P E B B L E L I T H O L O G Y

O F T H E

T I L L S O F S O U T H E A S T N O V A S C O T I A

By

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ABSTRACT

This preliminary investigation of coastal non-stratified glacial deposits was planned to study the regional pattern, and provide basic information necessary for the interpretation of Scotian Shelf sediments. It is a detailed-reconnaissance survey aimed at establishing the geographic distribution of till types as characterized by their pebble associations. The scope ranges from detailed pebble analysis to stratigraphy and chronology.

One hundred and sixty ground moraine samples were collected along road traverses over a 6000 square-mile area. The 5.6mm - 22.2mm pebble fraction was dry sieved in the field and wet screened in a rotary washing mill. Number frequency pebble counts were made on 500-grain samples and the data are examined variously as; unit percentages of all rock species, bedrock components versus foreign elements, relative proportions of the foreign species, and as relative source area influences.

Fifty rock species are traced to seven source regions, for which special topographic and geographic features pertinent to interpretation are set out. A bar diagram map of source area lithology, and triangular diagrams reveal that three monolithologic till types form the bulk of the ground moraine. Each contains at least 80 per cent bedrock material, and has a distribution matching the corresponding local source - granite quartzite or slate. Minor hybrid or mixed tills occur near source area contacts. Isopleth maps of the foreign elements, recalculated to 100 per cent, reveal a lobate dispersal pattern.

In the anomalous areas of foreign-pebble enrichment occur red clay drumlin fields which were sampled subsequently. Ternary compositional diagrams reveal a characteristic lithology for each field. Lithology of individual drumlins can be related to distance of travel over the underlying bedrock, and away from the distant sandstone area. The anomalous fine-grained red, 'drumlin' till matrix is interpreted as former alluvial, lacustrine, and tidal flat deposits winnowed during an interstadial from pre-existing red tills.

The lobate foreign-pebble distribution is interpreted as the result of currents created in the thin ice sheet margin, either by topographic channeling or confluence of local ice caps. A tentative sequence of glacial events is based on stratigraphic correlation of sections and radiocarbon dates. Linear outcrops of cemented outwash are assigned to a pre-Sangamon terminal moraine. 'Early' Wisconsin tills are present, followed by pre-classical Wisconsin regoliths underlying the compact sub-drumlin Tazewell till. The drumlin advance

dates from the 'Port Stanley' episode, and the drumlins were overridden during the 'Port Huron' glaciation.

A parallel study of beach sand heavy minerals reveals an identical dispersal pattern of indicator augite. The misleading occurrence of 'transported' geochemical anomalies in drumlin fields is emphasized. Applications to oceanographic sampling and sedimentary petrographic interpretation are cited.

CHAPTER ONE

INTRODUCTION

A. GENERAL STATEMENT

1. LOCATION AND SIZE OF STUDY AREA

The area of investigation lies along the Atlantic Coast of mainland Nova Scotia between Yarmouth on the extreme southwest, almost to Cape Canso on the northeast. It extends inland 25 miles from the coast to form an irregular northeasterly-trending tract encompassing over 6000 square miles.

The objective was to cover as much ground as possible adjacent to the Scotian Shelf, and transverse to the dominant southeast flow of glacial ice. As no pre-determined geographic limits could, or would, be set, the boundaries of the study area were simply extended coastwise from Halifax as far as possible during the available field season. Hence, the scope of the area is that which could be covered by motorized traverse in the months of November and December of 1961. This short working period was further reduced by inclement weather, as well as by teaching and course commitments.

2. PURPOSE

This study was entirely the idea of Dr. D.J.G. Nota from the Landbouwhogeschool, Wageningen, The Netherlands, who was a visiting associate professor of Marine Geology in the

Geology Department, and attached to the Dalhousie Institute of Oceanography during the period of study.

The project was initiated for four reasons:

(a) To Begin a Systematic Pleistocene Survey of Nova Scotia

Knowledge of the Pleistocene deposits of Nova Scotia is virtually non-existent. This study of tills by pebble analysis was launched to reveal the regional distribution of major till types. As such, this reconnaissance of glacial till would be the first real step toward a fuller knowledge of the Pleistocene history of the province, and would constitute a basis for future investigations.

(b) As Background for the Study of Scotian Shelf Sediments

As mentioned previously, the general location of the study area was chosen because it lay within the 'hinterland' of the Scotian Shelf, onto which the Pleistocene ice flowed from Nova Scotia. The information on the mainland glacial formations sought in this attempt would therefore be, in effect, a preview in space of what might be expected to occur on the Shelf. Thus, this pebble investigation was further justified because it would provide the only possible basis for interpreting the provenance of the Shelf sediments in terms of their coarse fraction.

(c) As a Testimony of the Value of the Method

The pebble method is not new, yet it has been used only occasionally, and then only in a very limited way, compared with other approaches to till lithology. Its record of success has always been surprisingly good and yet, oddly enough, it is not recognized as a valuable or practicable method of regional study.

As further justification for the project, the author hoped that by demonstrating the fruitfulness of the pebble method in a reconnaissance survey of virgin territory, its value as a tool of Pleistocene study might be appreciated and thereby established.

(d) As an Index of Ice Movement in the Important Thin Marginal Zone.

The pebble study was also prompted because it appeared to be a fruitful means of gleaning information on the movements of the thin edge of the continental ice sheet. Nova Scotia is well situated for such an investigation of peripheral complexities because it lies near the continental shelf edge where any and all ice sheets must necessarily have terminated.

As inequalities of flow are always more pronounced in the thin marginal zone, some of these should be reflected as inequalities of drift dispersion. The extent and transverse orientation of the study area makes it possible that such large regional features were recorded, and could be found, in it. The recognizability of the pebble fraction of the dispersed material enhanced the pebble method as a promising way of revealing such suspected movements.

B. ACKNOWLEDGEMENTS

The author especially wants to thank Dr. D.J.G. Nota for creating the opportunity to work on this aspect of the integrated sedimentological study of the mainland coastal and Shelf portions of Nova Scotia.

Dr. Friedlaender, Head of the Geology Department, critically read the early manuscript, and made available, jointly with the Institute of Oceanography, the necessary financial support of operating expenses.

The author is indebted to Dr. Cooke for giving so freely of his time in discussing the complexities of stratigraphy and chronology which arose during the final stages.

Dr. Dawson, Post-Doctoral Fellow, kindly suggested many essential changes in a large part of the final manuscript.

H.L. Cameron (Nova Scotia Research Foundation) and J.D. Hilchey (N.S. Soil Survey) are to be thanked for helpful discussion on the problem of the red drumlins, and Bill Take of the Nova Scotia Museum of Science who gave freely of his knowledge of certain local glacial features which proved to be essential in developing the stratigraphic system.

Frank Nolan, who was engaged in a companion project of province-wide heavy mineral analysis of beach sands, also initiated by Dr. Nota, worked closely with the author in all phases of collection, analysis, and interpretation of the mutually corroborative results. Many of the conclusions presented here were formulated during our 'intensive discussions'.

There were many among the author's colleagues who rendered valuable assistance during the production stages of this report. The author wishes to thank Fab Aumento and Ted Lawrence for some of the photographic documentation and reproduction during the final stages; and John Stewart for his donations to the collection of erratic pebbles.

I wish also to acknowledge the graduate assistantship made possible by the Institute of Oceanography during the second and final year of production.

Miss Pat Grant and Mrs. Mary Reynolds are to be congratulated for so ably typing the manuscript in the short time allotted to this formidable task.

C. PREVIOUS WORK

1. GENERAL PLEISTOCENE STUDY INVOLVING THE PRESENT AREA

The earliest worker in the area, Honeyman, recorded more observations pertinent to this study than any of his successors. He described a terminal moraine of red till characterized by abundant erratics from the North Mountain and the Cobequid Mountains, exposed in the 'red heads' east of Halifax Harbour; and he was able to delineate the eastern boundary of the field of North Mountain erratics. (Honeyman, 1878, 1882, 1886, 1890).

He was succeeded by Prest who described the superposition of tills in the Lunenburg area (1896), and made excavations in the eskers of southwestern Nova Scotia (1919, 1923).

Bailey (1896) mapped the southwestern sector and made many observations on the glacial geomorphology.

Dawson (1893) was the first to recognize evidence of northward-moving ice off the Southern Upland in the presence of granites of southern provence on the North Mountain.

Goldwait (1924) collated all the observations available on glacial forms, dispersion of stones, drumlins in Lunenburg County and the Halifax region, evidence of flow divergence in northern Nova Scotia and Cape Breton.

Recently, the Geological Survey of Canada has begun Pleistocene surveying in Nova Scotia with Hughes (1957) who traced the sequence of deglaciation in the intricate meltwater deposits of the Shubenacadie area.

Hickox (1958, 1962a, 1962b) did geological mapping in central Annapolis Valley and was able to prove the very early theory of late-glacial northward flow by means of detailed provenance study.

MacNeill (1960a, 1960b) has recently been doing detailed reconnaissance over the entire southern mainland. He has been co-operating with H.L. Cameron of the Nova Scotia Research Foundation who has been mapping Pleistocene geomorphological features with aerial photographs.

W.F. Take of the Nova Scotia Museum of Science is also actively engaged in regional Pleistocene study.

The Nova Scotia Soil Survey has been mapping the province by county since 1943. Only the report for Halifax and Guys borough Counties remains to be published.

As the soils of these provinces have developed almost exclusively from the surface mantle of glacial deposits, and as the soil classification is based primarily on the lithology of the parent material and secondarily on the drainage characteristics (Table 1), the soil maps proved to be of inestimable value in outlining many of the glacial features. The more important of these are the major till types (Plates 5 and Fig. 16), till overlap (Figure 16 Plate 5), drumlins (Plates 9&10), drumlin migration (Plate 5), and till plain lineation (Plate 41).

Table: 1. Nova Scotia Soil Survey Classification of Soils Based on Lithology of Parent Materials (Tills, Outwash)

LITHOLOGY	PODZOLIC SOILS		GLEYSOLIC SOILS
	PODZOLS		ELUVIATED GLEYSOLS
	Well-drained	Imperf.dr.	Poorly drained.
TILLS			
Quartzite & Slate	Halifax (Hx)	Danesville (Dv)	Aspotogan (As)
Quartzite & Schist	Mersey (Me)	Liverpool (Li)	Pitman (Pt)
Quartzite & Schist or Granite	Port Hebert (Po)	Lydgate (Lg)	Roseway (Rw)
Hornblende & Mica Schist	Yarmouth (Y)	Deerfield (Df)	Pitman (Pt)
Granite	Gibraltar (Ga)	Bayswater (By)	Aspotogan (As)
Slate	Bridgewater (Bw)	Riverport (Rp)	Middlewood (Mw)
Red-brown sandstone and black slate	Wolfville (W)	Hantsport (Ha)	Mahone (Mh)

Slate, quartzite, granite	Farmville (Fa)
Red-brown and grey sandstones & shales with metamorphics	Woodburne (Wo) Millbrook (Mi)
<u>Reddish-brown sandstones & shales</u>	Queens (Q)

<u>OUTWASH</u>

Granite	Nictaux (Nc)
Slate	Lahave (La)
Quartzite, Schist & Granite	Medway (My)
Granite, slate metamorphics	Hebert (He)

2. ELSEWHERE WITH THE PEBBLE METHOD

Analysis of till lithology using the pebble fraction has had a short history compared with the other approaches. One of the earliest studies was that of MacClintock (1933) who correlated the pre-Illinoian drifts of Illinois by distinguishing the Nebraskan advance from the Keewatin centre, from the Kansan advance from the Labradorean centre.

Holmes' (1952) pebble analysis of 168 till samples collected over 5500 square miles was almost identical in scope and detail with that attempted here. From the pebble counts he was able to discern a lobate distribution of ice currents, which was not surprising inasmuch as they coincided with the axes of deep trough-shaped valleys.

Maarleveld (1952, 1956) in a classic study of north-eastern Europe, refined the method by establishing the optimum sample size as 300 grains, and the optimum size range as 5mm-20mm. Accordingly, his recommendations are followed strictly in this study.

Later applications of the method were in the differentiation of lower and upper tills (Dreimanis & Reavely, 1953), lithological variation over a till sheet (Anderson, 1955), discovery of an anomalous drift in Montana and North Dakota (Howard, 1956), lithological characterizations of major glacial lobes in central North America (Anderson, 1957), and finally, in the correlation of Wisconsin drifts in the same region (Zumberge, 1960).

In view of the above mentioned successes with the method where it was attempted in flat regions with flood-type ice flow, the method seemed to offer attractive prospects in this region because of the geographical situation near the ice margin, and because of the topographical setting amidst deep embayments and transverse ridges.

D. PLEISTOCENE CONCEPTS AND TERMINOLOGY

As this study is concerned with one size fraction (pebbles) and a specific approach (lithology) to the study of a certain kind of glacial deposit (till), it is essential to orient the study with respect to the origin and development of the various glacial deposits which are present in the study area.

Over most of the study area the surface is mantled with an unsorted glacial deposit of variable thickness known as "till". A simple classification of tills based on the origin and occurrence is given by Flint (1957):

"(1) Lodgment Till, deposited from drift in transport in the base - specifically the under surface - of a glacier. Slow pressure melting of the flowing ice frees the drift particles and allows them to be plastered, one by one and under pressure, on to the sub-glacial floor and there 'lodged' (in Chamberlin's words) in the accumulating drift. No size sorting is involved, but stones tend to lodge with their long axes paralleling the direction of flow. Crushing and abrasion of particles is intense, and the till is compact and may acquire fissile structure (Plates 25 & 28) as it is built up.

(2) Ablation Till, deposited from drift in transport within or upon the ternial area of a shrinking glacier. The drift is let down on to the ground as the thin inclosing ice melts inward terminus, top, and base, and hence is loose, noncompact, and nonfissile, and probably lacks a fabric. In places fine-grained particles may be absent, having been washed away by trickling meltwater during the settling process (Plate 13)."

Goldthwait (1924) adds that this 'ablation' or "upper till is . . . composed of more angular fragments, with a larger percentage of far-travelled stones (than the lower, or lodgment, till). This is natural for the material higher in the ice sheet would be the last to reach the ground. When studying the dispersion of stones in the drift, shallow sections . . . afford the very best material, because they contain fragments from the most distant sources."

In several parts of Nova Scotia the ground moraine (till sheet) (composed of the upper and lower tills) thickens into hills of peculiar dome-like, or half-ellipsoidal, form called 'drumlins'. These 'whalebacks', as they are sometimes called, are hills of boulder clay, elliptical or oval in plan and arched in profile, with very smooth slopes that seldom exceed 20 or 30 degrees. They range in size from 40 to 100 feet high, and from one-half to three-quarters of a mile long. The ratio of length to width is commonly 2 to 1 although in some cases the drumlins are more nearly circular and in others the ratio may exceed even three to one. The long axis runs parallel to the ice movement, and the drumlins occur in fairly definitely limited groups or fields containing hundreds or even thousands of individuals.

CHAPTER TWO

METHODS

A. FIELD WORK

1. RECONNAISSANCE SAMPLING OF THE TILL SHEET

The first phase of the field work, carried out from November 1961 to January 1962, was reconnaissance sampling of the till sheet. The aim was to cover as great an area as possible before winter curtailed operations and, because of the limited time available, collection of samples necessarily had to be made along road traverses. Nonetheless, as the area chosen is fairly accessible, reasonable coverage was obtained.

Although at first the tendency was toward unduly close spacing of the sampling sites, it soon became apparent that the large areas of apparently homogeneous till could be adequately sampled at five-mile intervals. When winter terminated this phase of the field work, one hundred and sixty samples had been collected over a 6,000 square mile area.

Method of Sampling

Every sampling site was individually assessed in order to ensure that the sample would be representative of the till at that point, and would not differ greatly from the till between stations. Every attempt was made to obtain fresh, unaltered material. For this reason, only recent roadcuts, borrow pits, and stream sections were used, and no slumped material was taken. As it was essential that the pebble surfaces be clean, and the fine matrix be unaltered, the sample was taken from that part of the soil profile which was unaffected by either leaching or enrichment. Accordingly, it was necessary to penetrate to the 'C' soil zone'; and since podzol soils are maturely developed in this humid, sub-boreal climate, it was simple to recognize the 'C', or parent material horizon, which invariably occurred at depths between 15 and 30 inches. (Cann & Hilchey, 1958, 1959; Hilchey et al, 1960) (Plate 3').

Although these practices introduced a certain subjectivity into the choice of the sample, they avoided the collection of minor and abnormal variations of till types which, in this reconnaissance study, would have only complicated the regional picture of the general trends which it was desired to obtain.

Sieving

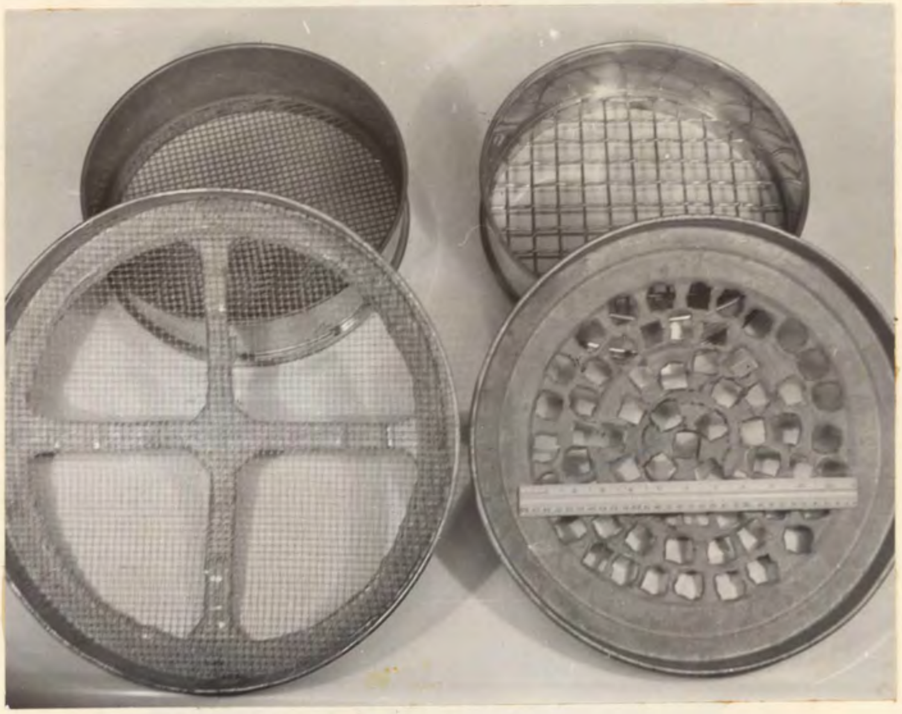
Generally the till was sandy and loose-textured, and five pounds of the 5mm to 25mm gravel fraction could be extracted at the site by sieving. Standard screens were unavailable during this first phase of the work, and suitable substitutes had to be hand-fashioned from nesting garbage can lids; one was fitted

PLATE 1

U. S. Standard Sieves with 5.6mm and 22.2mm openings, with handmade prototypes for field use in front.

PLATE 2

Gravel washing mill.



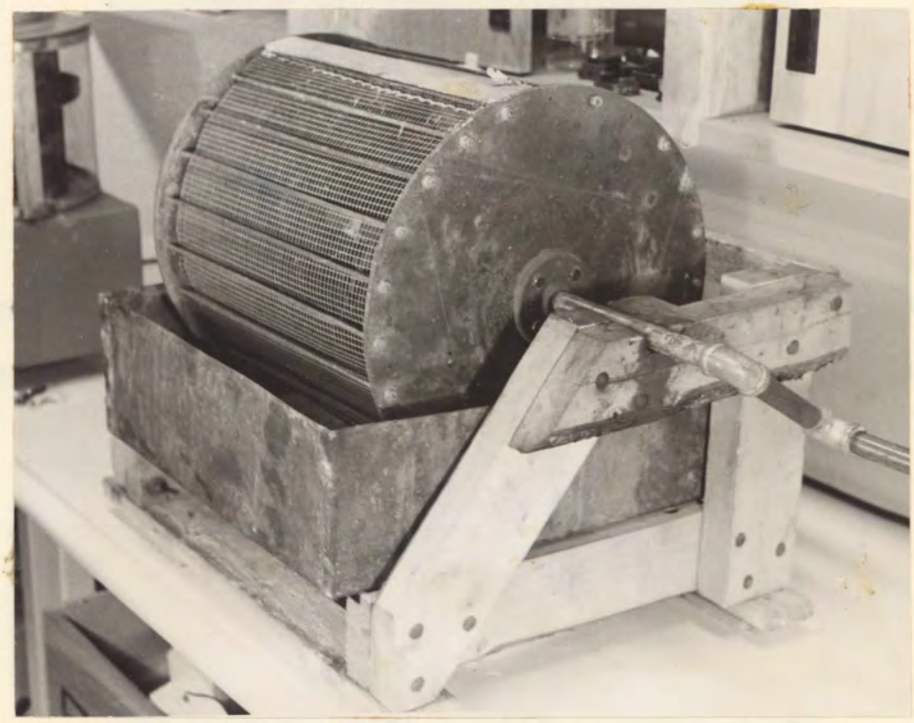


PLATE 3

Operation of the washing mill.

PLATE 3'

Podzolic soil profile on granitic till. Hammer imbedded in base of leached A zone, spanning iron stained B zone.

with ¼-inch wire mesh, and the other punched with one-inch square holes (Plate 1). Later the sample was run through U.S. Standard (ASTM) sieves having 5.66mm and 22.2mm openings. Two pounds of the undersized portion were also bagged for later mechanical analyses and heavy mineral studies.

In the case of the few tills with a high silt and clay content, field screening was impossible. In such cases, a 30 to 50-pound bulk sample was taken and processed in the laboratory.

CHAPTER TWO

METHODS

A. FIELD WORK

2. DETAILED SAMPLING OF RED CLAY DRUMLINS

The second phase of the field work was carried out in June and July of 1962. During the previous winter, pebble counts had given results indicating the need for a detailed investigation of certain red clay drumlins which, although widely scattered throughout the area, were of such small total area (and hence relatively insignificant compared to the other till types) that they had been omitted during the first phase.

Sixty bulk samples of this material were returned to the laboratory for further treatment. In a few cases, for determination of the inherent granular variation, samples were taken at different places on the same drumlin in order to gain some indication of how well a single sample characterized a drumlin. The results of this are shown in Appendix I .

At the same time, wherever possible, beaches associated with drumlins were also sampled. This was to ascertain whether they were reliable samples of the adjacent drumlin because, if the analyses proved to be similar, this naturally-cleaned, polished and concentrated pebble sample could then be used directly, instead of the sticky clay till from the drumlin itself which required laborious processing. The conclusions of this comparative study, contained in Appendix III, show that the beach pebble assemblage has suffered differential destruction.

CHAPTER TWO

M E T H O D S

B. LABORATORY METHODS

1. PREPARATION OF THE SAMPLE

Washing

The clay-rich tills were washed in an apparatus especially built for treating this bulky, cohesive material. Modelled after the style of a ball mill, it is a sturdily constructed 'squirrel' cage 20 inches long and 16 inches in diameter, lined with ¼-inch (5mm) wire mesh (Plate 2). The 5 to 30-pound sample is placed inside the cage which is then supported on a trestle so that it is partly submerged in a water bath containing a clay dispersant (very dilute acetic acid). Manual rotation (Plate 3) of the cage produces a violent simulation of natural stream attrition. The tumbling action is singularly effective in disaggregating firmly consolidated lumps of gravelly clay. The fines are flushed away in the voluminous flow of water which is passed through the system. Unfortunately, sediment disposal problems eventually became insuperable, and the operation had to be shifted to a nearby stream.

Splitting the Sample for Analysis

To obtain from the reference sample a portion small enough for counting, the five-pound lot was made into a homogeneous 5-foot ridge. From this, enough small portions were selected symmetrically along the ridge to fill a 15-ounce soup can. This size container invariably held the statistical minimum of 500 to 600 grains. These were freed of surface dirt by shaking in sodium oxalate solution, and were examined in wet condition.

Fractional Analysis

In addition to routine counting of the 5mm to 22mm fraction, fractional analysis was carried out on selected samples (ground moraine, drumlin, beach). This consisted of splitting the original bulk sample into subfractions, with lower size limits at 5.66mm, 7.93mm, 12.7mm, and 22.2mm. Each fraction was weighed and the lithology determined by routine counting to test for the presence of compositional sorting. The data, and conclusions therefrom, are contained in Appendix VIII.

CHAPTER TWO

METHODS

B. LABORATORY METHODS

2. ANALYSIS OF SAMPLE

Principles

Lithologic description was based on visual recognition and identification of individual rock species. At the beginning of the study, it was deemed advisable to recognize as many distinct types as possible, even at the risk of over-differentiation, for two reasons:-

1) it could not be suspected which apparently minor varieties might later reveal themselves as important ice flow indicators.

2) the source rock geology was not sufficiently well-known to permit any discrimination between major rock types and minor sub-varieties.

Codification and Notation

At the outset, the major rock types were assigned arbitrary designations according to the following alphabetical code, in the order in which they were encountered (Table 2).

TABLE 2: Notation of the Major Pebble Types

A	Granitic rocks	G	Basalt
B	Quartzite and Greywacke	H	Lamprophyres
C	Slate	I	Diorite
D	Sandstone	J	Tuff, Felsite, Andesite
E	Siltstone		
F	Quartz and Chert		

Other letters were applied to minor types which subsequently appeared.

Similarly, varieties or species of the major groups were denoted by numerical subscripts, which were applied in chronological order. For example, the granitic rock family, 'A', was subdivided as follows:-

TABLE 3: Designation of Species: Granite Family

A_1	Fine-grained pink contact phase of A_2
A_2	White, biotitic granodiorite
A_3	Coarse, Granodiorite with red stained potash feldspar
A_4	Aplite, leucocratic
A_5	Granite, hornblendic
A_6	Leucogranite, red, gneissic
A_7	Granodiorite, biotitic, suffused with iron oxide matrix

TABLE 3: Designation of Species: Granite Family (continued)

A_8	Granodiorite, similar to A_2, but with minor hornblende, foliated
A_9	Syenite; hornblende-plagioclase
A_{10}	Quartz monzonite, red potash feldspar, chloritized pyriboles
A_{11}	Granite, binary, pink
A_{12}	Granodiorite, rich in biotite

When this designation was extended to other rock families, over fifty rock species were recognized. *

Number Frequency Versus Weight Per Cent

The percentage composition by species was determined by number frequency analysis. It was found that, because of the demonstrable lack of compositional sorting (Appendix VIII) (which implies an even distribution by numbers throughout the size range), the number per cent of any species was equal to the weight per cent. The only exceptions were the few that had high specific gravities, or occurred in very minor quantities. It was fortunate that the number frequency method was proven acceptable (remembering that a glacier mixes till ingredients by weight, not by number), because it was decidedly easier to count the pebbles by species as they were being separated than to laboriously weigh each tiny subfraction.

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* Three reference suites are on file in the Geology Department, Dalhousie University

Treatment of Data

Initially the number per cent by rock species was determined directly from the pebble count. When the various species were related to their respective source regions, the initial unit percentages could be grouped to give the relative source area lithologies. These results were expressed on a map showing the composition of each sample by source area as a coloured bar diagram, to give a visual representation of the pebble associations (Figure 21; in pocket).

Additionally, the unit percentages were regrouped ~~so~~ into the subjacent (underlying) bedrock fraction and foreign fraction so as to give indications of mixing and dilution, etc. Finally, the foreign assemblage was examined separately by recalculating the constituents to a 100 per cent basis. Variations within the foreign fraction are known to be useful indicators of till evolution, but these subtle relationships can only be revealed by nullifying the dilution effect of the dominating local rock species.

CHAPTER THREE

R E SU L T S

A. RECOGNITION OF THE SOURCE AREAS

General Indications

Impressions gained from field observations were confirmed by the analyses of percentage composition. Together, these results have outlined the following features:

1) there are several till types in the area
2) each is characterized by the dominance of one rock species
3) the preponderant component is clearly derived from the local or underlying bedrock
4) the remaining minor components are apparently derived from more distant sources.

Before any pertinent and definite conclusions could be drawn from the data, it was imperative to find the sources of the pebble species, the reason being that tills are formed to some extent from transported materials. So, in order to make inferences from pebble content regarding the evolution of a till type, some considerable knowledge of sources is required.

The distinctive lithology of the pebbles made possible a complete and positive delimitation of all their source areas. This was achieved for most of the rock species primarily through personal acquaintance with the local geology; secondarily, by study of all relevant geological maps and reports, most of the remainder were assigned to definite sources; and, lastly, by special collecting trips to key outcrop areas. By these methods, the fifty rock species encountered were related to seven well-defined source areas (Figure 1). The pebble types derived from them are tabulated in Table 4 with brief descriptions, arranged in order of abundance.

Table 4: Source Areas of Pebbles in Coastal Moraine

Note 1. (Explanation of code, designations on Pages 24, 25)

2. (# denotes the major rock type in the source area)

3. (Notation in parentheses gives colour equivalents according to the Munsell Rock Colour Chart)

Devonian Granite Batholiths

A_2 GRANODIORITE: biotitic

A_1 Contact metamorphic phase, may be granitized Meguma

A_3 GRANODIORITE (A_2) with red-stained potash feldspar

A_4 APLITE

A_8 GNEISS, hornblendic, phase of A_2, from Barrington pluton

A_7 HEMATITE STAINED A_2, found along northeast-trending shear zones

A_{11} GRANITE, binary, mod. orange pink (10R 7/4) Yarmouth

A_{12} GRANODIORITE: rich in biotite, from Barrington pluton

Meguma Group

B_1 SUBGREYWACKE, chloritic; Goldenville Formation (Taylor, 1960)

C_1 SLATE, black, carbonaceous, pyritic; Halifax Formation

C_3 SLATE, dark grey (N 3)

B_2 SUBGREYWACKE, biotitic, weakly schistose

B_5 SUBGR#YWACKE, Goldenville Fm, white-weathering, arenaceous, feldspathic

C_4 SLATE, 'spotted', contact metamorphic, near Devonian granite

C_6 SCHIST, sericitic, with conspicuous metacrysts of staurolite, andalusite, garnet and biotite

C_7 SLATE, greenish-grey (5G 6/1), Sheet Harbour, Halifax County

F_1 VEIN QUARTZ, white

B_3 ORTHOQUARTZITE, pink to buff, White Rock Fm, Kentville area

Z_4 GNEISS, hornblende-plagioclase, Yarmouth-Pubnico area

C_2 SLATE, red, hematitic, Nictaux-Torbrook iron mining area

H QUARTZ-GABBRO, Triassic(?) dyke, Shelburne County (Taylor, 1960)

Minas Basin

#	D_3	SANDSTONE; iron oxide cemented, pale reddish-brown (10R 5/4)
#	D_2	SANDSTONE; greyish-orange (10YR 7/4)
	D_1	SANDSTONE; very pale orange (10YR 8/2)
	E	SILTSTONE; yellowish-grey (5Y 8/1)
	D_5	SANDSTONE; ferruginous, greyish-brown (5YR 3/2)
	D_6	ARKOSE; coarse (2mm), iron oxide cemented
	D_7	SANDSTONE; black, carbonaceous
	O	LIMESTONE, LIMEY SANDSTONE, CALCARENITE, fossiliferous; very pale orange (10YR 8/2)

North Mountain

#	G_2	BASALT; greyish-red (10R 4/2), medium-grey (N 5) abundant amygdules of zeolites (Klein, 1960)
	G_1	BASALT; massive, brown weathering (10YR 5/4) (Klein, 1960)
	F_3	CHERT, JASPER, CHALCEDONY; varicoloured

Cobequid Mountains

#	J	TUFF, FELSITE, IRON FORMATION, ~~cherty;~~ LAMPROPHYRE /porphyritic; dusky red (5R 3/4); ANDESITE, epidote-veined, grey
#	A_6	GRANITE; moderate reddish-orange (10R 6/6)
#	I	DIORITE; medium light grey (N 6)
	A_9	SYENITE; hornblende-plagioclase
	Z_4	MAGNETITE; from beds in abandoned mining area, Londonderry, Colchester County

Antigonish Highlands

G_3 BASALT; vesicular, and with calcite amygdules, (Williams, 1914)

Caledonian Upland of New Brunswick

A_{10} QUARTZ MONZONITE; red-stained potash feldspar, original pyriboles completely chloritized (Hickox, 1962; 1962b, p.13)

B. SPECIAL FEATURES OF THE SOURCE REGIONS

Successful location of the pebble sources warranted a detailed examination of these regions, for aspects which may have been contributing factors in pebble distribution.

The source areas do, in fact, exhibit certain features which have an important bearing on the interpretation of the pebble analyses. These features, arranged in order of importance, are:

1) Lithologic Assemblage of Each Area
2) Mechanical Properties of the Rock Types
3) Geological Boundaries
4) Size
5) Shape
6) Orientation Relative to Ice Advance
7) Relative Positions
8) Geographic Setting

1. Characteristic Lithologic Assemblage of Each Area

Of paramount importance is the fact that each source area contributes a unique assemblage of rock species, so that there was little doubt as to the source of each pebble type, nor was there any which may have come from more than one area. For this reason, the contribution of each source to the till at any point may be assessed singly, as well as in combination to show the mutual interplay of sources.

2. Mechanical Properties of the Rock Types

Secondarily are the singularly favourable mechanical properties of the species themselves. All of the Cobequid rocks, the Triassic cherts, and Meguma types are very tough, whilst the basalt and Devonian granite rank only slightly lower in their resistance to crushing and attrition. The only divergence from an almost ideal set of circumstances is caused by the sandstones and siltstones of the Minas Basin source area, which are susceptible to decimation during transport; even in this case, however, pulverization of the softer sediments has created a distinct till, to be discussed later. This preponderance in the till of mechanically sound components helps to minimize the 'internal' or granular variation of the sample. It makes the numerical values of compositional percentages more significant. And, plainly, this feature greatly increases the chances of recognizing long-distance transport.

It should be noted, however, that the reduction in particle diameter by attrition which invariably occurs in transport, may sometimes be accompanied by an increase in the number of fragments, if the process is one of division rather than comminution. Some indication of the extent to which this process obtains is given in Appendix VIII.

3. Accurate Delimitation of Geological Boundaries of Source Regions

Complete geological mapping coverage of Nova Scotia has furnished accurately known boundaries for the lithological units important to this present study. In the case of the North Mountain, the Cobequids and the Antigonish Highlands, on Figure 1, it is apparent that their outline is simple and that there are no important outliers. These conditions permit a reliable reconstruction of ice flow directions, at least to the extent of connecting lateral boundaries of source areas with those of the corresponding erratic fields.

4. Size

Even if the limits of a source area are known, the area is also an important factor in the evolution of till lithology (Stalker and Craig, 1956). This is especially true when information about flow directions is desired. Clearly, the smallest sources are best suited for this purpose, for erratics may be projected back to such 'point sources', thereby giving direct evidence of flow trends (provided they were involved in only one advance). The Triassic basalt outliers at Five Islands and Bass River are local examples of such point sources.

All the source areas defined in this study are much too large to be used in this way. Their lateral termini can, however, be connected with the boundaries of the corresponding erratic fields to reveal generalized flow directions. Paradoxically, their virtue actually lies in their great extent. Providing they have the right shape (see below), dispersion of their erratics may give information on the larger features of ice advance, such as lobation.

5. Shape

The quantitative aspects, in particular, of pebble associations depend largely on the outline of the source areas, since the origin and development of till lithology will be more easily deduced if the source regions have the optimum shape.

The desirability of more or less constant width for a source area is based on the assumption that, under these conditions, a uniformly-advancing ice sheet will incorporate equal quantities of material along the length of the source, with the result that the till deposited over the foreland will have a uniform background admixture of erratic material. From this premise it might then be inferred that a locally higher-than-average erratic content over the foreland is suggestive of non-uniform flow. In other words, anomalies in erratic content imply the operation of more rapid portions or currents in the ice sheet, capable of local accelerated erosion and increased deposition downstream.

Of the seven source areas, at least three have favourable characteristics (Figure 1). The North Mountain of Triassic basalt extends 125 miles along the south shore of the Bay of Fundy.

Over this length the width varies only a little - from one mile at the sharp western terminus to four miles at the equally abrupt eastern end. Outliers do, however, occur at Five Islands and Bass River, but these conveniently provide excellent additional point sources and extend the effective length to 155 miles.

Similarly, the Cobequid upland has a length of 90 miles and a width of about 10 miles. Fortunately, the narrower western portion is not a disadvantage, as it overlaps the North Mountain.

Thirdly, the Antigonish Highlands have an east-west dimension of 60 miles and range in width from 12 to 25 miles, overlapping the Cobequids for 10 miles.

Together, these three parallel units have a minimum effective length of 245 miles, thus providing coverage for the entire mainland Atlantic Coast of Nova Scotia.

An additional control, especially for studies in the vicinity of Annapolis Valley, would be given by the Caledonian Massif of southern New Brunswick. This unit varies in width from 10 to 18 miles along its 75-mile length.

In the present case, the situation approaches the ideal, with but one exception - as is evident from Figure 1 . The 'Minas Basin' source area extends from Windsor to Canso and lies immediately to the north of the study area. It has the advantage of great length, for it extends some 150 miles, but the outline is quite irregular. This disadvantage, together with the mechanical instability of its rocks, combine to limit the value of this source area as an aid to understanding the pebble analyses.

6. Orientation Relative to Ice Advance

The attitude of the three important long, narrow source regions with respect to the dominant flow of ice is ideal. Multitudes of striae (Figure ___) and ground moraine lineation (Plate 41) indicate a general southeast-to-south flow during the last major advance, which has been reasonably well-determined as the Mankato Substage of the Wisconsin Glaciation - 18,000 to 11,000 years B.P. (Hughes, 1957; Hickox, 1962). With the source areas striking north-east to east, the direction of glaciation and the elongation of the source regions are mutually perpendicular.

Glacier ice crossing the source areas at right angles assures that:

a) the area of influence downstream from a source is a maximum

b) the glacial stream lines cross the ridges without suffering deflection or destructive turbulence

c) the erosion width is a minimum, and equal to the outcrop width.

7. Relative Positions of the Source REgions

The location of the source areas relative to one another and to the area of study is highly favourable. They are collinear, slightly overlapping, and lie both within and just to the north of the area sampled. In short, assuming the ice came from the north-east, they are so situated that, for the study area, the coverage by source regions is virtually complete. As a result, the processes of both local and long-distance transport can be studied quantitatively by comparing the ratios of local-to-foreign pebbles.

8. Geographic Setting of Source Regions and Study Area

Lastly, the four main source areas form topographically prominent ridges to the north of a relatively featureless foreland. This foreland, the southernmost portion of the Atlantic Upland (Goldthwait; 1924, p.4), may be referred to as the granite-Meguma upland (now the area of study). It was peneplaned in Cretaceous time and tilted to the southeast (King; 1960, p.163) so that it slopes from summit elevations of 600 to 900 feet along the northern edge at Annapolis Valley, to the Atlantic Coast where it passes gently beneath the sea. The region is, for the most part, devoid of topographic features large enough to influence the dominant flow of ice. However, it is possible that the few large coastal embayments, notably St. Margaret's and Mahone Bays, exerted some control on flow during the waning stages. The numerous fault-line valleys trending northwesterly across the study area

(Johnson; 1925, p.40) are, in a few cases, incised into the peneplain, but these could, at most, have succeeded in diverting only the basal ice. The topographically subdued nature of the study area would seem to afford no hindrance to the free movement of both the major ice sheet and any minor lobes which may have existed. This particular area, then, is favourable for testing the pebble method, as it could not in itself have been the cause of complications of the ice flow.

Summary

Prior to starting analyses, it was possible to discover, define and evaluate a number of factors affecting glacier movement, till formation and interpretation of the data. The factors are summarized as follows: the pebbles in the tills of southeastern Nova Scotia are endowed with superior toughness, and have distinctive appearances which enabled them all to be traced to definite source areas; these regions supplied to the overriding ice unique suites of rock species and, from a geographical aspect, these source areas possess the advantages of accurately-known boundaries, simple elongate outlines of uniform width, mutual parallelism, perpendicularity to ice advance, and situation both within and to the north of the study area.

For these reasons, the early appreciation of critical source regions became the most valuable asset to the study in general, as it facilitated interpretation of the data, and promoted confidence in the results.

C. DESCRIPTION OF SPECIFIC INDICATOR PEBBLES

When the countings were studied, it was apparent that most of the species occurred in minor and inconsequential amounts, or could be justifiably combined with certain others. In contrast, a much smaller number were found to be either in significant quantities, or of remarkably persistent occurrence, but in relatively minor amounts. Most of the species in this latter group possessed certain characteristics, notably superior toughness and/or recognizability, which made them useful erratics. And erratics whose sources are known, as was the case, are termed 'indicators'. It was the distribution of the indicators which gave the results embodied in this report. Accordingly, a more detailed lithologic description of each is given below.

Characteristics of the Indicators

A_2

Name: Granodiorite (Hattie; 1959, p.10)

Source: Devonian plutons of the coastal region from Yarmouth to Cape Canso

Crystallinity: Holocrystalline, equigranular (5mm) to porphyritic

Colour: Light grey (N 7)

Appearance: Angular, pitted surface, equidimensional

PLATE 4

Cobequid Indicator rock species

Top row, varied volcanics, hypabyssal, lamprophyres, and metasediments of the 'J' assemblage;

Bottom row, left to right - two pink granites, 'A6'; Syenite, 'I'.


J
J
J

PLATE 4'

Samples of Tills and Other Formations.

Top row, left to right - compact quartzitic till; red clay till; Bridgewater Conglomerate;

Bottom row, left to right - grey Cretaceous clay; red Carboniferous sandstone; red Pleistocene lacustrine clay, Lantz; red and grey varied clay, Bayside.

Composition: Quartz; 30%, transparent

Feldspar; Potash, 25%, white or flesh-coloured, sometimes as phenocrysts up to 6cm. which are zoned and perthitic with up to 30% oligoclase

Plagioclase, 20% fresh oligoclase and 10% saussuritized plagioclase

Biotite; 15%

A_6

Name: Leucogranite (Plate 4)

Source: Cobequid Mountains, various-sized plutons

Crystallinity: Holocrystalline, equigranular

Colour: Moderate reddish-orange (10R 6/6) to moderate orange pink

Appearance: Fresh, subrounded, smooth-surfaced, polyhedrons

Composition: Quartz, 30%, translucent to transparent

Feldspar; Potash, 65%, reddish-orange, partly kaolinized

Hornblende, 5%, fibrous to prismatic

Structure: Massive to gneissic

A_9

Name: Syenite (Plate 4)

Source: Cobequid Mountains, dykes and small plutons

Crystallinity: Holocrystalline, equigranular, medium-grained

Colour: Dark greenish-grey (5GY 4/1)

Appearance: Fresh, subrounded, smooth-surfaced, polyhedrons

Composition: Hornblende, 60%, fibrous aggregates

Potash feldspar, 30%, moderate orange pink (5YR 8/4) interstitial to hornblende

Quartz, 10%, transparent

Structure: Massive

B_1

Name: Subgreywacke (Taylor, 1960);(Stevenson; 1959,p.12)

Source: the Goldenville (Quartzite) Formation of the Meguma Group, outcropping over most of the area between Yarmouth and Canso, up to fifty miles inland

Texture: Grain-size - 250u to 500u in sandy beds, 10u to 15u in slaty beds

Colour: Medium dark grey (N 4) to greenish-grey (5G 6/1)

Appearance: Angular to subangular, rough polyhedrons

Composition: Quartz, 40%, angular, transparent
Feldspar, 10%, sericitized (clouded)
Chlorite, 20%, matrix
Magnetite, octahedra, 100u, in sandy beds, 0.5%
Biotite, 2%, porphyroblasts, 100u, in slaty beds
Matrix, 15-75%, silt and clay

Structure: Massive to schistose

C_1

Name: Slate (pyritic)

Source: the Halifax (Slate) Formation of the Meguma Group, outcropping in synclinal belts from Liverpool to Canso

Texture: Aphanitic matrix with porphyroblasts

Colour: Black, with brownish limonitic stain near the sulphides

Appearance: Smooth-surfaced tablets and blocks

Composition: Clay minerals, quartz, carbonaceous material
Pyrite and pyrrhotite metacrysts usually 2-3mm.

Structure: Slaty cleavage, fair to good

C_3

Name:	Slate
Source:	The Halifax (Slate) Formation of the Meguma Group, outcropping in synclinal belts from Liverpool to Canso
Texture:	Aphanitic
Colour:	Dark grey (N 3)
Appearance:	Smooth, often shiny, chips and tablets
Composition:	Clay minerals, quartz, carbonaceous material

C_4

Name:	Slate (spotted)
Source:	Meguma Group - Halifax-Goldenville transition zone exposed from Liverpool to Canso
Texture:	Glomeroporphyroblastic with aphanitic matrix
Colour:	Medium light grey (N 6) with black spots
Appearance:	Smoth blocks and tablets
Composition:	Garnet-to-sillimanite-grade clay minerals, quartz biotite and cordierite clusters 1-2mm. across

C_6

Name:	Schist
Source:	Top of the Goldenville Formation of the Meguma Group outcropping from Liverpool to Yarmouth
Texture:	Porphyroblastic
Colour:	Light grey (N 7)

Appearance: Subrounded blocks and flattened ovoids studded with metacrysts

Composition: Quartz-sericite matrix with porphyroblasts of:

Biotite, brown, equidimensional books, 2-3mm.

Garnet, pink to red, 0.5mm to 1.5mm

Staurolite, brown, 2-30mm, cruciform twins

Andalusite, pink, up to 20cm, rectangular prisms

Chiastolite, pink, transparent, 20mm, needles

Structure: Well-developed schistosity in the sericite matrix, metacrysts rarely aligned

D_1

Name: Subgreywacke (arenaceous-weathering)

Source: Goldenville (Quartzite) Formation of the Meguma Group

Texture: Granular, poorly sorted (25u to 250u)

Colour: Greyish-orange (10YR 7/4), weathers pale orange (10YR 8/2)

Appearance: Subrounded polyhedrons

Composition: Quartz, transparent

Feldspar, keolinized

Sericite

Structure: Slightly schistose

D_2

Name: Feldspathic Sandstone and Siltstone

Source: Middle member, Horton Bluff Fm, Horton Group Mississippian Age, Minas Basin area (Bell;1960,p.13)

Texture: Granular, well-sorted (150u-200u), 30% porosity moderately well-cemented

Colour: Greenish-grey (5G 7/1) to pinkish, weathers greyish-orange (10YR 6/4)

Appearance: Well-rounded to subrounded ellipsoids

Composition: Quartz, transparent
Feldspar, 30-50%, kaolinized
Iron oxide, red, in interstices

D_3

Name: Hematitic quartzose and feldspathic, sandstone and siltstone, Ferruginous arkose; (Bell, 1960; Stevenson, 1959) (Plate 4')

Source: Windsor/Horton Groups of Mississippian Age, widely scattered throughout the Minas Basin source area

Texture: Granular, well to poorly sorted

Colour: Dark reddish-brown (10R 3/4)

Appearance: Subrounded polyhedrons and well rounded ovoids, gritty surface

Composition:	Quartz, angular, transparent
	Feldspar
	Iron Oxide
Structure:	Massive (no lamination visible in pebble sizes)

F_1

Name:	Vein Quartz
Source:	Veins and saddle reefs in the Goldenville Formation of the Meguma Group
Texture:	Holocrystalline, dense, medium-grained
Colour:	White to very light grey
Appearance:	Angular to subangular fragments, or very well rounded ovoids
Composition:	Silica
Structure:	Usually massive, sometimes com-structured, rarely with partings of graphitic slate

F_2

Name:	Quartz (yellow)
Source:	Problematical; possibly kame material of last interglacial, or pre-Pleistocene alluvial gravels
Crystallinity:	Holocrystalline, equigranular
Colour:	Dark yellowish-orange (10YR 6/6) to moderate yellowish-brown (10YR 5/4)
Appearance:	Well rounded ellipsoids, sometimes with a fine matte finish, usually pitted with crescentic gouges

Composition: Silica, iron oxide as stain

Structure: Massive to comb-structured

F_3

Name: Chert, Jasper, Chalcedony, Agate

Source: North Mountain; vein, vug, and geode fillings

Crystallinity: Microcrystalline to cryptocrystalline

Colour: Reds, browns, purples, greys

Appearance: Subangular to subrounded polyhedrons, smooth

Composition: Silica, colouring matter

Structure: Massive to very thinly banded

G_1

Name: Basalt (dolerite) (Klein, 1957)

Source: North Mountain, and outliers at Five Islands and Bass River

Crystallinity: Holocrystalline, porphyritic to diabasic (ophitic)

Colour: Fresh surface - dark grey (N 3)
Weathered surface - moderate yellowish-brown (10YR 5/4)

Appearance: Subrounded, weathered surface pitted and friable

Composition: Labradorite, 38-52%, laths, sometimes conspicuous
Augite, 20-40%, fine grained mesostasis
Pigeonite, 10-15%, fine grained mesostasis
Glass, chlorite, hornblende, magnetite, 5-10%

Structure: Massive, columnar jointing

G_2

Name: Basalt (amygdaloidal) (Klein, 1957)

Source: North Mountain, and outliers at Five Islands and Bass River

Texture: Holocrystalline, amygdaloidal

Colour: White to pinkish zeolites in a greyish-red (10R 4/2) matrix

Appearance: Rounded ellipsoids, smooth surface, amygdules commonly protruding rather than embayed

Composition: Same as massive basalt

Labradorite, 38-52%

Augite, 20-40%

Pigeonite, 10-15%

Glass, chlorite, hornblende, magnetite, 5-10%

Amygdules, 5-30% invariably filled with zeolites (stilbite, heulandite, analcite, laumontite, natrolite, chabazite, apophyllite; Aumento, 1962)

Structure: Massive, but tending to crumble readily

I

Name: Diorite (Plate 4)

Source: Cobequid Mountains, stocks, bosses and dykes

Crystallinity: Holocrystalline, equigranular, hornblende laths commonly have subparallel alignment

Colour: Medium light grey (N 6)

Appearance: Subrounded blocks, smooth-surfaced

Composition: Hornblende, 40%, laths
Plagioclase, 50%, matrix (interstitial)
Quartz, 10%

Structure: Massive

J (Plate 4)

Name: Originally a 'restgroup' to include a number of ill-defined rock types, subsequently traced to the Cobequid Mountains and identified as follows:

Name: Felsite (Plate 4)

Crystallinity: Holocrystalline, porphyritic

Colour: Moderate reddish-orange phenocrysts in a dark reddish-brown (10R 3/4) matrix

Appearance: Subrounded, very smooth surfaced polyhedrons

Composition: Potash Feldspar, 15-20% phenocrysts, 1-2mm
Quartzo-feldspathic groundmass with iron oxide

Name: Lamprophyre (Plate 4)

Crystallinity: Holocrystalline, porphyritic

Colour: Greenish phenocrysts in a very dusky red purple (5RP 2/2) matrix

Appearance: Subrounded to subangular, rough polyhedrons

Composition: Feldspar, plagioclase, phenocrysts, 2-8mm
Groundmass, mafic, aphanitic

Name: Andesite (eipdote-veined) (Plate 4)

Crystallinity: Holocrystalline, aphanitic

Colour: Dark greenish-grey (5G 3/1) weathers greenish-grey (5G 6/1)

Appearance: Subrounded to subangular polyhedrons, mat surface

Composition: Feldspar and ferro-magnesians

Structure: Massive, with thread-like veins of epidote

Name: Tuff (crystal) or Rhyolite (flow banded) (Plate 4)

Crystallinity: Holocrystalline, porhyitic with aphanitic matrix

Colour: Light brown (5YR 6/4) to greyish-red (10R 4/2)

Appearance: Subrounded polyhedrons

Composition: Feldspar, phenocrysts, 1-2mm
Quartz, ferro-magnesians, iron oxide

Structure: Thin foliae (0.1-2.0mm) alternating light and dark layers, often wrapped around the phenocrysts giving pseudo-augen effect).

D. PEBBLE ASSOCIATIONS IN THE TILL SHEET

GENERAL INDICATIONS

The pebble content of the tills is, at first glance, apparently quite simple. Most samples are characterized by the dominance of one species which is usually present in amounts ranging from 80-100 percent. Moreover, it is always plain to see that this same species underlies the till as bedrock, indicating that the bulk of the till is locally derived. The remainder of the pebble content - that is, the 'non-local' component - is made up of species from nearby and remote sources.

The dominant component varies in (a) type, according to the local geology, and (b) amount. These latter variations of volume are related to:

1) the proximity of adjacent source areas
2) the stratigraphic position in the till sheet.

The vertical variation of 'local' material is explained by the bipartite division of the till sheet (see page 11). In the lower zone, the 'local' or bedrock component increases to 100 percent as the bedrock interface is approached. Conversely, foreign pebbles become more abundant towards the upper surface of the till sheet. (As this study was implicitly concerned with the exotic material, in addition to regional variations in bulk composition, it was for this reason that the sample was taken as high as possible in the till sheet, just below the altered 'B' soil zone).

It follows that the pebble fraction of a till may be considered as a combination of three components:

1)	dominant:	subjacent source	(derived locally)
2)	minor:	adjacent source	(derived nearby)
3)	accessory:	distant source	(derived remotely)

The relative proportions of the three components may vary widely. Such variations reflect the mutual interplay of the various factors involved in the formation of the till. Where the controlling factors were not varying, as under identical conditions of formation, the relative proportions of the three pebble components in the resulting tills would have certain values. For this reason, the pebble ratios or 'associations' may be used to characterize till types.

Needless to say, of the three parameters, the dominant component gives the best statement of the essential differences between tills. The preponderance of bedrock material in a till implies a close spatial correspondence between till lithology over an area, and the bedrock units therein.

Consequently, it was found that, for each major bedrock map unit, there is, overlying it, a till type of that lithology (Cameron, 1961, p. 111). As the study area lies essentially within the confines of the 'granite-Meguma' upland, the till sheet was therefore found to have three dominant lithologies, namely: granite, quartzite and slate, in decreasing order of areal extent. Other tills were mixtures from these three sources, and were termed 'hybrids'.

1. GRANITE TILL

Pebble Associations

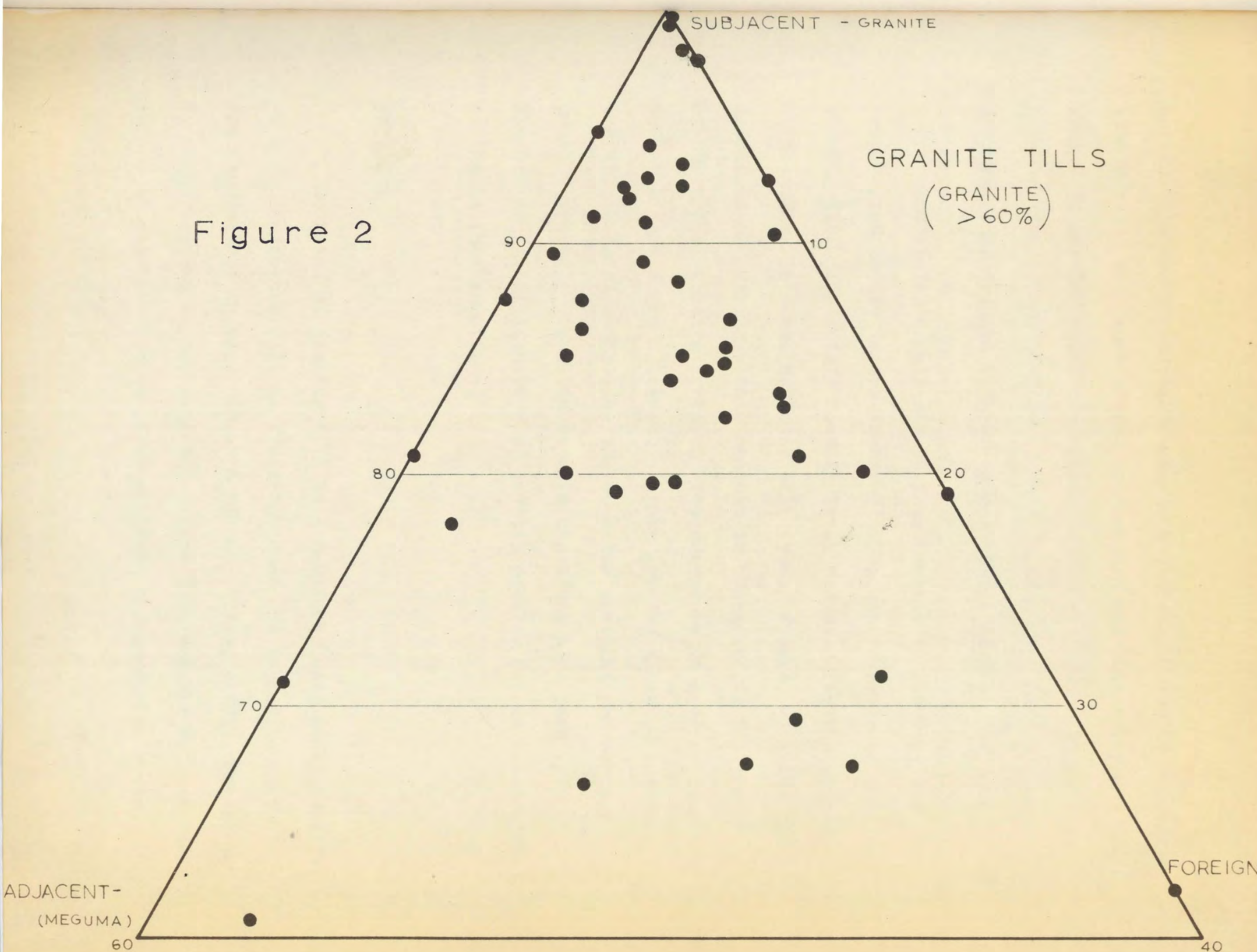
Some forty samples contained Devonian granite, chiefly species A_2, in amounts of at least 60 percent, and usually 80 to 95 percent (Figure 2). The admixture of non-granite pebbles has a marked maximum at 20 percent; and the figure also shows this dilution to be slightly weighted towards the 'foreign' apex.

Distribution

All these samples are situated within the confines of the Devonian granite batholiths. The granite-rich till type substantiated by these samples is the parent material of the 'Gibraltar' soil catena (Cann, 1954, p.48). The distribution of 'Gibraltar' soil (or granite till) coincides almost perfectly with the outlines of the granite batholiths (Figure 3).

One reason for this is obvious. The parent material, or till, from which this soil formed is pale yellow (2.5Y 7/4) to yellowish-brown (10YR 5/6) and is characterized by extreme stoniness, angular fragments, coarse texture, and a sandy matrix. Understandably, this harsh mixture of sub-glacial debris would have the mechanical stability to resist displacement by the forward shearing action at the sole of the ice sheet. This accounts for the marked lack of evidence of mass movement of granitic material

Figure 2


SUBJACENT - GRANITE
GRANITE TILLS
(GRANITE >60%)
90
10
80
20
70
30
ADJACENT-
(MEGUMA)
FOREIGN
60
40

per se. In short, there appears to have been virtually no wholesale glacial transport of the accumulated pre-Pleistocene weathered granite mantle (Cameron, 1961, p.111).

Dispersion of Granite Pebbles Beyond Source Area

Subglacial debris may be incorporated in the ice, and transported bodily in the faster-flowing upper levels of the ice sheet. This 'englacial' load is later let down, by the process of ablation, into the adjacent till type. Figure ___ shows the isopleths of granite-pebble content in non-granitic till south of the Meguma-granite contact. The admixture is seen to decrease markedly in a short distance, so that granite erratics become negligible in quantity only twelve miles south of the nearest granite outcrop. Thus, it appears there has also been very limited englacial transport of granite pebbles beyond the confines of the source batholiths.

Drumlins

Drumlins of granite till have developed only exceptionally in areas where the till is finer-textured and deeper, notably in the vicinity of Chester (Cann & Hilchey, 1958, p.30). Moreover, detailed mapping by the soil scientists has revealed no drumlinoid masses of granitic till in adjacent slate and quartzite areas.

These features suggest they were formed more probably by a process of erosion and sculpturing of thick accumulations than by lodgement and accretion of transported material. Aside from the question of how they are built, it appears that the reason for their very limited development lies in the physical properties of the till. The till inherently resists transport, thus preventing the accumulation of sufficiently thick deposits for drumlin formation.

It is interesting, and perhaps has a bearing on the question of genesis, that the pebble association in the drumlin phase differs from that of the granite till sheet, in that fully half of the pebble content is non-granitic material. More remarkable is that virtually all of this non-granitic fraction is from distant sources.

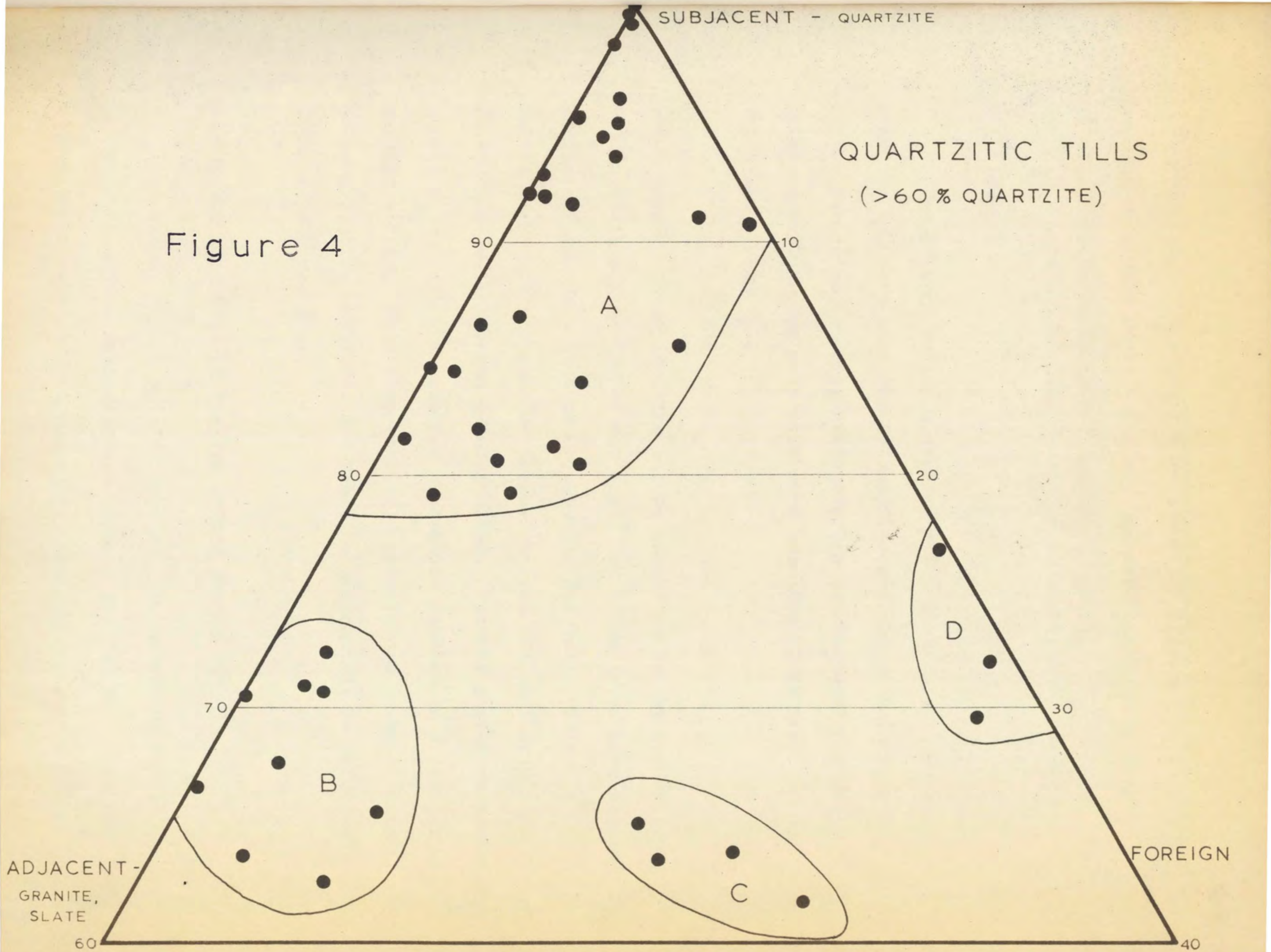
2. QUARTZITE TILL

Pebble Associations

Forty-five samples have a markedly high content of subgreywacke from the Goldenville Formation (species B_1). The ternary diagram, Figure 4, shows the relative proportions of the three source components: Subjacent (subgreywacke), Adjacent (granite, slate), and Distant (Cobequid, Minas, North Mountain) in these samples. They contain at least 60 percent subgreywacke and most contain over 80 percent. It is interesting that in this later, more restricted group (A), the foreign component is sharply delimited at 10 percent. Outside the major field are three smaller groups of samples.

The samples (B) clustering at the granite-slate apex are explained by their proximity (one to two miles) to outcrops of these rocks.

Group (C) appear to be otherwise average quartzite tills with an anomalously high content of foreign material. The explanation may be their proximity to drumlin fields composed largely of the same foreign material. It may be outlined here that it is believed these drumlins, in overriding the till sheet, impressed into it a portion of their exotic pebble content, thereby enriching it with respect to the 'foreign' component.


SUBJACENT - QUARTZITE
QUARTZITIC TILLS
(>60 % QUARTZITE)
Figure 4
90
10
80
20
70
30
60
40
A
B
C
D
ADJACENT -
GRANITE,
SLATE
FOREIGN

Similarly, the samples in group 'D' happened to have been taken within drumlin fields, and may therefore be samples of more or less contaminated drumlin material.

Distribution

The Halifax soils (quartzite till) show a good correlation with the boundaries of the Goldenville quartzite, but there is, at the same time, a conspicuous overlap of the quartzite till sheet as much as one mile southward onto the slate areas (Figures 3 and 16).

Again, these features may be accounted for by the origin and physical properties of the till. It is believed that glacial erosion of the well-jointed Goldenville quartzite yielded a debris with more and smaller fragments than did similar action on the less well-jointed granite areas. Further attrition produced a pale olive till with smaller subangular pebbles in a siltier, clayier matrix. This finer-textured material would be expected to have greater mobility, and hence be susceptible to relatively farther mass transport.

Dispersion of Quartzite Pebbles Beyond Source Area

Compared to the granite pebbles, the quartzite pebble fraction is more widely dispersed and in greater quantity, constituting as much as five percent of the non-quartzitic tills, even thirty to forty miles south in the granite and slate areas.

One explanation for this phenomenon lies in the structure of the Goldenville strata. Over the quartzite terrain the bedding dips at moderate angles, and is oriented normal to the ice flow. Under these optimum plucking conditions, it is likely that the ice sheet developed the hogback terrain which is still a characteristic morphological feature of the quartzite areas. This strongly-corrugated surface, in turn, activated shear planes in the sole of the ice, causing much debris to be incorporated.

Drumlins

Quartzite drumlins occur frequently over the quartzite till sheet where sufficient till has accumulated (Cann & Hilchey, 1959). Very likely, the finer texture of the till was favourable to their formation. It is interesting that their formation, whether by erosion or accretion, was accompanied by measurable translation in the direction of ice advance. In many places they are displaced at least two miles southward into the adjoining slate areas (Plate 5).

As with the granite till, the drumlin phase of the quartzite till also shows an above-average proportion of foreign components.

3. SLATE TILL

Pebble Associations

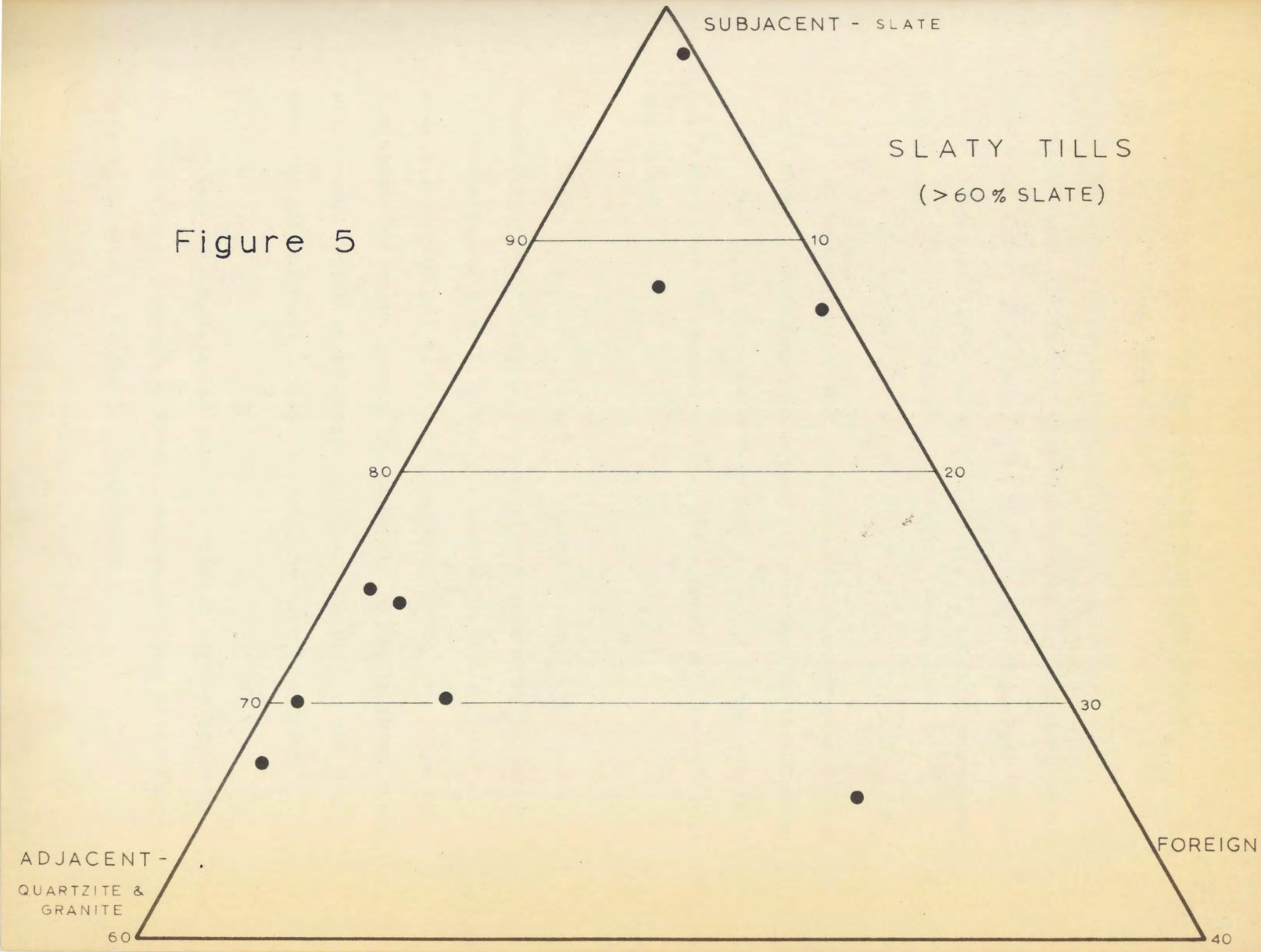
Eight samples only were found to contain more than 60 percent slate (C_1) from the Halifax Formation (Figure 5). Those on the left of the ternary diagram are believed to represent normal slate lodgement till, with the normal admixture from nearby granite and slate sources. On the other side of the diagram, samples #32, #38 and #39 are conspicuously high in foreign elements. These were collected in the north of the study area, where they were strongly influenced by the nearby Minas Basin and Cobequid source areas.

Distribution

These eight samples are taken from a group of seventeen which happened to have been collected from slate areas. It is not surprising there are so few such samples, as the slate areas are of relatively minor extent.

East of Halifax, the slate occurs in long narrow synclinal belts which were found by planimeter to cover about 10 percent of that part of the study area. Like the granite and quartzite areas, these slate areas also support their own slaty till, which covers perhaps one to two percent of that area. The discrepancy in areal extent between slate outcrop and slate till is due to the

Figure 5


SUBJACENT - SLATE
SLATY TILLS
(>60% SLATE)
90
10
80
20
70
30
ADJACENT -
QUARTZITE &
GRANITE
FOREIGN
60
40

southward migration onto the slate belts of the adjacent quartzite till (see page 60).

West of Halifax, in Queens and Lunenburg Counties, however, the areal extent is greater. The slate covers 30 percent of the area, and the overlying slaty till covers 27 percent, or exactly 600 square miles.

It is consistent that one-tenth of the study area is slate and one-tenth of the samples happen to have been collected over slate. But it is surprising that only one-half of the samples assay more than 60 percent slate. There appears to be more than one reason.

East of Halifax, it may be a simple case of the small slate areas having their slaty till excessively diluted by an influx of quartzite and granite. Yet the aberrant samples occur at widely-separated points (Uniacke and Ecum Secum) and there does not appear to be any reason why there should be, in these areas, any greater influx of quartzite pebbles. Indeed, it was found that the dilution was caused, instead, by foreign elements.

West of Halifax, the strongly-diluted samples occur in the vicinity of the LaHave River, and the diluting material was again found to be foreign components.

PLATE 5

Migration of slate Till (dark grey) and slate drumlins (black) over quartzite areas (white). Note that the quartzite drumlins (light grey) do not move outside the quartzite area.

The tightly-folded, cleavable slate of the Halifax Formation yielded vast quantities of clayey debris to form the thick blanket of fine-textured olive grey (2.5Y 4/2) till. Concomitant with the ease of till formation was the extent of till transport. East of Halifax, synclines of slate one to three miles wide provide localities where the mass transport of this till may be compared with that of the other tills. North of Sheet Harbour near Killag River, slate-rich till (Bridgewater soil) extends almost one mile south onto the quartzite (Figure 3). In Lunenburg County where the outcrop area is larger, and the supply therefore greater, the overlap is two miles (Plate 5).

Drumlins

In Lunenburg County the excessive supply of slaty debris is sufficiently thick to support a remarkably well-developed drumlin phase. These remarkably symmetrical masses, numbering over 1,000, have migrated two to six miles onto the quartzite terrain (Wilson, 1938) (Plate 5).

Like its granite and quartzite counterparts, the drumlin phase of the slate till is also richer in non-slate pebbles; and this non-slate fraction is similarly composed largely of foreign components.

PLATE 6

Stratified 'Bridgewater Conglomerate' at Musquodoboit.

PLATE 7

'Bridgewater Conglomerate' on Slate outcrop, Armdale, Halifax Co.

The "Bridgewater Conglomerate" - a Phase of the Slate Till

Widely scattered over the slate areas from Sheet Harbour to Yarmouth are small areas of till-like slate debris, which is singularly cemented with iron and manganese. (Plate 6) Typically, this rock-hard material is firmly bonded to the underlying, sometimes striated slate surface (Plate 7). The grain size is extremely variable, ranging from dust to tremendous monolithic blocks. The grain size distribution of the minus 22.2mm fraction is not that of a till, but is bimodal like a river gravel. A rude stratification is often present (Plates 6 and 8) and thin seams of waterlaid sand are interlaminated.

Pebble Associations

Owing to the difficulty of obtaining a clean, disaggregated sample suitable for analysis, only a few approximate pebble counts could be made. However, the average pebble count given below in Table 5 has been largely substantiated by visual estimates made at numerous outcrops.

Table 5. : Pebble Lithology of the Bridgewater Conglomerate

Granite	(local, A_2)	10 - 35 percent
Slate, black	(C_1)	45 - 70 percent
Quartzite	(B_1)	15 - 20 percent
Granite	(A_6)	0.9 -1.3 percent

Many of the minor foreign components are doubtless present, but masked by cement. The lithology, then, is not unlike the rest of the slaty till.

Distribution

The literature mentions occurrences at Cape St. Mary, Greenfield, Bridgewater, Maitland, Martin's River, Chester and Halifax. During this study, it was found additionally at Western Shore, Purcell's Cove, York Redoubt (Plate), and Musquodoboit Harbour. Perhaps coincidentally, these exposures fall very nearly along a straight line extending for one hundred and seventy miles along the south coast of Nova Scotia.

The singularly indurated character led some to assign it to the Carboniferous period, owing to its similarity to the auriferous Gay's River conglomerate of Mississippian Age (Honeyman, 1870; 1882; Poole, 1903). Sage (1959) interprets the Martin's River deposit as Tertiary river gravels. Prest (1896) advocates an early Pleistocene age, because of included erratics of northern provenance, while Bailey (1896) and Honeyman (1886) believe that a special set of conditions operating in comparatively recent times could be responsible.

Aside from its attraction as a curiosity, its peculiar occurrence, and till-like texture and lithology relate it to the present problem. Therefore, the question of its age will be discussed with the stratigraphy of the various other tills.

4. HYBRID TILLS

It has been shown that, over most of the study area, the tills are mono-lithologic, and overlie their source areas with remarkable conformity. However, the lithology of an appreciable number of samples does not fit this pattern. These tills do not have a component present in sufficient amount, that is, more than 60 percent, to give them lithologic identity. Thus, they are essentially mixtures of pebbles from several sources, and are accordingly termed 'hybrids'.

The hybrid tills are plotted on Figures 6 and 7 . Figure 6 is a conventional ternary plot; the three components being 'granite', 'foreign', and 'quartzite plus slate'. The points appear to fall in very interesting groups.

In order to clarify the picture, it was decided to separate the quartzite and slate end members which, after all, could not be justifiably combined since they are, by nature, mutually exclusive. Thus, it was necessary to deal with a four-component system. The result - Figure 7 - was derived from a tetrahedron resting on a triangular base, the corners of which were the granite, quartzite and slate end-members. The apex of the pyramid was the foreign component. Seven equi-spaced levels parallel to the base represented 15 percent ranges in concentration of the foreign component. To plot a sample, it was first assigned to

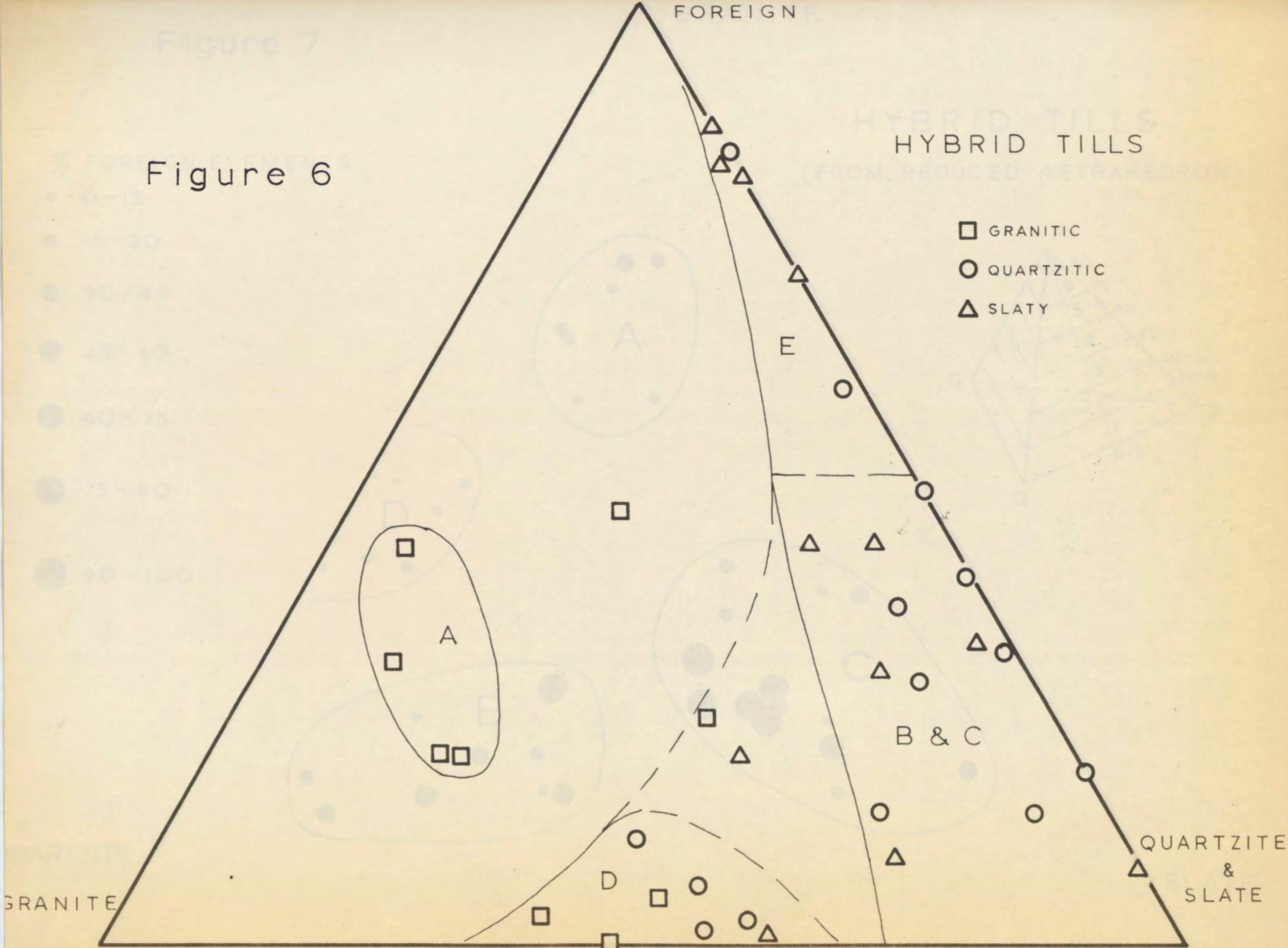


Figure 6

HYBRID TILLS

the proper level according to its degree of enrichment in foreign material, and then plotted on that particular triangle using G + Q + S = 100 percent. The seven concentric triangles and their plotted points were then projected to the base by a vertical 'reduction' of the tetrahedron, and were identified by various sizes of plotting circles. As each of the seven concentric triangles had a different linear scale according to its level in the tetrahedron, the composition ranges covered by the resulting fields of points cannot be read on the base triangle. For this purpose the other Figure has been used.

These figures show the points to be grouped in distinct fields. The compositional ranges of the fields, the geographic locations of the samples and interpretation of the results, are summarized in Table 6 .

Table 6 : Description of the Hybrid Tills

Field: "A"

Range:	Granite	50 - 60 percent
	Q plus S	5 - 25 percent
	Foreign	20 - 45 percent

Characterization:

Granitic tills with some local material conspicuously enriched in foreign material.

Location:

1. Sambro area, east side St. Margaret's Bay

Interpretation:

Granite till influenced by nearness to, or position within fields of red-coloured, non-granitic (foreign?), drumlins.

Field: "B & C"

Range:	Granite	0 - 35 percent
	Q plus S	10 - 95 percent
	Foreign	8 - 88 percent

Characterization:

Quartzite till and slate tills with some local granite; greatly enriched with foreign material. Figure 7 shows slaty tills have relatively more distant material. Some of these tills are so rich in foreign material (more than 50 percent) to distinguish them as a separate type. (E).

Location:
1. Scattered
2. LaHave River
3. Cow Bay to Chezzetcook
4. Owl's Head
5. Ecum Secum
6. Moose River
7. Musquodoboit
8. Windsor

Interpretation:

1. Originally normal slate or quartzite tills, diluted by 'overlap' from adjacent source areas immediately to the north.

(2-6) Quartzite and slate tills influenced by their nearness to, or position within fields of drumlins composed largely of red-coloured, non-local (foreign?), material. Tills situated within the source areas of foreign pebbles (Minas) or near others (Cobequids and North Mountain). (7&8)

Field: D

Range:	Granite	35 - 60 percent
	Quartzite	40 - 55 percent
	Slate	0 - 10 percent
	Foreign	0 - 10 percent

Characterization:

Roughly equally mixed amounts of granite and quartzite pebbles; with minor amounts of slate and foreign pebbles.

Location:

1. Yarmouth
2. Shelburne
3. Musquodoboit Harbour

Interpretation:

Granite tills diluted by overlap from adjacent quartzite areas; quartzite tills diluted by overlap from adjacent granite areas.

Summary

The hybrid tills appear to be of two major types. Most are mixtures of pebbles from the three local sources. They are widely dispersed, and are invariably found near the mutual contacts of the local sources. They are believed to be the result of simple mixing by 'overlap'.

There are, in addition, a certain number of hybrid tills which are conspicuously enriched with foreign material. Such tills are not scattered randomly, but are localized in certain areas, namely: Lunenburg-LaHave River, St. Margaret's Bay, Sambro, Cow Bay-Chezzetcook, Owl's Head, Moose River, and Ecum Secum.

When it was detected that foreign pebbles were more than a minor constituent in some tills, and that they were non-uniformly distributed, these discoveries indicated the need for a separate, more detailed, analysis of the distribution of these exotic pebbles in the till sheet.

E. DISTRIBUTION OF EXOTIC PEBBLES IN THE TILL SHEET

In the till sheet, the content of exotic or foreign material - that is, pebbles derived from outside the area sampled - rarely exceeds twenty percent; but its very presence, however seemingly insignificant by actual numbers, proves the existence of an influx from sources thirty to seventy miles distant.

This fact alone justified a detailed analysis of the foreign components. Their combined percentage was plotted on a map. As expected from results given in the previous section, concentrations of foreign pebbles were outlined over several areas, namely: Yarmouth, Lunenburg, St. Margaret's Bay, Sambro, Cow Bay, Musquodoboit Harbour, Owl's Head, and Ecum Secum.

With this fact established, it was desired to find which species within the foreign group were responsible for the trends. By the same process, it was found that each and every one of the species in the Cobequid and North Mountain assemblages were similarly concentrated in the localities listed above. On the other hand, pebbles from the Minas Basin source group, plotted separately by species and combined as a group, gave relative concentrations in the intervening areas between the above-mentioned localities.

This latter result pointed to the likelihood of an interdependence of the three source area assemblages. To test this probability, the constituents of the foreign admixture were recalculated on a 100 percent basis, thereby nullifying the dilution effect of the local elements. This operation was expected to clarify and accentuate the apparent numerical relationship between the source area pebble groups.

The results were confirmatory. As before, the Cobequid group was most abundant in the same localities. Again, the North Mountain pebbles were similarly distributed, although the influence from the main mass of Triassic basalt terminated abruptly at Chezzetcook. Minor concentrations of basalt pebbles at Owl's Head and Ecum Secum could be projected northwestward and northward along striation directions to their very likely sources at the Five Islands-Bass River outliers, and the Antigonish Highlands, respectively. The Minas Basin assemblage was distributed slightly more erratically, but was still relatively concentrated in the areas between the concentrations of Cobequid and North Mountain pebbles. It follows from this that the content of Minas Basin pebbles in the till sheet is inversely proportional to the sum of the pebbles from the other two distant source areas.

The distribution of the Cobequid pebbles is the most widespread laterally, and the relatively greater amount of this material gives a stronger, more reliable pattern. The dispersal of North Mountain pebbles is less extensive, but nonetheless follows exactly the same trends.

Figure 9 has been constructed by combining the mutually-corroborative results given by separately plotted distributions of pebbles from the distant source areas, namely: Cobequid Mountains, Minas Basin, North Mountain, and Antigonish Highlands. Note that the levels of concentration are on a geometric, rather than a linear scale. The isopleths, or lines of equal quantity, show the concentrations in the various areas to have a conspicuously lobate form.

Summary

The following features about the distribution of exotic pebbles in the till sheet are outlined:

1) Considered as groups, North Mountain and Cobequid pebble assemblages are concentrated in the same restricted areas

2) The Minas Basin pebble group is concentrated in the intervening areas

3) Plotted separately, the individual species in each source group show essentially the same distribution

4) Isopleths outlining areas of anomalously high foreign pebble content have a lobate shape

5) In the anomalous areas, there occur drumlins of reddish-brown clay till, not sampled during the first phase of the field work.

CHAPTER FOUR

THE RED CLAY DRUMLINS

A. INTRODUCTION

The explanation for the peculiar distribution of the foreign pebbles was sought for in the drumlins which occur in the same areas as the pebble concentrations (Figure 14)

The soil maps of Lunenburg County by Cann and Hilchey (1958) show a mass of drumlins texturally and compositionally quite distinct from the flanking slate till drumlins. (Plates 9&10). These drumlins are composed of plastic, reddish brown (5YR 4/4) clay loam till which supports the 'Wolfville' soil catena, as designated by the soil scientists. Henceforth in this paper, these particular drumlins will be referred to as the 'Wolfville' or 'red clay' drumlins.

The red clay drumlins are separated by the loose slate till sheet, but are observed to rest on an underlying, more compact, slaty till. A few slate drumlins are interspersed with them. Over two hundred occur in a belt six to ten miles wide, bounded on the west by the Lahave River, and on the east by Mahone Harbour. The axis of the belt passes north-westerly through Blue Rocks and Lunenburg, thence curving north-northwesterly at Lantz, thirty miles distant. (Plate 10).

The red colour and clay-rich matrix of the drumlin

PLATE 9

Juxtaposition of the Bridgewater Slate drumlins (Bwd) and the Wolfville Red loam drumlins (wld) along the Lahave River at Bridgewater.


62-13
61-136
Bridgewater
LA HAVE
RIVER
Blysteiner
Lake
Covey L.
Oak Hill
Lake
Pernette
Lake
Dares
Lake
HEBB
LAKE
LAKE
Bw
Wld
Bwd
Sp

PLATE 10

Divergence of the slate drumlins and the red clay drumlins in the Bridgewater-Lunenburg area.


LA HAVE
ISLANDS
GREEN
BAY

material virtually precludes the possibility of its being locally derived. The association of fields of distantly derived drumlins with areas of abundant exotic pebble content in the surrounding till sheet was a strong indication of a genetic relationship. However, the next step, before actually investigating the drumlins in detail, was to test the significance of the connection by demonstrating the recurrence of the phenomenon.

With the exception of the Lunenburg area, all the other localities of anomalous erratic-pebble content occurred in Halifax and Guysborough Counties. No published soil report is available for this area as yet. However, the area has very recently been mapped by the soil scientists, and the author was very kindly furnished with a map of the preliminary results by H.L. Cameron of the Nova Scotia Research Foundation.

This map, on a scale of four inches to the mile, showed very clearly numerous red clay drumlins arranged in groups or fields most of which matched in position, size and shape the remaining areas of maximal foreign pebble concentration. Other drumlin fields occurred outside the area of study at Liscomb and Canso.

This final confirmation of an association of drumlins and exotic pebbles made a separate study of the red clay drumlins imperative.

B. METHODS OF STUDY

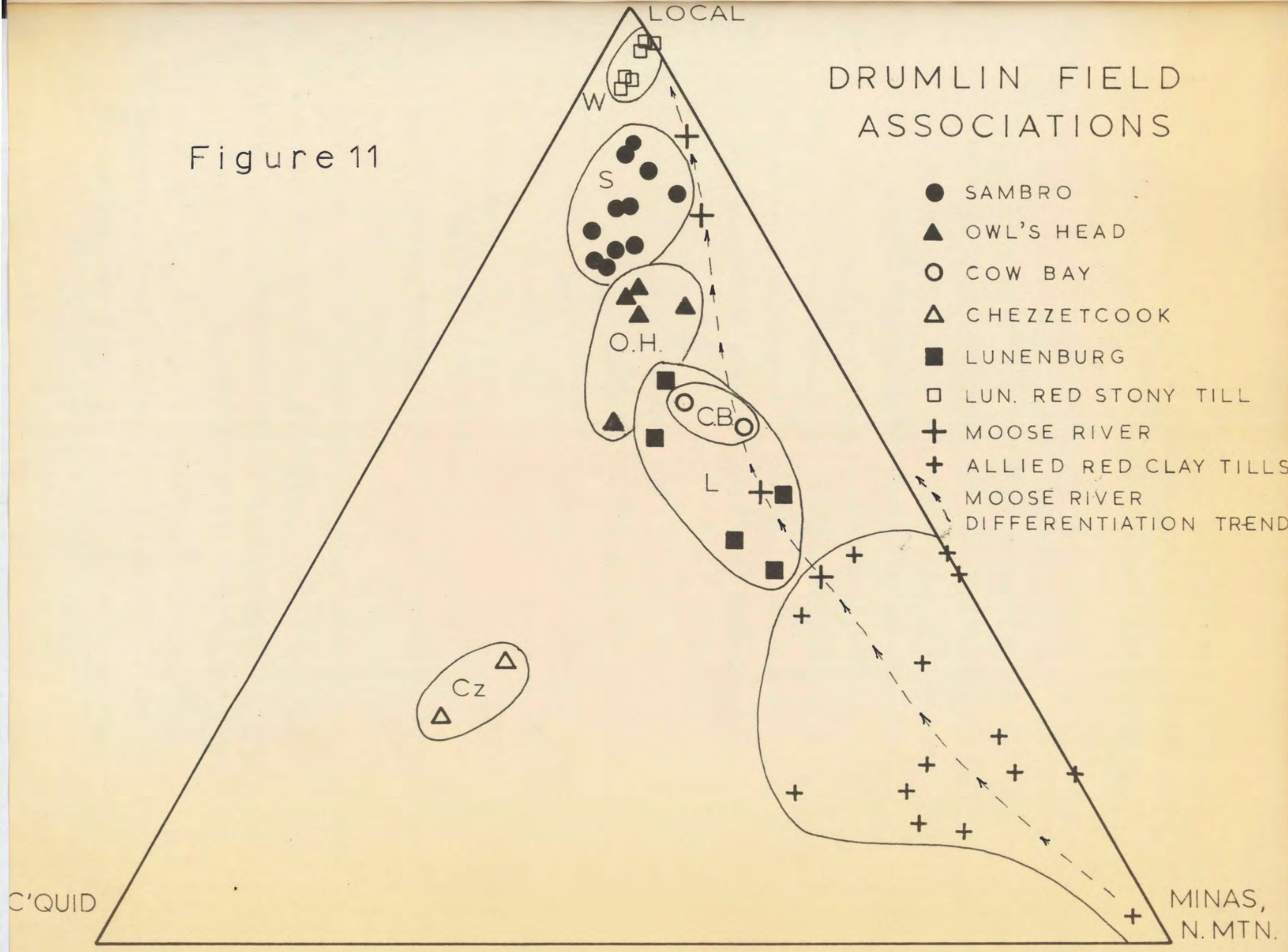
The red clay drumlins were sampled as outlined on page 19. It was deemed advisable to consider each drumlin field as a unit for three reasons:

1) the geographically distinct grouping
2) the exotic appearance of the red clay matrix
3) the strong geographic variation of exotic pebble content in the surrounding till sheet.

The discussion of each drumlin field is divided into three sections. First, the physical characteristics of the drumlin field are described. Being virtually the only cultivable land in the area, most were cleared by the early settlers for small farms. (Cann and Hilchey, 1958, p.37). Otherwise, they support rich stands of mixed forest, in contrast to the scrubby black spruce and heath vegetation of the granite till. Thus, both the cleared and the forested drumlins are conspicuous on aerial photographs, so a good map can be drawn showing their precise locations, and exact shapes.

Secondly, the pebble lithology is expressed as a plotted point on a triangular diagram, the components of which are: (a) granite, quartzite and slate; taken as a composite variable because one or other of these rock types underlies the drumlin as bedrock and till type; (b) Cobequid rocks; (c) Minas Basin

Figure 11


DRUMLIN FIELD
ASSOCIATIONS
LOCAL
C'QUID
MINAS,
N. MTN.
W
S
O.H.
C.B.
L
Cz
SAMBRO
OWL'S HEAD
COW BAY
CHEZZETCOOK
LUNENBURG
LUN. RED STONY TILL
MOOSE RIVER
ALLIED RED CLAY TILLS
MOOSE RIVER
DIFFERENTIATION TREND

and North Mountain; the minor quantities of the latter group (less than 2%) do not distort the spatial relations of the plotted points.

Thirdly, there is a section on field observations relating to the stratigraphic position of the red clay till with respect to the other till types. These facts are interjected at this point as they have an important bearing on the genesis of this somewhat enigmatic formation. In a later chapter on stratigraphy, these observations will be synthesized with the general picture of pebble associations to form conclusions about the origin and sequence of till formation.

C. DESCRIPTION OF DRUMLIN FIELDS

1. THE SAMBRO FIELD

Introduction

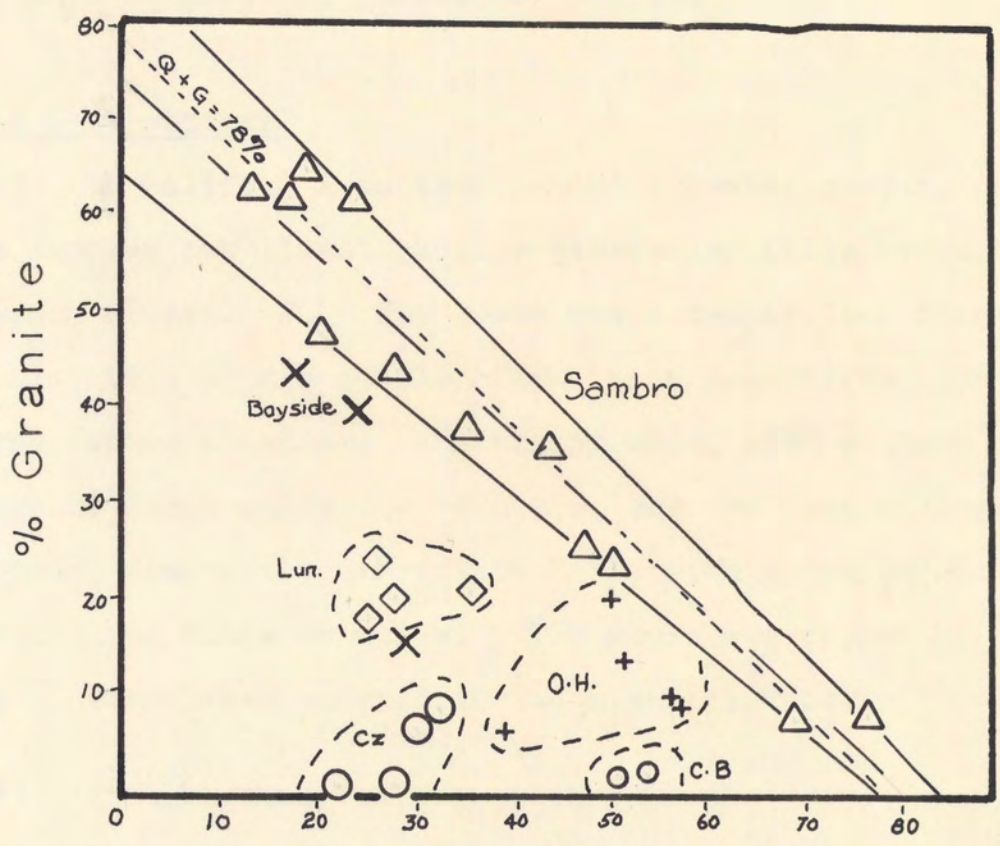
The field is perched on the elevated interior of the lobe of granite bounded by Halifax Harbour and St. Margaret's Bay. Figure 10 shows the distribution of the 90 drumlins in this group, and the intervening areas of hummocky ground moraine and bare glaciated granite outcrop. They lie in a swath five miles wide, extending thirty miles northeast from Chebucto Head to Glen Haven. The long axes of the drumlins are parallel and oriented in a direction bearing 173 degrees (true). They appear as well-formed, ellitical hills 2000 feet long, 700 feet wide and rising 100 feet above the surrounding thin mantle of granitic till, or flat glaciated granite pavement on which they are sometimes observed to rest. At present, the drumlins in this area are providing choice building lots.

Pebble Lithology

The pebble composition of the eleven drumlins visited and sampled is shown in Figure 11. The lithology of the Sambro drumlins may be summarized as follows:

Component	Range	Median
Local	72-85%	78
Minas	7-14%	12
Cobequid	6-17%	9
N. Mtn.	0.2-2.0%	1

The local component, (in these drumlins, granite and quartzite) is relatively less variable than the other components. This suggested that possibly that: G plus Q equals K; where K would have the value of 78% (the median). So a plot of granite content versus quartzite content was made. The result, Figure 12, shows a rather well-defined linear function between the two variables. The function to which they seem to be approximating is the line drawn down the middle of the zone of plotted points. Also drawn for comparison is a line G plus Q equals 78%. The near parallelism of the two straight lines strongly suggests that in the Sambro drumlins, granite pebble content varies inversely with quartzite pebble content.



80
70
60
50
40
30
20
10
% Granite
0
10
20
30
40
50
60
70
80
% Quartzite
Q + G = 78%
Sambro
Bayside
Lun.
O.H.
Cz
C.B

Figure 12

Next, the actual geographic location of the samples was considered in relation to their position on the curve. There was found a good correlation between higher granite contents and more southerly locations within the field. This trend was then related to the local geology, and it was found that the farther a drumlin had migrated into the granite area and away from the quartzite area, the more granite pebbles it contained relative to quartzite pebbles.

Field Observations

(1) In Halifax, a cutting behind a lumber company on Kempt Road exposes two lithologically dissimilar tills in superposition (Plate 11). The lower was a twenty foot thickness of red clay till with a pebble composition essentially like that of the Sambro drumlins. Overlying this, with a sharp contact marked by large quartzite boulders, was ten feet of loose-textured, dominantly quartzitic till, with a few per cent of Cobequid and Minas erratics. The whole was capped by ten feet of stratified quartzitic sands and gravels.

(2) Another observation relating to the development of pebble associations was made one mile west of Bayside on Highway #33, near Halifax. A borrow pit exposed a large block of contorted, laminated clay and silt, and masses of homogeneous red clay till imbedded in granitic till. Overlying this confused mixture was outwash-type granitic material with thin laminae of red silty sand (Plate \ ).

PLATE 11

Superposed upper quartzitic mantle till and lower red clay drumlin till, Kempt Road, City of Halifax.

PLATE 12

Late Pleistocene outwash overlying grey quartzitic till, Kempt Road, Halifax.

PLATE 13

Granitic mantle till, showing upper loose ablation member and lower compact basal member, Bayside, Halifax County.

The block of laminated clay and silt is unique and deserves further description. It is composed of 5mm thick structureless units of dark reddish brown (10R 3/4) clay composed of greenish flakes and red particles ½ micron to 2 microns, interbedded with 5mm beds of very light brown (5YR 6/4) silty matter ranging in size from 3u to 30u. The silty bands are conspicuously graded on a very small scale, the individual units being only ¼mm to 2.0mm thick, separated by exceedingly thin red clay partings (Plates 14,15). Floating in the laminated material are numerous pebbles and cobbles, and interrupting the fine alternations are irregular lenticular masses of red clayey till-like material, very much like the masses adjoining the laminated block.

Pebble counts of the various formations exposed gave the following results:

Enclosing granite till: - Sample #62-39

Local	97.6%
Minas	0.4
Cobequid	2.0

Red clay till masses: - Sample #62-38

Local	45.4%
Minas	32.0
Cobequid	20.8
N. Mtn.	1.8

PLATE 14

Sample of folded mass of graded grey silt and red clay interlaminations, Bayside, Halifax County.

PLATE 15

Sample showing alternating bands of grey silt and red clay, with interbedded mass of t ill-like diamicton, Bayside, Halifax County.

Till-like units in Laminated Clay and Silt:

- Sample #62-40

Local	64.6%
Minas	12.2
Cobequid	23.0
N. Mtn.	0.2

N.B. The pebbles in this material are strangely decomposed and stained, rendering the identification of the less common species somewhat doubtful.

The abnormality of the samples from this enigmatic exposure is underlined by their nonconformity to the granite-quartzite relation established by the rest of the drumlins in the Sambro group. (Figure 12)

(3) Sandwich Point - At a very late stage in the project an exposure was visited on the advice of W.F. Take (N.S. Museum of Science) (personal communication). Just south of Sandwich Point on the west side of the Halifax embayment, in a 25 foot wave-cut cliff of till resting on granite ledges, the following stratigraphic sequence was revealed by trenching.

(a) At the base was found a moderate yellow brown (10YR 5/4) layer of granite debris. This extremely compact material was excavated with difficulty, yet the fragments could be crumbled with the hand they were so rotten.

(b) Overlying this, with a very sharp contact (Plate 17), was a dark yellow brown (10YR 4/2) till composed essentially of subrounded quartzite pebbles and cobbles in a very

PLATE 16

View of the Sandwich Point section.

PLATE 17

Basal compact weathered granitic regolith overlain by compact quartzitic till. Sharp contact passes through coin.

PLATE 18

Contact of quartzitic till with overlying red stony clay. Note large striated quartzite boulders along contact.

PLATE 19

Contact of red stony clay (showing shovel marks) with upper graniti mantle till.

PLATE 20

Quartzitic phase at base of upper granitic till, with sand lens.

PLATE 21

Coarse ablation zone of upper granitic mantle till.

compact clayey matrix. About 5 per cent of the sample was Cobequid pebbles.

(c) Above, with an equally distinct contact marked by large quartzite boulders, (Plate 18), was an eight-foot thickness of stony red clay with few pebbles, about half of which were foreign types. The lower portions were greyish brown (5YR 3/2), firm, with a blocky parting, and a rough, uneven fracture. Innumerable tiny shreds of yellow silt and sand were intermingled. The middle of the member was moderate brown (5YR 3/4), and quite soft. At the top, the member was very firm, with a subconchoidal fracture. The colour was greyish brown (5YR 3/2), and it appeared to be more silty.

(d) Overlying the red clay member with a very sharp contact (Plate 19), was the complex uppermost stratum. At its base was one foot of waterlaid sand and pebbles (Plate 20), overlain by one foot of granite boulder clay with 30 per cent subrounded quartzite cobbles (Plate 20). On top were stratified lenses of sand, inturn overlain by the surface layer of angular granite-boulder till (Plate 21) on which was littered very large granite blocks.

An overall view of the exposure is shown in Plate 16 . Discussion and interpretation of the sequence is in Chapter 5 , (Stratigraphy).

(4) Harrietsfield (near Halifax) A borrow pit along the Old Sambro Road exposed a red clay drumlin overlain by a 10-foot thickness of rhythmically banded layer of red silty sand

PLATE 22

Sandy red Wolfville till plastered on glaciated granite roche moutonée, near Card Lake, Lunenburg County.

PLATE 23

Thin bedded, red silty sand and gravelly sand, Harrietsfield, Halifax County.

PLATE 24

Section through red clay drumlin with large surficial granite erratics, Prospect Road, Halifax County.

PLATE 25

Pink fissile hybrid till by mixture of red clay till and local sandy granite till, Dover, Halifax County.

(Plate 23)
and pebbly sand, mantled with five feet of granite till.

(5) Near Dover, Halifax County (loc. # G/62-41) A small borrow pit on highway #33 showed a fissile silty, sandy pink-coloured granitic till. (Plate 25) It is texturally and geographically related to the Sambro drumlins, but Figure 12 shows the sample to be compositionally dissimilar. Similar pink granitic till was noted in numerous exposures along the east side of St. Margaret's Bay. Some of these were sampled and show a similar discordance.

2. THE COW BAY DRUMLIN FIELD

Introduction

This concentration of Wolfville clay till lies on the east side of the Halifax embayment, and is bounded on the east by Cole Harbour Lake. Its north edge is in the City of Dartmouth, and Hartlen Point and Osborne Head on the Atlantic are its southernmost outcrops.

In this 'field', the red clay is not present as discrete drumlins, but as a 25-square mile discontinuous sheet with a drumlinoid surface. Their appearance is like those in Prest (1957; p.490). The relatively higher plasticity of the till in this locality is manifested by the exceptional length (up to two miles) of the drumlinoids, and the faint parallel flutings on their flanks (Charlesworth, 1957; p.395).

Pebble Lithology

Samples were taken of three widely spaced drumlins, and a beach, the analysis for which was corrected for differential destruction according to the procedures outlined in Appendix III. As the pebble counts conform to a relatively restricted field on Figure 11, this may be accepted with some confidence as a fair representation of the pebble associations in the Cow Bay field. For comparison with the other fields, the medians may be given:

Local	55%
Minas	30%
Cobequid	14%
N. Mtn.	1%

It is quite clear from Figures 11 and 12 that their lithology is quite distinct from that of the nearby Sambro field.

Field Observations

(1) Hartlen Point The cliffs at Hartlen Point are another exposure of the relation of the red clay till to the underlying material. There, fronting the ocean, a vertical wall of dark grey dominantly quartzitic till is overlain by 12 feet of the red clay till in drumlinoid form (Plate 26). The firmness of the lower member is clearly indicated by the cobbles jutting in sharp relief on the cliff face. The compactness and dark colour are in marked contrast to the loose light-coloured quartzite till sheet surrounding the drumlins. The lowest exposed levels of the quartzitic member are coarser, stonier,

PLATE 26

Till cliff at Hartlen Point. Note stony compact lower quartzitic till and slumping upper red clay till.

PLATE 27

Quartzite boulders at intertill contact.

PLATE 28

Fissility of the red clay drumlin till, Hartlen Point, Halifax County.

PLATE 29

Imbrication in the basal portion of the lower quartzitic till, showing ice motion toward the left or southwest, Hartlen Point.

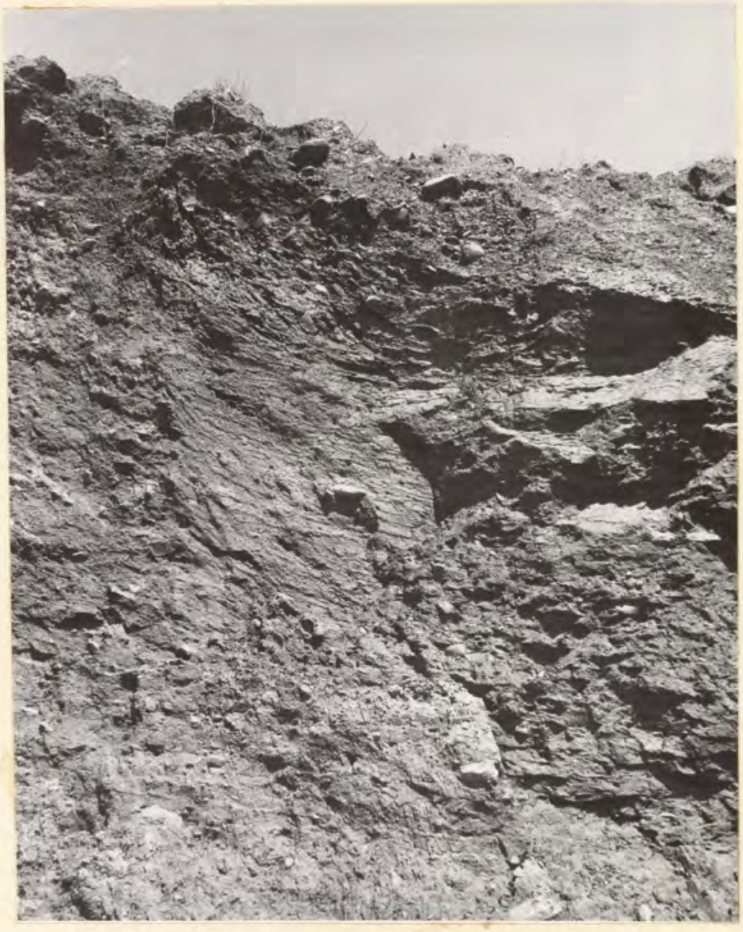


PLATE 30

Schuppen structure, or folded mass of phyllite debris underlying lower quartzitic till, Hartlen Point, Halifax County.

PLATE 31

Detail of above, showing excellent foliation of the platy and rod-shaped phyllite fragments.

and exhibit an easterly dipping imbrication of the cobbles (Plate 29). At one place along the base is a folded mass of pure slate debris (Plates 30 and 31), identical in appearance to that outcropping nearby. Large, rounded quartzite boulders occur along the sharp contact (Plates 26 and 27) with the overlying red clay till, which, though possessing stiffness and fissility (Plate 28), readily absorbs water on exposure, and is susceptible to sudden slumping. Otherwise, when in situ, this till has a 60 degree angle of repose.

3. THE CHEZZETCOOK DRUMLIN FIELD

Introduction

This group of one hundred individuals whose long axes strike 150 degrees (true), is bounded on the west by Cole Harbour, on the east by Chezzetcook Inlet, and on the north by Highway #7. (Figure 10). The red clay till in this concentration is present mainly as solitary drumlins, which, in a few places, coalesce to form a drumlinoid sheet. In the author's opinion, nowhere else in Nova Scotia are the drumlins so perfect in line and symmetry, or so well exposed as in this area (Plate 33).

Pebble Lithology

Figures 11 and 12 show the pebble composition of these drumlins relative to the other fields. There is clearly a marked dissimilarity to the adjacent Cow Bay group. The Chezzetcook field may be characterized as a group and identified

PLATE 32

Remnant of red clay drumlin at Sleepy Head, Halifax County, showing surficial quartzite erratics forming boulder beach.

PLATE 33

Gaetz Head - a Wolfville red clay drumlin of remarkable symmetry.

by the relative source area influences:

Local	27%
Minas	22%
Cobequid	50%
N. Mtn.	1%

Field Observations

For this drumlin field as well, coastal erosion has provided an exposure which at once reveals the stratigraphic situation of the drumlins, and thereby the relation of foreign pebble association to that of the local till. The following structural features were discovered in the cliffs southeast of the entrance to Cole Harbour Lake.

Two tills are in superposition.

(a) The lower member is hard and compact, and forms a straight wall fronting the sea with a slope of 60 degrees. In this tough material, a wave-cut bench has been developed. It extends seaward from the base of the drumlin, and, by removing the thin mantle of beach rock, may be exposed as a beveled surface from which cobbles are seen to jut in sharp relief (Plate 35).

The colour is dark grey (N7), and the lithology is:

Local	94%
Minas	1%
Cobequid	5%

PLATE 34

Close-up of lower grey compact quartzitic till at Cole Harbour, showing fine-grained granite debris (white particles).

PLATE 35

Compact grey quartzitic till outcropping in beachrock.

no!

is a type of sandstone formed on beach in tropical (warm) areas

PLATE 36

Cole Harbour superposed tills, showing soft red clay till flowing down gullies cut in the underlying compact quartzitic till. Note red mud on beach and erratics of Horton conglomerate (hammer) and sandstone.

PLATE 37

Cole Harbour cliffs, showing different angles of repose of the two tills, and half of a giant kettle hole at left with base at same level as the intertill contact.

Except for the presence of 16 per cent granite pebbles and fragments of quartz and feldspar (Plate 34), which have come from the nearby batholith, this till is similar in all appearances to the lower quartzitic till at Hartlen Point and very different from the quartzite till sheet surrounding the drumlins. At the top are the usual large boulders of quartzite, which project from the very distinct contact (Plate 36) with the overlying. . .

(b) Reddish brown Wolfville clay till, which here forms a drumlinoid sheet with a maximum thickness of twenty-five feet.

The crest line of the cliffs undulates as it transects the drumlins, and in one place it outlines the bowl-shaped profile of a large kettle nearly 500 feet in diameter. The flat floor of this basin is coplanar with the contact of the two tills (Plate 37).

The high permeability of the red till leads to saturation, which, on erosional slopes such as shore cliffs, permits frequent slumping with a resulting angle of repose of 45 degrees. The mud flows down gullies cut in the more competent quartzite till and disgorges onto the quartzite beach rock its exotic assemblage of conspicuous red sandstones and conglomerate boulders (Plate 36).

4. OWL'S HEAD DRUMLIN FIELD

Introduction

This group of solitary scattered drumlins is situated on the promontory of Owl's Head, between Jeddore and Ship Harbours (Figure 10). Of the sixteen drumlins, eleven are inland, heavily forested and inaccessible, and five are on the coast in various stages of destruction (Plate 32). The long axes of the drumlins trend 145 degrees (true).

The bulk of the drumlin material is very fine textured with less than 20 per cent above sand size, but superficially the smoothly moulded contours of the drumlins are littered with large quartzite boulders which, during coastal erosion, slide down the receeding cliff face to remain as a coarse residue and form a boulder pavement (Plate 32).

Pebble Lithology

Pebble counts on samples from five widely spaced drumlins demonstrate their non-affinity to the other fields on Figures 11 and 12. The following medians express the pebble associations in terms of the relative influence of the source area components:

Local	66%
Minas	18%
Cobequid	16%

Field Observations

Although North Mountain species are not present in pebble size, several cobbles and boulders were collected from the beaches; but it is estimated they do not constitute more than half of one per cent. Still, these very sparse erratics may be traced back along striation directions to their very probable source in the Bass River outlier.

5. MOOSE RIVER DRUMLIN FIELD

Introduction

Twenty miles northeast of Sheet Harbour, covering 200 square miles, lies a group of one hundred drumlins whose consistent trend of 145 degrees is very like that in the other fields. They are well-formed, but heavily forested and most are inaccessible, except for the ten or so which are intersected by the secondary highway traversing the field from north to south.

Pebble Lithology

Pebble counts on drumlin till from this field furnish another clue to the origin of the enigmatic red Wolfville clay till. The data also give further insight into the quantitative aspects of pebble associations relating to the change in till lithology with transport away from source.

Four drumlins, spaced at five, six and two miles, were sampled on the north-south traverse. The results of the pebble counts, plotted on Figure 11 , show that the ratio of local to foreign types increases southwards.

To the north the drumlin field merges with a sheet of reddish brown clay till derived from Carboniferous red shales and mudstones, which forms the parent material of the 'Queens' soil catena (Cann, Hilchey & Smith, 1954, p.23). Thirteen samples of Queens till are also shown on Figure 11, and appear to be transitional to the Moose River trend, and to the other drumlin field pebble associations.

If this related red clay till is, in fact, the parent till sheet from which the Moose River drumlins have been derived, then it appears from the graphical relations that the farther south the drumlins have migrated away from the parent till, the more they have become diluted with pebbles of subjacent granite and quartzite. Moreover, this postulated dilution appears to be a linear function. For each five miles of movement over the granite-quartzite terrain, the drumlin has acquired an additional 12% of these local rock types. In summary, the parent(?) till sheet in the north, with a composition of:

Local	13%
Minas	77%
Cobequid	10%

has been transported thirty miles and reduced to discrete drumlin masses, the till of which still retains its red clay matrix, but has a pebble composition of:

Local	86%
Minas	13%
Cobequid	1%

Field Observations

It is interesting to note the occurrence, in one of the drumlins at Mooseland, of a large, several cubic foot block of highly plastic, very light grey (N8) fireclay. It was probably derived from the Elmsvale outlier of the Cretaceous Shubenacadie Formation, as it is virtually indistinguishable from the clay of the type locality at Shubenacadie.

6. THE LISCOMB DRUMLIN FIELD

Introduction

This group of 125 drumlins has a bilobate outline, covers 200 square miles, and extends along the coast from Sheet Harbour to Liscomb, and inland for 15 miles. The drumlins near the coast are cleared and cultivated by the fishermen, whereas those inland remain thickly timbered. The trend of the drumlins is noticeably different from that in other fields. The long axes in the larger western lobe bear 172 degrees, or almost due south from the Antigonish Highlands. Numerous striae on published maps also give evidence of flow from this source area.

Pebble Lithology

It has already been shown in the Moose River field that the lithology of drumlins varies systematically in the direction of travel. The Liscomb field, on the other hand, gives evidence of an additional lateral variation.

The pebble analyses plotted on Figure 11 show a progressive enrichment in foreign components toward the centre of the field:

Sample No.	59, 60, 61, 62, 63
Local	75 - 71 - 69 - 64 - 52%
Minas	25 - 26 - 28 - 25 - 32%
Cobequid	0.4 - 2 - 3 - 11 - 16%

Specifically, the foreign pebble content has increased from 25% to 48%, or just doubled, in the 12 miles between samples 59 and 63.

Pebbles recognized as having come from the less well known Antigonish Highlands source area were fragments of vesicular basalt with amygdules of calcite. It should be noted that only a general knowledge of this potential source was necessary as the eastern edge of the study area is barely within its zone of influence.

Field Observations

An exposure on Highway #7, near Beaver Harbour, showed the red drumlin till mantled with loose-textured, light coloured, local quartzite debris, much like the till sheet surrounding the drumlins. The sequence appeared identical to that observed in the North End of Halifax.

7. THE LUNENBURG DRUMLIN FIELD

Introduction

As mentioned before, this group of 200 drumlins lies in a ten mile wide swath extending northwest from Lunenburg (Plate 10). Their contact with the underlying compact slaty till, different from the surrounding slate till sheet, can be seen in a few shore exposures. Several slate drumlins are interspersed, but are mainly restricted to the highlands to the west of the Lahave River, which serves to demarcate the boundary between the two different groups (Plate 10).

Pebble Lithology

Five analyses of the red Wolfville Loam drumlin phase (Wld) gave the following medians:

Local	49%
Minas	18%
Cobequid	17%
N. Mtn.	16%

Plotted on Figure 11 they occupy a central position, between the Owl's Head and Musquodoboit fields.

To the north, along a line between New Germany and Sherbrooke Lake, the belt of red clay drumlins abuts against, or is truncated by, a northeast-trending swath of reddish brown till. This shallow till sheet is the parent material of the 'Wolfville Stony Loam' (Cann & Hilchey, 1958, p.21).

Having a high content of local pebbles, it occupies an apical position of Figure 11 , and is characterized by an average composition of:

Local	93.5%
Minas	3.6%
Cobequid	0.1%
N. Mtn.	2.5%

The red stony till sheet supports a sandy drumlin phase. Some of those lying within a hypothetical extension of the adjoining red clay drumlin field were sampled and found to have an average composition of:

Local	77%
Minas	7%
Cobequid	6%
N. Mtn.	10%

Figure 18 shows their composition to be intermediate between the red stony till sheet, and the red clay drumlins. Two explanations may be tendered here.

1) The red sandy drumlins may be a hybrid phase created by the blending or dilution of early red clay drumlins by the overriding, southward-advancing, stony till sheet.

2) Alternatively, they may simply be a further example of what has already been shown by the slate, quartzite and granite drumlins - that the drumlin phase is generally richer in foreign components than is the sheet phase of any till type.

8. OTHER DRUMLIN FIELDS

Other drumlin fields occur outside the area of study and hence could not be visited during this preliminary study, but their general features should be considered in relation to the fields studied.

(a) A group of thirty individuals trending 145 degrees occur sparsely over an area of 100 square miles south of Governor's Lake in northeastern Halifax County, on quartzite till.

(b) The eastern lobe of the ~~Moose River~~ Liscomb field centred around Ecum Secum in southwestern Guysborough County contains about 40 drumlins which have a uniform trend of 130 degrees.

(c) In central Guysborough county, north of Indian Harbour, a field of 25 drumlins trending 150 degrees, covers about forty square miles.

(d) The easternmost field on mainland Nova Scotia occurs at Cape Canso where 25 drumlins trend 172 degrees over an area of 15 square miles. These drumlins tend [This drumlin field tends] to be elongated transverse to the ice flow, and this may be due to their position on the edge of the steep Chedabucto fault-line scarp against which the ice impinged.

(e) Other very small fields with the same trends as the larger ones occur near Lake Charlotte in Halifax County, and in the vicinity of Slate Brook and Gaspereaux Brook in Guysborough County.

D. DISCUSSION OF THE PEBBLE LITHOLOGY OF THE RED CLAY DRUMLINS

Figure 11 , the compositional triangle, reveals many interesting features about the pebble associations in the Wolfville drumlins, especially the relation of lithology to geography.

1) Just as the drumlins tend to be gathered in distinct groups, so the lithology of the drumlins tends to be restricted to fields on the ternary diagram. Not only are these fields relatively small, they are also mutually exclusive of one another, or, at most, only slightly overlapping.

2) The range of variability, as given by the size of the field on the diagram, seems to vary directly with the area of the drumlin field. It is believed that the larger the area over which the drumlins are dispersed, the more influential will be the dominant modifier of till lithology - the availability of other till types for intermixture. Other factors which might conceivably contribute to the variability are:

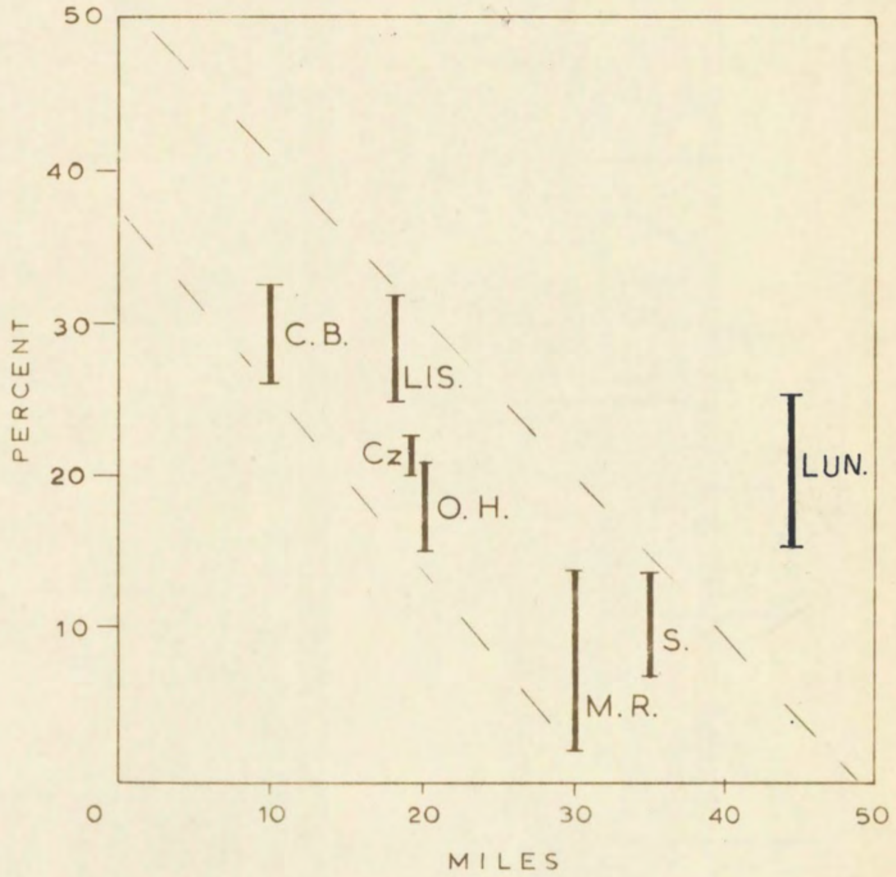
- (a) the density of the drumlin population in the field.
- (b) the topography of the hinterland.
- (c) texture and composition of the surrounding till sheet.
- (d) distance from the parent till sheet.

3) The reality of this last-named factor can be assessed quantitatively. On figure 11, the fields of plotted points lie end to end along the 'local' - 'Minas' axis. This pattern indicates that the lithology varies essentially with respect to the Minas component; and that it is to some extent independent of the Cobequid component as this latter appears to be restricted to the 5% - 20% range.

This is manifested in several ways. For one, in the Moose River field there is a progressive decrease in the 'Minas' component southwards in the drumlin field, or away from the parent (?) till sheet at Musquodoboit. The drumlins of the Sambro field provide a second example of this. Thirdly, in the Liscomb field, the content of 'Minas' material decreases laterally outwards from the centre of the field. Fourthly, there is similar relation between the distance of a whole drumlin group from the south edge of the Minas source area, and the average amount of 'Minas' material in that drumlin group (Figure 19).

It would appear from the linear relationship, that for each one mile of transport away from Minas Basin source area, the till in the drumlin field as a whole loses one per cent of its content of Minas pebbles.

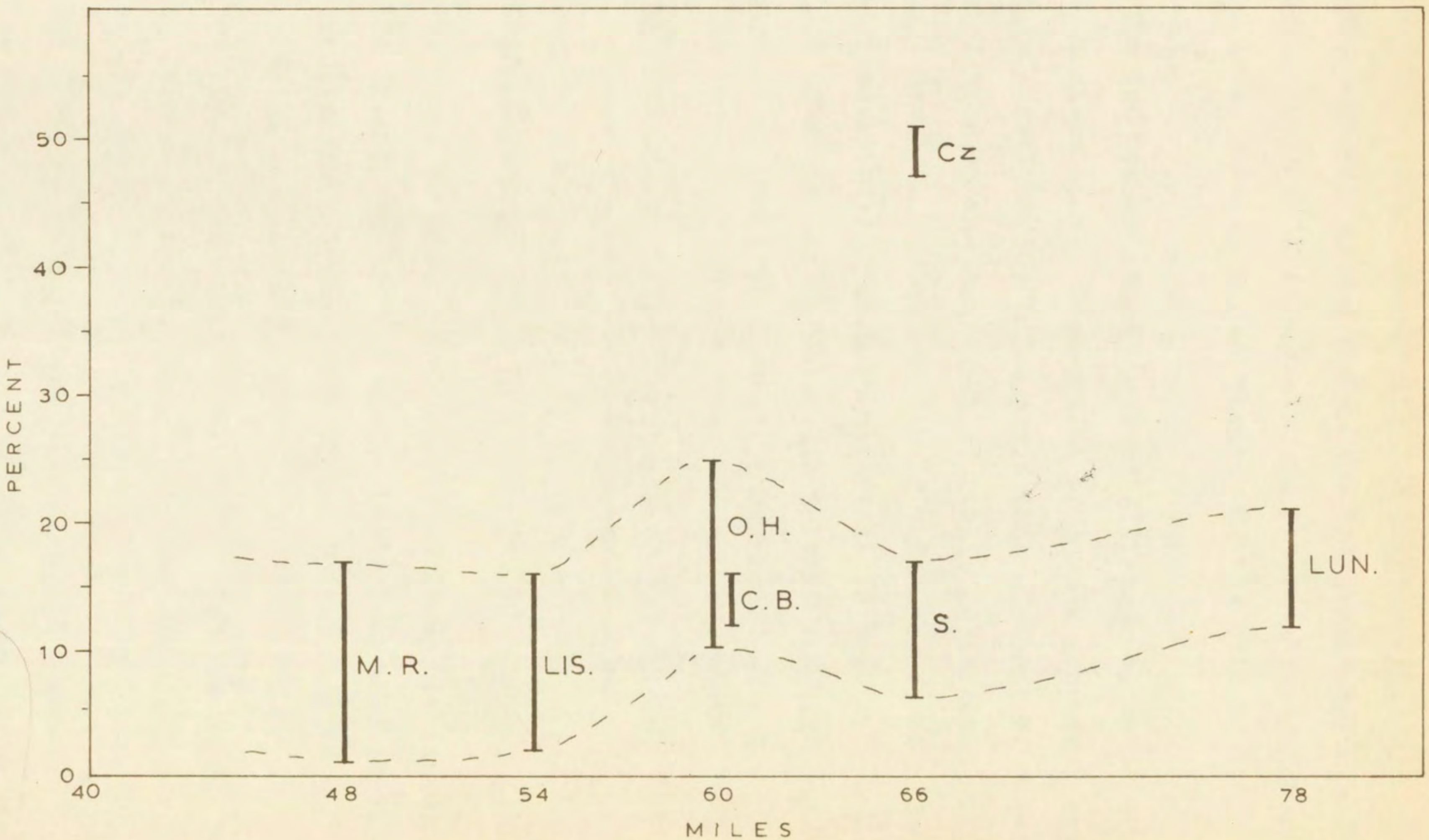
The only exception to this well-documented relationship is the Lunenburg field. It appears to have more Minas pebbles



DISTANCE OF DRUMLIN FIELD SOUTH OF MINAS SOURCE REGION VERSUS CONTENT OF MINAS MATERIAL

Figure 19

Figure 20



DISTANCE OF DRUMLIN FIELD SOUTH OF COBEQUID MOUNTAINS
VERSUS CONTENT OF COBEQUID MATERIAL

than it ought to have, considering its distance from the source area. The explanation may lie in the 'strength' of this field, suggested by the size of the field and the relatively lower amount of local pebbles in, or purity of, the till.

The four cases cited above of different kinds of progressive dilution by the destruction of a weak component are believed to constitute definite proof that distance of travel is a real factor in the evolution of pebble associations in migrating drumlins. The reality of this process of differential removal of incompetent materials is further proven by the lack of a similar relationship in the Cobequid component, which consists of rocks of superior toughness (Figure 20)

E. SUMMARY OF SALIENT FEATURES OF RED CLAY DRUMLIN FIELDS

Morphological Features

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

(130° - 150°). The two exceptions are southerly trends (172°).

6) Most of the drumlins in the area have similar dimensions:

Length:	3000 - 4000 feet	Width:	1000 - 1300 feet
Height:	75 - 150 feet	Length : Width	= 3 : 1

Stratigraphy

1) The drumlins are surrounded by the loose-textured, light coloured till sheet and rest on a firm, dark, underlying till, the lithology of which strongly reflects the underlying bedrock.

2) The contact of drumlin and underlying compact till is very sharp, and is marked by large quartzite boulders.

3) In drumlin areas, the underlying till is unusually compact and stands vertically on erosional slopes, compared to the distinctly lesser slope maintained by the overlying drumlin till, and associated loose-textured till sheet.

4) There are signs, in a few localities, of a third member underlying the compact till.

5) Similarly, in a few localities the drumlins are mantled with a member of local till.

Pebble Lithology

1) Each drumlin field has a distinctive pebble association.

2) All fields, except that at Chezzetcook, have 10% - 20% Cobequid pebbles.

3) The lithologic differences between fields are created by variations in the ratio of 'Minas' to 'local' pebbles.

4) The average quantity of 'Minas' pebbles in the till of a drumlin field varies inversely, and linearly, with the distance of the field away from the Minas Basin area. The decrease in transport is due to the differential destruction of these softer species.

5) The Lunenburg and Chezzetcook fields are characterized by their much greater contents of North Mountain and Cobequid pebbles respectively.

6) As a drumlin field migrates from a northerly source area onto a southerly source area, within the study area, the drumlin till is progressively enriched in pebbles from the southerly source, according to a linear function.

7) Similarly, there is a progressive increase in local pebbles toward the fringes of the field.

8) In the Lunenburg field, the red clay drumlins and a red stony till sheet are related to a red sandy drumlin phase with an intermediate composition.

9) The data strongly suggest the red drumlin till is transitional to (or has been derived from?) a similar red till developed on the shales and sandstones of the Minas Basin area.

CHAPTER FIVE

INTERPRETATION

A. BASIC CHRONOLOGY AND STRATIGRAPHIC IMPLICATIONS

Introduction

This pebble investigation of the tills bordering the Scotian Shelf is basically a study of comparative till lithology. It has been possible to define and account for several characteristic pebble associations. In addition, some peculiar dispersal patterns are revealed. To complement the descriptive part, it is desirable to offer some explanations of why and how these phenomena originated. The peculiarity of the situation invites premature speculation; but, any attempt to deduce the mechanisms responsible for the distribution of drumlins and foreign pebbles must be based on a clear understanding of the relative ages of the various formations.

Correlation of Sections

An attempt was made to correlate the several exposures of superposed tills described here and in the literature. It was assumed that the red drumlins in all areas represented a single event. Starting from this marker horizon, correlations were sought in the underlying and overlying members. In most cases, it was possible to demonstrate equivalence of formations between the various locations on the basis of similar physical and compositional characteristics.

The loose-textured till sheet, however, presents a special problem because of its vague relation to the drumlin till. Where the red till is deep enough to form drumlins, these rest either on bare glaciated bedrock (page 84), or on a very firm stony till apparently unlike the till sheet. On the other hand, when the red till occurs in shallow patches, these are observed to form a thin layer over slate till (Cann & Hilchey, 1958), over granite till near Halifax (page 83), and plastered on granite bedrock (Plate 22). And to complicate matters further, the drumlins are occasionally mantled with another loose-textured locally-derived till.

The best way to describe the relationships without risking gross misinterpretation, is to say the drumlins swim in, rather than on or under, the till sheet. This implies that the two formations are roughly contemporaneous, but it is more probable that the drumlins are the older of the two, having apparently been the first to cover the earlier compact till. It appears, then, that the compact till is an early event, followed by the drumlins and till sheet in close succession or simultaneously, and closing with a minor advance causing intercalations of the drumlin till and local till.

Correlation of the sections (Table 7) appears to present a uniform, well-documented sequence of the latest Pleistocene events in this area. Having arrived at a reasonable approximation to relative sequence, it was desired to relate this to the Pleistocene chronology of eastern North America. The general validity of the extrapolated correlations is supported by the few available radiocarbon datings. Accordingly, the localities from which these dates were derived deserve some detailed description.

Description of Age Determination Locations

1) A study of the pollen stratigraphy of the gyttja in Gillis Lake, Richmond County, Cape Breton by Livingstone and Livingstone (1958) reveals three late-glacial zones (L1-L3), which correlate with the Aroostook County, Maine sequence described by Deevey (1951). An age of 10, 340 ± 220 years B.P. was obtained on the transition from non-arboreal open tundra vegetation (L zones) to arboreal conditions (A to C zones). Both authors believe the climatic amelioration represented by the vegetational change to be equivalent to the Two Creeks-Allerød oscillation, and state further that the last ice to cover the area was of Cary (Wurm 2) age (12,000 - 14,500 years B.P.) (Appendix VII

On the other hand, Deevey et al (1959) subsequently gave a revised age of 10,160 $\pm$ 160 years B.P. for the same sample (y-524). Necessarily, they concluded that the uppermost non-arboreal zone (L3) correlates with late Valders time. So, if heath vegetation reflects climatic severity, and a layer of such pollen was deposited in Valders time, then it might mean that an ice advance of Valders age made an approach to, but did not override southern Cape Breton.

2) This implication appears to be supported by a radiocarbon date from Port Hood Island, Cape Breton. Wood and peat occurring between two tills yields an age of 10,710 $\pm$ 240 years B.P. (y-762; Stuiver and Deevey, 1961), and is accordingly assigned by them to the Two Creeks interval. This implies that the overlying till represents the Valders advance. If this is so, then the Valders advance which overrode the interstadial growth in this northwestern Cape Breton site, effected only a vegetational change further south at Gillis Lake.

3) Closer to the study area, at the Dutch Settlement gypsum quarry near Milford, wood from beneath 40 feet of till gave an infinite age of >18,000 years B.P. (Hughes, 1957). He states that "this falls within the range of 'younger dates' from deposits of Cary and Tazewell age." In other words, the site was overridden about the same time as the Wisconsin glacial maximum

(19,500 years B.P.; Flint, 1963) was attained in the Great Lakes region.

Major Till Formation Events

A working hypothesis can be formulated even on this meagre evidence. There is reason to believe that the Dutch settlement till is equivalent to the lower, compact, locally-derived tills at Milford and Eagle's Nest, and that these, in turn, are contemporaneous with the compact till underlying the drumlins. Thus, the first dated event which produced an extensive deposit in the study area seems to have been the Wisconsin maximum of Cary-Tazewell subage.

Gillis Lake rests on till of drumlinoid surface form (Livingstone and Livingstone, 1958) and the drumlins must be pre-Valders in age. Red clay drumlins occur extensively in south-east Cape Breton. A cursory inspection showed them to be identical with the local red drumlins. In fact, the soil scientists (J.D. Hilchey, personal communication) refer them to the Wolfville soil catena, together with those in the study area. This means that if the soils developed on the drumlins have the same parent material, and exhibit the same profile characteristics, then the Cape Breton drumlins are almost certainly equivalent lithologically to those in the study area, and therefore probably belong to the same glacial episode.

Hence, the drumlins in the study area, and possibly the surrounding loose-textured till sheet, date from the glacial substage following the Tazewell. Or, in conformity with Flint's (1963) revised Wisconsin stratigraphy, the drumlins may correlate with the Port Stanley event (16,000 years B.P.).

It is possible, on the other hand, that the till sheet surrounding the drumlins is a later influx, which may therefore represent the next later substage, or the Port Huron event (13,000 years B.P.; Flint, 1963). If this is the case, then the locally developed thin mantle of indigenous till on the drumlins (pages 85, 90, 94, 112, Tab.7,) might be contemporary with the till sheet. Alternatively, the mantle may be a late phase of the till sheet event, deposited during an oscillation of the waning ice sheet, or more probably during the drawdown of the nearest radially dispersing, isolated, remnant ice cap.

However, as the mantle is seen to overlie, and have included in it stratified materials related to the drumlins, it is more probable that an interstadial period intervened between the deposition of the till sheet and the mantle till. So, if the drumlins and till sheet are equivalent and date from Port Stanley time, as surmised above, then the mantle till was laid down during the next substage, or the 'Port Huron' glaciation (13,600 years B.P.; Flint, 1963).

If this latter interpretation is correct, and the mantle till records the last ice advance, it is consistent with the previous supposition that the subsequent Valders advance did not cover Nova Scotia, though it apparently just affected the Port Hood area. Flint (1953) places the limit of the Mankato (Valders) advance along a line through Glens Falls, N.Y., St. Johnsbury, Vt., and Gorham, N.H. to the south base of the Shickshocks. Manley (1955) supports this climatologically and accounts for the evidence of local glaciers on highlands south of the ice sheet limit by demonstrating that outlying highlands likely had only local glaciation in the minor latest Wisconsin substages. Thus, the trees at Port Hood grew close to the ice margin (Manley, 1955) and were overridden, not by a continental advance from the north, but by local glaciers radiating from the adjacent Cape Breton Highlands.

Summary

The tentative chronology and stratigraphy of the three superposed till formations are:

3. Mantle Till 'Port Huron' glaciation (Mankato Substage) - 13,600 years B.P.
2. Red Drumlins 'Port Stanley' drift (Cary Substage) - 16,000 years B.P.
1. Compact Till Tazewell Substage - 19,500 years B.P.

The problematical loose-textured till sheet might be contemporaneous with any one of these three.

a) It may have evolved in transit with the drumlins,

although

b) It may be an uncompacted phase of the older firm till, possibly reworked during the influx of the drumlins,

and yet,

c) It is just possible that it may be temporally equivalent to the mantle till, either created entirely during this latest advance, or reconstituted from an older till, or a combination of both.

B. SEQUENCE OF PLEISTOCENE EVENTS

The stratigraphic relations of the three major Pleistocene formations in the study area has been given above. These may be used as a basis to which can be related the subordinate underlying, intermediate, and overlying formations. From the resulting comppsite picture it is possible to reconstruct the sequence of Pleistocene events in the area.

1. FORMATION OF THE BRIDGEWATER CONGLOMERATE

In the study area this deposit underlies all other known glacial formations, and therefore may be considered the oldest. It is believed this formation is (a) of glacial origin, and (b) of Pleistocene age, but the product of an earlier glacial stage than the last, or Wisconsin stage for the following reasons:

(a) All known exposures overlie, and are largely composed of slate heavily charged with pyrite, the oxidation of which presumably wss responsible for the limonite cement. If pyritic slate was the only condition for its formation, then it should occur widely over the large expanses of pyritic slate. Instead, the occurrences fall along an almost straight line between Cape St. Mary and Musquodoboit Harbour. The localization of the deposits at particular places along the line seems to be topographically controlled, as they are usually found in the larger valleys, or in the lee of steep slopes. At a glance, the debris appears till-like, and may be in a few places, but more typically it shows some kind of stratification. This waterlaid appearance is supported by the bimodality of the size distribution, which Pettijohn (1957) claims is the mark of alluvial gravels.

On the basis of its peculiar distribution, waterlaid character and minor, but significant content of North Mountain and Cobequid erratics, a different origin is postulated. The 'Bridgewater Conglomerate' is interpreted as the outwash apron associated with a major frontal, and probably terminal moraine. The remnants now occur chiefly in valleys where presumably the greatest thicknesses accumulated.

(b) Although this enigmatic deposit has been referred to the Tertiary (Sage, 1954) and to the Carboniferous (Honeyman, 1870; Poole, 1903), the present author feels that, if the glacial interpretation is correct, then it is probably safer to assume it is a Pleistocene formation.

This outwash must have been deposited and well-cemented prior to the major glaciation which formed the till sheet over southeast Nova Scotia because:

a) It is usually overlain by the till sheet

b) It is overlain by 60 feet of fresh, uncemented kame gravels at Blockhouse, Lunenburg County (Prest, 1896)

c) This study revealed that pebbles of the 'conglomerate' are occasionally found in the till sheet south of its outcrops. Additionally, Poole (1903) records blocks of Bridgewater Conglomerate in the loose slate till of Spectacle Island, Purcell's Cove, Halifax County, and fragments imbedded in the loose blue slate till on Tower Road in the City of Halifax.

The question of absolute age may be considered. An age of more than 18,000 years B.P. was measured on spruce logs underlying the compact till at Dutch Settlement, Halifax County (Hughes, 1957). Owing to lack of interest, no organic material or fossil remains of any kind have been discovered in the 'conglomerate', which can therefore only be described as older than the compact till or of pre-Tazewell age. 'Early' Wisconsin or pre-Tazewell tills in eastern North America (MacClintock and Apfel, 1944; Dreimanis, 1960) range in age from 70,000 years B.P. to 25,000 years B.P. (Flint, 1963). None of these deposits, even the oldest, - the Bécancour till of southern Quebec (Gadd, 1960) with an age of 67,000 years - are as deeply weathered or at all indurated like the Bridgewater Conglomerate.

The pronounced weathering and ferruginous cementation, compared to the negligible alteration of the overlying tills, is more suggestive of interglacial weathering than of interstadial weathering. Also, a great length of time between its consolidation and the present is indicated by the fact that these deposits have been breached by the rivers before they were mantled with later till (Prest, 1896).

Deposits antedating the last interglacial, the Sangamon (Riss-Würm), as described in the literature, seem to embody the characteristics of the Bridgewater Conglomerate. For example, Coleman (1927) interprets "hard and ancient" tills and kame gravels in Newfoundland as remnants of Kansan or Jerseyan Stages. Leighton (1963) described a deposit of indurated iron-cemented ice-marginal gravels underlying unaltered Wisconsin till in Illinois and referred it to the Illinoian glaciation, implying Sangamon weathering. Similarly, Taylor (1961) considered an occurrence of river gravel with a goethite matrix containing leaf imprints, in ø northern Manitoba, to be interglacial (Sangamon?) because it underlay soft Wisconsin tills. And Leonard (1916) found a limonite-cemented deposit underlying loose Wisconsin tills in North Dakota.

Hence, there appears to be reason to believe the weathering of the 'conglomerate' is entirely pre-Wisconsin and related probably to the Sangamon, or possibly to earlier interglacial periods. As this interpretation is based solely on the degree of weathering, it is highly speculative. It is possible the prevailing maritime climate of this region was effective in accelerating and intensifying the weathering process, thereby completely invalidating these conclusions.

2. EVIDENCE OF POSSIBLE 'EARLY' WISCONSIN GLACIATION

For the sake of completeness it might be well just to mention the presence of an old till outside the study area, but still within the province. At Hillsborough, Cape Breton, two till sheets are separated by stratified sediments containing peat and spruce logs which yielded an age of more than 38,000 years B.P. (W-157; Hughes, 1957; Stockwell, 1957). If this is really a Wisconsin deposit, then the embedding tills probably represent 'early' Wisconsin, or post-Sangamon, pre-classical-Wisconsin events (Flint, 1963). Dreimanis (1960) has found that such 'early' Wisconsin tills in the Great Lakes area were deposited by an ice advance emanating from a Labradorean centre, in contrast with the more westerly Laurentide centre which dominated during the middle and late Wisconsin episodes. Nova Scotia is due south of the hypothetical 'early' Wisconsin centre in Labrador. The major set of north-trending valleys in the Cobequids and along shear zones in the Devonian granite batholith, which transect the dominant northwest-southeast lineaments in Nova Scotia, could have been initiated, or at least accentuated, during this early glaciation.

Nova Scotia is closer to this indicated centre than the Great Lakes and for this reason it is expected that further studies will reveal more evidence of this glaciation. Coleman (1927) found evidence in Newfoundland that an early severe, and very extensive pre-Wisconsin or Kansan glaciation (pre-classical-Wisconsin?) was responsible for the major physiographic modifications, while the (classical) Wisconsin glaciation was only effective in cutting U-shaped valleys and producing the latest striations and the freshest till.

3. 'BASAL REGOLITH'

Above the Bridgewater outwash, the next highest stratigraphic unit is a peculiar formation which can only be described as broken bedrock. It is composed entirely of the underlying rock type. The extremely angular fragments are often aligned parallel to the bedrock strata, as at York Redoubt (Plate ___). At Hartlen Point, this foliation is deformed as if by the shear stress of the overriding ice (Plate 30). The inclined folds of perfectly-aligned phyllite slabs are exactly like those pictured by Sardeson (1906), and fit the description of 'schuppen structure' or sub-ice deformations, given by Charlesworth (1957, p.256). Lastly, the debris is often friable and rotten-looking, as at Sandwich Point (page 90), and Blockhouse Point (Prest, 1896).

It does not have the appearance of a till and its size distribution, from 22mm to 50 microns, plots as a straight line on Rosin's Law paper (Pettijohn, 1957). Therefore, this mono-lithologic material is interpreted as the product of intense mechanical disintegration by deep secular weathering. It is believed the deposit was formed under periglacial conditions when frost action, predominating over chemical alteration, acted on the apparently clean (glaciated?) bedrock surface to produce a thick mantle of disaggregated indigenous material.

In northern New Brunswick, Lee (1955,1957,1962) finds a regolithic layer up to 20 feet of decomposed bedrock underlying pre-(classical?)Wisconsin till.

Its smooth upper contact with, and apparent failure to contaminate, the overlying till of different lithology, are reasons for believing the frost-riven detritus was firmly frozen in place by connate water as the ice readvanced.

The age can be stated only as older than the base of the till sheet, or older than 18,000 years B.P. It appears to represent an interstadial period. If Flint's (1963) reassessment of Wisconsin chronology can be used, this basal 'regolithic' debris can be no younger than the 'Plum Point' Interstadial (about 27,000 years B.P.) and probably represents an 'early' Wisconsin non-glacial interval.

4. DEPOSITION OF THE COMPACT TILL

The type location of this formation is the sea cliffs near Halifax. Only a few pebble counts were made on this material, but they serve to show that it is analogous to the till sheet, in having been derived locally and enriched with a minor amount of erratic pebbles.

It appears to have been the first deposit to cover the 'basal regolith'. At least 18,000 years ago, the Pleistocene forests near Milford were overridden by the advancing ice and mantled with a till, now compact (Hughes, 1957). If the two compact tills can be correlated, this episode would correspond to the Tazewell Substage, in the terminology of the 'older' literature. On Flint's (1963) 'newer' representation, it would correspond to the largest peak denoting the Wisconsin glacial maximum which overwhelmed the Ontario-St.Lawrence Basin 25,000 to 17,000 years ago.

Although this deposit has so far been seen only in a few shore exposures, these are nonetheless widely separated. This could mean it is fairly extensive, and underlies much of the younger formations. In fact, it is expected that continuing study will bring to light numerous exposures.

5. NON-GLACIAL INTERVAL

Along the Atlantic coast in the vicinity of Halifax, the compact till - red drumlin interface is marked by a concentration of boulders. The common occurrence of this feature compared with other New England and Maritimes drift sections is a striking feature which merits special comment.

The boulders are invariably unweathered quartzite, about one foot in diameter, subrounded and striated, and typically form a discontinuous layer one boulder in thickness.

The boulder horizon might be a lag concentrate formed by aeolian deflation of the till surface following an ice retreat. Alternatively, the zone might simply be the buried equivalent of the locally common, surficial boulder accumulation comprising the uppermost level of the loose, clean ablation till formed by the settling-out of the englacial load during downward wasting.

The boulder patches are comparable to the well-known pebble band at the top of the Iowan till, except for the apparent absence of ventifacts (Wilson, 1946) and can be regarded as a type of "erosion pavement" (Shaw, 1929). As such, they record accelerated erosion (Lowdermilk and Sundling, 1950). They are believed to be analogous to the pebble zones of Horberg (1952) produced by sheet- and rill-wash on surfaces unprotected or poorly protected by vegetative cover; and to the non-glacial "carpedoliths" of Parizek and Wilson (1957) who interpret them as coarse lag concentrates after aggravated run-off and sheet erosion.

It has not been ascertained whether the initial boulder accumulation was subsequently modified by the overriding drumlins to form a true boulder pavement; but, whatever the origin and history, the boulder zone must, in any case, represent non-glacial conditions following a retreat of the ice margin. If the formation of the compact till records the major Wisconsin maximum, or Tazewell Substage of the Great Lakes area, then the postulated non-glacial interval would correlate with Flint's (1963) Lake Erie Interstadial (17,000 radiocarbon years B.P.).

This Tazewell-Cary interval, also termed the Bradyan Interval, is believed by many to be a significant break in (the latter half of) Wisconsin time (Frye and Leonard, 1955; references in Ruhe, 1952), and is differentiated from the later interstadials by weathering and marked erosion. Flint (1955) states that, in the New England region, evidence of intra-Wisconsin weathering and dissection occurs exclusively in the Tazewell-Cary or Bradyan interval.

The firmness, dark colour and infrequent occurrence of the sub-drumlin Tazewell till are regarded as indications of post-depositional weathering and dissection during the period of climatic amelioration in Tazewell-Cary (or Bradyan) time. Further evidence of a lengthy melting interval is provided by the sixty-foot thickness of stratified, lightly-cemented, red gravelly clay overlying the compact lower till at Blockhouse, Lunenburg County (Prest, 1896).

6. INFLUX OF THE RED DRUMLINS (AND DEPOSITION OF THE TILL SHEET)

Following the post-Tazewell non-glacial period, the lower compact till was overridden by an ice advance which brought into the study area an erratic-rich, drumlin-forming red till. This fine-grained till is characterized lithologically by erratics of northern provenance. It has been demonstrated that the till evolved during migration from the sources southwards to the study area.

Closely associated, and in lateral contact with the drumlins, is the locally-derived till sheet which has been tacitly defined as that widespread Pleistocene formation which mantles the bedrock surface in the study area. Its lithology indicates development in situ, and modification by admixing of introduced material. On the basis of its texture, consolidation, and lack of weathering, it has been assumed for purposes of pebble-count interpretation, that all exposures of this upper loose-textured till sheet in the study area were formed during one glacial episode. This assumption is supported by rates of advance calculated by Flint (1955) for the Great Lakes region which, if applied locally, show that the ice front traversed the 100-mile distance from the Cobequids to the Atlantic Coast in a relatively short time - about 350 years. The till sheet so generated can therefore be considered time-equivalent throughout the area. It might have been during this episode of till formation that certain, yet undetermined, mechanisms were operating to produce the peculiar distribution of foreign pebbles in the till sheet. The possibilities will be discussed in a later section.

It has been shown that the substage which was responsible for the local thin mantle of till on the red drumlins had to antedate Valders time (10,160 $\pm$ 160 years B.P.), which is recorded in the Gillis Lake stratigraphy. Thus the mantle till represents the Port Huron Glaciation or Mankato Substage of 13,600 years ago.

As stated before, it is believed the lower compact till at Milford, dated as older than 18,000 years B.P. (Hughes, 1957) is contemporaneous with the compact tills exposed in the vicinity of Halifax. The overlying erratic-rich red till at Milford is therefore probably equivalent, if not identical, to the coastal red drumlin phase. The drumlin till is regarded as representing a post-Tazewell Substage. Moreover, there is every reason to believe that this same substage was responsible for the till underlying Gillis Lake, the upper till near Milford, and the affiliated drumlin till.

These uncertain correlations limit the formation of the drumlins (and the associated till sheet?) to a period after 18,000 years B.P., and before 13,600 years B.P. Hence, the drumlins probably arrived in the study area during an advance contemporaneous with the Port Stanley glaciation which culminated approximately 16,000 years ago (Flint, 1963).

This interpretation is at variance with that of a previous worker in a nearby area. Hickox (1962), working in the Annapolis Valley, believes that his local sheet till, "identified by included erratics of northern provenance only", was deposited during Port Huron time. In addition, his study of erratic dispersion seems to demonstrate conclusively the occurrence of a later northerly ice flow off the South Mountain bighlands. He compares a pollen profile studied in his area by Odgen (1960) with Livingstone and Livingstone's (1958) profile dated at 10,340 $\pm$ 220 years B.P., and understandably derives a Valders age for this latest episode.

This conclusion is weakened by the fact that there was no correlation of the two profiles, and must in any case be revised in the light of Deevey's corrected age of 10,160 $\pm$ 160 years (late-Valders) for the Gillis Lake material.

Furthermore, his sheet till "of northern provenance" is probably not equivalent to the compact till deposited in the study area during the last continental glaciation, for two reasons:

1) The north-facing, or stoss, slope of the South Mountain upland forms the southern boundary of his map area. Plastered near the bottom of this slope is a mass of Wolfville red clay till (Harlow and Whiteside, 1943).

2) Wolfville red clay drumlins are scattered from the crest of this slope southwards to merge with the Lunenburg field (J.D. Hilchey, N.S. Soil Survey, personal communication).

These facts indicate that Hickox's map-area lies wholly within the influence of the 'Lunenburg' red drumlin lobe. Therefore, it is felt that his upper till was not deposited during the last continental, or Tazewell, glaciation, but is very likely the sheet equivalent of the red drumlin phase related to the subsequent Fort Stanley drift, or Cary Substage. Of necessity, this implies that remnants of an equivalent of the coastal Tazewell compact till might be expected at depth in that portion of Annapolis Valley.

7. POST-DRUMLIN INTERVAL OF CLIMATIC AMELIORATION

There is evidence of deglaciation following the superposition of the red drumlins. The boulder horizon overlying the red till on Kempt Road in Halifax (page 85) is a direct indication of ice retreat. Evidence that the retreat was probably accompanied by melting conditions is given by the Harrietsfield exposure (page 94) where an outwash-type deposit of rhythmically banded red sand and silt overlies the red drumlin till.

Indirect indications of melting are found at:

1) Sandwich Point, where stony red clay with light silty shreds, overlies the compact quartzite till. This member appears identical to a formation interpreted by Lee (1962, and personal communication) as a glacio-marine sediment deposited by an ice lobe ending in the open sea (Charlesworth; 1957, p.479).

2) Bayside, where a block of varved red sediment has been incorporated in the till of a post-drumlin substage (page 85). The varving required fresh water; the graded bedding suggests turbidity current action; and the suspended pebbles and cobbles indicate floating ice. The interbedded till-like units are

similar to deposits described by Ferrians (1962, and personal communication) as 'diamicton', a deposit by subaqueous mudflows originating from a nearby ice front. These four features are typical of glacio-lacustrine sediments deposited in a proglacial lake environment. The white quartz silt and red clay in the graded layers suggest the lake was fed by meltwater draining areas of granite till, as well as red drumlin fields.

3) Prest (1896) ascribes the stratified deposits overlying his "northern boulder clay" (red drumlin till) in the Mahone Bay area, to a second 'interglacial' period.

The period of melting occurred after the advance of the red drumlins which has been referred to the Port Stanley glaciation (page 126). The regression might therefore be time-equivalent with the Lake Arkona recession in the Great Lakes area which occurred about 15,000 years ago (Flint, 1963).

8. DEPOSITION OF THE MANTLE TILL

There is widespread evidence of an ice advance which occurred after the slight dissection of the drumlins. Prest (1896) found an upper layer of local till over the post-drumlin stratified sediments. In Halifax, near Ecum Secum, and at Capelin Cove, Cape Breton (Plate ___), cliff sections showed a mantle of local till over the drumlins. The Bayside exposure of local till with its included mass of red varved clay is regarded as a strong indication that this event was a separate advance, and not merely a late phase of the drumlin emplacement.

It has already been stated that the Mankato (Valders) ice margin barely reached northern New England. The end moraine has been recognized in northern New York, Vermont and New Hampshire, and just south of the Shickshocks (Flint, 1953). The Massive Grand Falls (N.B.) end moraine (Lee, 1959b) might mark the maximum southward extension of the Shickshocks ice cap. There is evidence in the White, Green, Adirondack, and Catskill Mountains, as well as the New Brunswick Highlands, that the latest glacial action was a radial outflow of valley glaciers (Clark,1937; Johnson, 1916)(Rich, 1906; MacKay, 1921; Chalmers, 1894). There is evidence from pebble dispersion, striations, and stoss-and-lee topography that the granite upland of Southwestern Nova Scotia was another of these late Wisconsin centres of radial outflow (Dawson, 1893; Bailey, 1896; Walker and Parsons, 1923; Swayne, 1952; Hickox, 1962). Manley (1955) shows that growth of local ice caps on highlands even quite distant from the continental ice sheet is to be expected, from climatological reasoning.

Flint's (1951) suggestion that the Cape Breton Highlands was another possible centre is therefore not unreasonable. The absence of till on the central plateau is not contradictory; there is hardly any such evidence in the Central Highlands of New Brunswick (Flint, 1951), or along a portion of northern Gaspé (Chalmers, 1904), yet multitudes of striations prove the reality of radial outflow from these neighbouring centres. The late Wisconsin (Valders) till at Port Hood is most easily accounted for by a local centre, which incidentally might have removed earlier till from the central plateau and swept it down the flanks.

This latest advance seems to have been endowed with the ability to override the drumlins, deposit a till on them, while leaving them apparently undisturbed. This may be contrary to expectation, but is not without precedent (Bretz, 1951); and as Thwaites (1943) pointed out in connection with the Cary drumlins overridden and mantled with Valders till in northeastern Wisconsin, a till (such as the Nova Scotian drumlin till) which is cohesive, well-packed, and joint-free will not be vulnerable to erosion by glacier ice which operates chiefly by plucking, rather than by abrasion.

The Sambro drumlin field, however, is an exception, and shows some signs of disruption. The drumlins on the west side of the field seem to have been re-oriented from their original southerly trend to their present southeasterly trend (Figure 10) as if swept by the fringes of a lobe of ice deploying out of St. Margaret's Bay. The granitic, erratic-rich, pink-coloured hybrid tills (Figure 12), common along the east side of St. Margaret's

Bay from Tantallon to Dover, are regarded as the result of the blending of red drumlin till with white granite till, by this lobe.

Further afield, the southerly alignment of the Liscomb field (Figure 10) may have been the work of this latest Wisconsin advance. And it can even be imagined that this advance created the present orientation and distribution of the drumlins, by remodelling an earlier, more extensive deposit.

It is not known, however, whether the movement outward from these centres was sustained by nourishment of the separate ice caps, or whether it was simply a case of 'drawdown' from masses of ice detached from the main ice sheet by thinning over topographic barriers (Hughes, 1957).

9. FINAL DISSIPATION OF THE PLEISTOCENE ICE SHEETS

As the latest Wisconsin Substage drew to a close, the gradually-waning outflow from the local centres finally stagnated. The inert ice masses wasted in situ by marginal melting and surface ablation. As the divides were freed of ice, voluminous meltwater receding from the receding ice margin cut rill channels and reworked the till, flushing out the fines and leaving a stony lag concentrate (Lee, 1955, 1957, 1959a, 1959b). Proof that the ice disappeared from the high ground by downward melting with no radial outflow, is seen in the remarkably long eskers (up to 70 miles) on the granite upland of southwestern Nova Scotia (Prest, 1919, 1923; McIntosh, 1927), and in the kame terraces banking the still perfectly-aligned drumlins (Cann and Hilchey, 1958).

Finally, ice tongues were isolated in the valleys and constructed massive deposits of ice-contact stratified drift (Hughes, 1957; Hickox, 1962). Kame terraces and lacustrine clays were deposited in ponds along the valley walls. At Bayside, the upper part of the exposure shows lenses of till-like granite debris interbedded with laminae of red sand. These structures are to all appearances identical to those interpreted by Wright (1953) as mud-flows which disgorged into a lake bordered by contiguous ice lobes carrying drifts of differing lithologies. Eskers were formed under the inert ice and built deltas and outwash plains as they disgorged downvalley from the ice margin. In the study area, remnants of former glacio-fluvial valley fillings are still seen clinging to the slopes of most of the larger drainage systems along the coast. These are well shown on the soil maps as the parent materials of the LaHave and Medway soil series (Cann and Hilchey, 1958, 1959; Hilchey, Cann and MacDougall, 1960; MacDougall, Cann and Hilchey, 1961).

C. CONFORMITY OF DRUMLIN FIELDS AND FOREIGN PEBBLE CONCENTRATIONS IN THE TILL SHEET

1. INTRODUCTION

In addition to describing the various pebble associations in the till sheet, this till-pebble study has revealed that concentrations of foreign pebbles are associated with fields of drumlins. (Figure 14) The facts bearing on this relationship may be summarized as follows:

a) A loose-textured, light-coloured till is the surface formation in the study area

b) Locally, this till contains concentrations of foreign pebbles

c) Occurring in the same areas are fields of drumlins

d) The drumlin till is a red silty clay with an erratic-rich pebble assemblage

e) The drumlins are surrounded by the till sheet, but where their bases are exposed, they are observed to rest on another till type

f) This underlying till is lithologically similar to the till sheet, but is distinguished from it by marked compactness and darker colour

g) Locally, the drumlins are overlain by a fourth till type texturally and lithologically similar to the till sheet.

Any explanation of the mechanism which produced the observed phenomena must involve:

a) Formation of four texturally and/or lithologically dissimilar tills of at least three ages

b) Long-distance transport of exotic material (foreign pebbles and red clay)

c) Concentration of the exotic materials into pebble 'highs' and drumlin fields

Explanation of the related phenomena is fraught with several vexations. First, the relative ages of the till sheet and drumlins are not at all certain. The till sheet may quite easily be equivalent to one or other of: (a) the lower compact till, (b) the drumlins, or (c) the upper mantle till. Obviously, accounting for the lobate foreign-pebble distribution in the till sheet will be either simplified or complicated, depending on whether or not it is time-equivalent with the drumlins.

Secondly, even if the exact period of formation was known, there would still be reason to wonder if it had been generated wholly during the phase when it was deposited; that is, if it was first-cycle, or if it was a reworked older till and therefore second-cycle. It would then be imperative to know if all the properties of the newer, reworked till had been inherited from the parent, or whether certain added properties - namely, the foreign pebbles - had been impressed during the reconstitution. The question is not "when was the till sheet deposited?", but "when was the peculiar distribution of foreign pebbles created?"

Thirdly, it has, up until now, been implied or tacitly assumed that the pebble 'highs' and 'lows' are the result of differential addition of material. But just as a hill is a topographically positive feature - more probably because valleys have been eroded around it rather than because it was thrust up relative to the valleys - so the pebble 'high' may exist because the adjacent 'lows' were created by decreasing the foreign pebbles in adjoining areas. This depression of the foreign pebble content along certain strips may have occurred after the creation of the till sheet, when a later advance may have effected a dilution by addition of local material, or simply eroded the pre-existing erratic-rich till and replaced it with an erratic-poor substitute.

It will be evident from the foregoing that there is still much uncertainty about the stratigraphic relations of the various formations, uncertainty about the age of emplacement of the erratic pebbles, and uncertainty about the true meaning of the pebble concentrations. It is therefore not possible to apply any single theory to such a flexible set of circumstances. Necessarily, for each interpretation, there must be an independently credible explanation.

Several alternative explanations are developed below. Although differing in detail, each is based on the operation of faster-moving currents within the ice sheet. This underlying principle is discussed at length first.

2. THE ICE CURRENT PRINCIPLE

a) The fact that the problem basically involves an influx of particles not indigenous to the study area implies a long-distance movement of the transporting medium (ice). Secondly, the non-uniform distribution of the particles requires corresponding non-uniform movement of the ice. Thirdly, as the particles are dispersed in a lobate pattern, the differential movements of the ice sheet must have taken the form of distinct currents. At the ice margin, such currents would be manifested as lobes or protuberances.

If ice lobes existed they might first have carried in the foreign pebbles, then the drumlins. The combined weight of ice and drumlins might compress the previously deposited till sheet. The till between drumlin fields would escape compaction because it was outside the lobes.

If ice lobes did actually bring in the drumlins, then the drumlins - at least the outer ones in the field - should be arranged radially to the edges of the lobe, and there should be concentric morainal features from ice margin fluctuations. The drumlins, instead, have parallel alignment and there are no recorded observations of morainal features. Therefore, the position of an active lobate ice margin in the drumlin areas is not indicated and the ice current mechanism, per se, must be evoked as the alternate hypothesis.

Thus, the problem of explaining the drumlins and foreign pebbles resolves itself into the problem of proving the existence of, and elucidating the operation of certain hypothetical ice currents which, by deduction, have been evoked to account for the observed phenomena.

Field Evidence

If such narrow zones of swift flow are to be held responsible for the localized deposition of material, then there should be field evidence of localized erosion at the sources to lend support to the hypothesis.

Some time ago, H.R. Cameron of the Nova Scotia Research Foundation drew my attention to two great welts on the one-inch: four-miles topographic map of the province. Each was twenty-five miles in diameter, and they were centred on Paradise and Gaspereaux Lakes. They involved both North and South Mountains. Mr. Cameron suggested they were due to differential iso-static uplift following deglaciation.

Although the explanation for the welts has not yet been proven, the valley between them seems to be relevant to the present problem. It is a perfect extension of the axis of the Lunenburg drumlin field. The thought naturally occurred that this valley might have been glacially eroded by the ice current evoked to explain the drumlin field.

Dr. H.B.S. Cooke pointed out that this suspicion could be checked quantitatively. The actual figures used in the calculations are set down in Appendix V, but briefly the results were this: The volume of material eroded from the slot across the North Mountain is a minimum of 1.244 cubic miles. The amount of North Mountain basalt in the till along the course of the ice current was calculated by:

1) using the areas of the drumlins and intervening tills given in the Lunenburg Soil Report (Cann and Hilchey, 1958).
2) assuming reasonable thicknesses to get the volumes of the various tills.
3) using the gravel, and sand plus silt values from the soil mechanical analyses (Cann and Hilchey, 1958).
4) applying my figures for the amount of North Mountain pebbles in the various tills.
5) applying Nolan's (1963) figures on the North Mountain augite content of the beaches bordering the Lunenburg drumlins.

The resulting figure for the amount of North Mountain basalt in gravel sand and silt sizes in the till along the Lunenburg lobe, was not less than 0.530 cubic miles. Most of the assumed values are believed to be good approximations. No account could be taken of the possible material underwater on the Scotian Shelf, to the above figure should be larger. It fits the figure for erosion only by fortuitous coincidence. Even so, the agreement is astounding, and is believed to constitute proof that currents actually existed during the drumlin-forming Cary advance, which currents were effective in eroding the foreign sources and depositing the exotic pebbles downstream along their courses.

This behavious is typical of the Cary ice front elsewhere in eastern North America. Moreover, it is believed that the Cary margin in New England, from its limit somewhere between Boston and Cape Cod, was continuous across the Gulf of Maine to a position offshore from Nova Scotia on the Scotian Shelf. This is suggested by the facts that: (1) the Cary limit matched the maximum Wisconsin limit in New England by reaching Long Island, (2) that both these limits are parallel to the curves of both rate and amount of post-glacial isostatic uplift, (3) that both limits are coincident with the zero isobases, and (4) that these lines of no uplift (which mark the limit of ice) extend from Cape Cod straight across the deep (300m) water of the Gulf of Maine to a position on the Scotian Shelf just beyond the coast of Nova Scotia (Flint, 1953, 1957). In other words, the main mass of the Cary ice sheet made a wholesale advance across Nova Scotia at least as far south as the present coast.

Now that it seems reasonably certain that ice currents were operating in the Cary ice sheet as it advanced across the study area (and were manifest as ice lobes offshore south of the study area), it now remains to show how these facts are depicted by the configuration of the foreign-pebble isopleths.

Isopleths as Indices of Ice Motion

The proof will be more easily understood if a parallel case is cited first. Where ice currents are known, as in valley glaciers, the velocity profile across the current is measured by setting a row of precisely-located stakes in a line perpendicular to the flow. At any instant after, the line will approximate to a parabola, convex downstream, provided the flow is bilaterally symmetrical about the median line of the glacier. The amount of distension of the original straight line (or the elongation of the parabola) is a function of time and glacier velocity. The axis of the parabola is the line of maximum velocity (Meier, 1960)

The principles of the technique described above are believed to be analogous to the conditions which obtained over Nova Scotia during the dispersion of the foreign pebbles. The original straight control line is comparable to the foreign rocks in place at their sources which have been described as having linear shape, uniform width, great extent, and being perpendicular to the ice flow. The progressively displaced positions of the original line are likened to the new positions of the foreign rocks; that is, the isopleths of their occurrence in the till sheet.

It is presumed that a uniformly-advancing ice sheet will erode equal quantities along the lengths of source areas having such properties, and deposit the same equal quantities in the tills downstream. Isopleths of the resulting pebble distributions should be straight lines parallel to the sources, falling off in a regular, featureless way. Therefore, any departure from ideal uniform flow should cause differential erosion, and matching deposition., The configuration of resulting distorted isopleths should reflect the shape, size, velocity gradients in, and duration of the responsible ice currents (or lobes).

Applying these principles to the results of this pebble study, it can be seen that the isopleths of the foreign pebbles are a series of connected parabolas. The axis of each set of concentric parabolas or 'lobes' is parallel to the latest glacial striae, and to the trend of the drumlins in the enclosed field. Nearest the axis of the lobe, the drumlins are most elongated, which substantiates the premise that maximal velocities occurred in this part of the ice current (Charlesworth, 1957, p.394).

It is therefore concluded that ice currents were active in the Nova Scotia ice sheet, and that these currents impressed higher-than-average amounts of foreign indicator pebbles into the till sheet. Continued operation of the currents eventually brought in groups of drumlins which assumed positions over the foreign pebble concentrations.

Some considerations remain. The different degrees of development of the isopleth lobes and the drumlin fields can be explained as due jointly to different velocities and durations of the ice currents. The reasons for the inception of the ice currents are obscure. It can only be stated that they were well established before they impinged on the Cobequid Mountains. The controls on their paths across Nova Scotia are also problematical. They do not seem to have been influenced by the underlying topography, except perhaps in the case of the Lunenburg current which follows the Lahave River valley. Although it has a depth to width ratio of only 1:100, Horberg and Anderson (1956) found that the long broad valleys of the Central United States were effective in creating and directing flow units within the main ice stream; and they further believe that these same currents could explain the lithological differences between drift sheets, and even the various facies of an individual till sheet.

3. ORIGIN OF THE ICE CURRENTS

Two different possible reasons for the inception of the ice currents can be imagined:

a) by topographic control; interaction between the thin marginal portion of the Cary ice sheet and the topography of the study area hinterland, resulting in a channeling of the ice into streams, or

b) by confluence and interaction of two (or more) opposed local ice caps resulting in accelerated flow along their line(s) of juncture.

Topographic Control

Since it does not appear that either the foreign-pebble isopleths or the drumlin fields are related to topographic channels, such as valleys, in the study area, it is possible that the physiography of the hinterland north of the study area was effective in directing the flow of the thin Cary ice. Below is a list of the flow units revealed by the isopleth maps, with the possible topographic elements which may have caused them (Figure 15):

(1) Yarmouth: the Saint John River valley in New Brunswick,

(2) Lunenburg: Petitcodiac River, New Brunswick, Chignecto Bay, and the Lahave River valley,

(3) Sambro: initiated in Parrsboro Pass, buttressed and confined by Cape Blomidon, and guided south along the valley of the Avon River,

(4) St. Margaret's Bay: a distributary of the Parrsboro-Avon River stream diverted to the west by the St. Margaret's lowland,

(5) Cow Bay: a branch of the above major current diverted to the east by the Sackville River-Bedford Basin-Halifax Harbour valley, and confined on the east by the steep bluffs of the 'Gibraltar' granite batholith,

(6) Chezzetcook: possibly another ramification of the Avon River ice stream, intensified by confluence with a ~~content of~~ major stream created in Wentworth Valley (explaining the anomalously high content of Cobequid material), channeled south along the valley of the Shubenacadie, and diverted to the west across a pass in the Gibraltar batholith occupied by Porter Lake,

(7) Owl's Head: the main stream of the Wentworth Valley-Shubenacadie current, guided across the granite batholith by the Lake Charlotte lowland,

(8) Liscomb-Ecum Secum: initiated in the lowland formed by PictouHarbour and East and Middle Rivers between the flanking high points of Fitzpatrick Mountain on the east end of the Cobequid Mountains, and MacLellan Mountain on the west end of the Antigonish Highlands.

Confluence of Opposed Local Ice Caps (Interlobate Ice-Current Theory)

An alternate explanation for the development of the currents can be reconstructed from clues gleaned from Prest's (1957) account of the glaciation of the maritime region. Based on currently accepted doctrine on the inception of glaciation, his sequence accounts for most striation directions, including most of the hitherto unexplained discordant and contradictory directions.

He envisions that, long before the Laurentide ice sheet neared the Maritimes, local ice caps had formed and were spreading radially from the New Brunswick and Cape Breton Highlands. Ice from the Cape Breton centre advanced westward onto Prince Edward Island as far as New London Bay, and southwestward along the Atlantic Coast of mainland Nova Scotia. Simultaneously, the New Brunswick ice advanced across the Bay of Fundy to Nova Scotia, and eastward across Northumberland Strait to Hillsborough Bay on Prince Edward Island, where it met the westerly tide of Cape Breton ice.

The confluence produced a generally southerly flow which seems to have been manifest in various major currents:

1) the 'Chignecto glacier' (Chalmers, 1894), moving southwesterly across the Isthmus and Bay of Chignecto.
2) a southerly tide at right angles to the Cobequid Mountains.
3) southerly and southwesterly flow from George's Bay.

It has been shown that the necessary conditions were currents, or zones of accelerated flow. It now remains to show that these currents could have been set in motion by the confluence and interaction of the mutually-opposed New Brunswick and Cape Breton local ice sheets.

As may have been inferred from previous statements, the western border of the Cape Breton sheet extended with an arcuate front south from New London Bay, west of Joggins, and across Nova Scotia to a point on the South Shore somewhere west of Halifax. On encountering this front, the stronger flow from the larger New Brunswick centre would be expected to halt the advance of the Cape Breton ice. The New Brunswick ice would react to the opposition by changing its southwesterly course and shearing southward along the front. Damming of the Cape Breton ice would result in a similar southerly redirection of its initially westward advance. Together, the two new southerly components would reinforce one another and, by combination, create a zone of stronger flow, or a current, localized along the line of confluence. This hypothetical ice current created by the confluence of the ice sheets will be here= after termed the 'interlobate current'.

The New Brunswick ice would continuously, but intermittently, adopt and convert to its own flow pattern, the sluggish peripheral zone of the Cape Breton sheet. In this way, the line of confluence of the two sheets would be spasmodically shifted eastwards, and this migration would, in turn, carry the axis of the 'interlobate current' to successive new parallel positions.

The first position of the interlobate ice current is envisioned to have extended southerly and southeasterly down Chignecto Bay and across the Bay of Fundy to Morden on the North Mountain shore, thence through Kingston and New Germany to Lunenburg on the South Shore. By its relatively greater erosion on the transversely situated Cobequid and North Mountain ramparts, the current transported a larger load of foreign pebbles than the imbedding ice sheet, southward to the Lunenburg area of concentrated deposition.

In each new position of the current, the process of intensified erosion and accelerated transport was repeated, and similar concentrations of exotic pebbles were created in the till sheet along the Eastern Shore.

If the mode of origin of the foreign pebble concentrations has been correctly deduced then, by inference, the associated red drumlin fields probably originated by the same mechanism. Most of the fields coincide with the foreign pebble accumulations, but some are displaced slightly to the north of the 'highs' and a few even lie in the intervening 'lows'. The northerly displacement could have occurred if the drumlin till originated at a point upstream in the interlobate current from the foreign pebble sources. Similarly, the lateral discrepancies would result as the New Brunswick sheet assumed dominance and impressed its southeasterly flow on the earlier southerly-moving currents.

Vague indications of the former southerly direction of transport still remain. Usually, drumlins are arranged in parallel belts athwart the ice flow (Charlesworth, 1957, p.391-6). The Nova Scotia drumlins are instead grouped in fields, but these fields lie in three parallel swaths bearing 080°-084°, or nearly east-west, and transverse to the hypothetical former north-south ice flow.

If it is true that the drumlin fields have been displaced to the southeast of their parent ice current and affiliated pebble 'high', it should be possible to get a better fit by shifting them northwesterly. The operation does, in fact, greatly improve the agreement, and resolve most of the inconsistencies.

1) the Sambro-Hammond Plains group now fits the drumlin-less St. Margaret's lobe.

2) the small Cow Bay field is a better fit in the smaller Sambro lobe.

3) the Chezzetcook field, formerly in a pebble 'low', now fits the Cow Bay lobe.

4) the Moose River field, also formerly in a 'low' together with the Owl's Head field, seem to belong in the drumlin-less Musquodoboit lobe.

5) the massive Liscomb-Ecum Secum field is better matched with the larger Owl's Head lobe.

6) the Indian River field makes a more symmetrical fit with the Liscomb lobe.

Directional indications of the southwesterly flow from Cape Breton is given by:

1) Striae on the headlands of the Eastern Shore (G.S.C. Map 910A).

2) A deep glacial groove near Lake Echo bearing 250°, with superimposed striae bearing 160° (true) (Plate 38).

3) Schuppen, and imbrication of the basal till sheet at Hartlen Point (page 102 , and Plates 30 and 29).

4) Quartzite till derived from Eastern Passage on the granite bedrock at Sandwich Point (page 90).

PLATE 38

Early glacial groove bearing 250 degrees, transected by later striations bearing 160 degrees from the last continental advance, Echo Lake, Halifax County.

Prest's theory also explains the superposition of lithologically dissimilar, and apparently penecontemporaneous till sheets at Joggins, Nova Scotia (Table 7). The lower member with few erratics may have been formed by the westerly-flowing Cape Breton ice carrying a slight contribution of foreign pebbles from its contact with the north flank of the Cobequids. The erratic-rich middle member may be accounted for by the subsequent arrival of New Brunswick ice heavily laden with foreign material from its recent traverse of the nearby Caledonian massif. The upper till, with its paucity of erratics, would represent deposition by the final resultant southwesterly flow out of Northumberland Strait.

The ability of Prest's theory to account for details, some of which were unknown at the time of formulation, attests to its general validity as one basis for reconstructing the conditions responsible for the distribution of drumlins and foreign pebbles over southeast Nova Scotia.

Summary of Interlobate Ice Current Theory

1. Ice sheet currents, not manifest as lobes (at least in the study area), are indicated as the transporting agent of drumlins and foreign pebbles.

2. The lobate configuration of the foreign pebble isopleths is explained by the ice current theory by drawing an analogy with the velocity profile of a known ice current, the valley glacier.

3. The role of the source areas in minimizing variables is described.

4. The hypothetical ice currents are believed to have been caused by the confluence of the New Brunswick and Cape Breton local ice sheets.

The interlobate ice current theory accounts for many of the observed phenomena, but is weak in the following ways:

1) The lower firm till is also darker than the loose-textured till sheet, suggesting that other processes besides compaction have operated on it. The coloration hints at a fundamental chemical difference, or a secondary alteration such as weathering.

2) The theory does not account for the source of the drumlin clay. This fundamental question is therefore dealt with in a separate chapter.

3) The reason(s) for the inception of the currents still remains obscure.

4) The imbalance in size between pebble 'highs' and drumlin fields is only explained with difficulty.

5) It gives no explanation whatever for the fact that Minas Basin pebbles form intervening 'highs' between concentrations of the other foreign types.

6) The secondary southeasterly alignment of the drumlins impressed on an earlier southerly disposition is not well accounted for.

4. POSSIBLE ORIGINS OF DRUMLIN FIELDS AND RELATED LOBATE DISTRIBUTION OF FOREIGN PEBBLES IN THE ASSOCIATED TILL SHEET BASED ON THE OPERATION OF ICE CURRENTS

However these currents might have originated, it almost is certain they did exist in at least one of the late Wisconsin ice advances over Nova Scotia. Depending on how the stratigraphy is interpreted, these currents may be brought into play in various ways and at different times to account for the creation of remotely-derived drumlin fields and lobately-distributed erratic pebbles.

Interpretation One

The till sheet is a loose-textured equivalent of the compact till, and both are pre-drumlin phase.

Variation (a)

In this case the erratic-pebble content of these two members of the same formation may have had the same lobate distribution as present, thus requiring an early operation of currents, then a later one along nearly the same courses for the influx of the drumlins.

Variation (b)

The erratic-pebble content was initially at a featureless high level in the compact till, which was then recnnstituted into a loose till in the vicinity of the drumlins during the drumlin advance, while in the inter-drumlin field areas it was eroded together with its high erratic content, and slightly enriched in Minas Basin lithologies.

Interpretation Two

The till sheet is equivalent to, or possibly just slightly younger than the red drumlin till, and both are more recent than the compact till.

Variation (a)

Here, too, the compact till may initially have had a lobate, current-induced didtribution of foreign pebbles, in which case later ice currents brought in the drumlins and, in so doing, reworked the underlying older till into a loose till which inherited the characteristics of erratic dispersion of its parent.

Variation (b)

All aspects of the older compact till might be entirely unrelated to the present picture. This creates two further possibilities:

Subvariation (b_1)

The currents which brought in the drumlins also transported related lithologies of erratic pebbles along their courses, and impressed these concentrations into the associated, contemporary, loose-textured, local till.

Subvariation (b_2)

The discrepancies in the matching of drumlin fields and till sheet erratic fields can be explained if the till sheet is a late phase of the drumlin advance. This advance had currents operating which may have cut the drumlin belts into fields, realigned the drumlins, and carried in foreign pebbles.

Interpretation Three

The deposition of the lower compact till and overlying red drumlins are respectively early and middle classical Wisconsin events; and the till sheet together with the uppermost mantle till are products of a late Wisconsin advance.

In this case, the compact till may have had an initially high content of erratics. Following the influx of the drumlins (as belts), the late Wisconsin ice currents (lobes) cut these belts into fields and, in the inter-drumlin field areas, eroded the compact till, depressed the erratic content by substituting the later erratic-poor loose local till, and enriched this with Minas Basin lithologies.

Comment

The number of possible interpretations may be even greater. The only way to eliminate some of the possibilities and approach a solution is (1) to get more information on transport directions by study of till fabric and detailed provenance, and (2) to solve the stratigraphy by deducing the true relationships of the various formations by comparing colour, particle size analyses, carbonate contents, index heavy minerals, and sand petrography.

D. ORIGIN OF THE RED DRUMLIN TILL

It has been possible to show how the pebble content of the red drumlins evolved by processes of progressive dilution and differential comminution in transport. The pebbles have been referred back to their respective sources, but the 'vehicle' for the pebbles is not so easily explained. This matrix, non-pebble fraction, or less-than-2mm part of the till, is between 70 and 85 percent of the volume (Cann et al, 1954; Cann & Hilchey, 1958). About half of the matrix is silt and clay (Figure 16). What then is the source of this very-fine-grained portion of the till?

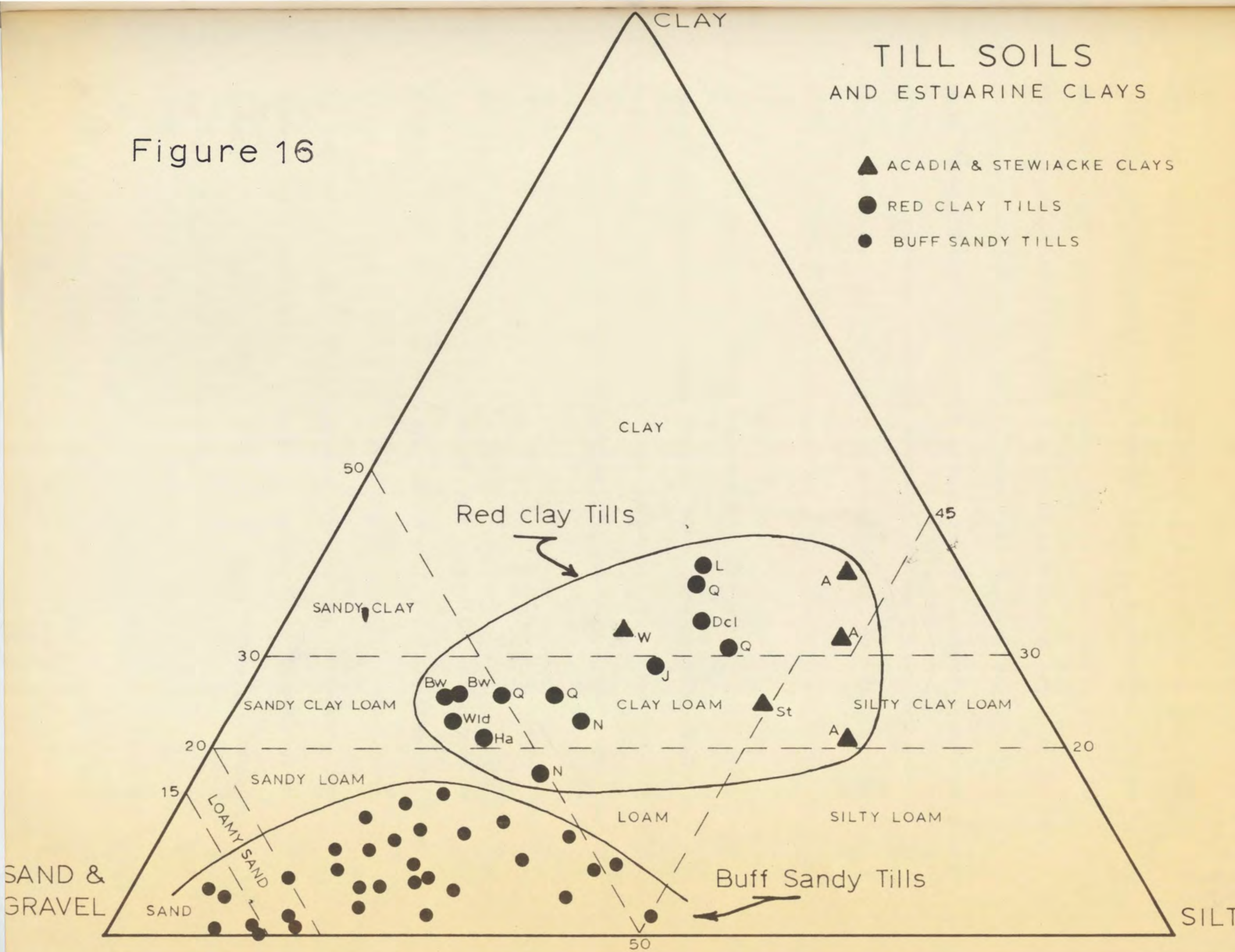
There are several possibilities. The till could have been derived from:

1) rocks presently outcropping in Nova Scotia
2) rocks not visible; present, but covered by water
   or, pre-existing, but since eroded
3) rocks outside Nova Scotia
4) sources other than rocks

1) Local Rock Sources

Figure 16 shows that the Wolfville and Hantsport soils which are developed on the red till, are related texturally to certain other soil groups developed on similar red-coloured tills. Only slates could yield the debris necessary to form such fine-

Figure 16



TILL SOILS
AND ESTUARINE CLAYS
ACADIA & STEWIACKE CLAYS
RED CLAY TILLS
BUFF SANDY TILLS
CLAY
SAND & GRAVEL
SILT
CLAY
SANDY CLAY
SANDY CLAY LOAM
CLAY LOAM
SILTY CLAY LOAM
SANDY LOAM
LOAM
SILTY LOAM
LOAMY SAND
SAND
Red clay Tills
Buff Sandy Tills
50
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20
15
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grained till. And of the nine fine-grained tills in the group, only the Bridgewater was derived by glacial erosion of slates (of the Halifax Formation) (Cameron, 1961). The others occur in the Carboniferous Lowlands, overlying formations composed largely of sandstone with minor shale. The soil reports repeatedly state that "these heavy clay parent materials are derived from sandstones" frequently not even red, but brown and often grey. Not only are the supposed source rocks too coarse-grained, but they are not even the right colour.

Furthermore, these same reports frequently note anomalous phases of these soil groups having "much heavier clay texture, a more cheesy consistency, and (so) comparatively stone-free that no satisfactory evidence of (its) origin has been noted" (Whiteside et al, 1945, p.33, 34).

I know of no way by which red clay-rich debris can be produced from the brown and grey sedimentary rocks on which these tills rest, UNLESS IT BE BY A PROCESS OF SORTING. Therefore, it is not believed that the presently outcropping formations are themselves fine enough, or contain enough shale interbeds, to constitute a logical source from which these tills may have been derived directly by glacial erosion.

2) Rocks Not Presently Outcropping

Cameron (1961), in attempting to explain the anomalous "reddish material in.....Halifax, Lunenburg and Hants Counties", circumvented the problem of lack of suitable existing rocks by stating that "this material is believed to be the result of erosion by the ice....of a mass of soft Triassic shales, which once occupied what is now Minas Basin. The shales were unprotected by a basalt lava cap...."

It is true that (1) the North Mountain basalt does not overlie Minas Basin, and (2) the shales (of the Blomidon Formation) underlie the basalt, and (3) pre-basalt sediments outcrop around the shores of Minas Basin, and finally that (4) Minas Basin has been 'recently' formed judging by the pairing of streams on the north and south shores (H.L. Cameron, personal oral communication). But this does not mean that the 55-cubic mile capacity of the Basin was excavated during the Pleistocene, or even that glacial erosion could have accomplished such a feat; and, further, there is no way of knowing how much of the eroded sediments was Blomidon Shale. The recently discovered Triassic outliers in Chedabucto Bay (Stevenson, 1961) are regarded by students of the Triassic as strong indication that sediments of the Triassic basin were once present continuously between Minas Basin and Chedabucto Bay. Although the absence of these rocks between the two localities is undoubtedly due to erosion, it is very unlikely it was accomplished during the Pleistocene.

There are no signs of extensive glacial scour in the Minas Basin region. The major rivers, the Avon and the Shubenacadie, seem to be well-graded, with no declivity where they discharge into the Basin, unless these rivers have masked such features with VOLUMINOUS SEDIMENTS DERIVED FROM THE FINE-GRAINED TILLS ON THEIR WATERSHEDS.

3) Rocks Outside Nova Scotia

There are no large areas of shale of any colour outside the province in either Prince Edward Island or New Brunswick. The only red rocks are the Carboniferous formations, but these are mainly sandy and could not produce the silty clay matrix of the till UNLESS THE FINE FRACTION OF THE ROCKS IN THIS LARGE AREA WAS CONCENTRATED IN SOME WAY.

4) Sources Other Than Present or Pre-Existing Rocks

Krumbein (1933) stated that unconsolidated surface sediments have more effect on till composition than bedrock even as soft as shale. It seems safe to assume the source was sedimentary material, but as no suitable sedimentary rocks appear to have been available as direct sources for the till, it is inferred by elimination that the material was unconsolidated at the time of erosion.

Such fine-grained sediments are presently accumulating in quantity in the tributary basins of the Bay of Fundy, namely Shepody and Chignecto Bays and Cumberland and Minas Basins. Rivers tributary to these basins are carrying vast quantities of silt and clay winnowed from the surrounding red rock and tills. This suspended load is sedimenting at the margins as estuarine deposits, and accumulating on extensive tidal flats by the settling lag effect (van Straaten and Kuenen, 1958). Most of the rest is flocculating to form basinal deposits.

Soils developed on the emergent portions of such deposits belong to the Acadia and ~~Wolfville~~ Stewiacke catenas. They appear on Figure 16 at the opposite end of the field from the Wolfville till. Certain facts appear to relate the soils in this group. Locally in Lunenburg county, the Wolfville clay till has become Wolfville sandy loam drumlins by admixture of coarse material from the underlying granite (Cann & Hilchey, 1958). Secondly, it has been shown that there is a lithological trend from Wolfville drumlin till to the till south of Minas Basin belonging to the Queens soil catena (Q), which occupies a central position in the field on Figure 16. Cann et al (1954) further state that the Hantsport soil, the poorly-drained equivalent of the Wolfville soil, "in many respects resembles the Joggins (J) and Diligence (Dcl) soils mapped in Colchester and Cumberland Counties" on the north side of the Cobequid Mountains. Personal observation of these same red sticky plastic tills showed them to be visually indistinguishable from the red till of the local drumlins.

There appears to be remarkable textural affinities between the local drumlin till and those tills distant in the Cumberland and Hants-Colchester lowlands. Although widely separated geographically, there is one unifying element: all these tills are the sources of the silty clay forming the base of the Acadia-Stewiacke soil group.

That common feature is the connecting link and the clue to the origin of the Wolfville red clay drumlin till. During the post-Tazewell interstadial following deposition of the compact till, when the ice had retired to its minimum retreat position in the St. Lawrence Valley, sea level was still depressed at least 300 feet below present sea level. Under these conditions all of Chignecto Bay, Northumberland Strait, and Minas Basin would be emergent. (The sill depth for Minas Basin is only 30 feet on the submerged ridge connecting Cape Split and Cape Spencer across Minas Channel). Meltwaters draining the large adjacent areas of red rocks and tills would have carried off the fines and deposited them in extensive alluvial and deltaic plains, as is occurring presently on a small scale, and further out in the estuaries like the late-Pleistocene Fash clay of the Annapolis Valley (Harlow & Whiteside, 1943; Hickox, 1958). If the basins were landlocked, as Minas Basin very probably was since the sill depth is only 30 feet over the submerged ridge connecting Cape Split and Cape Spencer across Minas Channel, then the sediments would be laminated clays with silt partings like that used at the Lantz brick works (Hughes, 1957).

Readvance of the ice during the drumlin-forming Port Stanley or Cary Substage scooped up this plastic sediment and moved it forward by "a combined plastering on and rubbing away process". The coherent material picked up whatever coarse debris was present in the overridden till, so that at any time it had inherited a variable lithological affinity which depended on the local rock type. Because of its derivation, the pseudo-till appeared native to the Carboniferous region as long as it remained in the Hants-Colchester lowland, but it revealed its true nature when it encroached on the whitish tills of the study area.

Consistent with the postulated depositional environment is the discovery by Walker and Parsons (1923) that the ratios of certain oxides in a chemical analysis of a mass of Wolfville till on the Fundy slope of North Mountain "suggest previous leaching and weathering". Also, the depositional sites are well situated with respect to the drumlin field-forming ice currents seemingly localized by Chignecto Bay and the major rivers of Minas Basin.

To the writer's knowledge, this is the first time such an hypothesis of origin has been postulated for the red till of Nova Scotia, but this general idea is not novel. Alden (1918) was the first to suggest that the red Valders drift of Wisconsin was derived from red lake clays deposited in Lake Chicago during Two Creeks time, as the fine fraction of the pre-existing red Cary till. Thwaites (1943) substantiated this belief by comparing mechanical analyses of the till and lake clay. Murray (1953) gave further support with data on relative carbonate contents and heavy mineral associations. Recently, Shepps (1953) has emphasized that this is a general process whereby younger tills become finer by incorporation of loess and lake sediments winnowed from older tills during interstadials.

The mode of occurrence of the red drumlin till in Nova Scotia is similar in many respects to that of the above-mentioned Valders till in Wisconsin. Leighton (1957b) states that "the Valders smeared the land surface with a clay till, moulded numerous drumlins, and built almost no moraines". According to Thwaites and Bertrand (1957), the Valders is a thin till which smooths or imitates the contours of the underlying Cary till. This mimicry is very complete. It veneers and caps eskers and kames (Wright, 1956), copies underlying moraines (Bretz, 1951), and even preserves the form of older overridden drumlins (Thwaites, 1943).

It would appear that, when dealing with a till of such properties, glacial geomorphic forms cannot be taken at face value.

CHAPTER SIX

COMPARISON WITH RELATED STUDIES

A. EARLY WORKERS

Almost a century ago Honeyman recognized the reality of long-distance glacial transport in the presence of North Mountain and Cobequid erratics on the Atlantic Coast (1878, 1882, 1886, 1890). By many observations of surface erratics he was able to precisely delimit the North Mountain erratic field as a line extending southeastward from Cape Blomidon, through Goff's, and Preston, to Three Fathom Harbour (Chezzetcook). Other amygdaloid erratics to the east at Petpeswick, Jeddore and Owl's Head, he referred to as the Bass River and Five Island outliers.

The present study confirms the validity of his general conclsions, and adds to his basic plan the details of ice movement.

He also noted the relationship of abundant foreign rocks with their occurrence in "red banks" and "red heads" (cliffed drumlins). These "accumulations of the Cow Bay type" were, however, never contrasted with the local drift, nor was their peculiar morphology as drumlins noted; instead, they were interpreted as a "terminal moraine". Yet, in a sense, this conclusion was not entirely incorrect since, if drumlins are accumulations under the peripheral zone of the ice, then the ice margin is probably not far south of the present coast.

Prest's (1896) inferences on glacial events from his observations on till sequence in Lunenburg County cannot be improved upon, if his statements are interpreted in the light of the terminology of his day.

The summary of ice movements inferred from collated evidence of dispersed erratics by Goldthwait (1924) is a masterly one. He did not, however, differentiate between the red drumlins and the slate drumlins in Lunenburg County.

Similarly, Wilson (1938) mapped the Lunenburg and Queens County drumlins from aerial photographs and, on the assumption that all drumlins were of slate till and never of quartzite till, consequently gave exaggerated figures of the amount of advance of the slate till onto the quartzite areas. This points up the importance of field observations as the fundamental prerequisite for regional photo-geological mapping.

B. CONTEMPORARY WORKERS

MacNeill (1960a), in a brief summary of his long-term Pleistocene survey of Nova Scotia, speaks vaguely of "evidence of two, possibly three, ice advances" in the Mahone Bay drumlins. There is no mention of contrasting till types. Comparison with the present work will have to await publication of his findings.

Hickox (1962a) confirms Dawson's (1893) conclusion of northerly ice flow off South Mountain with a well documented study of the distribution of South Mountain granite indicators on North Mountain. If this ice cap moved radially, as he implies, no evidence of its having impinged on the nearby Lunenburg drumlin field is seen. It is suggested that his "local ice cap" was a remnant isolated during the waning stages by the effect of the intervening Bay of Fundy, and moved off the South Mountain into the depths of the Bay by 'drawdown' while the southerly portions of the residual mass on the upland wasted in situ over the drumlins by surface ablation and marginal recession. Its behaviour is analogous to the locally controlled drainage of the ebbing following the cessation of a unidirectional flood.

Pezzetta (1962) reported on the physiography of the western part of the Scotian Shelf. From a perusal of the appended descriptions of the pebble material in the associated sediments, it was discovered that erratics of the drumlin till pebble association were present at least on the inner part of the shelf.

A.E. Cok (personal oral communication) drew my attention to an extensive zone of coarse material extending the full width of the shelf between Lunenburg and Chezzetcook. This, he suggested, could be reworked morainal material: evidence of far-reaching activity of the stronger western drumlin-forming lobes.

Corroboration of the indicated pebble and drumlin distributions comes from Nolan's (1963) heavy mineral analysis of the beach sands of Nova Scotia. No variations "slipped through the fence" of closely-spaced samples encircling Nova Scotia. As all the beaches are derived from adjacent till cliffs, this line effectively sampled the material transported across it by seaward-moving ice.

He is able to sharply define heavy mineral associations related basically to bedrock lithology. Additionally, he finds that augite, because of its unique occurrence in the North Mountain basalt, is the key indicator mineral of long-distance transport. To reveal the true degree of augite enrichment, he nullifies the dilution effect on the augite content by sporadic occurrences of bedrock rich in heavies. This is done by reducing all heavy mineral contents to that yielded by barren granite.

The resulting values for augite content of the beach sands from Yarmouth to Canso are shown varying longitudinally in Figure 17. It is remarkable, and yet not unexpected, that each drumlin field is matched by a peak on the curve. Furthermore, the amplitude of the peak is in direct proportion to the observed purity (lack of local dilution) of the red clay till, to the size of the drumlin field, and to the density of the drumlin population in the field. He finds three additional concentrations between Liverpool and Yarmouth. The negligible quantity of basalt pebbles and absence of red drumlins in these latter areas is presumed to mean that during the initial advance the basalt was comminuted during the longer transport over this wider portion of Nova Scotia, and that there were no ice lobes operating in this sector during the drumlin-forming Cary advance.

The results of this study give an independent line of evidence which is in complete agreement with those of the pebble investigation, and for this reason gives undeniable proof that heavy mineral analyses, too, can be an equally fruitful technique in provenance study of glacially-disturbed terrains, providing there are sources of indicator minerals.

Geochemical surveying over mainland Nova Scotia gives results which, in the study area, appear to be related to the till type. Holman's (1959) studied the heavy metal content of stream sediments in the eastern mainland. His anomalies, defined as regional changes above the background maximum of 5 ppm., correspond in position and shape to the drumlin fields (Figure 10). The only fields not matched by anomalies occur in areas too remote or inaccessible for sampling. In other words, where it has been possible to sample the stream sediment in drumlin fields, anomalously high heavy metal contents are revealed.

Similar, but more extensive anomalies occur in the region overlain by the related red till north of the study area in the Minas Basin source region. It is therefore believed that the anomalies in the study area are not indigenous, but occur because the red drumlin till to which they are due, acquired this property as it advanced over the metallized Horton-Windsor contact extending from Windsor to Canso.

By contrast, a companion study of heavy metals in water and sediments of southwestern Nova Scotia by Boyle et al (1958) shows, however, no such regional anomaly ~~occurs~~ in the Lunenburg drumlin field; only small spot highs related directly to the gold-sulphide lodes of the Meguma domes. If the interpretation of the heavy metal source is correct, then no such anomaly should be expected in the Lunenburg field since this till was derived outside the Horton-Windsor region.

Conversely, there would be anomalies associated with the drumlin fields of southwestern Cape Breton because these lie downstream from a large area of Horton-Windsor contact, also locally metallized.

This study of till has thus also served to point out that caution must be used in the assessment of anomalies in glacially transported materials. This is especially important in Nova Scotia where:

1) the metal sources are numerous, small, and widely scattered,

2) certain till phases are far-travelled,

3) directions of glacial flow are greatly divergent.

CHAPTER SEVEN

OCEANOGRAPHIC IMPLICATIONS

This study was initiated primarily to determine the provenance of the glacial deposits on the hinterland, or landward continuation, of the Scotian Shelf. Future petrographic investigations of the Shelf surface sediments should be guided by the following principles.

A. RECOGNITION OF INDIGENOUS MATERIAL

By demonstrating the essentially local derivation of the glacial deposits it makes it possible to predict what elements of the sample belong in situ over the underwater extensions of the granite and meguma terrains.

B. PEBBLE-MAPPING OF ROCK UNITS

From the proven correspondence of till and bedrock lithology on the mainland, it should be possible to map the geological boundaries of rock units yet unknown on the shelf, from pebble analysis of grab samples taken on eroding morainal deposits. Similar drift-mapping of rock formations by boulder type has been used successfully in the deeply till-mantled areas of this province.

Such attempts must take cognizance of two complications:

1) the demonstrated long distance transport of a small proportion of the pebble sizes, and of entire till masses as

drumlins,

2) the addition of foreign material of all sizes to the Shelf surface sediments by ice-rafting from remote coastal sources.

1. INFLUX OF FOREIGN MATERIAL

It has been shown that a small percentage of exotic pebbles has been impressed into the indigenous fraction by the action of ice currents, which appear to have proceeded along fairly straight courses from the northern sources to the present coast. It is therefore possible to account for any North Mountain or Cobequid erratics which may be found in the Shelf sediments along projections of the stronger currents at Lunenburg, Sambro, Owl's Head, and Liscomb.

Some of the red drumlin fields pass offshore. Underwater erosion and reworking of this till type would be inhibited by the clay-rich nature. Therefore, direct corings of this material, or penetration of any winnowed concentrations of the fine fractions, should be easily recognizable by their colour and texture. Detailed bottom configuration should reveal any drumlinoid forms which may be present.

2. THE ICE-RAFTED COMPONENT

The reality and signification of local ice-rafting has been verified by repeated observation of debris-loaded bergs on the Shelf, and by the fact that sand, gravel and boulders comprise about 10 per cent of the volume of the very fine-grained pelitic sediments in the Laurentian Channel*. It is therefore a certainty that sediments in certain portions of the Shelf will have a considerable ice-rafted component. If this factor is not precisely evaluated, it will tend to invalidate any conclusions drawn from pebbles regarding the provenance of coarse shelf deposits of assumed glacial origin.

The area of influence of ice-rafting can be delineated using the presently available maps of ice movements out of the Gulf and southwards away from Newfoundland. Determination of potentially occurring rock species could only be done by actual sampling of shore exposures in the indicated areas.

* This figure is a rough estimate based on preliminary inspection by the author of numerous samples recently taken from Gulf and Shelf areas of the Laurentian Channel.

C. DIMENSIONS OF SAMPLING GRID

The drumlin fields are, in a sense, major variations in, or departures from, the more or less uniform background of local tills. The features have an oval shape, and range in size from a maximum of 25 miles in the Lunenburg field to a minimum of 2 miles in the Lake Charlotte field. Most are about 10 miles in diameter. This means that the spacing of sampling stations on the Shelf can be no greater than 10 miles if any such features are to be revealed.

D. POSSIBLE DISCOVERY OF NEW ROCK FORMATIONS ON THE SHELF.

Honeyman (1878) stated that pebble (and boulder) collection on local beaches 80 miles from the Cobequid Mountains gave a better representation of the Cobequid rock types than could actual sampling in the heavily forested source region, and that the suite of drift pebbles added to the knowledge of the source region because it was a sample of the whole massif, including minor phases yet undiscovered in situ.

This fact can be applied to a study of the bedrock lithology of the Shelf. Many Upper Cretaceous and Tertiary invertebrate-bearing rocks have been dredged from outcrops in the Georges Bank canyons (Stetson; Stephenson; Bassler; Cushman; 1958). Refraction seismic shooting shows that all portions of the New England-Acadian shelf are similar structurally, and that the surface unconsolidated layer ranges in age from Upper Cretaceous to Quaternary (Officer & Ewing, 1954; Press & Beckman, 1954; Drake, Worzel & Beckman, 1954; Bentley and Worzel, 1956). If such formations outcropped on the Shelf and were glaciated, a pebble study of the coarse morainal clastics should verify this.

CHAPTER EIGHT

RECOMMENDED FURTHER STUDIES

While this study has yielded many facts about local till lithology and the evolution of till types in general, it has created as many more problems and raised as many more questions about the stratigraphy of the various formations and members. To resolve these uncertainties other methods of till study allied to pebble lithology must be brought to bear on the key exposures.

Continued Field Observation

First, detailed field observations must be continued on the present exposures of superposed tills, and more such exposures should be sought. Shoreline traverses will be more fruitful than inland search. The intertill contact should be scrutinized for signs of weathering, periglacial phenomena, organic remains, and any other structures which might indicate whether a non-glacial did, in fact, intervene and, if so, whether it was only a minor fluctuation or of interstadial duration.

Textural Properties

The size distributions of the various formations should be investigated first by seiving the 22mm to 50 micron range. The supposed correlations will then be either verified or disproved.

Using mechanical analyses Shepps (1953) was able to differentiate Tazwell, Early and Late Cary tills; and Zumberge (1960) demonstrated how younger tills were blended from older tills; and Dreimanis and Reavely (1953) used such techniques as an aid in distinguishing the lower and upper till north of Lake Erie.

Sand Petrography

Of the total lithology the pebble fraction can yield only so much information. Petrography of the sand fraction affords complementary and additional indications of genetic relationships (Anderson, 1957; Potter, 1955). Of the sand fraction the heavy mineral concentrate should be the most intensively studied, especially, since in this area, directional indicator mineral species such as augite are present. Kruger (1937) has shown that most heavies are chemically resistant to weathering so that they can be used to advantage even in the older tills. As proof, Dreimanis (1960) investigated the ratio of red to purple garnets in pre-classical-Wisconsin tills and was able to show that the 'early' Wisconsin ice centre was far to the east of that which obtained for classical Wisconsin advances.

Carbonate Content

For additional indications of provenance and possible correlations, it would be advisable to try some carbonate determinations, since calcareous rocks (the Carboniferous Windsor Group) abound in certain sectors of the hinterland.

The success of this approach has earned it recommendations from Dreimanis and Reavely (1953).

Additional Pebble Counts

For obvious reasons it is suggested that the pebble method be repeated with more intensity on the key horizons, as well as extended to new areas. Naturally it would be wisest to build outward from the present study area as a basis; specifically, eastward to Canso, and into Cape Breton where the outlying red drumlins and the question of a plateau ice cap could be tackled. Additionally, this expanded data field would complete the coverage for that part of the Scotian Shelf presently being studied by A.E. Cok of the Dalhousie Institute of Oceanography.

Till pebble study could also be extended in the other direction to the interior of southwestern Nova Scotia where Nolan (1963) found anomalous augite concentrations.

Chronology

Once the various sections have been fitted to a stratigraphic system, the absolute chronology will follow by using a chain of correlations from the radiocarbon-dated sections, such as Dutch Settlement.

Zumberge (1960) recommends that a geological calendar of Pleistocene events, in any area, be based on the activity of a single ice lobe (the "type-lobe concept") to which the activity of neighboring lobes is related stratigraphically.

Application of radiocarbon dates to the type lobes creates an absolute chronology of the whole regional assemblage of glacial formations. The type lobe can be located on aerial photos from ice-marginal geomorphic forms, and by graphic analysis of drift topography (Ruhe, 1950, 1952). Knowledge of lobes will render the pre-determined lithological parameters more meaningful in terms of till provenance, mixing, dissipation, etc.

Provenance and Ice Movements

Essential in understanding the provenance is a thorough knowledge of the potential till ingredients. The necessary reference collection can only be accumulated by actual sampling at the sources. With such material, ice movements can then be deduced more accurately, and substantiated by till fabric study (Dreimanis and Reavely, 1953). This latter technique should be applied particularly to the drumlins to see if they really are the product of a single advance, and also to the underlying compact till to see if it actually was laid down by southwestward-moving ice.

ALLIED PROJECTS

Soil Mechanics

From an engineering standpoint, it would be extremely valuable to know something of the physical and chemical make-up of the local tills in order to predict or prevent the recurrence of the recent disastrous slumping induced by saturation of this "hydroscopic"material.

Drumlins

The origin of the drumlin till is still a most pressing and intriguing question. Comparison of properties should be made with allied red tills, recent Fundy sediments, and the widespread Pleistocene layer of red pelite in the Gulf of St. Lawrence (Dr. W.M. Ewing, personal oral communication), of which samples have been generously donated to Dalhousie by the Lamont Geological Observatory.

For purely academic reasons, it would be interesting to investigate the three phases of the Wolfville till in Lunenburg County, namely the clayey drumlins, the sandy drumlins, and the stony till sheet. Their apparent stratigraphic sequence, and their relation to the underlying slate till sheet could be verified by the several lithologic approaches.

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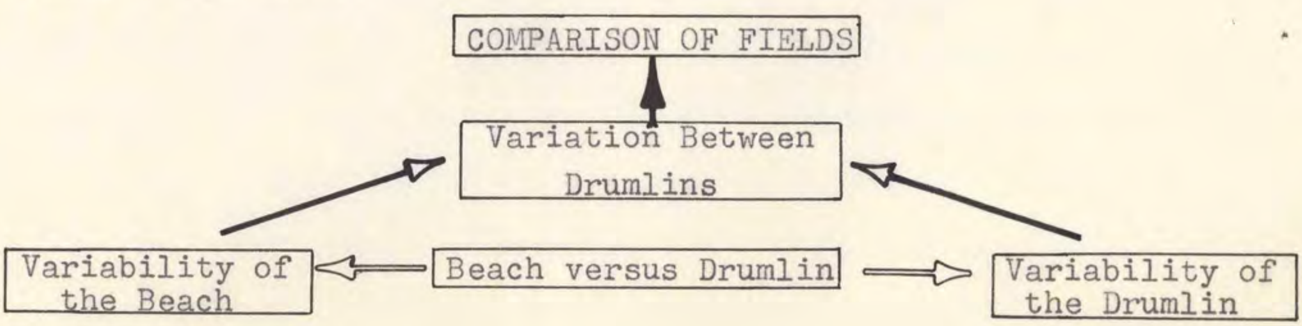
STUDIES OF LITHOLOGIC VARIATION

FOREWORD

Most of the conclusions drawn above are based on the positions of plotted points on triangular diagrams. This presupposes that a plotted point has a fixed position. In actual fact, however, the position is not fixed, but may occur anywhere within a certain small triangular area, the size of which is dependent on the granular variation or degree of non-homogeneity of the mixture of components. To get some measure of the variability of drumlin fields, it requires that the variations between adjacent drumlins be evaluated. But before it is possible to compare the drumlins, the variability of a single individual must be known and since many drumlins were sampled indirectly by means of their derived beaches, it is therefore necessary to determine first the inherent variability of a beach sample, and then to establish the relationship of beach lithology and drumlin lithology.

The schematic diagram below shows how the second-order comparison of fields must be based on a rigid framework of independent analyses whose mutual relations are fixed by first-order comparisons.



APPENDIX I

LITHOLOGIC VARIATION WITHIN A SINGLE DRUMLIN

These examples, drawn from drumlins in Harrietsfield and Hartlen Point respectively, are typical of most of the drumlins in the area.

	#57	#58	#17	#20
Local	78.0%	78.3%	57.1%	54.7%
Minas	17.9 - 21.4	9.4 - 20.7	24.5-41.9	31.9-45.0
Cobequid	3.5	11.3	16.4	11.1
N. Mountain	0.6	0.8	1.0	2.0

There is an excellent correlation in the basalt and local elements, presumably because of their competence and recognizability. The inherent variations in the Minas component is due to its susceptibility to mechanical crushing, and in the Cobequid component to the great diversity of the species, the darker ones of which may sometimes be confused with the local greywacke. In general, however, the ratio of 'local' to 'foreign' elements is fairly constant for one drumlin.

APPENDIX II

LITHOLOGIC VARIATION ON A SINGLE BEACH

Hartlen Point:

	#18	#19	#21	Average
Local	80.9%	83.1%	81.7%	81.9
Minas	7.4	8.5	10.0	8.6
Cobequid	10.7	7.4	8.6	8.9
N. Mtn.	0.2	0.3	1.3	0.9

Petpeswick Head:

A2	2.0%	... 1.5%
A6	10.3	... 9.9
A9	3.5	... 5.2
B1	42.3	... 37.5
D2	3.9	... 4.4
D3	2.6	... 1.7
F	0.3	... 0.4
G	0.0	... 0.0
I	0.3	... 0.0
J.	35.1	... 41.7

On the same beach the lithology is fairly constant. This may be attributed to the method of sampling. The technique was 'composite grab sampling', at many points along the beach between high and low water. The minor components would be expected to vary inherently because of their small proportions. The Minas lithologies vary because of their susceptibility to destruction.

APPENDIX III

COMPARISON OF BEACH WITH PARENT DRUMLIN

Petpeswick Head:	Beach			Drumlin
	(Avg. of #43 & #44)			(#42)
	A2	1.7%	....	14.6 x
	A6	10.1	....	4.4 x
	A9	4.3	....	1.8 x
	B1	39.9	....	45.5 x
	D2	4.1	....	8.6 x
	D3	2.1	....	8.2 x
	F	0.3	....	0.0
	G	0.0	....	0.0
	I	0.1	....	0.0
	J	38.4	....	10.4 x

On the beach the coarse brittle local granite has been somewhat destroyed, and the Minas sandstones, D2 and D3, have decimated to one-third their abundance in the parent drumlin. This has the effect of bolstering the proportions of the stable components, such as the Cobequid group, which is tripled.

These relations can be applied to the Hartlen Point beach-drumlin system. There the beach is derived from two tills of equal thickness, the lower quartzitic and the upper red drumlin. If these are mixed in equal proportions on the beach the sandstone destroyed to one-third, the granite to one-tenth, and the remaining strong types augmented proportionately thus:

	Upper Till #20		Theoretical Upper Till Beach
Local	54.7 + 17.8 + 1.5	....	74.0
Minas	31.9 - 21.3	....	10.6
Cobequid	11.1 + 3.5 + 0.3	....	14.9
N. Mtn.	2.0 - 1.8	....	0.2

	Lower Till #27		Theoretical Lower Till Beach
Local	93.9 + 0.7	....	94.6
Minas	1.0 - 0.7	....	0.3
Cobequid	5.0	....	5.0
N. Mtn.			

Theoretical Beach Lithology Derived From Equal Proportions of Upper and Lower Till Beaches:

Local	84.3
Minas	5.4
Cobequid	9.9
N. Mtn.	0.1

Actual Beach Lithology:

Local	81.9
Minas	8.6
Cobequid	8.9
N. Mtn.	0.9

The correlation of the calculated beach lithology with the actual beach lithology strongly indicates the validity of the indicated laws of differential destruction bj rock species. If necessary, then, a beach pebble count can be onverted to its equivalent in terms of the parent drumlin litiology.

APPENDIX IV

VARIATIONS BETWEEN ADJACENT DRUMLINS IN A GROUP

Appendix I has shown that the maximum variation of any component is about 6 per cent. If the plotted point represents the actual analysis, then it may be taken as the centre of a tiny field containing all the variations; and this field is then assumed to have a radius (on the triangular diagram) of 3 per cent.

If all the points are then drawn as the centres of circles having this radius, then the line enclosing all the analyses of drumlins in a group will encircle them with an ample margin. The fields on the triangular diagram representing the group of drumlins only overlap one another in these marginal belts; there is no overlap if the field is drawn tightly enclosing the plotted points (Figure 11).

The variations between drumlins does not seem inordinately large. The larger the drumlin field the larger is the field of plotted points representing that group. This is expectable since the larger fields will have more chance of overlapping more different till types which, by dilution of the red proto-till, will tend to disperse the plotted points.

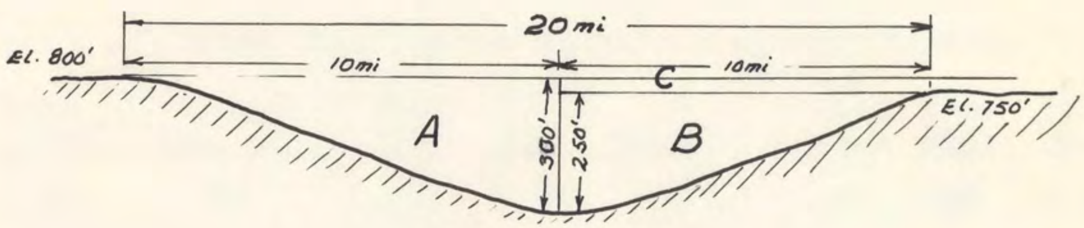
APPENDIX V

QUANTITATIVE COMPARISON OF ERODED VS DEPOSITED NORTH MOUNTAIN MATERIAL

The purpose of this diversion was to compare the volume of the transverse depression or valley on the North Mountain between Harbourville and Port George (which seems to have been eroded by the action of the Lunenburg ice current) with the volume of North Mountain material in the till downstream from the valley (along the course of the current).

A. Volume of Rock Removed

Area of Cross-section:



Area of A = $\frac{1}{2}$.b.h.

= $\frac{1}{2}$. (0.0568mi.) . (10mi.)

= 0.284 sq. miles.

Area of B = $\frac{1}{2}$.b.h.

= $\frac{1}{2}$. (0.0475mi.) . (10mi.)

= 0.238 sq. miles.

Area of C = (0.01mi.) . (10mi.)

= 0.100 sq. miles

Area of Cross-section = A + B + C = 0.622 sq. mi.

The north-south length of the valley is 4 miles, and the depth decreases to zero on the Fundy shore.

Therefore the volume of the valley is:

$(0.622 \text{ sq. mi.}) \cdot (4.0\text{mi.})\frac{1}{2}$

= 1.244 cubic miles

B. Volume of the Material Downstream from the Valley

1. Pebbles

(a) Lunenburg County

Using the planimetered areas of the various tills (Wld; Wolfville Loam Drumlins, Wsd; Wolfville Sandy Drumlins, and W; Wolfville Stony Loam) given in Cann & Hilchey (1958)

Till	Area (acres)	Area (sq. mi.)	Depth (50')	Vol.	% Gravel	Vol. Gravel	% N. Mtn.	Vol. N. Mtn.
Wld	45,800	72	0.01mi.	0.72	67%	0.48	16%	0.08 cu.mi.
Wsd	13,000	20	0.01mi.	0.20	89%	0.18	10%	0.02 cu.mi.
W	107,000	167	0.01mi.	1.67	92%	1.53	2.5	0.04 cu.mi.

Total Volume of Pebbles = 0.14 cu.mi.

(b) Kings County

From the Lunenburg County line to the North

Mountain the till present is Wolfville Sandy Loam (Wsd), covering an area 12 miles wide, 24 miles long (J.D. Hilchey, personal communication).

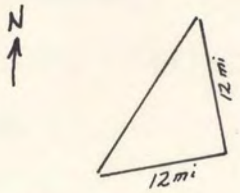
Area of Till = 12 miles x 24 miles
= 288 sq. miles

Volume = 288 sq. miles x 0.01 mi. thick
= 2.88 cu. miles

Vol. Till	% Gravel	Vol Gravel	% N. Mtn.	Vol.N. Mtn.
2.88	89	2.56 cu.mi.	10	0.256 cu.mi.

(c) In Mahone Bay among Drumlin Islands of Wolfville Loam (Wld)

Shape of Area:



Area = $\frac{1}{2}$ (12) . (12)
= 72 sq. mi.

Volume = 72 sq. mi. (0.01mi.)
= .72 cu. mi.

Vol. Till	% Gravel	Vol. Gravel	% N. Mtn.	Vol.N. Mtn.
0.72	67	0.48	16	0.08 cu.mi.

Total Volume of North Mountain Pebbles in the till between the valley and the South Shore is therefore: 0.476 cubic miles

2. Sand

By extrapolations from Nolan's (1963) data, the amount of augite in the sand derived from Wolfville Loam Drumlins (Wld) was 0.80%, and from the Slate Till (Bridgewater Loam), 0.15%.

Till	% Aug.	% Sand & Silt	% Aug. of till	Vol.Till Lun.	Kings	Mah.B.	Vol.Aug.
Bw	0.15	60	0.09	0.67	0.96	0.001	0.002
Wld	0.80	66	0.53	0.72			
Wsd	(0.80)	68	0.53	0.20	0.29	0.12	0.016
W	(0.80)	68	0.53	1.67			———

Total Volume Augite = 0.018 cu.miles

If augite makes up approximately 30% of the volume of the basalt (Klein, 1957) then this represents a volume of basalt of 0.054 cu.mi.

This may appear a small amount compared to that for the pebble fraction, but inasmuch as glacial erosion is chiefly by plucking of boulder and pebbles sizes which are then reduced directly to dust by grinding, the small amount of sand produced by subordinate crushing is not surprising.

Conclusions:

The total amount of pebble-, sand- and silt-sized basalt accounted for in the tills south of the valley is 0.530 cubic miles, compared to the 1.244 cubic miles of the valley. The comparability of the results based upon real figures and reasonable assumptions tends to support the thesis that the Lunenburg drumlin field ice current was in fact responsible for the erosion of the valley between Harbourville and Port George.

Although the two figures are of the same order of magnitude, less than half the eroded volume can be accounted for. This is due to at least two reasons:

(1) Inability to include the clay fraction. A large amount of basalt is probably present here, since the plucked pebbles pass directly into the dust or clay sizes by attrition during transport.

(2) Most of the balance is thought to have been transported off mainland Nova Scotia onto the Shelf. The 'strength' of the drumlin field at Lunenburg suggests it continues in force some distance onto the Shelf. If this is true the augite tracer should show up in a heavy mineral analysis of J.M. Pezzetta's (1962) samples.

From the foregoing it might be inferred that the red Wolfville SANDY Loam is a hybrid till with sandstone (Triassic Wolfville Formation?) affiliations.

PLATE 39

Compositional sorting of beach material at foot of Wolfville drumlin east of Petpeswick Head.

PLATE 40

Detail; of sorting; white granite in cobble size, light grey quartzite in coarse pebble size, dark grey Cobequid erratics in fine pebble size.

PLATE 41

Lineation of bogs (dark grey) and lakes (white) south of Lake Rossignol. Port Mouton in extreme lower right.

APPENDIX VI

RECOMMENDATION FOR FUTURE WORK

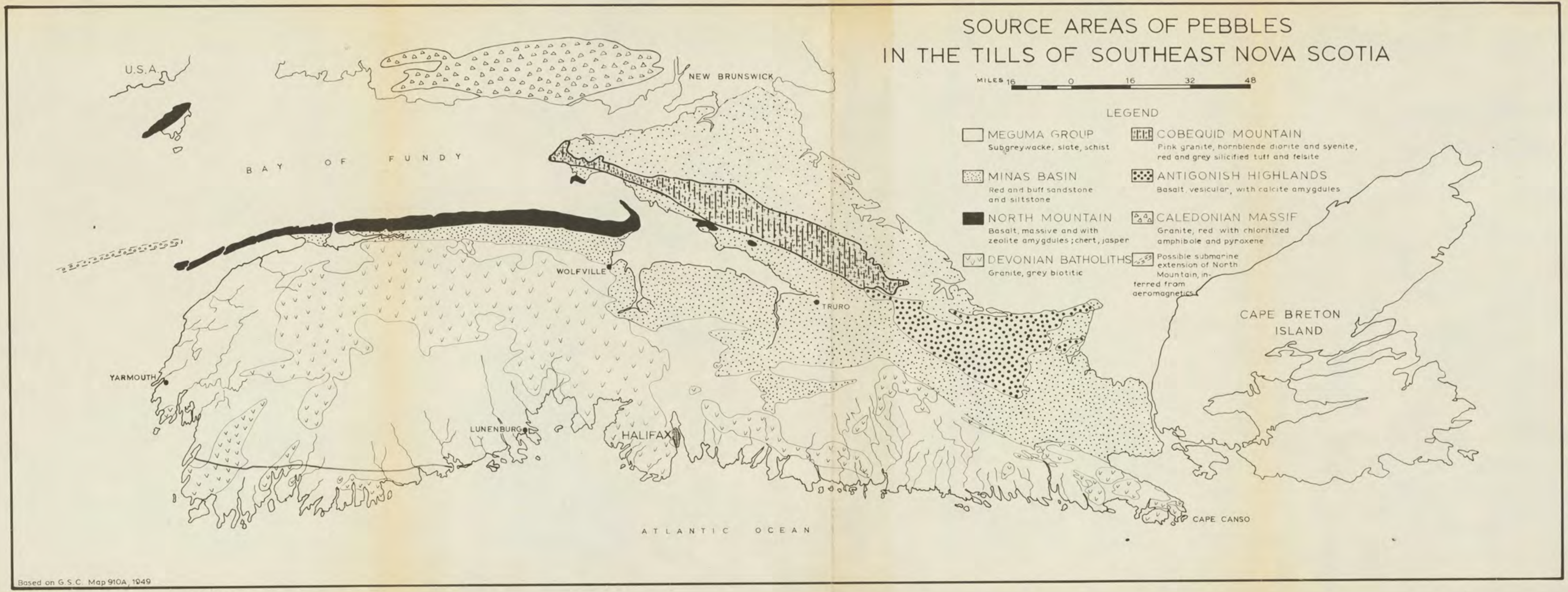
The several hundred man hours spent merely preparing the material for analysis could have been more profitably utilized. With this in mind, one strongly-recommended improvement in technique for future investigators would be a portable, engine-driven washing mill which could be set up in a stream while the samples are being collected. This would save: 1) the scientist 2) time 3) water bills 4) cleaning clogged sediment traps and drain pipes 5) lugging sand and granules back to the field.

APPENDIX: 7 CORRELATION OF SCHEMES OF SUBDIVISION OF THE QUATERNARY

(From: Gromov et al, 1960, Int. Geol. Cong.
Rpt. 21st Session, Part 4, pp. 23-24.
(Dates from Prest, 1957 & Flint, 1963))

NORTH AMERICA	ALPS	NORTHERN PART WESTERN EUROPE - Germany, Poland and N. France.
Cochrane - 7,500		
Timiskaming Interval - 10,000		
Valders - 11,200	One of the stages in the mountains	Salpusselka Stage (Younger Dryas)
Two Creeks, 11,400		Allerød
Mankato - 13,600	Würm 3	Langeland Stage (Older Dryas)
(Lake Arkona) - 15,000	Interstadial	Interstadial (Bolling)
Cary - 16,000		
Tazewell - 19,500		Pomeranian Stage
	Würm 2	Interstadial
Iowan 20,000-21,000		Brandenburg Stage
Peorian Interstadial	Interstadial	Rixdorf Interstadial
Glaciation?	Würm 1	Stettin Stage before advance of main glacier
Sangamon	Riss - Wurm	EEmian Transgression

NORTH AMERICA	ALPS	NORTHERN PART WESTERN EUROPE - Germany, Poland and N. France.
	Riss 2	Warthe (Saale 2) Stage
Illinoian	Interstadial	Interstadial
	Riss 1	Drenthe (Saale 1) Stage
Yarmouth Inter-glacial	Interstadial Glütsch Glaciation Interstadial Kanderian Glaciation Interstadial	Mazovian 1
	Mindel 2	
Kansan Glaciation	Interstadial	Elster Glaciation
	Mindel 1	
Aftonian Inter-glacial	Günz - Mindel Interglacial	Cromerian Warm Era
	Günz 2	
	Interstadial	
Nebraskan Glaciation	Günz 1	Weybournian Cold Era
	Donau Stages	Tegelen Warm Era
	Oldest Phases	Brachtian Cold Era


SOURCE AREAS OF PEBBLES
IN THE TILLS OF SOUTHEAST NOVA SCOTIA
MILES 16 0 16 32 48
LEGEND
MEGUMA GROUP
Subgreywacke, slate, schist
MINAS BASIN
Red and buff sandstone and siltstone
NORTH MOUNTAIN
Basalt, massive and with zeolite amygdules; chert, jasper
DEVONIAN BATHOLITHS
Granite, grey biotitic
COBEQUID MOUNTAIN
Pink granite, hornblende diorite and syenite, red and grey silicified tuff and felsite
ANTIGONISH HIGHLANDS
Basalt, vesicular, with calcite amygdules
CALEDONIAN MASSIF
Granite, red with chloritized amphibole and pyroxene
Possible submarine extension of North Mountain, inferred from aeromagnetics
U.S.A.
NEW BRUNSWICK
BAY OF FUNDY
WOLFVILLE
TRURO
YARMOUTH
LUNENBURG
HALIFAX
CAPE BRETON ISLAND
CAPE CANSO
ATLANTIC OCEAN
Based on G.S.C. Map 910A, 1949

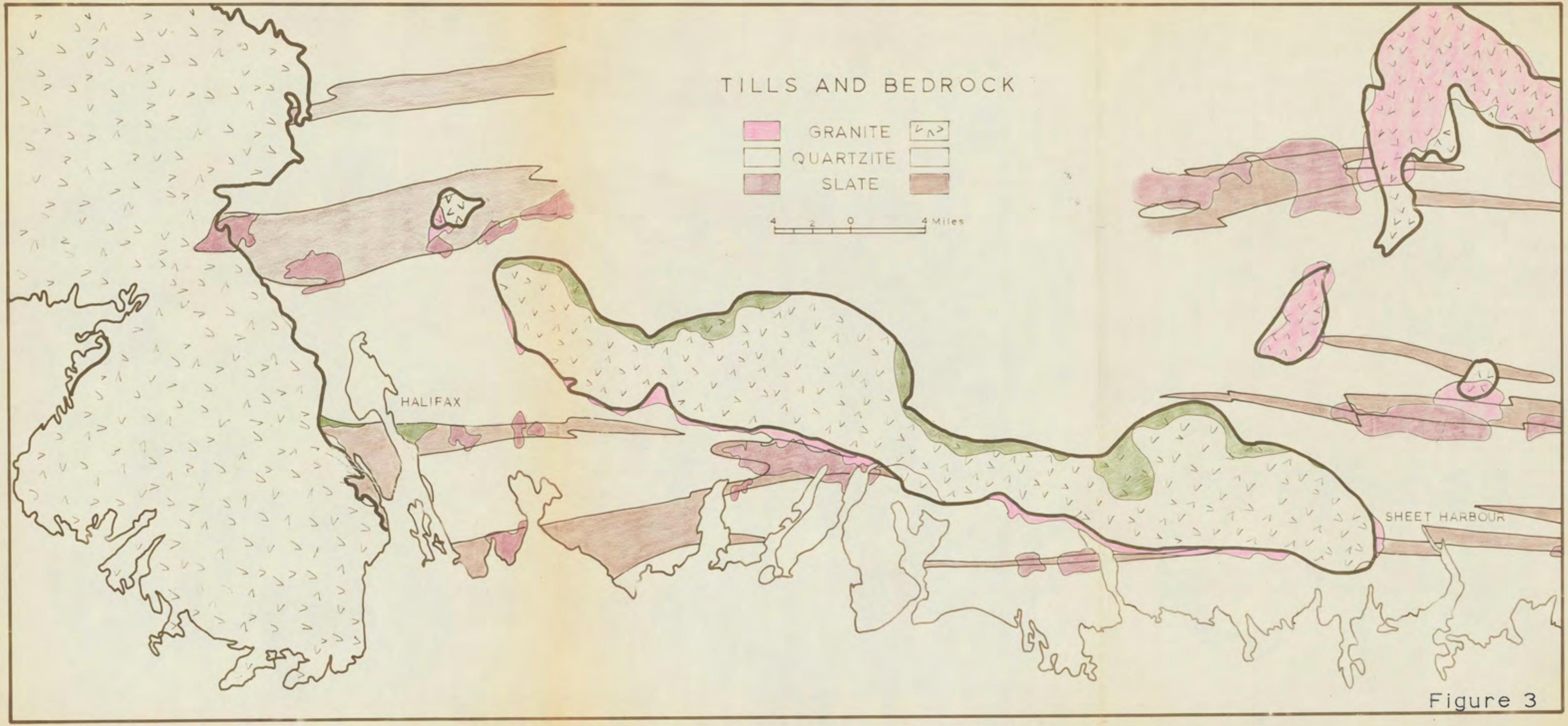
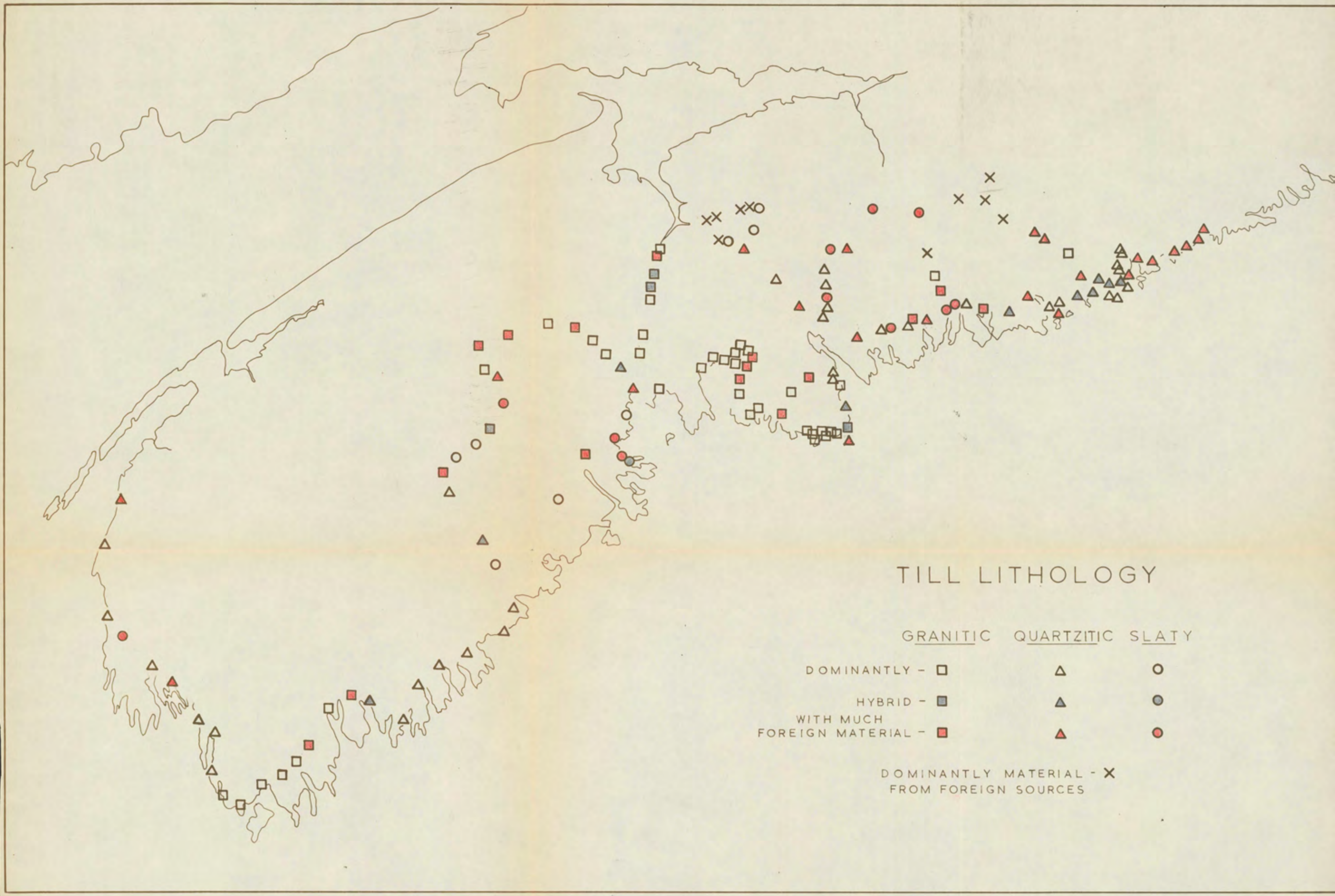
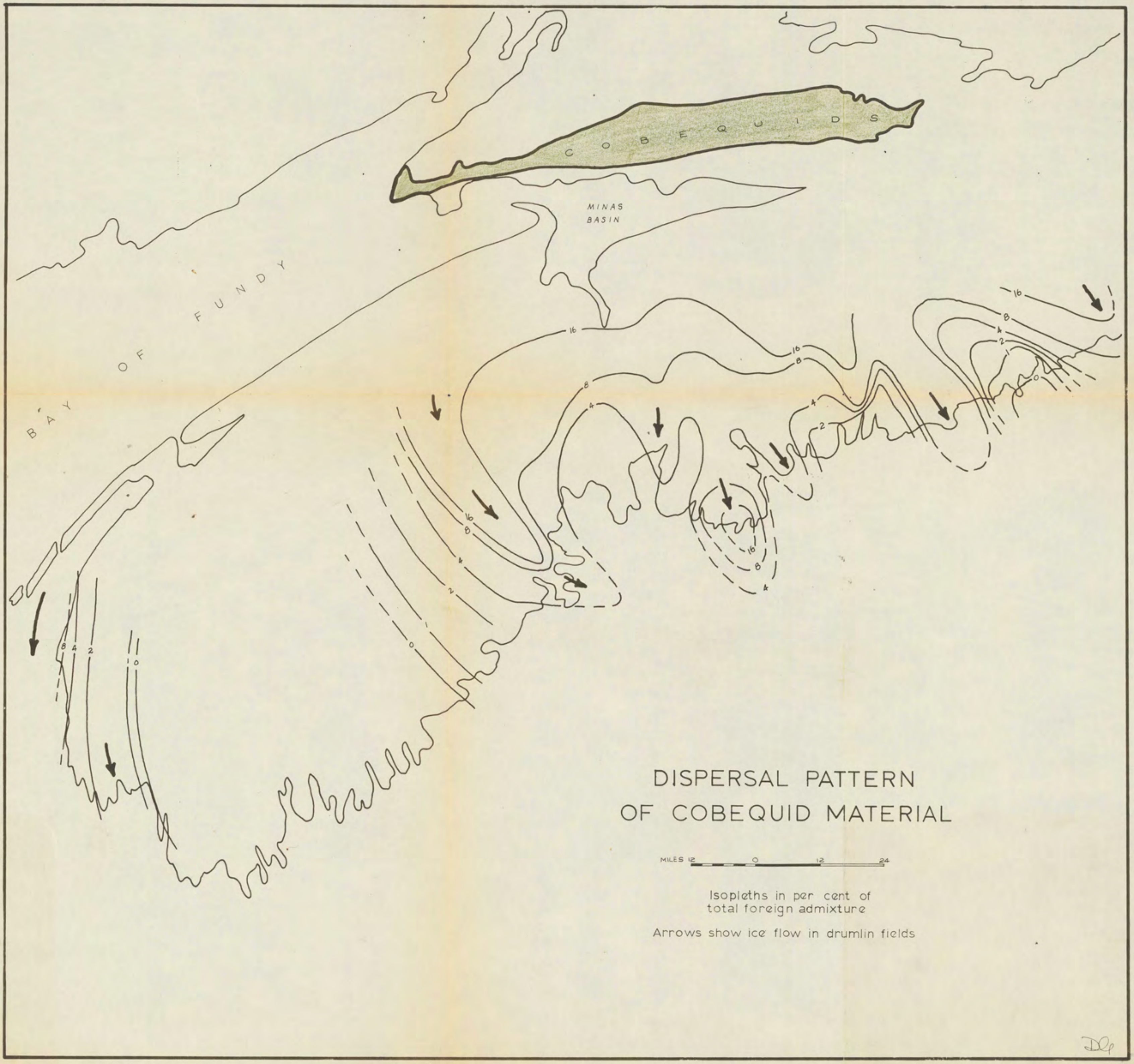

TILLS AND BEDROCK
GRANITE
QUARTZITE
SLATE
4 2 0 4 Miles
HALIFAX
SHEET HARBOUR

Figure 3

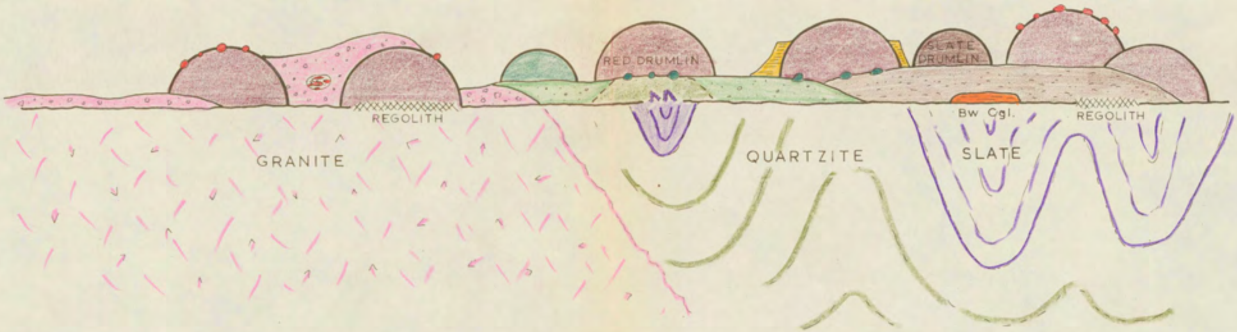
Figure 8


TILL LITHOLOGY
GRANITIC QUARTZITIC SLATY
DOMINANTLY -
HYBRID -
WITH MUCH
FOREIGN MATERIAL -
DOMINANTLY MATERIAL -
FROM FOREIGN SOURCES

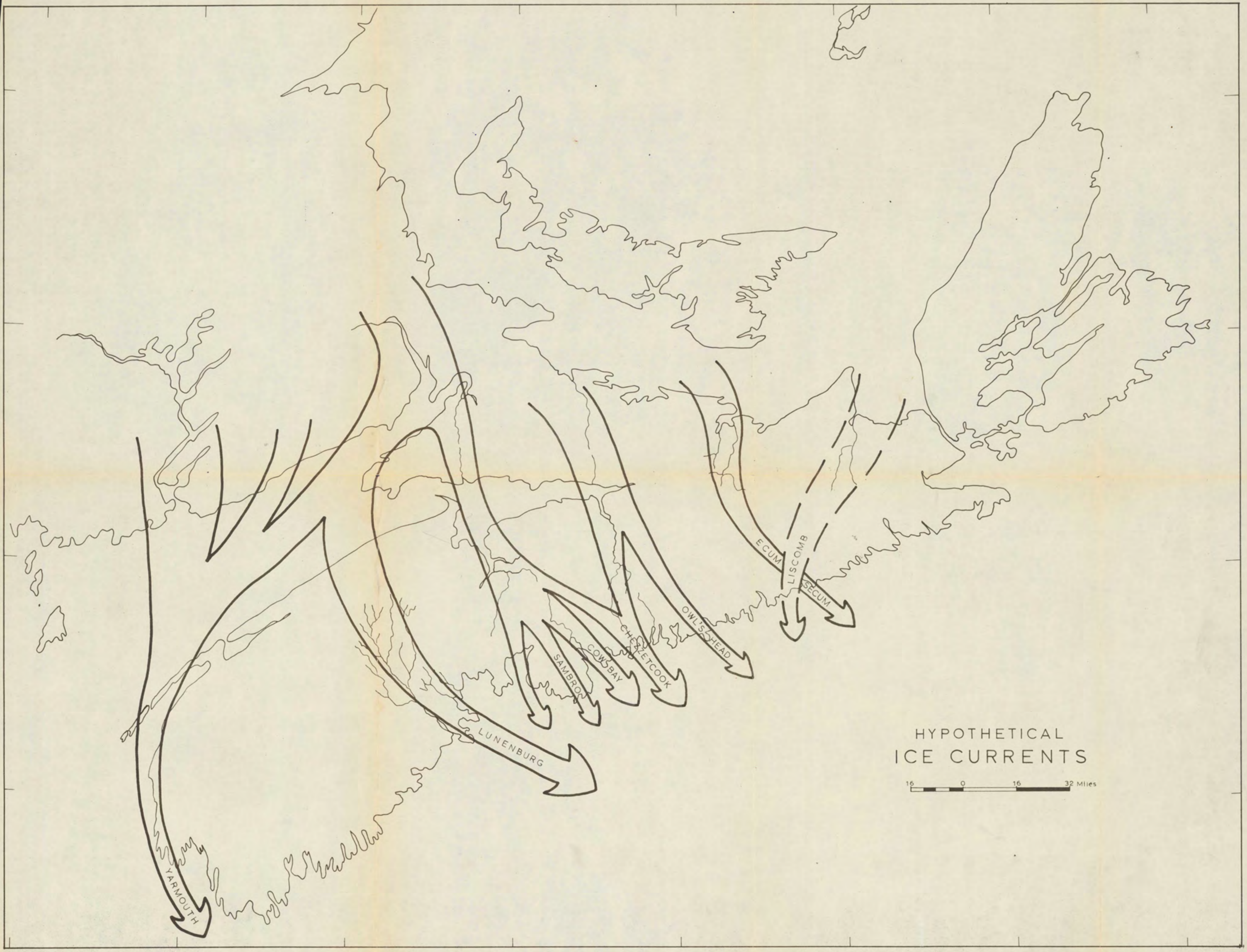

COBEQUIDS
MINAS BASIN
BAY OF FUNDY
16
8
4
2
0
DISPERSAL PATTERN
OF COBEQUID MATERIAL
MILES 12 0 12 24
Isopleths in per cent of
total foreign admixture
Arrows show ice flow in drumlin fields

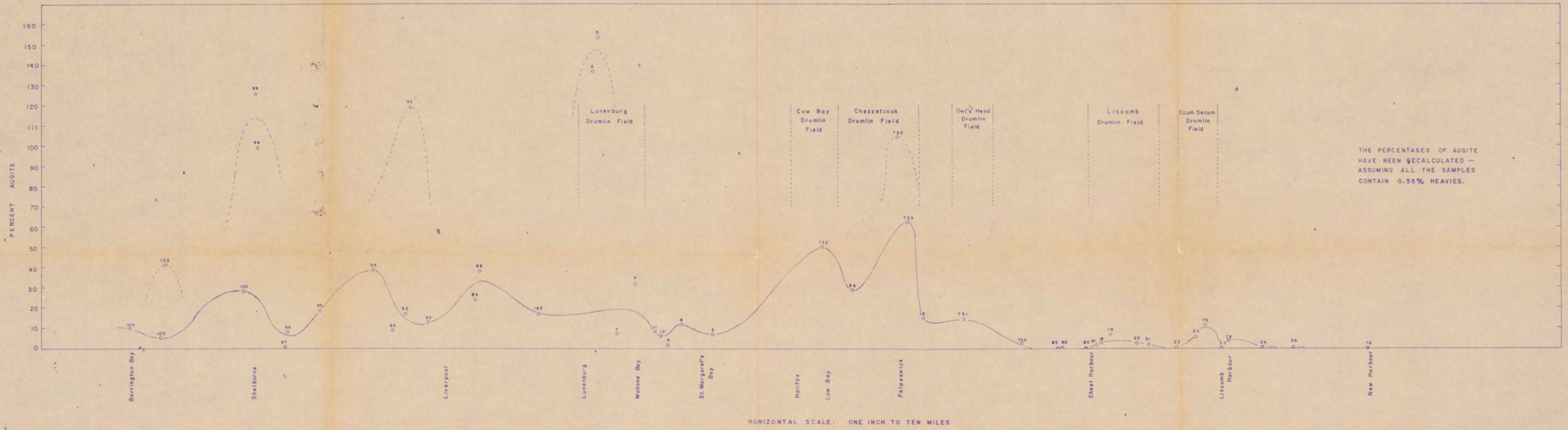

DRUMLIN FIELDS
4 0 4 8 12 MILES
DRUMLINS - WOLFVILLE RED TILL
DRUMLINOID RED TILL SHEET
GEOCHEMICAL ANOMALIES
LUNENBURG
SAMBRO
COW BAY
CHEZZETCOOK
LAKE CHARLOTTE
OWL'S HEAD
MOOSE RIVER
GOVERNOR'S LAKE
LISCOMB
ECUM SECUM
INDIAN RIVER
CANSO
IN PART FROM GOVERNMENT SURVEYS

SCHEMATIC CROSS-SECTION OF GLACIAL FORMATIONS



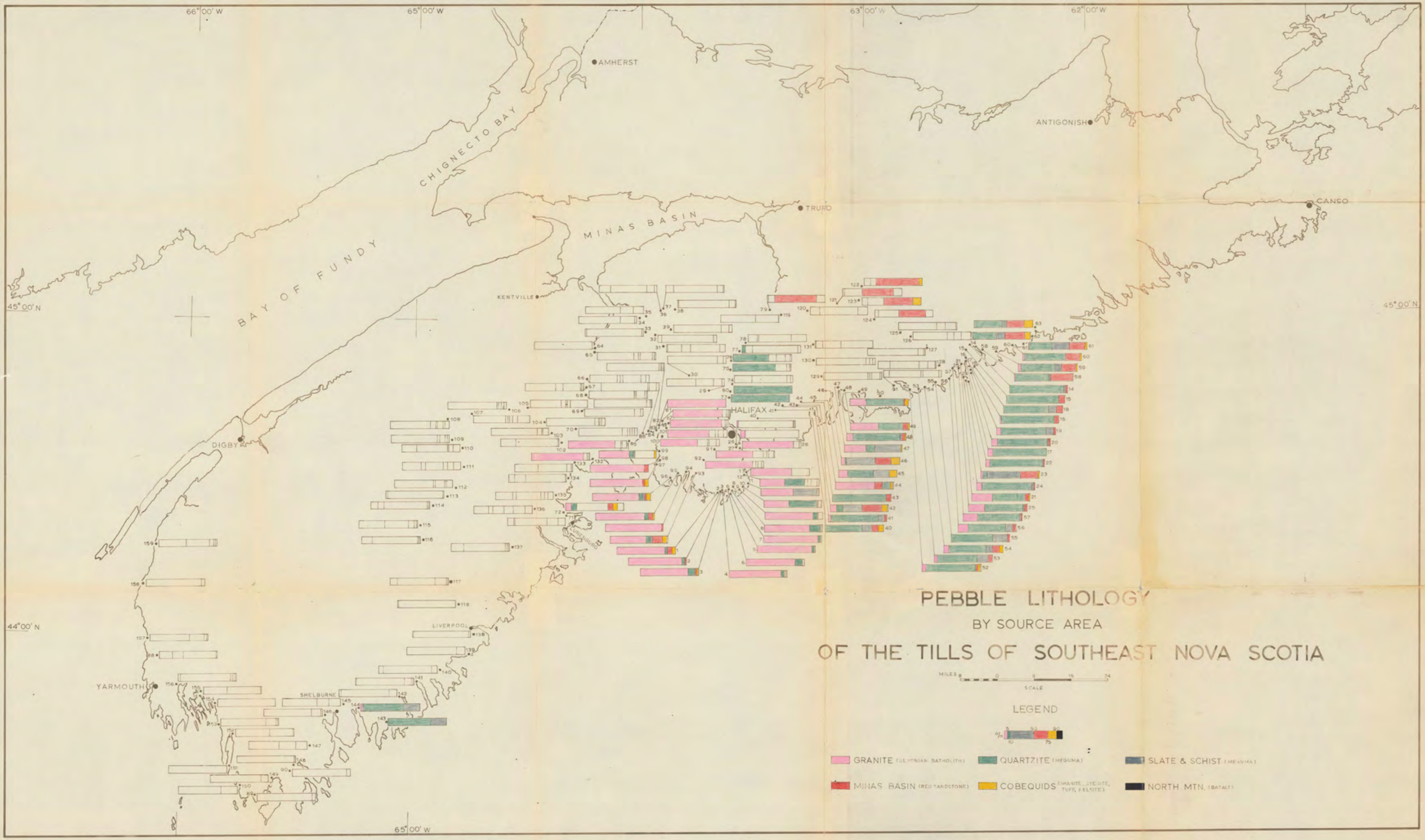

DRUMLIN FIELDS
AND
FOREIGN PEBBLE LOBES
12 0 12 24 Miles


HYPOTHETICAL
ICE CURRENTS
16 0 16 32 Miles
YARMOUTH
LUNENBURG
SAMBRO
COW BAY
CHEZZETCOOK
OWL'S HEAD
ECUM
LISCOMB
SECUM



HYPOTHETICAL UNDILUTED AUGITE CONTENT OF BEACH SANDS

F.J.N.



PEBBLE LITHOLOGY
BY SOURCE AREA
OF THE TILLS OF SOUTHEAST NOVA SCOTIA
MILES 8 0 8 16 24
SCALE
LEGEND
GRANITE (DEVONIAN BATHOLITH)
QUARTZITE (MEGUMA)
SLATE & SCHIST (MEGUMA)
MINAS BASIN (RED SANDSTONE)
COBEQUIDS (GRANITE, SYENITE, TUFF, FELSITE)
NORTH MTN. (BASALT)
66° 00' W
65° 00' W
63° 00' W
62° 00' W
45° 00' N
44° 00' N
AMHERST
ANTIGONISH
CANSO
TRURO
KENTVILLE
CHIGNECTO BAY
MINAS BASIN
BAY OF FUNDY
DIGBY
HALIFAX
LIVERPOOL
SHELBURNE
YARMOUTH

TABLE 7: CORRELATION CHART
Pleistocene Formations:
Nova Scotia - New England

LOCALITY / EVENT	JOGGINS (Wickenden, 1941)	BRIDGEWATER (Frost, 1896)	EAGLE'S NEST COLCH.CO. (Hughes, 1957)	MILFORD STATION (Hughes, 1957)	DUTCH SETTLEMENT (Hughes, 1957)
LATE PLEISTOCENE STRATIFIED DEPOSITS		Stratified drift and erosion			
DEPOSITION OF MANTLE TILL	15 feet yellow till (limestone w. igneous rocks)	local till			
NON-GLACIAL INTERVAL		erosion			
TILL SHEET? / RED DRUMLINS (AND TILL SHEET?)	12 feet Grey-brown till (much foreign material)	"Dark northern boulder clay" (red drumlin till)	42 feet Red sandy till (30° slope)	7.5 feet Till with much foreign material	
INTERSTADIAL (BRADYAN INTERVAL)	15 inches laminated silt and clay	Stratified local material	15 inches clay	4 feet Faintly laminated clay	
COMPACT TILL	38 feet Red-brown till (limestone with igneous rocks)		24 feet Compact, clay-rich stony, locally-derived till (60° slope)	4 feet Very slaty till	40 feet Compact slate-rich till (>18,000 yr.B.P.)
BASAL REGOLITH		Partly cemented slaty debris			
EARLY WISCONSIN GLACIATION / BRIDGEWATER CONGLOMERATE		Bridgewater conglomerate			
BEDROCK	Sandstone	Slate	Sandstone	Red Calcareous Shale	

(2)

(3)

LOCALITY / EVENT	BAYSIDE	HARRIETSFIELD	HALIFAX	SANDWICH POINT (PERSONAL)	HARTLEN POINT (OBSERVATION)	COW HARBOUR	ECUM SECUM	CAPELIN COVE
LATE PLEISTOCENE STRATIFIED DEPOSITS			Outwash		(Outwash nearby)	(Outwash nearby)		
DEPOSITION OF MANTLE TILL	Local granite till w. inclusions of red clay till and laminated clay	local granite-till	local quartzite till	local granite till with quartzite phase			local quartzite till	local till
NON-GLACIAL INTERVAL	(laminated clay)	Varved red sand and silt	------0------ (boulder horizon)	Stony red clay				?
TILL SHEET? / RED DRUMLINS (AND TILL SHEET?)	(red clay till)	Red drumlin	Red Drumlin	(Red drumlin nearby)	Red drumlin	Red drumlin	Red drumlin	Red drumlin
INTERSTADIAL (BRADYAN INTERVAL)				------0------	------0------	------0------		?
COMPACT TILL			(quartzite till)	Quartzite till	Compact quartzite till	Compact quartzite till		local granite till
BASAL REGOLITH			(slate regolith nearby at York Redoubt)	Consolidated weathered granite debris	Schuppen of phyllite fragments			
EARLY WISCONSIN GLACIATION / BRIDGEWATER CONGLOMERATE			Bridgewater Conglomerate					
BEDROCK	Granite	Granite	Slate and Quartzite	granite	Phyllite	Slate	Quartzite	Granite

(4)

(5)

(6)

LOCALITY / EVENT	GILLIS LAKE RICH. CO. (Livingstone & Livingstone, 1958)	PORT HOOD C.B.	CARIBOU BOG (Hickox, 1962a)		ST. JOHN N.B. (Flint, 1953)	MAINE	BOSTON	
LATE PLEISTOCENE STRATIFIED DEPOSITS			Sediments - - - - - - Outwash				Marine silt and tidal marsh peat	
DEPOSITION OF MANTLE TILL		till from local ice cap on Cape Breton	till from ice cap flowing northward off South Mountain	PORT HURON	Till		Loose, sandy younger till	
NON-GLACIAL INTERVAL	Lake sediments dated as 10,160 ± 160 yr.B.P.	Sediments with logs dated as 10,710 ± 240 yr.B.P.		LAKE ARKONA PHASE	Stratified drift	Marine sediments with marine fauna as below	Marine clay derived from underlying hill	
TILL SHEET? / RED DRUMLINS (AND TILL SHEET?)	Red drumlin	local till	(Red drumlin till)	PORT STANLEY	Till, with marine invertebrates	Till	Clay-rich till - (forming drumlins)	
INTERSTADIAL (BRADYAN INTERVAL)				BRADYAN INTERVAL	Laminated clay with shells and ice-rafted boulders	Marine sediments with boreal invertebrates		
COMPACT TILL				TAZEWELL	Till	Till		
BASAL REGOLITH								
EARLY WISCONSIN GLACIATION / BRIDGEWATER CONGLOMERATE				'EARLY WISCONSIN' PRE-WISCONSIN				
BEDROCK			Sandstone	Pre-Pleistocene				