H., and Kelley, D. G., 1972. Geology of southeastern Canada. In Geology and economic minerals of Canada, Geol. Surv. Can., Econ. Geol. Rept. No. 1, p. 229-304.

Prest, V. K., 1972. Quaternary geology of Canada. In Douglas, R. J. W. (Ed.), Geology and economic minerals of Canada, Geol. Surv. Can., Econ. Geol. Rept. No. 1, p. 676-764.

Prest, V. K. and Grant, D. R., 1969. Retreat of the last ice sheet from the Maritime Provinces - Gulf of St. Lawrence region. Geol. Surv. Can., Paper 69-23.

Prest, V. K., Grant, D. R., MacNeill, R. H., Brookes, I. A., Borns, H.W., and Ogden, J. G. III, 1972. Quaternary geology, geomorphology and hydrogeology of the Atlantic provinces. XXIV International Geol. Congress, Montreal, Field Excursion A61-C61.

Prest, W. H., 1896. Glacial succession in central Lunenburg. Proc. Trans. N. S. Inst. Sci., 9, p. 158-170.

Prest, W. H., 1919. On the nature and origin of the eskers of Nova Scotia. Proc. Trans. N. S. Inst. Sci., 14, Pt. 4, p. 371-393.

Prest, W. H., 1922. Esker excavation in Nova Scotia (at Middlefield, Queens County). Proc. Trans. N. S. Inst. Sci., 15, Pt. 1, p. 33-45.

Price, R. J., 1973. Glacial and fluvioglacial landforms. Oliver and Boyd, Edinburgh, 242 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.

Ramsden, J. and Westgate, J. A., 1971. Evidence for reorientation of a till fabric in the Edmonton area, Alberta, In Goldthwait, R. P. (Ed.), Till, a Symposium. The Ohio State University Press, p. 335-344.

Rankama, K. (Ed.), 1965. The Quaternary. Vol. 1, Interscience Publishers, New York, 300 p.

Rose, J., 1974. Small-scale spatial variability of some sedimentary properties of lodgement till and slumped till. Proc. Geol. Assoc., 85, Pt. 2, p. 239-258.

Ruitenberg, A. A., 1967. Stratigraphy, structure and metallization, Peskahegan-Rolling Dam area (northern Appalachians, New Brunswick, Canada). Leidse Geol. Mededel., 40, p. 79-120.

Savage, W. Z., 1968. The application of plastic flow analysis to drumlin formation. M.Sc. Thesis, Syracuse University, 60 p.

Schofield, W. B., and Robinson, H., 1960. Late-glacial and postglacial plant macrofossils from Gillis Lake Richmond County, Nova Scotia. Am. J. Sci., 258, p. 518-523.

Shepps, V. C., 1953. Correlation of the tills of northeastern Ohio by size analysis. J. Sediment. Pet., 23, No. 1, p. 34-48.

Shepard, F. P., 1930. Fundian faults or Fundian glaciers. Bull. Geol. Soc. Am., 41, p. 659-674.

Shilts, W. W., 1973. Glacial dispersion of rocks, minerals and trace elements in Wisconsinan till, southeastern Quebec, Canada. Geol. Soc. Am., Memoir 136, p. 189-219.

Shilts, W. W., 1975. Principles of geochemical exploration for sulphide deposits using shallow samples of glacial drift. Can. Inst. Mining Bull., May, p. 73-80.

Sitler, R. F., 1963. Petrography of till from northeastern Ohio and northwestern Pennsylvania. J. Sediment. Pet., 33, No. 2, p. 365-379.

Slatt, R. M., 1971. Texture of ice-cored deposits from ten Alaskan valley glaciers. J. Sediment. Pet., 41, No. 3, p. 828-834.

Smitheringale, W. G., 1973. Geology of parts of Digby, Bridgetown, and Gaspereau Lake map-areas, Nova Scotia. Geol. Surv. Can., Mem. 375.

Smith, T. E., 1974. The geochemistry of the granitic rocks of Halifax County, Nova Scotia. Can. J. Earth Sci., 11, p. 650-657.

Snedecor, G. W., 1966. Statistical methods. 5th ed. Iowa State University Press, Ames, Iowa.

Stevenson, I. M., 1958. Truro map-area, Colchester and Hants Counties, Nova Scotia. Geol. Surv. Can., Mem. 297.

Stevenson, I. M., 1959. Shubenacadie and Kennetcook map-areas, Colchester, Hants and Halifax Counties, Nova Scotia. Geol. Surv. Can., Mem. 302.

Stewart, D. P. and MacClintock, P., 1971. Ablation till in northeastern Vermont, In Goldthwait, R. P. (Ed.), Till, a Symposium. The Ohio State University Press, p. 106-114.

Taylor, F. C., 1967. Reconnaissance geology of Shelburne map-area, Queens, Shelburne and Yarmouth Counties, Nova Scotia. Geol. Surv. Can., Mem. 349.

Taylor, F. C., 1969. Geology of the Annapolis-St. Mary's Bay map-area, Nova Scotia. Geol. Surv. Can., Mem. 358.

Taylor, F. C. and Schiller, E. A., 1966. Metamorphism of the Meguma Group of Nova Scotia. Can. J. Earth Sci., 3, p. 959-974.

Terasmae, J., and Mott, R. J., 1971. Postglacial history and palynology of Sable Island, Nova Scotia. Geoscience and Man, III, p. 17-28.

Terasmae, J., 1974. Deglaciation of Port Hood Island. Can. J. Earth Sci., 11, p. 1357-1365.

Thomas, M. L. H., Grant, D. R. and de Grace, M., 1973. A late Pleistocene marine shell deposit at Shippegan, New Brunswick. Can. J. Earth Sci., 8, p. 1329-1332.

Thompson, J. P., 1974. Stratigraphy and geochemistry of the Scots Bay Formation, Nova Scotia. M. S. Thesis, Acadia University.

Trescott, P. C., 1968. Groundwater resources and hydrogeology of the Annapolis-Cornwallis Valley, Nova Scotia. N. S. Dept. Mines, Mem. 6.

Vincent, P. J., 1974. The classification of glacial tills. A factor analytical study. Geog. Polonica, 28, p. 49-57.

Watson, G. S., and Irving, E., 1957. Statistical methods in rock magnetism. Monthly Notices of the Royal Astronomical Society, Geophysical Supplement, 7, No. 6, p. 289-300.

Weeks, L. J., 1948. Londonderry and Bass River map-areas, Colchester and Hants Counties, Nova Scotia. Geol. Surv. Can., Mem. 245.

Wicklund, R. E. and Smith, G. R., 1948. Soil survey of Colchester County, Nova Scotia. N. S. Soil Survey, Rept. No. 3, 57 p.

Worsley, P., 1973. The first report on "till wedges" in Europe. A discussion. Geol. Fören. Förh., 95, p. 152.

Worsley, P., 1974. Further discussion of the "till wedge" concept in the light of replies from Professor Dreimanis and Dr. Mörner. Geol. Fören. Förh., 96, p. 279-282.

Worsley, P., 1975. Till dike genesis: A discussion. Can. J. Earth Sci., 12, p. 1249-1250.

Worth, J. K., 1969. Stratigraphy of the Horton Bluff Formation, Wolfville, Nova Scotia. M.Sc. Thesis, Acadia University.

Wright, H. E. Jr., 1957. Stone orientation in Wadena drumlin field, Minnesota. Geog. Ann., XXXIX, p. 19-31.

Wright, W. J., 1931. Data on the method of granitic intrusion in Nova Scotia. Trans. R. Soc. Can., 25, 3rd Ser., Sec. 4, p. 309-330.

Zingg, Th., 1935. Beitrag zur Schotteranalyse. Schweiz. mineralog. petrog. Mitt., 15, p. 39-140.

ADDENDA

Dreimanis, A. and Vagners, U. J., 1971. The effect of lithology upon texture in till. In Yatsu, E. and Falconer A. (eds.), Research Methods in Pleistocene Geomorphology, 2nd Guelph Symposium on Geomorphology.

Flint, R. F., 1957. Glacial and Pleistocene geology. London (Wiley).

Gwyn, H. and Sutterlin, P. G., 1971. Computer applications in the analysis of heavy mineral data from tills. In Yatsu, E. and Falconer, A. (eds.), Research Methods in Pleistocene geomorphology proceedings; 2nd Guelph Symposium on Geomorphology.

Harris, S. A., 1971. The nature and use of till fabrics. In Yatsu, E. and Falconer A. (eds.), Research Methods in Pleistocene Geomorphology, 2nd Guelph Sumposium on Geomorphology.

MacNeill, R. H. and Purdy, C. A., 1951. A local glacier in the Annapolis-Cornwallis Valley. (Abstr.) Proc. Nova Scotia Insti. Sci., Vol. XXIII, part 1, p. 111.

MacNeill, R. H., 1960. Surficial geology maps of Nova Scotia 1:50,000. Nova Scotia Research Foundation, Dartmouth, Nova Scotia.

Wilson, J. T., 1938. Drumlins of southwestern Nova Scotia. Roy. Soc. of Can. Trans. Ser. 3, Vol. 32, sec. 4, p. 41-47.

APPENDIX I

Till fabric diagrams

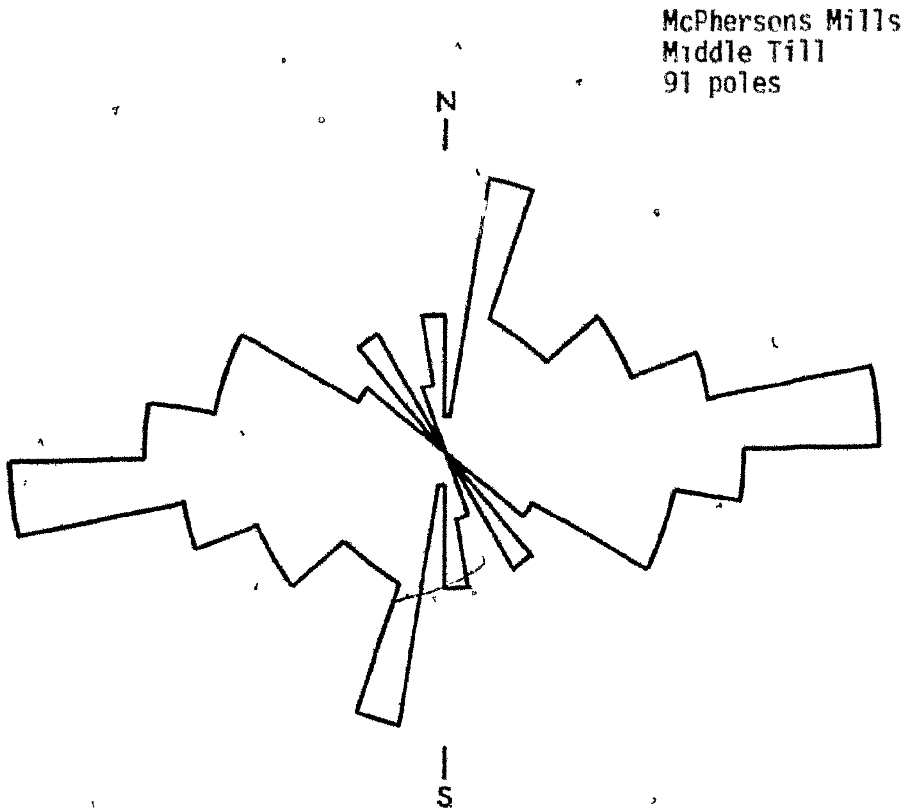


Figure I-1. Pebble fabric in a horizontal plane (drawn from radiograph).

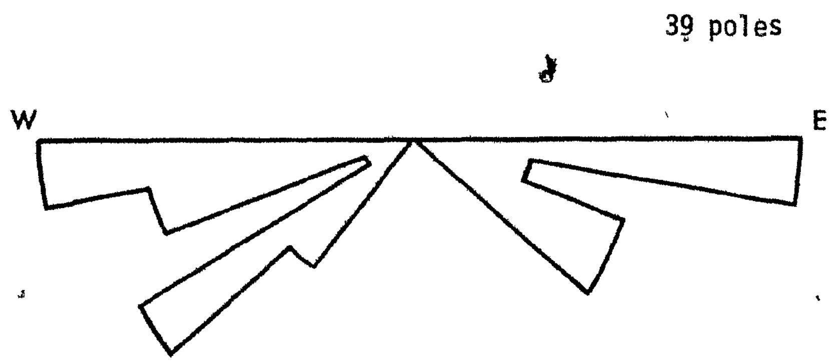
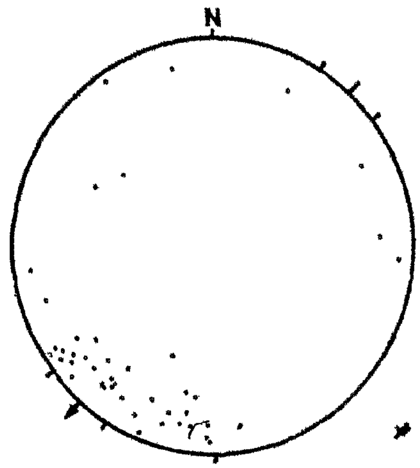
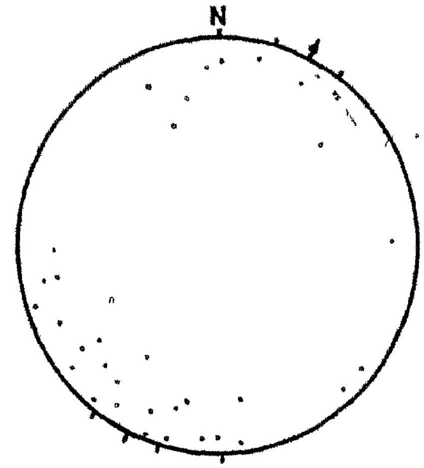


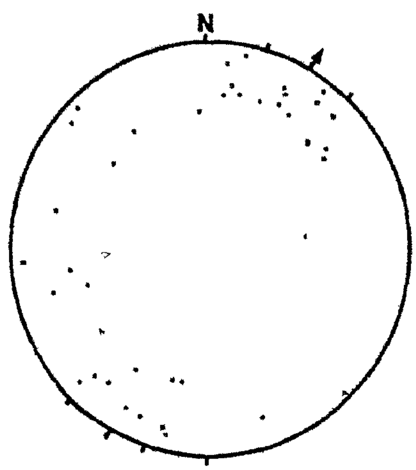
Figure I-2. Pebble fabric in a vertical profile through the vector mean in fig. I-1 (drawn from radiograph)



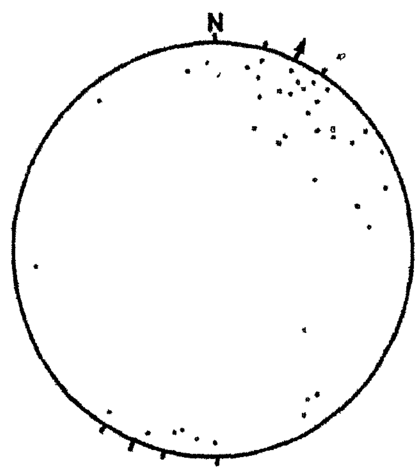
McPherson's Mills, 50 poles



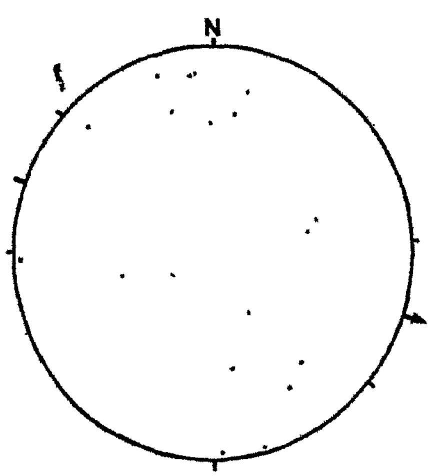
Mount Thom, 50 poles



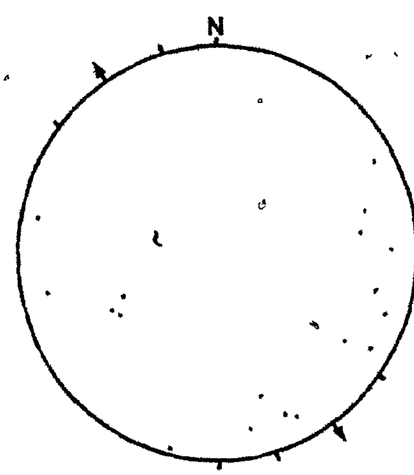
Riversdale, 41 poles



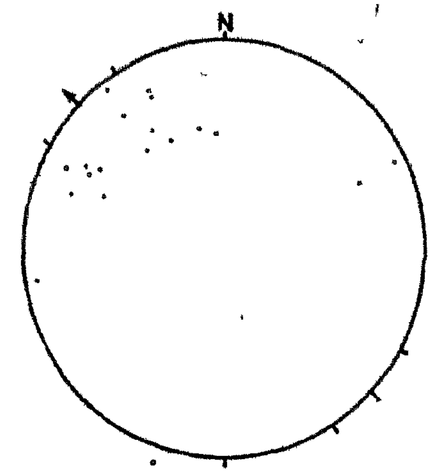
Lorne, 50 poles



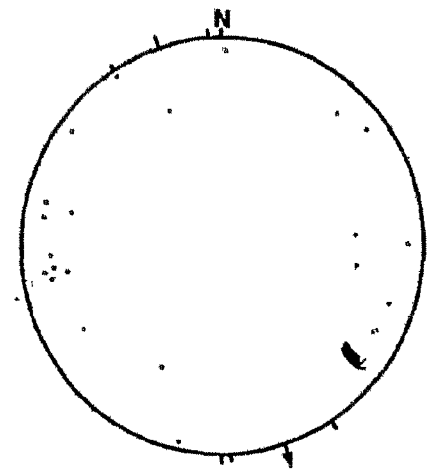
Chaplin, Station 1
25 poles



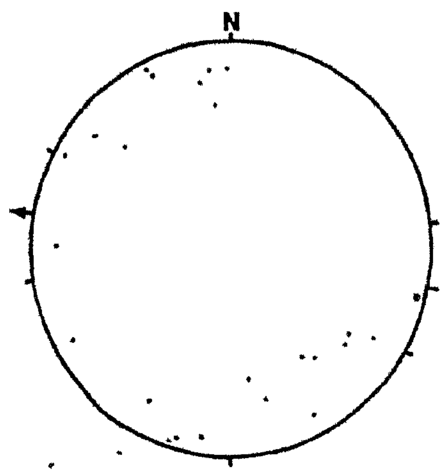
Chaplin, Station 2
25 poles



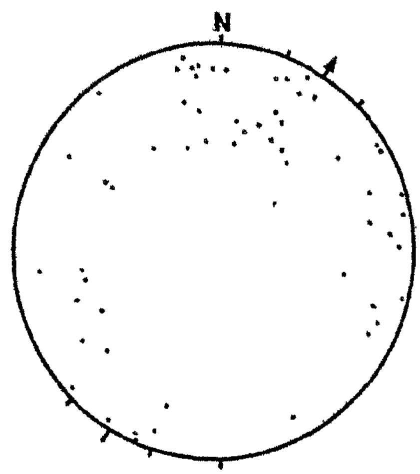
Plainfield, 25 poles



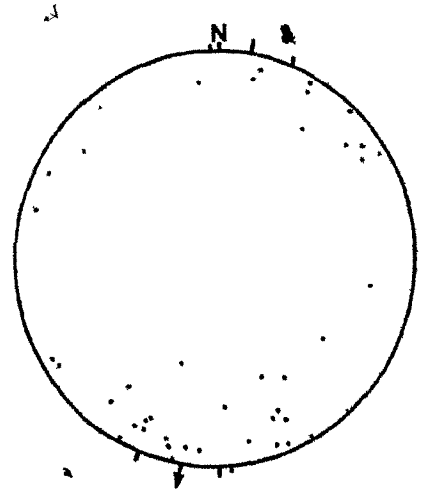
Tatamagouche
Station 1, 24 poles



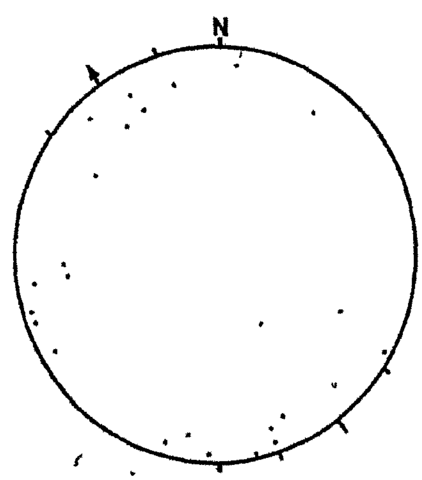
Tatamagouche
Station 2, 25 poles



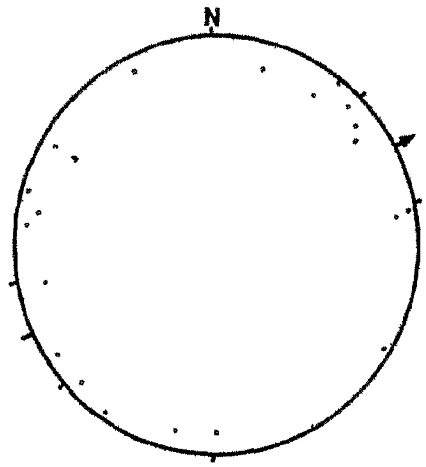
Debert, 59 poles



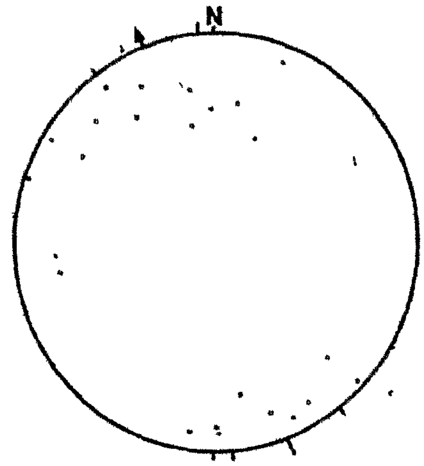
Lower Selma, 50 poles



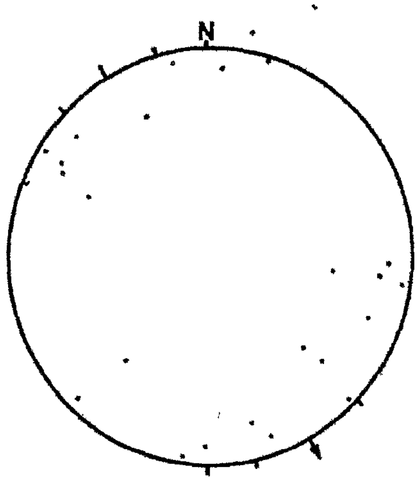
Eagles Nest Point
Upper Till, 25 poles



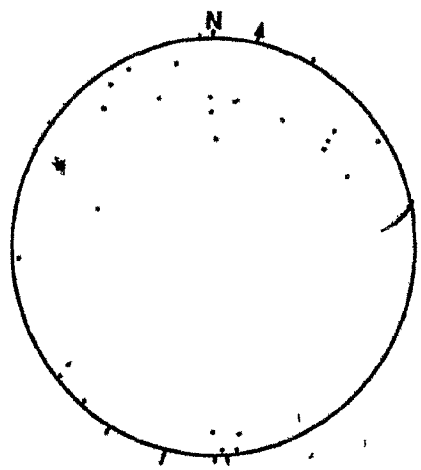
Eagles Nest Point
Lower Till, 25 poles



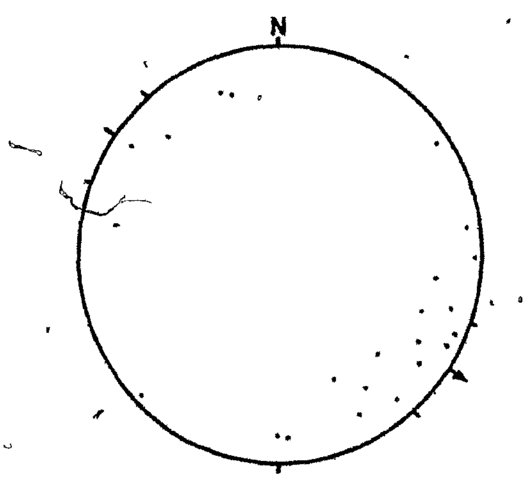
Eagles Nest Point
Lower Till, 25 poles



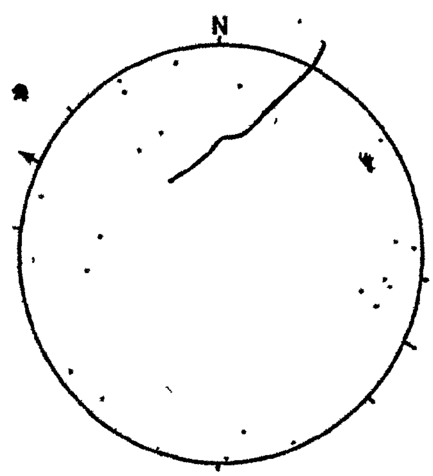
Mutton Cove, 25 poles



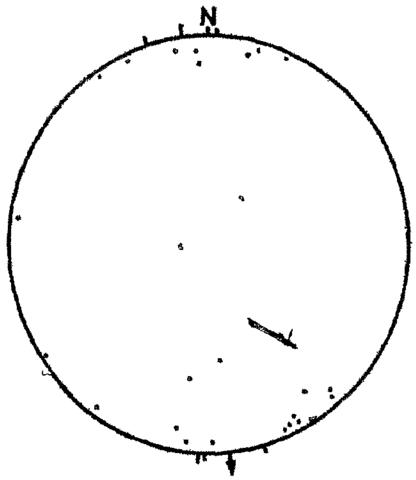
St. Croix, 25 poles



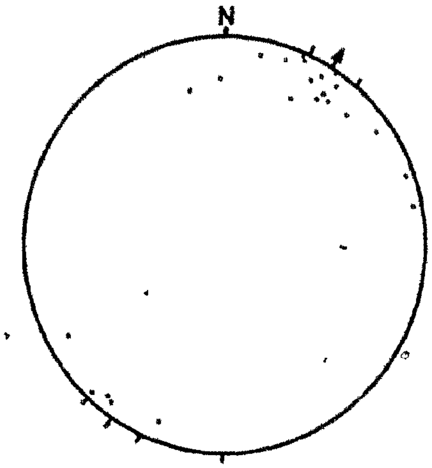
Windsor, 25 poles



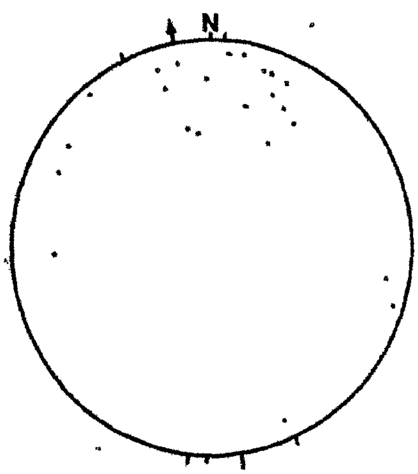
Avonport, 25 poles



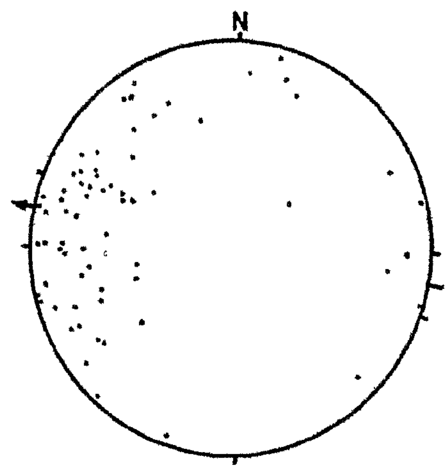
Wolfville, 25 poles



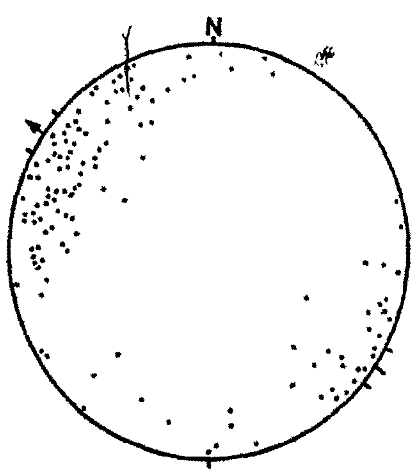
New Minas, 25 poles



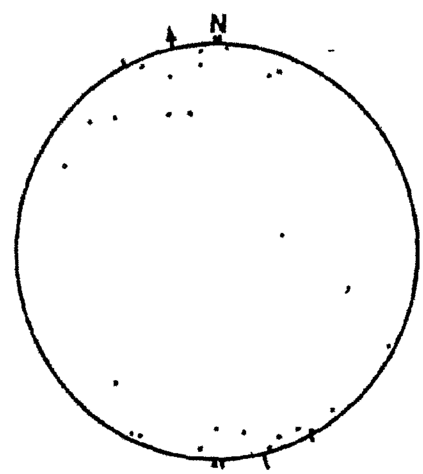
Hartlen Point Upper Till
Station 1, 25 poles



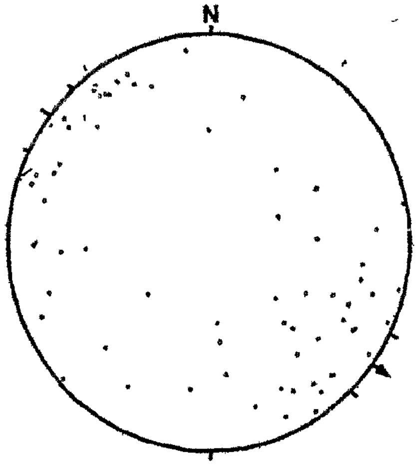
Hartlen Point Upper Till
Stations 2, 3, 4, 75 poles



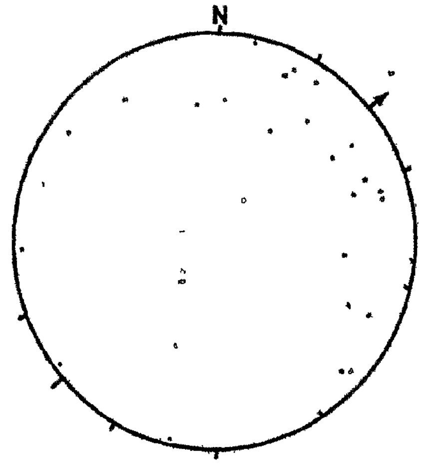
Hartlen Point Lower Till
Stations, 1, 2, 3, 4, 5, 6,
140 poles



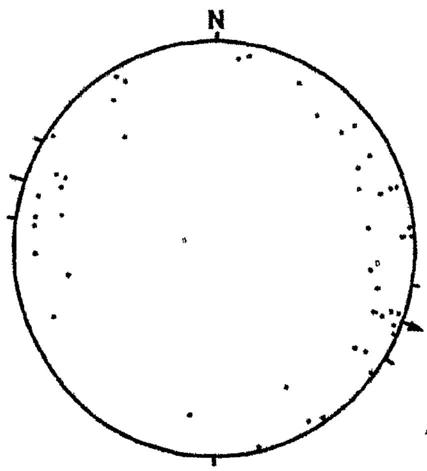
Whites Lake
Station 2, 26 poles



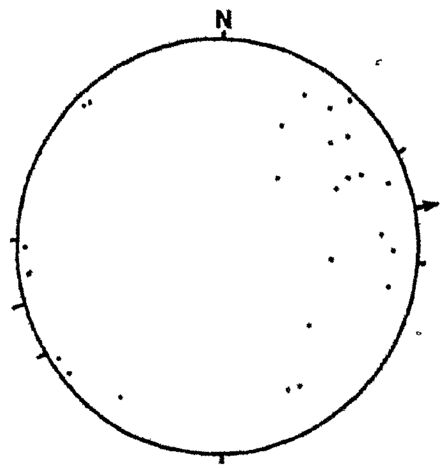
Whites Lake
Station 1, 3, 4, 73 poles



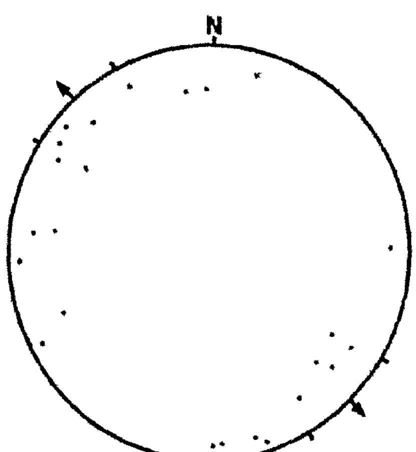
Cornwallis Station 1
25 poles



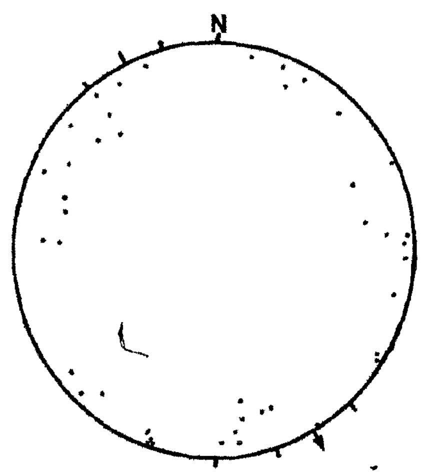
Cornwallis
Stations, 2, 3 50 poles



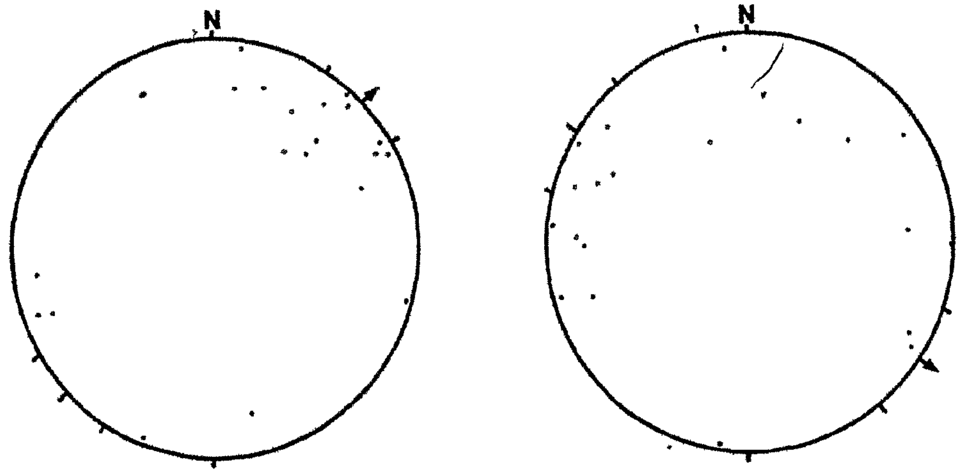
Perry Brook
25 poles



Salmon River, Till
underlying marine sand
25 poles



Salmon River Till
immediately overlying marine
sand 25 poles



Salmon River, Middle Till
overlying marine sand
Station 1, 25 poles

Salmon River, Middle Till
overlying marine sand
Station 2, 25 poles

Figure I-3. Till fabric data for 25 locations in Nova Scotia plotted on the southern hemisphere of an equal area projection.

APPENDIX 2

- Percent gravel, sand, silt, and clay.
- Percent granitic and basaltic pebbles.
- Mineral suites IA, II, III, and IV. Mineral suite IB is listed in Appendix 4 as the percent augite.

SAMPLE NO.	% Suite IA	% Suite II	% Suite III	% Suite IV	% Gravel	% Sand	% Silt	% Clay	% Granitic Pebbles	% Basaltic Pebbles
201.	63.3	11.3	6.6	22.5	29.9	33.4	33.6	3.1	71.9	9.7
202.	71.3	24.9	5.7	11.9	27.7	38.8	30.3	3.2	68.2	.8
203.	58.7	17.3	3.8	30.8	37.9	37.4	20.8	3.9	83.8	.6
204.	71.5	5.6	10.2	13.7	[illegible]	57.6	16.7	2.8	57.4	2.0
205.	63.7	11.7	7.0	22.1	[illegible]	27.7	9.1	7.9	44.8	0
208.	31.6	2.9	0	48.5	63.9	31.4	4.5	.2	99.9	0
209.	14.2	.4	1.6	3.2	52.7	30.7	15.9	.7	2.8	0
210.	33.5	.6	2.6	6.2	37.7	39.7	13.4	3.2	17.0	1.0
211.	19.1	0	3.7	21.6	32.3	55.2	11.3	1.2	11.5	.2
212.	84.6	25.8	1.5	8.6	15.1	25.7	33.4	25.8	5.1	.6
214.	76.0	36.5	0	6.4	15.0	28.9	31.6	24.5	10.0	.7
216.	42.5	7.4	7.4	43.8	40.9	46.8	11.9	.4	82.6	.6
916.	45.8	26.3	0	6.6	35.1	24.5	35.4	4.0	4.2	0
217.	30.5	0	23.1	46.2	60.4	23.9	14.0	1.7	0	0
218.	65.7	50.8	10.9	14.8	22.1	30.1	28.3	19.5	12.0	0
219.	76.7	41.6	7.9	5.0	24.1	27.6	27.5	20.8	8.5	4.0
220.	78.7	37.3	1.1	6.0	40.0	33.7	22.4	2.9	16.9	1.3
221.	87.0	25.3	8.6	5.2	53.9	36.5	9.0	.6	0	0
222.	84.6	20.7	7.0	1.4	45.8	27.6	26.2	.4	0	1.3
223.	91.0	14.9	3.0	11.9	51.2	30.4	17.5	.8	1.0	1.1
224.	70.3	34.6	2.4	7.9	73.1	20.3	6.2	.4	2.7	0
225.	87.0	16.1	0	16.1	59.5	28.2	11.3	1.0	0	0
226.	78.0	32.1	5.1	0	16.9	29.3	32.2	21.6	6.9	-0
227.	62.1	40.6	1.8	21.4	78.0	19.9	1.9	.2	.3	.3
228.	64.7	40.5	4.4	3.2	47.0	32.5	16.5	4.0	4.4	0
229.	91.4	45.1	1.6	1.6	33.1	33.3	21.7	11.9	7.6	0
230.	38.5	.9	2.4	27.1	42.6	44.9	12.4	.1	77.5	.3
231.	24.2	.7	10.8	45.0	68.7	25.7	5.4	.2	99.9	0
232.	8.0	0	0	0	55.0	23.8	18.0	3.2	1.4	97.1
237.	24.4	.7	3.8	1.1	22.3	28.7	34.4	14.6	18.5	26.7
238.	11.3	0	0	0	65.3	32.7	1.5	.5	29.5	1.0
239.	79.1	40.6	0	2.3	24.2	34.2	23.8	17.8	16.3	2.9
240.	67.4	42.7	7.2	10.2	13.9	38.2	27.8	20.1	16.3	2.9
241.	63.6	17.2	5.9	8.1	41.9	48.7	9.3	.1	4.4	0
243.	38.5	.6	2.8	1.5	29.1	50.7	15.3	4.9	28.8	1.4
244.	54.2	1.1	5.5	12.6	33.9	41.5	22.1	2.5	15.9	1.1
247.	25.8	1.0	5.6	1.8	39.0	46.4	13.2	1.4	33.5	1.6
249.	8.7	0	2.7	3.5	28.8	41.8	20.0	9.4	52.3	0
250.	19.9	.4	1.1	1.9	25.1	32.4	25.4	17.1	21.1	14.7
251.	13.4	1.3	2.8	1.0	75.0	16.6	7.9	.5	5.9	4.6
252.	59.3	9.0	3.9	2.0	30.7	54.3	14.2	.8	11.2	6.9
253.	12.5	1.6	.7	.3	63.5	25.8	10.2	.5	5.2	24.8
257.	59.4	1.4	1.4	0	9.5	25.9	59.3	5.3	7.0	0

258.	49.7	3.7	7.2	5.5	30.1	46.1	19.1	4.7	15.8	4.1
259.	60.1	1.2	13.8	0	32.0	41.2	21.0	5.8	11.6	1.6
260.	52.9	2.6	2.3	2.3	26.9	34.3	24.5	14.3	41.9	0
261.	42.1	3.9	9.1	13.0	57.6	33.7	3.1	.4	13.5	1.1
262.	34.3	5.0	3.7	7.5	22.9	40.1	23.7	13.3	27.4	1.6
264.	32.8	0	0	5.4	27.8	39.8	25.7	6.7	17.5	0
265.	72.7	6.3	6.3	12.6	52.4	24.0	23.2	.4	0	0
266.	58.4	7.6	51.5	6.4	50.1	34.0	14.4	1.5	0	0
267.	62.7	5.2	19.0	25.2	20.7	29.1	49.5	.7	18.3	0
268.	31.6	1.3	68.5	23.7	51.4	30.6	17.8	.2	12.8	0
269.	35.9	0	89.2	6.9	33.8	44.3	21.5	.4	3.8	0
270.	15.3	.4	2.6	19.3	41.9	41.8	16.2	.1	22.9	.5
271.	32.2	.7	1.2	7.5	19.9	47.5	27.8	7.8	82.4	4.8
272.	48.4	5.1	3.3	17.2	24.6	34.8	24.4	16.2	73.2	1.2
273.	29.6	0	0	24.4	28.2	61.3	10.4	.1	73.2	.6
274.	28.4	2.2	1.0	9.3	40.4	41.6	15.4	2.6	71.2	0
275.	71.6	4.5	1.4	12.0	44.9	29.7	19.2	6.2	71.3	.7
276.	55.0	2.1	2.1	22.7	16.8	33.7	31.1	18.4	87.9	3.5
277.	80.9	6.7	7.8	3.0	20.3	44.0	23.0	12.7	52.6	3.4
278.	34.5	2.7	1.4	.6	28.5	27.6	33.6	10.3	7.6	0
280.	30.0	14.7	6.4	0	26.4	29.4	25.1	19.1	5.4	.7
283.	44.1	.7	4.4	0	58.9	18.1	20.4	2.6	0	0
284.	68.9	62.0	0	2.8	13.1	27.4	32.5	26.9	16.7	0
285.	58.5	66.4	2.7	1.4	26.7	39.0	20.4	13.9	24.9	1.3
286.	72.2	47.7	2.3	0	17.9	34.5	25.1	24.5	13.1	4.1
287.	86.5	51.7	7.8	0	13.5	30.0	29.3	27.2	9.8	0
288.	61.1	15.7	2.6	9.3	11.8	46.9	25.3	15.0	1.8	0
289.	90.1	39.1	10.9	23.9	21.7	22.7	28.9	26.7	13.3	0
290.	52.4	59.5	0	2.3	12.1	39.1	31.5	17.3	20.8	3.6
291.	95.2	21.7	10.8	21.7	9.4	47.0	24.4	19.2	24.0	0
292.	104.6	25.7	11.4	0	13.3	27.9	42.6	16.2	2.9	1.9
293.	88.8	36.9	3.5	3.5	36.4	41.6	19.8	2.2	14.5	0
294.	67.8	25.0	0	63.6	71.9	13.8	7.7	.6	97.5	0
295.	72.9	59.3	5.5	3.8	12.0	38.1	38.8	11.1	11.2	3.2
296.	86.6	36.7	10.0	6.7	50.8	39.5	9.1	.6	2.0	.5
297.	69.3	55.7	10.1	0	29.6	24.7	31.7	14.0	4.9	1.6
298.	71.0	40.4	6.4	0	31.4	32.0	32.4	4.2	2.0	.7
299.	69.8	45.4	5.7	1.7	32.9	30.9	23.3	6.9	1.1	.5
301.	67.4	34.0	3.2	6.4	33.5	13.1	37.1	15.3	10.5	0
302.	84.7	40.6	6.9	3.4	12.3	34.1	31.1	22.5	14.8	2.7
304.	98.2	0	0	33.6	17.4	36.4	35.5	10.7	0	0
305.	113.3	12.3	0	0	21.6	14.8	46.4	17.2	0	0
306.	7.4	93.7	0	0	13.7	31.7	49.3	6.3	78.9	3.0
307.	72.3	35.8	0	0	67.1	27.0	5.3	.5	0	0
308.	40.8	92.1	0	.9	68.3	21.8	9.3	.6	14.8	4.3
309.	102.6	4.0	8.0	48.0	57.0	15.2	20.2	7.6	.4	0
310.	45.5	16.1	0	0	67.9	28.6	3.2	.3	96.4	3.9
311.	74.1	66.5	2.1	0	50.2	29.3	16.0	4.5	4.9	0
312.	26.5	60.7	0	0	67.0	27.4	3.0	.6	57.0	1.6
313.	100.0	0	0	0	54.5	36.7	7.6	1.2	11.6	0
314.	103.2	27.0	4.4	3.6	67.3	27.7	3.4	1.6	14.1	2.8
315.	57.9	85.6	0	0	49.3	23.3	10.6	7.3	1.8	0
316.	82.7	25.7	0	2.2	65.0	20.9	10.0	3.2	50.0	0
317.	32.9	97.1	0	0	85.0	9.5	4.3	1.2	12.8	0
318.	26.2	90.1	0	1.1	46.9	46.1	6.4	.6	96.9	0

319.	84.8	84.2	2.6	2.6	65.0	30.0	4.6	.4	5.5	0
320.	140.5	11.9	14.3	0	34.8	43.0	19.4	2.8	.1	0
321.	111.7	2.6	20.2	29.8	21.5	25.9	34.1	18.5	1.4	0
322.	108.0	15.7	35.1	6.7	10.4	36.9	29.0	23.7	1.9	0
323.	120.4	15.4	15.4	24.5	20.7	26.4	34.4	18.5	.5	0
324.	99.2	54.5	11.4	11.4	16.3	29.7	37.9	16.1	0	0
325.	91.9	60.0	0	0	38.2	22.4	25.3	13.1	1.3	0
328.	64.1	76.0	0	0	43.6	27.1	20.8	8.5	.9	0
329.	122.4	9.6	15.4	13.5	10.7	30.2	38.5	20.6	2.3	0
330.	90.7	69.6	3.9	0	30.5	35.0	23.1	11.4	10.9	0
331.	113.7	13.6	6.8	0	20.1	19.8	41.3	18.8	2.3	0
332.	78.5	66.1	1.4	2.5	24.9	30.8	25.6	18.7	11.7	0
333.	37.7	1.1	5.0	51.4	31.9	45.6	20.6	1.9	27.3	0
334.	48.3	0	5.6	32.6	45.7	49.8	3.9	.6	91.7	.6
335.	40.5	1.6	0	27.8	48.2	39.9	11.0	.9	99.5	0
337.	36.4	6.8	10.4	49.2	16.2	56.4	24.6	2.8	83.7	0
338.	57.7	3.5	3.5	5.5	56.9	29.8	11.1	2.2	33.0	0
339.	10.3	2.1	3.3	19.4	52.9	36.5	9.6	1.0	38.7	.2
340.	64.3	0	9.4	40.3	30.3	54.6	13.3	1.8	93.0	0
341.	75.5	14.2	3.7	10.0	20.2	35.6	25.9	17.3	14.7	1.3
342.	72.9	25.2	0	0	17.9	37.0	30.5	14.6	10.9	0
343.	60.8	11.5	55.2	1.6	35.0	21.7	30.8	12.5	.4	0
344.	72.5	1.6	4.9	3.3	39.1	21.0	28.3	11.6	10.3	0
345.	76.9	11.5	3.4	9.2	26.3	30.3	23.0	20.4	6.5	0
346.	66.5	3.8	3.8	7.6	16.5	29.5	30.1	23.9	4.3	27.6
347.	40.8	20.4	0	.9	18.6	28.5	38.3	14.6	20.6	0
348.	53.2	15.0	15.0	25.7	62.8	23.8	8.1	.3	16.4	0
349.	47.2	10.9	12.3	37.9	44.6	37.6	15.6	1.2	52.6	0
350.	30.1	26.2	12.1	9.2	57.0	20.1	20.8	2.1	.5	0
351.	35.6	17.2	20.5	10.6	51.3	28.5	13.6	1.6	.8	0
352.	75.2	53.2	19.1	2.1	39.4	36.0	21.0	3.6	4.4	0
353.	62.1	62.0	18.4	0	25.8	40.5	25.4	8.3	12.4	4.1
354.	77.7	39.0	22.0	0	27.4	27.1	34.3	11.2	0	0
355.	75.9	31.9	14.1	0	49.9	27.9	20.0	2.2	0	0
357.	77.0	51.2	20.5	7.8	42.6	37.2	17.5	2.7	6.6	.5
358.	33.6	43.5	4.8	8.1	54.1	26.1	9.9	.9	0	0
359.	54.0	45.5	1.5	2.7	42.2	27.5	26.6	3.7	1.6	.8
360.	63.5	45.5	23.5	2.5	33.7	35.5	28.5	1.3	5.7	0
361.	84.3	7.2	52.3	10.5	55.9	24.4	18.9	.8	0	0
362.	52.3	18.2	55.7	3.2	62.7	25.1	11.4	.8	2.0	.7
363.	64.0	15.5	70.9	2.7	45.3	34.2	19.7	1.8	.5	0
364.	69.3	72.1	4.5	0	57.4	25.7	14.8	2.1	.9	0
365.	66.4	88.9	0	0	50.4	32.4	10.2	1.0	19.8	3.0
366.	73.8	93.7	0	0	36.9	23.9	22.3	16.9	5.7	0
367.	57.7	87.9	0	0	49.9	18.4	24.6	7.1	9.9	5.0
368.	58.8	78.3	2.2	2.2	45.7	24.0	18.9	11.4	20.3	1.3
369.	113.8	48.4	0	4.3	52.4	26.1	16.7	4.8	18.5	0
370.	133.6	42.9	0	0	67.6	18.5	8.6	5.3	3.7	.3
371.	135.2	26.5	0	0	23.8	25.3	26.0	14.9	1.5	0
372.	89.4	44.4	0	0	51.4	33.3	13.9	1.4	0	0
373.	117.7	36.7	0	0	54.9	31.5	10.9	2.7	.5	0
374.	85.0	41.1	2.3	5.7	33.3	25.5	25.0	16.2	1.8	0
375.	82.4	76.8	0	0	33.8	48.6	12.9	4.7	7.0	0
376.	92.5	71.3	0	0	55.5	15.2	16.1	13.2	2.0	0
377.	51.3	87.1	0	0	44.3	27.9	20.3	7.5	14.4	.5

378.	130.5	14.9	3.6	0	42.3	27.8	18.4	11.5	1.7	0
379.	9.6	0	0	0	47.9	38.4	12.6	1.1	1.0	99.0
380.	10.1	0	0	0	49.2	43.7	6.5	.6	1.2	98.0
381.	4.3	0	0	0	41.6	40.1	15.3	2.0	0	99.9
384.	17.7	.6	.6	.6	24.1	34.0	32.8	9.1	20.7	53.4
385.	14.2	.4	.4	.4	21.0	34.0	33.5	11.5	15.1	84.0
386.	32.1	2.0	2.0	2.8	17.8	29.7	31.1	23.4	30.2	59.8
387.	44.4	0	0	15.4	19.5	55.3	20.6	4.6	18.5	26.7
392.	47.6	.7	1.5	6.7	21.1	30.9	27.1	20.9	18.7	13.4
396.	23.8	.6	1.5	.3	17.8	40.8	32.3	9.1	43.1	0
397.	0	0	7.1	50.0	47.3	46.6	5.6	.5	97.2	0
398.	55.3	2.5	7.5	1.7	27.8	32.7	23.1	11.4	76.8	2.8
399.	47.4	5.8	13.3	13.6	35.9	32.4	20.2	11.5	32.2	5.9
400.	62.6	1.2	4.8	1.2	41.2	32.0	23.7	3.1	7.0	0
401.	42.8	2.2	4.1	8.3	54.9	40.9	3.7	.5	44.0	4.0
402.	36.4	2.1	6.9	15.9	59.5	35.1	4.3	1.1	94.4	0
403.	52.0	0	39.1	0	38.9	45.7	13.8	1.5	99.0	0
404.	32.8	0	2.1	1.6	22.1	29.9	23.5	24.5	28.0	6.5
405.	40.9	4.3	4.8	6.1	20.0	21.5	31.5	27.0	13.7	89.0
406.	28.0	1.2	.8	0	22.2	46.8	25.5	5.5	19.7	79.0
407.	19.2	.4	2.5	.4	51.6	42.5	5.2	.7	9.8	90.0
408.	99.3	9.5	3.1	6.1	12.0	29.9	20.5	28.6	11.5	82.7
409.	33.5	1.7	.5	6.4	7.0	48.1	30.4	14.5	8.2	72.1
410.	36.3	0	1.1	1.1	12.1	46.7	27.8	13.4	2.8	12.3
411.	16.9	0	.6	.6	50.9	29.6	16.6	2.9	0	99.9
412.	70.5	3.2	11.5	3.2	19.4	32.6	25.7	23.3	1.3	1.5
413.	79.4	6.9	5.2	3.4	31.2	35.3	13.6	13.9	1.3	3.2
414.	52.5	.7	8.0	4.1	27.2	37.0	13.7	21.9	21.3	19.1
415.	52.9	1.4	2.9	4.3	9.0	44.3	25.1	21.6	62.0	24.0
416.	51.8	.9	2.7	1.8	57.7	35.0	5.9	.4	4.2	0
417.	87.7	0	0	14.0	3.7	64.7	19.1	12.5	11.1	0
418.	51.2	1.4	4.6	0	6.2	37.2	39.8	16.8	0	22.2
419.	21.0	.6	0	.6	61.2	27.9	9.4	1.5	.7	99.0
420.	13.0	.4	.4	0	43.0	34.2	20.4	2.4	1.1	98.9
421.	2.4	0	0	0	72.2	16.2	10.7	.9	.2	99.8
422.	15.7	.6	.6	1.4	29.1	31.9	30.4	8.6	2.4	66.1
423.	8.9	0	0	0	60.9	22.2	15.4	1.5	0	99.9
425.	18.0	0	1.5	16.4	54.4	35.2	8.5	1.9	99.0	.5
426.	8.3	0	.7	1.8	51.3	43.7	4.2	.8	73.2	9.1
427.	9.2	4.6	0	69.0	48.0	44.3	6.9	.8	99.9	0
428.	21.1	.6	1.4	4.0	46.0	46.9	6.6	.5	70.4	1.7
429.	21.2	0	1.9	10.2	52.6	37.8	3.0	.6	96.1	2.8
430.	78.3	1.9	14.3	1.9	65.4	28.1	3.9	2.6	0	1.8
431.	64.4	5.3	4.2	2.1	23.3	35.6	23.6	17.5	0	6.2
432.	51.3	2.3	5.1	3.4	7.1	54.5	19.6	18.8	16.2	21.4
433.	62.2	2.0	4.9	1.0	21.5	50.6	20.5	7.4	12.0	15.7
434.	50.0	0	0	35.3	32.7	19.0	29.6	18.7	1.8	0
437.	97.4	0	0	0	11.5	0	1.8	0	0	0
438.	45.1	7.0	0	0	38.2	21.6	25.3	14.9	1.3	0
439.	64.3	13.4	4.5	11.9	73.0	14.6	11.5	.9	0	0
440.	4.5	1.6	43.8	39.1	34.7	50.1	13.0	2.2	98.7	0
441.	84.1	31.7	2.9	2.9	34.9	26.3	25.3	13.5	37.1	.6
442.	40.5	25.0	32.8	25.0	53.9	31.7	12.7	1.7	86.9	0
443.	100.2	0	11.3	14.5	2.8	52.0	26.6	18.6	-0	-0
444.	100.2	2.1	14.3	4.8	11.6	44.1	24.8	19.5	20.7	1.2

445.	128.0	8.5	3.2	7.4	11.7	40.9	28.4	19.0	3.5	0
446.	95.7	8.6	11.4	11.4	37.6	31.1	19.3	12.0	1.4	2.1
448.	72.1	9.1	9.1	6.7	29.8	38.3	20.6	11.3	2.0	2.1
449.	18.3	.6	38.5	45.2	33.3	49.4	17.7	.6	33.8	.3
450.	13.0	2.8	28.1	33.7	27.3	48.2	23.7	.8	67.7	.2
451.	27.2	3.0	34.3	8.1	69.0	27.7	2.9	.4	54.4	0
452.	15.3	24.3	36.1	28.5	44.0	36.6	18.1	1.3	97.1	0
453.	25.9	17.3	23.7	38.0	26.7	46.8	25.3	1.2	80.7	0
454.	31.9	29.3	50.2	9.9	55.7	31.0	12.1	1.2	37.8	1.4
455.	48.4	3.6	70.3	14.5	26.4	35.2	36.8	1.6	3.4	0
456.	54.4	13.3	49.0	2.0	50.0	24.0	25.3	.8	3.1	0
457.	87.7	6.7	39.5	6.7	40.8	28.8	29.3	1.1	2.0	.3
458.	24.8	40.9	37.1	4.4	58.7	38.3	[illegible]	.1	2.7	0
459.	29.6	51.0	20.0	.5	57.3	35.1	7.5	.1	9.8	1.0
460.	26.1	48.2	34.1	2.5	46.4	26.4	25.2	2.0	7.2	.9
461.	36.2	26.4	7.3	0	57.7	27.3	14.8	.2	1.4	1.9
462.	27.6	2.4	3.8	3.0	56.3	37.6	3.4	.7	.9	1.9
463.	52.6	7.5	2.1	0	55.4	35.3	3.0	.3	2.1	1.3
464.	9.0	0	1.0	.7	31.8	37.6	20.4	10.2	25.6	0
466.	123.3	17.3	15.4	17.3	25.2	36.4	26.2	12.2	.9	0
467.	165.5	0	0	0	51.0	22.4	19.4	7.2	0	0
468.	79.9	26.5	23.2	17.7	14.5	25.6	34.3	25.5	8.4	0
469.	122.5	5.5	24.5	31.8	12.2	44.0	36.5	7.3	.6	0
470.	89.1	0	29.6	40.8	17.4	44.2	25.8	11.6	0	0
471.	120.5	2.6	29.9	16.9	10.6	51.6	34.4	3.4	.3	0
472.	137.8	21.0	24.2	6.5	21.8	34.6	23.6	14.0	1.9	0
473.	70.9	83.2	0	5.6	18.5	23.9	34.1	23.6	5.1	0
474.	56.7	1.6	3.8	12.2	25.9	37.4	35.6	1.1	53.5	1.2
475.	79.1	14.6	5.0	6.5	21.0	32.2	30.9	15.9	39.0	1.6
476.	26.0	66.7	3.8	0	49.3	38.9	8.8	3.0	0	0
480.	92.8	22.7	0	0	15.1	13.8	44.5	26.6	2.4	0
481.	101.0	5.4	15.2	5.4	21.0	34.5	26.0	18.5	5.0	0
482.	52.3	2.1	6.3	9.7	44.7	27.5	19.1	8.7	2.0	0
483.	56.2	0	34.1	9.1	65.3	24.6	7.7	2.4	5.2	0
484.	55.3	2.8	8.4	8.4	48.6	33.2	11.0	1.2	10.9	0
485.	91.1	6.4	4.7	16.3	14.3	40.6	39.8	5.3	10.4	1.3
486.	45.5	12.4	7.1	12.9	37.1	41.8	17.9	3.2	13.5	.6
487.	87.3	0	0	18.8	22.0	24.8	35.5	5.7	9.8	.3
488.	12.6	.9	1.9	1.5	39.0	42.2	14.9	.9	31.8	1.7
489.	17.4	0	2.6	7.2	35.0	49.2	14.8	1.0	38.9	0
490.	29.0	1.5	.8	0	44.2	38.8	13.8	1.2	21.0	-0
491.	33.0	7.3	2.1	11.5	64.1	29.8	5.8	.3	0	0
492.	67.7	5.2	1.8	4.4	48.7	24.7	23.6	3.0	.7	0
493.	50.5	3.1	0	0	64.1	13.7	21.0	1.2	0	0
494.	28.1	6.8	4.1	3.9	16.6	34.2	28.6	20.6	19.6	14.0
495.	34.3	1.4	1.4	11.7	27.6	45.6	25.5	1.3	18.4	7.4
501.	108.4	5.7	17.1	5.7	40.4	36.8	13.7	3.1	.7	0
502.	75.5	62.0	2.1	0	17.4	34.0	27.0	21.5	16.3	1.0
503.	143.0	31.1	0	0	28.5	24.8	30.5	16.2	1.0	0
504.	93.2	10.8	4.6	5.7	21.1	27.3	28.2	23.4	7.5	1.7
505.	90.3	63.3	0	2.5	38.3	20.6	28.7	12.4	4.3	3.8
506.	42.1	4.5	8.7	.8	66.3	22.1	9.3	2.3	2.4	1.2
507.	70.2	5.3	9.9	0	32.1	51.6	11.2	5.1	8.5	1.3
508.	48.4	3.3	2.5	7.5	19.7	44.3	22.5	13.5	50.0	6.2
509.	37.1	0	1.5	11.1	67.0	23.4	8.9	.7	1.5	0

510.	36.0	2.4	3.3	4.5	57.1	34.8	7.1	1.0	99.9	0
511.	108.0	17.1	0	8.5	17.6	20.5	39.6	22.3	2.9	0
512.	86.0	92.2	7.8	0	70.1	23.1	4.7	2.1	0	0
513.	80.3	62.9	3.8	0	68.7	17.9	10.5	2.9	5.7	.3
514.	103.9	53.6	5.4	0	19.5	34.8	35.1	10.6	.5	0
515.	147.7	21.2	0	0	29.7	35.9	31.9	3.5	.9	1.2
516.	165.8	0	0	0	39.3	15.0	34.0	11.7	.0	0
517.	111.6	6.3	0	26.6	28.4	13.3	44.5	13.8	0	0
518.	143.9	0	0	9.7	23.2	24.9	45.4	6.5	.7	0
519.	109.3	31.1	4.4	0	60.2	19.2	13.7	6.9	.9	0
520.	73.6	64.3	1.9	1.9	37.3	22.9	23.9	15.9	1.0	0
521.	84.9	57.4	2.2	0	35.3	24.2	23.8	10.7	5.3	0
522.	34.5	30.8	1.5	48.5	53.9	27.6	15.0	2.5	8.2	0
523.	48.0	71.7	0	0	39.1	18.0	21.5	21.4	9.9	0
524.	54.1	77.3	1.5	0	24.2	37.7	28.9	9.2	5.4	1.1
525.	52.9	71.1	2.5	0	36.0	20.5	24.5	19.0	2.9	0
526.	117.4	12.4	5.5	2.1	11.1	56.2	22.5	10.1	13.7	0
527.	92.5	33.7	3.3	6.1	15.8	35.2	27.4	21.6	10.8	0
533.	31.8	2.0	2.6	3.4	35.6	35.6	19.3	3.5	6.6	2.9
534.	29.4	5.1	3.1	4.2	26.8	31.8	24.6	16.8	2.9	7.0
535.	24.2	3.9	3.9	3.0	19.4	41.8	25.5	12.3	5.9	3.7
537.	22.0	3.4	1.7	4.5	52.1	26.3	13.5	3.1	6.[illegible]	15.4
538.	21.3	.8	4.7	61.9	42.1	41.1	15.1	.7	9[illegible].3	0
539.	28.4	13.4	10.0	19.8	45.1	29.8	22.2	2.9	13.6	7.7
540.	19.0	73.3	2.2	5.6	65.2	27.0	6.9	.9	29.5	3.5
541.	17.0	24.9	15.9	.5	69.8	20.2	9.6	.4	2.7	1.2
542.	34.2	35.0	13.0	4.1	53.0	27.6	18.8	.6	4.0	5.3
543.	38.1	4.4	13.6	39.3	39.4	22.8	35.8	2.0	21.1	0
544.	69.6	15.7	14.0	6.4	38.8	31.0	23.4	.8	5.4	.8
545.	37.7	9.2	13.6	8.3	54.2	35.5	9.9	.4	5.4	5.6
546.	63.1	37.3	21.5	0	44.7	28.0	26.4	.9	.3	0
547.	14.2	4.5	1.7	4.1	9.3	30.4	54.9	5.4	3.4	1.7
549.	44.8	2.0	2.0	44.4	29.9	41.7	22.0	6.4	81.6	1.1
550.	22.5	0	4.8	54.2	53.7	32.9	12.1	1.3	99.3	.2
551.	48.0	2.3	13.6	31.8	44.4	42.8	12.0	.8	97.7	0
552.	38.6	4.1	2.0	34.5	40.1	39.1	16.0	4.8	87.9	1.9
553.	133.1	0	7.1	7.1	4.1	35.7	47.0	13.2	3.4	0
554.	131.9	12.5	0	20.0	26.4	22.7	27.0	23.9	0	0
555.	146.3	0	6.6	19.7	30.1	23.4	27.6	18.9	1.4	0
556.	119.4	21.5	0	17.7	18.4	19.7	30.7	31.2	3.6	0
567.	24.6	5.3	3.2	1.9	62.6	18.2	18.4	.8	1.9	3.9

APPENDIX 3

Spearman rank correlation matrices and dendrograms for selected multiple till samples and surrounding till sheet samples.

The correlation is significant if the coefficient is greater than .497 at the 95% level of significance and with 14 degrees of freedom (Snedecor, 1966, p. 174).

	287	343	342	229	228	227	226	225	224	223	222
221	.706	.324	.758	.750	.729	.750	.824	.608	.825	.868	.850
222	.665	.464	.815	.834	.782	.738	.845	.655	.792	.899	
223	.636	.465	.750	.780	.682	.734	.712	.725	.796		
224	.653	.184	.680	.806	.805	.884	.614	.674			
225	.411	.183	.743	.602	.684	.724	.490				
226	.711	.494	.831	.750	.668	.589					
227	.465	.193	.696	.675	.790						
228	.662	.301	.778	.831							
229	.744	.347	.871								
342	.638	.322									
343	.415										

Table III-1. Correlation matrix for till samples from the Dartmouth-Enfield area.

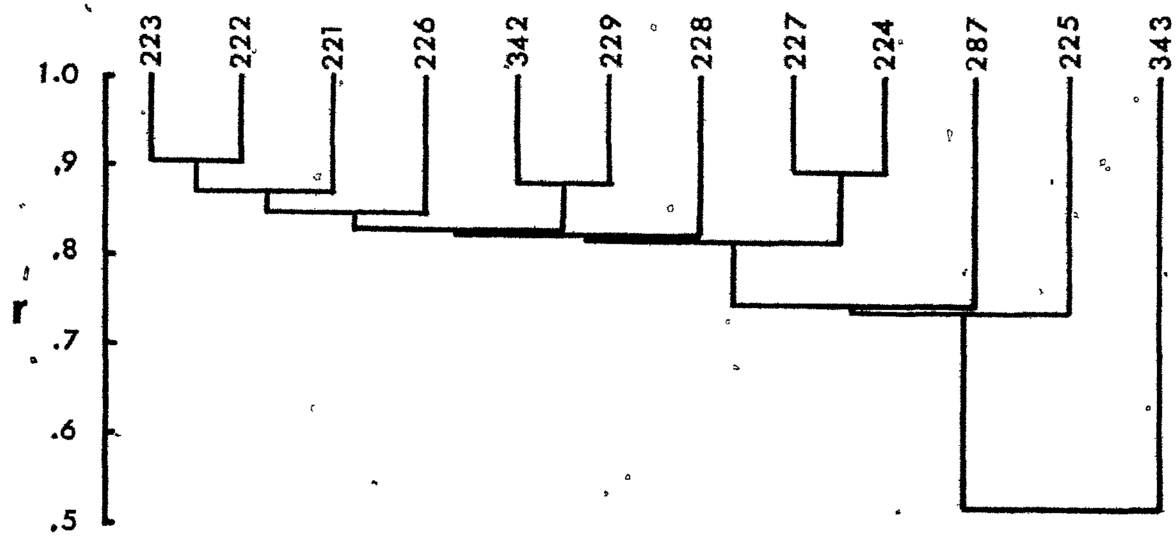
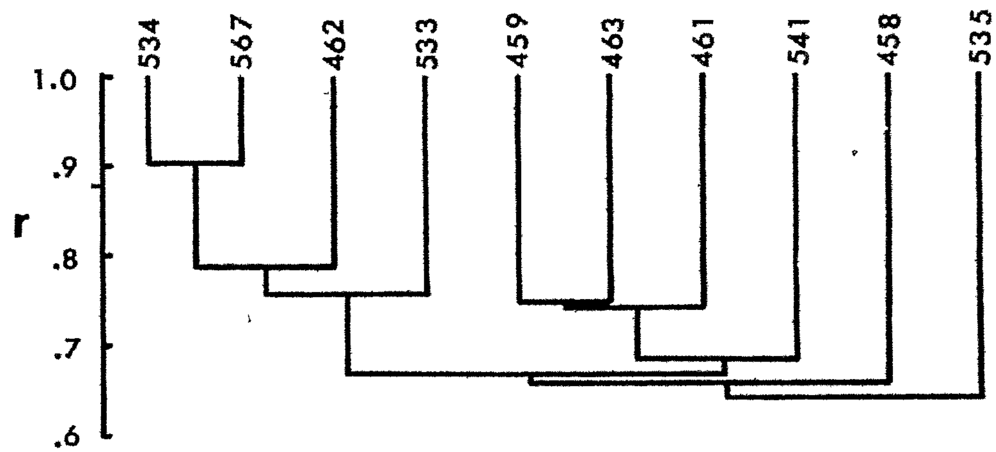


Figure III-1. Dendrogram constructed from the data in Table III-1.

Figure III-2. Dendrogram constructed from the data in Table III-2.



	541	459	458	463	462	461	535	534	533
567	.651	.631	.558	.672	.756	.593	.636	.902	.758
533	.497	.468	.559	.663	.498	.347	.482	.742	
534	.567	.553	.656	.605	.780	.532	.638		
535	.390	.528	.640	.305	.381	.422			
461	.587	.742	.480	.669	.613				
462	.453	.35	.271	.471					
463	.679	.745	.469						
458	.310	.66							
459	.556								

Table III-2. Correlation matrix for till samples from the Salmon River area.

Table III-3. Correlation matrix for till samples from the Joggins area.

	556	555	554	324	323	322
321	.204	.566	.229	.062	.600	.277
322	.264	.466	.389	.268	.518	
323	.631	.744	.577	.327		
324	.318	.085	.139			
554	.891	.628				
555	.561					

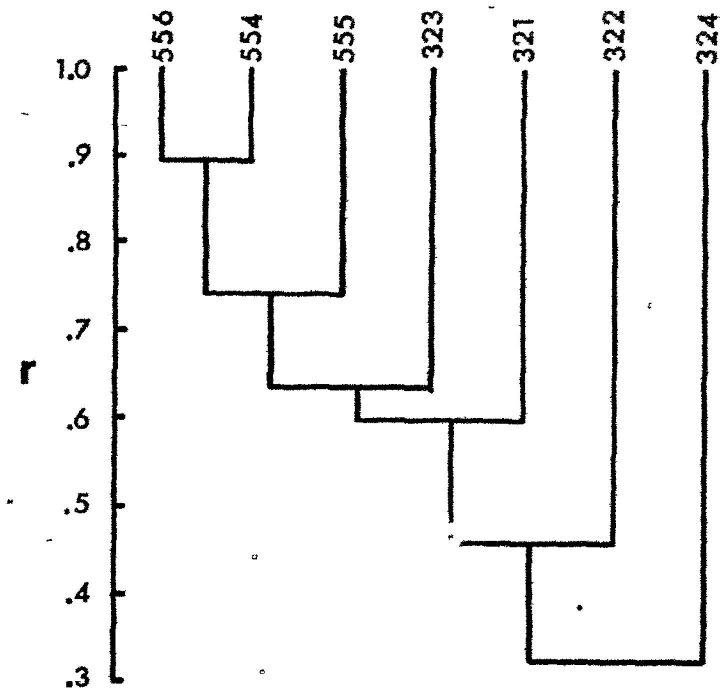


Figure III-3. Dendrogram constructed from the data in Table III-3.

Table III-4. Correlation matrix for till samples from the New Glasgow area.

	519	517	516	370	373	372
371	.833	.135	.629	.761	.412	.689
372	.678	.236	.156	.447	.713	
373	.696	.232	.033	.350		
370	.658	.081	.526			
516	.415	.247				
517	.335					

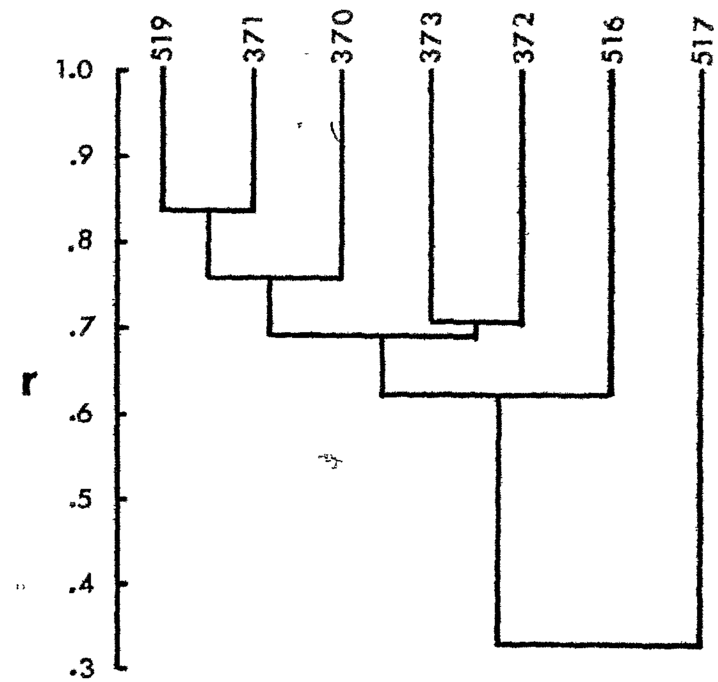


Figure III-4. Dendrogram constructed from the data in Table III-4.

Table III-5. Correlation matrix for till samples from the Chaplin area.

	525	441	440	439	438
437	.336	.696	.232	.033	.350
438	.374	.658	.081	.526	
439	.279	.415	.247		
440	.167	.335			
441	.469				

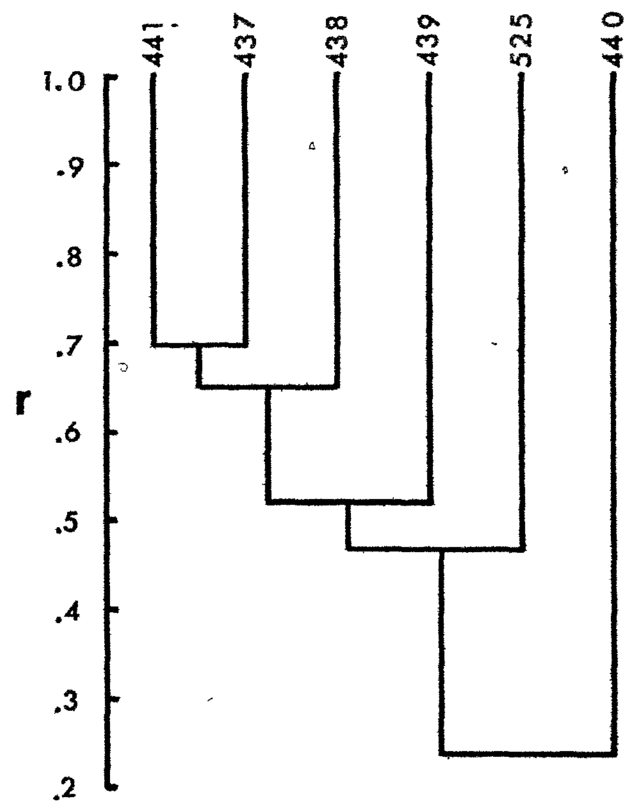


Figure III-5. Dendrogram constructed from the data in Table III-5.

Table III-6. Correlation matrix for till samples from the Bridgewater area.

	262	257	260	495
494	.676	.793	.761	.628
495	.804	.525	.813	
260	.784	.574		
267	.600			

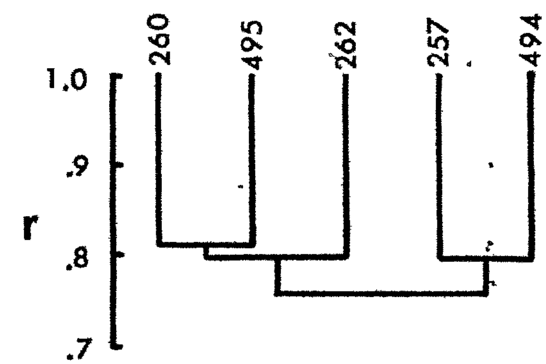


Figure III-6. Dendrogram constructed from the data in Table III-6.

Table III-7. Correlation matrix for till samples from the Whites Lake area.

	475	474	216	205	204	203	202
201	.798	.834	797	.857	.689	.874	.769
202	.771	.578	.794	.866	.742	.875	
203	.782	.668	.867	.873	.699		
204	.721	.686	.676	.696			
205	.784	.765	.870				
216	.630	.787					
424	.663						

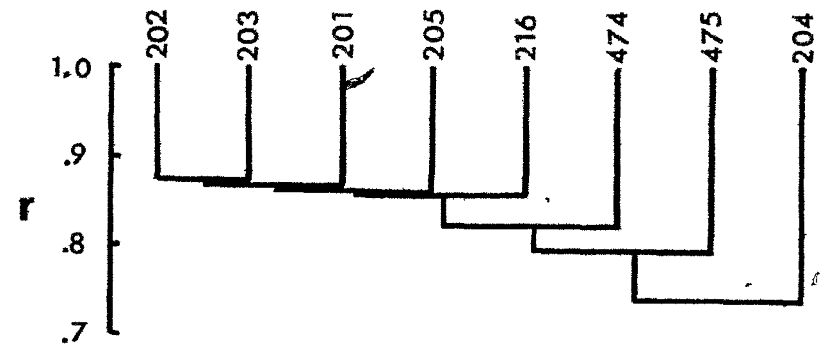


Figure III-7. Dendrogram constructed from the data in Table III-7.

Table III-8. Correlation matrix for till samples from Eagles Nest Point area.

	527	526	302	291	290	289
288	.768	.747	.426	.812	.569	.397
289	.500	.253	.561	.430	.436	
290	.822	.358	.733	.330		
291	.495	.571	.433			
302	.724	.428				
526	.752					

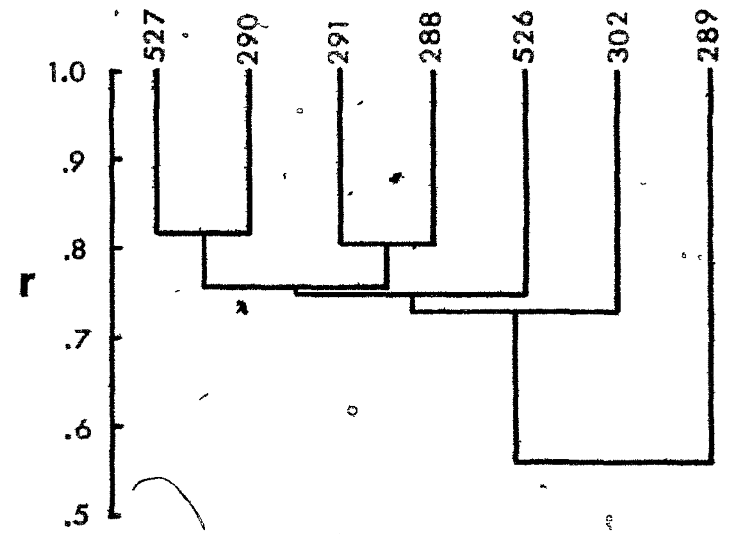


Figure III-8. Dendrogram constructed from the data in Table III-8.

	530	529	583	582	581	580	579	578	577	576	575	574	573	572
571	.725	.515	.689	.377	.806	.704	.681	.778	.816	.809	.888	.694	.690	.620
572	.597	.483	.742	.428	.854	.742	.790	.552	.615	.638	.665	.791	.802	
573	.759	.623	.708	.597	.809	.753	.750	.696	.751	.713	.760	.888		
574	.763	.514	.727	.427	.696	.754	.590	.800	.827	.755	.760			
575	.810	.474	.721	.311	.807	.781	.628	.872	.824	.899				
576	.892	.701	.860	.471	.796	.852	.600	.947	.933					
577	.891	.705	.896	.635	.732	.890	.652	.955						
578	.930	.641	.793	.465	.642	.809	.490							
579	.507	.510	.850	.746	.884	.834								
580	.762	.648	.950	.698	.834									
581	.683	.631	.852	.523										
582	.531	.672	.805											
583	.796	.748												
529	.793													

Table III-9. Correlation matrix for till samples from Sandwich Point, Hartlen Point, and Cole Harbour. Figure 34 shows the corresponding dendrogram.

APPENDIX 4

- List of the drumlin and non-drumlin samples overlying the Meguma Group east of Halifax.
- List of the drumlin and non-drumlin samples overlying the Meguma Group in the area of the Lunenburg drumlin field.
- Result of point counts of heavy minerals on duplicate samples of red clay till and grey till from Hartlen Point, Cole Harbour and Sandwich Point.
- Result of point counts of heavy minerals on till samples. Nonopaques have been recalculated to 100%. The last 14 point counts are duplicates of 7 samples.

Samples overlying Meguma bedrock in the area of the Lunenburg drumlin field.

Red clay drumlin samples

258

259

494

495

Slate drumlin samples

243

244

247

262

487

488

Granite drumlin samples

489

Non drumlin samples

209	483
210	484
211	485
257	486
260	490
261	491
265	492
482	493

Samples overlying Meguma bedrock east of Halifax

Drumlin Samples	Non Drumlin Samples
212	241
214	293
219	294
220	296
239	347
240	348
295	349
297	350
298	351
299	355
352	358
353	359
354(?)	360
357	361
	362
	363

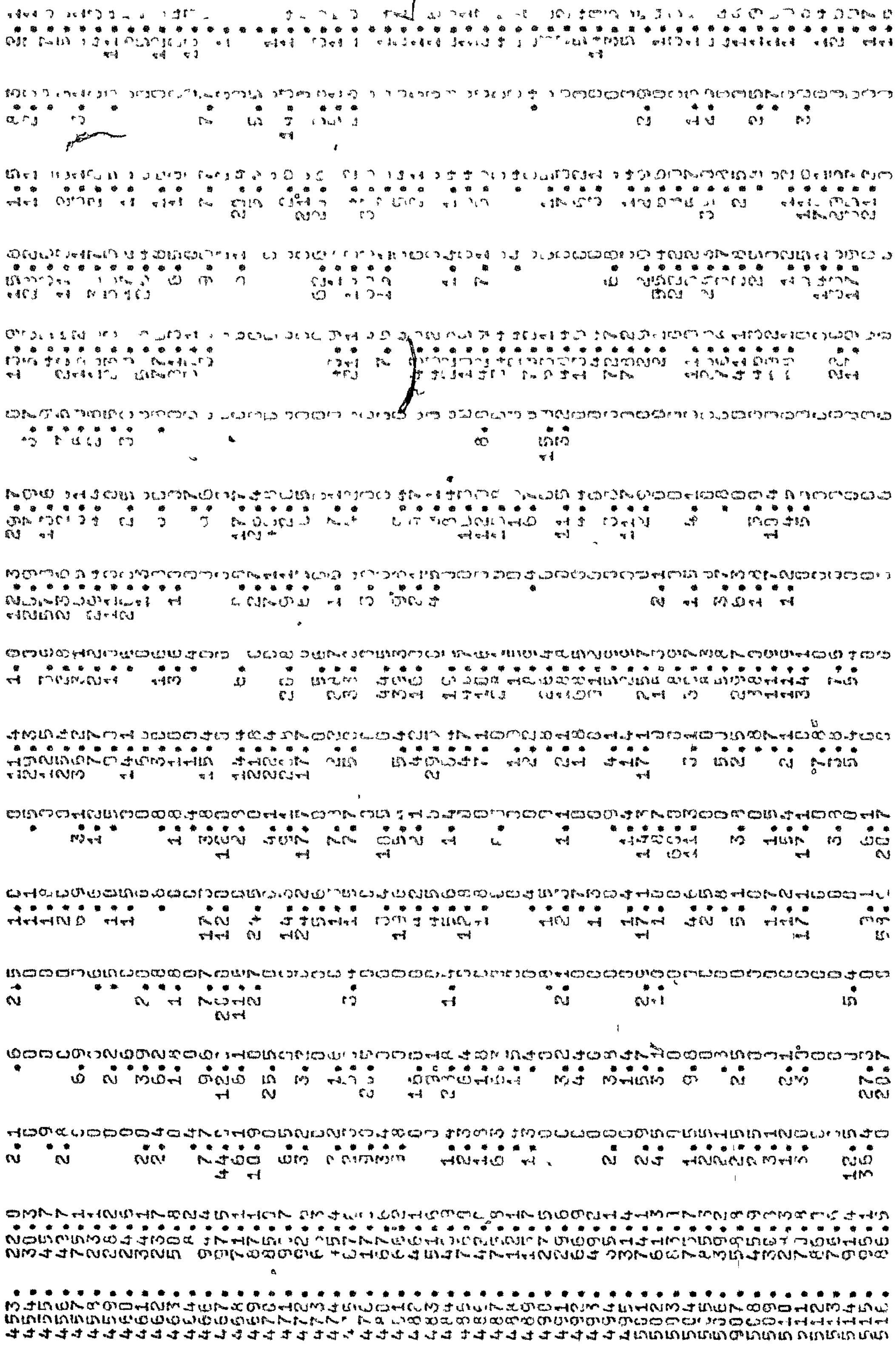
Sample No.	Opaques	Zircon	Rutile	Sphene	Tourmaline	Anatase	Almandine	Spessartine	Staurolite	Andalusite	Sillimanite	Augite	Amphibole	Epidote	Apatite	% Heavy Minerals
571	70	8			12			32				24	12	12		2.0
572	75		6			12	5	6				42	18	12		2.9
573	62	3	6			8	12	20		9		14	12	11		3.1
574	67				4	11	4	11		11		30	19	11		3.2
575	76	6			12	6	5	36				10	18	6		3.1
576	53	6	3		16	13		28		3		9	16	6		2.7
577	57	2	2		17	5		24		9		7	24	10		2.5
578	58	3			14	14		31		7		3	17	10		2.6
579	68		23		4		7	17				10	23	17		3.7
580	62		12		17	9	3	15		3		6	21	15		3.7
581	73	4	14		10	5	5	14				20	14	14		4.3
582	38		42		3		3	16		16			10	10		3.3
583	41	2	20		7	5	2	21		5		5	25	9		3.6
529	47	3	19		7	9		25		12		6		19		2.6
530	48	9	3		8	11	3	23		9		6	9	20		3.9

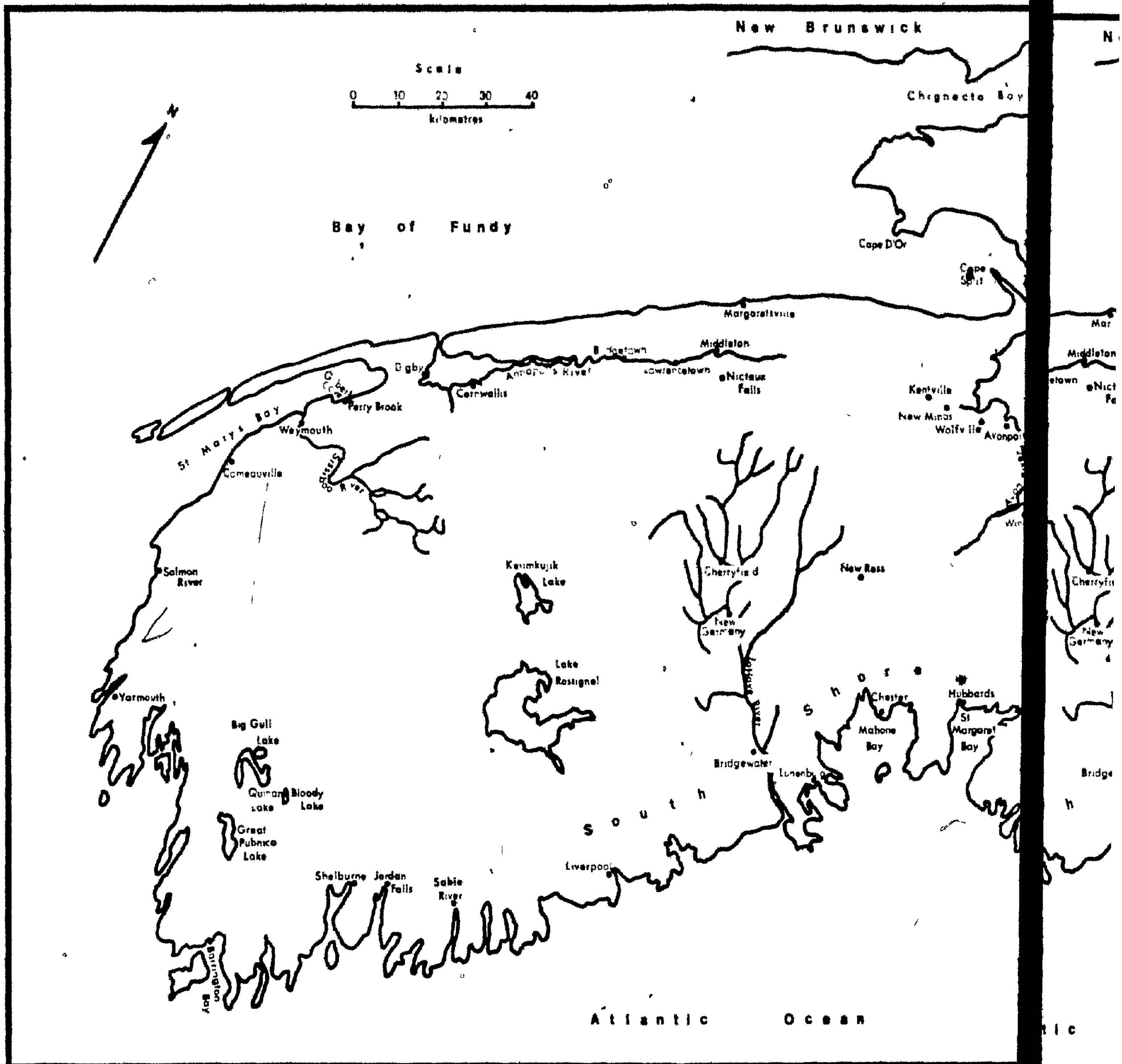
SAMPLE NO.	Opaques	Zircon	Rutile	Sphene	Tourmaline	Anatase	Almandine Garnet	Spessartine Garnet	Staurolite	Andalusite	Sillimanite	Augite	Amphibole	Epidote	Apatite	% Heavy minerals
201.	53.4	1.6	3.3	0	0	8.2	4.9	16.0	1.6	16.0	1.6	23.7	[illegible]	[illegible]	[illegible]	[illegible]
202.	58.6	2.3	4.6	0	5.9	3.4	3.4	22.6	2.3	7.3	0	17.6	[illegible]	[illegible]	[illegible]	[illegible]
203.	49.1	0	1.9	1.0	3.8	3.8	3.8	13.5	0	23.1	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
204.	65.4	0	4.1	0	4.1	2.0	8.1	23.4	2.0	13.7	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
205.	51.5	5.2	3.3	1.9	3.3	3.8	5.2	15.0	1.9	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
208.	17.9	13.8	0	0	0	0	0	0	0	4.8	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
209.	11.8	.8	0	0	1.6	0	1.6	58.5	0	3.2	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
210.	31.5	1.3	0	0	.6	0	2.6	47.3	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
211.	17.8	0	0	0	1.3	0	3.7	45.2	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
212.	63.9	1.5	8.6	0	7.6	11.6	1.5	31.8	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
214.	68.1	1.5	8.4	3.0	0	6.4	0	33.0	0	.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
216.	31.5	2.6	2.6	0	4.8	3.7	6.3	11.0	1.4	19.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
916.	36.7	4.5	34.3	0	4.5	0	0	23.7	0	6.6	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
217.	10.3	0	7.7	0	20.1	0	23.1	2.0	0	46.2	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
218.	59.2	0	4.4	0	6.6	0	4.4	12.6	6.6	14.8	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
219.	70.8	3.0	0	0	1.5	1.5	1.5	30.2	6.4	5.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
220.	58.7	4.6	8.1	2.5	7.7	7.7	1.1	21.5	0	3.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
221.	75.0	1.7	1.7	0	6.9	3.4	6.9	27.0	1.7	5.2	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
222.	57.9	4.2	7.0	0	14.0	8.4	2.8	13.7	4.2	1.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
223.	61.5	6.0	3.0	0	11.9	11.5	3.0	17.4	0	6.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
224.	44.3	2.4	0	0	21.3	2.4	0	23.6	2.4	7.3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
225.	59.7	8.4	5.6	2.8	18.9	0	0	15.1	0	13.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
226.	69.8	0	12.2	0	5.1	3.1	3.6	30.6	1.5	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
227.	52.9	1.8	1.8	1.8	5.5	1.8	0	5.5	1.8	21.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
228.	50.2	5.7	1.6	2.8	7.3	1.6	1.6	24.4	2.8	1.6	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
229.	75.8	5.7	1.6	0	5.7	4.1	0	24.4	1.6	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
230.	32.2	1.6	3.1	1.6	1.6	3.1	2.4	29.3	0	29.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
231.	15.7	.7	2.6	0	.7	7.1	10.8	13.0	0	21.2	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
232.	8.0	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
237.	22.8	0	0	0	1.1	.4	3.8	5.4	0	.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
238.	11.3	0	0	0	0	0	0	.5	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
239.	69.3	2.3	4.6	2.3	4.6	2.3	0	21.7	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
240.	63.3	0	3.1	0	3.1	1.0	3.1	22.9	4.1	6.1	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
241.	55.5	2.2	0	0	0	5.9	5.9	58.6	0	2.2	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
243.	37.2	.6	.6	0	.6	0	2.8	7.2	0	1.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
244.	49.9	3.3	0	1.1	1.1	0	4.4	17.8	1.1	12.6	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
247.	20.4	1.0	0	1.0	4.4	0	4.6	7.2	1.0	1.8	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
249.	8.7	0	0	.8	0	0	2.7	1.2	0	1.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
250.	19.5	.4	0	0	0	0	1.1	1.1	0	1.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
251.	11.7	.4	.4	0	1.0	.4	2.2	2.2	.6	.6	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
252.	50.3	0	3.4	0	3.1	5.9	3.9	[illegible]	0	2.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
253.	12.2	0	0	0	.3	0	0	1.0	.7	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
257.	56.6	2.8	0	0	0	0	1.4	14.6	0	0	0	73.8	1.4	[illegible]	[illegible]	[illegible]

259.	47.9	2.8	2.8	0	5.3	4.1	11.0	8.1	2.8	0	0	61.8	1.2	0	0	0.8
260.	47.7	1.3	9.8	0	2.6	1.3	2.3	9.8	0	2.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
261.	33.4	0	0	0	1.2	2.4	7.5	5.2	1.2	13.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
262.	31.3	.7	.7	0	2.3	0	3.7	3.2	0	5.8	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
264.	29.0	2.1	3.3	0	1.6	0	0	[illegible]	0	5.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
265.	62.7	1.9	1.9	0	3.3	1.9	3.1	22.6	3.1	9.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
266.	52.8	2.8	.8	0	2.8	0	41.2	23.2	10.4	1.7	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
267.	50.5	0	0	0	13.1	0	14.8	19.3	4.3	15.7	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
268.	29.8	0	.5	0	1.8	0	26.1	.5	42.4	23.2	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
269.	33.6	.6	0	.6	1.7	0	30.5	0	58.7	6.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
270.	17.1	.9	.9	.4	.9	.4	2.2	31.5	.4	16.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
271.	30.2	.7	1.2	.7	.7	.7	0	6.5	1.2	.2	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
272.	44.[illegible]	1.8	0	.8	2.6	0	2.5	8.5	.8	17.2	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
273.	25.2	1.9	2.4	1.0	.5	2.0	0	11.0	0	16.7	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
274.	21.[illegible]	.5	.2	0	2.8	3.3	.5	0.6	.5	6.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
275.	53.4	7.6	4.5	1.4	3.1	7.6	1.4	39.6	0	5.3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
276.	43.[illegible]	1.8	1.0	0	1.0	3.3	1.0	35.8	1.[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
277.	70.1	4.9	1.9	0	4.1	1.9	6.0	11.4	1.[illegible]	.9	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
278.	32.0	1.4	.6	0	.6	.6	0	35.1	1.4	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
280.	66.4	5.4	17.3	0	2.9	1.3	6.4	86.7	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
283.	41.[illegible]	.7	7.7	0	2.2	0	4.4	7.7	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
284.	59.7	1.4	1.4	1.4	3.2	4.6	0	[illegible]	0	1.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
285.	64.[illegible]	4.4	8.3	0	0	0	1.4	11.9	1.4	1.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
286.	59.4	2.6	3.3	0	4.9	5.3	1.1	9.0	1.1	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
287.	67.9	4.8	1.5	0	10.6	3.0	7.8	20.4	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
288.	42.0	2.6	.9	0	9.5	6.7	1.7	52.5	.9	7.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
289.	74.9	0	2.2	0	7.5	8.7	8.7	0	2.2	13.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
290.	45.0	2.4	0	0	0	4.4	0	14.7	0	2.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
291.	75.3	2.4	0	2.4	10.6	6.6	4.2	22.6	16.6	10.8	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
292.	31.8	5.7	11.4	2.5	8.6	8.6	2.2	17.1	13.6	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
293.	67.4	5.3	7.0	1.3	19.6	5.3	1.8	8.8	1.0	1.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
294.	56.4	11.4	0	0	0	0	0	0	0	52.3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
295.	52.6	9.3	0	0	11.0	0	5.5	5.5	0	3.8	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
296.	66.5	10.0	10.0	0	10.0	0	10.0	15.7	0	.3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
298.	64.7	6.4	21.6	0	0	0	6.4	6.4	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
299.	53.1	5.7	19.0	0	9.2	1.7	4.0	7.5	1.7	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
301.	61.0	0	1.6	1.6	3.6	4.8	3.2	19.2	0	5.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
302.	75.2	0	0	0	3.4	5.1	1.7	17.7	5.1	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
304.	71.9	6.4	0	0	0	20.0	0	33.6	0	13.6	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
305.	79.4	7.7	7.7	0	21.5	4.6	0	7.7	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
306.	7.4	0	0	2.5	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
307.	63.3	1.6	0	0	3.7	3.7	0	7.3	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
308.	35.5	1.8	0	0	3.5	0	0	1.8	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
309.	78.6	3.0	0	0	9.0	8.0	8.0	4.0	0	48.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
310.	43.3	2.2	1.1	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
311.	63.9	0	2.1	0	3.7	3.7	2.1	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
312.	26.5	0	3.3	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
313.	100.0	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
314.	81.3	2.2	3.6	0	2.2	17.5	2.2	25.5	2.0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
315.	55.7	2.2	8.3	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
316.	73.9	4.4	58.8	0	4.4	0	0	2.2	0	2.2	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
317.	32.0	.9	.5	0	0	0	0	.5	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
318.	18.7	7.5	.4	.4	0	0	0	0	0	1.1	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
319.	84.9	0	0	2.6	0	0	0	0	2.6	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
320.	75.4	14.3	8.7	0	42.1	8.7	11.1	0	3.2	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

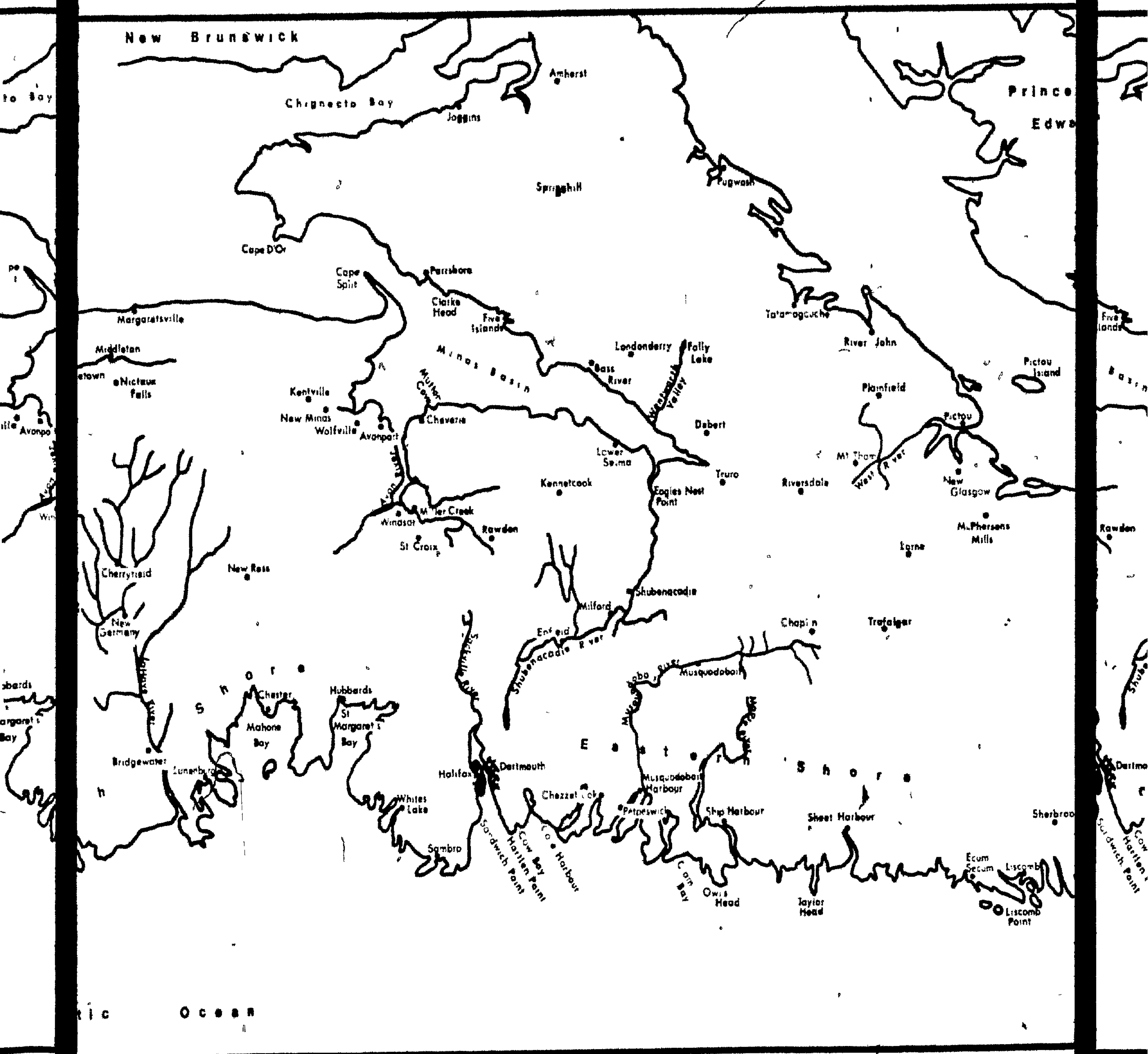
321.	85.3	5.3	5.3	7.9	10.5	13.5	7.9	2.6	12.3	12.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
322.	83.3	2.2	11.3	0	11.2	11.2	30.6	6.7	4.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
323.	81.3	14.0	4.9	1.4	18.2	6.3	3.1	0	6.0	15.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
324.	87.8	11.4	0	11.4	0	0	11.4	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
325.	81.9	10.0	10.0	10.0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
328.	51.4	3.6	0	0	3.6	5.4	0	1.8	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
329.	70.5	17.3	3.8	0	25.0	9.6	15.4	1.9	0	11.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
330.	73.3	9.6	2.5	0	5.2	2.6	3.9	6.5	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
331.	79.6	6.8	6.3	6.8	20.5	6.8	6.9	31.8	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
332.	64.4	4.3	4.0	0	0	5.8	0	14.1	1.4	1.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
333.	35.5	0	0	1.1	1.1	1.1	5.8	8.6	0	51.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
334.	36.4	3.9	3.3	1.7	0	7.9	5.6	13.5	0	27.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
335.	17.1	5.6	3.2	1.5	11.9	11.3	0	14.3	0	22.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
337.	26.0	5.2	7.2	0	1.6	3.6	8.8	7.2	1.6	38.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
338.	44.9	0	65.3	0	5.9	0	3.5	[illegible]	0	35.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
339.	15.8	1.4	2.6	2.1	1.4	.7	3.3	56.3	0	15.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
340.	31.2	3.4	0	2.2	5.8	18.0	9.4	20.8	0	18.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
341.	[illegible]	1.8	1.8	1.8	3.7	0	1.8	37.4	1.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
342.	[illegible]	5.4	7.0	0	5.4	0	0	24.8	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
343.	53.7	0	.3	.8	3.6	3.6	55.2	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
344.	54.4	1.6	4.3	0	4.9	11.5	0.3	65.4	1.6	1.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
345.	67.7	1.1	2.3	1.1	4.5	3.4	1.1	47.7	2.3	9.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
346.	61.5	1.9	0	1.0	1.0	1.9	3.8	28.7	0	4.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
347.	32.5	2.2	11.1	0	3.1	3.1	0	59.3	0	.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
348.	42.5	6.5	0	0	4.2	0	6.5	32.6	8.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
349.	34.3	3.8	.3	2.4	3.5	0	8.5	30.4	0.3	23.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
350.	23.2	.6	2.3	0	6.0	0	5.3	34.2	6.8	8.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
351.	31.4	1.4	2.5	2.5	2.8	0	23.6	3.3	0	9.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
352.	52.4	0	0	2.1	4.3	8.5	10.6	5.4	8.5	2.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
353.	55.5	0	3.3	0	4.3	1.5	14.6	6.5	3.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
354.	60.6	2.4	12.2	0	4.3	6.3	5.9	2.4	7.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
355.	55.1	5.9	19.3	8.1	6.7	8.1	12.7	[illegible]	8.1	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
357.	74.6	0	7.3	2.4	2.4	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
358.	28.7	4.8	0	19.4	0	0	1.5	11.2	4.8	8.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
359.	41.3	4.2	0	22.3	8.5	0	13.5	4.5	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
360.	52.9	4.0	1.5	1.5	5.1	1.5	27.5	6.5	10.2	2.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
361.	71.9	7.2	5.2	0	7.6	2.2	45.1	7.2	14.7	5.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
362.	47.5	0	1.6	0	1.6	2.7	45.6	15.0	25.3	3.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
363.	56.4	2.7	0	0	2.3	0	2.8	1.1	1.6	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
364.	62.2	2.8	4.5	0	4.5	0	0	5.7	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
365.	60.8	1.9	1.9	0	1.9	1.9	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
366.	69.7	0	0	2.1	4.2	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
367.	54.5	1.1	2.1	1.1	1.1	1.1	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
368.	58.8	0	0	0	0	0	2.2	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
369.	83.7	0	0	0	8.6	21.5	0	17.2	0	4.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
370.	90.8	14.3	14.3	0	0	28.6	0	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
371.	90.3	0	14.3	0	6.1	38.8	0	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
372.	89.4	0	0	0	0	0	0	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
374.	73.7	2.8	16.3	5.7	8.5	0	2.8	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
375.	71.9	8.4	4.2	0	2.1	0	0	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
376.	47.2	1.3	7.0	1.3	0	4.0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
377.	51.3	0	9.2	3.7	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
378.	81.1	17.0	7.7	0	7.7	24.4	3.6	24.4	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
379.	9.5	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
380.	10.1	0	0	0	0	0	0	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

381.	4.3	0	0	0	0	0	0	0	0	0	0	130.0	0	[illegible]	0	30.0
385.	13.6	0	0	0	.6	0	.4	1.2	0	.4	0	[illegible]	.4	[illegible]	[illegible]	[illegible]
386.	30.7	.5	.5	0	.9	0	1.4	9.8	.5	2.0	0	[illegible]	.5	[illegible]	[illegible]	[illegible]
387.	44.4	0	0	.7	0	0	0	0	0	15.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
392.	43.1	.7	.7	0	0	3.7	1.5	15.1	0	6.7	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
396.	22.6	.3	0	0	.6	.3	1.2	2.8	.3	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
397.	0	0	0	0	0	0	7.1	0	0	21.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
398.	44.6	.8	.8	.8	.8	9.1	2.5	22.4	5.1	.8	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
399.	41.3	1.3	0	0	2.9	1.6	5.8	7.4	7.4	13.6	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
400.	47.1	3.6	1.2	1.2	3.3	3.6	6.6	12.8	1.2	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
401.	35.3	2.0	1.4	0	3.4	2.2	3.4	12.2	.7	3.4	.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
402.	13.7	22.8	0	0	0	0	6.9	2.1	0	15.9	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
403.	33.3	13.0	0	0	8.7	0	39.1	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
404.	29.7	.8	.5	0	1.0	1.0	1.3	11.2	.3	.3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
405.	33.5	1.9	1.3	0	3.7	1.9	3.0	12.8	1.3	4.3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
406.	26.3	.8	.3	0	.8	0	.3	4.0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
407.	18.8	.4	.4	0	0	0	2.1	4.2	.4	.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
408.	68.5	3.1	0	3.1	15.6	12.6	3.1	46.9	0	6.1	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
409.	32.6	0	0	0	.5	.5	.5	8.7	0	4.7	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
410.	35.3	1.1	.5	0	0	0	.0	8.7	.5	1.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
411.	15.7	0	0	0	1.2	0	.6	3.1	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
413.	67.8	6.4	1.7	0	5.2	0	1.7	30.0	3.4	3.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
414.	47.4	1.7	.7	0	3.4	0	3.2	22.4	1.9	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
415.	50.8	.7	0	0	1.4	0	1.4	13.2	1.8	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
416.	49.2	2.7	2.7	0	0	0	.9	13.0	0	.8	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
417.	83.3	0	0	0	4.7	0	0	58.1	0	14.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
419.	21.0	0	0	0	0	0	0	2.6	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
421.	2.4	0	0	0	0	0	0	.2	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
422.	14.3	1.4	.6	0	0	0	.6	3.0	0	1.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
423.	8.9	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
425.	14.1	3.9	0	0	0	0	1.6	1.6	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
426.	8.3	0	0	0	0	0	.7	.0	0	.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
427.	0	4.6	0	0	4.6	0	0	0	0	34.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
428.	20.3	.8	.3	0	0	0	1.4	1.4	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
429.	11.3	2.8	0	0	7.1	0	1.9	0	0	5.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
430.	67.9	8.4	0	0	1.9	0	14.3	8.4	0	1.9	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
431.	59.2	2.1	2.1	0	3.2	0	1.1	39.6	3.2	1.1	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
432.	44.7	2.5	3.2	0	.9	3.0	3.4	15.6	1.6	1.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
433.	48.0	2.0	4.2	1.0	10.3	1.0	2.0	15.2	2.0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
434.	50.0	0	64.7	0	0	0	0	0	0	35.3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
437.	62.2	0	25.7	0	0	0	0	57.1	5.7	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
438.	41.5	3.5	7.7	0	0	0	0	81.7	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
439.	55.3	4.5	0	0	4.5	0	4.5	51.2	0	11.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
440.	4.5	0	0	1.6	0	0	43.8	14.1	0	12.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
441.	71.6	5.7	9.0	2.6	3.8	0	2.9	37.5	0	2.3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
442.	26.4	0	0	0	14.1	0	32.8	3.1	0	14.1	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
443.	77.6	0	0	3.2	5.6	16.9	0	45.2	11.3	8.9	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
444.	74.8	4.8	2.1	2.1	2.1	18.5	9.5	47.1	4.8	4.8	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
445.	72.6	11.7	0	0	13.7	23.3	3.2	22.3	0	5.9	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
446.	89.3	2.9	0	0	5.7	2.3	8.6	34.3	2.9	11.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
448.	66.2	2.4	4.3	0	.5	0	6.7	35.8	2.4	35.5	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
449.	15.3	.6	0	0	1.2	.5	26.2	.5	12.2	43.5	4.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
450.	9.5	.5	0	0	1.2	1.7	21.4	0	6.7	19.5	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
451.	27.2	0	0	0	0	0	34.3	0	0	5.4	51.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
452.	13.3	2.1	0	0	0	0	16.0	0	26.1	17.4	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

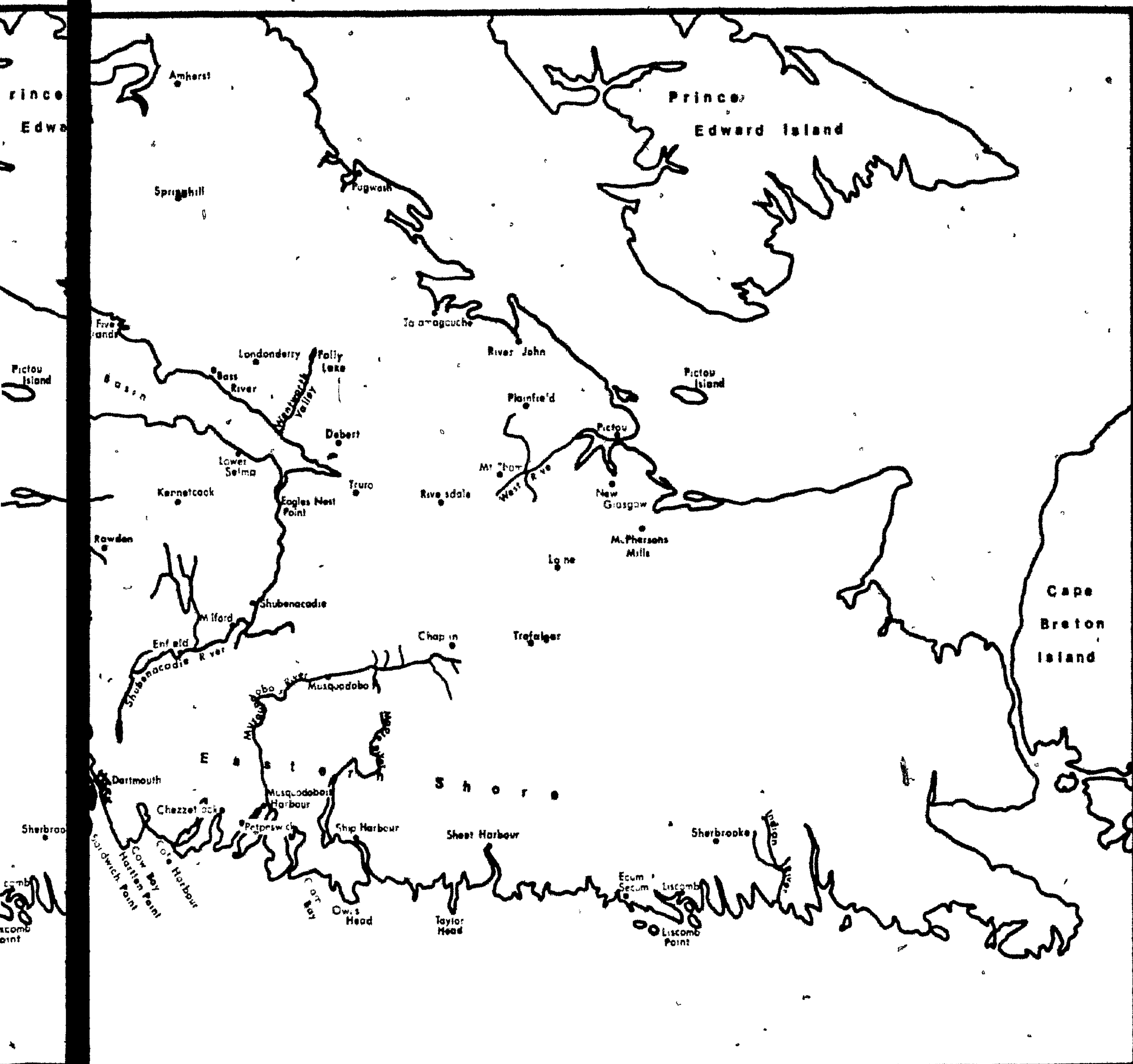



New Brunswick
Scale
0 10 20 30 40
kilometres
N
Chignecto Bay
Bay of Fundy
Cape D'Or
Cape Split
Margaretsville
Middleton
Bridgetown
Lawrencetown
Nictaux Falls
Annapolis River
Digby
Cornwallis
Bear River
Weymouth
St Marys Bay
Comeauville
Sissiboo River
Kentville
New Minas
Wolfville
Avonport
Salmon River
Kejimkujik Lake
Cherryfield
New Ross
New Germany
Lake Rossignol
Yarmouth
Big Gull Lake
Quinan Lake
Bloody Lake
Great Pubnico Lake
Chester
Hubbards
Mahone Bay
St Margaret Bay
Bridgewater
Lunenburg
LaHave River
South Shore
Liverpool
Shelburne
Jordan Falls
Sable River
Barrington Bay
Atlantic Ocean

1 OF


New Brunswick
Chignecto Bay
Joggins
Amherst
Springhill
Pugwash
Prince
Edwa
Cape D'Or
Cape Split
Parrsboro
Clarke Head
Five Islands
Margaretsville
Middleton
Nictaux Falls
Minas Basin
Kentville
New Minas
Wolfville
Avonport
Cheverie
Avon River
Windsor
St Croix
Rawdon
Londonderry
Folly Lake
Bass River
Wentworth Valley
Debert
Lower Selma
Truro
Kennetcook
Eagles Nest Point
Tatamagouche
River John
Pictou Island
Plainfield
Pictou
West River
New Glasgow
Riversdale
McPhersons Mills
Earltown
Cherryfield
New Germany
New Ross
Shubenacadie
Milford
Enfield
Shubenacadie River
Chapin
Trafalgar
Musquodoboit
Musquodoboit Harbour
Chester
Mahone Bay
Hubbards
St Margaret's Bay
Bridgewater
Lunenburg
Halifax
Dartmouth
Whites Lake
Sambro
Sandwich Point
Cow Bay
Hartlen Point
Cole Harbour
Chezzetcook
Petpeswick
Ship Harbour
Sheet Harbour
Owls Head
Taylor Head
Ecum Secum
Liscomb
Liscomb Point
Sherbrooke
Eastern Shore
South Shore
Ocean

2 OF


Amherst
Springhill
Pugwash
Prince
Edward Island
Five Islands
Londonderry
Folly Lake
Bass River
Wentworth Valley
Basin
Pictou Island
Debert
Lower Selma
Truro
Kennetcook
Eagles Nest Point
Rawdon
Shubenacadie
Milford
Enfield
Shubenacadie River
Musquodoboit River
Musquodoboit
River John
Plainfield
Pictou
West River
New Glasgow
McPhersons Mills
Riversdale
Trafalgar
Chaplin
Cape Breton Island
Dartmouth
Musquodoboit Harbour
Ship Harbour
Sheet Harbour
Sherbrooke
Cow Bay
Hartlen Point
Sandwich Point
Owls Head
Taylor Head
Ecum Secum
Liscomb
Liscomb Point
Shore

3 oF 3