AN APPLICATION OF PLEISTOCENE GEOLOGY TO MINERAL EXPLORATION IN SOUTH-WESTERN NOVA SCOTIA

by

Paul E. Sinclair

B.Sc. Thesis

Dalhousie University

1978

C O N F I D E N T I A L I T Y

DEPARTMENT OF GEOLOGY
DALHOUSIE UNIVERSITY
HALIFAX, NOVA SCOTIA
CANADA
B3H 4J1

DALHOUSIE UNIVERSITY, DEPARTMENT OF GEOLOGY

B.Sc. HONOURS THESIS

Author: Paul E. Sinclair

Title: An Application of Pleistocene Geology to Mineral Exploration in Southwestern Nova Scotia

Signature of author

Date: March 15, 1978

Distribution License

DalSpace requires agreement to this non-exclusive distribution license before your item can appear on DalSpace.

NON-EXCLUSIVE DISTRIBUTION LICENSE

You (the author(s) or copyright owner) grant to Dalhousie University the non-exclusive right to reproduce and distribute your submission worldwide in any medium.

You agree that Dalhousie University may, without changing the content, reformat the submission for the purpose of preservation.

You also agree that Dalhousie University may keep more than one copy of this submission for purposes of security, back-up and preservation.

You agree that the submission is your original work, and that you have the right to grant the rights contained in this license. You also agree that your submission does not, to the best of your knowledge, infringe upon anyone's copyright.

If the submission contains material for which you do not hold copyright, you agree that you have obtained the unrestricted permission of the copyright owner to grant Dalhousie University the rights required by this license, and that such third-party owned material is clearly identified and acknowledged within the text or content of the submission.

If the submission is based upon work that has been sponsored or supported by an agency or organization other than Dalhousie University, you assert that you have fulfilled any right of review or other obligations required by such contract or agreement.

Dalhousie University will clearly identify your name(s) as the author(s) or owner(s) of the submission, and will not make any alteration to the content of the files that you have submitted.

If you have questions regarding this license please contact the repository manager at dalspace@dal.ca.

Grant the distribution license by signing and dating below.

______________________________ ______________________________

Name of signatory Date

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF APPENDICES

ABSTRACT

An esker complex near Yarmouth, Nova Scotia has been investigated to determine the mode of origin of the eskers and to evaluate their usage in mineral exploration. Field work involved describing sections through eskers, boulder counts, collecting esker materials, and geochemical sampling. Lab work involved grain size analysis, heavy mineral identification and geochemical analysis.

Stratigraphic units of glaciofluvial material within the eskers range from well sorted sandy units to poorly sorted units containing clay to boulder size material. The eskers appear to have formed in subglacial tunnels and are composed of a series of nodes or beads of massive material connected by a topographically lower ridge of relatively well sorted material.

Most esker material is derived from local bedrock and the presence of mineralized clasts in eskers may be used to define regions of interest for mineral exploration. Geochemical sampling for elements of As, Zn, Cu and Pb in the hydromorphic dispersal zone of eskers appears to indicate the abundance of mineralized clasts present. This type of geochemical sampling may be useful in areas where exposure of esker material is masked by a cover of vegetation.

ACKNOWLEDGEMENTS

I wish to thank my supervisor, Dr. Marcos Zentilli for his expert advice and guidance which made this thesis possible.

Special thanks to Dr. D. J. W. Piper, Dr. H. B. S. Cooke, and Dr. W. B. Ervine whose suggestions regarding this thesis are highly appreciated.

I also wish to thank Shell Canada Resources Ltd. for permission to use this topic as a thesis, and for the financial assistance in collecting data. I am indebted to Gordon Dickie for his suggestion of this thesis topic and invaluable assistance in organizing the project. The writer wishes to thank Terry Warner for his able assistance in collecting field data.

Special thanks to Dianne Crouse for typing the final draft of this thesis.

CHAPTER I

INTRODUCTION

General Statement

Mineral developments in Southwestern Nova Scotia were triggered by the discovery of mineralized boulders in glacial deposits in 1975. This thesis attempts to evaluate the potential of the detailed study of eskers in mineral exploration using examples from the above area.

Regional prospecting for mineralization in some parts of the study area is hampered by the presence of salt marshes and swamps. Preserved esker material is often the only prospecting medium available which has not been disturbed by post depositional processes.

Location of Study Area and Accessibility

The study area (Figures 1-3) lies between latitudes 43°50'N and 43°41'N and longitudes 66°05'W and 65°58'W. It includes Pinkney's Point and those areas east of the Tusket River.

As this study involves the transport of glacial materials, regions to north ('up-ice') of the outlined area must be discussed. This larger district (Figure 2) will be referred to as the 'study region', while the specific area of study (Figure 3) will be referred

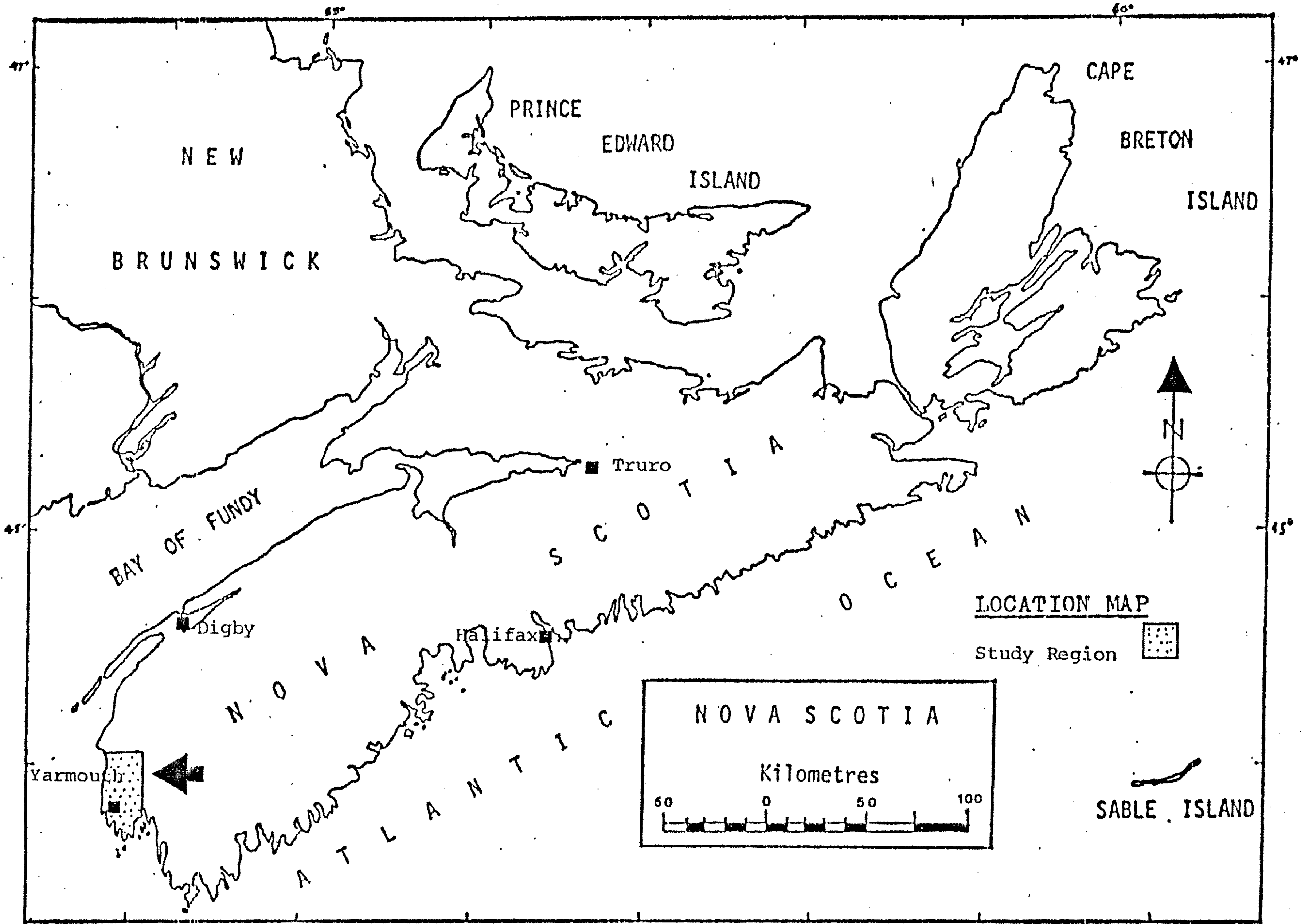


Figure 1

Location of study region

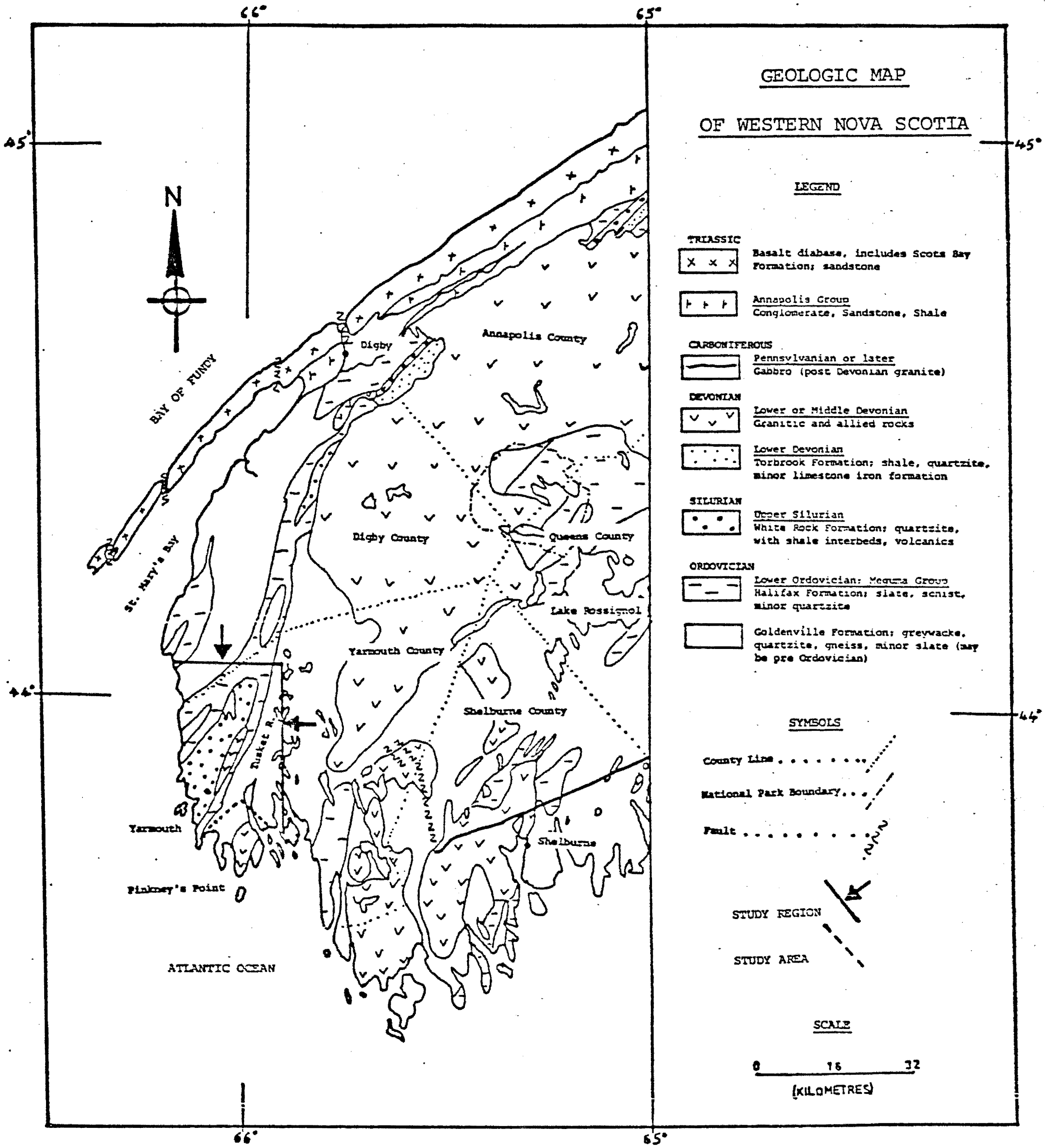


Figure 2

Geologic map of Southwestern Nova Scotia

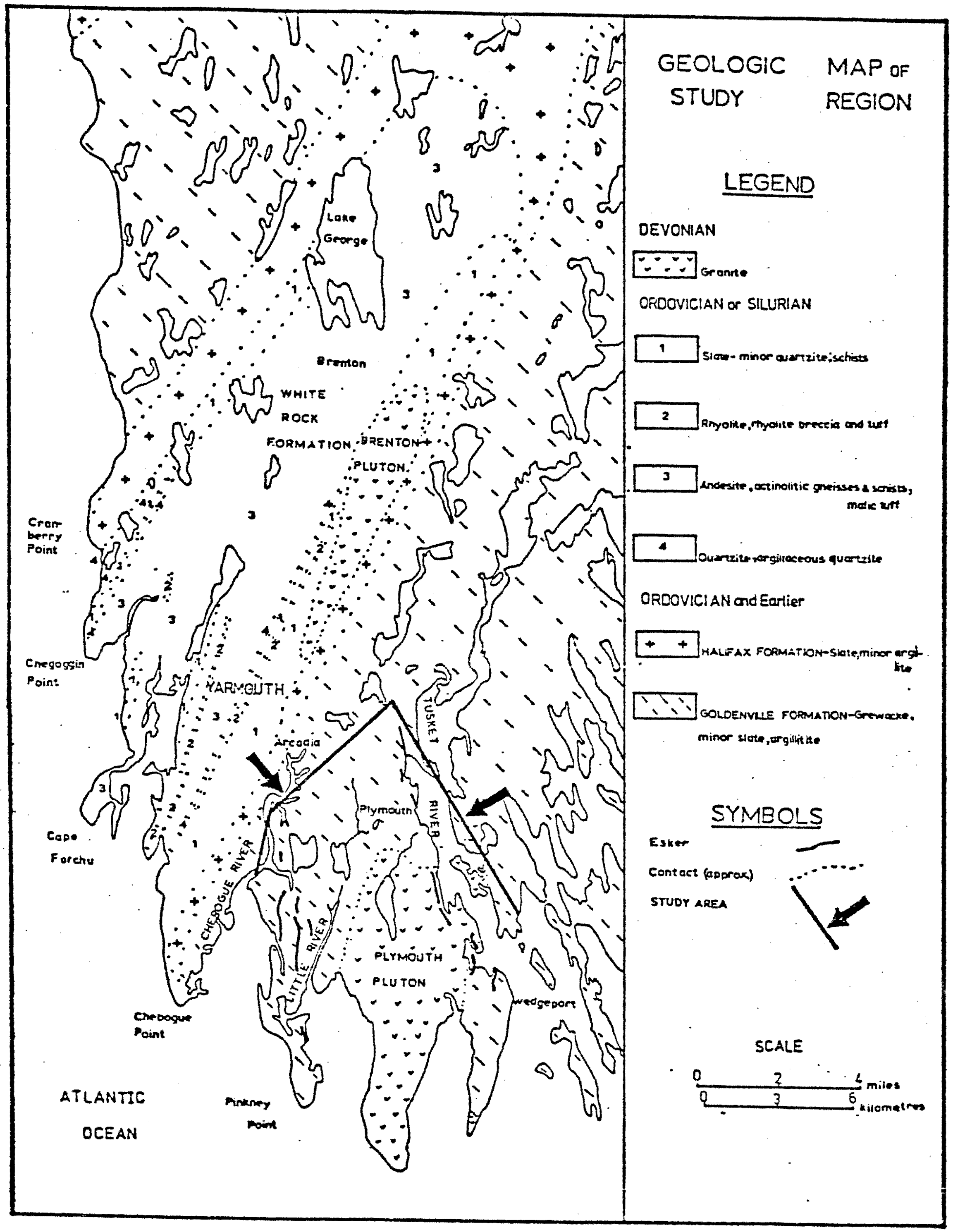


Figure 3

Geologic map of study region (modified from Taylor, 1967, G.S.C. Mem. 349) to as 'study area'.

The study region is readily accessible, with Highway 3 extending from Halifax to Yarmouth and Highway 1 extending along the northwest side of the province. Travelling roughly parallel to these highways are the C.N.R. and C.P.R. railways, both of which link Yarmouth to Halifax. Air Canada makes regular flights into Yarmouth from Halifax, St. John and Boston. Ferry service between Bar Harbour, Maine and Yarmouth is provided by Canadian National Steamships.

The study area is criss-crossed by roads which extend throughout the district. Away from roads the terrain is often covered with thick forest growth. Salt marshes occur in the vicinity of the coast and Tusket River, and many of these areas are accessible only at low tide.

Physiography and Drainage

The highest relief in the study area is approximately 50 m and generally the topography is gently-undulating to undulating. The coastline is ragged, and includes numerous bays, peninsulas and tidal flats.

Regionally, drainage is toward the south which generally follows the same direction as glacial movement. In the specific study area, three rivers are present. The largest, the Tusket River borders the study area on the east and trends in a southerly to southeasterly direction. The Chebogue River borders the study area on the west and trends generally south with slight bends to the southwest and southeast. Little River runs through the centre of the study area and flows toward the south-southwest.

Previous Work

The best available compilations of previous geological work are by Taylor (1967, 1969) and Smitheringale (1973) who mapped the region for the G.S.C. Geological maps produced by Taylor (1967-69) are at 1:125,720, and by Smitheringale (1973) 1:50,000.

A study of glacial deposits was made by Grant (1971) and Nielsen (1976). Sarkar (1978) mapped and described in detail the metavolcanics of the White Rock Formation. Recent work by Lane (1975) (and M.Sc. thesis, in preparation) adds further stratigraphic information.

Aeromagnetic maps produced by the G.S.C. in the late 1950's are available on the area. A detailed aeromagnetic and radiometric survey was carried out by the Nova Scotia Department of Mines and DREE during 1975. Results of the radiometric survey have been published, but as of yet the aeromagnetic results have not been disclosed.

A geochemical survey of waters and stream sediments was carried out by Boyle in 1958 for the G.S.C. (Taylor, 1967).

Previous to 1975, mineral exploration in southwestern Nova Scotia was minimal. Three abandoned gold mines are found in the vicinity of Arcadia, Chegoggin and Cranberry Head (Graves, 1976). Near Chegoggin Point silica has been quarried from quartzite beds in the White Rock Formation.

Preliminary exploration for Cu, Pb, Zn, Sn, W, Ag and Mo was carried out previous to 1977 by Chib-Kayrand Copper Mines, Cuvier Mines, Quebec Uranium Mining Corp., and the Millmore Syndicate. During 1977, Shell Canada Resources carried out an intensive exploration program involving an airborne geophysical survey, detailed geologic mapping, geochemical sampling, overburden drilling, ground geophysics and diamond drilling.

Scope and Methods of Investigation

This study is designed to assess the feasibility of reconnaissance prospecting and geochemical sampling in an esker complex. An attempt is made to compare esker materials to bedrock geology of the region, and to assess esker matieral as a prospecting medium for mineral exploration. To accomplish this, most emphasis of the study is directed at determining a mode of origin for eskers in the study area, and from this implications regarding mineral exploration are made.

Two eskers were geochemically sampled, one 'up-ice' from known occurrences of Cu, Pb, Zn, Ag, Sn and W and one 'down-ice' from the mineralized areas. It is not the intention of this thesis to investigate in detail the geochemical theory of the sampling method, but rather to determine if geochemical anomalies appear in eskers containing mineralized clasts.

It is beyond the scope of this thesis to describe and sample in detail all eskers in the study area. However, after a preliminary survey the writer decided that a study of several of the larger, better preserved eskers would be sufficient to answer questions pertaining to mineral exploration.

The author was first exposed to the problems of prospecting and geochemical sampling an esker complex during the summer of 1977 while employed with Shell Canada Resources Ltd. Work involved: mapping 2 eskers (1:2200) from aerial photographs, supervising backhoe operation, sampling esker material, geochemical sampling, boulder counts, detailed drawings and descriptions of esker characteristics.

Further analyses were carried out during the winter of 1977-78 which involved sieving, pipette analysis, heavy mineral separations and heavy mineral identification.

Geochemical analyses were performed for Shell Canada Resources Ltd. by Atlantic Analytical Services Ltd., of Saint John, New Brunswick.

CHAPTER II

GENERAL GEOLOGY

As a background for the studies of the glacial deposits, it is convenient to understand the bedrock geology, especially with regard to lithologies present. As described by F. C. Taylor (1967, 1969) the oldest rocks in the region are schists, greywackes, argillites and slates of the Meguma Group. The uppermost rocks comprise the Halifax Formation and are Early Ordovician in age. Conformably overlying the Meguma Group is the White Rock Formation, composed of quartzites, slates, and volcanic rocks of Silurian age.

These rocks were regionally metamorphosed and folded into a series of anticlines and synclines running generally in a NNW-SSE direction. During the Devonian these rocks were intruded by granites, and some basic dykes of several ages are present.

Pleistocene glaciation left large areas of bouldery till and some drumlins and eskers.

In the specific study area, rock types consist of greywackes and argillites of the Goldenville Formation (Lower Meguma Group) and granite of the Devonian Plymouth Pluton (see table of formations Figure 4).

Table of Formations

Era	Period or Epoch	Group	Formation	Lithology
Cenozoic	Recent			Tidal alluvium, stream alluvium, peat, beach sands and gravels, dunes
	Pleistocene			Drift, drumlins, eskers, kames, outwash
Unconformity				
Palaeozoic				Quartz diabase, biotite diorite, olivine diabase, hornblende-quartz diorite, basalt, diorite
	Intrusive contact			
	Devonian			Granite, granodiorite, quartz diorite, minor hornblende diorite and pegmatite
	Intrusive contact			
	Silurian		White Rock	Andesite, actinolitic gneisses and schists, mafic tuff, slate, quartzite, conglomerate, rhyolite, rhyolite tuff and breccia, minor argillaceous quartzite, greywacke and schists of sedimentary origin
	Conformable			
	Early Ordovician	Meguma	Halifax	Slate, siltstone, minor argillite; in part recrystallized to schists and gneisses characterized by andalusite, staurolite, cordierite, and sillimanite
	Conformable			
	Early Ordovician or earlier, possibly Late Cambrian		Goldenville	Greywacke, minor slate, argillite, conglomerate; in part recrystallized to schists and gneisses characterized by andalusite, staurolite, sillimanite and cordierite

Figure 4

Table of Formations for Study Region
(from Taylor 1967, G.S.C. Mem. 349)

Meguma Group

The work of F. C. Taylor (1967, 1969) is the most recent comprehensive regional survey material available on the study region. Much work has been done by other individuals on the Meguma Group in other part of Nova Scotia in recent years. However, for the purpose of this thesis the descriptions and interpretations of the above geologist will be generally drawn upon.

Goldenville Formation - Distribution and Thickness

Vast areas of the Goldenville Formation occupy the northwestern part of the study region (see Figure 3). As the base of the Goldenville Formation is nowhere exposed, the exact thickness is unknown. However, Faribault measured 18,348 feet (5592 m) of Goldenville along Liverpool Bay, and this is the most acceptable figure available on the maximum thickness (Taylor 1967, p. 7).

Lithology

The Goldenville Formation consists mainly of light to medium grey, medium grained biotite metagreywacke, with small quantities of metaconglomerate, meta-argillite and slate.

Bedding is visible in some areas ranging from a fraction of an inch (2.54 cm) to twenty feet (6 m), while in others it appears rather massive. Primary structures consist of bedding, cross-bedding, graded bedding, slump breccia and ripple marks (Taylor 1969, p. 10).

Thin sections from different areas reveal a high quartz content and the presence of biotite, muscovite, sericite, chlorite, plagioclase and locally epidote. Apatite, magnetite, ilmenite, pyrite and limonite are also present in some locations. In some areas foliation is present with alignment of biotite flakes, and quartz and feldspar grains are strained parallel to the foliation (Taylor 1968, 1969).

In the specific study area the Goldenville rocks occur as meta-greywackes and meta-argillites.

Structural Relationships

The Goldenville Formation grades conformably into the Halifax Formation. Contacts between the two formations are of two types (1) an abrupt change stratigraphically upward to pelitic rocks (2) a gradational change from greywacke to slate with the appearance of slate beds in greywacke (Taylor, 1967, p. 13).

Origin and Age

Smitheringale (1973) mentions previous work by others who postulate deposition of Meguma Group rocks in an environment of north and westward trending paleocurrents. Schenk (1975) suggested the source of the Meguma Group rocks was located to the southeast.

The Goldenville Formation is believed to be Late Cambrian or early Ordovician in age as it grades conformably into the Halifax Formation which is of Tremadoc age or earliest Ordovician (Taylor 1967, p. 14).

Halifax Formation - Distribution and Thickness

Rocks of the Halifax Formation lie in a long belt north of the specific study area. They are well exposed in the Yarmouth syncline (see Figure 3). A large area also lies further to the east of the study area.

The thickness of the Halifax Formation varies in the study region, with a thinning towards the southwest. Measurements in the region vary from 1500 feet (457 m) to a maximum of 4,950 feet (1508 m).

Lithology

The Halifax Formation consists predominantly of grey and black laminated slates. Laminae with a thickness of one millimetre to several centimetres may be continuous or lenticular and discontinuous.

Primary structures are rare and although scour and fill structures, cross bedding and ripple marks have been reported in the Halifax Formation elsewhere in Nova Scotia, no primary structures other than bedding were observed by Taylor (1967) in the Yarmouth region. Cleavage has destroyed bedding in many areas which is also masked in exposed outcrops by the weathering of pyrite (Taylor 1967, p. 15).

Typically the slate consists of subangular to subrounded silt size and smaller grains of quartz and feldspar. A certain proportion of the epidote and muscovite may be detrital, while apatite and tourmaline are metamorphic minerals in most cases. Presently the matrix consists of chlorite and muscovite in the lower parts of the formation; and in upper areas, depending upon the degree of metamorphism consists of chlorite, sericite, biotite, garnet, andalusite, cordierite and staurolite. Some magnetite, ilmenite and graphite occur (Taylor, 1967, p. 15-16).

Structural Relationships

The Halifax Formation is conformably overlain by the White Rock Formation in the region and is exposed only along the west side of Chebogue Point. The contact is arbitrarily placed at the base of the stratigraphically lowest bed of volcanic rocks (probably tuffs). These volcanic beds are intercalated with slate beds, which are indistinguishable from the slate beds of the Halifax Formation (Taylor, 1967).

Age

Fossil evidence found in other areas of Nova Scotia show the Halifax Formation to be Early Ordovician in age. However, no fossils from the Halifax Formation have been reported in the study region.

White Rock Formation

The White Rock Formation conformably overlies the Meguma Group and is well exposed in the Yarmouth Syncline (see Figure 3). Maximum thickness is difficult to determine as there are no overlying rocks. A maximum of 15,500 feet (4,724 m), depending upon where the contact was placed, has been measured in the Yarmouth region (Taylor, 1967, p. 24). The White Rock Formation consists of two main lithologies, sedimentary rocks and volcanic rocks.

Sedimentary Rocks - White Rock Quartzite

Typical White Rock Formation quartzite is present on both limbs of the Yarmouth Syncline. Bands ranging in thickness from 12 to at least 80 feet (24 m) were once quarried for silica rock. The distribution of quartzite in the region establishes the existence of more than two quartzite beds within the formation (Taylor, 1967, p. 25).

The quartzite is composed of recrystallized quartz averaging 0.15 mm grain size, and typically composed of more than 97 per cent silica. Detrital minerals include tourmaline, apatite and perhaps epidote. Small amounts of sericite, chlorite, magnetite, garnet, biotite, and cummingtonite are present locally (Taylor, 1967, p. 26).

Conglomerate

Conglomerate occurs on the west side of the Yarmouth Syncline in the Cape Forchu area (Figure 3). Approximately 100 feet (30 m) of conglomerate, with a maximum thickness of 250 feet (76 m) is exposed.

Fragments range from pebbles to boulders up to 2 feet (.6 m) in greatest dimension. Fragments are composed of quartzite, basic volcanics, rhyolite, and rare quartz pebbles. The matrix varies from being composed of minerals derived from volcanic rocks to those derived from sedimentary rocks (Taylor 1967, p. 26).

Argillaceous Quartzite

Argillaceous quartzite 490 feet (149 m) thick occurs north of Chegoggin Point. It consists of light grey, medium grained, well bedded and thin bedded biotite quartzite. Feldspar content is very high locally (Taylor, 1967, p. 30).

Slate

Slate occurs in the contact area with the Halifax Formation north of Chebogue Point. It is dark grey, thinly laminated, and indistinguishable from the Halifax Formation rocks (Taylor, 1967, p. 30).

Volcanic Rocks

The volcanics comprise the largest part of the White Rock Formation in the study region. They can be divided into two units, one consisting of mafic volcanic rocks which include flow tuffs and probable associated sills, and the second consisting of rhyolite, rhyolite tuffs and some rhyolite intrusive rocks.

All but 600 feet (182 m) of the 9,000 (2,743 m) to 11,000 (3,352 m) feet of volcanic rocks in the White Rock Formation are mafic rocks, and many of them have been metamorphosed to schists and gneisses. However, primary structures are preserved locally and flows and tuffs are distinguishable. Some volcanic bombs have been found.

Microscopically, the mafic rocks are found to be composed of actinolite, epidote, plagioclase, and chlorite, with lesser amounts of quartz, biotite, apatite, sphene, calcite, magnetite, and ilmenite (Taylor, 1977, p. 38).

Age of White Rock Formation

Taylor (1967) concluded that the White Rock Formation in the region is post-Lower Ordovician and probably pre-Upper Silurian. Lane (M.Sc. thesis in prep.) has further refined stratigraphic relationships and suggested modification in previous correlations.

Granitic Rocks

Much of western Nova Scotia is underlain by granitic rocks. In the region of interest, granitic rocks are exposed near Brenton (Brenton Pluton) and in the Plymouth area (Plymouth Pluton).

Brenton Pluton

Brenton granite is different from other granitic rocks in the region as it is strongly foliated due to the planar orientation of biotite. The rock is chiefly a coarse-grained cataclastic granite with augen-shaped feldspar phenocrysts up to one-quarter inch separated by envelopes of quartz, biotite and muscovite. For the most part the granite is well foliated, but some outcrops do reveal minor amounts of massive rock (Taylor, 1967, p. 48).

Plymouth Pluton

The Plymouth Pluton is rather poorly exposed in most areas, but the contact is visible at Pinkney's Point between the granite and the Goldenville Formation. The granite is unfoliated, and is medium to coarse grained, light grey to pinkish grey, and massive to slightly porphyritic. Potash feldspar (chiefly microcline) is the dominant feldspar. Some plagioclase is partly altered to fine-grained sericite. Muscovite is rare, and biotite forms up to 7 per cent in some places (Taylor, 1967, p. 48). In some areas, this pluton shows effects of hydrothermal alteration in the form of greisen, which also extends into the contact-metamorphosed Goldenville Formation.

Age

The granites are considered to be of Devonian age. The Plymouth granite is believed to be somewhat younger than other granites in Western Nova Scotia, and has been dated at 245 m.y. (Ar/K)(Taylor 1969).

Post-Granitic Basic Intrusive Rocks

Taylor (1967) reports a 5-foot thick olivine diabase sill near the top of the Goldenville Formation at Chebogue Point. It is composed of medium grained material consisting of well developed laths of labradorite, olivine, augite, minor serpentine and iddingsite. Chlorite and magnetite are also present.

The rock resembles those of the Triassic North Mountain Basalt (Figure 3) and may possibly have originated at the same time (Taylor, 1967, p. 54).

Metamorphism

Regional Metamorphism

Both the Meguma Group and White Rock Formation were regionally metamorphosed. The study region involves the greenschist and almandine-amphibolite facies. Metamorphism involves recrystallization accompanied in some places by orientation of newly formed minerals, which is the result of high temperature, pressure, and in part shearing stress (Taylor, 1967, p. 60). With the exception of some intrusive varieties, most rocks display a strong foliation (slaty cleavage or schistosity).

Contact Metamorphism

Contact metamorphism is not extensive, and visible contacts are scarce. At Pinkey Point, areas of Goldenville Formation contain spots composed of sericite, quartz, albite, tourmaline and sphenes up to 1,000 feet (304 m) away from the granite. Other clearly defined contact metamorphic phenomena are unknown in the region (Taylor, 1967, p. 65).

Mineralization

Greisen mineralization containing Cu, Pb, Zn, Ag, Sn, W, and Mo are present in many localities near the contact of the Plymouth Pluton and surrounding Goldenville Formation. North of the Plymouth Pluton are occurrences of Sn and Zn which may be of economic importance. Occurrences of gold associated with quartz veins of the Meguma Group are also present in the study region.

Structural Geology

Folds

The Meguma Group and White Rock Formation were folded and regionally metamorphosed during the Acadian Orogeny. Principal structural features are northeasterly trending folds.

The Yarmouth syncline (extending from Yarmouth Harbour to north of Lake George) has preserved the White Rock Formation from erosion. The fold is mainly horizontal but plunges locally as much as 50° to the north and south (Taylor, 1969).

Faults

Few faults have been mapped in the study region, partly due to lack of horizon markers and lack of outcrop in many areas. Taylor (1967) believes that faulting in the region is of minor importance and rather rare in comparison to folding in the study region's structural history. Some faults are known to displace Triassic dykes and volcanic rocks, and are thus relatively young features.

Summary

In summary, the major bedrock lithologic types can be grouped as follows:

Rock Type	Possible Sources
(a) granitoids - foliated	- Brenton Pluton
(b) granitoids - non-foliated	- Plymouth Pluton
(c) metagreywackes meta-argillites metaquartzites	- mainly from Meguma Group also from White Rock Formation
(d) metamorphosed mafic volcanics	- White Rock Formation
(e) metamorphosed felsic volcanics	- White Rock Formation
(f) unmetamorphosed diabase or basalt	- Triassic dykes, sills (Chebogue Point or less likely North Mountain)
(g) vein quartz	- from quartz veins in Meguma Group
(h) greisen mineralization	- Plymouth Pluton area

Pleistocene and Recent Deposits

During the Pleistocene Nova Scotia underwent glaciation and earliest ice movement in southwestern Nova Scotia was in an easterly and southeasterly direction (Grant, 1971). Subsequent ice moved southward leaving a linear pattern of eskers, drumlins, and fluting. During regression of the ice, crossed striations and intersecting drumlins indicate movement was south to southeast (Grant, 1971). The general directions of ice currents which crossed Nova Scotia are shown in Figure 5.

To the north and northeast of the Yarmouth area, most drift lineations do not trend southward, but form a radial pattern (see Fig. 6). Grant (1971) attributes this to the presence of a late stage ice mass centred northeast of Salmon River (see Fig. 6) to which the final ice retreated. However, there is no indication that the study region was affected by the late ice cap, and the Yarmouth area may have been occupied by a stagnant ice sheet during late stage deglaciation.

In the study area, the writer has observed the presence of meta-volcanic clasts characteristic of the White Rock Formation and clasts of foliated Brenton Pluton granite in tills and outwash material. The source of these clasts lies to the north indicating transport was in a southerly direction. Cross bedding in exposures of outwash sand and gravels also indicate deposition took place in a southerly direction.

Most of the study area is covered with till which varies in thickness from approximately 1 m to more than 10 m, and drumlins, kames, eskers and outwash materials are also present (see Fig. 7). Nielsen (1976) implies most tills in southwestern Nova Scotia are related to the underlying bedrock. The writer has observed large angular boulders of Plymouth Pluton granite (of local derivation) more than 6-7 m high within the study area.

Sea level has encroached on and drowned forest growths at several locations along the coast. Grant (1971) attributes this to tidal increase and local subsidence.

The distribution of eskers subject to this study are shown in Figure 7 and discussed in detail in Chapter IV.

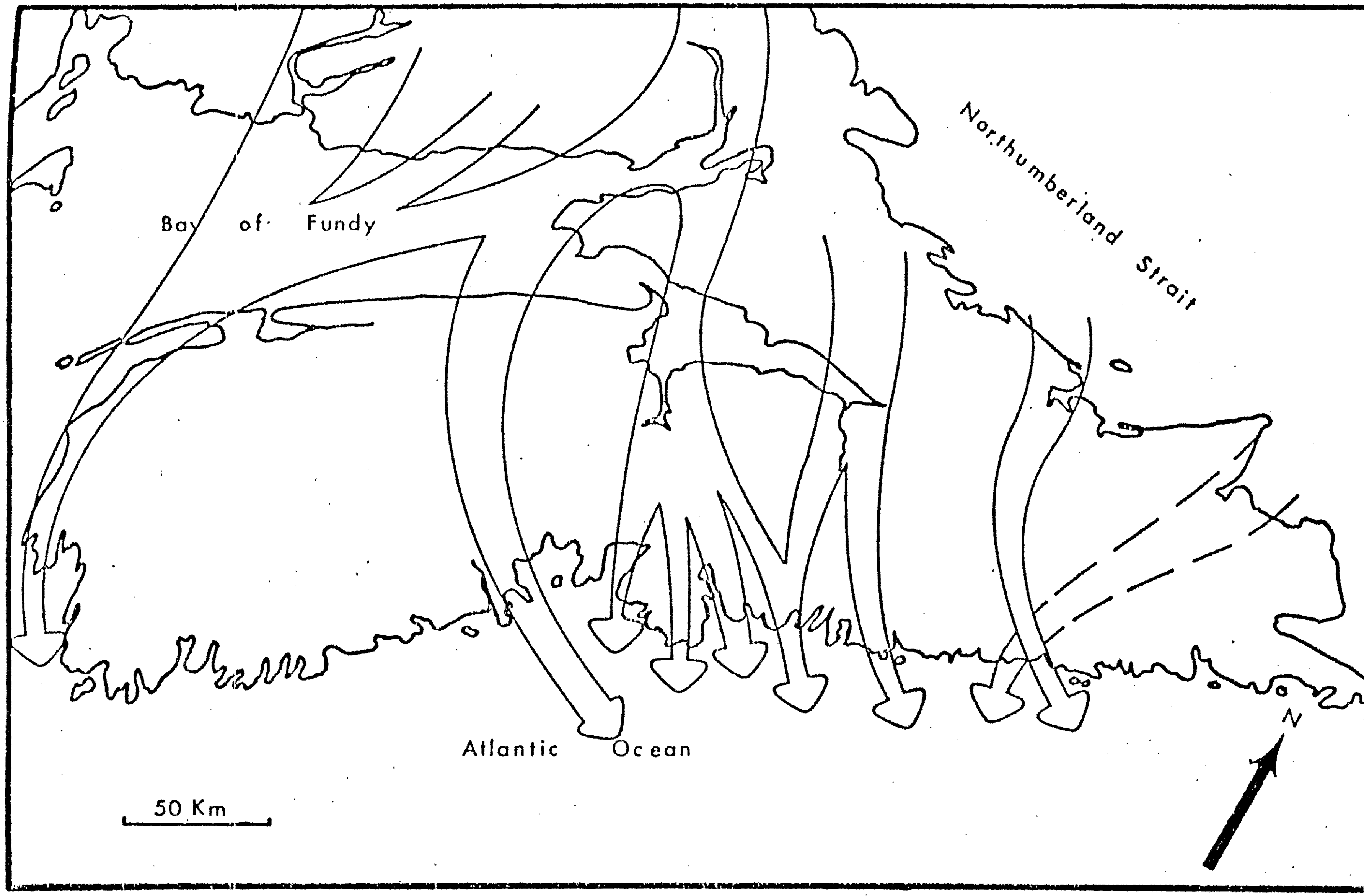


Figure 5 - Hypothetical ice currents across Nova Scotia
(from Nielsen, 1976, p. 18)

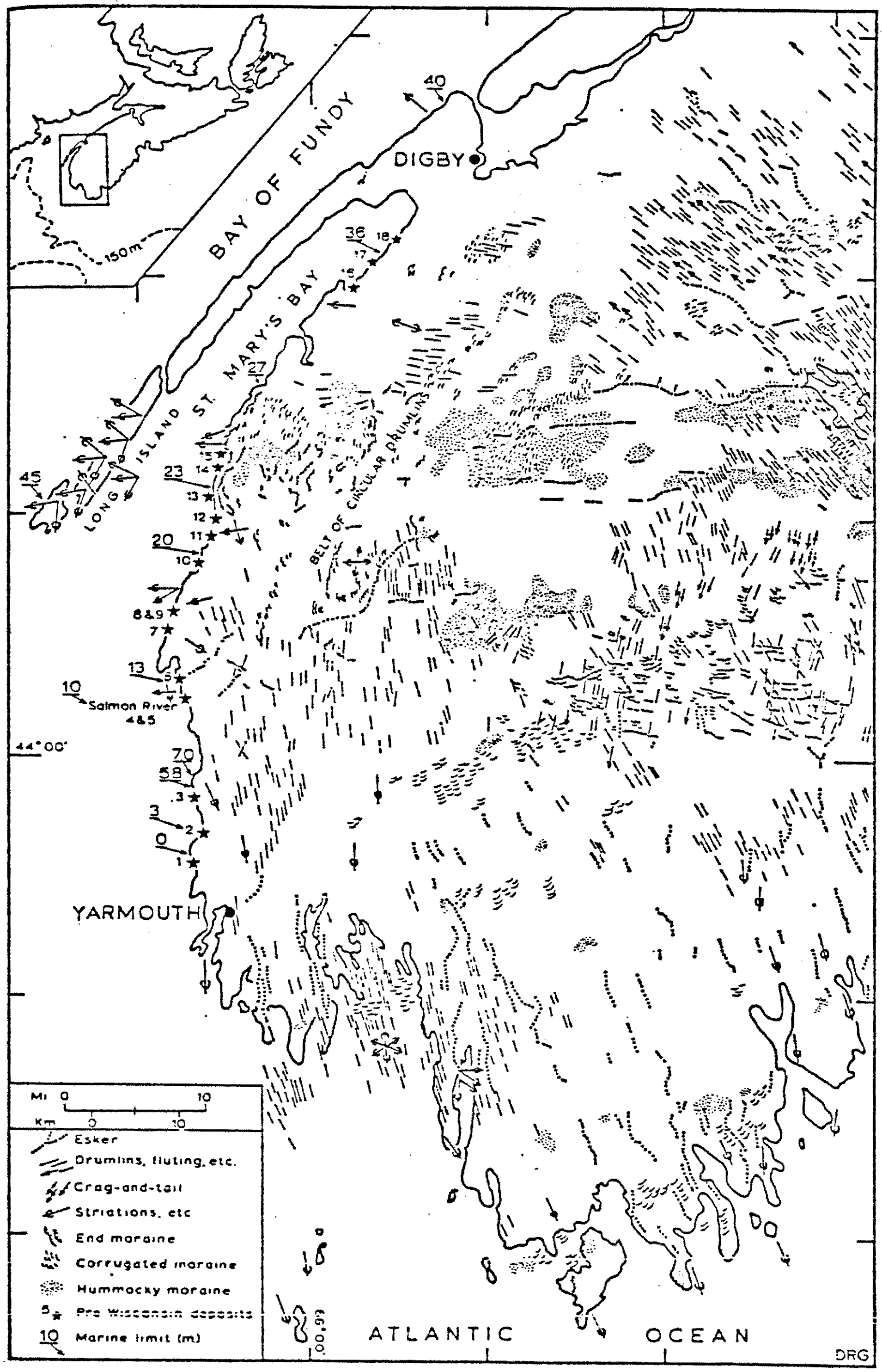


Figure 6

Map showing glacial features of Southwestern Nova Scotia (from Grant 1971, G.S.C. Paper 71-1, Part B, Report of Activities)

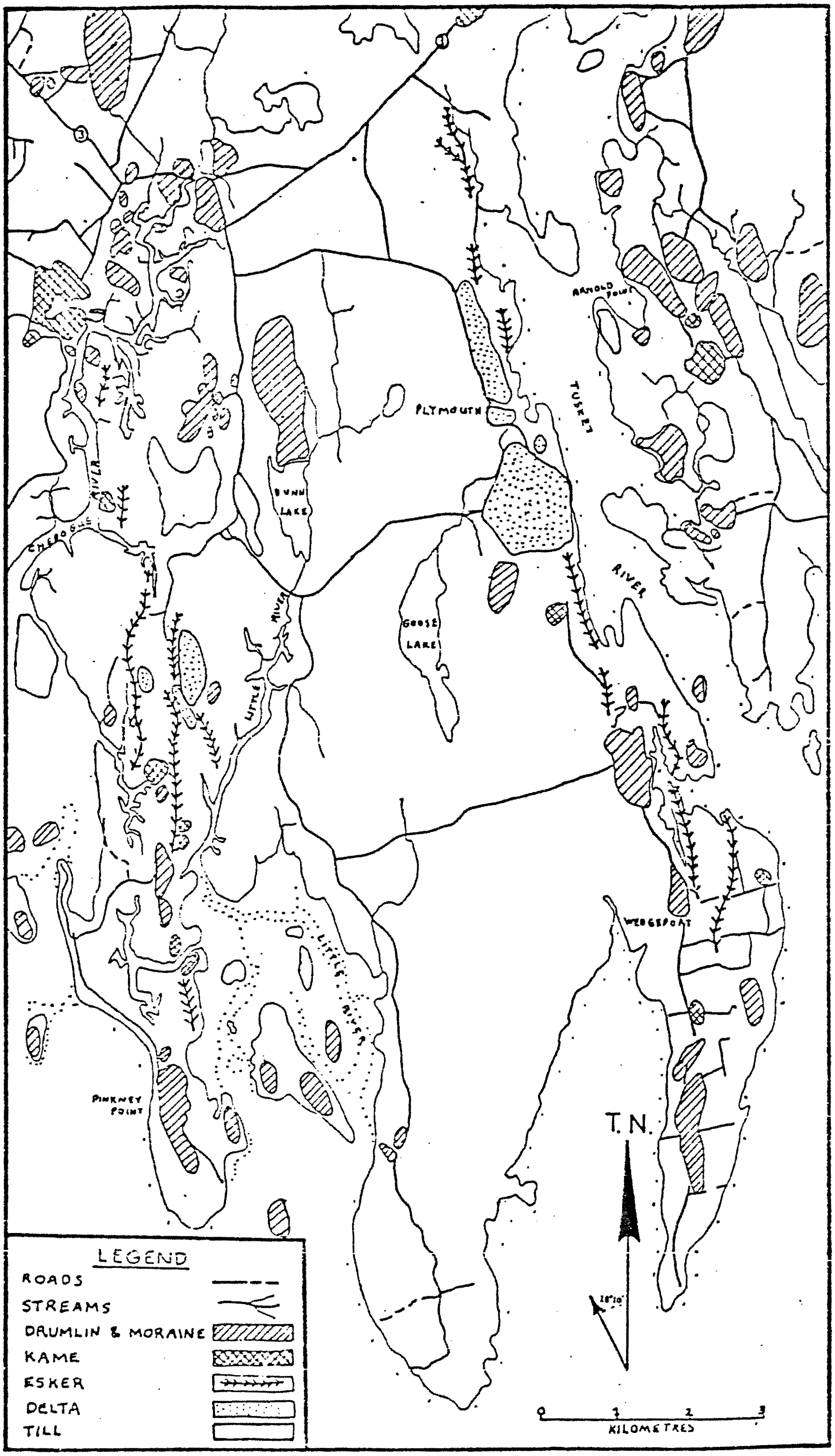


Figure 7 - Surficial Geology of Study Area
(modified from maps 20-0/16, 20-0/9E, 20-P/13W, 20-P/12W by R. H. MacNeill, 1960)

CHAPTER III

ESKERS: BACKGROUND INFORMATION

Eskers consist of long sinuous ridges of ice contact glaciofluvial sediment formed in conduits of subglacial, englacial, or supraglacial streams. They generally trend parallel to the direction of the most recent regional ice movement. Their position indicates the major flow routes of meltwater and associated debris toward the ice margin. Most eskers occur in areas of low relief and often follow valley floors; however some have been described that appear to trend uphill.

Eskers range in height from 2 or 3 m to more than 200 m, and in breadth from a few metres to 3 km. Their length varies from less than 100 m up to more than 500 km (including gaps) (Flint, 1971, p. 214). The ridges of eskers may be uniform and continuous or they may be composed of separate mounds or beads of material which are sometimes connected by a low ridge.

Previous Work

Esker studies are numerous and involve a number of objectives. Studies to determine the mode of formation of eskers have been carried out by Banerjee and McDonald (1973), Saunderson (1973), and McDonald and Shilts (1973). Modern day formation of eskers have been observed by Price (1966); King and Buckley (1969); Lewis (1947); and Howarth (1971). Dispersion of clasts in esker materials has been studied by Lee (1965); Trefethen (1944); Hellaakoski (1930) and Van Beever (1971). Eskers have been investigated for mineral prospecting by Lee (1965); Shilts and McDonald (1975); Shilts (1973); Allan (1973); and Cachau-Herreillat and LaSalle (1969).

The most comprehensive and up-to-date summaries on eskers are provided by Banerjee and McDonald (1973) and Price (1973).

Origin of Eskers

Theories of the origin of eskers are numerous and varied. Sedimentary structures and morphologic characteristics of eskers and associated glacial deposits may be used to classify the different types of eskers and their modes of formation.

The formation of eskers has been explained by at least 5 different processes acting in different parts of a glacial system: (a) formed in tunnels (less commonly in open channels) at the base of the glacier during a late stage of deglaciation when the ice was thin and stagnant (Flint, 1971, p. 216).

(b) formed as a series of deltas composed of material transported through subglacial tunnels and deposited at the ice margin. This type of esker is believed to be added to in an upstream direction with the addition of another segment or mound of material during each ablation season.

(c) deposited as a series of nodes in a manner resembling a mud flow or debris flow in an open ice channel, followed by quiet water deposition between nodes. Each node represents the seasonal discharge of debris during periods of high meltwater discharge, and the esker is added to in an upstream direction.

(d) formation of eskers in supraglacial streams

(e) formation of eskers in englacial tunnels

Two major arguments are presented by Flint (1971) which oppose the last two models:

(1) Eskers do not generally trend indiscriminantly across country as would be implied by a position upon or within the ice. Instead eskers tend to follow valleys and cross divides at conspicuous low points (Flint, 1971, p. 218).

(2) The process of lowering the sediment from an englacial or supraglacial position would result in large scale collapse structures, which are not common features of eskers.

The concept of glacial debris moved under hydrostatic pressure during formation of subglacially derived eskers is discussed briefly by Charlesworth (1957) and Price (1973). Such a concept is instrumental in answering questions pertaining to eskers involved in this study. A considerable hydrostatic head may be developed as a result of meltwater in cracks and channels descending to the base of the ice, and also as a result of ice movement (Price, 1973). Deposition of esker material under the influence of a hydrostatic head might explain why some eskers may trend uphill without being deposited in an englacial or supraglacial position.

Four major parameters must be considered when attempting to determine a mode of origin of a particular esker or esker system (from Banerjee and McDonald, 1973):

(a) Formation and maintainence of the conduit - the process by which meltwater localized in specific channels

(b) Position of the sediments with respect to the glacier - whether the esker stream occupied a subglacial, englacial, or supraglacial position

(c) Nature of the Conduit - whether the esker flowed in an open channel or in a tunnel flowing full

(d) Site of Deposition - whether deposition took place inside the conduit before reaching the glacier terminus, or at the glacier terminus where flow conditions probably changed radically.

All of these parameters are considered in the following chapters.

Transport Distance of Esker Materials

Studies of the transport distances in eskers by Lee (1965), Van Beever (1971), Trefethen (1944), Hellaskouski (1930), Shilts and McDonald (1975) are summarized in Figure 8 under various headings. Although much variation exists between the dimensions of the various

Worker and Location of Study	Esker Dimensions and Depositional Environment	Description of Sample Studied	Size Fractions and Number of Clasts Counted	Transport Distance (i.e. distance which peak abundance of material has moved from bedrock source)	Remarks
Shilts & McDonald (1975) - Southern Quebec, Canada	Length - 14 km Env. - Subglacial	Pebbles collected from different facies within esker at gravel pits	Intermediate diameter 2-5 cm - 100 clasts	3-4 km	
Van Beever (1971) - Maine, U.S.A.	Length - 80 km Height - 6.43 m Env. - Subglacial	Sample collected at a depth of approximately 1 m in crest of esker	5-15 cm - 100-300 clasts 2.5-5 cm - 123-256 " 1.9-2.5 cm- 140-308 " 1.27-1.9 cm - 200-320 "	3.8-5.44 km	Most clasts travelled less than 16 km Surface boulders first appeared 1.6 km downstream from source
Lee (1965) - Kirkland Lake, Ontario, Canada	Length - 400 km Width - 1.6-6.4 km Height - up to 88 m Env. - Subglacial	Approximately 1.3 cu ft. (.396 cu m) from 2 vertical channel samples in crest of esker	.8-1.6 cm - 300-500 clasts (trachyte) .335-.8 cm - 10,000 grains (dunite and magnetite) .05-.123 cm - entire sample (pyrope) >1x10^{-4}cm - entire sample (gold)	- trachyte 4.8±3.2 km - pyrope less than 12.8 km - dunite 12.8±3.2 km - gold 3.2±3.2 km	Larger clasts of dunite were deposited before finer dunite particles Most clasts travelled less than 16 km
Trefethen (1944) - Maine, U.S.A.	Length - 80 km Height - 6-12 m (ave.)	Collected at random in gravel pits	1.27-7.62 cm - 200 clasts sand size material - 100 grains	4.8-12.8 km	Larger clast deposited first, while finer clasts have a wider range of distribution
Hellaakowski (1930) - Finland	Length - 27 km Height - up to 20 m	From cross-bedded strata in centre of esker at a depth of 1-3 m	>6 cm - 100 (minimum) clasts 2-6 m - approx. 200 clasts	5-8 km	Surface boulders first appeared less than 1 km from bedrock source

FIGURE 8

Previous work involving transport distances of esker material.

eskers and types of samples investigated, most of the esker materials are a reflection of the local bedrock.

The literature reveals that clasts in an esker are not found in maximum abundance over or immediately adjacent to a bedrock source, but some distance downstream. Lee (1965) indicated that the distance of maximum transport in an esker is uniform for material having similar hydrologic characteristics of size, specific gravity, and shape.

Lee (1968) discovered a kimberlite occurrence by analyzing pyrope grains in an esker of the Kirkland Lake, Ontario area.

As esker materials have undergone ice movement as well as melt-water transport, it is expected that esker clasts have travelled further than the adjacent till. Van Beever (1971) showed that while most esker material had travelled at least 3.8 to 5.4 km in a down-stream direction from its source, material in the adjacent till had been transported at least .96 to 1.36 km. Hellakouski (1930) found similar results when he compared transport distances of clasts in an esker and adjacent tills.

Eskers as a Geochemical Sampling Medium

Shilts and McDonald (1975) obtained higher than background values for Ni and Cr by analyzing heavy minerals of sandy esker units downstream from known bedrock occurrences in Quebec.

Allan (1973) obtained high values of Ni and Cu downstream from known bedrock occurrences by sampling frost boil structures on the eskers in an area of permafrost. Shilts (1973) found similar results from an esker in a permafrost area, and concluded that near surface esker material was severely depleted in sulphides and carbonates due to internal chemical weathering. He recommended sampling of clays and secondary oxides in the minus 250 mesh fraction in areas of permafrost.

Cachau-Herreillat and LaSalle (1969) found that best results for geochemical sampling in eskers in the Abitibi region were derived from the 'C' horizon, and that results in the 'B' horizon failed to show geochemical anomalies in regions of known mineralization.

In summary, eskers may be formed in several ways and most material present in eskers has travelled less than 16 km and in many cases less than 12 km (see Figure 8). Geochemical anomalies in esker materials in regions of known mineralization indicate that esker materials may be utilized for reconnaissance geochemical sampling.

CHAPTER IV

ESKERS OF THE STUDY AREA

The esker system investigated is shown in Figure 10, p. 42. It lies on both sides of the topographically high Plymouth Pluton granite. The eskers trend generally in the same direction as the most recent movement of glacial ice in the region, and correspond with glacial striation directions of generally N to S.

Esker material along the east edge of the Plymouth Pluton extends for some 12 km (including gaps), and involves 8 individual parts of eskers. On the west side of the Plymouth Pluton, esker material extends for approximately 8 km (including gaps). Some of these individual accumulations of esker material may have been joined together at one time, but due to erosion are now separated.

As the eskers parallel all major drainage channels in the area (Little River, Tusket River, Chebogue River) and occupy areas of relatively low topography, the eskers may represent the major drainage routes of meltwater during deglaciation.

Most eskers described in literature are much larger than those found in the study area. Therefore generalizations which may apply to eskers elsewhere regarding transport distance of materials, mode of formation and geochemical sampling do not necessarily apply to eskers of the study area.

For the purposes of this study, the term "node" will be used to describe the successive mounds or beads of esker material which is characteristic of most eskers in the study area. The term 'inter-node' will be used to denote the low ridges of material connecting the nodes. Separate accumulations of nodes and inter-nodes are referred to as eskers or esker segments.

Methods of Analyses

1 Field Observations:

External characteristics of all eskers and esker segments were observed in the field. Morphologic characteristics were recorded and angles of the side slopes of esker material were measured at various localities.

2 Sections Through Eskers:

Road cuts and gravel pits at various locations in the esker complex expose both longitudinal and transverse sections of esker material. Disturbed material was removed with a shovel in some instances to provide a fresh face. Two transverse sections were dug with a backhoe, one through a node, and one through an inter-mode. All sections were drawn, photographed and described in detail.

3 Fabric Analyses:

Fabric analyses were performed on different units from the transverse sections which were dug with a backhoe. The long axis of clasts 5-15 cm were measured with a compass to determine the orientation of the clasts.

4 Boulder Counts:

Boulder counts were made at various localities throughout the esker complex. Ten to twenty boulders were counted in class sizes ranging from 7 cm to more than 1 m in diameter, depending upon the size and number of clasts present at a particular locality. Angularity and sphericity of clasts was determined with a visual comparison clast.

The author feels this method is accurate enough to determine if the larger clasts present are representative of local bedrock. Clasts were divided into four major lithologies: (a) Brenton Pluton granite (foliated) (b) Plymouth Pluton granite (unfoliated) (c) Goldenville Formation (argillites, greywackes, quartzites) (d) White Rock Formation (mafic volcanics).

5 Esker Samples:

A vertical channel sample of material was taken from the transverse sections through a node and inter-node. The samples represent material finer than approximately 6.4 cm diameter collected from a channel 1 m wide and extending from the top of the esker crest to the lowermost unit exposed. Each major unit was sampled and stored separately.

Treatment of the Samples - (a) Grain Size Analyses

(for comparison of mesh sizes, Ø sizes and measurements of each, see Appendix 1)

The samples from each unit were sieved by hand into the following size fractions: (a) greater than -6Ø (b) -5Ø to -6Ø (c) -4Ø to -5Ø, and (d) -3Ø to -4Ø. Enough sediment finer than -3Ø was then split from the sample to give a representative distribution of material in the finer fractions. This involved approximately 75 to 250 gms of sample, depending upon the grain size distribution in the particular sample.

The subsamples of the finer fracton were then sieved to 1/2 Ø size intervals ranging from -2Ø to +4Ø. Pipette analyses were utilized to determine silt and clay content.

Each fraction was then weighed and expressed as a percentage of the total weight with the exception of clasts larger than -6Ø. The presence of such clasts would tend to mask percentages of finer material due to the relatively heavy weight. Therefore clasts larger than -6Ø were omitted from weight percentages, and lithologies present were expressed as numerical percentages and included with boulder count data.

(b) Pebble Counts

Pebble counts were done on samples from different units to determine vertical variation in lithologies present. Weight percentages of all pebbles in the following size intervals were determined: -5∅ to -6∅, -4∅ to -5∅, -3∅ to -4∅. Clasts were divided into five major lithologies, and the relative abundance of clasts of each lithology was expressed as a percentage of the total weight of that size fraction. Only samples containing at least 30 pebbles in a particular size fraction were included. In some samples, more than 200 pebbles were present in a particular size interval. Because the finer fractions tend to have a much higher number of clasts, a statistical comparison between the different size fractions would not be meaningful.

(c) Heavy Minerals

(see Appendix 3 for further information on treatment and preparation of heavy minerals)

Heavy mineral separations were performed using tetrabromoethane (S.G. 2.97). Iron oxide was removed from grains (see Appendix 3 for method) prior to identification and counting. Approximately half the grains were mounted in Canada Balsam and sealed with a cover glass. Identification of minerals before counting was aided by reference slides, refractive index oils, microprobe analysis, and further heavy liquid separation of grains with Clerici Solution (S.G. 4.2).

Pilot counts were done at 1/2∅ size intervals from 2.5∅ to 4∅ to determine which size fractions were most convenient to study and which sizes represented the finer material. The 2.5∅ to 3∅ size fraction was chosen as it is fairly representative of all size fractions examined, and because the grains are large enough for easy counting and identification. Approximately 300 grains from each sample were counted using a mechanical stage and a binocular petrographic microscope (see Appendix 4 for method).

The remaining half of the heavy mineral samples was then inspected with an ultra violet light and the presence of scheelite was verified.

Minerals identified in grain mounts are opaques, garnet, andalusite, staurolite, sphene, augite, amphibole, apatite, sillimanite, tourmaline, epidote, rutile, cassiterite and zircon. Because of the difficulty in distinguishing rutile from casserite in the detrital grains, the two are expressed as a sum total of both minerals.

Other grains present (micas, chlorite, altered grains, rock fragments, etc.) were included in the total percentages of heavy minerals, but were excluded when calculating percentages of identified species. The percentage of opaques was determined as a number percent of the total number of identified species. The remaining thirteen species were then calculated as a percentage of the total non-opaque fraction. This technique is similar to that used by Nielsen (1976).

Inferences of Field Observations; Sections Through Eskers; Fabric Analysis

All eskers or esker segments in the study area display the same morphologic characteristics. These characteristics include (a) side slopes dipping at 20-30° (where not eroded) (b) composed of a succession of nodes separated by a topographically lower inter-node. The nodes vary in dimension, with a typical size of 20-40 m long, 20-40 m wide, and 4-8 m high. Locally however, they may occur larger.

The distance between nodes sometimes varies. In some areas the nodes are separated by a very pronounced inter-node, while in other areas the nodes occur rather close together with a poorly pronounced inter-node.

Field observations and sieve analyses (p. 52-54) allow the alternating stratigraphic units of esker material to be divided into six major facies. These facies include all material present except for the occurrence of very large boulders (approximately 1 m diameter). Description of facies is shown in Figure 9.

The location of eskers in the study area is shown in Figure 10. Locations of sections through eskers (Figures 11-14) may be correlated with Figure 10 by the corresponding numbers.

Detailed sections of esker material are presented in Figures 11-15. Figures 11, 14, and 15 represent longitudinal sections through esker material, while Figures 12 and 13 portray transverse sections of esker material.

Fabric analysis from several units in sections 2 and 3 (Figures 12 and 13) indicate clasts in the 5-15 cm size generally lie parallel to the N-S trend of the esker.

All sections show a capping of poorly sorted till-like material. The upper portion of this unit has been subject to subaerial conditions

FACIES

	Description	Distribution
Facies 1	Muddy, sandy gravel - poorly sorted (material ranges from clay size to boulder size) - heavily oxidized - resembles a till	- stratigraphically highest unit present in all exposed sections of esker material - is laterally continuous in all eskers observed except where eroded
Facies 2	Sandy gravel - massive to slightly bedded - poor to well consolidated - coarser clasts 8 - 16 cm diameter, with the presence of minor boulders	- occur mostly within nodes
Facies 3	Pebble-Cobble Gravel - pebble-cobble size material well washed, massive to poorly bedded	- pebble-cobble material generally found in upper units of inter-node (underlying till material)
Facies 4	Gravelly sand - massive to well bedded - poorly consolidated, resembles outwash gravel - may show some compressional features due to weight of over-lying material - mostly sand to fine gravel size material, with some clasts 5 - 10 cm diameter	- generally occurs deep in esker, underlying coarser, more poorly sorted units - also occurs as discontinuous channels which cut units of other facies
Facies 5	Sand - massive to well bedded - some cross-bedding, parallel bedding - some deformation of bedding due to weight of overlying material	- most commonly found in inter-node areas - also found in discontinuous channels in coarser, more massive units
Facies 6	Cobble-boulder gravel - cobble-boulder material generally massive, sometimes showing slight upward fining of material - some finer material between nodes	- cobble-boulder material which may be found in centre of some nodes

FIGURE 9

Description of Facies

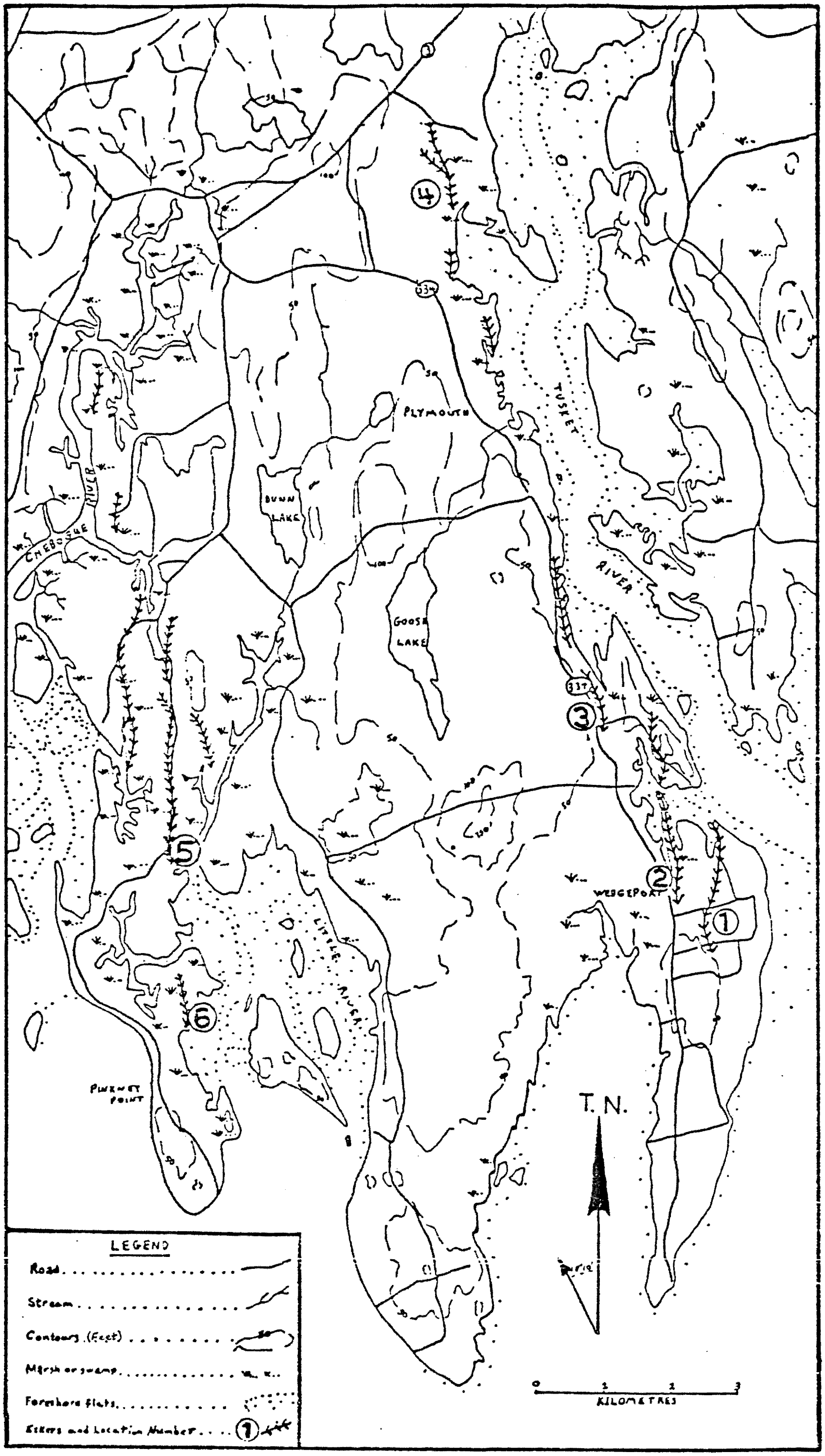


Figure 10 - Location map of eskers in study area. Esker numbers may be correlated with Figures 11-15 for location. (from N.T.S maps 20-0/16E, 20-0/9E, 20-P/13W, 20-P/12W)

LEGEND

Facies 1 - muddy, sandy gravel

Facies 2 - sandy gravel

Facies 3 - pebble-cobble gravel

Facies 4 - gravelly sand

Facies 5 - sand

Facies 6 - cobble-boulder gravel

Cross-bedded units

Graded units

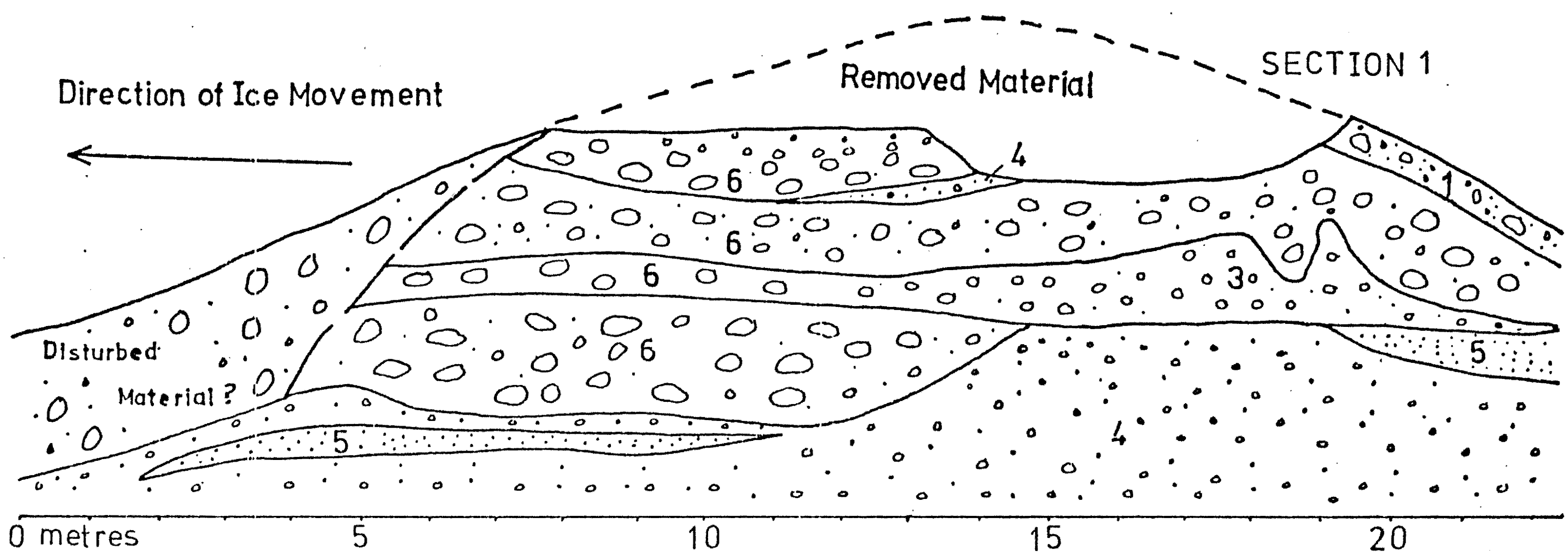


Figure 11

Longitudinal section through centre of node from Esker 5 (see Figure 10 for location)

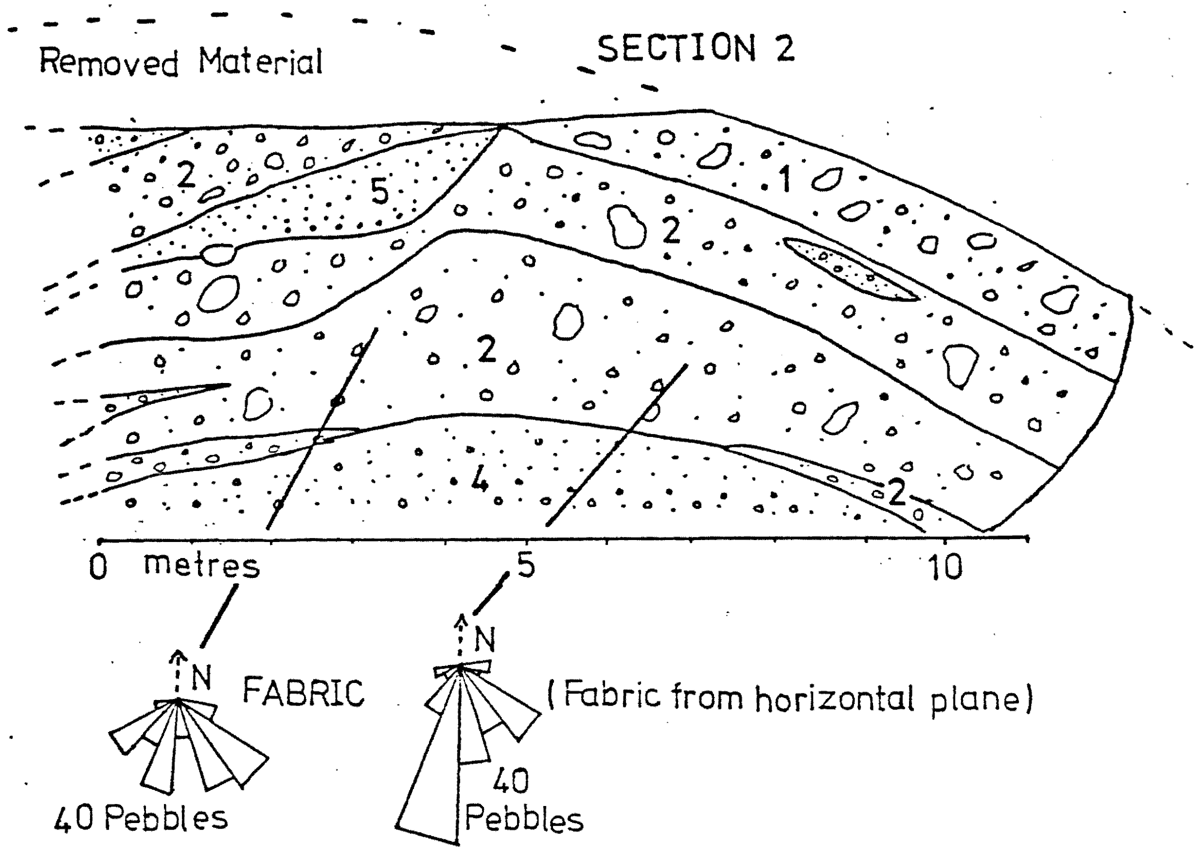


Figure 12

Cross section of node from Esker 2 - Rose diagrams represent fabric measured from 40 clasts 5-15 cm long (see Figure 11 for legend, and Figure 10 for location)

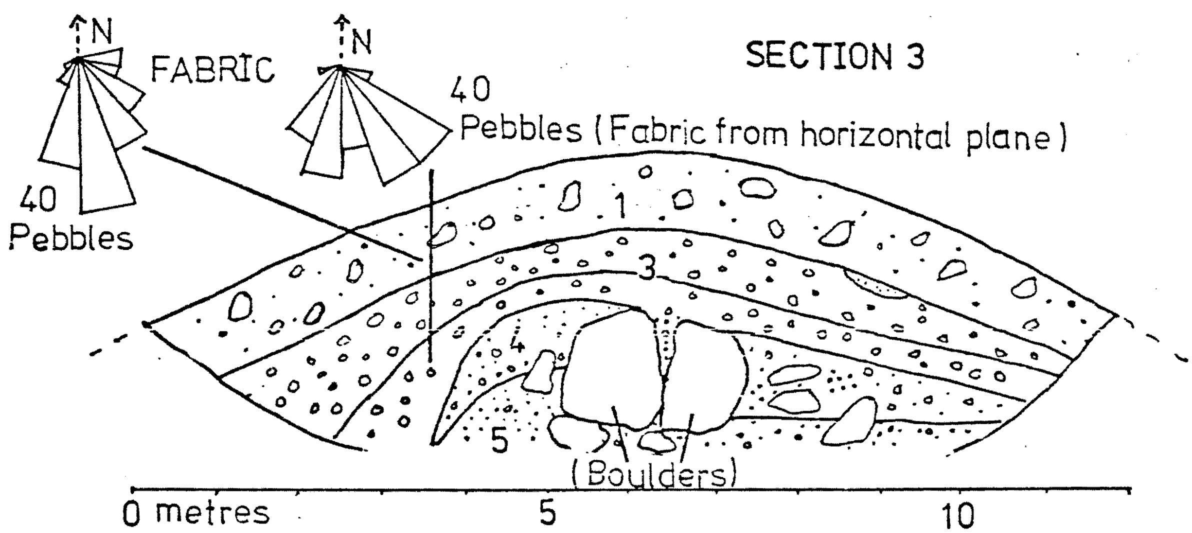


Figure 13

Cross section of inter-node from Esker 2. Rose diagrams represent fabric measured from 40 clasts 5-15 cm long (see Figure 11 for legend and Figure 10 for location).

* NOTE: Figures 14 and 15 not at same scale.

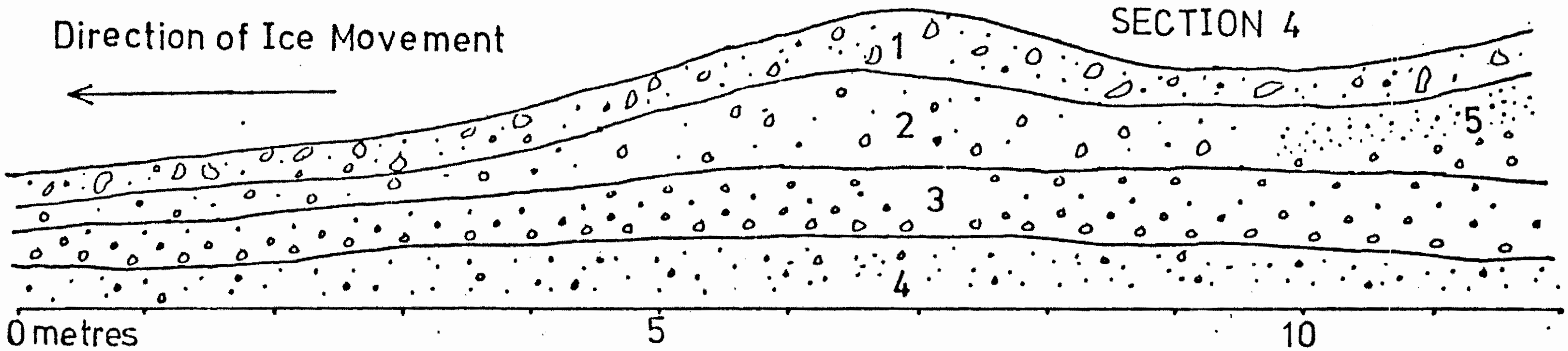


Figure 14

Longitudinal section through flank of node in gravel pit. (see Figure 11 for legend and Figure 10 for location).

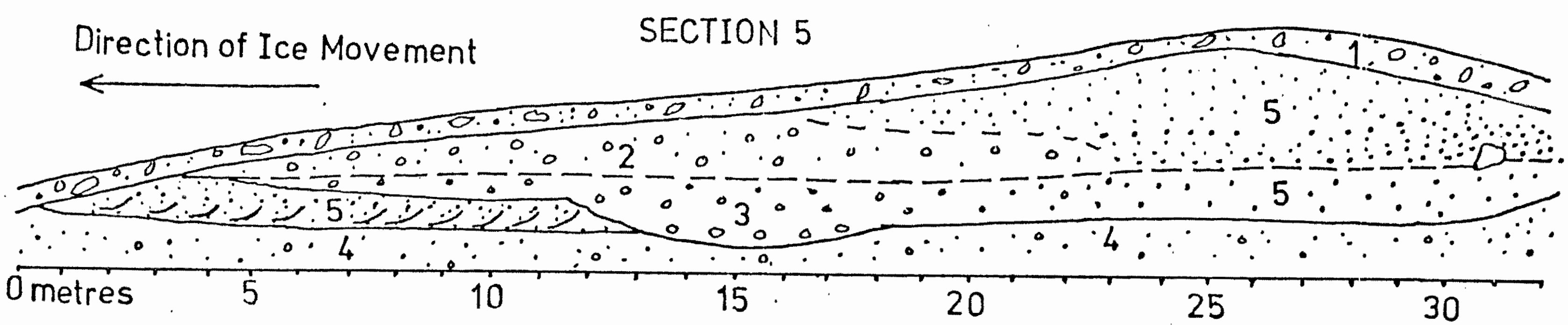


Figure 15

Longitudinal section through node from <u>Esker 6</u>. Section may represent material from flank area. (see Figure 11 for legend and Figure 10 for location).

of weathering and soil formation processes. The lower portion of this unit is fairly consolidated and shows a rather well developed fabric (Figure 13). This fabric may have been derived from alignment of clasts within the ice during active ice movement, with the orientation of clasts being retained during deposition. The unit appears to represent a flow till or meltout till which has undergone some degree of water working during deposition. The author observed similar characteristics in surrounding tills within the study area. Boulton (1971) described melt-out and flow till elsewhere which show both water working characteristics and a till fabric derived from depositional processes and retainment of englacial clast orientation.

Alternating stratigraphic units containing a wide range of clast sizes and the presence of erosive contacts between units indicate fluctuating energy levels within the glacial streams that formed the eskers. From the literature it appears that such observations are characteristic of many eskers (see plate 7, p. 73.

All sections show an upward coarsening of material from underlying outwash (facies 4) into coarser units interbedded with fine material.

Section 2 (Figure 12) depicts a transverse section through one half of a node, and Section 3 (Figure 13) is a transverse section through the adjoining inter-node. With the exception of several large boulders in the centre of the section, most material in the internode is well sorted and appears to have been derived from the poorly-sorted units within the node. The very large boulders in the centre of the inter-node are probably derived very locally, and were probably deposited before the upstream node material. This would be expected if the glacial stream flowed toward the terminus of the ice front, which is the generally accepted flow direction of esker forming streams. Cross bedding in Section 5 (Figure 15) is in agreement with this assumption (see Fig. 16 for location of cross sections).

The above evidence suggests that the nodes of material were deposited first, and material supplied from the nodes formed the inter-nodes.

Although all nodes show generally the same characteristics of successive units with erosive contacts, the size of clasts and thickness of units varies between the different sections. The cobble-boulder gravel (facies 6) present in Section 1 (Figure 11) is not present in other sections. The variation of clast size within the eskers is probably a function of energy levels associated with the esker forming streams. If this assumption is correct, the size of clasts may vary from one part of an esker to another, as well as from one esker to another. This would depend upon the nature of the esker-forming stream during deposition.

Cross sections of esker material resemble anticlinal structures. This may be the result of slumping of esker material on the flanks due to erosion of flank material or removal of supporting ice. The

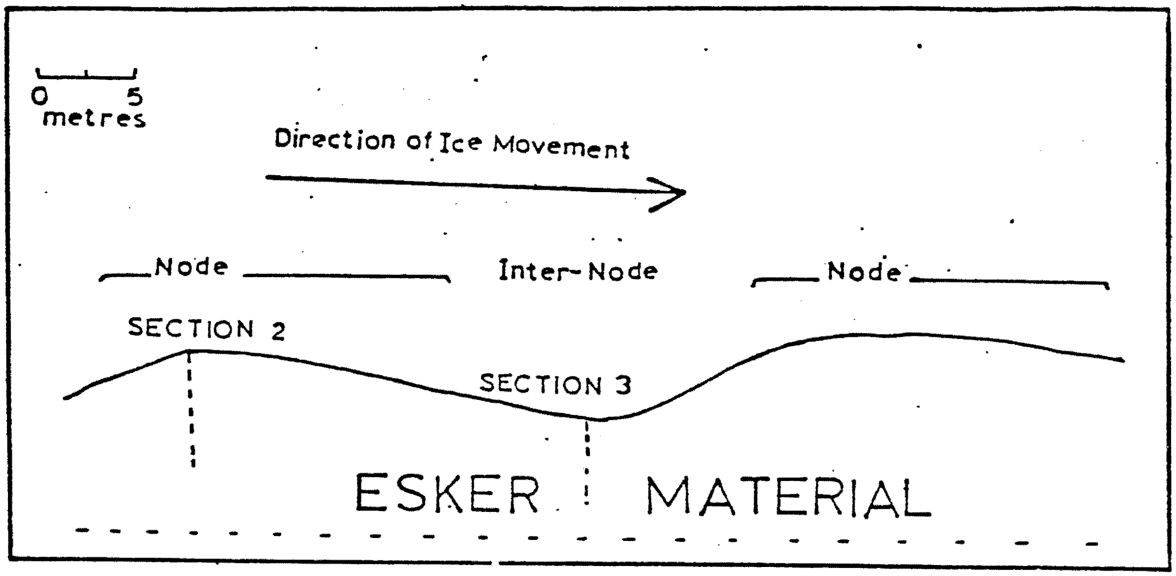


FIGURE 16

Location of sections through node and inter-node.

author noted that clasts in the flanks tended to be aligned with the dip of the side slopes.

Boulder Counts - Transport Distance

Boulder counts were made on various sizes of clasts throughout the esker complex. Clasts were divided into 3 major lithologies: (a) Goldenville Formation (argillites, greywackes, quartzites) (b) Plymouth Pluton Granite (unfoliated) (c) Brenton Pluton Granite (foliated) (see Geology Map, Figure 3, pg. 4 for source areas of lithologies).

To determine an accurate transport distance of macroscopic material, standard counts on various sizes of material would have to be performed at regular intervals throughout the esker complex on different lithologies. Such factors as the size of the source area, resistance of material, and mechanical weathering properties of each specific lithology would have to be considered. However, a general idea of transport distance for materials may be derived from random boulder counts on different lithologies present. Counts on cobble to boulder size material are depicted in Figure 17. Transport distance of materials show that for clasts counted, most had travelled less than 12 km, and it may be inferred from Figure 17 that much of the material has travelled less than 5-7 km. Granitic clasts which have travelled more than 12 km are well marked by their high degree of sphericity and roundness. The near absence of coarse clasts of material of White Rock Formation may be a function of the resistance of the material, and not the esker forming process. Boulders greater than 1 m in diameter were probably derived very locally, and the predominant glacial transporting mechanism of such boulders was probably not the esker-forming stream.

Clasts containing greisen-type mineralization in Plymouth granite and Goldenville Formation were observed in Eskers #1 and #2. These clasts (generally 10-25 cm, diameter) are believed to be derived from near the contact of the Plymouth Granite and Goldenville Formation. If this assumption is correct, some of the clasts travelled a maximum distance of 5 km.

Several clasts of White Rock Formation (mafic volcanics) and Brenton Granite (10-15 cm diameter) were observed in Eskers #1 and #2. These were well rounded and highly spherical, and by visual estimation composed less than 2% of the gravel to boulder size material. These clasts would have travelled a minimum distance of 14-20 km.

Clast Size	Location	# Clasts Counted	Indicator and percentage* of indicator clasts	Angularity and Sphericity	Minimum and Maximum** transport distance (± 1 km)
>1 m	Esker 1 (gravel pit)	10	Plymouth Granite - 60%	- moderate sphericity - sub-angular to sub-rounded	2 - 7 km
	Esker 2 (eroded exposure)	10	Plymouth Granite - 90%	- moderate sphericity - sub-angular to sub-rounded	0 - 5 km
50 - 75 cm	Esker 1 (gravel pit)	10	Plymouth Granite - 60%	- moderate sphericity - sub-angular to sub-rounded	2 - 7 km
	Esker 2 (eroded exposure)	10	Plymouth Granite - 70%	- moderate sphericity - sub-angular to sub-rounded	0 - 5 km
	Esker 4 (gravel pit)	10	Brenton Granite - 50%	- moderate sphericity - sub-rounded to rounded	4.5 - 12 km
40 - 70 cm	Esker 6 (eroded exposure)	20	Brenton Granite - 10%	- very high sphericity - well rounded	14.5 - 25 km
30 - 60 cm	Esker 5 (gravel pit)	20	Brenton Granite - 10%	- very high sphericity - well rounded	12 - 23 km
20 - 50 cm	Esker 4 (gravel pit)	20	Brenton Granite - 60%	- moderate to high sphericity - sub-rounded to rounded	4.5 - 12 km
7 - 15 cm	Esker 2 (dug sections)	30	Plymouth Granite - 30%	- moderate sphericity - sub-angular to sub-rounded	0 - 5 km
15 - 30 cm	Esker 2 (dug sections)	20	Plymouth Granite - 25%	- moderate sphericity - sub-angular to sub-rounded	0 - 5 km

* percentages expressed as percent of total number of clasts counted
** measured from closest and most distal bedrock source in an 'up-ice' direction

FIGURE 17

Results of boulder counts - transport distance
(see Figure 10 for esker locations).

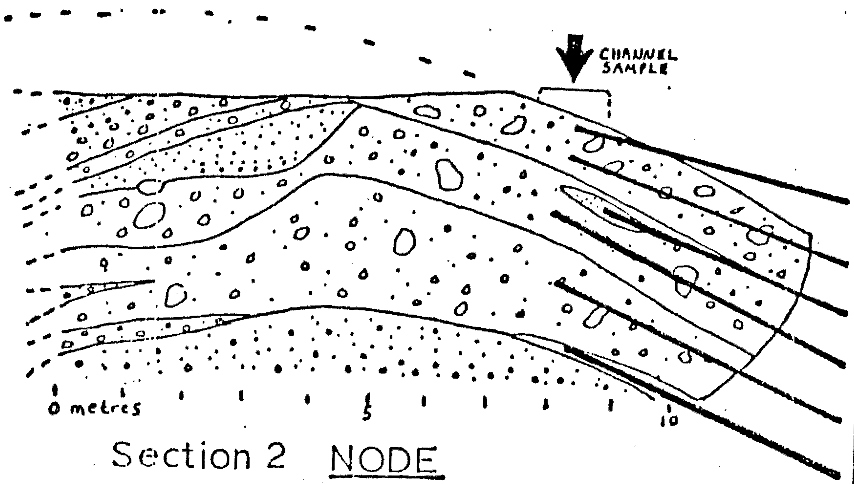
Sieve Analyses

Results of sieve analyses of material finer than -6Ø and sample locations are shown in Figure 19. Figures 20 and 21 show results expressed as cumulative percent.

It should be noted that sieve analyses and heavy mineral concentration in the -6Ø and finer material does not show a distinct difference between facies 1 and facies 3. The most distinguishing feature is the percentage of clasts coarser than -6Ø. Figures 20 and 21 show these differences in percentage of clasts coarser than -6Ø.

The stratigraphically uppermost units in all esker sections resemble tills elsewhere in the study area, however they are very low in clay content. This may be due to water working during deposition as a melt-out or flow till, and perhaps also due to error involved in laboratory procedures. Samples A-1 and A-2 show an unexplainably high percentage of heavy minerals. However, field observations reveal the unit to be distinctly till-like in nature (see plates 5 and 6).

Figure 22 shows the relationship between clay content and percent heavy minerals for all samples. Facies 1 (till) and facies 2 (sandy gravel) show a poor correlation between heavy mineral content and clay content. Facies 4 (gravelly sand) and facies 5 (sand) show

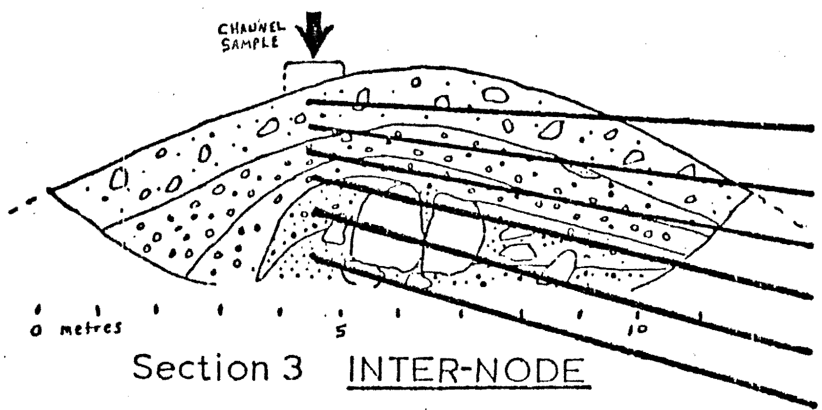


Sample Number	% Gravel	% Sand		% Silt		% Clay		% Heavy Minerals 2.5φ-3φ
B-1	58	30	(71)	9	(22)	3	(7)	4.49
B-2	55	29	(64)	14	(32)	2	(4)	4.07
B-4	15	28	(92)	5	(5)	2	(2)	17.62
B-3	74	21	(80)	4	(16)	1	(4)	6.39
B-5	73	22	(82)	4	(14)	1	(4)	9.51
B-6	51	47	(78)	1	(18)	1	(4)	7.88

(Material finer than -6φ)

Figure 19

Results of grain size analyses and percent heavy minerals from each unit. (Values in parenthesis represent sand-silt-clay fraction recalculated to 100%).



Sample Number	% Gravel	% Sand		% Silt		% Clay		% Heavy Minerals 2.5φ-3φ
A-1	58	30	(70)	10	(24)	2	(6)	7.15
A-2	60	28	(67)	11	(30)	1	(3)	9.33
A-3	78	16	(74)	5	(21)	1	(5)	9.87
A-4	84	10	(62)	5	(32)	1	(6)	6.87
A-5	26	71	(96)	2	(3)	1	(1)	12.07
A-6	1	93	(95)	5	(4)	1	(1)	10.35

(Material finer than -6φ)

Figure 18

Results of grain size analyses and percent heavy minerals from each unit. (Values in parenthesis represent sand-silt-clay fraction recalculated to 100%).

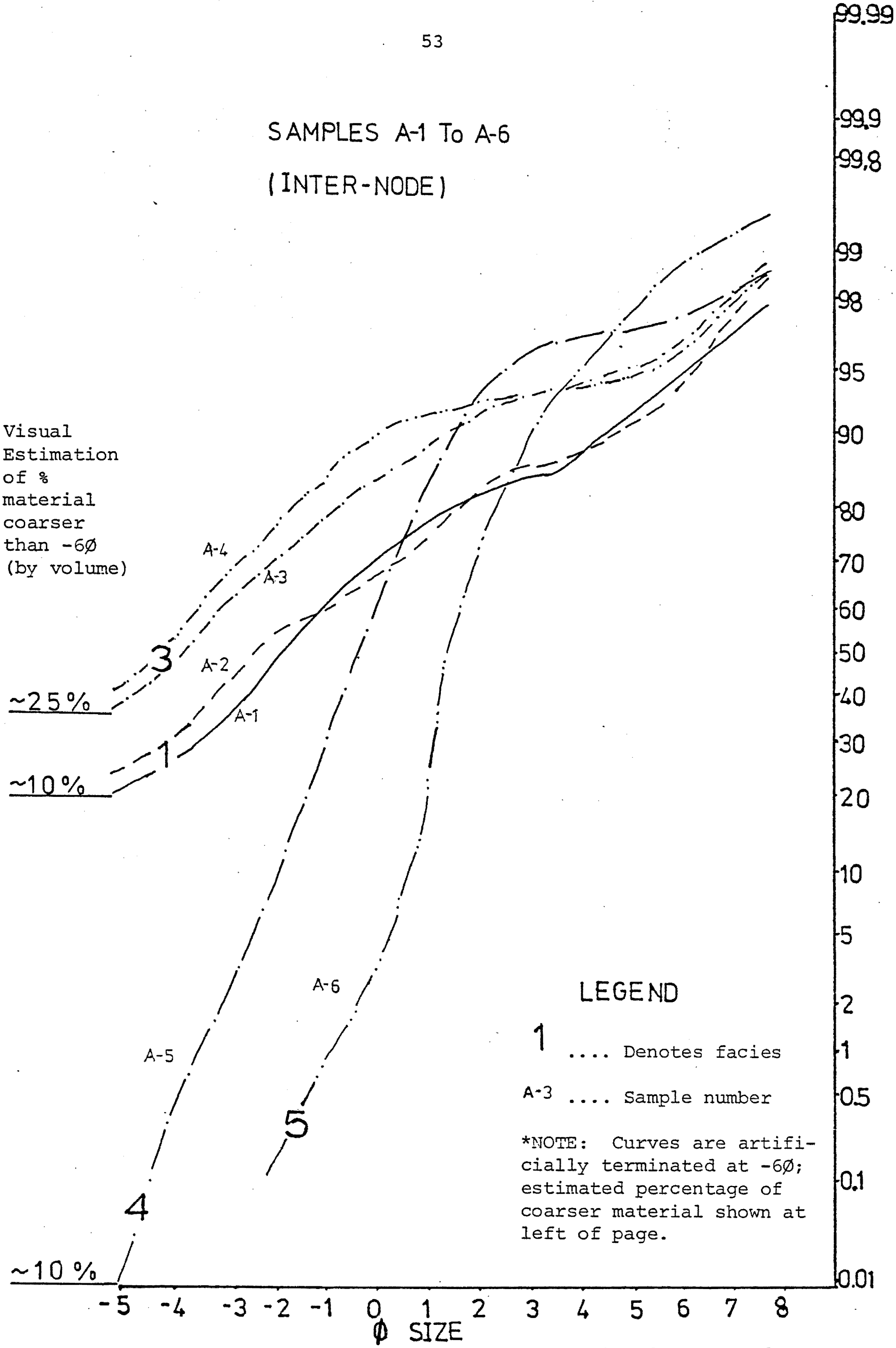


Figure 20 - Grain size analyses of units from section 3 expressed as cumulative % (see Figure 19 for sample location)

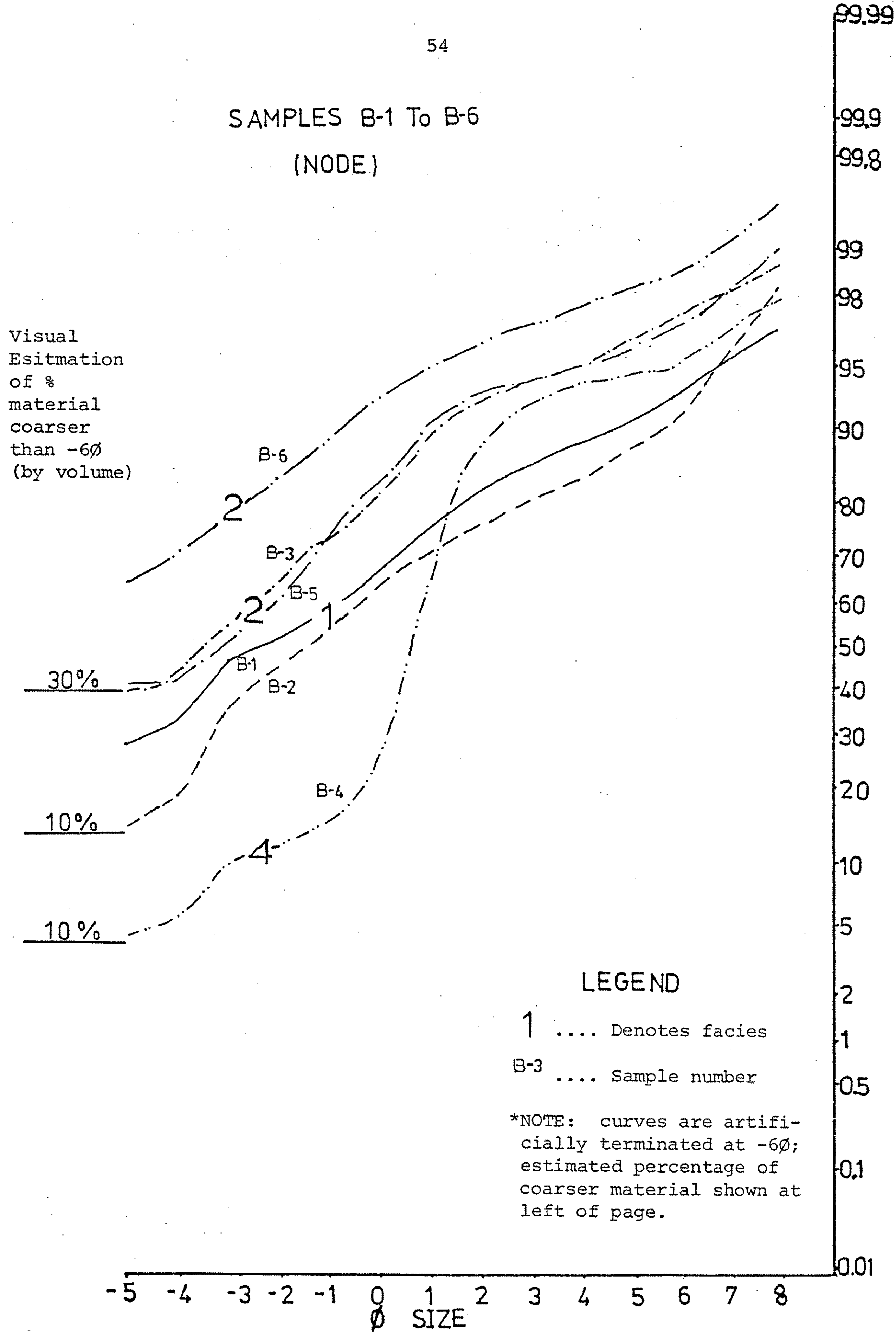


Figure 21 - Grain size analyses of units from Section 2 expressed as cumulative % (see Figure 19 for sample location).

a very good correlation between low clay content and high heavy mineral content. Facies 3 (pebble-cobble gravel) shows a good correlation between lower clay with increasing heavy mineral percentage, however the percentage of heavy minerals is somewhat less than those of Facies 4 and 5.

In summary, the highest concentrations of heavy minerals is found in the better sorted units containing high sand content.

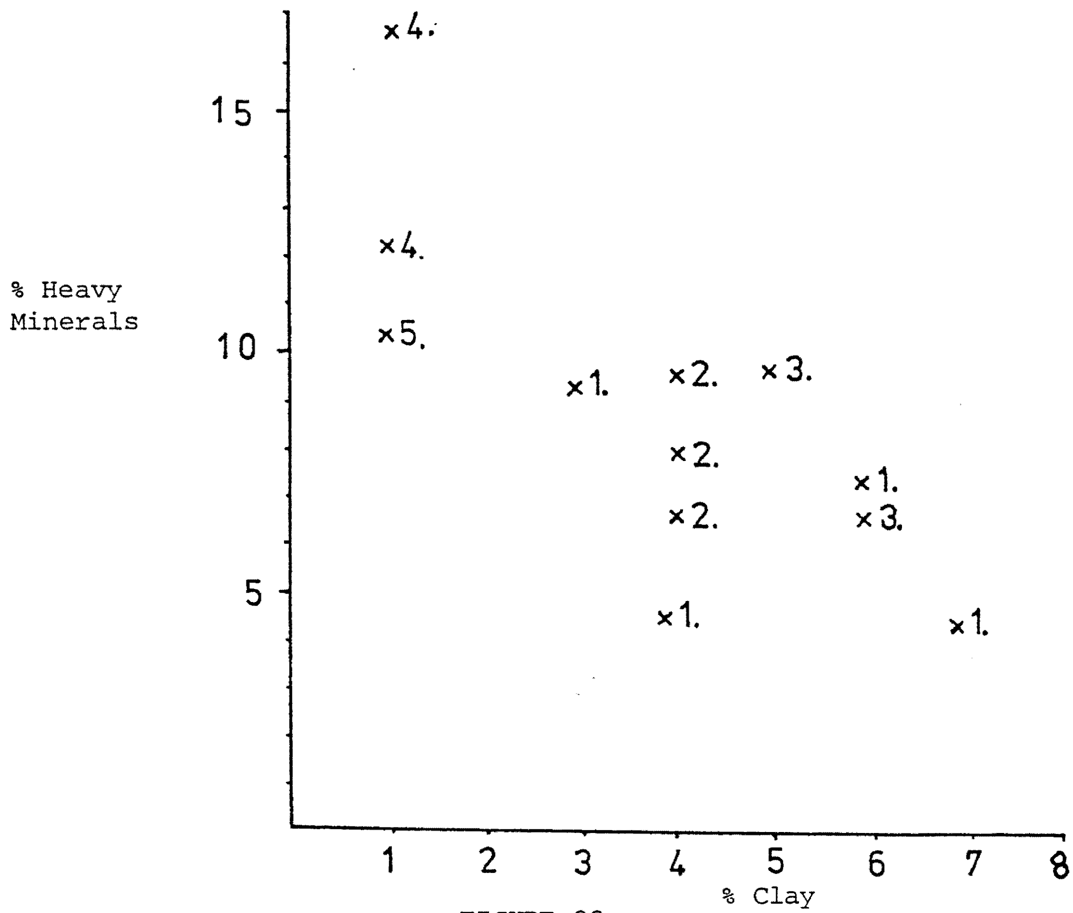


FIGURE 22

Relationship between heavy mineral and clay content (numbers refer to facies).

Vertical Variation in Pebble Lithologies - Pebble Counts

(see Figures 18-19 for sample locations)

Results of pebble counts from the vertical channel samples are presented in Figure 23. Four lithologies are recognized:

(a) Goldenville Formation (greywackes, argillites, quartzites)

(b) Plymouth Pluton granite (unfoliated)

(c) Brenton Pluton granite (foliated)

(d) Vein Quartz

Clasts of foliated Brenton granite were not present in the coarser than -5Ø and -4Ø size fractions, and not more than 2 pebbles were counted in the finer fractions of any one sample. As a result, weight percentages of Brenton granite clasts are not included in Figure 23.

Samples A-1 to A-4 (from Section 2, inter-node) show little variation in the percentage of different lithologies present. Granite abundances vary from 20% to 36%, increasing slightly to 44% in sample A-5. Quartz pebbles occur sporadically throughout the samples with abundances ranging from 1-5% when present.

Samples B-1 to B-6 (from Section 3, node) show slightly greater vertical variation in lithology percentages than does Section 2. Granite abundances range from 14% to 57%. Sample B-3 shows a relatively higher granite content, ranging from 48% to 57%. Quartz

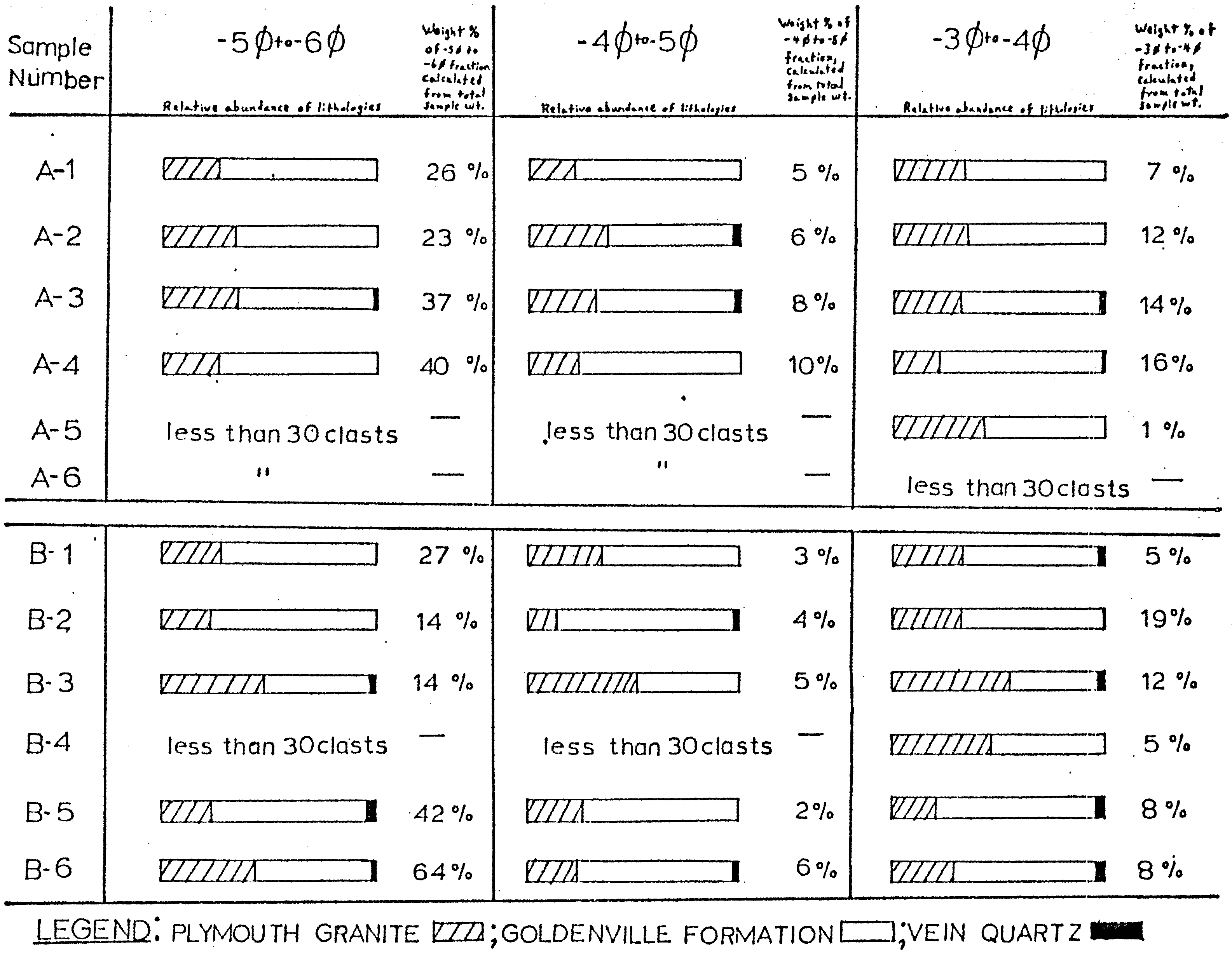


Figure 23

Results of Pebble Counts

(Sample numbers may be correlated with Figure 19) pebbles occur sporadically, ranging from 1-5% when present.

With the exceptions of quartz vein clasts, the three size fractions show little variation in the relative abundances of different lithologies for each sample. As clasts in the -3Ø to -4Ø size fraction are more numerous and are represented in most samples, they are probably the most consistent and reliable size fraction for pebble count work.

Clasts of vein quartz indicate the presence of a quartz vein in the upstream direction. Such veins are common in the Goldenville Formation, and three abandoned gold mines associated with quartz veins are found upstream from the study area. However, the exact location for the source of the quartz clasts is unknown.

Almost all lithologies present are a reflection of the underlying bedrock. Very few clasts (less than 2%) of Brenton granite is present in any sample. The closest contact of Brenton granite lies some 14 km to the north.

Vertical variation of lithological abundances may be due to :

(a) different source areas for materials composing the different units

(b) Lateral variations in clast abundances for each unit.

Heavy Mineral Investigations

Comparative results for heavy mineral counts in the plus 3Ø, 3.5Ø and 4Ø size fractions are shown in Appendix 5 and 6. Opaques, garnet, sphene, sillimanite, tourmaline, and rutile/cassiterite are heavily concentrated in the coarser fraction, while andalusite occurs most frequently in the finer fractions. Other minerals show considerable variation in some samples and much less in others, however the author feels that a study of the 2.5-3Ø fraction is adequate for the purposes of this study.

Total percentages of heavy minerals in the 2.5-3Ø fractions are shown in Figure 24 along with the number of scheelite grains counted. Abundances range from 4.07% to 17.26%. Nielsen (1976) reports an average abundance of 5-10% heavy minerals in the -1 to 4Ø fraction in tills in the area.

Percentages of the fourteen species of minerals counted are expressed in Appendix 7. The range of values and mean value for percentages are shown in Figure 25.

The majority of heavy minerals identified may be correlated with known occurrences in the local bedrock. The most abundant heavy mineral species present in the samples are opaques, garnet, and andalusite. The high percentage of opaques may be attributed to the known occurrences of sulphide mineralization within the study area as well as the widespread occurrence in the Goldenville and White Rock Formation (Sarkar, 1977, Taylor 1967). Garnet and andalusite occur in the local bedrock. The author observed garnet in several outcrops within the study area.

	Inter-node			Node		
	Sample number	% Heavy Minerals	# Scheelite Grains	Sample number	% Heavy Minerals	#Scheelite Grains
Top of Section	A-1	7.15	4	B-1	4.49	8
	A-2	9.33	4	B-2	4.07	4
	A-3	9.87	6	B-3	6.39	6
	A-4	6.87	4	B-4	17.62	8
	A-5	12.07	5	B-5	9.51	5
Bottom of Section	A-6	10.35	7	B-6	7.88	5

FIGURE 24

Percentage heavy minerals and number scheelite grains (see Figure 18 for sample locations).

Mineral	For SAMPLES A-1 to A-5 (section 3, 'inter-node') Range of Values (highest and lowest value) of samples A-1 to A-5	Average Value of samples A-1 to A-5	σ	For SAMPLES B-1 to B-5 (section 2, 'node') Range of Values (highest and lowest value) of samples B-1 to B-5	Average Value of samples B-1 to B-5	σ
Opaques	28 - 38%	32%	4	28 - 44%	36%	5
Garnet	12 - 30%	17%	4	9 - 30%	15%	8
Andalusite	14 - 29%	19%	6	10 - 17%	14%	3
Staurolite	9 - 13%	10%	2	6 - 15%	9%	3
Sphene	5 - 7%	6%	1	4 - 7%	6%	1
Augite	8 - 12%	9%	3	6 - 10%	7%	1
Amphibole	6 - 16%	10%	3	7 - 14%	10%	2
Apatite	2 - 9%	5%	2	6 - 12%	8%	2
Sillimanite	2 - 13%	6%	4	3 - 9%	6%	3
Tourmaline	3 - 9%	6%	3	3 - 9%	6%	2
Epidote	4 - 6%	5%	1	3 - 6%	5%	2
Rutile/Cass.	3 - 13%	7%	4	6 - 17%	12%	4
Zircon	not present	-		- not represented in all samples - constitutes 3% or less in any sample	-	

FIGURE 25

Percentages of heavy minerals present in Samples A-1 to A-5 and B-1 to B-5

(percentage opaques expressed as percent of total number of identified species, non-opaques are expressed as percentage of non-opaque fraction)

Zircon occurs in very low amounts or is virtually absent in the samples examined. These findings agree with those of Nielsen (1976) who reports a low abundance of zircon in tills in the vicinity of the White Rock Formation, and an absence of zircon in the area from which the samples are derived. Sarkar (1977) reports the presence of some zircon in the White Rock Formation.

Recent investigation by employees of Shell Canada Resources Ltd. reveal the presence of rutile, cassiterite and scheelite within the study area (personal communication with employees of Shell Canada Resources Ltd.). Sarkar (1977) also reports the presence of rutile in the White Rock Formation.

Nielsen (1976) ascribed the presence of most augite in tills of Western Nova Scotia to a derivation from Triassic Basalts of Northern Nova Scotia (see Figure 2, p. 3). However augite may be associated with the mafic volcanics of the White Rock Formation. Taylor (1967) reports augite in mafic dykes at Chebogue and Cranberry Point, both of which lie to the north of the esker complex (see Figure 3).

The existence of sillimanite in local bedrock is not verified, and known occurrences lie to the east of the study area. Nielsen (1976), believes that sillimanite in tills of the Yarmouth area is derived from local bedrock, and not from northwesterly ice movement.

Taylor (1967) reports the presence of amphibole, sphene, apatite, and epidote in the White Rock Formation, and occurrences of tourmaline, staurolite, epidote and apatite in the Meguma Group. Hornblende has also been reported in the Plymouth Granite.

In summary, it appears that heavy minerals are derived from the local bedrock of the study region. As discussed earlier, clasts of White Rock Formation meta-volcanics are extremely rare in the vicinity of the sample locations. However, many of the heavy minerals present such as zircon, augite, amphibole, sphene and some apatite may be derived from the White Rock Formation. Therefore, the finer material may have been transported farther than the coarser clasts.

Field observations indicate that the mafic volcanic rocks of the White Rock Formation have a relatively low resistance to mechanical weathering compared to the granitoid rocks. As a result, they may have been broken up into finer material which was further transported.

Summary and Interpretation

Material in the eskers is representative of the local bedrock. Finer material appears to have travelled somewhat farther than the coarser clasts.

The esker material shows a wide range in size distribution. Units within the inter-nodes tend to show a higher degree of sorting than the more massive, unsorted units in the nodes.

Fabric analysis and cross bedding suggest the esker forming stream flowed generally in a southerly direction.

A capping of till-like material indicates the eskers formed in an englacial or subglacial tunnel. The high amount of unsorted material representing local bedrock and the fact the eskers generally follow areas of low relief, suggests that formation in a subglacial environment is most acceptable. The presence of boulders which deform underlying bedding of finer, well sorted units indicates some material is probably derived from the overlying ice. This is further evidence of a subglacial environment (see plate 3).

With the exception of minor cross bedding, load structures, erosive contacts and some degree of sorting, few sedimentary structures are visible in the esker material. It appears deposition of node material took place rapidly with periods of non-deposition and erosion between units.

Deposition of node material appears to be controlled by the energy of flow of the esker-forming stream, indicated by erosive contacts and presence of small, well sorted channels between major units. Major fluctuations in energy levels may be due to the formation of a hydrostatic head which operates when the tunnel flows full during times of maximum water supply. Deposition would take place rapidly, and is probably the result of loss of the hydrostatic head upon leaving the enclosed tunnel and entering a less confined area. However, upon loss of the hydrostatic head, the esker forming material was still under the ice, perhaps in a cavern of larger diameter than the tunnel.

Meltwater flowing from the tunnel would tend to erode some of the esker material, especially on the flanks and would probably be added to by melting of overlying ice. Discontinuous, erosional channels are common in many units of the eskers.

Mode of Formation

None of the common models proposed for the formation of eskers can be directly applied to the eskers in the study area. Absence of varves, large scale cross bedding, foresets, climbing ripples, etc. suggest these eskers to be somewhat different than most eskers recorded in literature. A covering of till and mounds of material which lack pronounced deltaic features make the eskers of the study somewhat unique.

Two proposed models for the formation of eskers (pg. 28) may be applied partially to eskers in the study area. These are:

(1) Formed as a series of deltas composed of material transported through subglacial tunnels and deposited at the ice margin. Each delta is added in an upstream direction and represents one year of ablation.

(2) Deposition as a series of nodes in a manner, resembling a mud flow or debris flow in an open ice channel, followed by relatively quiet water deposition between nodes. Each node represents the seasonal discharge of debris during periods of high meltwater discharge, and esker material is added in an upstream direction.

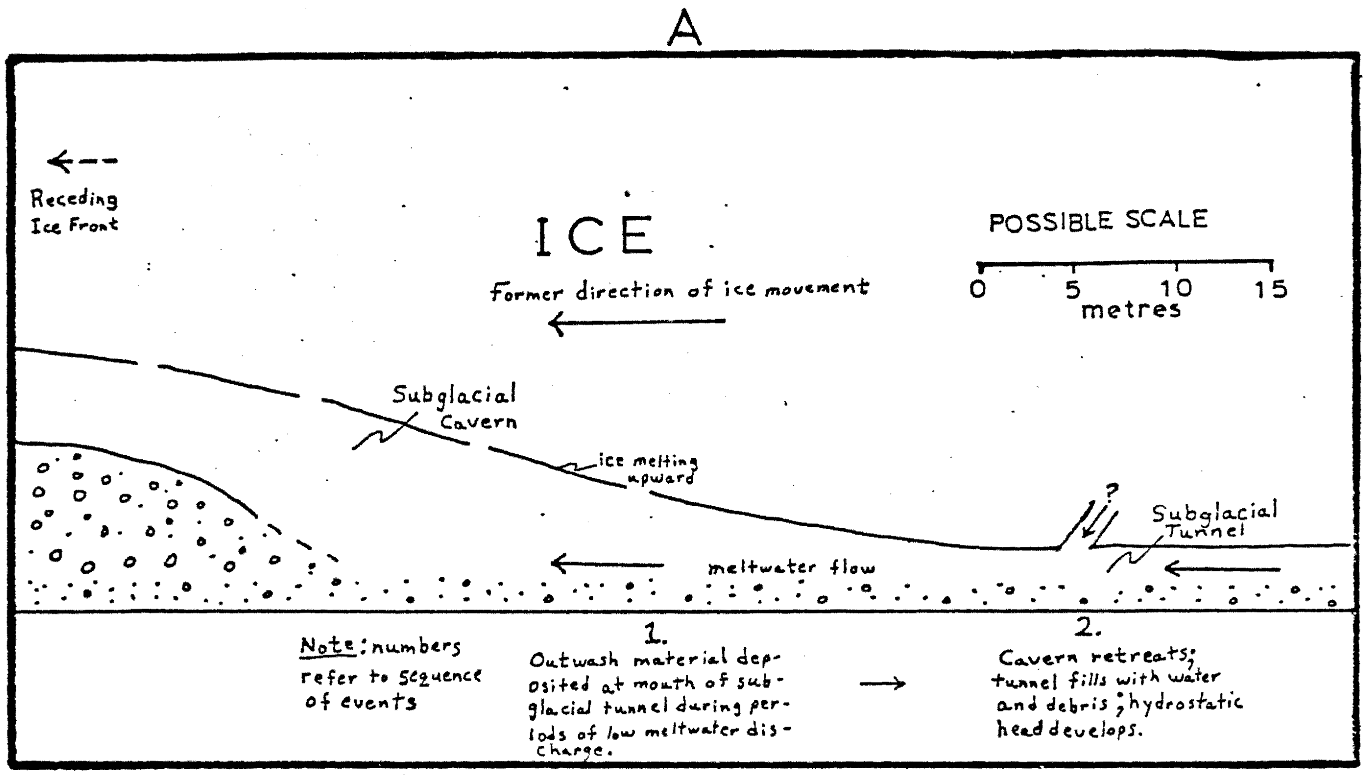
Although the two models mentioned above account for the formation of nodes or beads of esker material, there are several characteristics which are not accounted for. The absence of pronounced deltaic features in the internal structure of the eskers rules out deposition as a series of deltas. The covering of till negates the possibility of deposition in an open ice channel. Also, an open ice channel would not permit development of a hydrostatic head which would be capable of transporting large amounts of material at one time similar to a mud or debris flow which appears characteristic of node material.

Because of the many variables involved during deposition of eskers, the author feels that no one model absolutely describes the mode of formation of all material in an esker complex. It is conceivable that eskers may be polygenic as a result of variations in depositional environments. However, using general principles applied to other models of esker formation, the author feels a suitable model may be applied to most esker material in the study area. Following is a brief description of a possible mode of formation.

During deglaciation, a tunnel developed at the base of the ice and meltwater was piped toward the ice terminus. Such tunnels in modern day glaciers are described by Price (1973).

As the ice melted, the part of the tunnel nearest the ice terminus became larger in diameter due to increased melting as a result of closer contact with the outside environment. As the ice receded each year, so did the large cavern created by the melting of ice around the distal part of the tunnel. Outwash gravel was deposited in the tunnel and cavern by meltwater streams. During seasons of high meltwater discharge, water saturated debris underlying the ice was forced into the subglacial tunnel due to the pressure created by the overlying ice. Further accumulation of meltwater filled the tunnel and developed a hydrostatic head which moved the material accumulated in the tunnel downstream much like a debris flow or mud flow. Upon leaving the confines of the tunnel and entering the large cavern near the ice terminus, the hydrostatic head was lost and the massive units composing the nodes were deposited. Between intervals of massive deposition, meltwater continued to flow through the tunnel sorting some of the node material and depositing it in the inter-nodal area downstream. When the tunnel had again filled with water and debris more massive material was deposited in the cavern. As ice continued to melt at the sides of the cavern, meltwater was channelled towards the sides of the esker material eroding the edges. This resulted in slumping of units giving an anticlinal appearance in cross section.

During seasons of low meltwater discharge and prior to further deposition under influence of a hydrostatic head the cavern retreated farther and finer material was deposited upstream. Some cross bedding was developed in the inter-nodal area during this time of relatively quiet deposition. Melting ice from the top of the cavern added water and glacial debris to the underlying material creating small channels



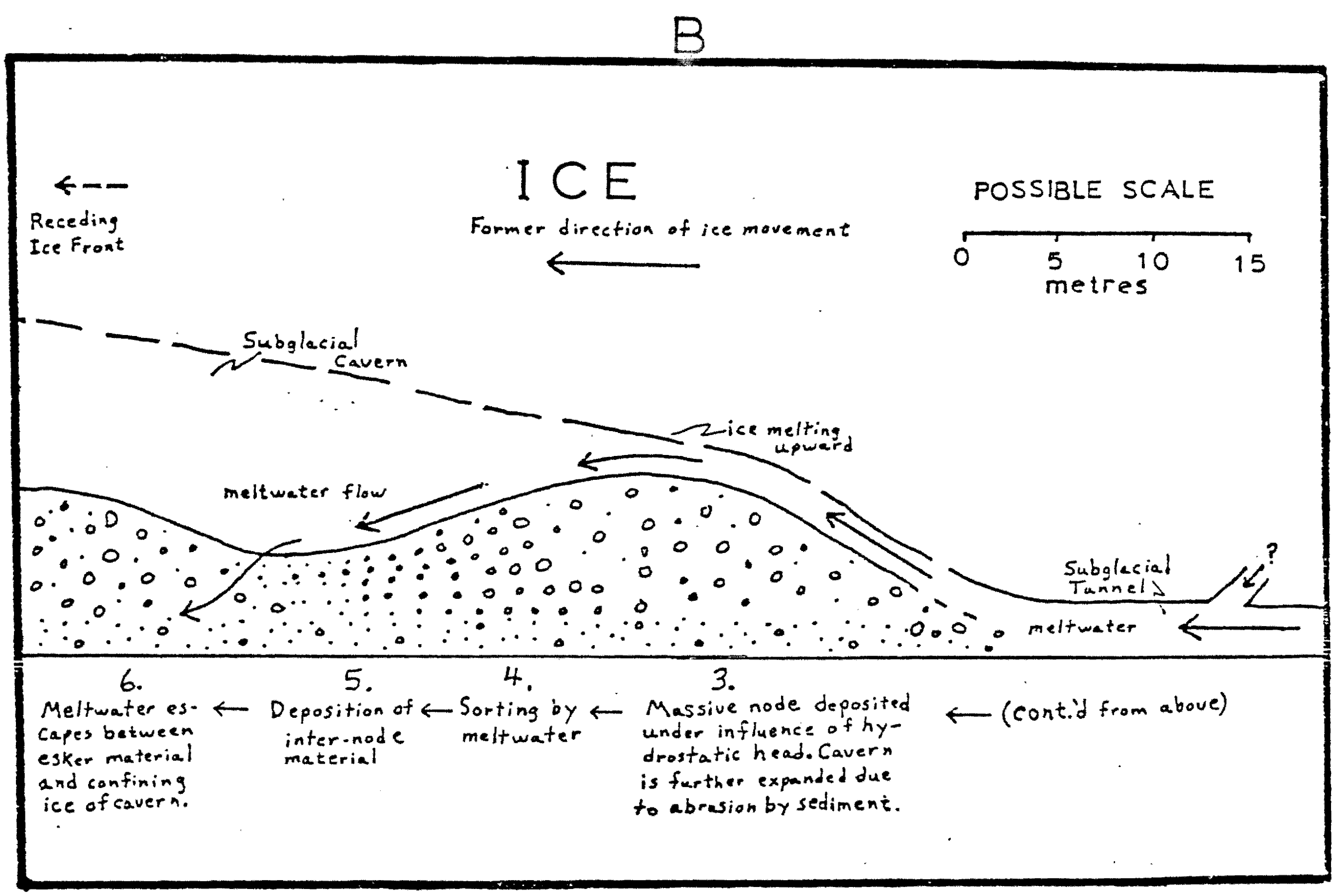


FIGURE 26 - Generalized model for esker-forming process.

and load structures in the underlying units. The cavern continued to retreat, and the next year when meltwater increased more outwash followed by massive deposition formed another node upstream.

Upon melting of the remaining ice near the glacier terminus, a layer of ablation till low in clay content due to basal melting and some degree of water working was deposited over the previous existing units.

PLATES

(esker numbers may be correlated with Fig. 10 for location)

PLATE 1

Cross section of esker material cut by seawater (Esker 2)

PLATE 2

Esker material bounded by foreshore flats, (centre of photo) (Esker 2)

PLATE 3

Boulders in well-sorted units, deforming underlying bedding. Source of boulders is probably from overlying ice (Esker 4).

PLATE 4

Post depositional slumping or minute faulting in well sorted sands from deep within inter-node (Esker 2).

PLATE 5

Poorly sorted till (in area of hammer) overlying better sorted units (dark layer) near esker flank. Photo from gravel pit (Esker 3).

PLATE 6

Thin covering of till (above arrow on shovel handle) underlain by a channel of well sorted sand. Photo from cross section of esker exposed in road cut (Esker 3).

PLATE 7

Contact between cobble-boulder gravel and underlying outwash material. Note alignment of clasts in centre of photo due to compression by overlying material (Esker 5).

CHAPTER V

GEOCHEMICAL SAMPLING OF ESKER MATERIALS

Methods

Two eskers were geochemically sampled, one 'up-ice' and one 'down-ice' from known areas of mineralization. Esker 4 (see Figure 10 for location) is the northernmost esker in the esker complex, and there are no known occurrences of mineralization north of this area. Esker 2 (see Figure 10 for location) lies 'down-ice' from several occurrences of Cu, Pb, Zn, Sn, W, and Ag mineralization. Mineralized clasts have been found in Esker 2 and in adjacent tills, while Esker 4 and adjacent tills have not revealed the presence of mineralized clasts. Both areas have been extensively prospected (personal communication with employees of Shell Canada Resources).

Sixty-eight samples were collected at 50 m intervals at the base of the esker flank (see Appendix 8 for method of sample collection).

To aid in locating sample sites and interpretation of results, pictures of the two eskers were taken from an airplane. Photos were enlarged to 8" x 10" and joined together, giving a scale of approximately 1:2200. For final drafting of esker maps, measurements taken on eskers were compared with those shown on esker photographs and appropriate adjustments were made. This method of mapping is rapid, inexpensive and very effective for interpreting geochemical data from unconsolidated sediments.

Orientation Studies

Orientation studies for geochemical sampling of eskers in the study area were carried out by consultant Dr. Hubert Lee.

Along the base of the flanks of eskers in the study area there exists a placon or iron oxide layer 20-60 cm below the surface. This layer represents the boundary between the vadose water and more neutral groundwater. Theoretically, the concentration of ions which collect at the vadose-groundwater interface is a reflection of the abundance of mineralized clasts in the esker material. The ions are concentrated as a result of rapid change in Ph upon encountering the groundwater.

Measurements of Ph from above and below the placon are shown in Figure 27 and location of sample sites relative to esker material is shown in Figure 28.

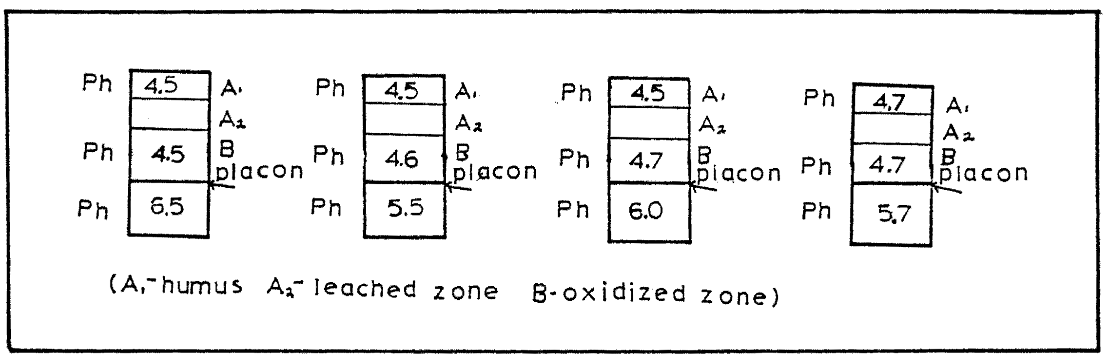


Figure 27

Ph measurements from above and below the placon at appropriate sample collecting locations at base of esker flank.

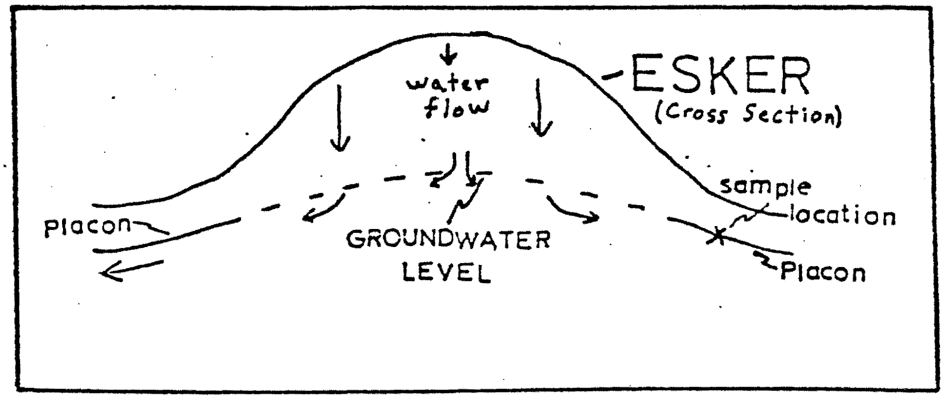


FIGURE 28

Cross section of esker showing location of placon sample horizon relative to esker material (location of groundwater level and placon position based on diagram by Tilsley (1977, p. 27).

Orientation results from the -80 mesh and -250 mesh are shown in Figure 29.

		(PPM)				
Sample No.	Fraction	Cu	Pb	Zn	Ag	As
X_1	-80	6	13	17	0.3	37
X_2 (duplicate of X_1)	-250	7	19	22	0.3	51
Y_1	- 80	8	11	19	0.2	34
Y_2 (duplicate of Y_1)	-250	18	26	31	0.3	61
Z_1	- 80	4	20	23	0.5	27
Z_2 (duplicate of Z_1)	-250	5	18	24	0.5	16

Figure 29

Comparison of Cu, Pb, Zn, Ag and As concentration in the minus 80-mesh and minus 250-mesh fractions.

Based on results displayed in Figure 29, the minus 250 mesh fraction was chosen for analysis. Samples Y_1 and Y_2 were collected close to known occurrences of mineralized clasts, and results show a good correlation between all elements except Ag in the minus 250 fraction. The concentration of Ag does not appear to be a function of the two size fractions.

Sample analyses were performed for Shell Canada Resources Ltd. by Atlantic Analytical Services Ltd., of Saint John, New Brunswick.

Procedures for sample preparation and analysis:

(1) samples dry sieved to minus 250 mesh

(2) For Cu, Pb, Zn, Ag; (a) .2 gms of sample were boiled for 2 hours in HNO_3-HCl

(b) Volume made up to 10 ml and analysed by atomic absorption

(3) For As; colorimetric

Geochemical Results

Samples locations and geochemical results are shown in Figures 30-35.

Error

Possible error involved in the study falls into two categories (a) error in lab procedures in determining results (b) variations in environmental conditions such as possible effects of seawater.

Three duplicate samples from various locations were analyzed to determine precision of laboratory results. Error displayed in results for Cu, Pb, Zn and As are shown in Figure 36.

Precision for copper values have been assessed at ±6ppm, lead ±4 ppm, and zinc ±5 ppm. Low values of Cu and Pb (under 10 ppm) show a much higher percentage of error than higher values.

Error for As values appear to increase with increasing value. Therefore, error was determined from the graph shown in Figure 36, and expressed as a function of the value obtained by the lab.

Samples from esker 4 were collected on two different occasions. Samples were first collected at 100 m intervals, and then at 50 m intervals. Results obtained on the two traverses are generally duplicated, with the exception of As which showed non-detectable in samples from the first traverse, and gave detectable but fairly low values on the second traverse. Therefore lower values of As may be somewhat erratic.

Two of three duplicate samples analyzed for Ag showed non-detectable results, while the third showed values of .5ppm and non-detectable. Therefore, values for Ag, especially in the lower values may be highly erratic.

Some environmental aspects may have an adverse effect on results. As parts of both eskers occur in areas of foreshore flats, they are subject to effects of seawater. Groundwater levels and

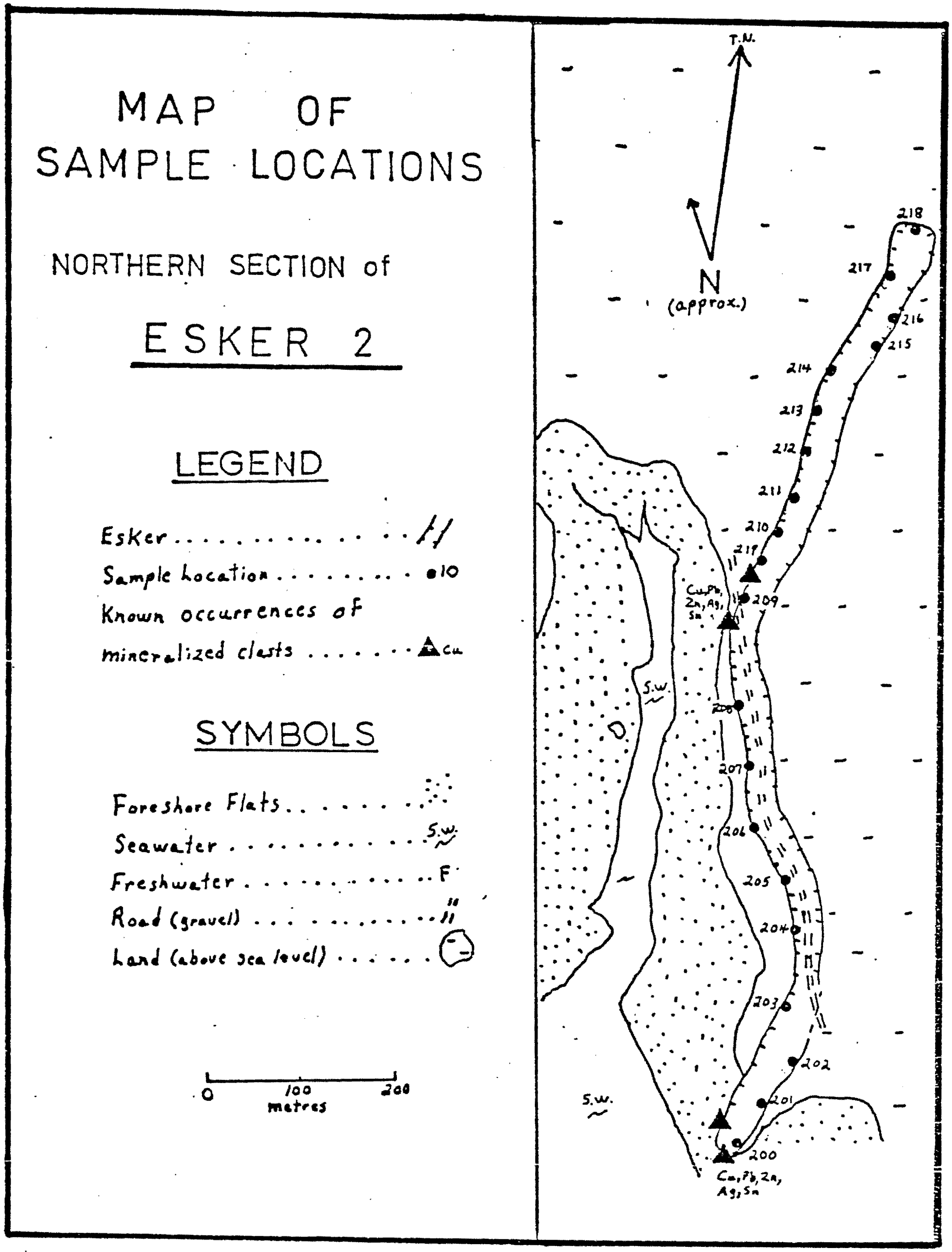


Figure 30

Sample locations on northern section of Esker 2 (see Figure 10 for esker location - correlate with Figure 31, next page).

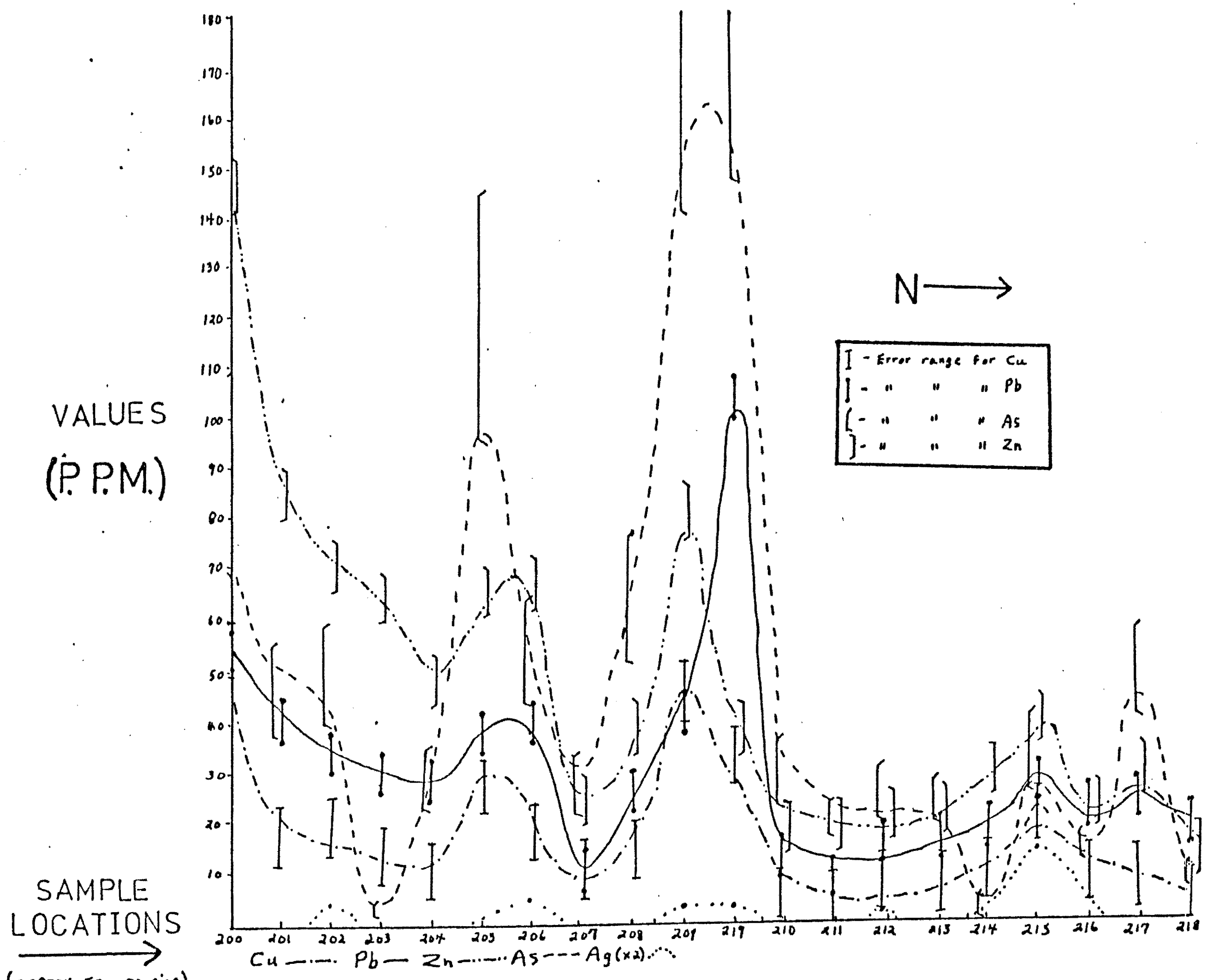


Figure 31

Geochemical results from northern section of Esker 2.

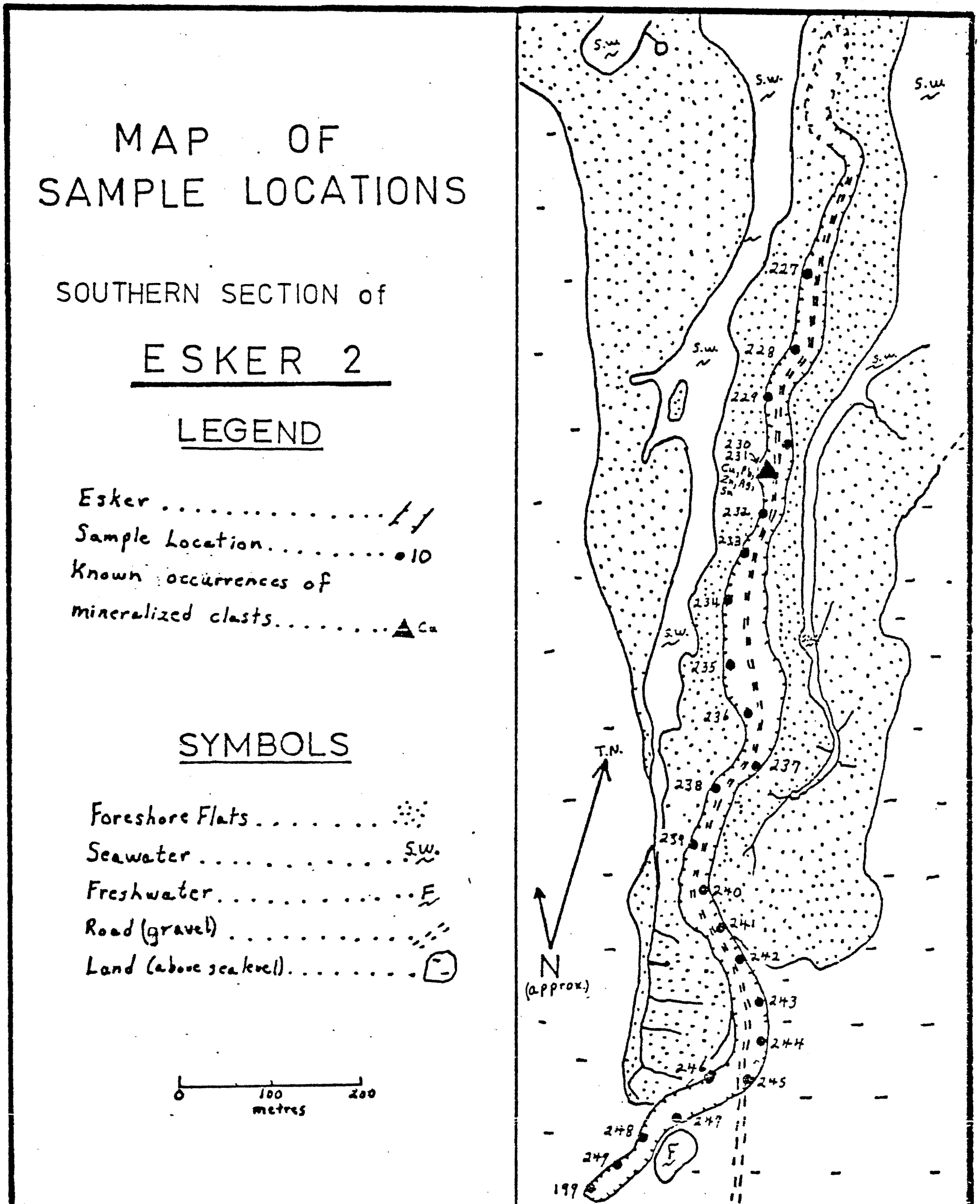


Figure 32

Sample locations on southern section of Esker 2 - see Figure 10 for location (correlate with Figure 33, next page)

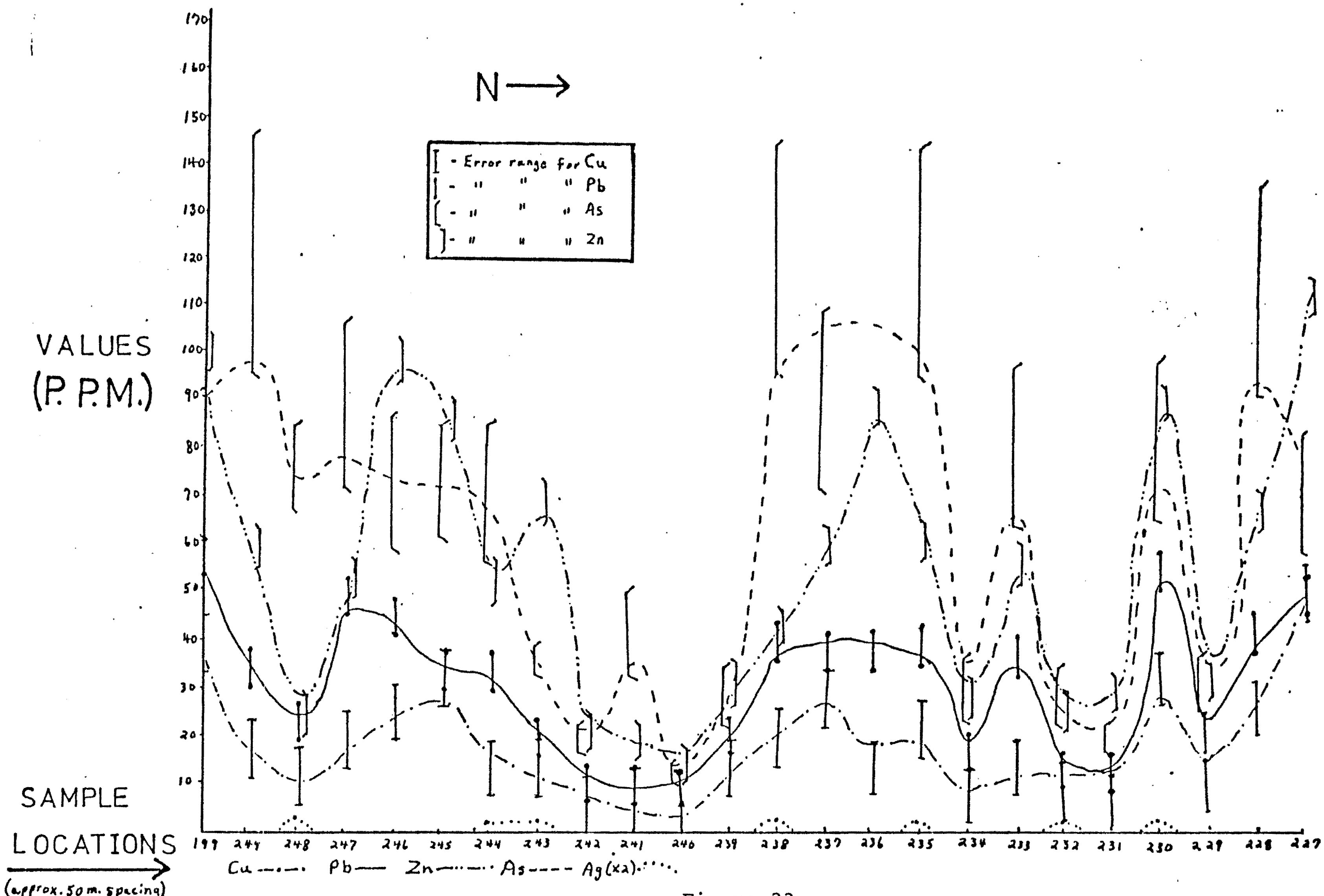


Figure 33

Geochemical sample results from southern section of Esker 2
(correlated with Figure 32)

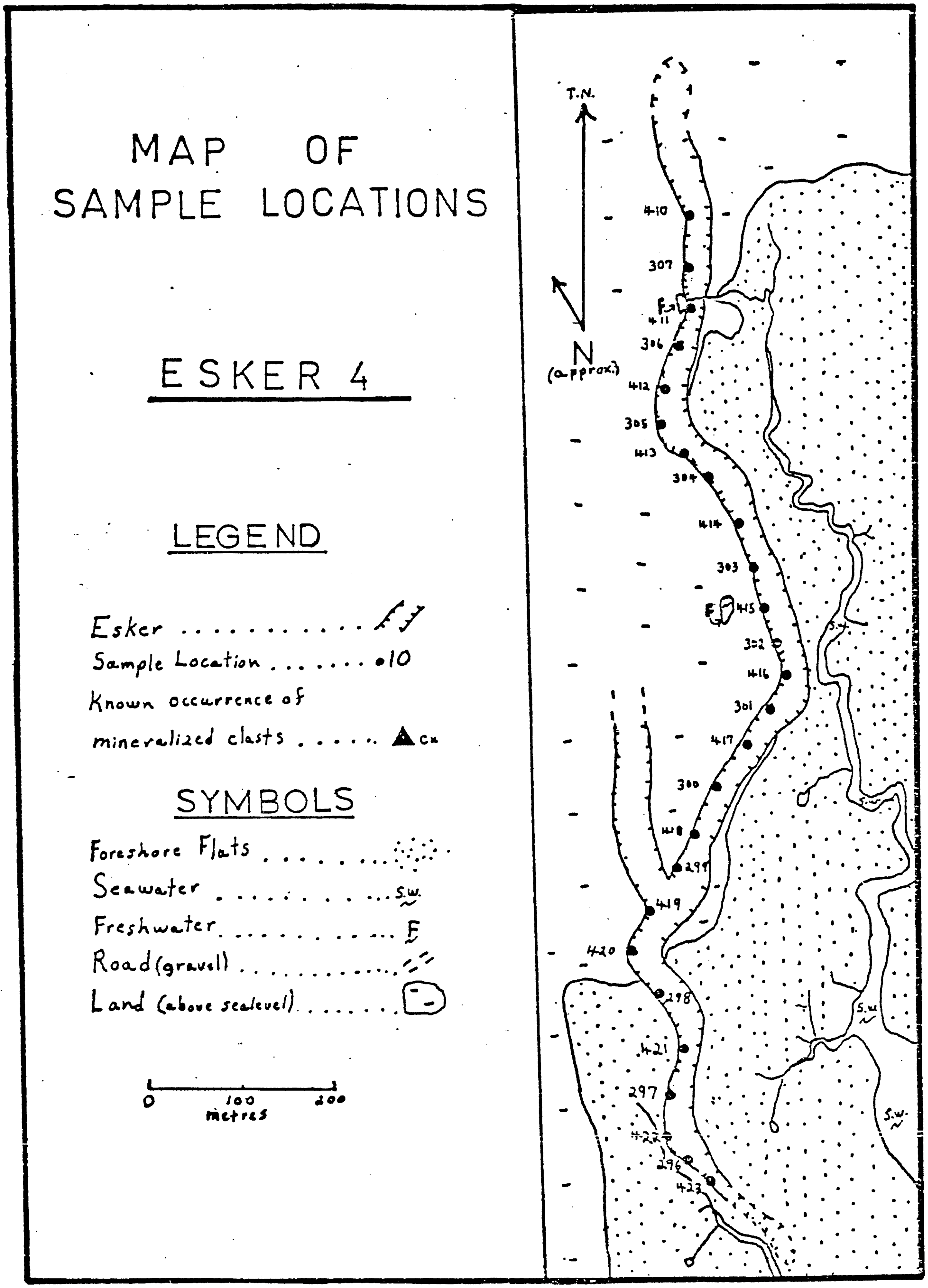


Figure 34

Sample locations for Esker 4 - see Figure 10 for location of esker (correlate with Figure 35, next page)

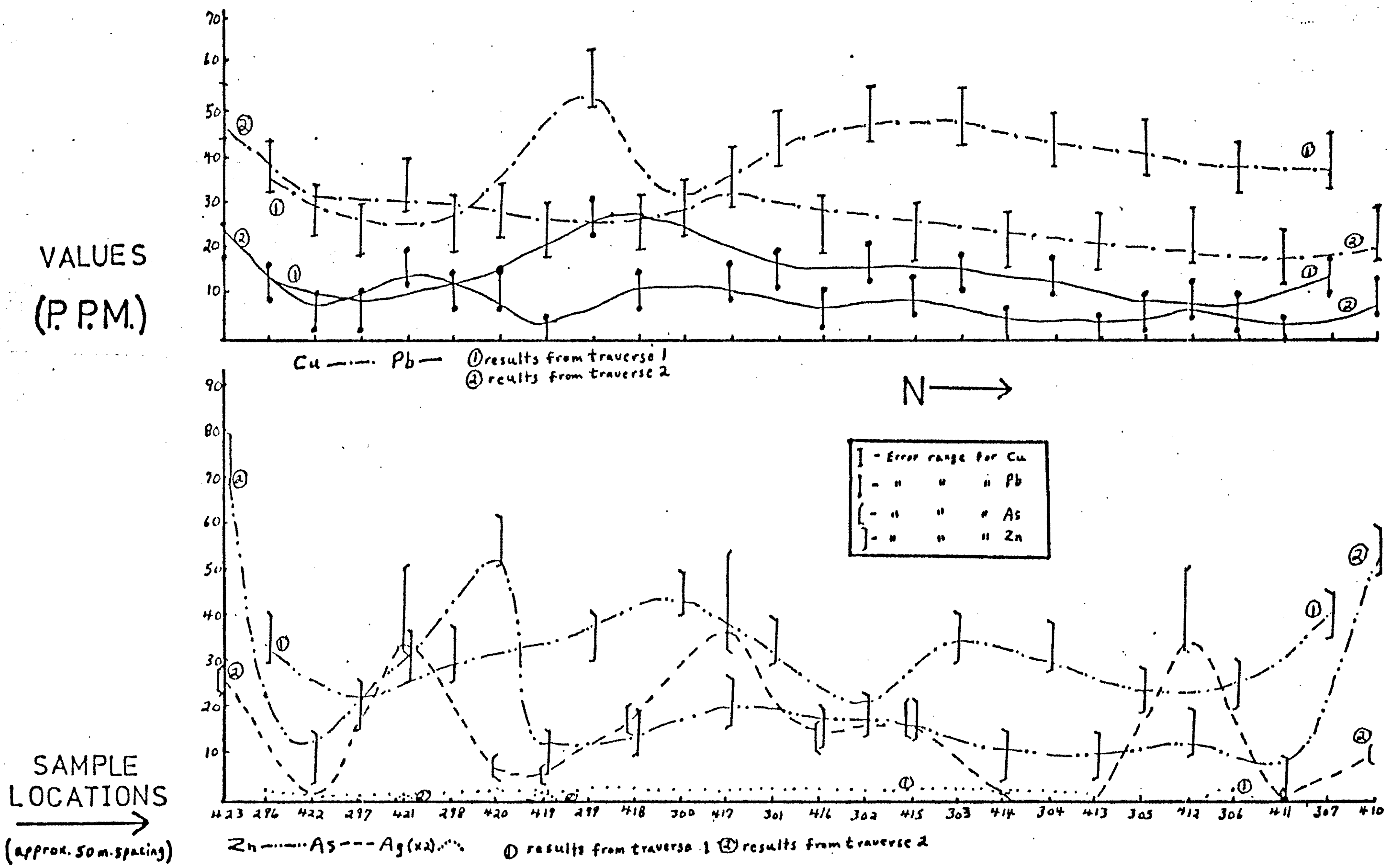


FIGURE 35 - Geochemical sample results from Esker 4 (correlated with Figure 34).

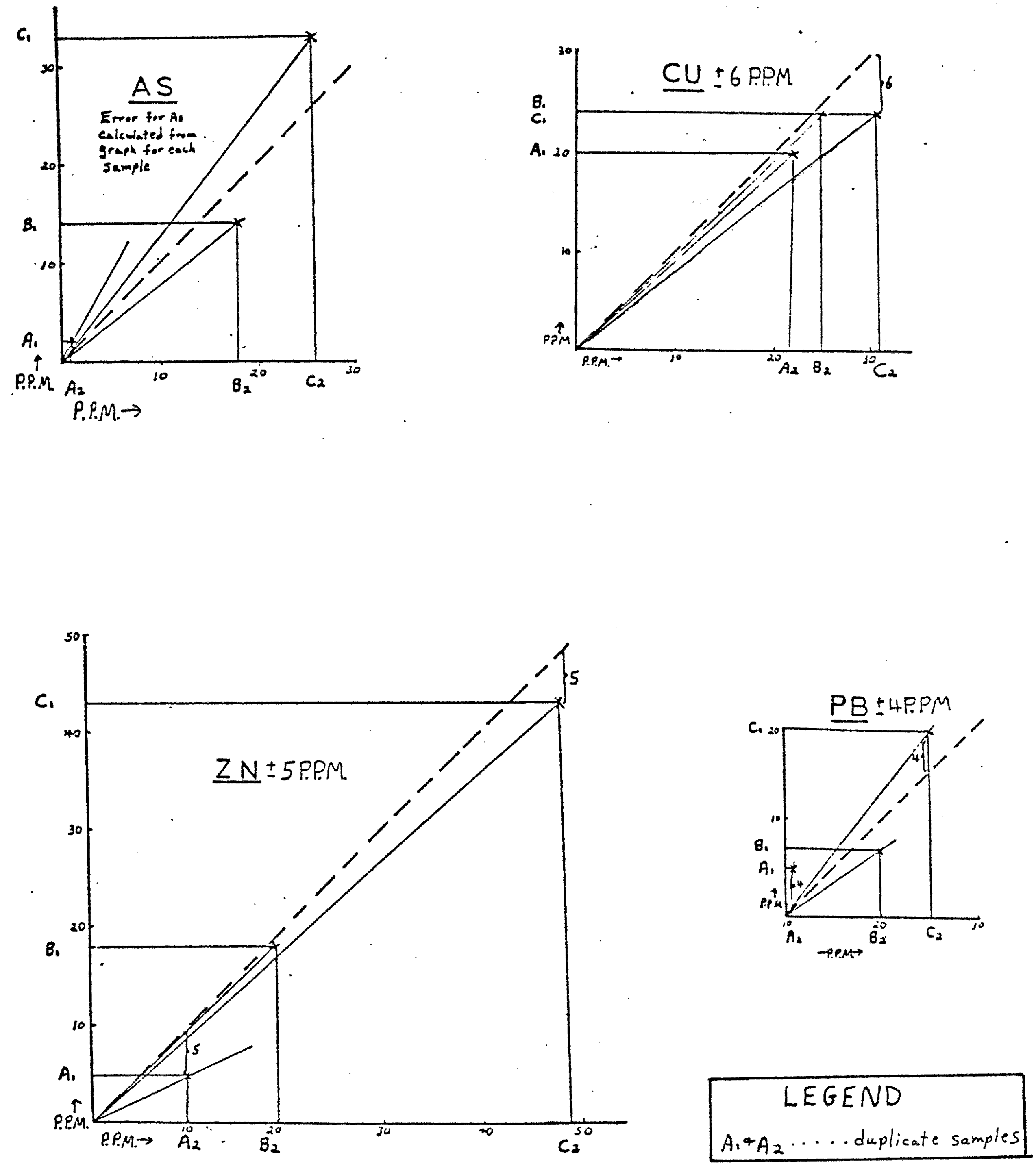


FIGURE 36

Calculation of error for values from geochemical analyses.

composition may also be effected. However, both eskers contain areas high enough above sea level that groundwater would not be affected (Figures 30, 32, 34).

Discussion of Geochemical Results - Esker 2

Elements of Cu, Pb, Zn, and As show a strong relationship throughout the esker and peak abundances of all elements are generally correlative. Pb, which generally has rather low mobility (Levinson, p. 43) relative to other elements shows a strong relationship with copper.

Ag occurs sporadically throughout the length of the esker, and all abundances may lie within the error range except for several sites which shows a peak abundance of 7 ppm. This occurrence is found at sample site 215 (see Figure 31) in an area which is fairly well protected from effects of seawater.

Most Cu values do not appear anomalous, however peak abundances correspond with what appears to be anomalous values of other elements. High values of As, Pb, Cu, and Zn in the vicinity of samples 207 to 219 (Figure 31) indicate abnormally high results. Results to the south also give this indication. Mineralized clasts containing Cu, Pb, Zn and Sn were discovered in esker materials in this vicinity. The high results in this area may therefore indicate the presence of mineralized clasts in the area.

High results in the vicinity of samples 238 to 235 (Figure 33) of As and Zn may also be anomalous. Cu and Pb values show a slight peak but do not appear anomalous.

High values of Zn and As are present on the southern tip of the esker.

Some rather high results are obtained in the vicinity of samples 234 to 227 (Figure 33). These results show a high variation between consecutive samples which may be due to effects of seawater. Because several consecutive high results in one area are not present, results from this vicinity are not considered anomalous.

Esker 4

Results from traverses 1 and 2 are generally duplicated by each other with some minor variations.

Elements of Cu and Pb show a strong relationship (Figure 34) with some minor fluctuations in the area of samples 300-299. However, these fluctuations do not appear anomalously significant.

Zinc is roughly correlative with other elements in most cases with some higher than average values at the southern end of the esker. However high values are represented in each case by only one value. Therefore, although a higher than normal value for Zn is present in the vicinity of samples 420 and 423, they are not considered anomalous.

Values for As were poorly duplicated on the second traverse, perhaps due to the relatively low abundance. All values from the first traverse revealed non-detectable quantities of As while the second traverse showed values over 40 ppm in some cases. Although As shows some fluctuation, peak abundances are unlikely to be anomalous, and generally are not correlative with other elements.

In all locations, abundances of Ag are low and fall within the error range.

In summary, it does not appear that any of the values from esker 4 are anomalous.

Discussion of Sampling Technique

The principle behind this type of geochemical sampling involves the fixation of mobile elements as a result of change in Ph. Meteoric waters take on humic acids which leach ions from sulphide bearing boulders in the esker material. Mobile elements like Cu, As, and Zn move in the vadose zone downward and outward toward the base of the esker flank. When these elements contact the more neutral groundwater, the mobile elements become fixed. The fixation of elements takes place over a relatively narrow vertical range, and concentrations of elements are a reflection of the amount of mineralized clasts within the esker (Lee, 1977, written communication).

In the study area, the narrow vertical zone where the vadose water meets the more neutral groundwater is well marked by the presence of a placon.

The Placon

Placosols, which develop in regions of cool moist climate have been described by Tilsley (1977). They consist of a humified organic layer above a leached near-surface soil horizon, underlain by an iron oxide layer which is impervious to water. This iron oxide layer is known as the placon, and is located 20 to 150 cm below the surface. The placon is almost completely impervious to the vertical migration of water and acts as a barrier to migrating metals, complexes and ions. Because of the impervious nature of the placon, two separate hydrologic systems are developed.

Above the placon, soil conditions are strongly acidic, and as a result base metals in the minus 80 mesh fraction are depleted or absent. Conditions below the placon are generally reducing and neutral to basic, resulting in relatively stable conditions for metals (Tilsley, 1977).

In the study area the placon exists 20-60 cm below the surface at the base of the esker flanks and is 10-20 cm thick. Its presence provides an easily recognizable horizon for collecting geochemical samples.

As some sample sites are in the vicinity of seawater, salt water spray may have some effect on the results of geochemical sampling.

Sea water would introduce Na and Cl, and in areas very close to seawater there may be a change in Ph of the groundwater. Studies to determine the effects of seawater were not carried out, however parts of both eskers are subject to effects of seawater and the author feels a comparison of geochemical results from the two eskers is valid.

Summary

In summary, the esker which is known to contain mineralized clasts shows some relatively high values of As and Zn. In areas of high As and Zn concentration, Cu and Pb are present in above average abundances. The esker 'up-ice' from mineralized areas gives little indication of anomalous values.

Based on the limited data provided, an indication is made that measurement of element concentrations in the hydromorphic dispersion zone of eskers in the study area reveals the presence of mineralized clasts. However, due to possible effects of seawater on elements and groundwater, further investigation would be required before the technique were recommended for systematic geochemical sampling elsewhere.

CHAPTER 6

ESKERS AS A PROSPECTING MEDIUM FOR MINERAL EXPLORATION

It is shown in Chapter IV that macroscopic esker material in the study area is derived from local bedrock. Heavy minerals present are also a reflecton of local bedrock although the finer fractions may have travelled farther than the coarser clasts.

The nodes of esker material probably formed in subglacial tunnels under the influence of hydrostatic pressure during seasons of high meltwater discharge. Inter-node areas appear to be derived from the sorting and deposition of node material.

Evaluation of Eskers for Reconnaissance Prospecting of Minerals in Southwestern Nova Scotia

Eskers of the study area contain a high abundance of macroscopic clasts which represents all major lithologies of the study region. Most coarse clasts have travelled less than 12 km, and clasts of White Rock Formation metavolcanics appear to be more readily broken up than clasts of granite. Mineralized clasts bearing sulphides of Cu, Pb, and Zn would be expected to have travelled relatively short distances, as esker forming processes would tend to break them down into finer components.

Gravel pits are common in eskers of the study area and provide an excellent location for reconnaissance prospecting for mineralized clasts. Abundances of mineralized clasts found in different eskers can be utilized to aid in establishing parameters for more detailed prospecting techniques.

Sandy, well sorted units have greater concentrations of heavy minerals, and the author suggests sampling of these units would be most useful in determining the presence of such minerals as sulphides and cassiterite in the finer fraction.

In areas of thick vegetation and poor exposure, prospecting for minerals in the manner described above would require extensive digging to expose esker materials. Measurement of elements in the hydromorphic dispersal zone of esker materials in the study area suggest that mineralized clasts in esker material are detectable with geochemical sampling techniques. This type of geochemical sampling is relatively inexpensive and rapid, and further investigation for use in areas of poor exposure is recommended.

Eskers are widely distributed in Southwestern Nova Scotia. North of the study area eskers trend generally E-W, and to the east of the area they trend S-SE (see Figure 5, pg. 23). These eskers overlie most major rock types of Southwestern Nova Scotia and in some cases extend for some 50 km (including gaps).

It is unrealistic to assume that all eskers in Southwestern Nova Scotia are identical in their mode of origin and generalizations which apply to eskers of the study area may not apply elsewhere. However, implications regarding mineral exploration derived from eskers investigated may apply to eskers in other regions. Transport distances of esker material in the study area as well as that discussed in literature indicates that esker material in general has been transported less than 12 km. It is not unreasonable to assume that most esker units which have undergone a high degree of sorting by water during deposition are most heavily concentrated in heavy minerals. Also, because the morphologic characteristics of all eskers are essentially similar, the principles of geochemical sampling the hydromorphic dispersal zone from eskers may be applied to eskers elsewhere.

Eskers represent material which has been twice removed from its source, first as till by ice movement, and then further transport as a result of esker forming processes. Therefore the clasts would be somewhat further travelled than those found in tills. The author feels (as does Shilts, 1973) that tills provide a more useful prospecting medium than do eskers with respect to detailed prospecting. However, for broad reconnaissance purposes eskers provide a better <u>concentration</u> of clasts indicative of the local bedrock. In some areas of swamp and marshland of Southwestern Nova Scotia, eskers are the most accessible prospecting medium available (see Plates 1 and 2, pg. 70).

FURTHER WORK

Future work which may be of interest regarding eskers in Southwestern Nova Scotia is discussed below:

(a) The presence of mafic dykes in Southwestern Nova Scotia provide excellent marker horizons from which transport distances of esker clasts may be derived. The post granitic basic intrusive dyke (Great Southwestern Dyke, see Figure 2, pg. 3) to the east of the study area runs generally perpendicular to regional ice movement is exposed in several localities (Taylor, 1967, p. 53). Systematic sampling of lithologies in eskers 'down-ice' from such a horizon would give an accurate transport distance for such clasts.

(b) A description of all major esker complexes (i.e. to determine if till covered, formed as series of nodes, etc.) in Southerwestern Nova Scotia may give some inferences as to late stage glacial conditions in Southwestern Nova Scotia. The northernmost eskers trend generally E-W, and to the south trend in a S-SE direction. Grant (1971) suggests the different esker trends are due to a change of ice flow from southwest to northwest. Major differences in esker characteristics between the two areas may be a reflection of change in glacial ice conditions during esker deposition.

CONCLUSIONS

From data presented, the following conclusions may be made of eskers in the study area:

(a) The eskers are composed of successive stratigraphic units of glaciofluvial material ranging from clay size to boulder size.

(b) The esker forming streams flowed generally in a southerly direction.

(c) The eskers are covered with till which is low in clay content.

(d) Little vertical variation exists between the percentage of lithologies present in the successive stratigraphic units in the pebble size fraction. Clasts in the -3Ø to -4Ø size fraction are best suited for pebble count work.

(e) Most esker material was deposited or added in an upstream direction, and each node probably represents material deposited during periods of high meltwater discharge. Inter-node material appears to be derived from sorting and deposition of node material.

(f) Deposition took place in an englacial or subglacial tunnel. A subglacial model is most acceptable.

(g) Most material present in the eskers represent the local bedrock, with finer material probably travelling somewhat further than coarse material. Most macroscopic clasts have travelled less than 12 km, and many have travelled less than 5-7 km.

(h) The eskers provide an excellent accumulation of lithologies of at the study region and can be utilized as a reconnaissance prospecting medium for mineral exploration.

(i) Measurement of element concentration in the hydromorphic dispersal zone of the eskers in indicative of the abundance of mineralized clasts present.

(j) Sandy, well sorted units of esker material contain the highest concentration of heavy minerals.

(k) Grains of scheelite and cassiterite which are believed to be derived from within the study region (less than 6 km in an 'up-ice' direction) are present in the esker material.

REFERENCES

Allan, R. J., 1973. Surficial Dispersion of Trace Metals in Arctic Canada: A Nickel Deposit, Raglan Area, Cape Smith-Wakeham Bay Belt, Ungova (New Quebec). Geol. Surv. Can., Paper 73-1, Pt. B, p. 9-20.

Banerjee, I. and McDonald, B. C., 1973. Nature of Esker Sedimentation. IN Glaciofluvial and Glaciolacustrine Sedimentation. Soc. Econ. Paleontol. Mineral., Spec. Publ., No. 23, 1975, p. 132-154.

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

Cachau-Herreillat, F., LaSalle, P., 1969. The Utilization of Eskers as Ancient Hydrographic Networks for Geochemical Prospecting in Glaciated Areas. Quebec Dept. of Natu. Res., Rep. No. 28401, 46 p.

Charlesworth, J. K., 1957. The Quaternary Era. Edward Arnold (Publishers) Ltd., London, England, vol. 1, 591 p.

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

Folk, R. L., 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Co., Austin, Texas, 182 p.

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

Graves, M. C., 1976. The Formation of Gold Bearing Quartz Veins in Nova Scotia: Hydraulic Fracturing under Conditions of Greenschist Regional Metamorphism during Early Stages of Metamorphism. M.Sc. Thesis, Dalhousie University.

Harris, I. M. and Schenk, P. E., 1975. The Meguma Group. IN Ancient Sediments of Nova Scotia. Eastern Section Soc. of Econ. Pal. and Min., Guidebook 1975 Field Trip, p. 17-38.

Hellaakoski, A., 1931. On the Transportation of Materials in the Esker of Laitila. IN Glacial Deposits, Douden, Hutchinson and Ross Inc., Strousburg, Pa. U.S.A., 1975, v. 21, p. 282-312.

Howarth, P. J., 1971. Investigations of Two Eskers at Eastern Breidamerkurjokull, Iceland. Arct. Alp. Res., Vol. 3, No. 4, p. 305-318.

King, C. A. M. and Buckley, J. T., 1969. Geomorphological Investigations in West-Central Baffin Island, N.W.T., Canada. Arct. Alp. Res., Vol. 1, No. 2, p. 105-119.

Lane, T. E., 1975. Stratigraphy of the White Rock Formation. IN Ancient Sediments of Nova Scotia. Eastern Section Soc. of Econ. Paleont. and Min., Guidebook 1975 Field Trip, p. 43-62.

Lee, H. A., 1965. Investigation of Eskers for Mineral Exploration. Geol. Surv. Can. Paper 65-14, p. 1-17.

Lee, H. A., 1968. An Ontario Kimberlite Occurrence Discovered by Application of the Glaciofocus Method to a Study of the Munro Esker. Geol. Surv. Can. Paper 68-7, 3 p.

Lewis, W. V., 1949. An Esker in Process of Formation: Bouerbreen, Jotanheimen, 1947. Jour. Glaciology, vol. 1, p. 314-319.

Levinson, A. A., 1974. Introduction to Exploration Geochemistry. Applied Publishing Ltd., Wilmette, Ill., U.S.A., 614 p.

McDonald, B. C. and Shilts, W. W., 1973. Interpretation of Faults in Glaciofluvial Sediments. IN Glaciofluvial and Glaciolacustrine Sedimentation. Soc. Econ. Paleontol. Mineral., Spec. Publ., No. 23, 1975, p. 132-154.

Nielsen, E., 1976. The Composition and Origin of Wisconsinan Till in Mainland Nova Scotia. Ph.D. Thesis, Dalhousie University, Halifax, N. S. Canada, 257 p.

Piper, D. J. W., 1977. Manual of Sedimentological Techniques. Dept. of Geology and Oceanography, Dalhousie University, Halifax, N.S. Canada, 52 p.

Price, R. J., 1966. Eskers Near the Casement Glacier, Alaska. IN Glacial Deposits, Vol. 21, Douden, Hutchinson and Ross Inc., Strousburg, Pa., U.S.A., p. 267-281.

Price, R. J., 1973. Glacial and Fluvioglacial Landforms. Oliver and Boyd, Edinburgh, 242 p.

Sarkar, P. K., 1978. Petrology and Geochemistry of the White Rock Metavolcanic Suite, Yarmouth, Nova Scotia. Ph.D. thesis, Dalhousie University, Halifax, Canada.

Saunderson, H. C., 1973. Sedimentology of the Brampton Esker and its Associated Deposits: An Empirical Test of Theory. IN Glaciofluvial and Glaciolacustrine Sedimentation. Soc. Econ. Paleontol. Mineral., Spec. Publ. No. 23, 1975, p. 155-176.

Saunderson, H. C., 1976. Paleocurrent Analysis of Large-scale Cross Stratification in the Brampton Esker, Ontario. Jour. Sediment. Petrol., Vol. 46, No. 4, p. 761-769.

Shilts, W. W., 1973. Drift Prospecting: Geochemistry of Eskers and Till in Permanently Frozen Terrains: District of Keewatin: Northwest Territories. Can. Geol. Surv., Paper No. 72-45, 34 p.

Shilts, W. W. and McDonald, B. C., 1975. Dispersal of Clasts and Trace Elements in the Windsor Esker, Southern Quebec. Can. Geol. Surv. Paper No. 75-1, Part A, p. 495-499.

Smitheringale, W. G., 1973. Geology of parts of Digby, Bridgetown and Gaspereau Lake map-areas, Nova Scotia. G.S.C. Memori 375, 78 p.

Taylor, F. C., 1967. Reconnaissance Geology of Shelburne map-area, Queens, Shelburne and Yarmouth Counties, Nova Scotia. G.S.C. Memoir 349, 83 p.

Taylor, F. C., 1969. Geology of the Annapolis-St. Mary's Bay map-area, Nova Scotia. G.S.C. Memoir 358, 65 p.

Tilsley, J. E., 1977. Placosols: Another Problem in Exploration Geochemistry. J. Geochem. Explor., No. 7, 1977, p. 21-30.

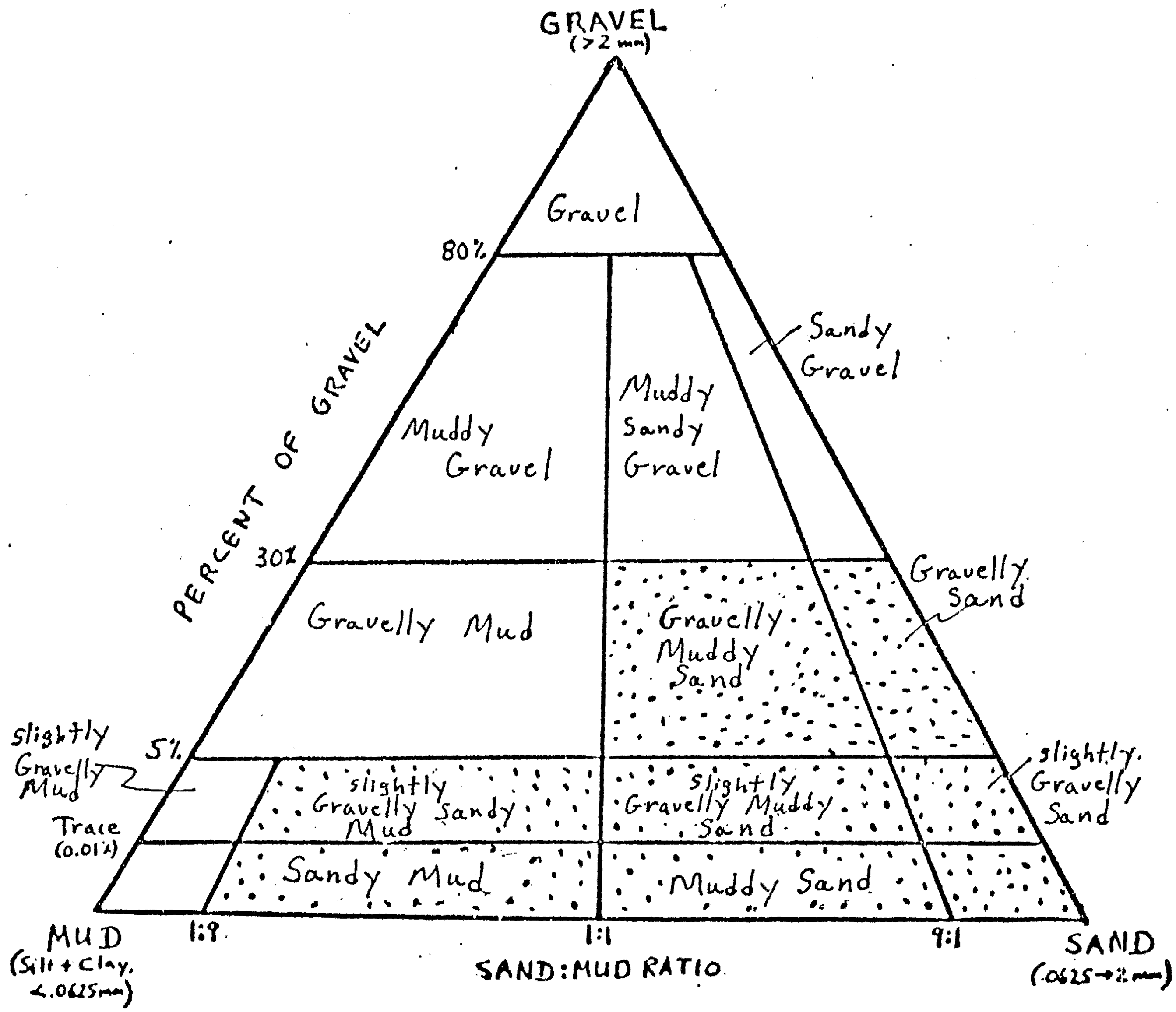
Trefethen, J. M. and Trefethen, H. B., 1944. Lithology of the Kennebec Valley Esker. Amer. Jour. Sci., vol. 242, p. 521-527.

Van Beever, H. G., 1971. The Significance of the Distribution of Clasts Within the Great Pond Esker and Adjacent Till (Hancock Co., Maine). M.Sc. thesis, University of Maine, U.S.A., 62 p.

U. S. Standard Sieve Mesh #		Millimeters	Microns	Phi (ϕ)	Wentworth Size Class	
		(1 Kilometer)		-20		
		4096		-12		
		1024		-10	Boulder (-8 to -12ϕ)	
Use		256		-8		
wire		64		-6	Cobble (-6 to -8ϕ)	
squares		16		-4	Pebble (-2 to -6ϕ)	
5		4		-2		
6		3.36		-1.75		
7		2.83		-1.5	Granule	GRAVEL
8		2.38		-1.25		
10		2.00		-1.0		
12		1.68		-0.75		
14		1.41		-0.5	Very coarse sand	
16		1.19		-0.25		
18		1.00		0.0		
20		0.84		0.25		
25		0.71		0.5	Coarse sand	
30		0.59		0.75		
35	1/2	0.50	500	1.0		
40		0.42	420	1.25		
45		0.35	350	1.5	Medium sand	SAND
50		0.30	300	1.75		
60	1/4	0.25	250	2.0		
70		0.210	210	2.25		
80		0.177	177	2.5	Fine sand	
100		0.149	149	2.75		
120	1/8	0.125	125	3.0		
140		0.105	105	3.25		
170		0.088	88	3.5	Very fine sand	
200		0.074	74	3.75		
230	1/16	0.0625	62.5	4.0		
270		0.053	53	4.25		
325		0.044	44	4.5	Coarse silt	
		0.037	37	4.75		
	1/32	0.031	31	5.0		
Analyzed	1/64	0.0156	15.6	6.0	Medium silt	
	1/128	0.0078	7.8	7.0	Fine silt	MUD
by	1/256	0.0039	3.9	8.0	Very fine silt	
		0.0020	2.0	9.0		
Pipette		0.00098	0.98	10.0	Clay	
		0.00049	0.49	11.0		
		0.00024	0.24	12.0		
or		0.00012	0.12	13.0		
		0.00006	0.06	14.0		
Hydrometer						

APPENDIX I

Comparison of U.S. standard mesh sizes with Phi (Ø) sizes (from Folk, 1974, p. 25).



APPENDIX 2

Classification scheme for determination of facies. (From Folk, 1974, p. 28)

APPENDIX 3

Heavy Mineral Separations (after Piper, 1977)

(a) Approximately .10 to .25 gm of sand from the desired size fraction was added to a separating tube containing tetrabromoethane (S.G. 2.97).

(b) Samples were stirred every 1/2 hour for 2 hours, then let stand for 1 hour.

(c) Heavy minerals were drained off and washed with acetone, then air dried. The light fraction was then drained off and air dried.

(d) Heavy and light fractions were weighed, then stored in separate vials.

Iron Oxide Removal (after Piper, 1977)

(a) 20 ml of .6M sodium citrate were added to 5 ml of 1 M sodium bicarbonate.

(b) Heavy minerals were washed into beakers using 20 ml of distilled water and heated to approximately 85 degrees C.

(c) 1 gram of sodium dithionite ($Na_2S_2O_4$) was added.

(d) Samples were stirred continuously for 2 minutes, then intermittently for another 13 minutes.

(e) Samples were removed from heat and filtered.

APPENDIX 4

Preparation and Counting of Heavy Mineral Slides (after Nielsen, 1976)

(a) Minerals were homogenized by stirring to avoid stratification of minerals during handling and storage.

(b) Grains were mounted in Canada Balsam and sealed with a cover glass.

(c) Point counts were done using a mechanical stage and binocular petrographic microscope. The ribbon method of point counting was used, whereby traverses were made across the slide and all grains in the field of view were counted. Approximately 300 grains were counted on each slide and the number percent of identified minerals was determined.

Sample No. &ϕSize	B-1 3ϕ	B-1 4ϕ	B-2 3ϕ	B-2 4ϕ	B-3 3ϕ	B-3 4ϕ	A-2 3ϕ	A-2 3.5ϕ	A-2 4ϕ	A-4 3ϕ	A-4 3.5ϕ	A-4 4ϕ
Opaques	37.50	36.47	34.59	27.33	34.74	31.17	35.15	31.97	31.07	34.25	28.57	28.97
Garnet	15.45	4.67	13.46	9.4	10.48	8.49	16.82	13.25	13.38	14.06	7.78	6.80
Andalusite	11.82	26.17	17.31	23.08	13.71	22.64	14.02	27.71	28.17	20.231	25.56	32.04
Staurolite	7.27	9.35	10.58	15.38	14.52	9.43	10.28	9.64	13.38	13.28	11.11	7.77
Sphene	4.55	2.80	5.77	5.13	7.26	4.72	7.48	4.82	6.34	7.03	5.56	6.80
Augite	6.36	10.28	7.69	9.4	8.06	7.55	9.35	8.43	6.34	7.81	6.67	10.68
Hornblende	10.91	13.08	12.42	10.26	10.48	10.38	5.61	10.84	10.56	8.59	8.89	11.65
Apatite	11.82	7.48	10.00	7.69	5.65	5.66	3.74	4.82	6.34	2.34	6.67	4.85
Sillimanite	8.18	-	3.0	.85	3.23	-	13.08	2.41	1.41	3.91	7.78	1.94
Tourmaline	6.36	9.35	5.77	9.4	5.65	12.26	9.35	8.43	7.75	4.69	10.00	5.03
Epidote	6.36	9.35	5.77	5.13	4.03	6.60	6.54	8.43	4.23	3.91	6.67	7.77
Rutile/Casserite	9.09	3.75	5.77	2.56	16.94	12.26	3.75	1.20	1.41	12.50	3.33	3.88
Zircon	1.82	.93	-	1.71	-	-	-	-	.7	-	-	-

APPENDIX 5

Relative abundance of heavy minerals in different size fractions from 5 samples ranging between 2.5 and 4ϕ

	5 Observations comparing percentage of minerals in the 2.5-3Ø and 3.5-4Ø fractions			2 Observations comparing percentage of minerals in the 3-3.5 and 3.5-4Ø fractions			
Mineral	# observations showing highest concentration in 2.5-3Ø size	# observations showing highest concentration in 3.5-4Ø size	mean difference in percentages	# observations showing highest concentration in 3-3.5Ø size	# observations showing highest concentration in 3.5-4Ø size	mean difference in percentages	Comments
Opaques	5	-	3.04	1	1		- highest concentration in 2.5-3Ø size - differences indistinguishable in finer than 3Ø fraction
Garnet	5	-	5.5	1	1		- much higher concentration in 2.5-3Ø size - differences indistinguishable in finer than 3Ø fraction
Andalusite	0	5	9.61	-	2	3.44	- much higher concentration in finer fractions
Staurolite	2	3		1	1		- <u>indistinguishable</u> with present data
Sphene	5		1.26	-	2	1.38	- highest concentration in 2.5-3Ø - in fraction finer than 3Ø, sphene tends to concentrate in 3.5-4Ø fraction
Augite	3	2		1	1		- <u>indistinguishable</u> with present data, however a higher concentration in the finer fractions is indicated
Hornblende	3	2		1	1		- <u>indistinguishable</u> with present data, however a higher concentration in the finer fraction is indicated
Apatite	2 (2 observations same as for 3.5-4Ø)	2		1	1		- <u>indistinguishable</u> with present data
Sillimanite	5	0	5.4	2	-	3.42	- generally concentrated in coarser fraction
Tourmaline	4	1		2	-	4.17	- mostly concentrated in coarser fractions, with some exceptions
Epidote	3	2		1	1		- <u>indistinguishable</u> with present data
Rutile/ Cassiterite	5	0	4.83	-	2	.38	- highest concentration in 2.5-3Ø - in material finer than 3Ø, highest concentration in 3.5-4Ø fraction
Zircon	1	2			1		- not enough observations for a meaningful comparison

APPENDIX 6

Relative abundance of heavy minerals in different size fractions based on results shown in Appendix 5.

APPENDIX 7

OPAQUES

Internode Sample #	Abundance	Node Sample #	Abundance
A-1	38 %	B-1	38 %
A-2	35 %	B-2	35 %
A-3	28 %	B-3	35 %
A-4	34 %	B-4	44 %
A-5	28 %	B-5	28 %
A-6	31 %	B-6	34 %
Av.	32. %	Av.	35.6%

GARNET

Internode Sample #	Abundance	Node Sample #	Abundance
A-1	17 %	B-1	15 %
A-2	17 %	B-2	13 %
A-3	20 %	B-3	10 %
A-4	14 %	B-4	30 %
A-5	12 %	B-5	11 %
A-6	22 %	B-6	9 %
Av.	17 %	Av.	14.6%

ANDALUSITE

Internode Sample #	Abundance	Node Sample #	Abundance
A-1	14 %	B-1	12 %
A-2	14 %	B-2	17 %
A-3	29 %	B-3	14 %
A-4	20 %	B-4	10 %
A-5	20 %	B-5	16 %
A-6	16 %	B-6	17 %
Av.	18.83%	Av.	14.33%

AUGITE

Internode Sample #	Abundance	Node Sample #	Abundance
A-1	10 %	B-1	6 %
A-2	9 %	B-2	8 %
A-3	6 %	B-3	8 %
A-4	8 %	B-4	6 %
A-5	8 %	B-5	8 %
A-6	12 %	B-6	8 %
Av.	8.8%	Av.	7.6%

AMPHIBOLE

Internode Sample #	Abundance	Node Sample #	Abundance
A-1	11 %	B-1	11 %
A-2	6 %	B-2	12 %
A-3	8 %	B-3	10 %
A-4	9 %	B-4	8 %
A-5	10 %	B-5	7 %
A-6	16 %	B-6	10 %
Av.	10 %	Av.	10 %

APATITE

Internode Sample #	Abundance	Node Sample #	Abundance
A-1	9 %	B-1	12 %
A-2	4 %	B-2	10 %
A-3	4 %	B-3	6 %
A-4	2 %	B-4	9 %
A-5	5 %	B-5	9 %
A-6	4 %	B-6	6 %
Av.	4.6%	Av.	8.6%

APPENDIX 7

Percentages of Heavy Minerals from Point Counts

APPENDIX 7 (con't.)

STAUROLITE

Sample #	Abundance	Sample #	Abundance
A-1.	9 %	B-1	7 %
A-2	10 %	B-2	11 %
A-3	9 %	B-3	15 %
A-4	13 %	B-4	7 %
A-5	10 %	B-5	6 %
A-6	11 %	A-6	10 %
Av.	10.3%	Av.	9.3%

SPHENE

Sample #	Abundance	Sample #	Abundance
A-1	6 %	B-1	5 %
A-2	7 %	B-2	6 %
A-3	5 %	B-3	7 %
A-4	7 %	B-4	5 %
A-5	6 %	B-5	4 %
A-6	7 %	B-6	6 %
Av.	6.3%	Av.	5.5%

EPIDOTE

Sample #	Abundance	Sample #	Abundance
A-1	5 %	B-1	6 %
A-2	6 %	B-2	6 %
A-3	5 %	B-3	4 %
A-4	4 %	B-4	3 %
A-5	4 %	B-5	6 %
A-6	4 %	B-6	3 %
Av.	4.6%	Av.	4.6%

SILLIMANITE

Sample #	Abundance	Sample #	Abundance
A-1	3 %	B-1	8 %
A-2	13 %	B-2	3 %
A-3	2 %	B-3	3 %
A-4	4 %	B-4	6 %
A-5	9 %	B-5	9 %
A-6	3 %	B-6	7 %
Av.	5.6%	Av.	6 %

TOURMALINE

Sample #	Abundance	Sample #	Abundance
A-1	9 %	B-1	6 %
A-2	9 %	B-2	6 %
A-3	4 %	B-3	6 %
A-4	5 %	B-4	3 %
A-5	6 %	B-5	7 %
A-6	3 %	B-6	9 %
Av.	6 %	Av.	6.1%

RUTILE & CASSITERITE

Sample #	Abundance	Sample #	Abundance
A-1	6 %	B-1	9 %
A-2	4 %	B-2	6 %
A-3	8 %	B-3	17 %
A-4	13 %	B-4	9 %
A-5	10 %	B-5	13 %
A-6	3 %	B-6	15 %
Av.	7.3%	Av.	11.5%

APPENDIX 7 (con't.)

ZIRCON

Sample #	Abundance	Sample #	Abundance
A-1	-	B-1	2 %
A-2	-	B-2	-
A-3	-	B-3	-
A-4	-	B-4	3 %
A-5	-	B-5	3 %
A-6	-	B-6	-
Av.	-	Av.	-

APPENDIX 8

Method for Collection of Placon Samples

(a) A hole was dug which extended through the placon (for positive identification and characteristics of placon).

(b) Material overlying placon was removed.

(c) The top of the placon was scraped off with a sampling spoon and stored in paper sample bags. Rock fragments and organic material were carefully avoided.