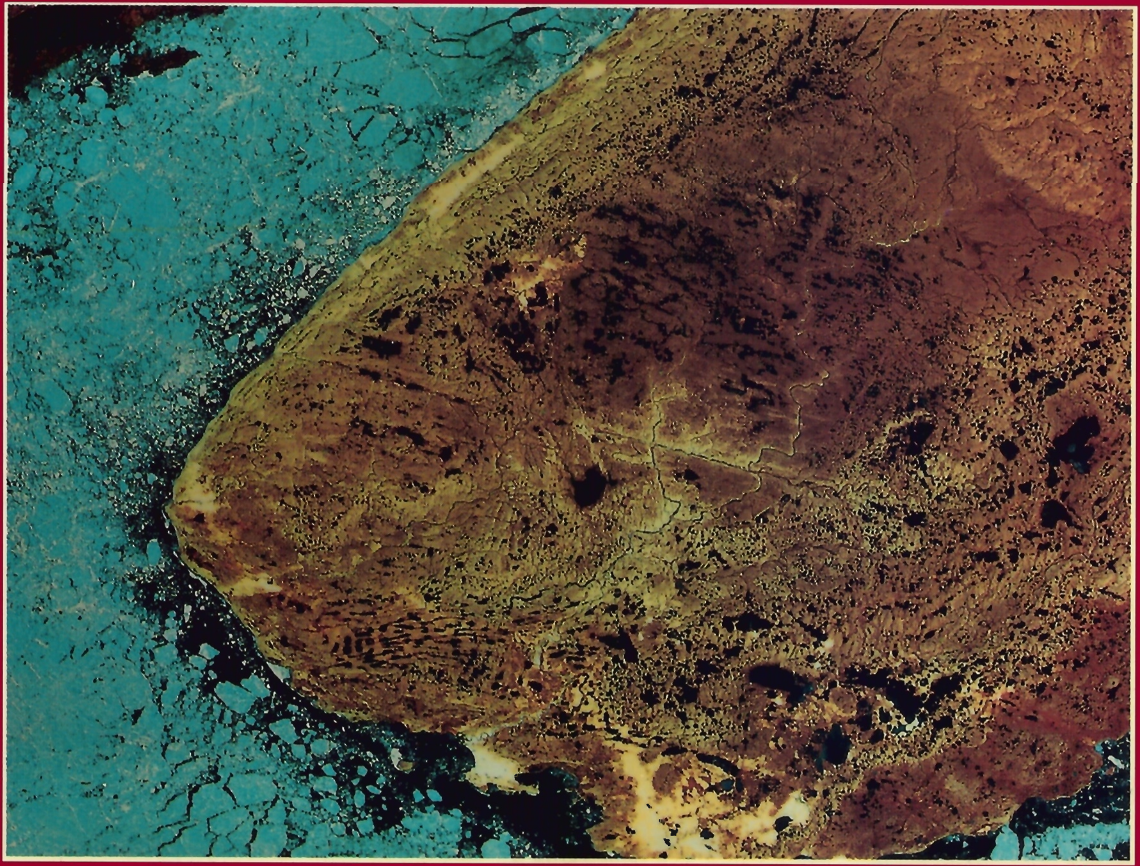
CANADA 1842 GEOLOGICAL SURVEY COMMISSION GÉOLOGIQUE 1992 ANNIVERSARY 150 ANNIVERSAIRE

GEOLOGICAL SURVEY OF CANADA
MEMOIR 434

QUATERNARY GEOLOGY OF WOLLASTON PENINSULA, VICTORIA ISLAND, NORTHWEST TERRITORIES

David R. Sharpe



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Available in Canada through authorized
bookstore agents and other bookstores

or by mail from

Canada Communication Group — Publishing
Ottawa, Canada K1A 0S9

and from

Geological Survey of Canada offices:

601 Booth Street
Ottawa, Canada K1A 0E8

3303-33rd Street N.W.,
Calgary, Alberta T2L 2A7

A deposit copy of this publication is also available for
reference in public libraries across Canada

Cat. No. M46-434E
ISBN 0-660-14426-3

Price subject to change without notice

Cover description

LANDSAT scene of northwest Wollaston Peninsula and Prince Albert Sound July 13, 1975. Early break-up of sea ice is visible offshore. Major landforms, lineaments and tonal patterns are visible onshore. See Figure 6A.

Original manuscript submitted: 1986 - 11
Revised manuscript submitted: 1989 - 10
Final version approved for publication: 1991 - 01

Preface

The Quaternary geology of Wollaston Peninsula, Victoria Island was investigated by the Geological Survey of Canada in early 1980s because of the need for terrain information due to exploration for oil and gas on northern islands, including Victoria Island. Potential development of these and other resources in the area requires support and transportation facilities which will draw on a knowledge of ground conditions - the surficial geology.

This report describes the surficial materials and summarizes the Quaternary history of Wollaston Peninsula, based on observations from the past 10 years. It provides the framework for and age of Quaternary deposits and landforms; the distribution of permafrost and ground ice relative to these various landforms and deposits; and the effect of recent, particularly periglacial, processes upon the landscape. These data provide an essential background for planning wise land use in an area of variable surface material and permafrost.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

Préface

La géologie quaternaire de la péninsule Wollaston, dans l'île Victoria, a fait l'objet d'une étude par la Commission géologique du Canada au début des années 1980 en vue de recueillir des données sur le terrain à des fins d'exploration du pétrole et du gaz dans les îles septentrionales, y compris l'île Victoria. L'exploitation éventuelle de ces ressources et d'autres dans la région exige des réseaux de soutien et de transport, qui dépendront d'une connaissance des conditions du terrain, soit de la géologie de surface.

L'auteur présente une description des matériaux en surface et une synthèse du Quaternaire de la péninsule Wollaston, qui se fondent sur des observations faites depuis 10 ans. Il fournit des renseignements sur les sédiments et les formes de relief quaternaires et leur âge; la répartition du pergélisol et de la glace dans le sol en regard de ces divers sédiments et formes de relief; et l'effet des processus récents, notamment des processus périglaciaires, sur le paysage. Ces données sont essentielles à la planification judicieuse de l'utilisation des terrains dans une région où les matériaux en surface et le pergélisol varient.

Elkanah A. Babcock
Sous-ministre adjoint
Commission géologique du Canada

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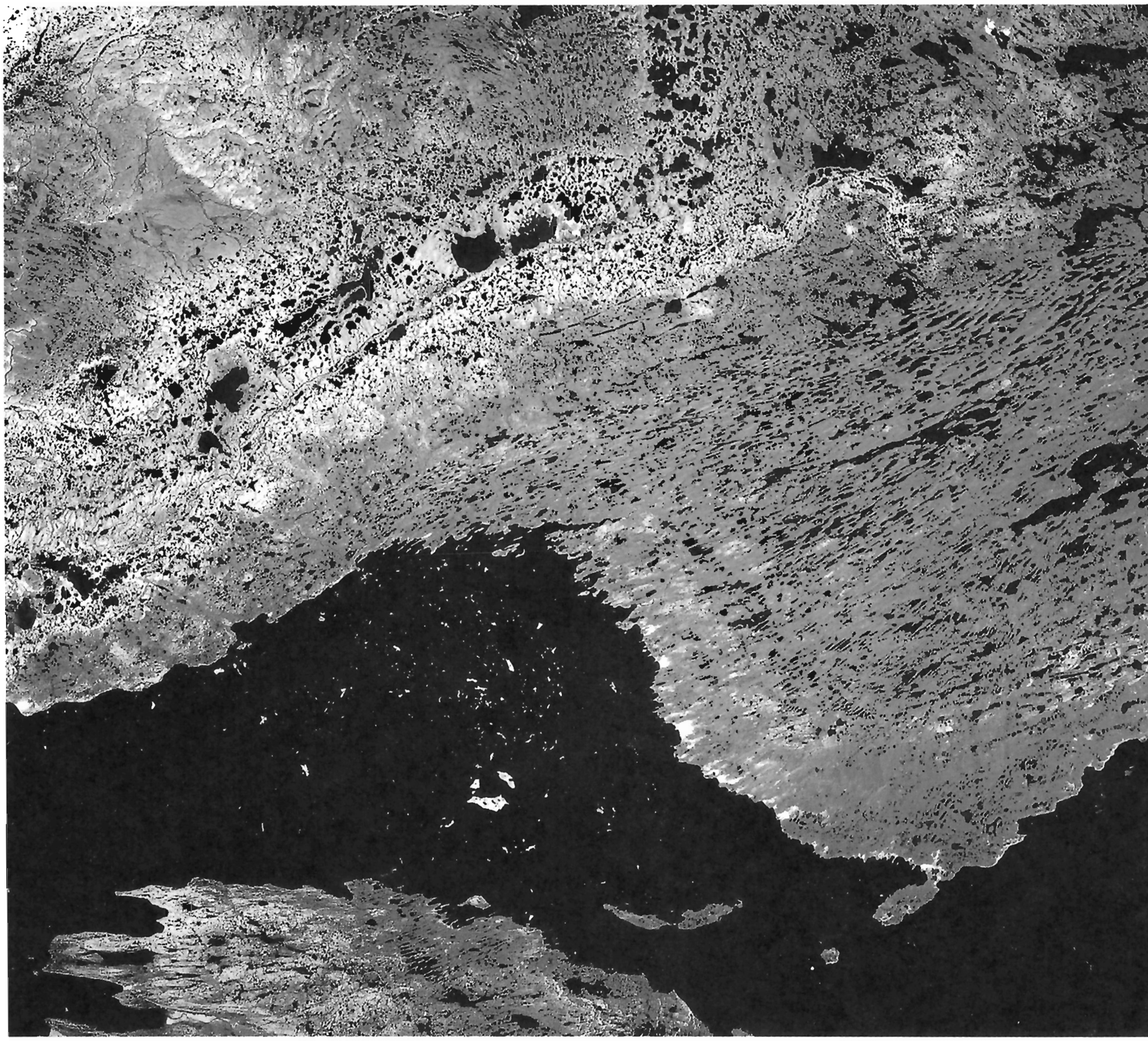


Frontispiece. LANDSAT scene of southern Wollaston Peninsula, July 29, 1973. Tonal patterns reflect sparse vegetation, sediment and moisture differences. Most sea ice and all lake ice has melted. Dark red tone with streamlined landforms shows former sea-covered area. Light-coloured area with dense lake pattern highlights thermokarst melting in a permafrost landscape. See Figure 6B.

QUATERNARY GEOLOGY OF WOLLASTON PENINSULA, VICTORIA ISLAND, NORTHWEST TERRITORIES

Abstract

Wollaston Peninsula in southwest Victoria Island comprises Paleozoic carbonate lowlands, scarps, and tableland situated between rises and arches of underlying Precambrian sedimentary and igneous rocks. Quaternary sediments overlie these rocks and form a thick cover near escarpments where resistance to ice flow concentrated glacial drift; thinner drift occurs in lowlands. Quaternary sediments are mainly Late Wisconsinan in age. Glacial sediments predominate but raised marine and periglacial sediments are noticeable among surficial deposits. Fluvial modification is minor.

Of the glacial landforms so spectacularly displayed on Wollaston Pensinsula, many are streamlined, which indicates that they formed under thick, warm-based (free subglacial water) glacial conditions. A set of distinctive landforms, ground moraine (with marginal channels), hummocky moraine, lateral-shear moraines, and streamlined forms relates to varying flow conditions within one major glacial advance. Stratified drift within many of these moraine forms identifies the importance of glaciofluvial processes in addition to ice action. These landforms record ice marginal retreat, marginal stagnation following compressional flow, surging, possible floods and regional stagnation during deglaciation. Ice stagnation trapped extensive ice in drift-rich hummocky moraine.

Late glacial events are dated in relation to the incursion of the sea during deglaciation of northwest areas of Wollaston Peninsula by about 12 000 BP. Active ice marginal conditions existed just before 10 000 BP during formation of the large Colville moraine system. Ice melted down in the area following glacial thinning.

Prominent periglacial landforms and ground-ice features include patterned ground, pingos, solifluction forms, thermokarst scars and lakes, and debris-flow lobes. Ground ice occurs as massive ice, wedge ice, and buried pingo ice. Based on its setting in hummocky moraine, and its stratigraphy, debris content, and isotopic composition, massive ice is likely buried glacial ice. Landscape modification by thermokarst erosion produces ubiqitous diamictons similar to till. Former thermokarst erosion was related to sea level such that present thick ground ice occurs above marine limit. Terrain sensitivity in future development will mainly relate to occurrence of massive ground ice.

Résumé

La péninsule Wollaston, dans le sud-ouest de l'île Victoria, comprend des basses terres carbonatées, des escarpements et un plateau du Paléozoïque qui se situent entre des massifs et des arches de roches sédimentaires et ignées sous-jacentes du Précambrien. Des sédiments quaternaires recouvrent ces roches et forment une couverture épaisse près des escarpements, où la résistance à l'écoulement des glaces a concentré les dépôts morainiques; des dépôts morainiques moins épais se présentent dans les basses terres. Les sédiments quaternaires remontent principalement au Wisconsinien supérieur. Les dépôts morainiques prédominent, mais il existe aussi des dépôts périglaciaires et des sédiments marins soulevés parmi les dépôts en surface. Le remaniement par les cours d'eau est peu important.

Bon nombre des formes glaciaires qui constituent le paysage spectaculaire de la péninsule Wollaston sont profilées, ce qui indique qu'elles se sont formées sous des glaciers épais, à base tempérée (eau sous-glaciaire libre). Une série de formes distinctives - moraines de fond, moraines bosselées, moraines de cisaillement latéral et formes profilées - sont attribuées à des changements survenus dans les conditions d'écoulement au cours d'une seule avancée glaciaire majeure. Bon nombre de ces moraines contiennent des sédiments stratifiés qui attestent l'importance tant des processus fluvioglaciaires que des processus glaciaires. Ces formes de relief témoignent du recul de la marge glaciaire, de la stagnation de la marge suivant un écoulement en compression, de crues, *d'inondations éventuelles et de la stagnation régionale au cours de la déglaciation. La stagnation de la glace a piégé de vastes étendues de glace dans des moraines bosselées à forte teneur en dépôts morainiques.*

L'âge des événements tardiglaciaires est établi en regard de la transgression survenue au cours de la déglaciation du nord-ouest de la péninsule Wollaston, il y a environ 12 000 ans. Une marge glaciaire active a existé il y a un peu plus de 10 000 ans, au cours de la formation du vaste complexe morainique de Colville. La glace a fondu dans la région suivant son amincissement.

La région comprend des formes périglaciaires proéminentes et des détails attribués à la glace dans le sol, notamment des sols structurés, des pingos reliques, des formes de solifluxion, des dépressions et des lacs thermokarstiques et des lobes de coulées de débris. La glace dans le sol se présente sous la forme de glace massive, de glace de fente et de glace de pingo enfouie. À en juger par sa présence dans des moraines bosselées et par sa stratigraphie, sa teneur en débris et sa composition isotopique, la glace massive représente vraisemblablement de la glace de glacier enfouie. L'érosion thermokarstique a modifié le paysage, produisant des diamictons ubiquites qui ressemblent à du till. L'érosion thermokarstique antérieure était associée au niveau marin, de sorte que de nos jours, on trouve de la glace dans le sol épaisse au-dessus de la limite marine. La sensibilité du terrain au cours des activités de mise en valeur ultérieures sera fonction de la présence de glace massive dans le sol.

SUMMARY

This report deals with the Quaternary geology of southern Victoria Island, particularly Wollaston Peninsula, southwest Victoria Island, south of Kagloryuak River and north of Coronation Gulf. Descriptions of the landforms and surficial materials of the area provide data for two basic endeavours. First, an understanding of Quaternary sediments provides baseline data for future economic activity. Victoria Island is an area of economic interest as gas pipelines have been proposed to cross western Victoria Island and Wollaston Peninsula in particular. Second, Victoria Island provides an unparalleled opportunity to study the effects of the last glaciation on the Canadian landscape.

Thin, flat-lying, lower Paleozoic (dominantly) carbonate rocks underlie Wollaston Peninsula and eastern Victoria Island. These rocks lie unconformably on Upper Precambrian sediments and older deformed rocks extensively exposed north of Wollaston Peninsula on Victoria Island and to the south on the mainland and islands in Coronation Gulf. Thelon Tectonic Zone metamorphic and granitic rocks were particularly good indicators of ice movement from the mainland onto Victoria Island.

Victoria Island is situated on the southern margin of a stable Paleozoic carbonate platform attached to the North American craton. The Arctic Platform comprises undeformed strata, of Lower-Middle Paleozoic age, that are preserved in postdeposition structural basins bounded by Precambrian highs (Minto Arch and Wellington high). Movement associated with possible structural basins, swarm dykes, or along fault-bounded blocks has affected arctic geology since Precambrian times (Kerr, 1980) and may have controlled part of the structural arrangement of Victoria Island. The interisland seaways may record some of this history; e.g. structural control for their origin expressed as creases between large fault-bounded blocks.

SOMMAIRE

Le présent rapport examine la géologie quaternaire de la partie sud de l'île Victoria, notamment de la péninsule Wollaston dans le sud-ouest de cette île, au sud de la rivière Kagloryuak et au nord du golfe Coronation. Les descriptions des formes de relief et des matériaux en surface de la région fournissent des données qui permettront de réaliser deux objectifs de base. Premièrement, l'étude des sédiments quaternaires fournit des données de base pour les activités économiques futures. L'île Victoria est une zone d'intérêt économique, car on a proposé d'y construire des gazoducs, notamment dans l'ouest de l'île et dans la péninsule Wollaston. Deuxièmement, l'île Victoria offre une occasion sans pareil d'étudier les effets de la dernière glaciation sur le paysage du Canada.

Des roches (principalement) carbonatées, peu épaisses et horizontales, du Paléozoïque inférieur se rencontrent dans la péninsule Wollaston et l'est de l'île Victoria. Elles reposent en discordance sur des sédiments du Précambrien supérieur et sur des roches déformées plus anciennes qui affleurent largement dans le nord de la péninsule Wollaston, dans l'île Victoria, et au sud sur le continent et dans les îles du golfe Coronation. Les roches granitiques et métamorphiques de la zone tectonique de Thelon attestent particulièrement bien l'écoulement des glaces depuis le continent jusque dans l'île Victoria.

L'île Victoria se situe sur la marge sud d'une plate-forme carbonatée stable du Paléozoïque, qui est rattachée au craton nord-américain. La plate-forme de l'Arctique se compose de strates non déformées, qui remontent au Paléozoïque inférieur et moyen et qui se présentent dans des bassins structuraux post-sédimentaires que limitent des hauteurs précambriennes (arche de Minto et hauteur de Wellington). Le mouvement associé à des bassins structuraux éventuels, à des essaims de dykes ou à des blocs limités par des failles a influé sur la géologie de l'Arctique depuis le Précambrien (Kerr, 1980); il pourrait avoir contrôlé en partie la structure de l'île Victoria. Les chenaux interinsulaires pourraient témoigner d'une partie de cette évolution, notamment du contrôle structural responsable de leur formation qui se manifestait par des plis entre de grands blocs limités par des failles.

Topography of Wollaston Peninsula is controlled by Paleozoic carbonate strata eroded to a prominent escarpment or series of escarpments that divides the peninsula into a broad, flat plateau having an interior and a coastal plain. This topography controlled the flow of ice, which deposited thick drift on the scarp and thin drift in lowlands. Although glacial landforms (drumlins, moraines) and raised beaches dominate regional physiography, local physiography reflects permafrost conditions, for example, pingos, rock-bursts, solifluction lobes, and patterned ground. Mean annual air temperature of -12.9°C and mean annual ground temperature of -13.8°C guarantee permafrost conditions. Vegetation consists of dwarf birch and some herbs. All soils are cryosolic as they are underlain by continuous permafrost, but few show extensive turbic or frost churned development. Many soils show recognizable and consistent textural and trace element trends in the soil profiles attributable to eolian and pedogenic effects.

A surficial geology map (Map 1650A) portrays the nature and distribution of surficial materials and landforms, together with an interpretation of their genesis. Carbonate bedrock is exposed in large regions, particularly lowland areas between drumlins and in scoured areas above Kugaluk River. Striae and sculpted meltwater erosion features are recorded on these bedrock areas. Ice marginal deposits consist of diamicton and coarse bouldery rubble on lateral and end moraines above marine limit; stratified sediment was common in subaqueously deposited moraines. Subglacial deposits include diamictons deposited as till as well as associated stratified sediment. These deposits include diamicton that moved downslope as solifluction material. Stratified sand and gravel is also included where it is interbedded with till or otherwise deposited contemporaneously with till; these deposits occur mainly in areas of ground moraine. Thicker subglacial deposits occur in the large drumlin fields.

Diamicton or till consists of loose to compact, sandy silt sediment, which is pale brown to pink in weathered field colour and light grey when frozen or unweathered. Till commonly contains striated (50-60%) local carbonate clasts indicative of transport in the base of glaciers. The abundance of mainland erratic (noncarbonate) clasts averages 10%.

Areas of large rounded hummocks and depressions are covered with diamictons interpreted as till, sediment flows, solifluction, and colluvial material. These diamictons were observed as interbeds with stratified sediments; some diamictons contain datable organic material. The presence of organic material suggests common slumping, much of which is paraglacial. The sediments within the hummocky moraine deposits are still undergoing redistribution because buried ground ice is exposed and melts to form

Des strates carbonatées paléozoïques contrôlent la topographie de la péninsule Wollaston; leur érosion a produit un escarpement proéminent ou une série d'escarpements qui divise la péninsule en un vaste plateau horizontal doté d'une plaine intérieure et d'une plaine côtière. Cette topographie a contrôlé l'écoulement des glaces, qui ont laissé des dépôts morainiques épais sur l'escarpement et d'autres dépôts morainiques peu épais dans les basses terres. Bien que des formes glaciaires (drumlins, moraines de surface) et des plages soulevées prédominent à l'échelle régionale, la physiographie locale traduit l'existence de pergélisol avec, par exemple, des pingos, des gélifractes, des lobes de solifluxion et des sols polygonaux. La température annuelle moyenne de l'air (-12,9°C) et la température annuelle moyenne du sol (-13,°C) garantissent la présence de pergélisol. La végétation comporte des bouleaux nains et quelques plantes herbacées. Tous les sols sont cryosoliques, car ils reposent sur un pergélisol continu, mais peu d'entre eux montrent des indices de géliturbation répandue. Dans de nombreux sols, la texture et les éléments en trace présentent des tendances reconnaissables et uniformes dans les profils pédologiques attribués à des effets éoliens et pédogéniques.

Une carte de la géologie de surface (carte 1650A) montre la nature et la distribution des matériaux en surface et le modelé et présente une interprétation de leur genèse. Le socle rocheux carbonaté affleure sur de vastes étendues, notamment dans les basses terres entre les drumlins et dans les zones décapées au-dessus de la rivière Kugaluk. Des stries et des formes sculptées produites par des eaux de fonte se rencontrent dans ces zones de roche en place. Les sédiments proglaciaires se composent de diamictons et de débris blocailleux grossiers sur les moraines latérales et les moraines terminales au-dessus de la limite marine; les sédiments stratifiés sont fréquents dans les moraines subaquatiques. Les dépôts sous-glaciaires comprennent des diamictons mis en place sous la forme de till ainsi que des sédiments stratifiés associés. Ces dépôts englobent des diamictons qui ont descendu les pentes sous la forme de débris de solifluxion, ainsi que des sables et graviers stratifiés là où l'on en trouve interstratifiés à du till ou déposés autrement en même temps que le till; ils se rencontrent principalement dans les régions de moraines de fond. Des dépôts sous-glaciaires plus épais existent dans les vastes champs de drumlins.

Les diamictons ou les tills se composent de sédiments silto-sableux meubles ou compactes, de couleur brun pâle ou rose lorsqu'ils sont altérés et gris pâle lorsqu'ils sont gelés ou non altérés. Les tills contiennent souvent des fragments striés (de 50 à 60%) de roches carbonatées d'origine locale qui ont été transportés à la base des glaciers. En moyenne, 10 % des fragments sont des débris erratiques (non carbonatés) en provenance du continent.

Les régions comportant de grands monticules arrondis et des dépressions sont couvertes de diamictons qui représentent des tills, des coulées de sédiments, des débris de solifluxion et des colluvions. Ces diamictons forment des interstrates au sein de sédiments stratifiés; certains d'entre eux contiennent des matières organiques datables. La présence de matières organiques porte à croire qu'il s'est produit des décrochements, en grande partie périglaciaires. Les sédiments contenus dans les moraines bosselées subissent encore un remaniement, car la glace dans le sol est exposée et fond pour former des lacs thermokarstiques, des cicatrices de décrochement et des coulées de sédiments. Les études thaw lakes, slump scars and sediment flows. Based on stratigraphic and isotope studies, much ground ice may be remnant Pleistocene ice or glacier ice.

Major moraine belts encircle Wollaston Peninsula and drape the carbonate escarpment. Low moraine gradients suggest low profile ice masses and possible rapid flow during formation. Streamlined landforms are predominant in lowland terrain and rest on scoured bedrock surfaces. The form and arrangement of drumlins suggest the action of one major flow that was turbulent rather than laminar. If mapped drumlins are depositional, then, stratified cores favour glaciofluvial formation and diamicton cores favour ice formation. The presence of rock drumlins, p-forms, and sediment free zones (tunnel valleys) supports glaciofluvial erosion as a former, widespread subglacial process.

Drift patterns on Wollaston Peninsula indicate prominent flow from the southeast from mainland Precambrian terrain. Carbonate dispersal in the lee of Richardson Mountains shows this dispersal from the southeast whereas the superimposed drumlin pattern is to the southwest. Soil geochemical profiles show small in situ variations that did not hamper studies of regional provenance.

Wollaston Peninsula lies within continuous permafrost and exhibits a variety of periglacial landforms and ground ice features. Total permafrost thickness is unknown. Active layer thicknesses range from 30 to 100 cm. Ground ice occurs as wedge ice, pingo ice, and massive ice. Massive ice, with oriented clasts, overlying debris flow sediment, and low isotope values occur in ice-cored moraine preserved above marine limit; all indicate buried glacier ice. Large (100 m) polygons and thermokarst lakes on hummocky moraine surfaces correspond with buried massive ice. Present thermokarst erosion is minor compared to past, paraglacial, thaw-disturbed terrain. Patterned ground is common.

On Wollaston Peninsula, evidence records two glacial advances separated by organic material beyond the limit of radiocarbon ages. Ice advanced well beyond Wollaston Peninsula in Late Wisconsinan time as defined by landform sets tied to raised marine sediments. Grounded ice, low ice profiles, and warm bed conditions are interpreted rather than extensive polar ice shelves. Ice marginal retreat marked early deglaciation while ice streaming (and possible surging) and calving evacuated ice prior to regional stagnation. Stagnation helped produce an erratic pattern of marine limit and postglacial emergence. Ice scours from icebergs or probably from recent sea ice cross raised marine muds.

stratigraphiques et isotopiques portent à croire que la glace dans le sol se compose en grande partie de glace pléistocène ou de glace résiduelle de glacier.

De grandes ceintures morainiques encerclent la péninsule Wollaston et drapent l'escarpement carbonaté. Les faibles gradients des moraines portent à croire que les profils des masses de glace étaient faibles et que l'écoulement glaciaire pourrait avoir été rapide durant la formation de ces moraines. Les formes profilées prédominent dans les basses terres et reposent sur une roche en place affouillée. La forme et la disposition des drumlins laissent croire qu'un des écoulements majeurs a été turbulent plutôt que laminaire. Si les drumlins cartographiés avaient une origine sédimentaire, les noyaux stratifiés témoigneraient d'une origine fluvioglaciaire et les noyaux de diamicton, d'une origine glaciaire. La présence de drumlins rocheux, de marques d'aspect plastique et de zones dépourvues de sédiments (vallées-tunnel) indique que l'érosion fluvioglaciaire était anciennement un processus sous-glaciaire étendu.

Dans la péninsule Wollaston, la configuration des sédiments glaciaires indique qu'il y a eu écoulement important du sud-est, à partir d'un terrain précambrien sur le continent. La dispersion des carbonates à l'aval des monts Richardson montre que ces carbonates proviennent du sud-est, tandis que la configuration superposée des drumlins indique un écoulement vers le sud-ouest. Les profils géochimiques des sols montrent de petites variations sur place qui n'ont pas nuit aux études de la provenance régionale.

La péninsule Wollaston se situe dans la zone de pergélisol continu et présente une gamme de modelés périglaciaires et de détails attribués à la glace dans le sol. L'épaisseur totale du pergélisol y est inconnue. L'épaisseur du mollisol varie de 30 à 100 cm. La glace dans le sol se présente sous la forme de glace de fente, de glace de pingo et de glace massive. De la glace massive contenant des fragments rocheux orientés, présentant de faibles valeurs isotopiques et reposant sur des sédiments de coulées de débris, se rencontre dans des moraines à noyaux de glace que l'on trouve au-dessus de la limite marine; il s'agit de la glace de glacier enfouie. De grands (100 m) polygones et des lacs thermokarstiques se rencontrent sur des moraines bosselées, à l'emplacement de la glace massive enfouie. L'érosion thermokarstique actuelle est peu importante en regard des anciens terrains périglaciaires perturbés par le dégel. Les sols polygonaux sont fréquents.

Des indices reconnus dans la péninsule Wollaston témoignent de deux avancées glaciaires que séparent des matières organiques trop vieilles pour être datées par la méthode du radiocarbone. La glace s'est avancée bien au-delà de la péninsule Wollaston au Wisconsinien supérieur, à en juger par la présence de formes de relief associées à des sédiments marins soulevés. Ces détails indiquent la présence de glaces échouées, aux profils faibles et à base tempérée, plutôt que de vastes plates-formes de glace polaire. Le début de la déglaciation a été marqué par le retrait de la marge glaciaire; la formation de courants glaciaires (et possiblement de crues) et le vêlage auraient emporté la glace avant la phase de stagnation régionale. La stagnation a contribué à la configuration erratique de la limite marine et de l'immersion postglaciaire. Des marques d'affouillement produites par des icebergs ou probablement par des glaces de mer récentes sillonnent les boues marines soulevées.

INTRODUCTION

Purpose

This final report on Wollaston Peninsula is the first of several to report on the Quaternary geology of Victoria Island. Wollaston Peninsula lies in southwest Victoria Island, west of 112°W and between 70°30′N, south of Kagloryuak River to 68°30′N and north of Coronation Gulf (Fig.1A,B). Descriptions of the landforms and surficial materials of the area provide data for two basic endeavours. First, an understanding of Quaternary sediments provides baseline data for future economic activity. This area is of economic interest as gas pipelines have been proposed to cross western Victoria Island and Wollaston Peninsula in particular. Second, Victoria Island provides an excellent opportunity to study the effect of the last glaciation on the Canadian landscape. The arctic landscape, with little obscuring vegetation, displays a spectacular array of glacial, periglacial, and postglacial landforms, which can easily be seen on LANDSAT imagery. Detailed mapping portrays an outstanding record of glacial processes and products. The study of landforms and sediments allows us to infer the style of glacial activity as well as the history of late glacial and marine events. The last major ice advance left behind an elaborate array of glacial landforms. Wollaston Peninsula, positioned near the margin of that advance, is the focus for this study (Fig. 1). The relationship between these dramatic landforms and the sediment sequences found within them provides a powerful, predictive, geological tool. Accurate prediction of geological materials (e.g., sediments and ground ice) is vital to sound economic and environmental planning.

This study supplements the geotechnical data base that was provided by preliminary terrain studies for gaslines across the area (E.B.A. Engineering Consultants Ltd.,1981, unpublished report). The Quaternary mapping aids our understanding of the relationships between frozen soil, ground ice, sediments, and landforms and allows better evaluation of the terrain.

The fieldwork was done in 1982 and 1983 by the author and F.M. Nixon out of seven camps and during 4 weeks of helicopter survey from Holman. Brief additional studies were conducted in 1987. Preliminary accounts of the area have been produced (Sharpe, 1984, 1987, 1988; C. Borowiecki, unpublished report, 1984).

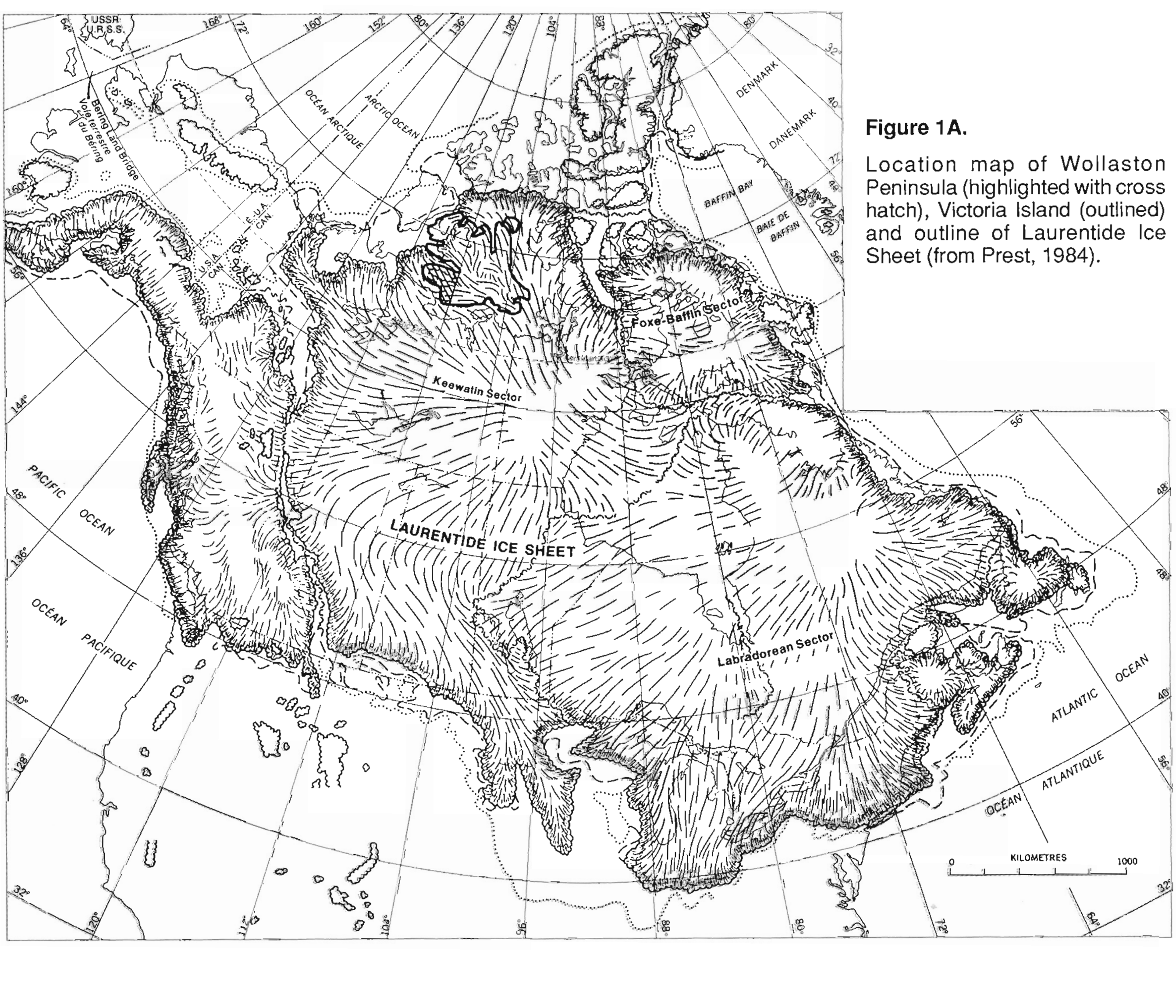


Figure 1A.

Location map of Wollaston Peninsula (highlighted with cross hatch), Victoria Island (outlined) and outline of Laurentide Ice Sheet (from Prest, 1984).

Previous Quaternary studies

Early maps showing the glaciated areas of North America failed to recognize that Victoria Island, except the southeast coast, had been ice covered (Chamberlain, 1907). Ice cover of southern Victoria Island was indicated by Chamberlain (1913), and this view prevailed until recently (Wickenden, 1947). An early map by Tarr and Martin (1914) showed an independent ice cap on Victoria Island and other Arctic islands. Most maps, however, clearly show northwest ice flow from an accumulation centre in Keewatin onto Victoria Island (cf., Alden, 1924; Prest, 1984; Fig.1). The concept of a single area of outflow, Hudson Bay, first proposed by Flint (1943), was revived by Denton and Hughes (1981). Their concept relied on the premise that a marine based ice sheet developed ice streams, which flowed outward along inter-island channels and overtopped most of Victoria Island from the southeast. The ice stream concept was extended by Dyke (1983), but he proposed major flow across inter-island channels and across Victoria Island from east to west, from M'Clintock Channel.

The earliest reports of Quaternary geology on Victoria Island are notes of Collinson (1889) and Jenness (1923) who noted erratic blocks. O'Neill (1924) reported morainic material and raised fossiliferous marine sediments on Wollaston Peninsula while Johansen (1924) observed much glaciated bedrock on Richardson Islands, off the south coast of Victoria Island. The earliest comprehensive study was by Washburn (1947) who reported on the glacial geology, uplift, periglacial landforms, and geomorphological processes of parts of Victoria Island and adjacent regions. Washburn noted that sea ice may have produced striae around coastal areas and that solifluction deposits are easily confused with till. He suggested that rugged glacial topography indicated glacial cover over all of Wollaston Peninsula and its subsequent stagnation there. Washburn noted many eskers and crevasse fillings on

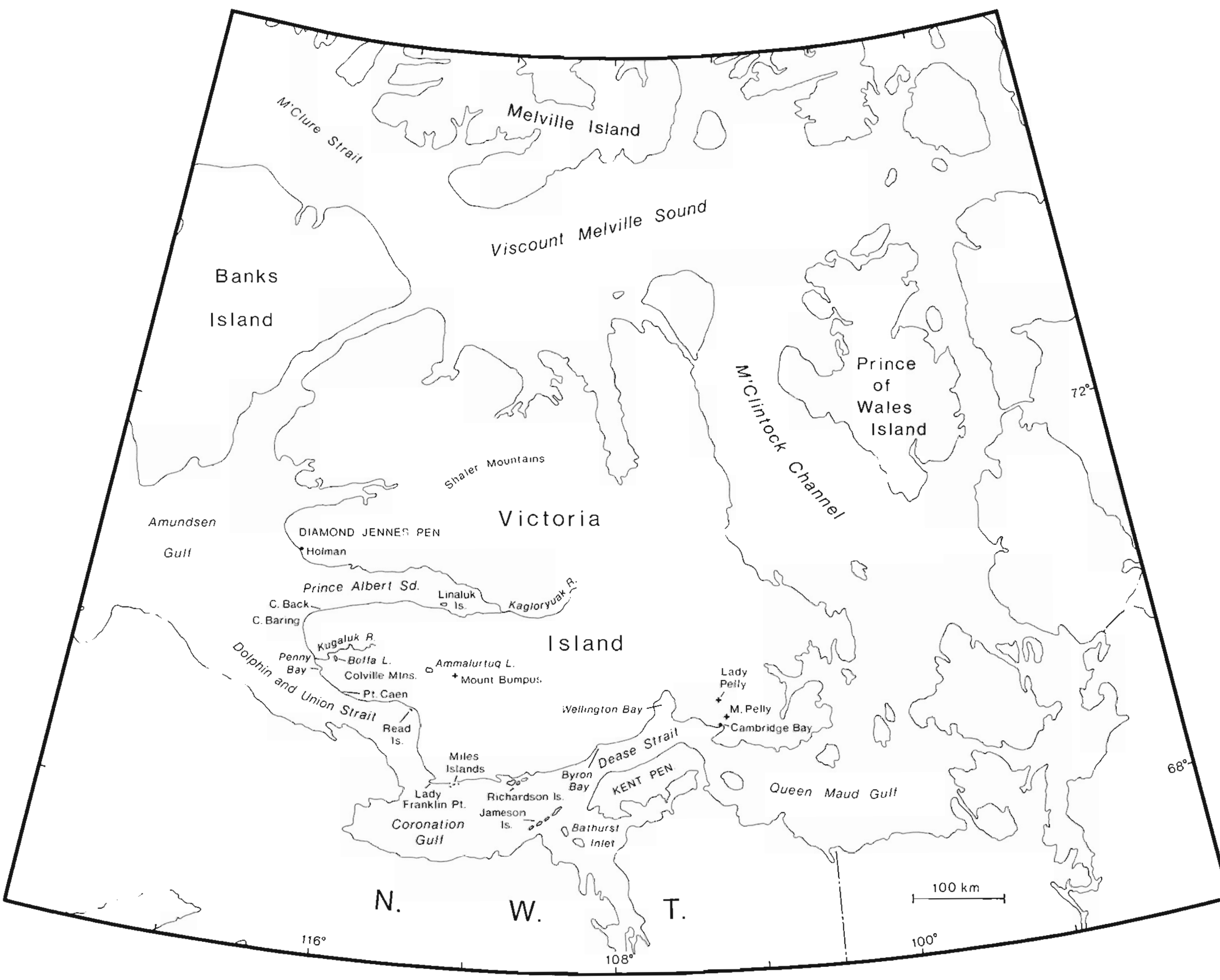


Figure 1B. Location of places mentioned in text.

southern Victoria Island and the glaciofluvial nature of Mount Pelly, in the southeast. He suggested an ice flow centre east of Victoria Island and north of Queen Maud Gulf.

Washburn made many observations on patterned ground and other periglacial forms. He also noted that mass wasting (solifluction) far outweighed fluvial activity.

Fyles (1963) mapped the surficial geology of Victoria and Steffansson islands and wrote a perceptive account of the features and deposits based on his brief reconnaissance survey. Of particular importance was his conclusion that latest ice occupied the major sounds and straits adjacent to Victoria Island. This relationship confounded the distinction between marine limit and lacustrine limits in many areas including Wollaston Peninsula. Fyles noted undeformed stratified sediments below a thin diamicton in many parts of the island. These and other similar thin diamictons are difficult to separate from colluvium or solifluction debris. Fyles paid particular attention to the variety of forms and the fresh topography of glacial landforms.

Studies by Vincent (1982) and Hodgson (1987) cover areas on Victoria Island north of this study area.

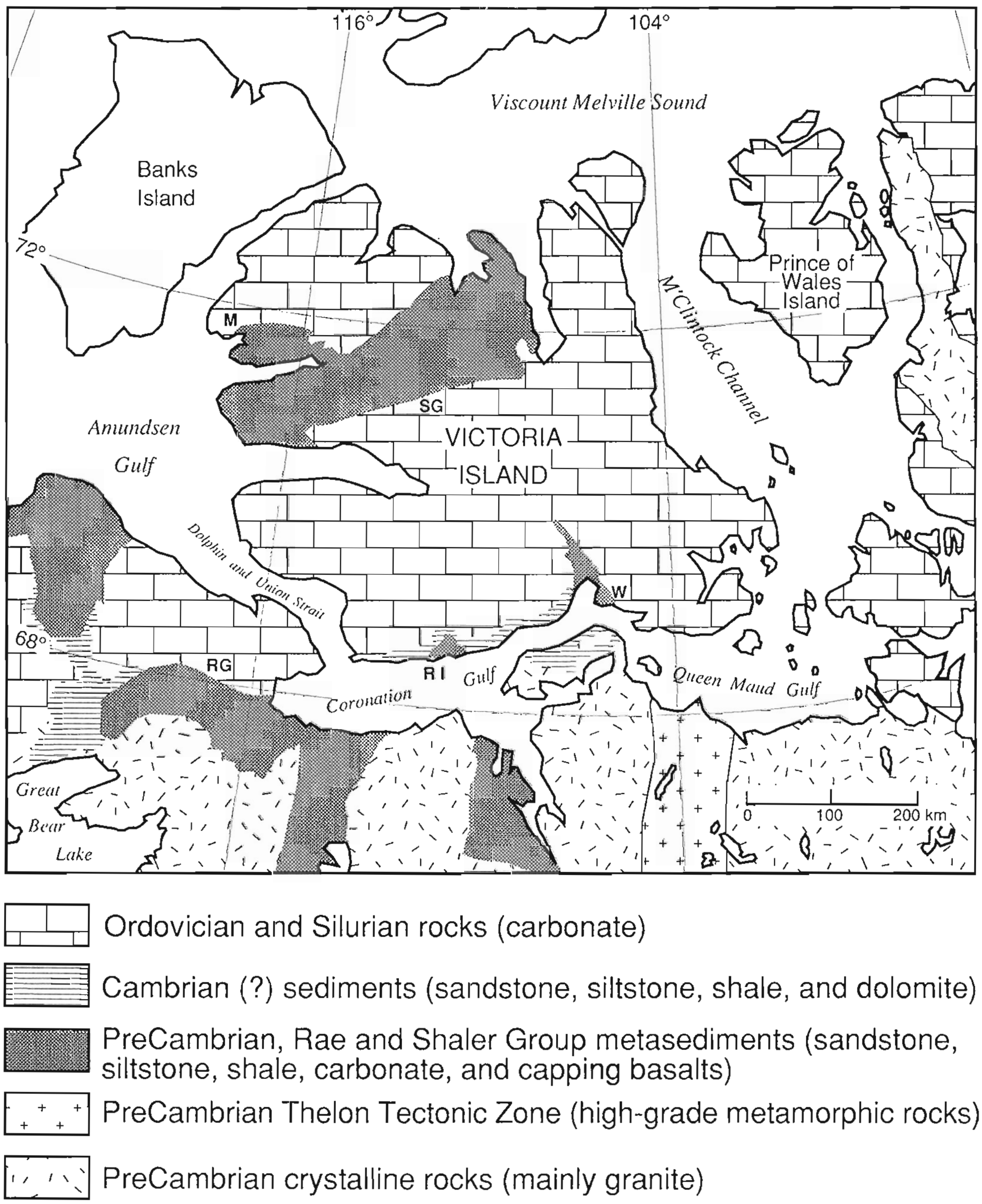


Figure 2. Generalized bedrock geology of Victoria Island and adjacent southern mainland. SG, Shaler Group; RG, Rae Group; RI, Richardson Islands; W, Wellington inlier; M, Minto arch.

Bedrock geology

The general bedrock geology of Victoria Island was reported by Thorsteinsson and Tozer (1962) and more recently for Precambrian areas by Christie (1964), Young (1981), and Campbell (1978, 1983). The generalized map of bedrock geology (Fig. 2) shows thin, flat-lying, lower Paleozoic (dominantly) carbonate rocks underlying Wollaston Peninsula and eastern Victoria Island. These rocks lie unconformably on Upper Precambrian sediments and older deformed rocks extensively exposed to the north of Wollaston Peninsula on Victoria Island and to the south on the mainland and islands in Coronation Gulf. Wollaston Peninsula is underlain by Ordovician and Silurian dolomite, minor chert, shale, and sandstone. Uniform, thick-bedded, drab grey and yellow-brown weathering dolomite is abundant. Underlying sandstone, minor shale, siltstone, and dolomite of Cambrian or early Ordovician age occur along the south coast of Wollaston Peninsula.

The major Precambrian formations in the area comprise terrestrial and marine sediments of the Rae and Shaler Groups. Southeast of Wollaston Peninsula (i.e., on Richardson Islands), the Glenelg Formation (lowest Rae Group) consists of Upper Precambrian sandstone, limestone, shale, siltstone, dolomite, and conglomerate (Campbell, 1985). Younger Rae Group rocks (and the Glenelg Formation) outcrop in the Miles Islands off the southeast coast of the map area. Correlative major Upper Precambrian formations (Shaler Group) are found in the Shaler Mountains north of Wollaston Peninsula.

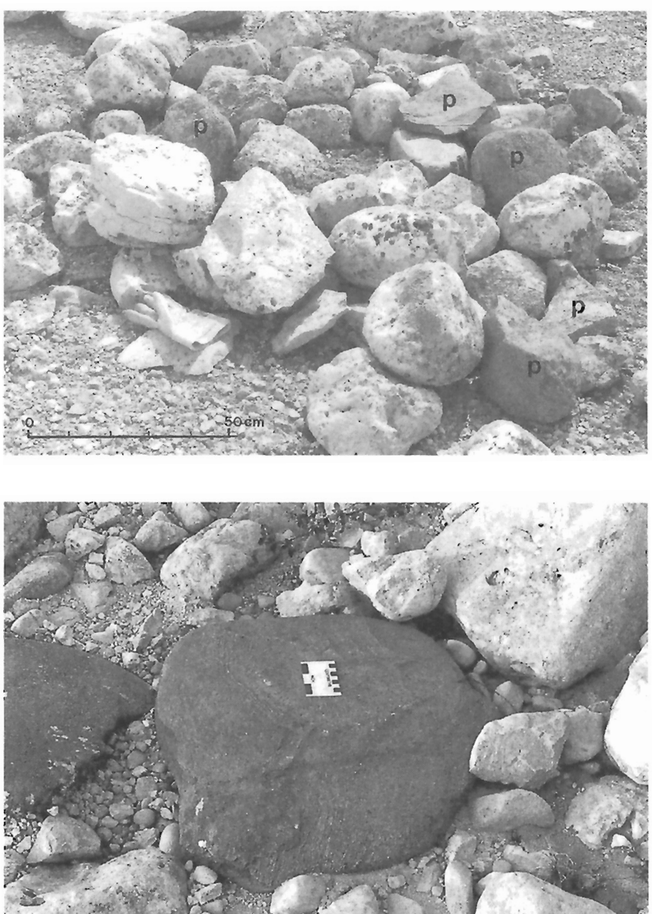


Figure 3A. Precambrian erratics (p) derived from areas southeast of study area. Glove is 20 cm long. GSC 204442-B
B. Rusty weathering biohermal carbonate with stromatolite. Scale is 8 cm long. GSC-1991-165

The bedrock of the mainland south of Queen Maud Gulf, Dease Strait, and Coronation Gulf is of interest in the context of this report as a source for Precambrian erratics (Fig.3A,B) carried onto Victoria Island during regional glaciation. Campbell (1983) described the Precambrian Rae Group rocks of the Coronation Gulf including the Richardson Island area and the Jameson Islands south of Victoria Island to Bathurst Inlet. The Rae Group rocks comprise red to white, fine grained sandstones, siltstones, dolomite, and shale. A diagnostic rock type is an orange to rusty weathering biohermal carbonate with stromatolites (Fig. 3B); these rocks have been identified in the drift of southern Victoria Island. Two formations originally considered as upper Rae Group formations were shown to be Paleozoic (Campbell, 1983). Rae Group rocks are correlatives of the Shaler Group of west-central Victoria Island, which consist of sandstone, siltstone, dolostone, and limestone (including distinctive orange-weathering stromatolites) and evaporite units (Young, 1981). Dixon (1979) showed that rocks of the Wellington inlier of southeastern Victoria Island are distinct from those of the Duke of York inlier north of Richardson Island. The rocks near Wellington Bay are red to pink quartzitic sandstone, conglomerate, or siltstone; cherty ironstone occurs near Washburn Lake. These rocks are considered to be of fluvial origin rather than marine like the Rae and Shaler groups. Rocks of the Burnside Formation, similar to those of the Wellington Bay area, occur to the south on Kent Peninsula (Dixon, 1979; Campbell and Cecile, 1981).

Thompson et al. (1985) have described the Thelon Tectonic Zone, which forms the boundary of the Slave and Churchill structural provinces. This zone marks the western extent of high-grade metamorphic terrain comprising pink gneiss, migmatite, and granitoid rocks from the unmetamorphosed Goulburn Group clastic and carbonate rocks (Campbell and Cecile, 1981; Hoffman et al., 1984). These metamorphic and granitic rocks are particularly good indicators of ice movement from the mainland onto Victoria Island.

Structural setting

Victoria Island is situated on the southern margin of a stable, Paleozoic, carbonate platform attached to the North American craton. The arctic islands in general comprise three major tectonic or structural elements: the Canadian Shield, the Arctic Platform, and the Innuitian Tectonic Province (Trettin, in press). The first two elements are found on Victoria Island; the Innuitian Province includes younger terrain of islands to the north. The Canadian Shield borders the Arctic Platform to the south but includes rises and inliers on Victoria Island, in particular Minto Arch and the Wellington and Duke of York highs (Fig. 2). The Arctic Platform comprises undeformed strata of Lower-Middle Paleozoic age, which are preserved in postdeposition structural basins bounded by Precambrian highs (Minto Arch and Wellington high). Movement associated with possible structural

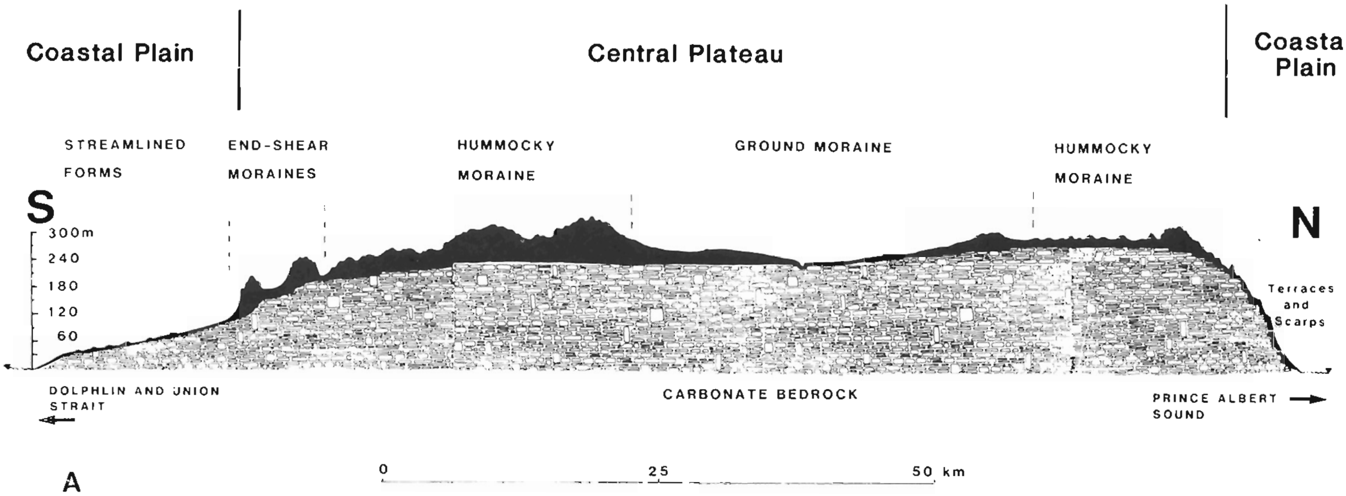


Figure 4A. Cross-section along longitude 114°W showing Paleozoic carbonate plateau and escarpment that is the core of Wollaston Peninsula; major landform belts are superimposed. **B**. Paleozoic carbonate rocks exposed in cliff along Back River. GSC 204535-F

basins or along fault-bounded blocks has affected arctic geology since Precambrian time (Kerr, 1980) and probably controlled part of the structural arrangement of Victoria Island.

Broad channels and sounds dissect Victoria Island (Fig.1B) and also occur adjacent to Wollaston Peninsula (Coronation Gulf, Dolphin and Union Strait, and Prince Albert Sound). These channels are part of the structural setting of Victoria Island and their origin is under debate in other areas of the Arctic. The controls on the origin of the channels are explained in a broad range of ways. Subaerial Tertiary drainage systems (Fortier and Morley, 1956; Bornhold et al., 1976), deep glacial scour (White, 1988), and tectonic or structural control (Kerr, 1980; Sanford et al., 1985; England, 1987) have all been advanced as primary mechanisms to explain channel formation.

A complex sedimentary and tectonic history affected a major portion of the Arctic (Kerr, 1980) since Cambrian time, but little of this record is present on the stable platform forming Victoria Island. The inter-island channels may record some of this history and structural control for their origin was proposed by Sanford et al. (1985, Fig. 4). Their synthesis pictures adjacent islands and Wollaston Peninsula as possible, large, fault-bounded blocks that may have been affected over time by periods of quiescence and periodic reactivation. The fracture patterns on LANDSAT images, which parallel some of the major structural lineaments identified from the Shield (Sanford et al., 1985), may support the idea of fault-block movement. These fractures and blocks are thought to reflect continuing tectonic activity along ancient orogenic belts such as the East Greenland orogeny. For Wollaston Peninsula, there is no evidence comparable to that which defines a fault and graben origin for Lancaster Sound (Kerr, 1980). Recent theories on the distribution of major ice streams (Denton and Hughes, 1981) and the effectiveness of continental ice sheets in producing deep erosion (White, 1988) have favoured a glacial and glaciofluvial erosional origin for the channels. This report presents evidence on the role subglacial erosion processes acting vigorously in topographic lows. Despite the importance of glacial and glaciofluvial erosion, structural control appears to be most probable. Marine surveys of the structure and nature of sediments in these channels could add further to this discussion.

Topography and physiography

The topography and physiography of Wollaston Peninsula reflect bedrock lithology and structure, glacial activity, and postglacial emergence. The topography is controlled by Paleozoic carbonate strata eroded to a prominent series of escarpments that encircle the peninsula (Map1650A). A major escarpment divides the peninsula into a broad, flat plateau comprising the interior and a coastal plain (Fig. 4A) of variable width (narrow along northwest Wollaston and wide along southern Wollaston).

The escarpments are drift-mantled exposures of Paleozoic carbonate rock that form 10-50 m high scarps or re-entrants along coasts and rivers (Fig. 4B). Many of these are fracture or joint controlled and delineate major fracture patterns (Fig. 5A,B) that can be well mapped on LANDSAT images (Fig. 6A,B). These fracture patterns may represent major northwest and normal fracture related to large fault-bounded blocks identified on a continental scale (Sanford et al., 1985). The major northwest fracture parallels the trace of magmatic dyke swarms (related to Proterozoic hotspots and rifting) which have a focal point off the northwest tip of Wollaston Peninsula (LeCheminant and Heaman, 1989). Smaller scarps, cuestas, and buttes form part of the coastal plain surrounding Wollaston Peninsula. The carbonate plateau lies at about 250-350 m a.s.l.; most of the overlying drift adds 60-100 m of relief, the highest drift reaches to 500 m a.s.l.

Figure 5. Major bedrock lineaments crossing Wollaston Peninsula: **A.** view to east along north coast of Wollaston Peninsula. Major lineament A-A′ can be identified on Figure 6. NAPL T345L-70

The major escarpment is draped by a dramatic, broad, and complex area of end, lateral, and hummocky moraines that encircles Wollaston Peninsula. This morainal pattern resulted, in part, from the carbonate plateau diverting the main glacial flow; its resistance initiated thick accumulation of sediment. In contrast, the drift on the lowlands and central plateau is thinner because of unimpeded flow. The striking, oriented, streamlined physiography of the lowland areas differs dramatically from the chaotic, rugged, and mountain-like morainal areas, the Colville Mountains.

In morainic terrain lake patterns are concentrated and random; they are less common but oriented in drumlin terrain. In contrast to the central plateau, these areas have many lakes.

The central plateau is a poorly drained, featureless plain underlain by level or shallow-dipping carbonate rock only thinly covered by unconsolidated sediment. The level area has a subdued look typical of older, weathered, drift surfaces as compared to the more youthful morainic topography.

Flights of raised beaches, bars, and bluffs, marking coastal areas from sea level to 110 m up to 150 m a.s.l., record the rapid topographic changes that resulted from land emergence during the postglacial period.

Although glacial landforms (drumlins and moraines) and raised beaches dominate regional physiography, permafrost conditions are reflected in local physiography expressed as pingos,

Figure 5B. Pattern of bedrock fractures controlling drainage along Kugaluk River. Lineament a-a′ parallels lineament A-A′ (Fig. 5A). Lineament b-b′ is one orthorhombic pair to lineament a-a′. NAPL T480R-17 rock-bursts, solifluction lobes, striping, ice-wedge polygons, and fissures. Thaw lakes and hummocky relief formed by the melting of ground ice in morainal areas are of particular importance. Their development continues. These ground patterns and landforms are prominent features of Wollaston Peninsula.

Climate

The closest climatic station with any long record is that at Lady Franklin Point (Atmospheric Environment Service, 1982) with records over 20 years. The mean annual temperature is -12.9°C and the mean temperature of the warmest month (July) is 6.6°C with daily maxima about 10°C. Nearby stations at Byron Bay, Holman Island, and Cambridge Bay on Victoria Island show similar temperatures.

Annual precipitation is low on western Victoria Island (11 cm) and especially Wollaston Peninsula. The maximum monthly value occurs as summer rains (2-2.5 cm/month) whereas snowfall is low. Snowfall peaks early in fall coinciding with the period of largest areas of open water. Lake ice usually remains on 30% of large lakes until early August. Scattered, wind-blown, late-lying snowbanks can persist until early August during years with cool, cloudy weather.

Figure 6. LANDSAT images of Wollaston Peninsula show tonal patterns related to vegetation, sediment type, and drainage: **A**. northwest Wollaston Peninsula showing bedrock lineaments and thin drift (LANDSAT B58-10-9 102-45 7, July 13, 1975). See colour photo on cover.

Permafrost is thought to be continuous under Wollaston Peninsula, and observed depths of >13 m have been reported (E.B.A. Engineering Consultants Ltd., 1981). However, permafrost to a depth of several hundreds metres is probable. Thicknesses of the active layer measured from ground surveys were 1.0-1.2 m in late July 1982 and 1983.

Winds of more than 100 km/h are commonly measured during winter by weather stations at Lady Franklin, Holman, and Byron Bay. Clearly such winds affect snow cover, vegetation, nature of active layer, and periglacial features as well as eolian processes.

The present tidal range on southern Victoria Island is less than 1 m, measured at 0.5 m at Cambridge Bay (Washburn, 1947).

Vegetation

The relationship between surficial materials, topography, climate, and plant communities was investigated on Victoria Island (Edlund, 1983; Edlund and Egginton, 1984). Three arctic ecosystems have been identified on western Victoria Island (Fig. 7A); on Wollaston Peninsula, the low (erect shrub zone) is most common.

The low arctic ecosystem has a rich flora (more than 150 vascular species) with common dwarf shrub (*Dryas* and *Salix*) and herbaceous legumes (*Oxytropis, Artemisia, Kobreisa*, and *Carex*). Wetlands have thicker vegetation of sedges, grasses, heaths, and especially dwarf willows that grow 25-50 cm in height (Fig. 7B). Sheltered sites may favour

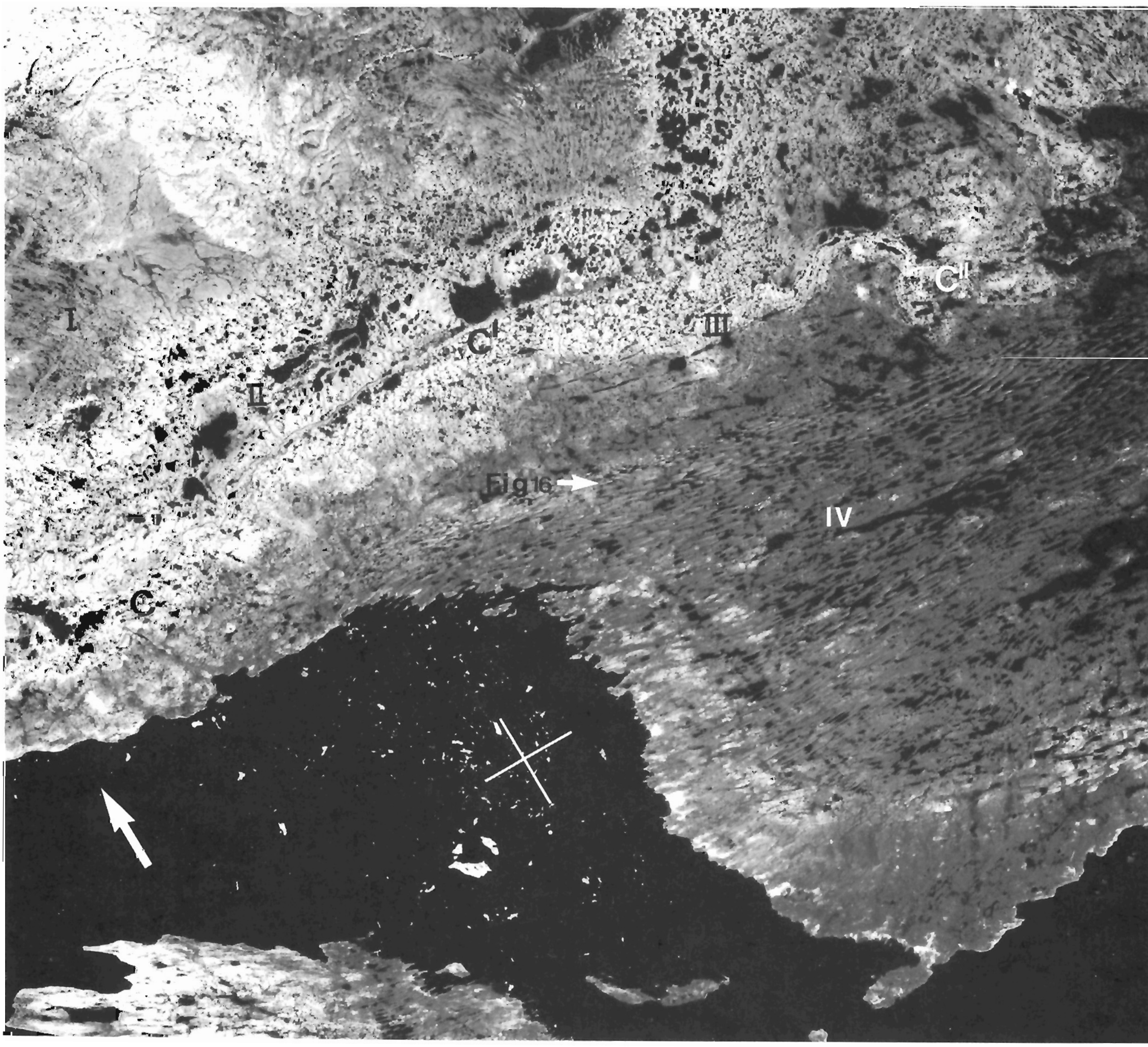
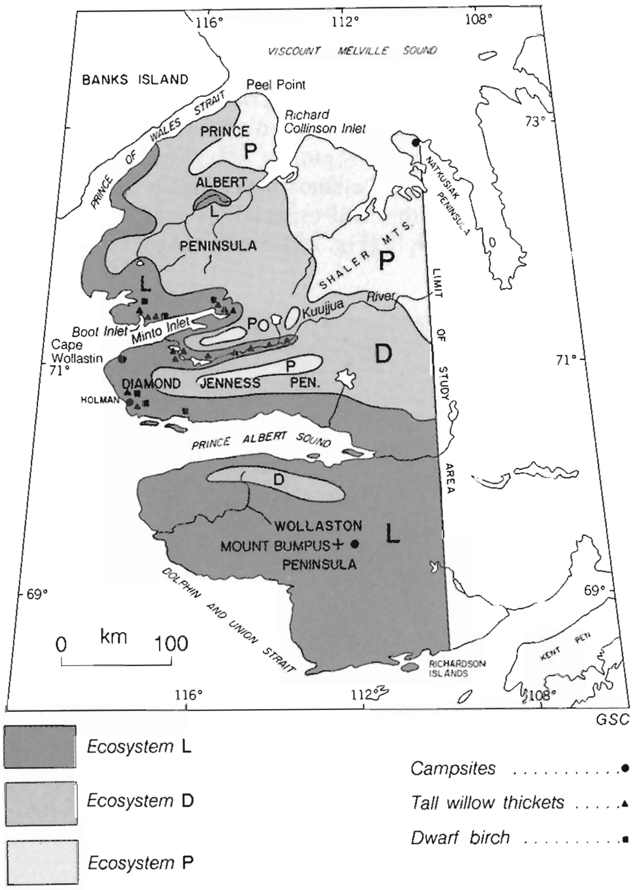


Figure 6B. Southern Wollaston Peninsula showing major glacial landforms. See Figure 16A for labels (I-IV); CCC" is Colville moraine system; large arrow is north arrow (LANDSAT A55-11-21 103-45 7). See colour photo in Frontispiece.

dwarf birch (*Betula glandulosa*). In some extremely protected sites, willows up to 5 m high have been reported north of Wollaston Peninsula (Edlund and Egginton, 1984).



The mid arctic ecosystem (dwarfed and prostrate shrub zone) in northern Wollaston Peninsula is marked by low diversity of low arctic herbs. Wetlands have prostrate shrubs of *Salix arctica* but not *S. reticulata* or *S. polaris*. Heath is represented only by *Cassiope* spp.

Soils

Soils integrate climatic variables, time, parent material, vegetation, and drainage and offer clues on past climatic conditions and the nature of climatic change. At a basic level they aid in differentiating between formerly glaciated and nonglaciated areas and in determining the length of time that regions have been ice free. In this report, soils are used as a means of providing relative dating information (e.g., Birkeland, 1978) and for inferring environment represented by active layer processes. The engineering aspects and behaviour of soils are discussed briefly in the section on *Terrain disturbance and terrain evaluation.*

As soils are important components of Quaternary work in arctic terrain, pits were dug to investigate: 1) the relative age of drift surfaces; 2) the role of depth-of-till-sampling on till geochemistry; 3) the nature of the active layer; and 4) soil and sediment genesis. All soils are cryosolic as they are underlain by continuous permafrost but only a few show extensive turbic or frost churned development. Many soils show horizon development. Detailed soil data are presented in the section dealing with *Economic and environmental geology*; they include parent material, colour, texture, trace elements, and age. In brief, Wollaston soils show recognizable and consistent textural and trace element trends in the soil profiles. Soil development is weak, however, and does not affect the depth of sampling for geochemical investigations. The soil profiles appear to be a response to several processes: pedogenic, cryogenic (periglacial), and eolian. Soils on

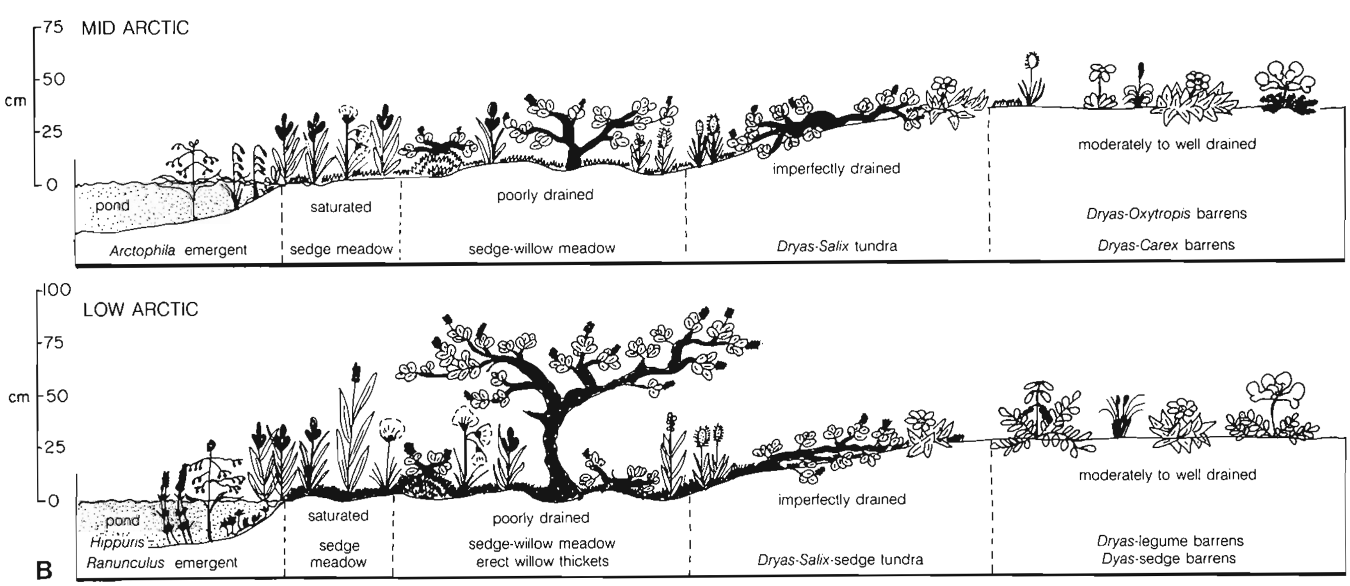


Figure 7. A. Arctic ecosystems of western Victoria Island (from Edlund, 1983). L=Low arctic zone with erect shrubs; D and P cover the mid arctic zone with dwarfed and prostrate shrubs. **B.** Catena showing plant communities of low and mid arctic ecosystems (from Edlund, 1983; 1989).

Wollaston Peninsula are Late Wisconsinan. Soil formation on Wollaston Peninsula may be faster because of climate and the texture of the carbonate substrate than in other studied Late Wisconsinan arctic terrains.

Methods of study and analysis

This study was based on field, office, and laboratory methods. Field work was carried out mainly in 1982 and 1983 from seven, week-long camps. Additional work was done in 1987. Ground surveys consisted of traverses using three-wheel Hondas and walking. Helicopter traverses were used from smaller camps, for till sampling traverses and detailed site investigations.

Detailed sediment logging was carried out at selected sites using helicopter, which brought in hand-portable water pumps to clean and expose sections. Trenching was used when no natural exposure or slope was available. Soil pits were dug as part of trenching and complete soil profiles were measured at many sites. Trenching also provided data on the depth of the active layer and the presence and nature of ground ice in permafrost.

Typical field surveys also included determinations of landform, sediment type, vegetation cover, bare soil area, stoniness, lithology of boulders and cobbles (in places), drainage conditions, and genesis of the material. Lengthy searches were made for datable material, particularly marine fossils.

Much of this work relied on mapping landforms and sediments on aerial photographs. By annotating more than 1000 photographs (scale of 1:60 000 flown in 1958), tonal patterns and forms could be related to ground observations (see numbers on Map 1650A). LANDSAT images were also used to allow regional patterns to be recognized.

Laboratory methods mainly involved standard techniques for analyzing samples submitted for textural, geochemical, and mineralogical determination. Laboratory analyses were conducted at the Geological Survey of Canada Sedimentology Laboratories, except for geochemical analyses, which were carried out at Bondar-Clegg and Co. Ltd. Methods are as follows: textural analysis consisted of disaggregation, sieving, and pipette analysis on particles 2.000-0.002 mm (2μm). Interpretation of geochemical results derives from study of the clay fraction (<2μm). The following trace elements were analyzed by atomic absorption following leach with hot nitric and hydrochloric acids: Co, Cr, Cu, Fe, Mg, Mn, Ni, Pb, and Zn. Colorimetric techniques were used for As analysis, and fluorometric methods were used for U determinations. Accuracy and precision criteria are available from Bondar-Clegg (Ottawa) for the trace elements.

Total and organic C contents were determined on the silt-plus-clay fraction using an electric induction furnace-combustion gas carbon analyser (LECO) and acid digestion techniques, the difference being taken as percent nonorganic carbon. The value produced is equivalent to a calcium carbonate content that would be required to give the measured result (and is expressed as a percentage by weight). The clay fraction was studied for clay mineral determinations.

Heavy mineral analysis was carried out on the fine sand fraction (63-250 μm). Bromoform (s.g. 2.83-2.85) was used to separate the light and heavy mineral fractions.

Evaluation using LANDSAT imagery

Rapid and periodic terrain evaluation is both feasible and efficient from LANDSAT imagery (Slaney, 1981). This section describes the geomorphological features and interpretations that were made from LANDSAT images of Wollaston Peninsula. Preliminary yet significant terrain evaluation was determined rapidly from these images (Table 1). Two LANDSAT images were used from the multispectral scanner (late July 1971) at the scale of 1:250 000 (Fig. 6A,B).

The immediate benefit of using LANDSAT imagery is that two images cover Wollaston Peninsula rather than the ~1000 aerial photographs at the scale of 1:60 000. Although small-scale resolution was lost, considerable detail was preserved. For example, many of the landform belts depicted on Map 1650A could be identified: ground moraine, hummocky moraine, individual end moraine ridges, (sheared or deformed moraine ridges, large outwash deposits, large deltaic accumulations, drumlin fields, other longitudinal landforms (fluting or drumlinoids), and marine limit where vegetation was variable (Sharpe, 1988). Large icings could also be readily identified. Recognition of such flooding events raises the potential of monitoring lake draining events such as those possibly triggered by permafrost degradation.

Large structural patterns, jointing, and faulting systems in the underlying carbonate bedrock could be readily identified because of the broad field of views on LANDSAT images. Colour and tonal patterns could be clearly distinguished on LANDSAT images. These patterns relate to moisture regime, vegetation, and, ultimately, soil textural and permafrost conditions on the ground.

Light-coloured areas are characteristically coarse textured, well drained, and poorly vegetated (less than 25% ground cover especially in morainal areas). White areas in lower topographic settings are mainly unvegetated deposits of marine silt (possibly later wind-blown), especially close to present seashore. Other light areas also indicate sparse vegetation on sandy soils in morainic or outwash areas. Dark colours commonly relate to well vegetated (<75% ground cover) areas and to coastal areas where marine fine sediments occur below marine limit.

SURFICIAL MATERIALS

This section describes the Quaternary sediments and landforms on Wollaston Peninsula corresponding to each of the map units (1-16) shown on the surficial geology map (1650A) from, in general, oldest to youngest. Some sediments do not readily fit a strict age order because they form facies equivalents in proximal and distal settings. Landforms are discussed briefly here, but a full discussion of what is known of the internal composition, formation, and origin of each landform is given in the next section on *Major landforms*. Ground observation sites are numbered on Map 1650A.

Table 1. Terrain characteristics identified from LANDSAT images of Wollaston Peninsula

Colours	Feature	Geomorphological unit	Comment
Dark green, black	Low relief or level	Featureless till plain or distal outwash sediments (fine sands); coastal plain	fine grained soil; poor drainage
Dark green/yellow	a) Upland morainic with many small lakes (transitional)	Hummocky moraine	Relief provides drainage; potential buried ice
	b) Lowland	Drumlin field (individual/ multiple)	Bedrock or silt between drumlin
Predominantly white	Upland crests and ridges with a few lakes, kettle lakes	End moraine; discrete moraines visible; hummocky moraine in smaller areas; felsenmeer	Joint pattern in carbonate bedrock
Bright white	a) Uniform silt, fine sand, or gravel; marine, alluvial, or outwash	Predominantly marine silt (distal deltaic) with less alluvial silt and marine flats; some uniform outwash gravel	Eolian influence
	b) Thin drift and bedrock areas		Joint patterns
Red	Lake ice, ocean ice saturated (isothermal)	Warm, isothermal ice	Late July image
Pink (white mottles)	River icings, ocean ice (cold)	Cold, coherent ice	Seasonal groundwater
Note: marine limit defined by boundary between dark green and predominantly white tones.			

The surficial geology map (Map 1650A) characterizes the surficial materials and landforms and interprets their genesis. This map portrays units defined in terms of geological or rock stratigraphic units and morphological units. Rock stratigraphic units define materials solely in terms of their lithology. Morphological units emphasize the landform in areas where it was not possible to make a clear lithological assignment. For example, diamictons produced by solifluction and debris flow are difficult to distinguish from direct glacial deposits or till, particularly in hummocky moraine and end moraines. These two landforms also comprise thick stratified sequences. Landforms were thus emphasized rather than mapping "surface diamicton," rock stratigraphic unit, over 75% of the map.

Morphological units, in addition, do not follow a strict time sequence as rock stratigraphic units do. Some of the map units are also time-transgressive and do not fall readily into one time order. Therefore ice marginal deposits appear below subglacial deposits and hummocky moraine because ice marginal deposits are first revealed upon retreat of the ice sheet. Not all ice-marginal deposits, however, should be so ranked in time because there are younger sets of these deposits.

The properties and genesis of the deposits are described in the map legend. Table 2 summarizes the geological units on Map 1650A and relates them to landforms and expected materials. Details of three landform-sediment associations, highlighted in the table, are each presented in a later section.

Sediments and bedrock areas

Bedrock areas (R, R)[1]

Paleozoic carbonate bedrock underlies all of mainland Wollaston Peninsula. Miles Islands off the southern coast consist of Precambrian or Cambrian sedimentary rocks or gabbros, or both.

[1]Unit designator on Map 1650A

Table 2. Summary of geological units

Geological unit	Landform	Sediments
Terrestrial deposits		
Eolian deposits	Dunes, loess cover	Fine and medium sand; minor silt
Organic deposits	Wetlands, swamp, fen	Peat, muck, minor mineral soil
Colluvial deposits	Solifluction lobes, aprons, debris flow lobes	Sandy silt diamicton with organic debris locally
Fluvial deposits	Floodplains, terraces	Gravel, gravel sand, and silty sand
Felsenmeer	Rock domes, blisters, block fields	Angular cobbles and boulders
Marine deposits		
Littoral deposits	Raised beaches	Sand and cobbly gravel
Tidal deposits	Tidal flats	Silt, sand, very minor gravel
Sublittoral deposits	Marine shelf	Sandy silt, silt, clay, minor gravel
Deltaic deposits	Marine delta	Gravel, sand
Glacigenic deposits		
Glaciomarine deposits	Fans and deltas	Gravel, sand, silt, minor clay
Glaciolacustrine deposits	Fans and deltas	Gravelly sand, silt, clay
Glaciofluvial deposits	Sandurs, terraces	Gravel, gravelly sand
Hummocky moraine deposits	**Hummocky moraine**[1]	Diamicton, gravel, sand, silt
Subglacial deposits	**Ground moraine (streamlined forms**, drumlins, drumlinoid, and flutings)	Diamicton, sand, silt, and gravel
Ice marginal deposits	**End moraine (lateral moraine**), shear moraine	Diamicton, sand, gravel, boulders
Bedrock	Carbonate plateau, escarpments; Precambrian hills	Felsenmeer (carbonate)

[1]Highlighted landforms are discussed in detail in the section *Major landforms.*

Carbonate bedrock is exposed in coastal and lowland areas, in areas between drumlins, and in scoured areas above Kugaluk River. Striae and p-forms (Dahl, 1965) (sculpted meltwater erosion features) are recorded on these bedrock areas. Striae are difficult to find because of bedrock weathering from frost action and solution of carbonates. Striae data are shown on Map 1650A from this survey and those of Washburn (1947) and Fyles (1963). Striae data generally show east to west flow, parallel to major streamlined landforms. Sculpted erosional features with scalloped, fluted, and trough-like forms or p-forms are common in the southern bedrock areas. These forms are oriented subparallel to streamlined landforms and show an east to west direction of paleoflow. Sculpted forms are identical to fluvial forms produced in laboratory flumes (Allen, 1982). This type of erosion complements erosion by ice as recorded by striae, quarrying, and plucking. In some locations larger forms, such as rock drumlins and roche moutonées occur.

Felsenmeer has developed on bedrock found above Kugaluk River. It occurs in areas that have been swept clean of sediment by meltwater discharges along the route of Kukaluk River high above its present course. The felsenmeer apparently formed during postglacial time. Some older felsenmeer may have escaped glacial transport. Most of the jointing patterns present on carbonate terrain are however, clearly younger than weathering patterns from preglacial features. Some jointing may be confused with linear glacial features whereas others have been enhanced by postglacial frost heave that has produced linear ridges of rocks along bedrock joints (Fig. 8A,B).

Ice marginal deposits (1)

Ice marginal deposits refer to sediment, from within end, shear, and lateral moraines, that is deposited at the ice margin. Much of their sedimentary character depends on the actual process of deposition, which can only be inferred from the landform and from a few exposed sections.

Diamicton and coarse, bouldery rubble occur on most end and lateral morainal surfaces, particularly the large, broad, multiple ridges that comprise the Colville moraine system. Some smaller, poorly vegetated, sand and gravel ridges were observed. The diamicton surface has both small (3 m) and large (30-50 m), nonsorted polygonal patterns developed on it. These large polygons are most prominent and they are different and larger than polygons on other surfaces (gravel and silt). This association of patterned ground aids in interpretation of diamicton from aerial photographs. Large polygons appear to be common on upland diamicton surfaces above marine limit (Fig. 9). Bouldery and stoney surfaces are common on moraine crests and in particular on deformed (shear) moraine ridges. The nature of subsurface sediment in ice marginal deposits is poorly known because of the lack of exposures beneath the active layer. In some areas thick ground ice is suspected (see section, *Nature of ground ice* and Fig. 9). In a few areas stream bluffs reveal thick sequences, and an abundance of stratified sediment was observed (e.g., Cape Back moraine – see section on *Major landforms*). Deposits of the Cape Back moraine consist of more than 20 m of interbedded diamicton, sand, gravel, and in some places silt and clay. Diamicton comprises only half of the sediment sequence and diamicton at the surface is either till or reworked slope deposits. Sand and gravel interbeds are massive to stratified and usually horizontal.

A more complete discussion of moraines is presented in the following section on *Major landforms*.

Subglacial deposits (2)

Subglacial deposits include diamicton deposited as till as well as related stratified sediment. The deposits include diamictons that moved downslope as solifluction material.

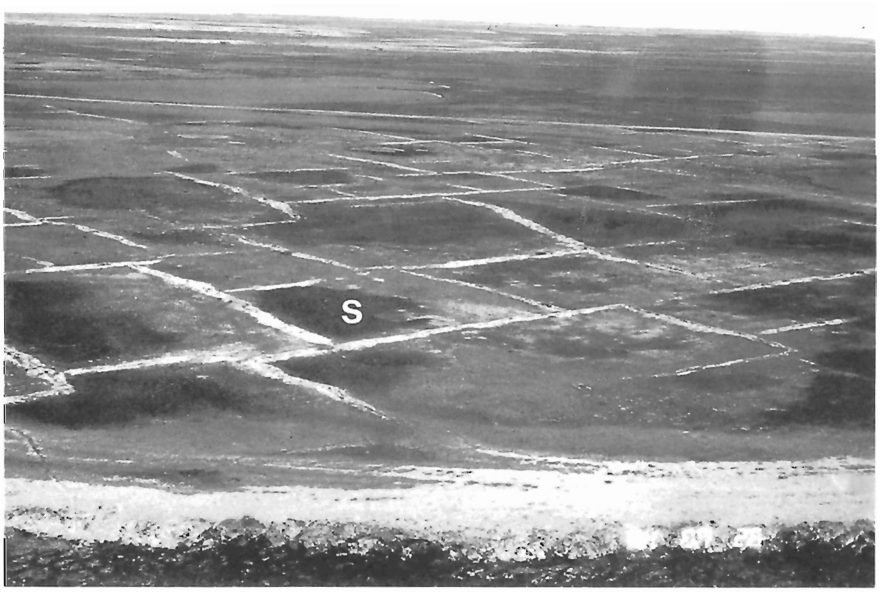


Figure 8A.

Rock heave along fracture and joint system in carbonate bedrock. Square 's' is 80 m. GSC 204439-A

Figure 8B.

Doming (rock heave), surface view. GSC 204535

Stratified sand and gravel is also included where it is interbedded with till or otherwise deposited contemporaneously with till.

These deposits occur mainly in areas of ground moraine on level terrain in central Wollaston Peninsula, where till is a few metres thick over bedrock. Thicker subglacial deposits occur in the large drumlin field on southern Victoria Island and in smaller drumlin fields on western Wollaston Peninsula.

Diamicton interpreted to be till consists of loose-to-compact, stoney, sandy silt (Fig. 10) that is pale brown, brown, and pink (field colours) when weathered, and light brownish grey to light pinkish grey when frozen or less weathered. Colours of dry sediments tested in the laboratory were about equal between 10 YR (pale brown) and 7.5 YR (pinkish grey). The 7.5 YR colours determined in the laboratory are overestimated compared to colour determinations made in the field. The pinkish coloration of the till is the result partially, but not entirely, of soil forming processes. There seems to be no clear spatial pattern to the pink coloration of the till, and no source rock has been positively identified that can readily explain its distribution. It is possible that Cambrian or lower Ordovician rocks (red shale and siltstone) from the south coast of Victoria Island (Fig. 2) might be a source. However, this possibility does not explain red colours in till located along northern Wollaston Peninsula because dispersal patterns from this source are not continuous.

The till commonly contains local striated carbonate clasts that indicate transport in the base of glaciers. Percentages of striated versus nonstriated carbonate clasts are as high as 50-60%. About 10% erratic nonpaleozoic clasts (gabbros, gneisses, metasedimentary rocks, and volcanic rocks) are found as boulders in the till. Although they may have been carried englacially for most of their transport, their greater hardness compared with carbonates may explain why they are usually not striated. Matrix material from the diamictons has uniformly high (50-60%) carbonate values (Appendix 1) in all till samples, which further indicates incorporation and deposition of local carbonate source-rock.

The lithological character (mineralogy and texture) of the till was effectively uniform over large areas of Wollaston Peninsula based on field and laboratory results (Table 3 and Fig. 11). This uniformity made it difficult to identify local lithological facies on the map. Local, distinctive rock types, however, allowed several dispersal patterns to be described. In the area west of the Richardson Islands the reddish till may relate to red-coloured metasedimentary rocks exposed to the east, and possibly west, of the Richardson Islands. Other reddish areas are noted but there appears to be no clear link to a source rock. The area west of the Richardson Islands also shows the only clear dispersal pattern, a negative dispersal train (low values) for matrix carbonate (Fig. 12). This pattern reflects regional ice flow from southeast to northwest.

Variation in matrix texture of till is indicated by several silty to clayey silt samples (Table 3; Fig. 11), which differ from the normal sandy texture. These sample areas are underlain by carbonate rocks similar to most areas of Wollaston Peninsula, which suggests that local, subglacial or ice-marginal ponding produced fine sediments that were later incorporated. In other areas some surface samples show evidence of contamination. Below marine limit, or within proglacial lacustrine basins, marine or lacustrine silt and clay has become mixed with till matrix by cyroturbation. Thin veneers of fine sand, silt, and clay cover till in patchy areas below marine limit and within lacustrine basins. Also in areas adjacent to broad alluvial plains (Kugaluk River) and marine deposits, eolian silt and fine sand are draped over till surfaces.

The regional till, where observed in a few places, was in contact with stratified sediment (Sharpe, 1988). This contact was conformable and sharp in places but neither deformed nor erosional in nature. In some places it was transitional and the two sediments were interbedded. No pattern of sand incorporation into overlying diamicton was observed in these areas. Bedrock formed the lower contact in ground moraine and in areas of thin, streamlined (fluted) forms. The till described within the map unit, is lithologically similar to that found both in morainal deposits and on the surface of hummocky moraine (Appendix 1).

Hummocky moraine deposits (3)

Deposits within such a complex landform as hummocky moraine are difficult to characterize, particularly with the limited exposure available; however, several major trends were identified. Areas of large, rounded hummocks and depressions are covered with diamictons interpreted as till, sediment flows, solifluction, and colluvial material. These diamictons were observed as interbeds with stratified sediments, and some contain datable organic material. The presence of organic material suggests common slumping, some of which could be part of the primary process of landform construction.

The sediments within the hummocky moraine deposits continue to be redistributed as buried ground ice is exposed and melts, which leads to thaw slumping and sediment flows (see ground observation site 135). Much of this ice may be remnant Pleistocene ice, possibly glacier ice, based on stratigraphic and isotopic studies (Sharpe and Michel, submitted). (This aspect of hummocky moraine development is further developed in the section on *Thermokarst activity*.)

Various forms and sediment comprise hummocky moraine: linear ridges and sediment plateau (Stalker, 1960) are locally common features. They are characterized by poorly exposed, coarse, bouldery sediment. Some exposures revealed poorly sorted, cobbly material that had the appearance of sorted outwash sediments. Most linear ridges appear to form ice-marginal accumulations and the plateau areas appear to form fans or small aprons within former ponded basins (Fig. 13). Sediment in the distal margins is pebbly gravel and fine, sandy diamicton in places. In other areas, kame-like accumulations contain well sorted sand and gravel. In places, the sediment is horizontally stratified. These small kames are shown on Map 1650A with a symbol. Landform-sediment association in hummocky moraine is discussed more fully in the section on *Major landforms*.

Glaciofluvial deposits (4a, 4b)

Glaciofluvial deposits form outwash terraces and plains (4a) and ice-controlled or ice-contact, fluvial landforms or eskers (4b). Outwash deposits form broad sheets situated on the level interior plains of Wollaston Peninsula adjacent to the large hummocky moraine belts. The sediments are of three types: mainly subrounded boulders in ice-proximal sites; subrounded cobbles to rounded pebbles in mid-distance sites 2-5 km from an ice margin; and pebbly sand and silty sand in distal areas (>5 km from source). The deposits are braided where sedimentation was high and terraced where later downcutting has occurred.

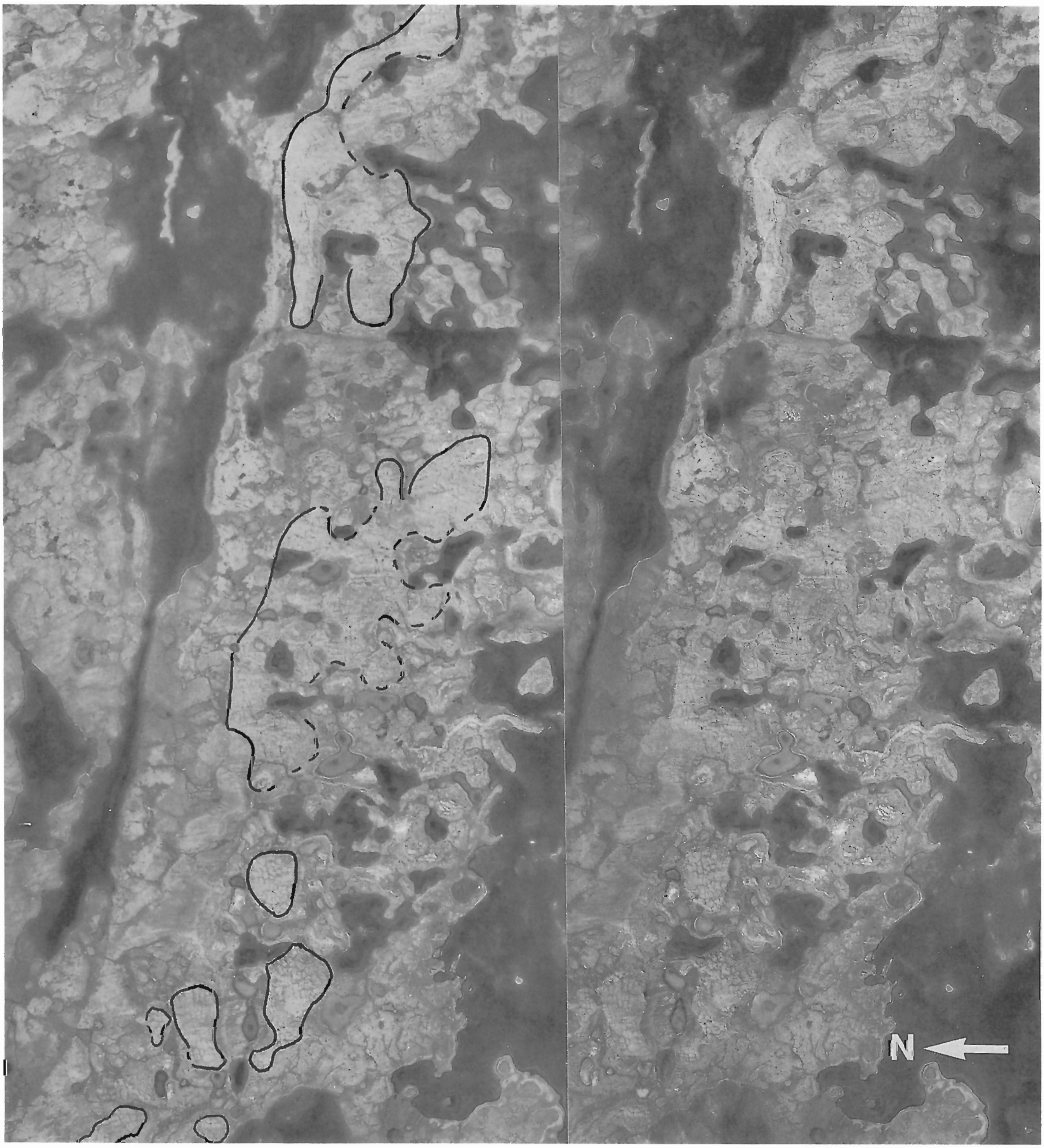


Figure 9. Large polygons developed on diamicton (morainic) surfaces above marine limit (highlighted). Polygons may indicate the presence of buried ground ice (see section *Nature of ground ice, massive ice*). (Stereopair from NAPL A15787-112,113)

Outwash also occurs in deposits 10-20 m thick adjacent to the Colville moraines in northern and southern Wollaston Peninsula where coarse, cobbly gravel is found. The deposits form thick, terraced sequences that merge downstream with a large glaciomarine delta (site 5, see Figure 16A). Outwash also forms prominent flights of terraces along the north coast of Wollaston Peninsula where meltwater drained westward along the margin of ice masses formerly situated in Prince Albert Sound. As ice melted down and retreated eastward, successively lower ice-supported terraces were formed.

Coarse bouldery and sandy sediment (in places a poorly sorted, matrix-supported diamicton) forms a portion of, or drapes, esker surfaces. Stratified cobbly (occasionally bouldery) gravel and sand and rhythmically laminated silt and clay also occur within eskers. These beds may be slumped, particularly near the flank of the esker ridge, but some beds are horizontal and undisturbed. The deposits within flat-topped eskers are also horizontally bedded, and they are typically undeformed (north coast, Map 1650A).

Figure 10. Till deposits, with 50% striated clasts and strong preferred fabric, Wollaston Peninsula, Victoria Island. GSC-1991-168

Glaciolacustrine deposits (5a, 5b, 5c)

Glaciolacustrine deposits are scattered across the map area above marine limit. Gravelly sand and, in places, bouldery sediment (5a) form large fans or deltas immediately above marine limit and adjacent to former ice margins (Map 1650A). These deposits (because they are unfossiliferous) can be confused with glaciomarine gravel where marine limit is neither prominent nor continuous (Map 1650A).

Adjacent to the margin of the southern Colville moraine (Map 1650A) prominent low areas are covered with a veneer of discontinuous sand, silt, clay, and diamicton (5b). This sediment apparently slumped into an ice-marginal lakes and was redistributed as buried ice melted. These deposits were formed by sedimentation into short-lived (tens of years) lakes.

In other areas, thicker, glaciolacustrine, fine sediments (5a) accumulated. These deposits are exposed in pingos on northeastern Wollaston Peninsula. Such deposits were apparently formed in longer-lived lakes (rhythmites indicate hundreds of years) and probably were associated with the initial melting and breaching of ice cover on Wollaston Peninsula (Sharpe, 1984).

Glaciomarine deposits (delta/fan) (6)

Glaciomarine deposits were emplaced while glacier ice was in contact with, or very close to, the sea; hence they represent a time during which maximum sediment was entering the sea. Deposits are coarse bouldery gravel and gravelly sand adjacent to former ice margins or adjacent to coarse outwash systems. The outwash is extensive (up to 400 km^2), thick (30 m), and consists of coarse deltaic sediments that define marine limit where topsets occur on foreset beds (see site 5, Fig. 16A). Much of the thick silt and clay deposited far from the coarse topset and foreset deposits is glaciomarine in origin, although it has been covered by thin marine silt and clay (Map 1650A). These fine grained deposits are glaciomarine because they were introduced into the marine

Table 3. Summary of textural properties and geochemistry of tills on Wollaston Peninsula

Summary statistics	Grain size[1]					Geochemistry[2]									
	Gravel	Sand	Silt	Clay	Carbonate	Cu	Pb	Zn	Co	Ni	Cr	Mn	U	As	Fe
Maximum	80.2	88.2	79.7	30.7	84.9	120	39	160	21	44	58	640	1.9	36	5.3
Minimum	1.4	9.3	10.2	1.6	13.4	13	5	16	2	5	8	130	0.0	0	0.5
Average	25.6	46.9	39.7	13.4	58.7	37	17	46	9	22	27	337	0.7	9	2.3
Standard deviation	11.2	10.8	8.3	4.9	12.3	16	6	19	3	8	9	90	0.9	5	0.9
N	179	179	179	179	190	187	187	187	187	187	187	187	187	187	187

[1]Gravel as % of total sample; sand/silt/clay as % of <2 mm fraction; carbonate is % ($CaCO_3$ equivalent).
[2]Iron is %; all other elements ppm in $2 \mu m$ fraction; 0 = below detection limit.

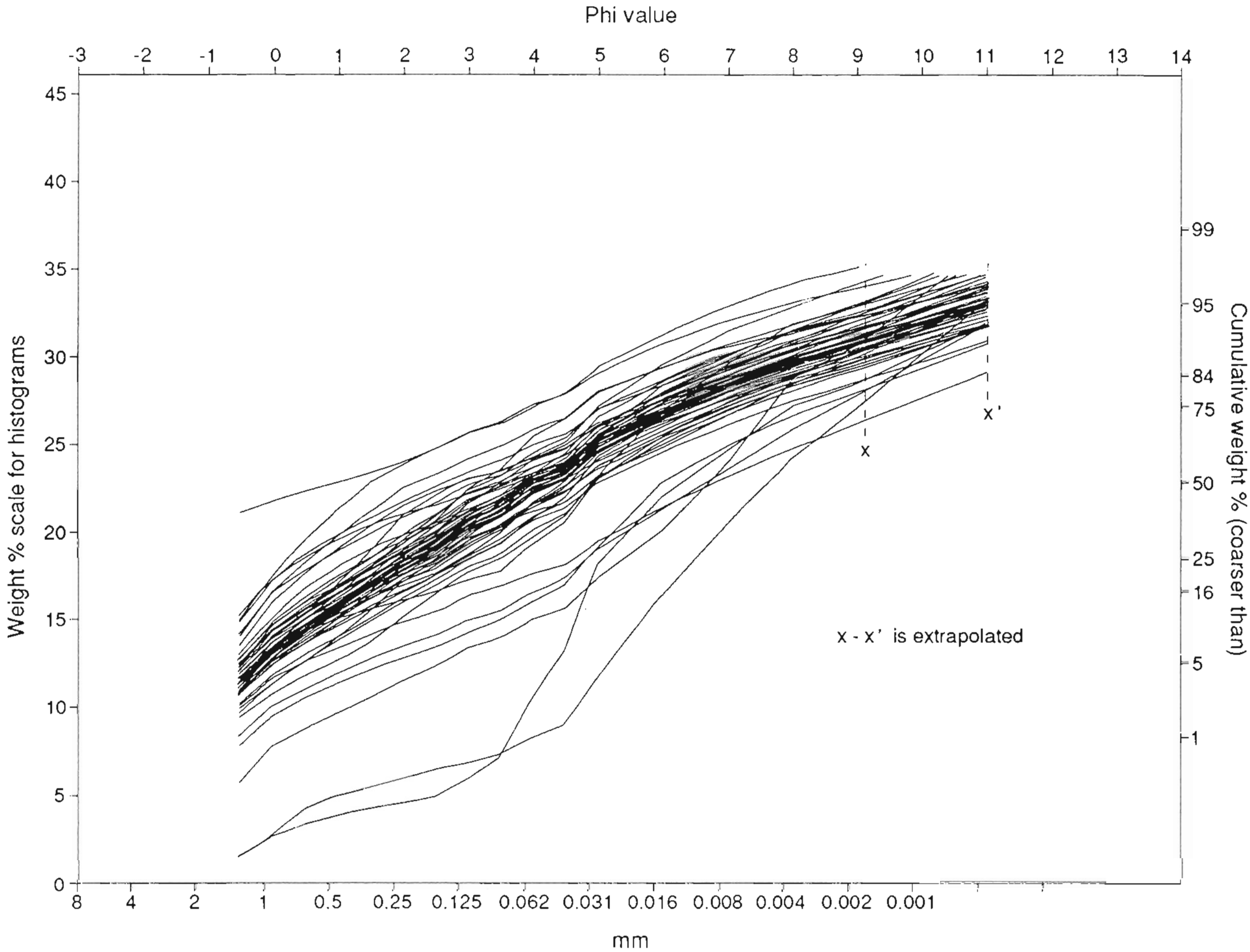


Figure 11. Logarithmic-probability graph of grain-size distribution of tills (50) from Wollaston Peninsula, Victoria Island.

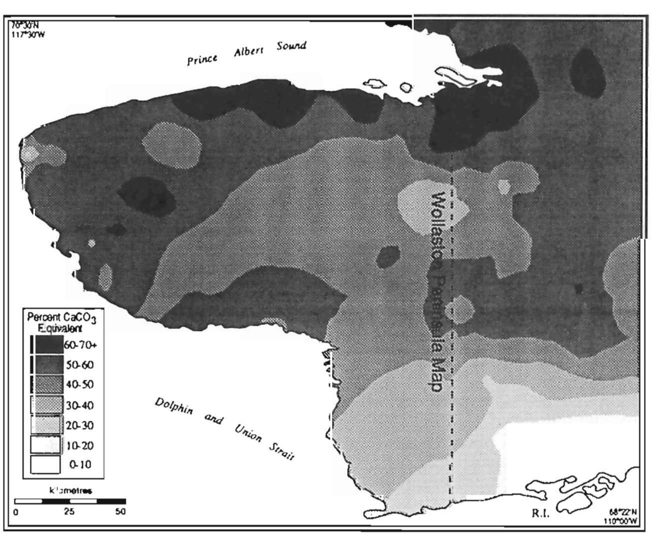


Figure 12. Distribution of matrix carbonate values in Wollaston tills. Pattern at 1:2 000 000 shows a carbonate dispersal shadow (low values) west of Richardson Islands (R.I.), a Precambrian complex off southeast corner of map. Ice flow was southeast to northwest, compare with Figure 2.

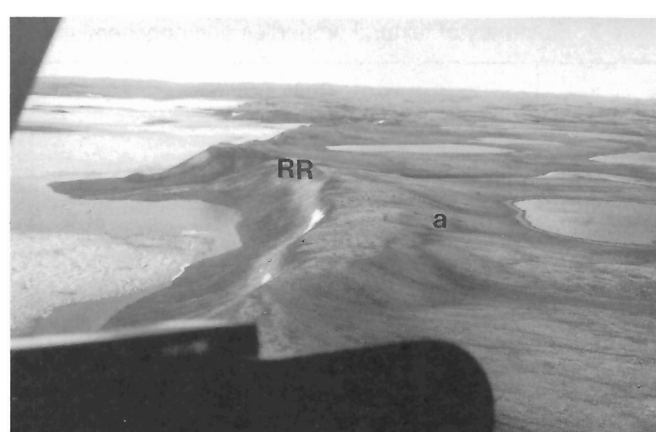


Figure 13. Small aprons (a) or fans in hummocky moraine showing prominent linear ridge (RR) feature. Relief from lake to top of feature is 35-40 m. GSC 204535-G

water column as overflow plumes while the ice was in contact with (or within a few kilometres of) the sea. The lateral transition from gravel to silt and clay is very rapid in many areas. These finer sediments were deposited close to the ice margin (and hence marine limit) because flocculation results in rapid sedimentation of fine particles in seawater. Fine sediments are commonly massive, infrequently banded, and may contain dropstones. Thick sediment packages connected to eskers and below marine limit are mapped as subaqueous fans on eastern Victoria Island (Sharpe, 1988b). Fan deposits are typically fine grained and massive; they have possibly been affected by slumping processes active during rapid deposition.

Deltaic deposits (7)

Small, thin (1-5 m) deltaic sediments found well below marine limit and along river courses are mapped as raised marine deltas. These deposits are not as thick as glaciomarine deltaic deposits because the sediment source was far removed. The deposits consist of gravelly sand and local cobble gravel that form dissected terrace flats along modern rivers. The deposits are analogous to adjacent raised strandlines but they are much less common than beach deposits.

Sublittoral deposits (8)

Marine silt, sandy silt, and clay form blankets close to glaciomarine deltas and fans. The deposits occur less continuously closer to present sea level. The deposits are massive to weakly laminated and do not commonly contain dropstones, although in places stones have slumped into the deposits from topographic highs. The deposits exhibit scour marks from icebergs or pack ice.

Tidal deposits (9)

Tidal deposits occur as minor deposits of silt and fine sand, but they are only recognized as tidal flats on western Wollaston Peninsula. Boulders can occur in these deposits either as a former lag or moved in by littoral processes, probably sea ice. The present tidal range on southwestern Victoria Island of <1 m was measured at about 50 cm at Cambridge Bay (Washburn, 1947). Resulting deposits may be difficult to distinguish from other shallow marine deposits.

Littoral deposits (10)

Littoral deposits comprise rounded, pebbly to cobbly gravel (1-5 m thick) that is typically well sorted and stratified (Fig. 14). Where abundant sediment was available for reworking, the deposits form continuous flights of raised former shorelines. Where they occur on bedrock, the deposits thin correspondingly (1-2 m) and can be confused with small bedrock scarps on aerial photographs.

Undifferentiated marine deposits (11)

Marine deposits consisting of silt and silty sand that occur as thin (1-3 m thick), patchy veneers are included as undifferentiated deposits. These deposits occur as patches on bedrock or till. The deposits are commonly scoured either by icebergs or, more probably, by sea ice.

Felsenmeer (12)

Felsenmeer deposits, consisting of platey angular gravel, are found on most exposed carbonate bedrock areas. They form mappable thicknesses (1 m) in meltwater-washed bedrock terrace areas along Kugaluk River. Locally, in other areas, rock heave forms (Fig. 8B) displaced 1-2 m indicate deformation of disaggregated blocks.

Fluvial deposits (13)

Fluvial deposits form gravel to gravelly sand terraces up to 10 m thick along the few major rivers in Wollaston Peninsula. Much of this coarse sediment is probably reworked from marine deltaic accumulations on smaller rivers or during large storms along Kugaluk River. However, the present annual floodstage appears to be too small to carry the largest clasts. Eolian silt and colluvial deposits are found on inactive parts of the floodplain. Extensive gravel deposits also occur on terrace sections where sand has been blown away.

Colluvial deposits (14)

Colluvial deposits consist mainly of a compact, stoney sand-silt diamicton (1-2 m thick) which occurs at the base of slopes clearly affected by solifluction, mass-movement, and thaw-generated slumping. When organic material or weathered debris is included in the diamicton or where the diamicton truncates lower beds (see Figure 30B), the sediment is more readily identified as colluvial debris. In other locations where mass-movement processes were either less active or older it is hard to distinguish colluvial diamictons from till. Colluvial diamictons may also be derived from till. In areas where thermokarst erosion is active, colluvial deposits are well defined. Upslope from the active slump sites are nested scars of older thermokarst slumping. This recognition of widespread colluvium suggests caution is needed before assigning the term till to unproven diamictons in arctic terrain. However, only the occurrences of colluvium that are clearly distinguished from till are shown on Map 1650A.

Organic deposits (15)

Organic deposits comprise sediment-rich (silt and fine sand) muck, and peaty material. The deposits are more extensive than shown on the map, and they commonly occur as veneers 50 cm or less in thickness. Local peat accumulations, adjacent to hummocks and willow thickets, are 1 or 2 m thick.

Eolian deposits (16)

Eolian deposits (silt, fine and medium sand), although extensive on Wollaston Peninsula, are commonly <50 cm thick (Fig. 15A). Mapped deposits occur as small dunes or blankets of fine sand and sandy silt adjacent to exposed fluvial or sandy marine sediments. Stony lags and ventifacts are common in areas affected by deflation (Fig. 15B). Eolian deposits can also be recognized in older sediments.

MAJOR LANDFORMS

The study of glacial landforms is closely linked to interpreting surficial deposits. The spatial arrangement of landforms may also be used to make inferences about glaciological conditions during their formation (Clayton and Moran, 1974; Aario, 1977; Boulton and Jones, 1979). Landform analysis is especially informative in small-scale mapping where regional relationships and transitions of the landforms can be observed (Aairo, 1977; Shilts et al., 1987).

Ground moraine, hummocky moraine, end moraine, shear moraines, and streamlined landforms (flutes, drumlinoids, and drumlins) are prominent on Wollaston Peninsula (Fig. 16A). These landforms occur as an array or as zones of landforms that are interrelated and may be related to different flow dynamics (Sharpe, 1984, 1988a). Because the landforms are arranged systematically in belts, they are discussed in that order (Fig. 16B). Streamlined landforms are also discussed more fully in a separate section. In addition, the internal sedimentary character of the few landforms that have sediments exposed are presented: 1) to describe the materials comprising landforms; 2) to map and predict the distribution of sediments; 3) to investigate the depositional or erosional origin of landforms; and 4) to allow sedimentological inferences to be drawn bearing on ice dynamics and retreat patterns.

Ground moraine

Ground moraine covers a large area of low-relief terrain underlain by flat-lying carbonate strata, particularly the central plateau (Fig. 4, 16A) where drift is thin. This generally featureless terrain is broken by segments of end moraines and by a network of drainage systems that mark a series of ice-marginal positions across the central upland (Fig. 4). The drift consists mainly of thin, sandy silt till, with minor areas of glaciofluvial sand and gravel and sporadic occurrences of

Figure 14. Littoral deposits show rounding, good stratification and sorting (pocket knife shows scale). GSC 204535-J

Figure 15A. Eolian deposits (E), with colluvial stones, over diamicton (D), northern Wollaston Peninsula. GSC 204442-A glaciolacustrine silt. Thicker sediments occur where ground moraine is transitional to local drumlin fields or fluted terrain. A sediment record for each of the thin and thicker drift areas is described from two measured sections.

Kugaluk River and Boffa Lake

The measured two sections in ground moraine record stratified sediments beneath till. The lower sediments are considered part of the ground moraine deposition because no deformation occurs at the contact between the units and because the contact is conformable and possibly gradational (Fig. 17A). The thick sediments at Kugaluk River consist of a lower massive, stony, sandy silt diamicton (A) and poorly sorted, matrix-supported gravel (B) with an erosional contact. This layer is overlain by a thick, stratified sequence of sand (graded and massive) (C and E) with some disseminated organic material and rhythmites (D and G). A transitional zone, with interbeds of thin silty diamictons (F), grades upwards to a rhythmic unit (G). A sharp conformable contact occurs at the base of a thick, massive pebbly, sandy silt diamicton (H), which is interbedded (upper portion) with a weakly banded silt unit (I) containing marine shells (Fig. 17A).

The origin of the upper diamicton and its relationship to underlying stratified sediments is significant. The massive nature of the diamicton, its thickness (5-10 m), the presence of striated clasts, and the strong preferred fabric all indicate subglacial or basal deposition. The fact that this sequence rests on underlying undisturbed stratified sediments is similar to melt-out sequences (Shaw, 1982). The lack of sandy lenses and sortings within the diamicton, usually indicative of former englacial conditions, may not however support a melt-out origin. Sediment gravity flows are generally not more than a few metres thick; preferred fabric does not agree with ice flow; and, they occur as multiple units. These considerations suggest that the subglacial diamicton may have been deposited from very debris-rich ice by melt-out following regional ice flow. Deposition by lodgment over frozen stratified sediments is a possible origin, but one that would have been unlikely because lodgment occurs in association with wet-based glaciers. The stratified sequence under the diamicton unit represents a sequence fining-upwards from gravels to rhythmically laminated silt and clay with no hiatuses. Organics, clearly not occurring in situ, were flushed into the site during sedimentation. The old date (infinite) presumably relates to a former ice-free period as discussed in the section on *Events prior to last glaciation*.

Most of the contacts, although abrupt, have interbedded units that appear to be gradational. This sequence is believed to have been deposited in standing water by high-energy density currents. The coarser sediments are interrupted by suspension deposits of low-energy density currents towards the base of the sequence. The silt bands in the top of the diamicton suggests a debris flow origin into marine water, for deposition of the upper part of the diamicton.

The sequence fining upwards from gravel to clay is opposite to that expected from a terrestrial ice advance. Therefore, it may either be older and unrelated to the overlying till, or be considered to represent glaciofluvial sedimentation in deep standing water (fan deposition) followed by occupation by debris-rich ice. A similar, yet thinner depositional sequence (diamicton over undeformed stratified sediment) is depicted at the Boffa Lake site (Fig. 17B).

Ground moraine transitional to hummocky moraine

Transitional landforms provide information on the nature and timing of the boundary between ground and hummocky moraine. Several large subaerial fans (OF, Fig. 16A) extend onto ground moraine from higher, hummocky moraine adjacent to and surrounding the ground moraine. These features have gentle gradients that merge at the distal end with the level ground moraine. An intricate braiding pattern has developed on their surface. Sections are not well exposed in this terrain whether within coarse gravel or within finer distal sediments.

At the distal end of the large fans are elongate ridges (Fig. 18A) that are generally level-topped and somewhat irregular in plan; these trend gently downslope from either hummocky moraine (Fig. 18B) or from the large fans. Sediments consist of interbedded sequences of pebbly sands,

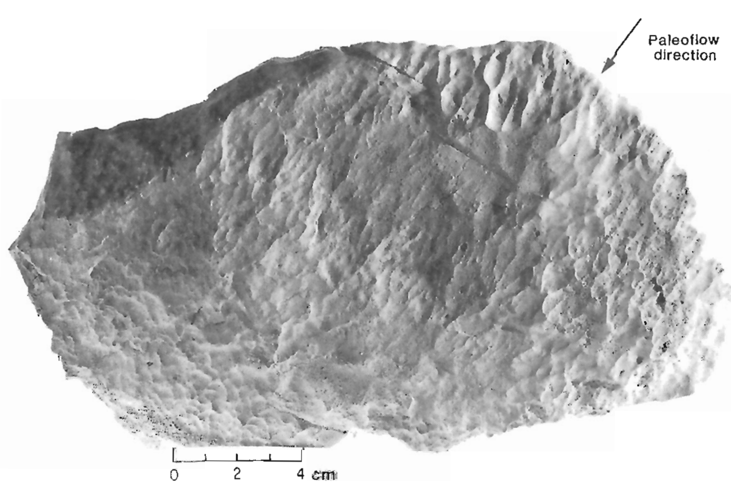


Figure 15B.

Ventifact showing characteristic sharp flute edges relating to flow separation in turbulent flow; flow (arrow) was from top right to bottom left. GSC 204441-A silt diamicton, and massive, moderate to poorly sorted fine sand with pebbles (Fig. 18C). Several small exposures in linear ridges show similar stratigraphy.

The linear ridges are interpreted as open crevasse fills created by meltwater and gravity flow of glacial debris. Sediment was deposited in subglacial cavities or open tunnels as the ice mass began final melting, probably at the end of ground moraine deposition and just prior to, or at the start of, hummocky moraine formation. It seems in this level terrain, that extending glacier flow predominated over compressive flow conditions prior to melt. Debris apparently did not move up onto the glacier to produce extensive supraglacial sediment flows within the ground moraine area but was later concentrated in linear ridges.

Hummocky moraine

A broad zone of hummocky moraine (up to 45 km wide and several hundred kilometres long) encircles Wollaston Peninsula, mainly above marine limit (Fig. 16A, 19). The hummocky moraine comprises large upland areas, depressions (many of which are lake filled), and plateaus (Hoppe, 1952; Stalker, 1973) that consist of linear, flat-topped ridges of stratified drift. The large hummocks are rounded but commonly have isolated mounds, ridges, or delta-like features perched near the top. These latter features are generally barren of vegetation, well drained, and composed of stratified and massive sand and gravel. In addition, large uplands of hummocky moraine commonly have thaw-slump scars ranging in age from very old (possibly early postglacial) to present day where there is active failure adjacent to buried ice (possibly glacial ice or Pleistocene age ice?). As much as 40% of the hummocky moraine area consists of kettle depressions and lakes formed by thawing of buried ice (Fig. 6B).

Fresh hummocky moraine occurs to about 400 m a.s.l., and this glacial limit suggests that extensive ice covered Wollaston Peninsula during formation of hummocky moraine.

Measured sediment sequences

Three major sections were measured in the hummocky moraine of Wollaston Peninsula near Ammalurtuq Lake (A, Fig. 19). These sections reveal a surprising frequency of stratified drift and a low percentage of diamicton beds. This finding contrasts with typical sequences that may indicate hummocky moraine formation by resedimentation of diamictic glacial debris from on top of the glacier (Lawson, 1981, 1984). The following

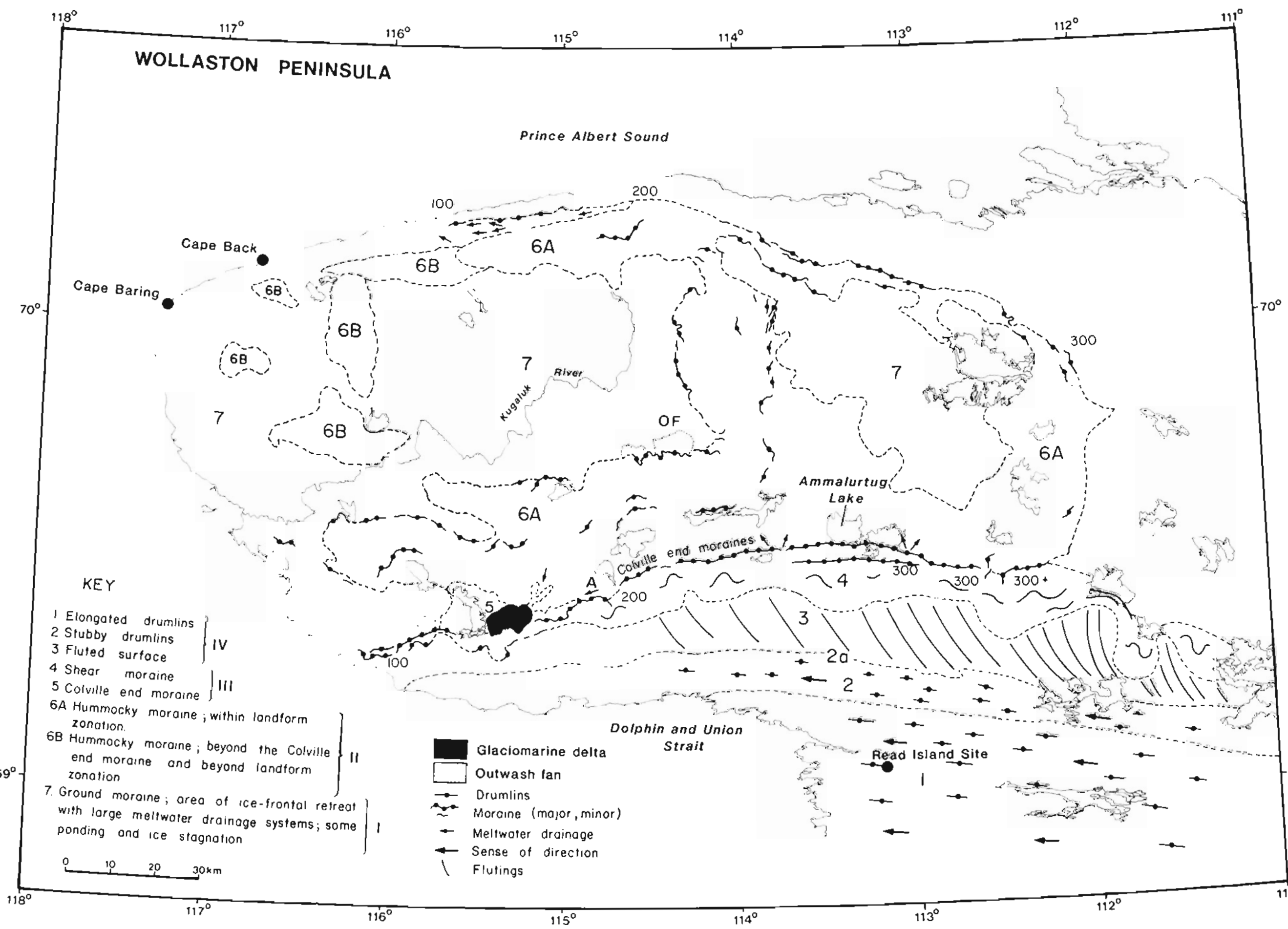


Figure 16A. Arrangement of major landform set on southern Wollaston Peninsula, Victoria Island. Unit 2a indicates margin of drumlin field. 100, 200, 300 indicate m a.s.l.

sections depict only a small portion of sediments from hummocky moraine (Fig. 20), particularly sections not associated with thermokarst erosion. Sections from these areas have more diamicton, similar to those of Lawson (1984), and they are reported in the section on *Thermokarst activity*.

Section 135. Section 135 shows an intact, horizontally bedded sequence consisting of thin diamictons, gravel, and sand capped by slope debris (Fig. 20A). Much of the sand in this section is massive. Fine sand and silt are normally graded. The underlying gravel is poorly sorted and weakly stratified. The gravel is interbeddded with lower diamicton. The lack of structure in the sand and gravel units suggests that these could be mass or highly concentrated flow deposits. The diamicton beds are interpreted as debris flows because of their thin and interbedded nature. The thin bedded, finer sediments (fine sand and silt) indicate deposition in quiet water or ponded conditions.

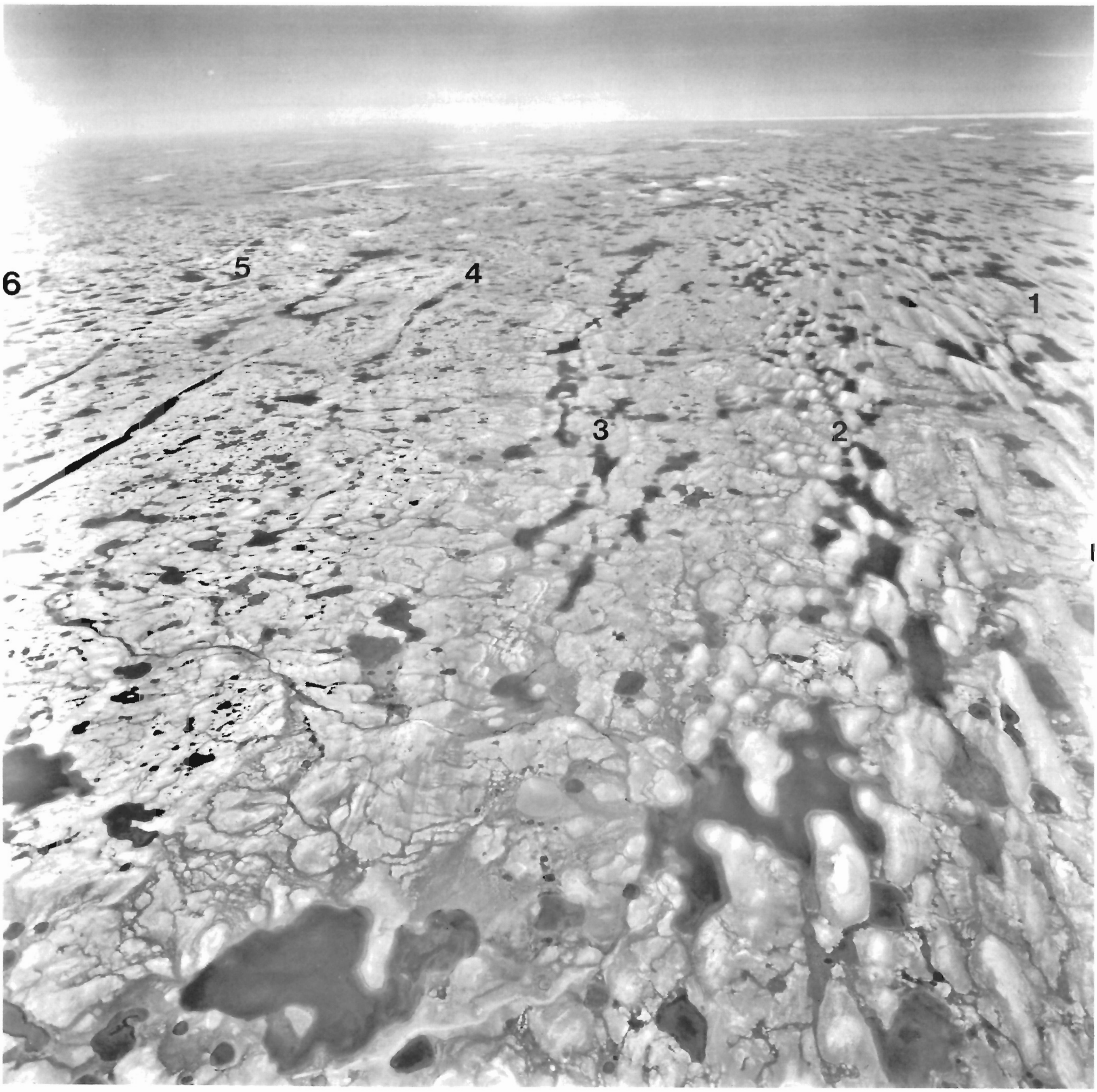


Figure 16B. Oblique aerial view of major set of landforms, Wollaston Peninsula, looking east. Numbers for landforms (I-IV) are the same as Figure 16A. NAPL T328L-204

Section 136II. In section 136II (Fig. 20B) beds that are tilted, faulted, and distorted are interbedded with undisturbed horizontal beds. Finely laminated silt, fine sand, and clay beds are interbedded with sand, gravel, or diamicton beds. Interbedding of disturbed and undisturbed units indicates that the disturbances are depositional. Presumably disturbance occurred by failure immediately after sedimentation on one unit and prior to deposition of the next unit.

Section 136III. Section 136III (Fig. 20C) occurs within large hummocks of 20-40 m relief. The measured section occurs low in the moraine landscape. At least 10-12 m of sediment displaying solifluction lobes is found above the section. This section also comprises beds that are all horizontally bedded including diamicton, gravel, sand, and laminated silt and fine sand. Some beds are normally graded. Sand, gravel, and diamicton beds are massive or crudely bedded.

Many of the beds in these three sections may indicate mass flow deposition. Suspension settling may explain deposition of graded fine sand. The repetition of several units may suggest some episodic sedimentation mechanism. Silt and fine sand beds suggest quiet water deposition. Repeated density underflow including debris flow activity may be inferred as processes of deposition. No extensive lake can be surmised but local ponding can clearly be established from these sedimentary features.

Models of hummocky moraine formation

Hummocky moraine is situated down-ice from, and partly mantles, a bedrock scarp or cuesta forming the core of Wollaston Peninsula (Fig. 4A). This type of topographic obstruction produces compressive flow in overriding ice. Topographic obstructions are key elements in some models of hummocky moraine formation (Clayton, 1967) as are groundwater flow and permafrost (Moran et al., 1980). Other models, from recent glaciers showing marginal compression (Lawson, 1984), rely more on explaining the sedimentary structure of hummocky moraine. By characterizing sediments from sections within hummocky moraine, models of their formation are evaluated.

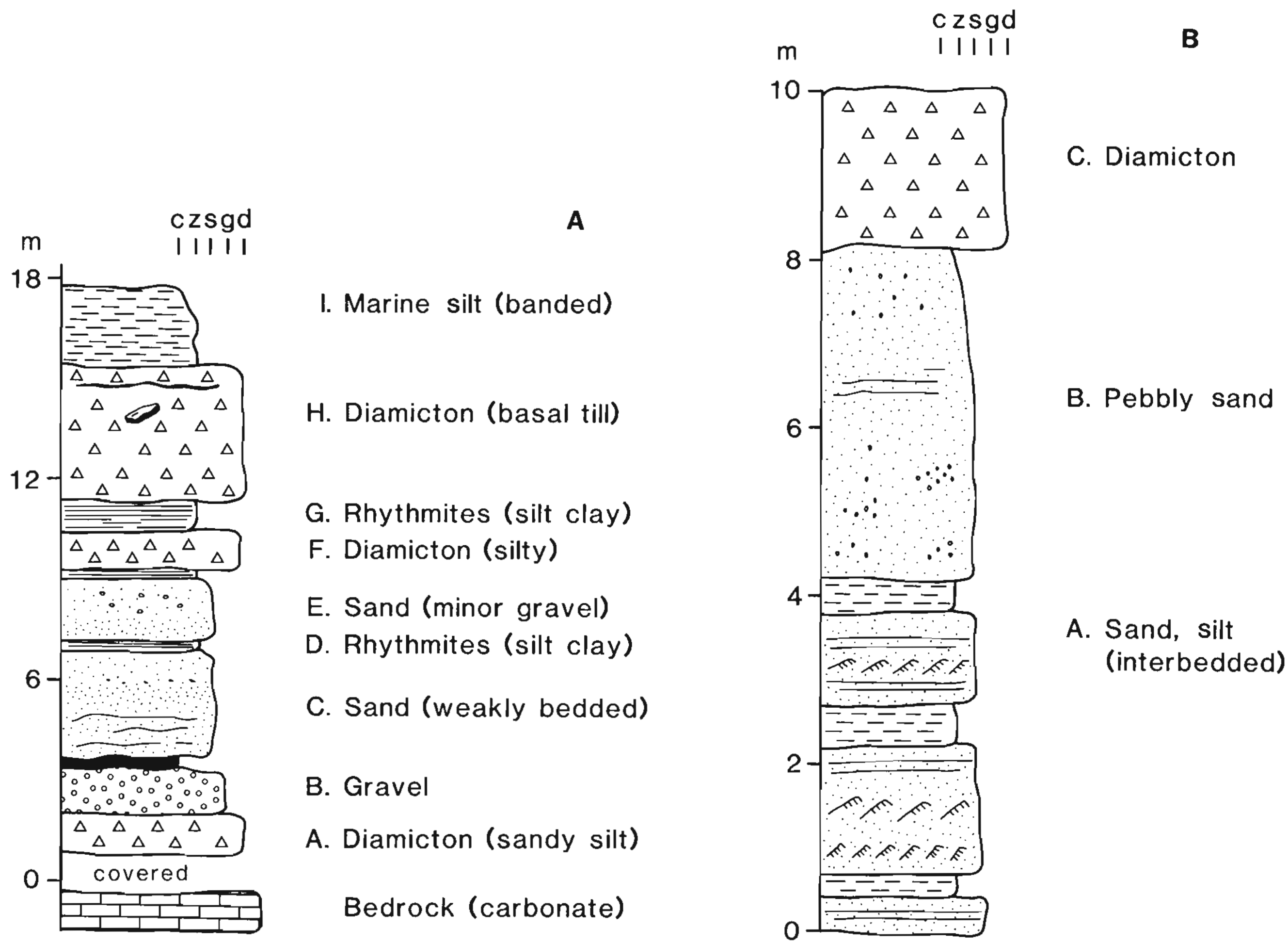


Figure 17. Measured sections and stratigraphy of diamicton and stratified sediments: **A.** at Kugaluk River (Site 872, Map 1650A); and **B.** at Boffa Lake (Site 846).

The horizontal bedding and intact nature of strata in described sections seem to be different than the sediment sequences expected in several common models of hummocky moraine formation (Clayton, 1967; Eyles, 1983; Lawson, 1984). The Missouri Coteau model of Clayton (1967) requires, first, that supraglacial drift melts out differentially from on top of ice by slumping, melting, and topographic inversion to produce a complex sequence of diamictons (Fig. 21). Second, the present day thaw of massive ground ice and slumping of accumulating sediment are actively eroding and resedimenting local debris and producing a thick, massive diamicton facies (Fig. 22A,B). Such massive diamicton facies were only recognized locally in the above measured sections. Adjacent surface slopes clearly show the effects of present day thaw-slump erosion and deposition of massive diamicton. Locally, the present thaw-slump environment produces stratified fine sediment in small ponds, although it is possible that supraglacial ponds were larger in immediate postglacial times. Strata were possibly preserved intact when thick sediments buried the massive ground ice and halted melting.

The origin of the exposed ground ice was tested independently by isotope analysis. Preliminary results indicate that the ice is at least of glacial or Pleistocene age based on stratigraphic position, low oxygen isotope values, and the trend of co-isotopic variation (Sharpe and Michel, submitted). Nevertheless there is little evidence of the large scale topographic inversion and deformation of sediments as suggested by the models of Clayton (1967) and Eyles (1983).

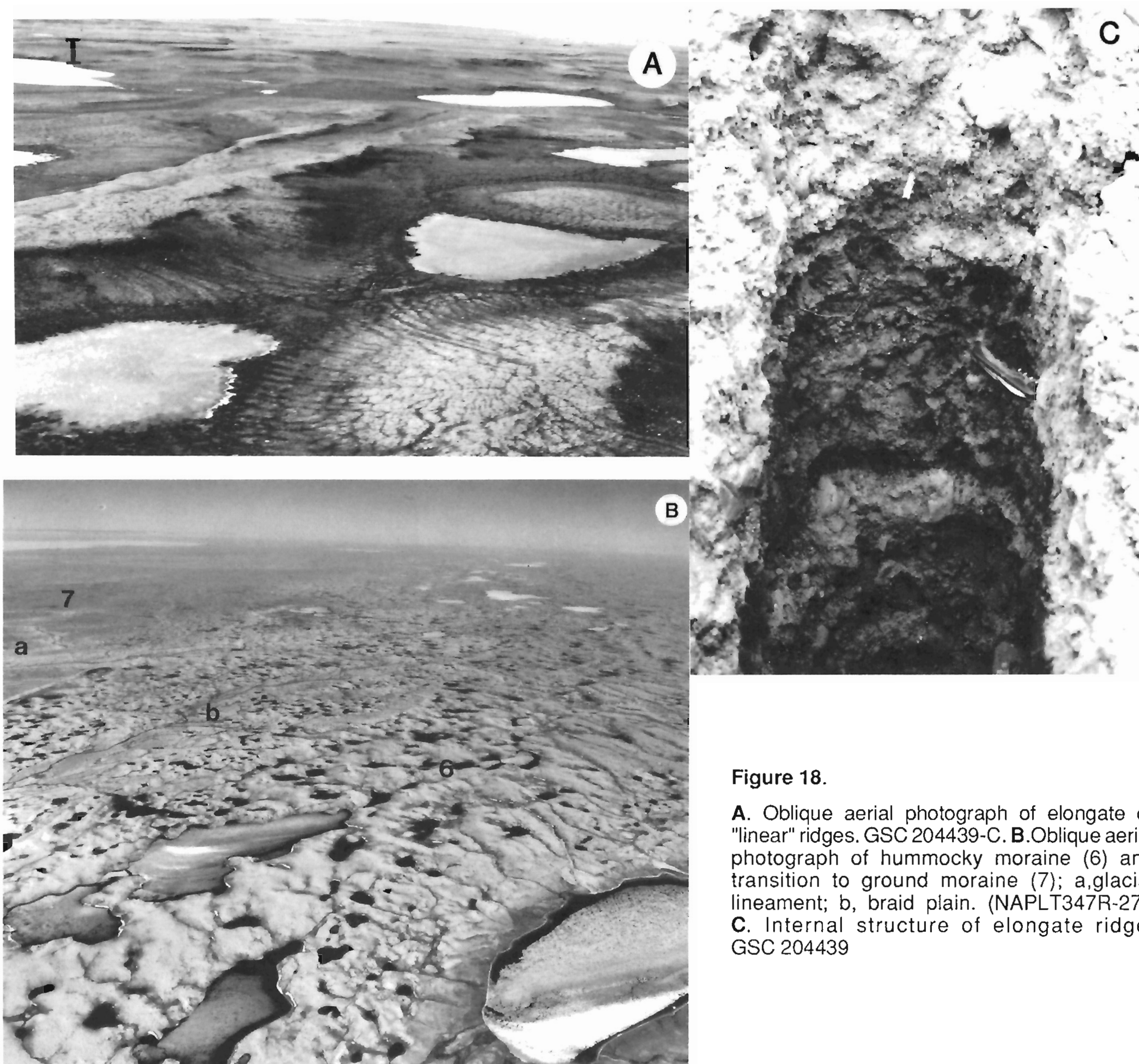


Figure 18.

A. Oblique aerial photograph of elongate or "linear" ridges. GSC 204439-C. **B**.Oblique aerial photograph of hummocky moraine (6) and transition to ground moraine (7); a,glacial lineament; b, braid plain. (NAPLT347R-27). **C**. Internal structure of elongate ridge. GSC 204439

The exposed sediments may not be those expected of topographic inversion but the topographic and glaciological constraints suggest that supraglacial sedimentation is a model to consider. The topography of Wollaston Peninsula may have affected glacial dynamics and helped to determine the formation of hummocky moraine. Hummocky moraine models use different positions of deposition and therefore different conditions of sedimentation. Hoppe (1952) and Stalker (1973) suggested a model of ice stagnation that included both supraglacial and subglacial deposition. Clayton (1967) proposed a model of supraglacial sedimentation based on observation in Missouri Coteau and at Matanuska Glacier, Alaska. Lawson has recently elaborated on the model of compressive flow and ice stagnation of debris-rich supraglacial ice (Lawson, 1979, 1984).

Thick glacial ice was present in the lowlands and major basins (Prince Albert Sound and Dolphin and Union Strait), adjacent to southern Victoria Island, while ice thinned at the margins over the central plateau of Wollaston Peninsula (Fig. 4A). This topographic arrangement suggests that thinning ice and rising flowlines occurred at the glacial margin, leading to a large area (on the scarp) of intense compressional flow that moved basal debris to a superglacial position. This topographic setting is very similar to the Missouri Coteau setting that Clayton (1967) depicted as a model hummocky moraine landscape.

The plateau setting adjacent to an escarpment suggests that hummocky moraine on Wollaston Peninsula may have formed under conditions of compressive flow. Such conditions occur at glacial margins and are enhanced by topographic obstructions. This flow regime would have been followed by thermokarst melting and redeposition of debris similar to that outlined for Missouri Coteau by Clayton (1967). Unfortunately there were no good descriptions of the sedimentary record that might be expected from Clayton's model of formation. Recently however, Lawson (1982, 1984) provided descriptions of sediment facies that may be expected from a similar model of hummocky moraine formation from Alaska (Fig. 21). As already described, these differ from the more stratified sediments on Wollaston Peninsula. Hummocky moraine areas are complex terrains in which a wide variety of sediment sequences has resulted. The sediment difference may relate to the large area of thicker hummocky terrain on Victoria Island compared with that at Matanuska Glacier. Another difference is that extensive ground ice may still underlie much hummocky moraine on Victoria Island (Sharpe, 1989, 1992). Additional details and discussion of the thermokarst model of hummocky moraine formation are considered in the section on *Thermokarst activity*.

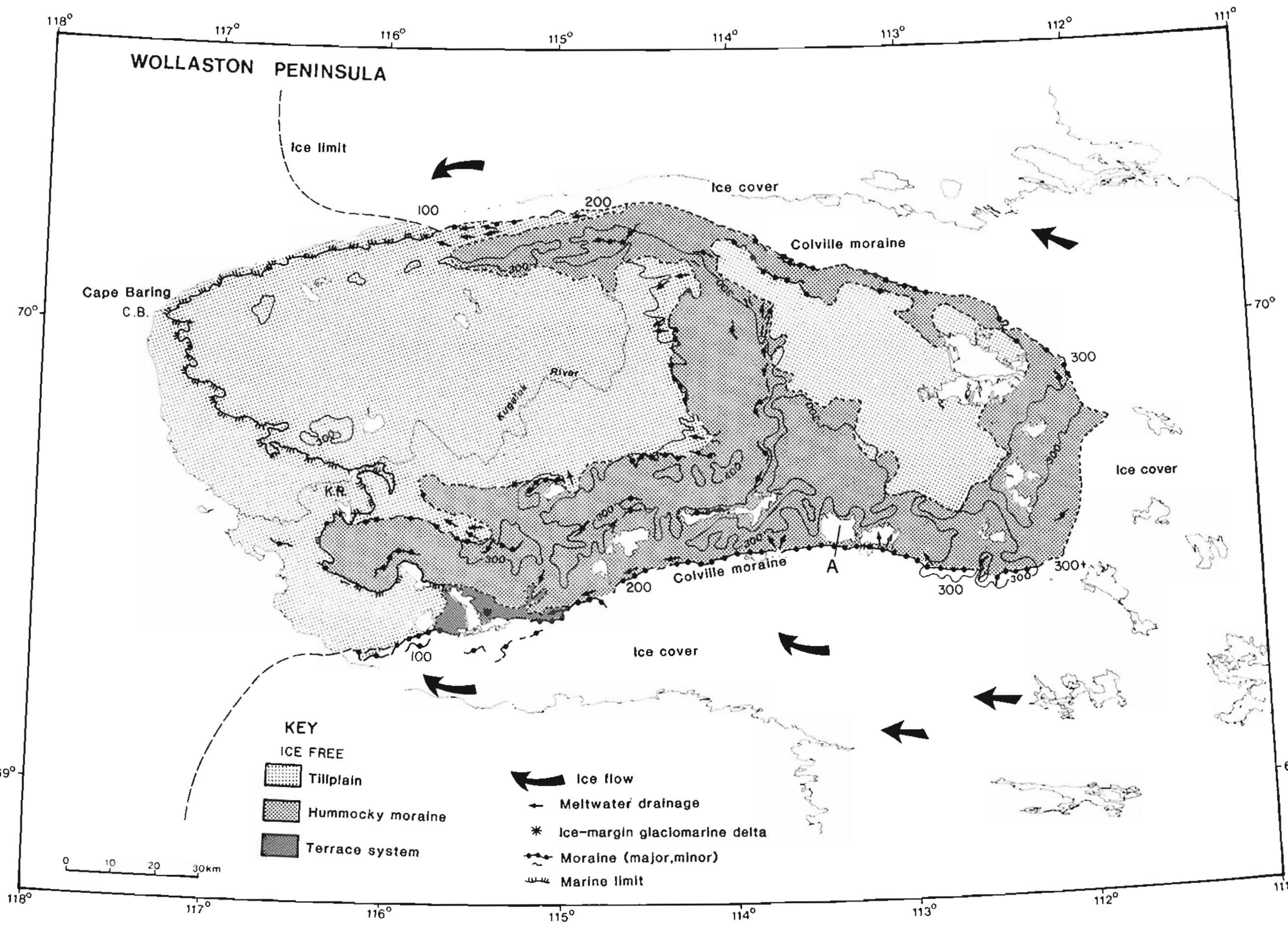


Figure 19. Map of hummocky moraine and ice configuration following formation of hummocky moraine. Elevations above sea level shown. A = Ammalurtuq Lake.

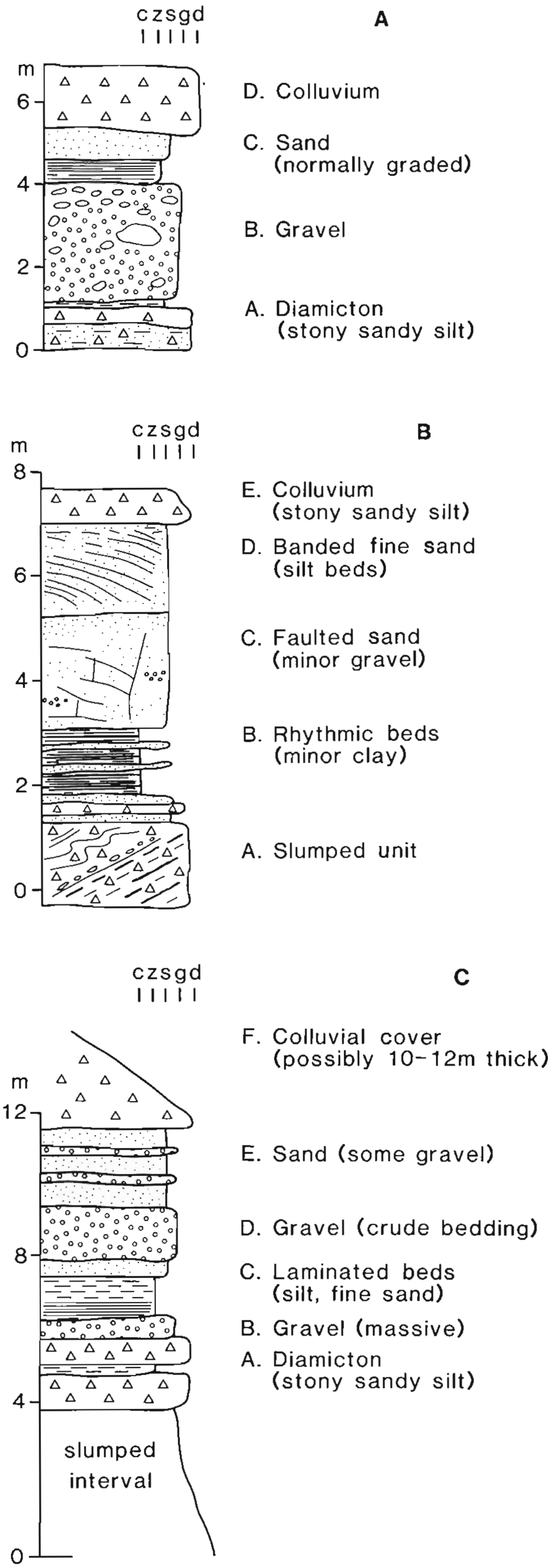


Figure 20. Sediment sequences in hummocky moraine from Ammalurtuq Lake: **A**. Site 135 showing horizontal strata; **B**. stratified beds with intra-bed disturbance within hummocky moraine, site 136II; and **C**. interbedded diamicton, sand and gravel and rhythmic silt within hummocky moraine, site 136III.

End moraine and deformed (shear) moraine

The major moraine belt that encircles Wollaston Peninsula (e.g., Colville moraines, Fig. 19) represents a massive amount of sediment. Volume calculations are high (5 x 10^8 m^3/km^2) compared to the ground moraine (2-3 x 10^6 m^3/km^2) that consists of relatively little sediment for the area covered. This large mass of sediment is considered to represent active ice-marginal deposition in two environments: first, subaqueous deposition where the glacier was in contact with the sea, and second, subaerial deposition where the ice was grounded above marine limit. These two depositional environments produced distinct suites of sediments. Deformed moraines will also be discussed but no exposed sections were available for detailed studies.

End moraines

An end moraine complex (informally named the Colville moraine system) comprises two or three sharply defined morainal ridges (identifiable on LANDSAT imagery, Fig. 6B) with an adjacent outwash system comprising ice-marginal terraces and fans. The moraine belt itself is 25 km wide and individual ridges may be 3-5 km wide in many stretches. The Colville moraine system has been traced for 200 km east-west (sea level at the southwest corner of Fig. 19 to more than 360 m a.s.l. on central Wollaston Peninsula). This suggests a former ice gradient of about 1.8 m/km for the glacier during the formation of Colville moraine system. This gradient is lower (possibly less than 1.0 m/km) when uplift is taken into account. Colville moraine system was constructed subaqueously west of a very large glaciomarine delta at 135 m a.s.l. (Fig. 16A) and subaerially for most of its extent eastward, despite this low profile.

The eastern sector of the end moraine is apparently folded and deformed into ridges that can be readily identified on LANDSAT images (Fig. 6B). The deformed moraines, which appear as thrust plates of sediment in places, form a 10-12 km portion of the 25 km wide Colville moraine system. The elevation of these thrust or shear moraines indicates active, intensely shearing ice up to at least 225 m a.s.l. at the north-south transect on Figure 16A. An ice gradient as low as about 1 m/km may be deduced for the glacier during this intense lateral shearing. Gradient of less than 2 m/km have been considered to be related to former surging conditions (Wright, 1973; Mathews, 1974; Clarke et al., 1984; Clayton et al., 1985). Kamb et al. (1985) have observed that intense lateral shearing and thrusting accompany glacial surging in Alaska.

Cape Back Moraine

Subaqueous ice-marginal deposition

Moraine segments mapped below marine limit were deposited subaqueously. Subaqueous ice-marginal sediments comprise the Colville moraines adjacent to, and west of, the large, glaciomarine, ice-marginal delta (Fig. 16A) on southern

Wollaston Peninsula and along much of northern Wollaston Peninsula. Local marine limit is 120 m, so that deposition occurred when ice was grounded in about 70 m of water.

An exposure in a 10 km long segment of lateral moraine (Fig. 23) on the north side of Wollaston Peninsula provides a detailed section at Cape Back (Fig. 24A). The section, situated about 50 m a.s.l., contains two massive diamictons and three interbedded diamicton units, gravel, silt, and fine sand. All beds are horizontal and undeformed. Several of the beds are transitional at their contacts; for example the sediments (Fig. 24A) pass from massive diamicton (D) into stratified sediments (E) and back to a diamicton (F) interbedded with sand, which represents a gradational sequence.

The style of deposition at the Cape Back end moraine is best depicted by interbedded diamictons that exhibit flow characteristics attributed to sediment flows, particularly debris flows (Lowe, 1982). Large flow noses, which appear to represent plugged or very viscous flow of a large debris flow, are found downslope from the massive diamicton (Fig. 24B). Many of the sand beds in the section are graded (Fig. 24C). They are similar to graded beds deposited by underflows or sediment gravity flows (Lowe, 1982). The tidewater setting and the sedimentary features indicate that the deposits represent episodic sediment pulses (McCabe et al., 1984) from a grounded subaqueous ice-marginal source. The site represents one of a series of lateral or end moraines adjacent to Prince Albert Sound and another set of moraines adjacent to Coronation Gulf.

Subaqueous deposition occurs below marine limit and is marked by interbedded gravity flow deposits. This style of landform development and sedimentation represents an actively

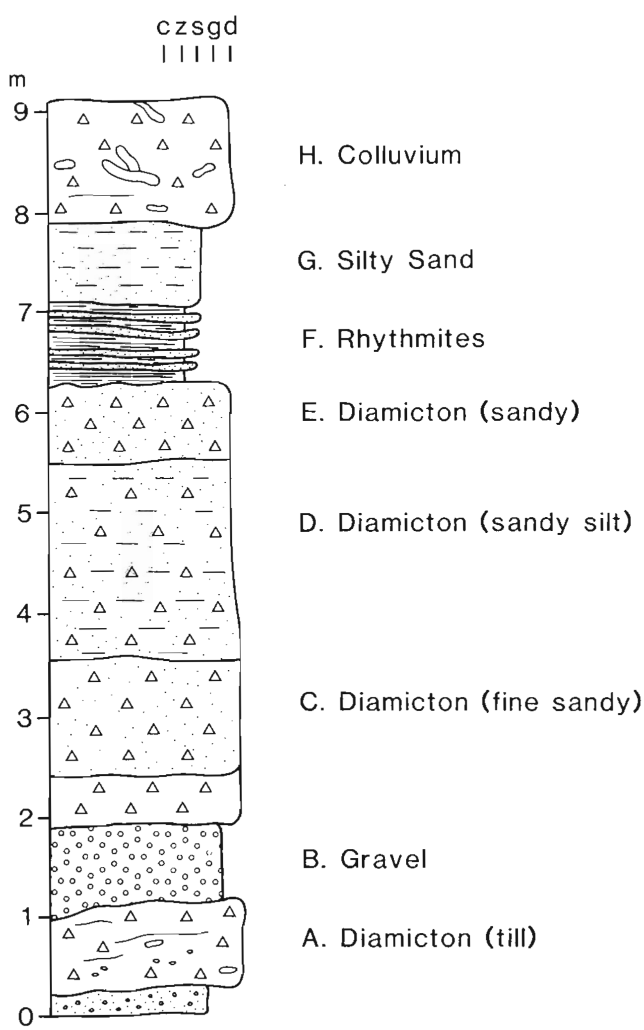


Figure 21. Idealized section in hummocky moraine from the Matanuska Glacier, Alaska (from Lawson, 1983).

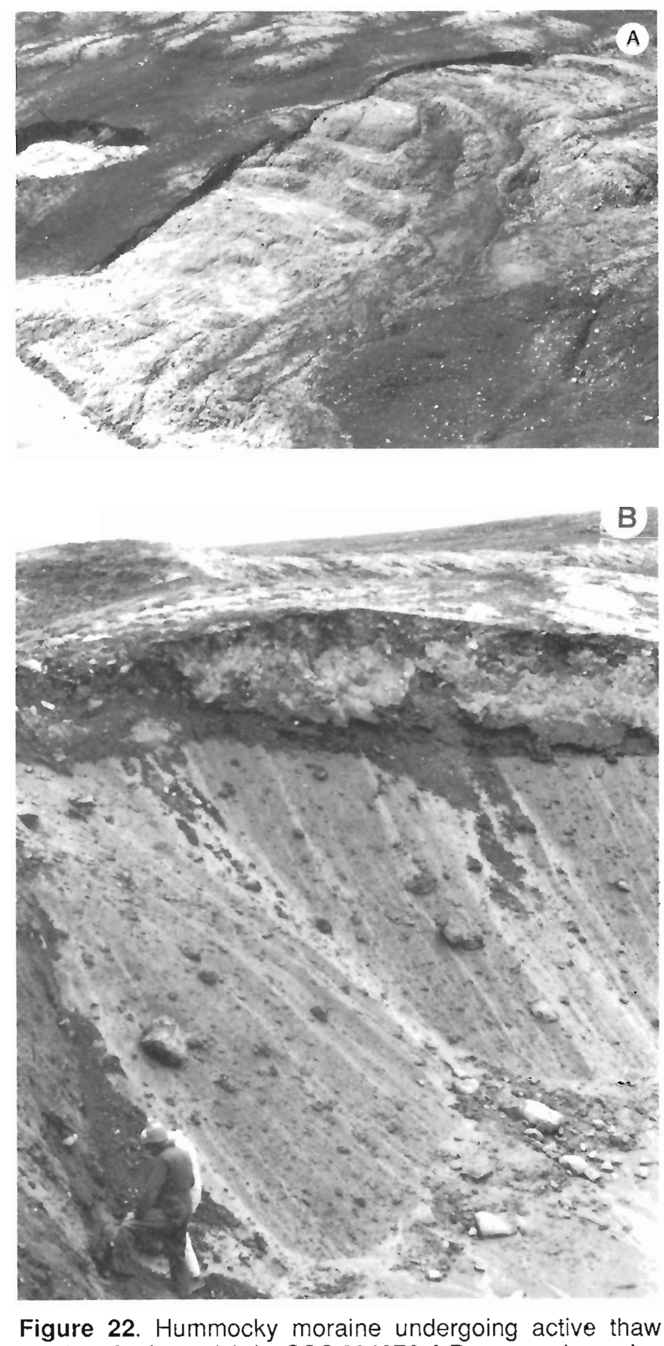


Figure 22. Hummocky moraine undergoing active thaw erosion: **A**. slump debris; GSC 204876-A **B**. exposed massive ground ice with diamicton cap. Note large clasts embedded in ice. GSC 204574

retreating, grounded ice margin highlighted by meltwater sedimentation and gravity flow processes. Lateral moraines produced in this way contrast with formation by subaerially grounded ice. End moraines may form as simple push moraines or marginal debris flows (Evenson et al., 1977) and consist of massive diamicton. Lateral moraines may form as sheared sediment ridges. Hummocky moraine may form by stacking from compressive flow and by stagnation leading to deposition by slumping, thermokarst erosion, and topographic inversion.

Subaerial deposition

Part of the subaerial, ice-marginal, depositional environment is portrayed by a cross-section (Fig. 25) of a terraced drainage system along the north shore of Wollaston Peninsula. These outwash terraces consist of coarse, cobbly boulder gravel that formed as ice melted down into Prince Albert Sound, trapping glaciofluvial sediment between the height of land and the ice margin. This style of deglaciation is common along inter-island channels.

Shear moraine formation

The low glacial profiles described earlier indicate that ice occupying Dolphin and Union Strait may have been surging during moraine formation. Recent observations from the Variegated Glacier, Alaska, show that a major shear zone occurs along the lateral margin of this surging glacier (Kamb et al., 1985). It seems that a large velocity difference developed along the glacier margin between ice confined against a height of land and free flowing ice. This situation caused a marginal wrench fault during surging, and debris accumulated. Similarly, major shearing at the glacier margins may have been responsible for deformed moraines within the Colville moraine system on Wollaston Peninsula. The edge of the carbonate plateau (Fig. 4A) acted as the confining margin. The deformed moraines are large, massive, broad ridges with very coarse bouldery sediment derived from the local carbonate bedrock. The ridges appear to comprise large plates or thrust sheets in some cases. Sharp (1985) has developed a local model of marginal, thrust sedimentation for surging of the Eyjabakkajökull Glacier front in Iceland. He suggested that individual ridges within the thrust complexes can be considered as surface expression, or the slices, of an imbricate thrust sheet (Fig. 26). The set of deformed ridges on southern Wollaston Peninsula may have been formed in this way by one or several closely spaced surge events (see Wright, 1980).

Outwash system adjacent to end moraine

Adjacent to Colville moraine is a prominent, continuous (about 100 km) glaciofluvial system too narrow to show on Figure 19. The system is composed of fans or deltas built by north and west flowing streams issuing from an active ice mass to the south. This glaciofluvial system confirms that thickest ice lay to the south of Colville moraines. All the large deltas and fans in this system occur on the north side of Colville moraines and paleoflow directions are to the north. Thicker accumulations of the Colville moraines were built by ice situated in the major coastal depressions to the south in Coronation Gulf. On the adjacent northern uplands smaller fans and deltas were formed, with southward paleoflows, by adjacent, thin, stagnating ice. Water and sediment beyond the margin of the Colville moraines remained in closed depressions in the hummocky moraine. The glacial trimline near the upstream end of the outwash system occurs to at least 325 m a.s.l. (Fig. 19).

Streamlined forms

Streamlined features form the final landform belt in a series of landforms comprising ground moraine, hummocky moraine, end-lateral moraine, and streamlined forms. This arrangement of landforms relates varying flow conditions within one major glacial advance (Sharpe, 1984, 1988a). This pattern is particularly evident for hummocky moraine, end-lateral moraine, and streamlined forms (Fig. 16A) and may relate to increasing resistance to flow between streamlined forms to hummocky forms. The streamlined landforms that are part of this belt also show a gradation of forms: flutings, drumlinoid ridges, and drumlins appear to reflect a change in flow strength from low to vigorous flow. The spectacular nature of these streamlined forms and the enigma of their origin require special attention; the next section is devoted to the description of their pattern, form, sedimentary character, and possible origin.

STREAMLINED LANDFORMS

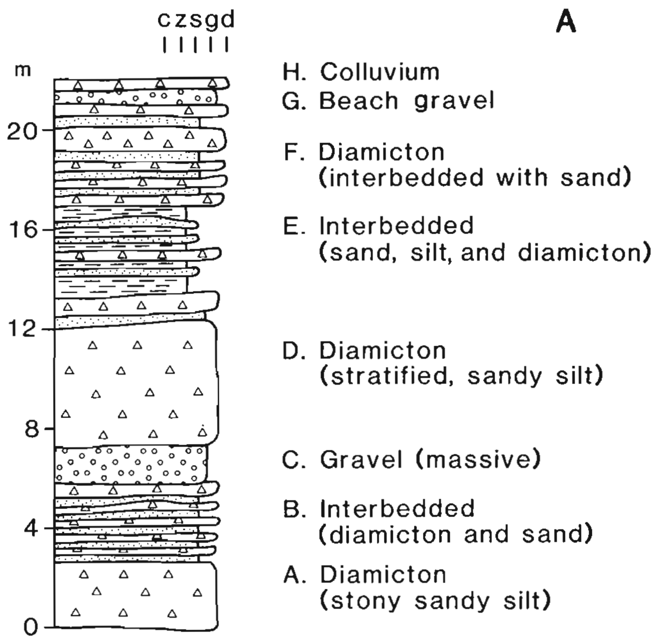
Setting, pattern, and form

Streamlined landforms are particularly prominent not only on Wollaston Peninsula (Fig. 27A,B) but all over Victoria Island. They include drumlins, drumlinoid ridges, and flutings consisting of ridges of sediment or rock oriented parallel to flow. Understanding the origin of streamlined landforms (particularly drumlins) is important in deciphering the timing, style, and nature of glaciological processes shaping the Pleistocene geology of Victoria Island.

Figure 23. Lateral moraine on the north shore of Wollaston Peninsula at Cape Back; oblique aerial view of exposed sediments and Prince Albert Sound in background to northeast. GSC 204223-W

Two prominent drumlin fields occur on Wollaston Peninsula – Read Island and Penny Bay. A major area of streamlined forms on southern Wollaston Peninsula occurs in a zone more than 50 km wide and 150 km long (see *Read Island drumlin field*). This field is the major field of study because of its size, spectacular drumlins, and its relationship to adjacent landforms already discussed.

The streamlined landforms rest on a flat to gently stepped lowland underlain by carbonate bedrock, which is exposed between the landforms. The bedrock exhibits few striations, partly because it has weathered. More common are erosional forms such as flutes, scallops, obstacle marks, and cavettos, collectively termed p-forms (Fig. 28A,B). These forms occur at scales ranging from centimetres to hundreds of metres. An additional large form, found within the field but east of the area, was rock drumlins with superimposed p-forms (Fig. 28C). The sediment-poor areas are semi-continuous in



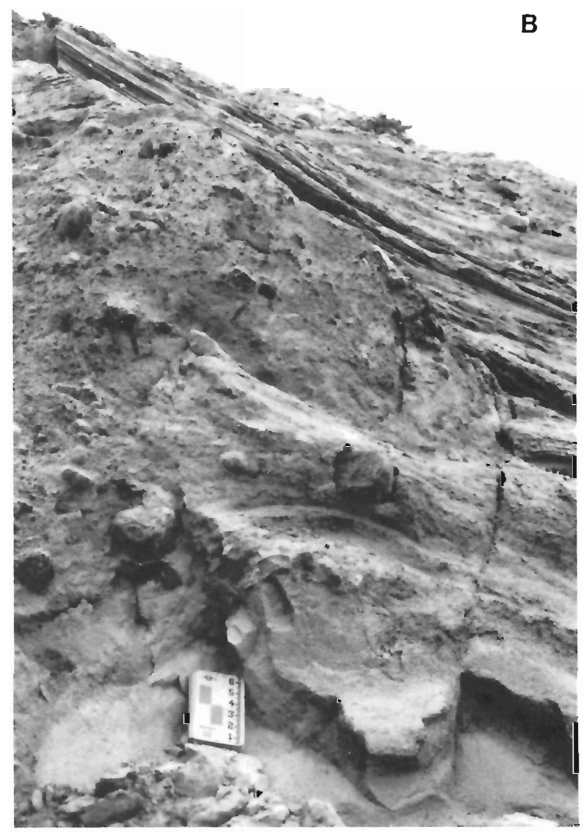


Figure 24. A. Section measured in lateral moraine at Cape Back, northern Wollaston Peninsula; moraine occurs at 50 m a.s.l. whereas marine limit is 100 m a.s.l. **B.** Thick massive diamicton with flow-nose structure adjacent to thin stratified beds in Cape Back lateral moraine. GSC 204223-T **C.** Graded sand bed (above knife) within morainal deposits of Cape Back moraine. GSC 204223-S

some areas and appear to define scour zones (Fig. 27A) or possible tunnel valleys where small eskers are found on the bedrock (Sharpe, 1992). Exposed bedrock areas are free of sediment except for sporadic large boulders.

Major drumlin fields on, and adjacent to, Wollaston Peninsula occur in low areas. The larger streamlined forms lie mainly in the centre and lowest parts of the field, and the size and definition of form decrease outwards. For example, the streamlined forms are arranged as elongate drumlins, shorter oval drumlins, and a field of flutings (1, 2, and 3 of Fig. 16A,B) from the centre to the perimeter. These features are discernible on conventional vertical aerial photography (e.g., 1:60 000 scale) or oblique aerial photography (Fig. 27A), as well as on LANDSAT images (Fig. 6). On the perimeter of these fields, flutings are developed as subtle forms adjacent to the lateral moraines or shear moraines. Details of three common streamlined arrays and their individual forms and patterns follow.

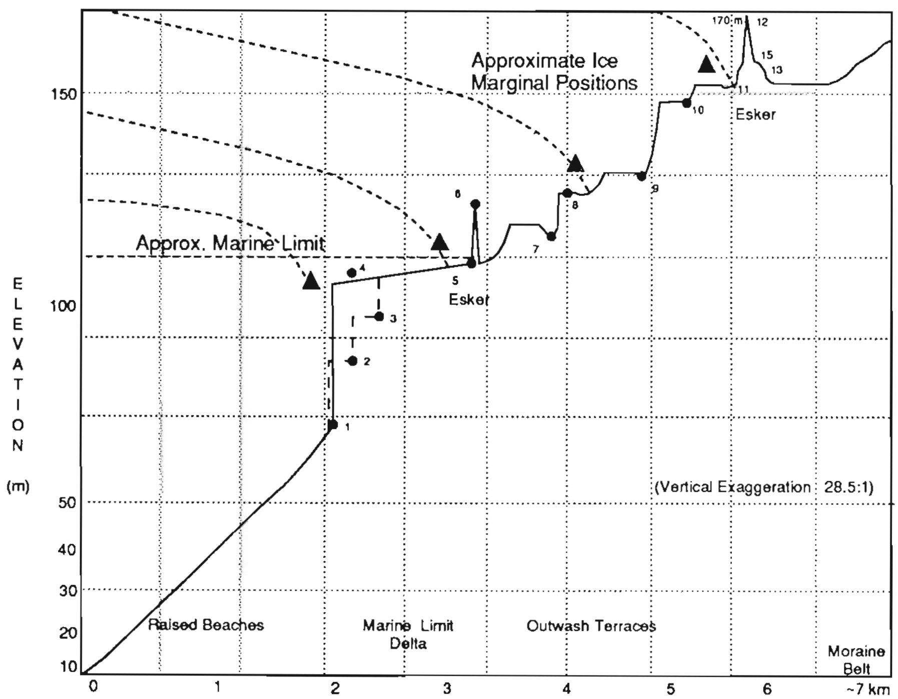


Figure 25.

Cross-section of eskers, ice-marginal terrace sequence, marine limit and approximate ice positions south side of Prince Albert Sound near Cape Back. Dots are measured elevations.

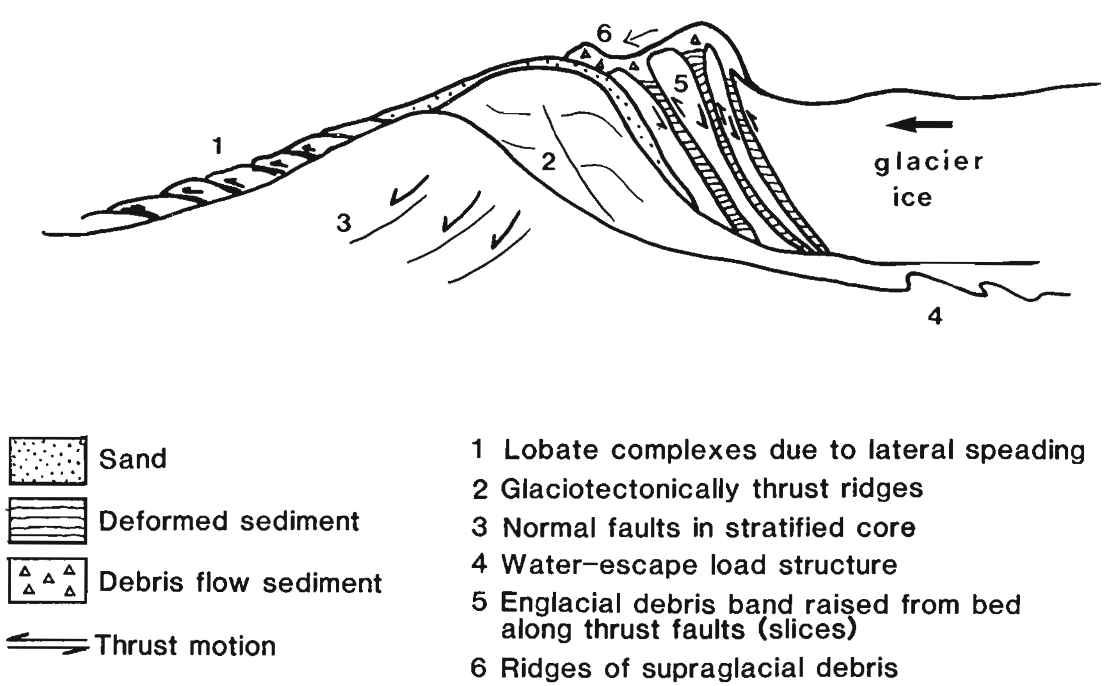


Figure 26. Ice-marginal thrust moraine formed by a glacier surge in Iceland (after Sharp, 1985).

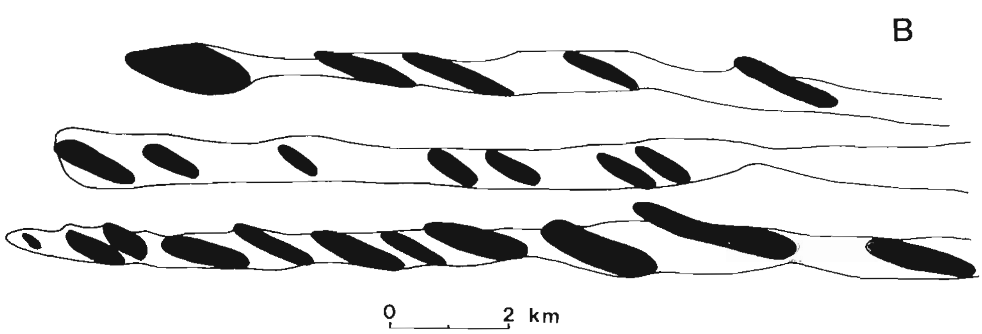


Figure 27. A. Oblique aerial view of large drumlin field along the south coast of Wollaston Peninsula shows transition from elongate forms (1) to curved composite forms (2) and drumlinoid forms (3). Note that comma shaped forms (CF) and herringbone pattern occur within elongate pattern (near 2) and sediment-poor scour zones (s) and erosional comma lakes (CL). See Figure 6A for LANDSAT location. NAPL T32-L-188 **B**. Cluster or group of drumlins showing transverse elements (near 2).

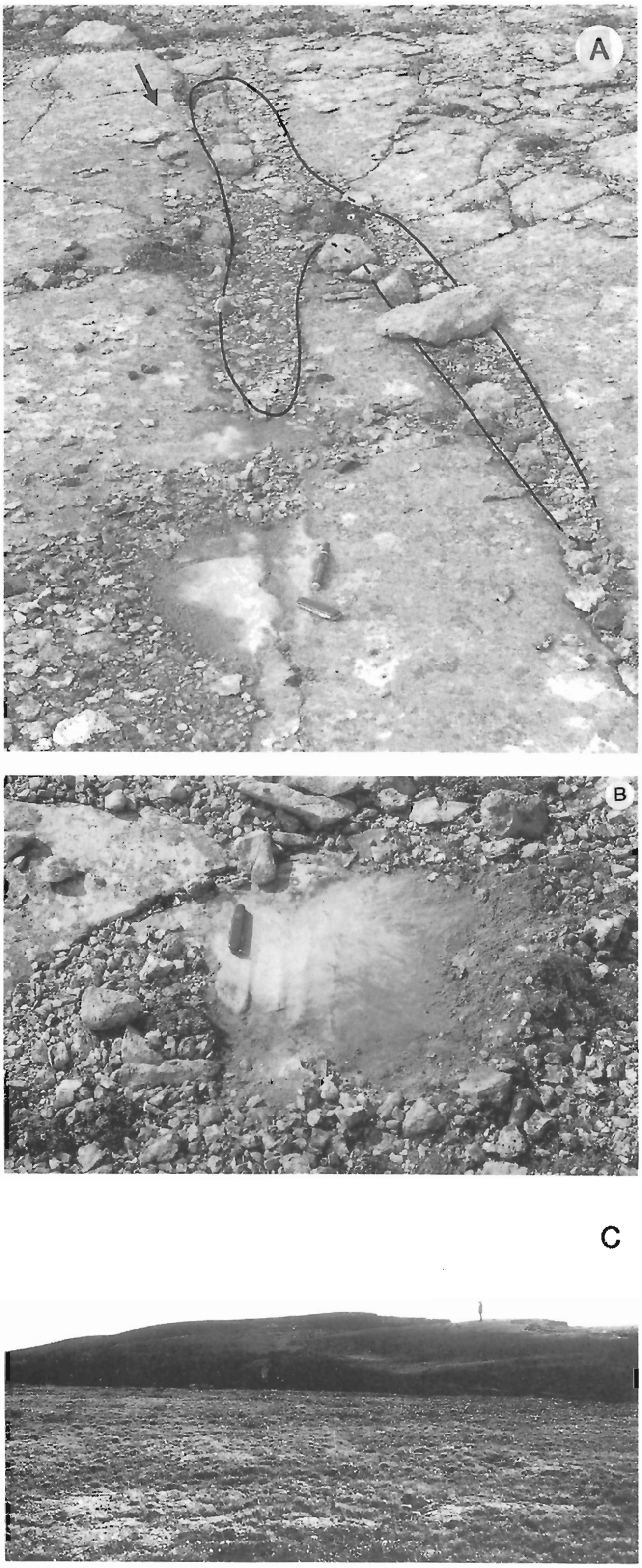


Figure 28. Sculpted forms on carbonate bedrock, Wollaston Peninsula (arrow gives flow direction): **A**. small p-form (sichelwanne, highlighted), GSC-1991-167; **B**. small "rat-tail" (Prest, 1983) erosional forms. GSC 204535-L **C.** Rock drumlin with superimposed sichelwannen (plural). Flow left to right. GSC 204763-Y

Elongate drumlins

In plan view, elongate drumlins occur (Fig. 27A) as symmetrical spindle forms and less common parabolic and asymmetrical forms (Allen, 1982, p. 185). The spindle shaped drumlins comprise a field 15-20 km wide and more than 50 km long. Individual drumlins are as much as 3 km long, 100 m wide, and 10-30 m high. Parabolic and transverse asymmetric forms occur together and adjacent to the spindle forms, and combined the field is 40 km wide. Some clusters of drumlins have elements transverse to flow (Fig. 27B). The transverse forms occur as offset or en echelon arrays (parabolic or comma shaped) that appear as major linear elements running at an oblique angle or parallel to the symmetrical spindles. In places the transverse arrangement gives a herringbone pattern to the field (Fig. 27A). This pattern consists of several drumlins forming an oblique (transverse) pattern (to larger elements) that appears to be en echelon in nature (Fig. 27B). These herringbone patterns occur as dominant elements of other larger drumlin fields on Victoria Island (e.g., north of Prince Albert Sound). The streamlined bedforms apparently indicate a rapid flow system with flow limits only up to 120 m a.s.l. (at 113°W) on Wollaston Peninsula.

Short, oval drumlins

Short, oval drumlins occur at the edge of the major field of elongate drumlins, as individual spindle or parabolic forms generally 100 m long, tens of metres wide, and 10-20 m high. Clusters of forms are less common than in the area of elongate drumlins. In this subfield, drumlins are more closely spaced than in the field of elongate drumlins; groups of drumlins form a divergent pattern, rather than being oriented parallel with, the elongate (Fig. 27A) drumlins. En echelon clusters are parallel to the elongate forms in the larger drumlin field. The transition from drumlins to no drumlin form is gradational and in places consists of poorly formed, small, oval drumlinoid features. This transition seems to be related to availability of sediment as the next landform suite, glacial fluting, has little drift. These smaller drumlin forms record a less energetic flow system up to 160 m a.s.l.

Flutings

A prominent band of fluted, thinly drift-covered terrain, 10-20 km wide, occurs between the drumlin fields and the large system of end and shear moraines. The flutings, which form curved bands of features from 1 to 5 km long, are prominent on aerial photographs yet are imperceptible on the ground. The longer elements occur closer to the drumlin field or other large streamlined forms. The fluted terrain represents a transitional zone of erosion or minor deposition between the formation of the large drumlin fields and the thick ice marginal deposition (moraines) upslope. Flutings record a less rigorous flow system, up to 185 m a.s.l.

Interpretation of pattern and form

The clear systematic arrangement of forms across the drumlin field requires explanation. It appears that the formative flows acted (rapidly?) to produce the field as one flow event. There are analogies between ripple fields showing transition from well developed forms in the main ripple field to poorly developed forms at the field margin. The pattern of offset or en echelon forms in drumlins also is common to sedimentary beds displaying groups of bedforms at two scales (Allen, 1982, fig. 5-4). For example, Dzulynski and Walton (1965) found similar en echelon forms that occurred as erosion marks formed on turbidite beds. The herringbone drumlin pattern is analogous to erosional flow marks produced experimentally in flumes by Allen (1969, 1971). The individual forms (spindles, parabolic, and asymmetric) also have clear analogues with turbulent flow forms (Allen, 1982). The drumlin location in low areas suggests fluvial bedforms in the main flow. Combined, the pattern and form of drumlins show links with glaciofluvial origins for drumlins (Shaw, 1983) although few data, except for evidence of turbulent flow in these elements, exclude the direct or additional action of glacial ice. In fact, an alternative, but unverified, explanation of the herringbone or apparent crosscut relationship suggests that two ages of iceflow were involved for drumlin formation on Wollaston Peninsula (Boulton, 1987). Crosscuts, however only affect the margins of the flow (Fig. 27A).

Sediments in streamlined landforms

Emphasis is placed on drumlins because no sections from fluted terrain were found. Fluted forms in southeastern Victoria Island are covered in more detail in another report (Sharpe, 1985). Detailed field investigations on drumlins were carried out in three different drumlin fields on Wollaston Peninsula – Read Island, Banning Lake, and Penny Bay (Fig. 29). Each drumlin field lies on the low coastal plains of southern Victoria Island. All are thought to be the products of latest (Late Wisconsinan) glacial activity (Sharpe, 1984). Borowiecki (unpublished report, 1984) also discussed these drumlin fields. The results of the work from Read Island are highlighted because the sections are the deepest and expose the greatest thickness of drumlin sediment. Read Island and Penny Bay drumlin fields are discussed here.

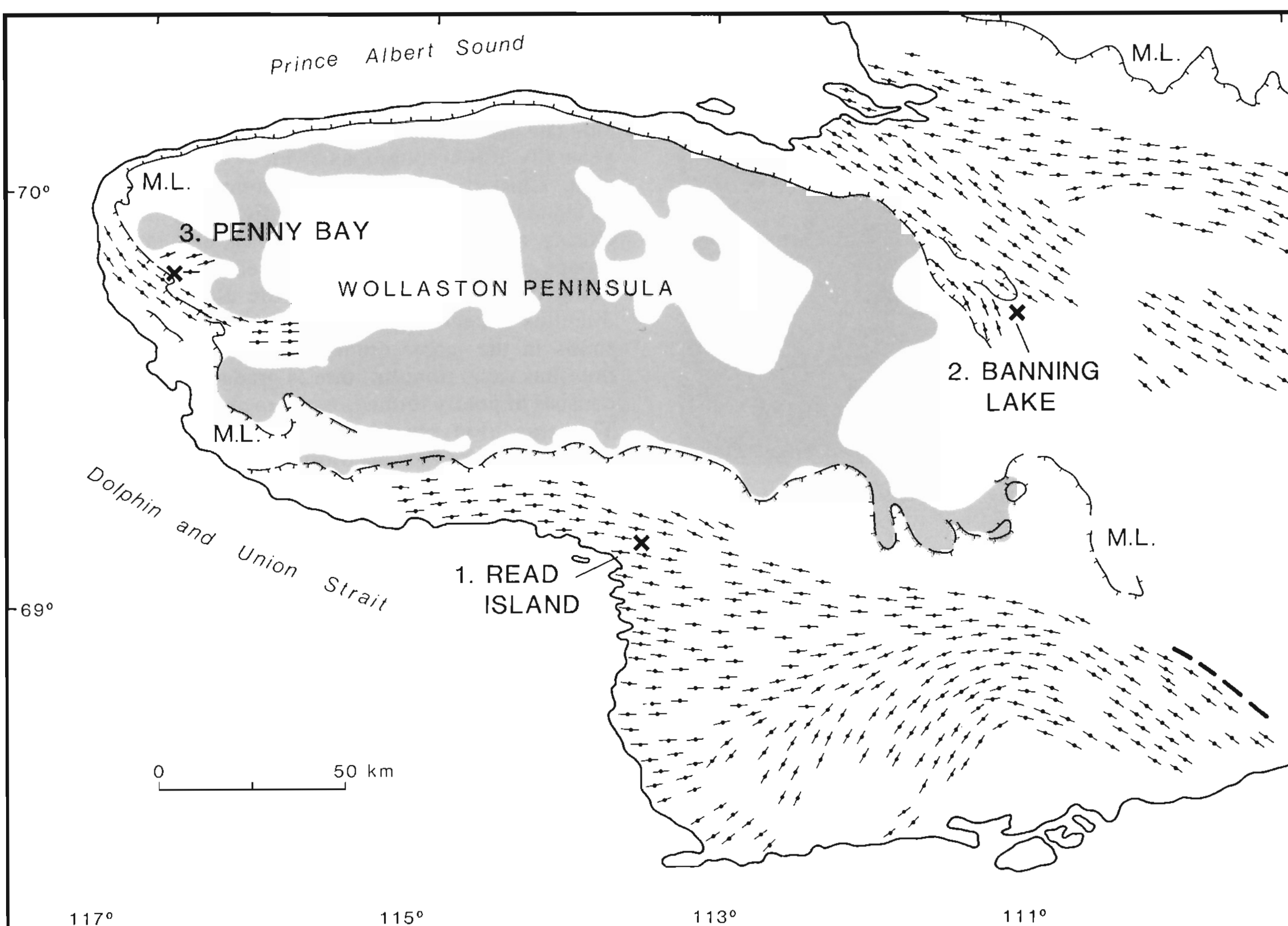


Figure 29. Three drumlin fields (Read Island, Penny Bay and Banning Lake) studied on Wollaston Peninsula, Victoria Island. M.L. is marine limit. Shaded area is hummocky moraine with ground ice.

Read Island drumlin field

The Read Island drumlin field is 250 km long and 80 km wide and comprises elongate and short, oval drumlins. The drumlin field is part of a series of landforms identified and considered to represent transitional forms from the former active ice margin towards its centre. This sequence of landforms comprises lateral (end) moraine, deformed (shear) moraine, a fluting field, and drumlins (Fig. 6A, 16A) from the margins towards the centre of flow. It seems clear (Fig. 27A) that ice melted in place following formation of these landforms as no ice-marginal deposits (e.g., morainal ridges or outwash systems) are found anywhere in the Read Island drumlin field. The only glacial deposits associated with the drumlins are small eskers that wind between the larger drumlins within tunnel valleys (Sharpe, 1988a).

The results from Read Island are based on a detailed examination of two drumlins (Fig. 30A): a large drumlin with exposures in the flank and the end, and a second, smaller, drumlin having a well exposed cross-section. Additionally, fabrics were measured in two trenches and two excavated pits.

Drumlin facies (side section 1)

A 5 m high exposure on the flank of a drumlin provides a good example of drumlin composition. Three major facies are exposed (Fig. 30B). The lower two facies are horizontally bedded and thus represent primary intact deposition. The sandy facies a (Fig. 30B) comprises normally graded sandy units 10-15 cm thick, massive medium sand, pebbly sand, and a few thin diamictons. Facies b consists of diamictons 10-15 cm and 60-70 cm thick that are interbedded with well sorted, very fine sand. Facies b is gradational in that the frequency and thickness of diamictons (Fig. 30B) increases upwards whereas the sand units are less frequent and thinner. Facies c has a sharp, unconformable contact with facies b and consists of a massive clayey silt and a lag of cobbles concentrated at the surface. Facies c, which dips with the slope of the drumlin and crosscuts the bedding in facies b, comprises reworked slope material. The clayey silt is marine sediment forming a colluvial unit that has moved downslope by gravity. This relationship between facies c and b also clearly shows that facies b and a are in situ sediment that have experienced little or no frost reworking. It is thought to reflect primary deposition during drumlin construction but other possibilities are discussed later.

Drumlin facies (end section 2)

The exposure is at the up-flow end of the drumlin (section 2; Fig. 30A). It comprises two facies (Fig. 30C). First, a lower facies (a) of pebbly medium sand with stratification in pebbly horizons includes sequences that fine upwards from gravelly sand to sandy diamictons. Striated clasts occur in the diamicton units indicating little secondary transport after glacial incorporation, transport, and abrasion. Second, an upper facies (b) consists of silty fine sand with occasional coarse clasts. The contact between these two facies is conformable in the upper trench where the beds are parallel to one another whereas the contact is sharp in a lower trench where facies b is horizontally bedded.

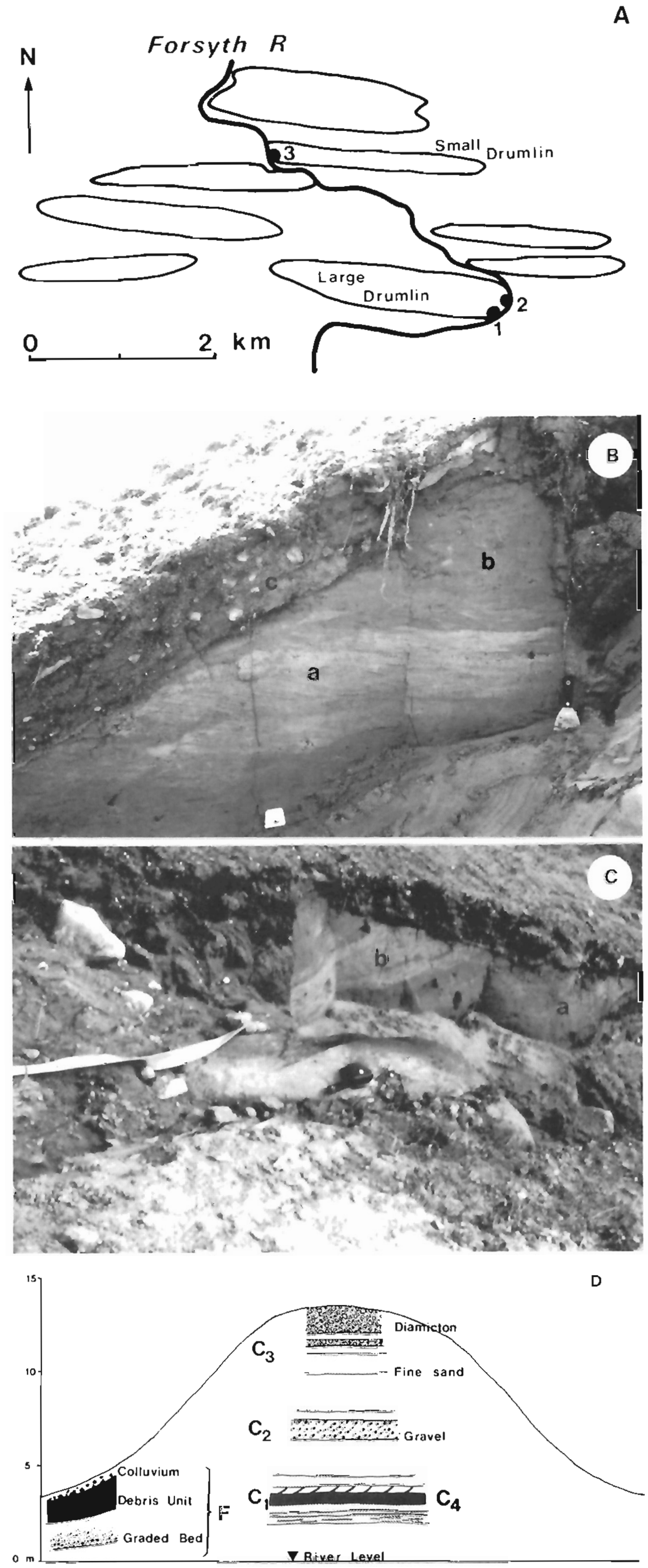


Figure 30. A. Location map of detailed drumlin sections 1-3, Read Island drumlin field. **B**.Exposed sediments (a,b,c) in side of drumlin, Read Island (section 1). **C**. Sediment sequence (a,b) in drumlin site, Read Island section 2. **D**. Cross-section through small drumlin (section 3) showing three sets (C_1-C_3) of sediments.

These sediments were reached in two trenches located 6-8 m below the top of the landform and hence show core sediments of the drumlin (Fig. 30C). They are quite distinct from surface diamictons produced by mass wasting.

Pits were dug on the drumlin surface to determine what sediments occur above the stratified core sediments. One pit revealed 70 cm of massive (to finely parted) sandy silty diamicton showing well developed fissility. The sediment has a fabric oriented southeast (transverse) compared to the southwest oriented fabric of the drumlin field. The second pit consisted of 50 cm of massive sandy silt diamicton with some sand partings and horizontal fissility. Above this are 50 cm of interbedded, fossilerous, marine gravel, pebbles and clay. The contact with underlying stratified sediment was not observed in the pits. It is considered that the surface marine gravel and sand represents washed diamicton or till material.

Small drumlin

A small, well-exposed drumlin occurs within a few kilometres of the two sections on the large drumlin features near Read Island (3, Fig. 30A). A river has cut through the distal end of this drumlin and provides an exposure (almost 10 m) of the internal composition of the drumlin (Fig. 30D).

The base of the sequence was exposed on the flank of the drumlin. A normally graded sand unit (1.5 m) grades from well sorted fine gravel at the base to coarse pebbly sand near the top. Overlying this with a sharp contact is 1 m of massive, fine sandy silt diamicton containing rip-up clasts. These two facies are located on the flank of the drumlin (F of Fig. 30D) and may represent later sedimentation. The exact relationship of these sediments to the stratified sediments in the drumlin core is not clear.

Core sediments

The sediments exposed in the centre of the feature occur 7 m away from the last section (F of Fig. 30D). The lower 1.5 m of sediment (C_1) consists of bedded sands alternating from 10-15 cm sets of massive very fine sand and massive fine sand to medium sand. Some reddish silty sand diamicton units occur in this sequence. In places, vague patterns of ripple drift cross-lamination are present (1-5 cm sets).

A covered interval (1 m) separates the lower (C_1) and intermediate (C_2) measured sections (Fig. 30D). Section C_2 consists of normally graded (fining-upward) sequences from gravelly sand to well sorted medium fine sand. There are several of these sequences and they are about 50 cm thick. Following another covered interval of 1 m additional graded units appear (C_3), consisting of gravel to diamicton facies that grade to fine sand.

The top of the section is capped by a massive diamicton consisting of loose stony sand silt material 0.5-1.5 m thick. Again, the exact nature of the contact between the top diamicton and the lower bedded sands was not seen. The sea has affected the surface, because marine shell fragments were found in the loose surface diamicton.

The small drumlin appears to be dominated by internal stratified sediments and glaciogenic diamictons. A colluvial unit covers the side slope and a lower debris unit may also represent a colluvial unit.

Interpretation of stratified drumlin facies

The undeformed planar geometry of the beds in the drumlin core suggest that other processes of deposition were more important than those associated with high subglacial stress or deformation. Consider the following points:

1) High percentage of stratified deposits are interbedded with diamicton units.
2) Deformation is lacking in any of the stratified units.
3) Graded beds, typical of sediment gravity flows, are common.
4) Some fine clay beds occur within the stratified sequence.
5) Stratified deposits and bedding may be conformable(?) with the drumlin form.

Few workers have attempted to evaluate the significance of stratified and nonstratified units within drumlins (Dardis and McCabe, 1983). For example De Jong et al. (1982) reported regular alteration of sedimentary layers (including graded units and deltaic deposits) within drumlins. They also included evidence of an undisturbed position for the sediments plus an absence of deformation structures but failed to assess the significance of these beds to drumlin formation. Dardis and McCabe (1983), in contrast, interpreted three sand-cored drumlins from Ireland as being deposited in water-filled subglacial cavities as cohesive sediment gravity flows, grain flows, turbidity currents, and deltaic lobes. They concluded, however, that drumlin shape resulted from ice erosion without sediment deformation. De Jong et al. (1982) also found evidence that the sedimentology of some drumlins shows a gradual accumulation of subglacial material (both till and water laid) sediments with synsedimentary deformation.

The Victoria Island drumlin data indicate a close relationship between stratified sediment and massive diamicton, which strongly confirms that both sediments were deposited at the same time. That the facies described at Read Island include debris units and normally graded units is compatible with the mode of origin of Dardis and McCabe (1983). They inferred subglacial deposition by sediment flow to explain a range of varied debris and sandy stratification that may occur in a subglacial cavity by sediment gravity flow. Dardis et al. (1984) favoured a lee-side position of deposition. Shaw (1983; Shaw and Kvill, 1984) also suggested cavity-fill mechanisms to explain the origin of some drumlins in Saskatchewan and Ontario.

Many earlier authors have described sedimentary structures of sediments in drumlins (e.g. Slater, 1929; Muller, 1974). They showed evidence of contemporaneous deposition of bedded sand, gravel, and diamicton that draped the bedded sediments with a conformable slope (see Menzies, 1984). Menzies (1984) reported that no deformation of stratified beds was observed by Upham (1897), Jewtuchowicz (1956), Jaatinen (1960), or Lamporski (1972) although deformation of drumlin sediments has been reported by Whittecar and Mickelson (1979). The author also made observations of undeformed sediments in streamlined landforms of southeastern Victoria Island (Sharpe, 1985).

The identification of undeformed, horizontally stratified sand and gravelly sand units interbedded with diamictons are deposits not normally associated with the origin and formation of drumlins. The conventional hypothesis (Gravenor, 1953; Smalley and Unwin, 1968; Menzies, 1979; Kruger and Thomsen, 1984; Boulton, 1987) is that stratified cores in drumlins represent pre-existing proglacial sediment that was reshaped and eroded by ice. However, clear proof of this theory has not been established in the literature. In fact, an alternate view that stratified cores may represent subglacial sedimentation has been proposed (Shaw, 1983; Dardis and McCabe, 1983; Dardis et al., 1984; Shaw and Kvill, 1984; Shaw, 1985).

The following evidence and reasoning places constraints on interpretation of stratified drumlin cores.

1) If stratified units are confirmed to be conformable with the landform then cavity-fill mechanism may explain drumlin cores.
2) Stratified sediments are interbedded with diamictons which represent "till"-flows.
3) If large drumlin fields are shown to be cored mainly with thick, stratified sand and gravel and if pre-existing proglacial sediment was entirely responsible for this deposition, then the geometry of the pre-existing outwash plain would have to be more extensive than known modern analogues.
4) Deformation of proglacial sediment would be expected in a subglacial environment where, high shear stress were thought to have operated (Boulton, 1982).
5) High-stress accretion models for drumlin formation require dissipation of porewater pressure through gravel, as a means of promoting lodgment (Menzies, 1979). This process appears to be self defeating for, when till started to lodge, drainage would be cut off and further lodgment would cease.
6) Drumlin cores may not allow direct understanding of drumlin formation if they are erosional forms.

Evidence from the sites described here is too scanty to support a clear explanation of drumlin formation by either deposition or erosion; but, the interbedding of sandy units and diamicton and the undeformed nature of finely preserved bedding do not favour wholesale subglacial deformation or shearing. Meltwater deposition and alternate release of debris from the ice appears to be important to drumlin formation at Read Island. Small crossbedding structures indicate flow to the southwest parallel to the drumlin field orientation and the sense of regional ice movement to the southwest. The diamictons could be till flows released by subglacial melting; such till facies are not compatible with high-stress subglacial sedimentation by rapidly moving ice. The combination of these features, although not exclusive, favours low-stress subglacial sedimentation. The low number of observed sites also leaves open the possibility of lee-side meltwater and debris flow deposition (Dardis et al., 1984), although one site examined at Read Island was a stoss exposure.

Penny Bay drumlin field

The drumlins studied at Penny Bay (Fig. 29) comprise two apparently separate drumlin fields that merge at angles of about 50° and that cut through a belt of hummocky moraine (Map 1650A). A smaller northern field of drumlins oriented northeast-southwest provided the best opportunity to study internal composition but the sections only revealed the top few metres of material. The drumlin fields consist of divergent forms (10-20 m) in the northern field and low-relief forms (5 m) in the southern field (Fig. 31); none of the drumlins have differentiated stoss or lee ends.

The sediment encountered is compact massive diamicton, moderately stoney (cobbles and pebbles); it has abundant sandy-silt matrix. The clasts in the diamicton are strongly faceted and striated and are clearly glacially abraded.

There are occasional sand stringers in the till but nothing to describe in detail except that minor sand occurs under cobbles and pebbles.

Fabrics

The massive character of the sediment dictated that fabric studies be used to help investigate its origin. Many authors have successfully employed fabric analysis of diamictons (e.g., Shaw, 1977; Lawson, 1979; Boulton, 1982) although they are not unique and are best combined with additional directional data.

A well formed northern drumlin, trending (northeast-southwest), and truncated by a stream, provides a 1-3 m exposure of its interior. It consists of organic-rich, oxidized sediment to 15 cm. Below, is 1 m of massive, moderately stoney, sandy silt diamicton, loosely compacted. A high percentage of the clasts are striated, polished, and faceted. Several large (15-25 cm long) clasts show highly faceted and striated, "bullet"-shaped forms (Boulton, 1982). The orientation of these large, abraded clasts is parallel to subparallel to the orientation of the southern (S) drumlin field (northwest-southeast; Fig. 31). Fabrics at Penny Bay generally show preferred orientation. Fabrics are oriented oblique to the axis of the southern (S) streamlined landforms but the fabrics are transverse to the northern (N) drumlin field (Fig. 31).

The sediment character and fabric indicate glacial transport and deposition as opposed to the debris-flow origin inferred from the sections at Read Island sites. Hence, the Penny Bay diamictons are designated as basal till – either lodgment or melt-out. Because of its massive nature, very dense character, lack of sand stringers or parting, and the presence of oriented (parallel to landform), polished, striated, "bullet"-shaped clasts, the facies is considered to be lodgment till. Drumlin sediment at Penny Bay appears to be similar (lodgment till) to drumlin sediment studied at Banning Lake (D. Sharpe, unpublished), although, a complete vertical section could not be established either at Banning Lake or Penny Bay to verify a complete till composition for the drumlins. Drumlins at Penny Bay may be erosional, to explain the fabric patterns and the fact that the drumlins cross-cut hummocky moraine (Fig. 29).

Discussion

The spatial arrangement of streamlined landforms on Wollaston Peninsula is significant. The landforms occur as a set of diverging forms ranging from drumlins to flutes. They form a set of transitional landforms that represent varying flow strengths and produced in one flow event. Their forms are analogous to bedforms produced by separated, turbulent flow (Allen, 1982; Shaw and Kvill, 1984). Their forms show composite or en echelon arrangement in parts of the landform set. This organization is again characteristic of complex turbulent flows (Allen, 1982).

If the drumlins are depositional in origin, their composition provides information as to their formation. In this regard the stratified cores of the Read Island drumlins favour a glaciofluvial cavity fill origin. The occurrence of meltwater erosion forms (p-forms) and sediment free zones

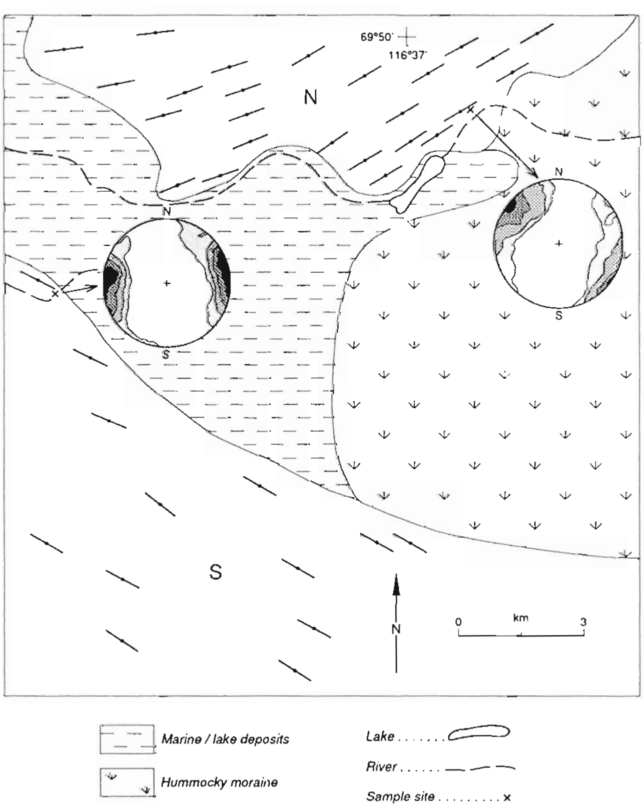


Figure 31. Till fabric plots from Penny Bay. Map shows location (X) of fabric sites on northern drumlin field (N) with northeast-southwest orientation. Southern drumlin field (S) is oriented northwest-southeast. Note that all data points (50) rotated by 40° to allow for compass declination.

(tunnel valleys) in interdrumlin areas supports the role of subglacial meltwater flows. The finding of rock drumlins requires an erosional model for their formation. Rock drumlins with superimposed small-scale water erosion forms suggests that the subglacial flows were powerful agents of erosion in places (Shaw and Sharpe, 1987).

The presence of till in the top portion of the Penny Bay drumlins favours an ice process for deposition of drumlin sediment. Erosional processes would also provide a viable explanation for their formation, because fabric axis does not match drumlin axis and diamicton was deposited previously. The fact that the drumlins cut hummocky moraine which encircles Wollaston Peninsula (Fig. 29) constrains their origin and favours an erosional mechanism.

ECONOMIC AND ENVIRONMENTAL GEOLOGY

Economic and environmental geology stresses the applied aspects of geological data. The mineralogical and geochemical characterization of glacial sediment is useful for drift prospecting, environmental base line and soil development studies as well as deciphering glacial history. Till soil data are means of conducting these studies and include 187 samples (Fig. 32).

Arctic terrains have other widespread applied aspects related to permafrost conditions particularly ground movement and stability, ground disturbance and the movement of groundwater in ice-rich sediments.

Glacial provenance

Much information exists that shows the utility of drift composition for inferring glacial movement (Dreimanis and Reavenly, 1953; Shilts, 1973; DiLabio, 1981). Nixon (1988) studied drift composition on western Victoria Island and described the methods, sampling design, and data display. This section interprets the data collected on Wollaston Peninsula.

The data set includes: grain size distributions, carbonate and trace elements concentrations, and colour (Appendix 1). Figure 32 shows the distribution of samples, bedrock geology, and simplified surficial geology of Wollaston Peninsula, much of which is underlain by Paleozoic carbonate rocks. Thus any Precambrian erratic material from the Shield is readily identified.

A good starting point in assessing drift composition is to consider two samples (33A and 33B; site 1001) collected directly overlying carbonate bedrock on Back River. The high percentages of striated clasts in these samples reflect mainly local transport. The samples provide a point measure of the trace element character of the local carbonate rock. Sample 33B, taken 20 cm above bedrock, has the second highest carbonate value (84.3%) of the 475 samples taken on western Victoria Island. An adjacent sample from a measured section has a similarly high carbonate concentration (79.2%) in till. The high percentage of striated clasts on local lithologies in this sample suggests that local basal transport and incorporation were important. Sample 33A, taken 20 cm above 33B and within 1 m of the surface, apparently reflects the effects of local weathering (leaching and oxidation). The carbonate content was 15% less. A reddish colour (7.5 YR 8/2) contrasts with the light yellowish brown colour (10 YR 8/2) typical for unweathered till, but no known local source of red bedrock would provide a unique provenance. A random pattern of "reddish" coloured till occurs on Wollaston Peninsula. Red colour may relate to hematite in clay, but no clear relationship exists between colour and clay content.

Six till variables produced statistically significant or nonrandom patterns for western Victoria Island. Carbonate values (Fig. 12A, 33A) provide the best lithological indicator of ice movements in southern Wollaston Peninsula. A broad area of very low values occurs west of Richardson Islands, which are underlain by Precambrian gabbroic and metasedimentary rocks (Figs. 2 and 32). This disperal pattern shows as a shadow effect and supports the southeast to northwest flow direction indicated by landform arrangement. Ni, Cr, and Zn (Fig. 33C,D,E) also show slight anomalies located over and downflow from Richardson Islands. Two restricted areas of Zn anomalies on the northern coast of Wollaston Peninsula may represent Mississippi-type Pb-Zn mineralization, although the Pb component is not present (Fig. 33F). Finally, Cu shows a strong anomaly west of the Richardson Islands, which suggests mineralization in this area (Fig. 33B).

The remaining trace element values show no statistically significant or nonrandom trends but some show weak patterns (Fe, Co, Mn, Appendix 2). Iron has a flat regional distribution with a weak westward pattern from Richardson Islands. If iron were glacially dispersed from a source dispersal train, a colour pattern would be expected. The lack of a clear dispersal pattern supports the concept that local weathering of red soil explains the colouration rather than dispersal from a red source.

The grain size characteristics of till from Wollaston Peninsula strongly reflect the influence of local carbonate bedrock in two ways.

First, the till matrix texture shows little significant regional variation (Fig. 34A, B). Some local variation in matrix was identified but no recognizable systematic

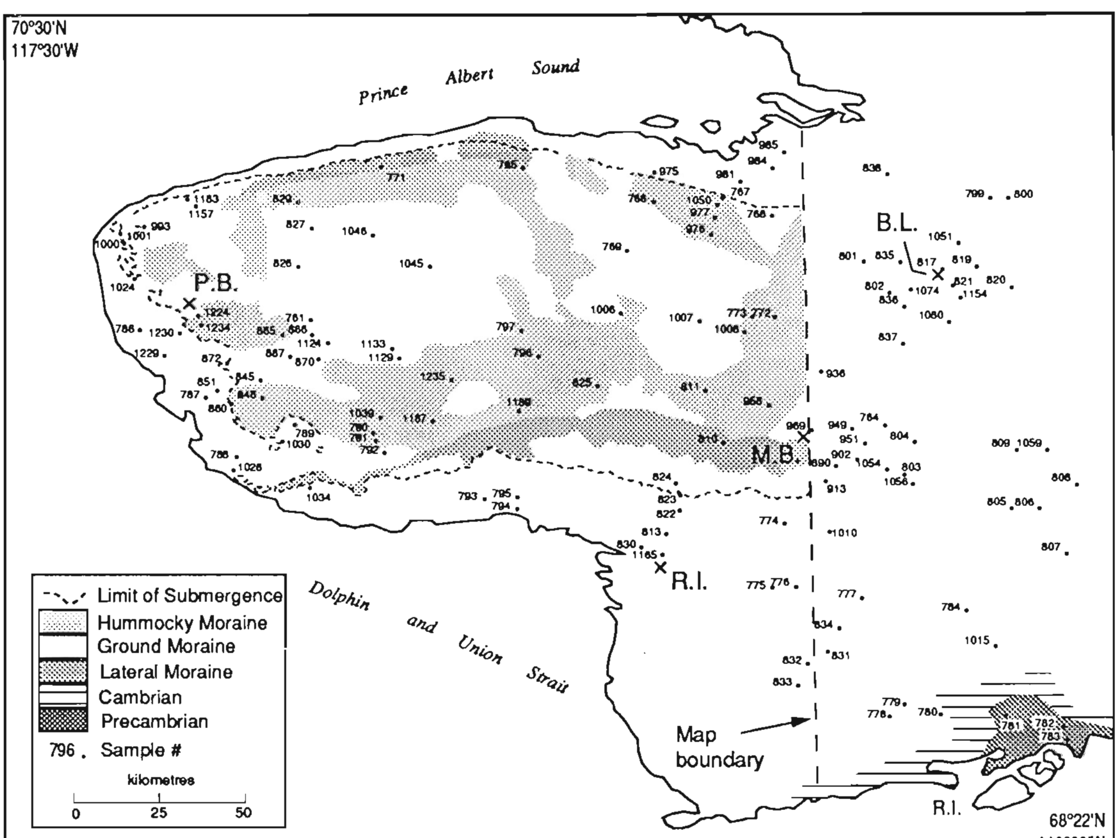


Figure 32. Distribution of till samples on Wollaston Peninsula and adjacent areas, Victoria Island. B.L. = Banning Lake; M.B. = Mont Bumpus; R.I. = Read Island; P.B. = Penny Bay.

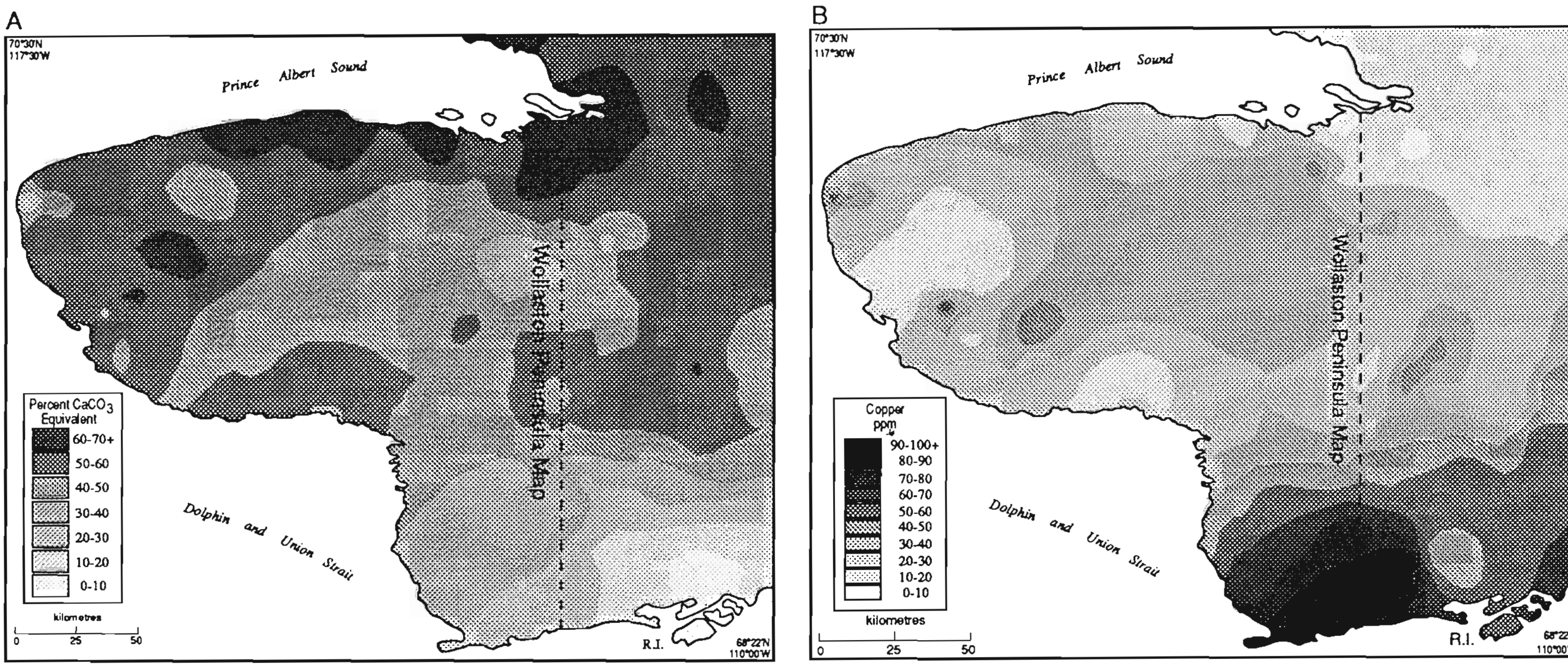


Figure 33. Contoured plots of till variables showing statistically significant patterns for western Victoria Island: **A**. carbonate content (2-81%); **B**. Cu (15-469 ppm); **C**. Ni (6-138 ppm); **D**. Cr (10-127 ppm); **E**. Zn (20-2950 ppm); **F**. Pb (4-84 ppm).

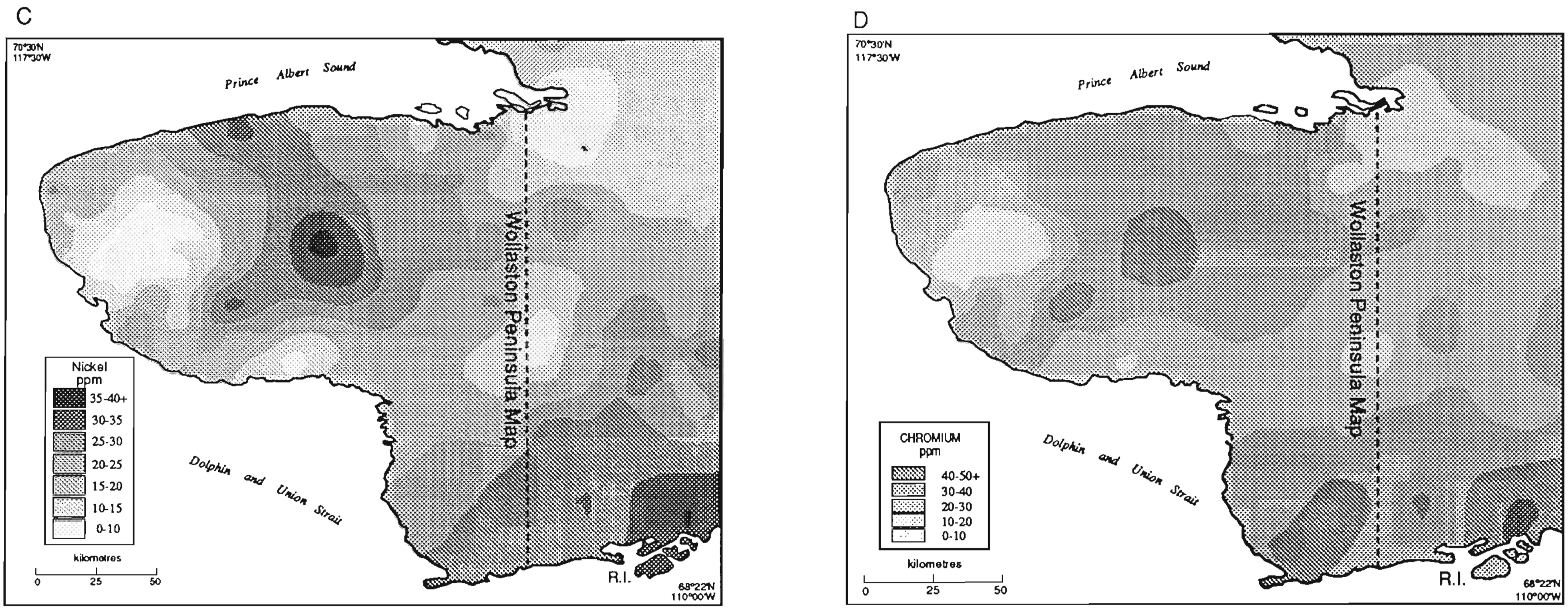
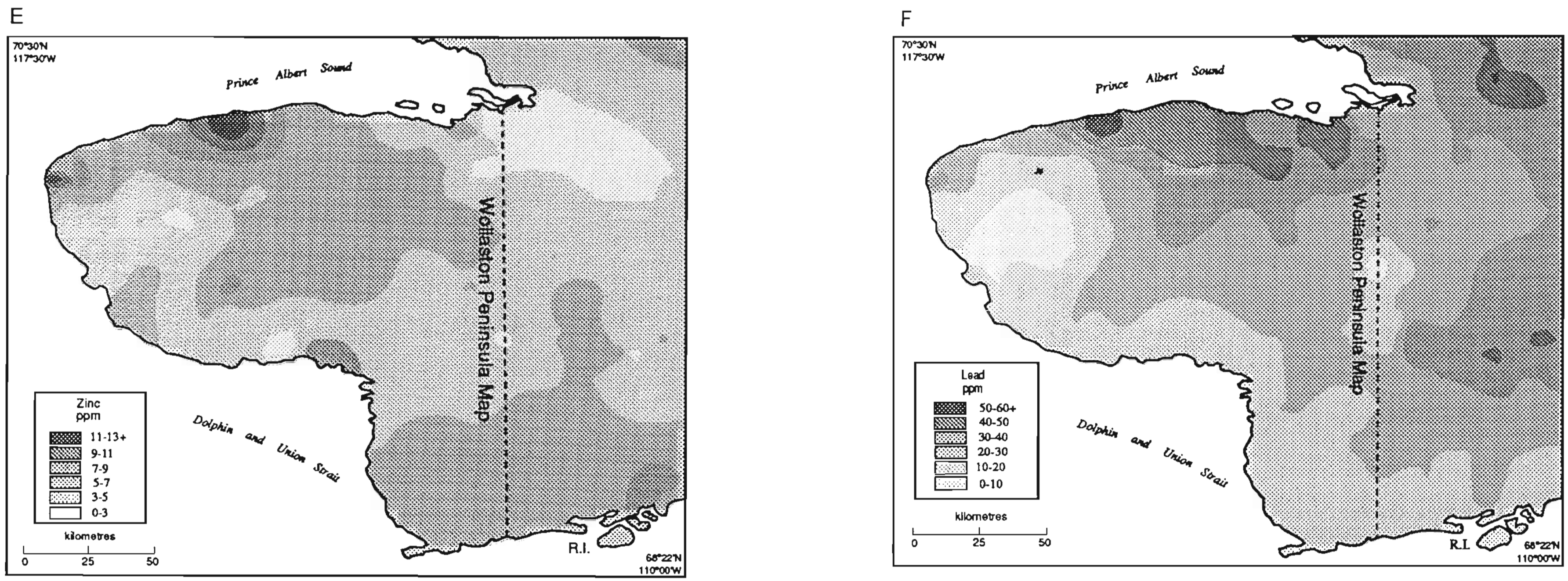


Figure 33 (cont.)



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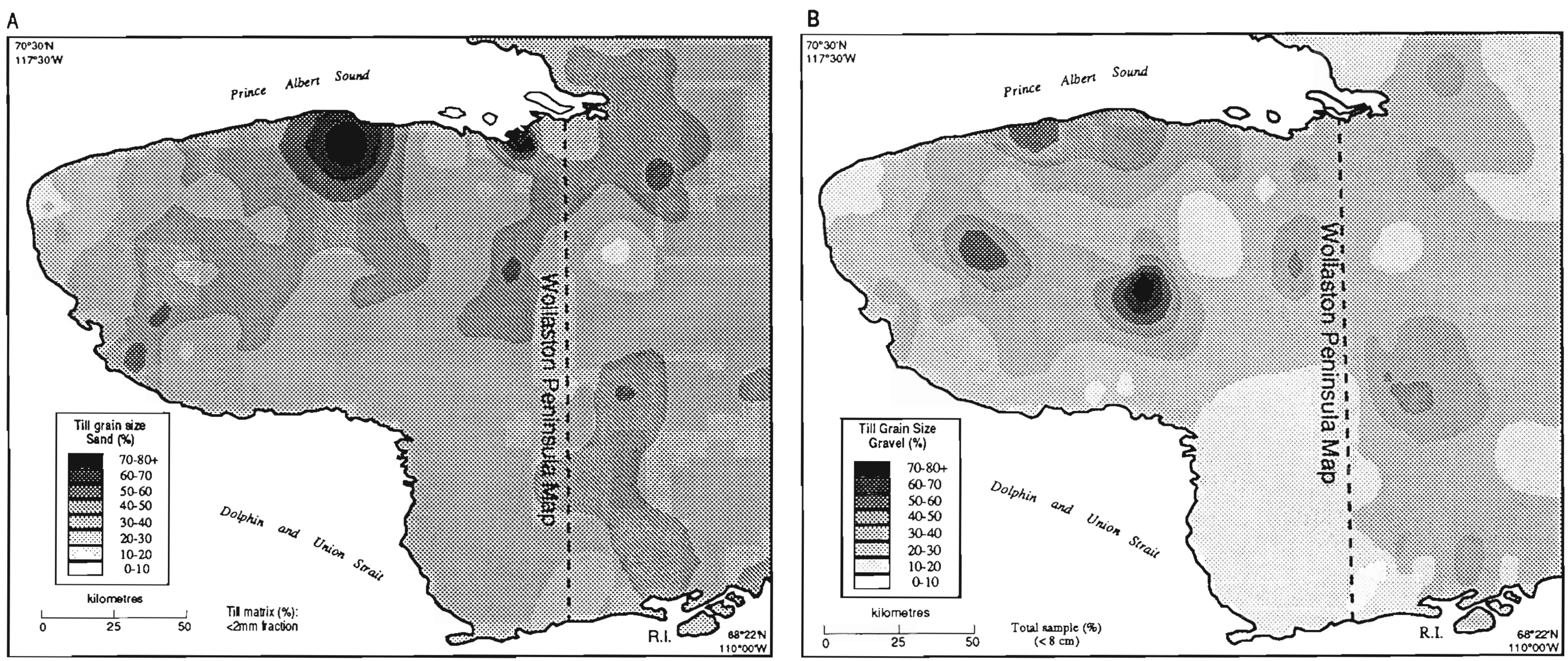


Figure 34. Regional variation of till matrix textures for Wollaston Peninsula: **A**. sand (% of <2 mm fraction); contour interval is 10%. **B**. gravel (% of total sample); contour interval is 10%.

variation in the field warranted mapping separate facies or rock stratigraphic units such as a silt till. At stratigraphic sections, diamicton units, although separately identified at Capes Back and Baring and Kugaluk River, have similar properties to the surface diamicton. In most cases these similar units were simply different depositional events within a single phase of glaciation.

Second, the till matrix textures from Wollaston Peninsula resemble those of tills formed on carbonate lithologies in other areas. For example, matrix textures from tills sampled close to bedrock in southern Ontario correspond to those for samples from Wollaston Peninsula (Fig. 35). This correspondence results from mechanical abrasion during glacial transport that produces a terminal grade or size range (silt) in similar rock types (Vagners and Dreimanis, 1971). Silt is also produced, in part, by in situ weathering of carbonate rock (Tedrow and King, 1982).

Sample variation with depth

Because of its uniform bedrock and drift composition, Wollaston Peninsula proved an excellent area in which to examine some aspects of regional sampling design. For example, what effect does depth of sampling have on assessing the geochemical signature of the till. Within-site or local variation (weathering) of soils is insufficient in Wollaston Peninsula to alter current sampling procedures (rapid surface sampling of nonsorted circles and mudboils) and design (Nixon and Sharpe, 1986). Some pedological variation in till characteristics did arise however, and they are discussed below.

Soils

Because soil studies are increasing useful for Quaternary work in Arctic regions (Birkeland, 1978; Ugolini et al., 1982), soil pits were dug and studied on Wollaston Peninsula: (1) to help distinguish the age of various landforms and drift surfaces relative to those on northwestern Victoria and Banks islands; (2) to help resolve potential depth variation in a regional till sampling program (Nixon and Sharpe, 1986); (3) to provide detailed soil and sediment descriptions in areas with no natural exposure; and (4) to examine the depth and character of the active layer and upper permafrost zone.

Soil profiles from Wollaston Peninsula were measured and described at well drained, upland sites in stony, silty sand till. Soil horizon, thickness, colour, texture, and geological comments were made in the field, and the results are listed in Table 3 and Appendix 2. The soil description in general follows the Canadian Soil Survey Committee (Agriculture Canada, 1978; 1987). This classification considers that cold

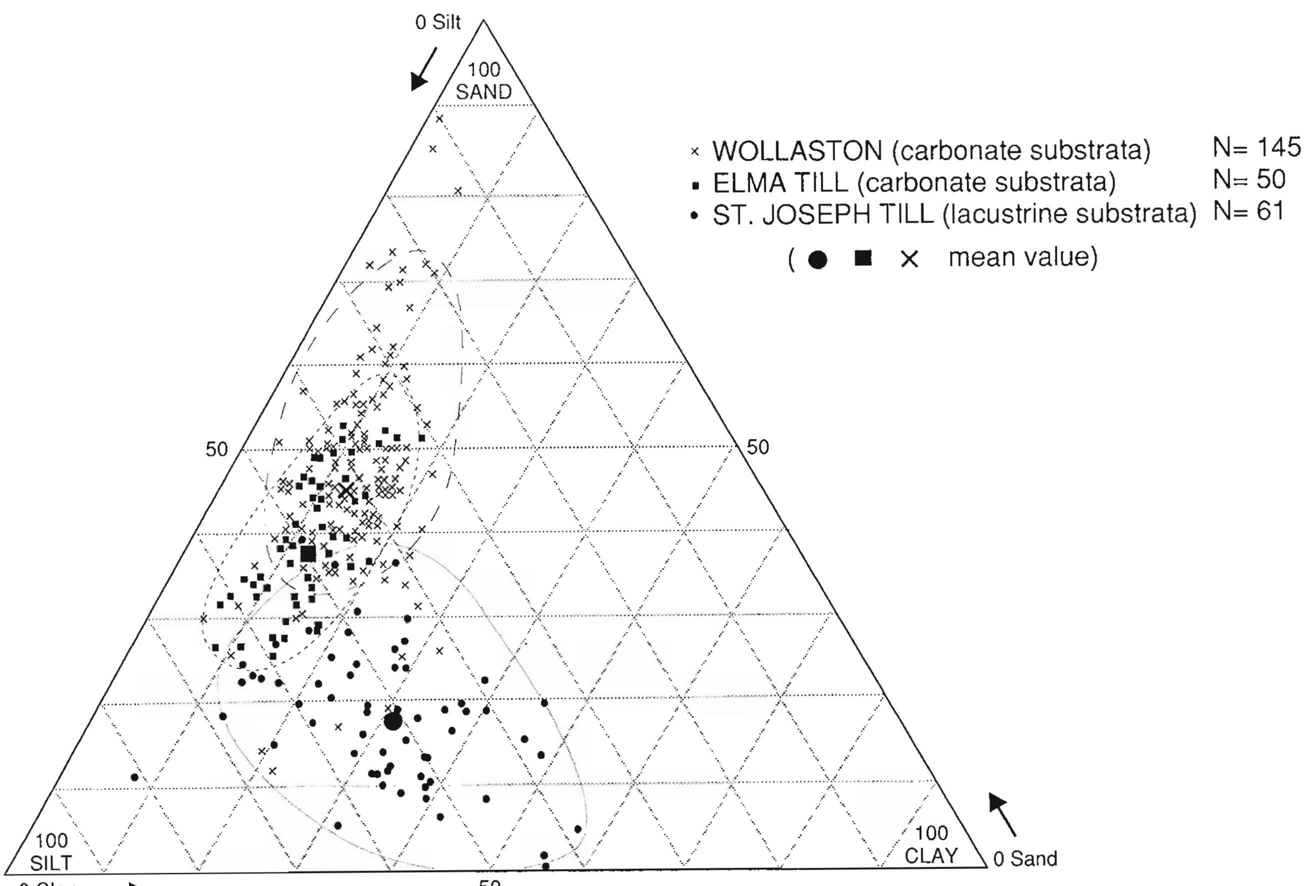


Figure 35. Ternary diagram comparing till matrix texture from carbonate terrain in Wollaston Peninsula (x), Northwest Territories and southern Ontario (circles and squares).

region soils show the pedological expression of cold tundra environments by such features as permafrost, impeded drainage, cryoturbation, and cold soil temperature. This contrasts with early soil work (e.g., Tedrow, 1966), who only considered frost as a physical process within soil development, e.g., a barrier to downward percolation of meltwater. The soils from the Cryosolic Order (Agriculture Canada, 1987) all have permafrost within 1-2 m of the surface, and permafrost has had a significant effect on soil development. The soils studied belong to the Static Crysol Great Group, although a few may be turbic crysols as they may have more than 33% of the pedon disrupted by churning. The soil subgroup is Brunsolic, a designation that indicates a Bm horizon, showing either strong chroma or granular structure with clay or silt skins on the soil aggregates (Agriculture Canada, 1987).

Parent material

The soil pits were all dug in well drained diamictons (Fig. 36) interpreted to be tills or sediment flows. The pits were located on dry, well drained uplands within large (50 m) polygons (Fig. 37). These sites are windswept in winter and dry in the spring even during snowmelt. Most sites were within the centre of small (3 m), nonsorted polygons where frost churning appeared minimal. Frost or soil churning was most readily detected by the presence of organic material more than 5 cm below the surface. Fabric studies at a few sites showed primary fabrics (oriented parallel to ice flow) close (50 cm) to the surface with little or no cryoturbation. The soil appears freeze-dried beneath the annual thaw layer. The parent material consisted of similar diamicton for all pits and the effect of cryoturbation was negligible or low for most sites.

Colour

The soil profiles on Wollaston Peninsula show a clear colour zonation. Several sites (14, 69, 92, Table 4) show colour or cambic B horizons (e.g., 7.5 YR 6/4) one hue redder than the A horizon (10 YR 6/4) and possibly the C horizon (10 YR 7/3; site 14). In some cases the parent material may have a reddish hue. In other soil profiles, the B horizon colour is more subtle, yet a decrease in value (lighter) and decrease in chroma (lower) was apparent.

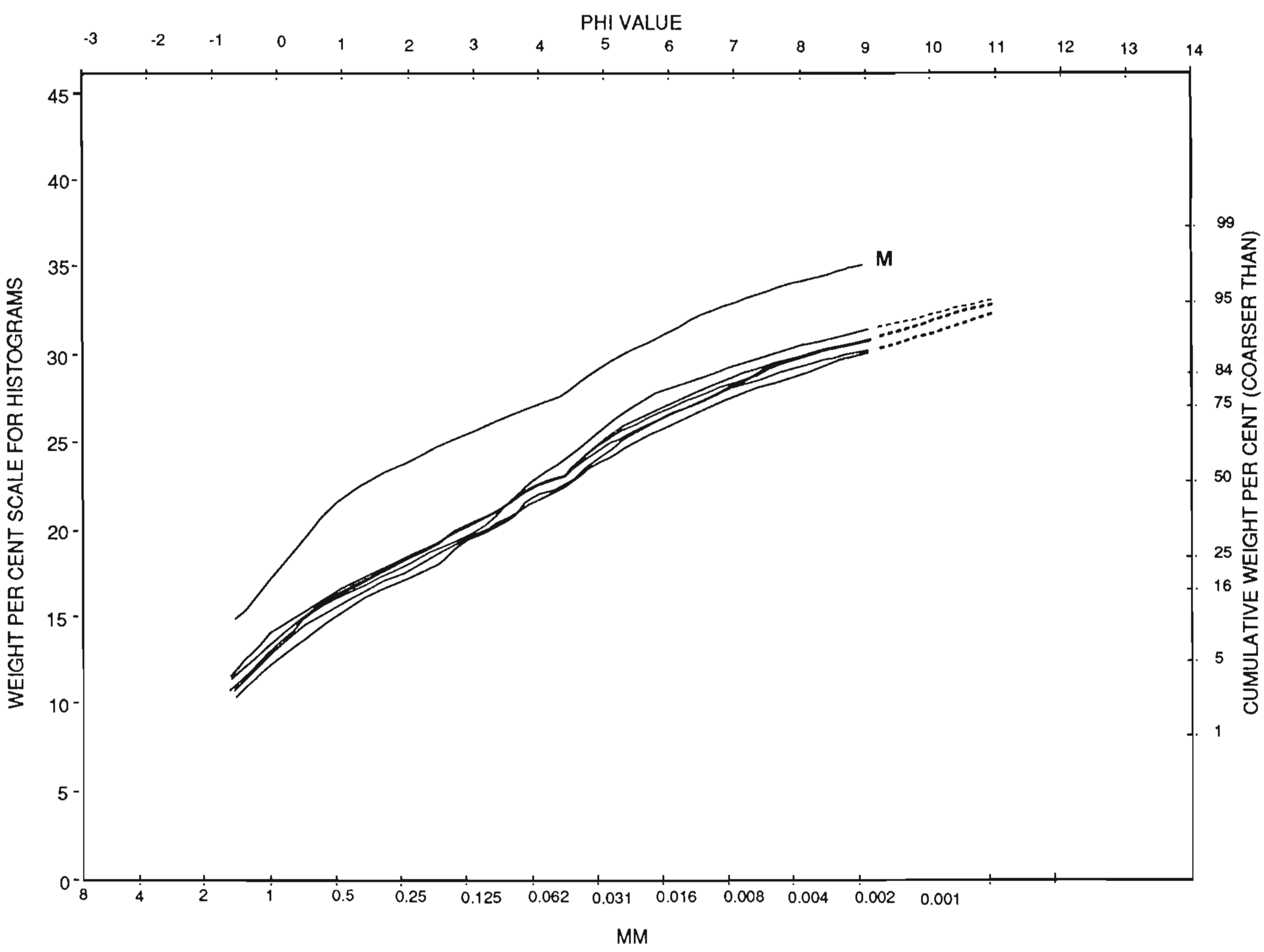


Figure 36. Graph (logarithmic-probability) of grain size distribution of six soil parent materials. All sites from ground moraine except the coarse curve (m), an end moraine.

Texture

The fines in soil profiles seem to increase slightly but clearly with depth, particularly in the B horizon (Fig. 38). This increase suggests a leaching or pedological process (downward percolation) that should appear in other soil pits. A pedologic translocation of fines, apparent in other soil profiles, is supported by colour zonation and possible clay or silt skins on till clasts. This leaching does not, however, explain the whole textural difference or trend to the top of permafrost noticed in some profiles. Other processes may have allowed fines to move to greater depths than the 30-40 cm apparent from soil development. A frost fracture effect is one possibility; however, it may not be expected to leave a regular trend noticed in some profiles. A periglacial effect from the migration of a freezing front may also have moved fines close to the permafrost level in combination with microfractures. The downward increase in fines could be explained by a single loss or removal in the upper soil column. Such a loss, reported by Shilts (1978) as caused by runoff, was enhanced by rapid turbation and little or no soil development on till surfaces in the Keewatin region. The Wollaston sites were chosen at more stable till sites with no noticeable cryoturbation and the soil profile development is good compared to other Arctic soil profiles (Woo and Zoltai, 1977). Therefore, either cryoturbation is not as active at Wollaston sites, or, runoff (low precipitation and snow accumulation) probably removes little material laterally from the soil system.

The increase in fines below permafrost in some pits may also relate to former, thicker active layers. In some profiles (14, 20, 43; Table 4), the increase in fines may indicate either eolian input or capillary action during dessication. A third alternative might involve migration of material upward during freezing of the active layer.

The soils studied on Wollaston Peninsula, Victoria Island, compare with those on Somerset and Prince of Wales islands, Northwest Territories, that have Brunisolic cryosol characteristics (Woo and Zoltai, 1977). In the latter two areas, the less common A horizons can be up to 10 cm thick. B horizons are 45 cm thick or less, are generally thinner and they have weaker textural B horizons than those on Wollaston Peninsula. It was impossible to distinguish between Cox (oxidized) and Cn (unoxidized parent material) in the Somerset and Prince of Wales Island soil sets. These C horizons are marked by vesicular, fissile structure, indicative of common frost effects (Woo and Zoltai, 1977).

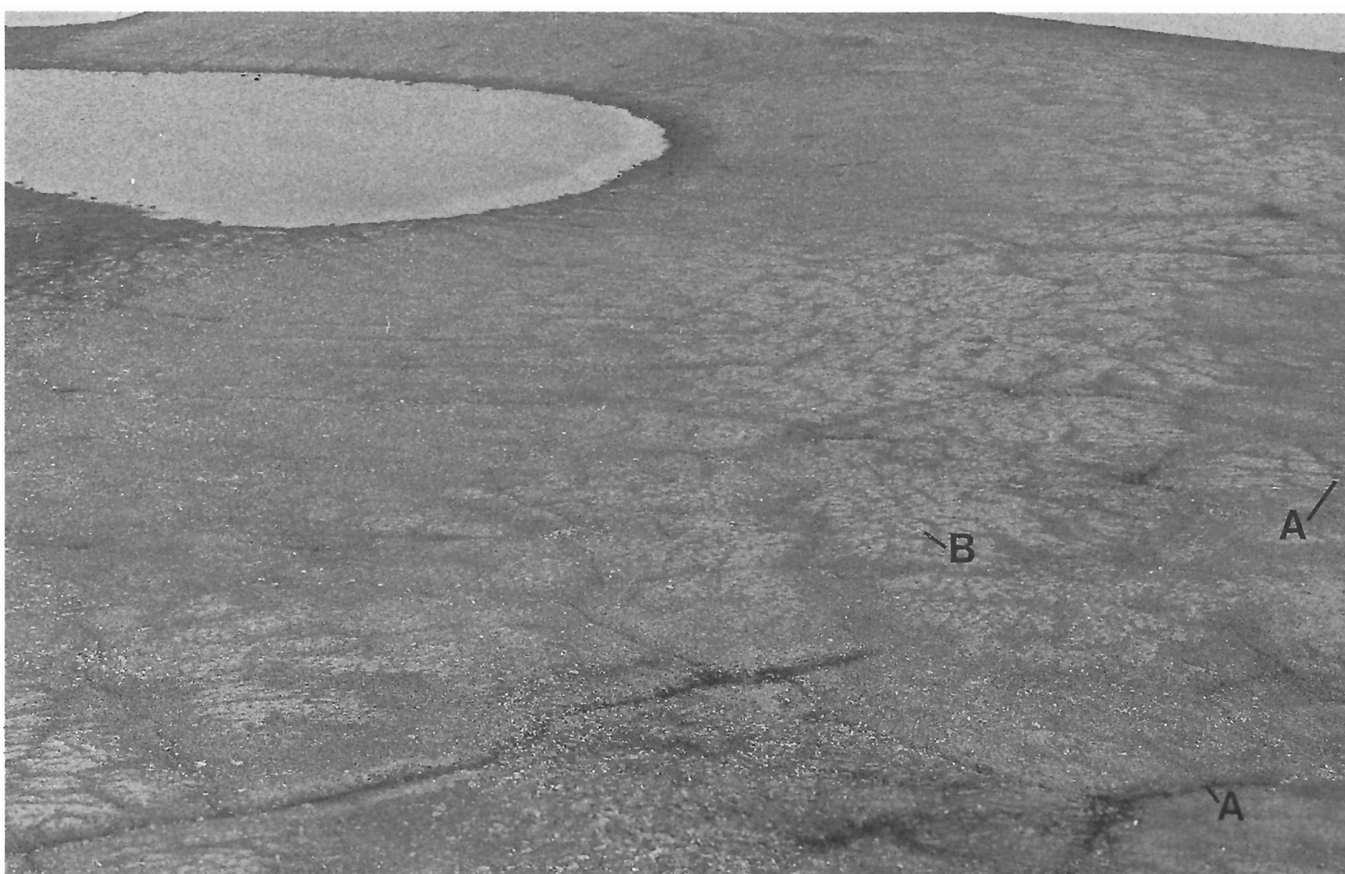


Figure 37. Patterned ground showing nonsorted polygons 50+ m (A) and 3 m (B) across. GSC-1991-166

Trace elements

Trace element composition was determined for the soil profiles (Fig. 39). Methods of analysis are discussed in the section on methods. The trace element values are based on study of the clay fraction (less than 2 μm). Interpretation of these geochemical data is preliminary because experience with soil profile data in arctic terrains is limited.

Half the elements analyzed from soils (Fe, Pb, Zn, Ni) show a trend (decrease in metal content) with the depth of profile (Fig. 39). The weak trends suggest no major flushing of the sediment and elements through the system (minor leaching may be occurring). Trends for Fe and Ni show a significant difference (enrichment) between weathered (soil zone) samples and parent material.The test

Table 4. Soil properties from soil profiles, Wollaston Peninsula

Site	Horizon	Thickness	Colour[1]	Texture	Comment
860	IAB	0-15	10YR 6/4	silty sand	eolian input; cryoturbated; organic matter present
	IB	15-35?	7.5YR 6/4	clayey silt	eolian input; cryoturbated; silt skins on stones
	II Cox	35+	10YR +10	silty sand	stony till; no ice
865	B[1]	0-10	10YR 6/6	silty sand	intermittent A; pebbly
	B_2	10-35?	10YR 7/6	silty sand	cryoturbated lenses
	Cox	35-60	10YR 8/3L	(silty) sandy	coarse, sandy till; no ice
866	AB	0-20?	10YR 4/3	(pebbly) silt loam	cryoturbated; (eolian?)
	B	20-30?	10YR 6/4	sandy loam	cryoturbated; (eolian?)
	Cn	30-60	10YR 8/4	silty sand	stony; no ice
887 (Camp 1)	AB	0-10	10YR 5/2	sandy loam	organic matter; granular
	B	10-25	10YR 7/4	sandy silt	compact minor cryoturbation
	Cox	25-4-	10YR 7/6	silty sand	minor fissile structure near clasts
	Cn	40-115	10YR 7/3	sandy silt	July 7, 1982
913	AB	0-15	10YR 6/3	silty sand	eolian input
	B	5-15	7.5YR 6/6	silty sand	cryoturbation evident
	Cox	15-40	7.5YR 6/4	silty sand	reddish parent till
	Cn	40-60	7.5YR 7/2	silty sand	
936	AB	0-12, 16	10YR 4/2		organic matter mixed
	B	16-27	7.5YR 6/6	silty sand	vaguely defined
	Cox	27-37	7.5YR 6/4	sandy silt	moist colour
949	AB	0-8, 10	10YR 5/3	silty, sandy loam	organic matter mixed
	Cox	10-30	10YR 7/6	silty, sandy	dry colour
	Cn	30-65	10YR 7/6	sandy silt	moist colour
951	AB	0-18	10YR 6/3	silty sandy	good soil profile
	B	10-28	10YR 6/6	sandy silt	
	Cox	28-55	10YR 7/4	silty sand	moist colour
969	AB	0-6, 10	10YR 6/2	fine sandy	fine granular structure
	B	10-30, 40	10YR 7/6	silty sand	massive to fissile structure
	Cox	30-120?	10YR 7/3	silty sand	permafrost reached (July 14, 1982)

[1]All colours are dry field colours except where noted. L are laboratory colours that are generally 1 value lighter and 1 chroma lower.
Note: oxidized C horizon (C) are Bm horizons and non-oxidized C horizons (Cn) are C horizons under Canadian soil classification.

statistic relating to this factor is not significant for other elements: U, Cu, Co, Cr, and As.) Dyke (1983) found no element trend with depth on Somerset Island, perhaps because the active layer is thinner there. Because the Somerset Island data contained only two plots with more than two samples in the active layer, trends can not be established. One Somerset site, however, shows a good profile trend for $CaCO_3$ and Pb.

The Victoria Island data show a weak decrease in values of trace element with depth – a result similar to that of Shilts (1977), although his sections run across the permafrost table. This decrease could be due to the weathering of metals and subsequent take-up by clay particles, rather than immediate loss from the system. A few increases in elements at the top of the soil profile possibly result from eolian input. This effect is most probable where higher silt to clay values occur in the upper soil profiles because these sizes may be enriched in trace metals. Several discontinuities in the trends occur at or close to the junction between the active layer and permafrost horizon. Plots for Somerset Island also showed this trend (Dyke, 1983). Soil moisture migration or diffusion of elements to the freezing front may also explain this effect (Mackay, 1975).

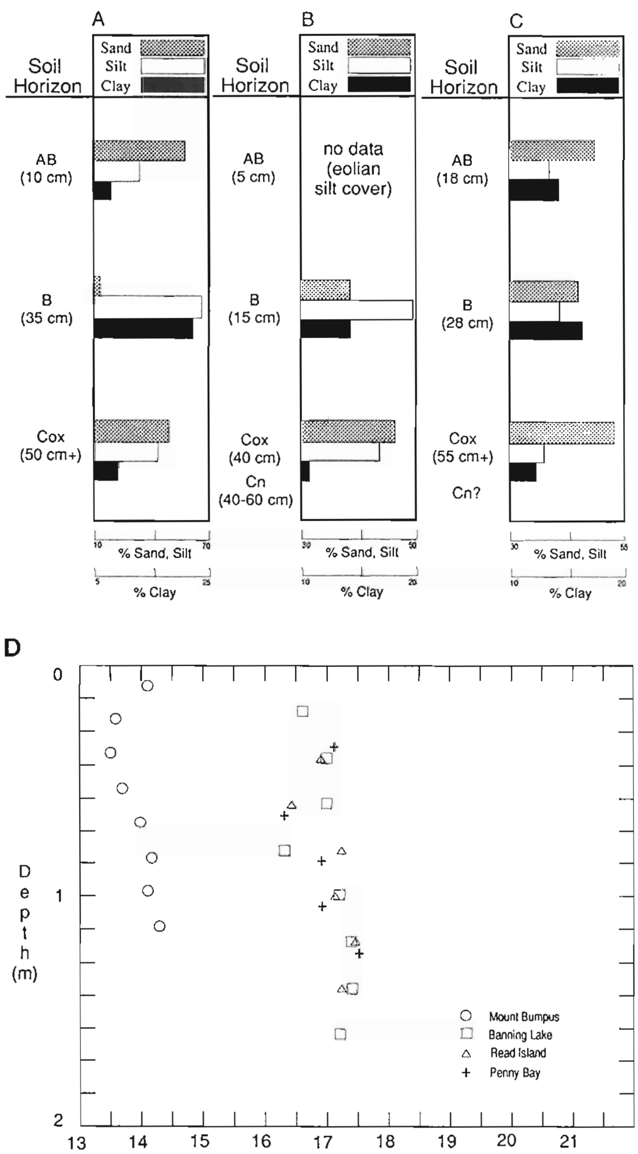


Figure 38. Plots of soil texture with depth in soil pits: **A.** site 860; **B.** site 913; **C.** site 951; and **D.** clay with depth, at four sites.

Site ranges

Trace metal values vary much more by region than by site (Fig. 40). Eolian input seems apparent (sites 860, 865, 887; Table 4). Overall, the site ranges indicate that variation in the profile, on the scale of our trends, is much less than regional variation. This result is significant for regional geochemical investigations. Although it is similar to findings in large geochemical studies in Keewatin (Shilts, 1977, 1984) verification in other areas with continuous permafrost and different bedrock types is now important.

Age of soils

Because the tills from Somerset Island were deposited by Late Wisconsinan ice (Dyke, 1983) their age can be compared based on profile development in the soils surveyed. Relative dating can also be done by comparing soil profile data used for dating deposits on Baffin Island (Birkeland, 1978). Late Wisconsinan soils from Baffin Island (different rock type, e.g., granitic) showed weak cambic B horizons of less than 9 cm and oxidation to 50 cm. The drift of Wollaston Peninsula is Late Wisconsinan in age (Sharpe, 1984). The stronger development indicates that soil forming processes may work faster on the sediments in the carbonate terrain(?) and climate of Victoria Island than of either Baffin or Somerset islands. Carbonate usually slows down soil development, which suggests that milder climate may be significant for sites on Victoria Island (Tarnocai, personal communication, 1988). Depth of permafrost may have been an important factor affecting the soil profiles.

Summary of soil studies

Soil profiles show recognizable and consistent textural and trace elements trends. Silt and clay contents increase with depth in the profile. Some trace elements (U) also increase with depth whereas others (Pb, Zn, Ni, and Cr) decrease. Some trends are supported by statistical testing indicating that the results are significant. These have pedological explanations in part. Eolian input, mechanical weathering, and soil moisture migration to the freezing front (up and down) may explain patterns that result from other than strictly traditional pedogenic processes. The tills appear physically more stable (less prone to moisture-related deformation or cyroturbation) on Wollaston Peninsula than in Keewatin (Shilts, 1977, 1978), which allowed "transport" trends (soil particle migration) to develop. The active layer is deeper on Wollaston Peninsula than Somerset Island; thus significant differences developed in trace elements between the active and frozen layers. In the relatively uniform carbonate terrain of Victoria Island, small variations of soil profile do not affect sampling procedures for provenance studies or orientation surveys for drift prospecting. Soil profiles are developed enough to suggest milder conditions allowed the young (Late Wisconsinan), carbonate soils of Wollaston Peninsula to progress ahead of soils in adjacent areas.

Periglacial environments and terrain disturbance

Victoria Island, lying within the zone of continuous permafrost (ACGR, 1988), exhibits a variety of periglacial landforms and ground ice features which are inter-related with glacial landforms. Periglacial features on Victoria Island have resulted from frost action above continuous permafrost rather than simple proximity to glacial ice as it retreated from

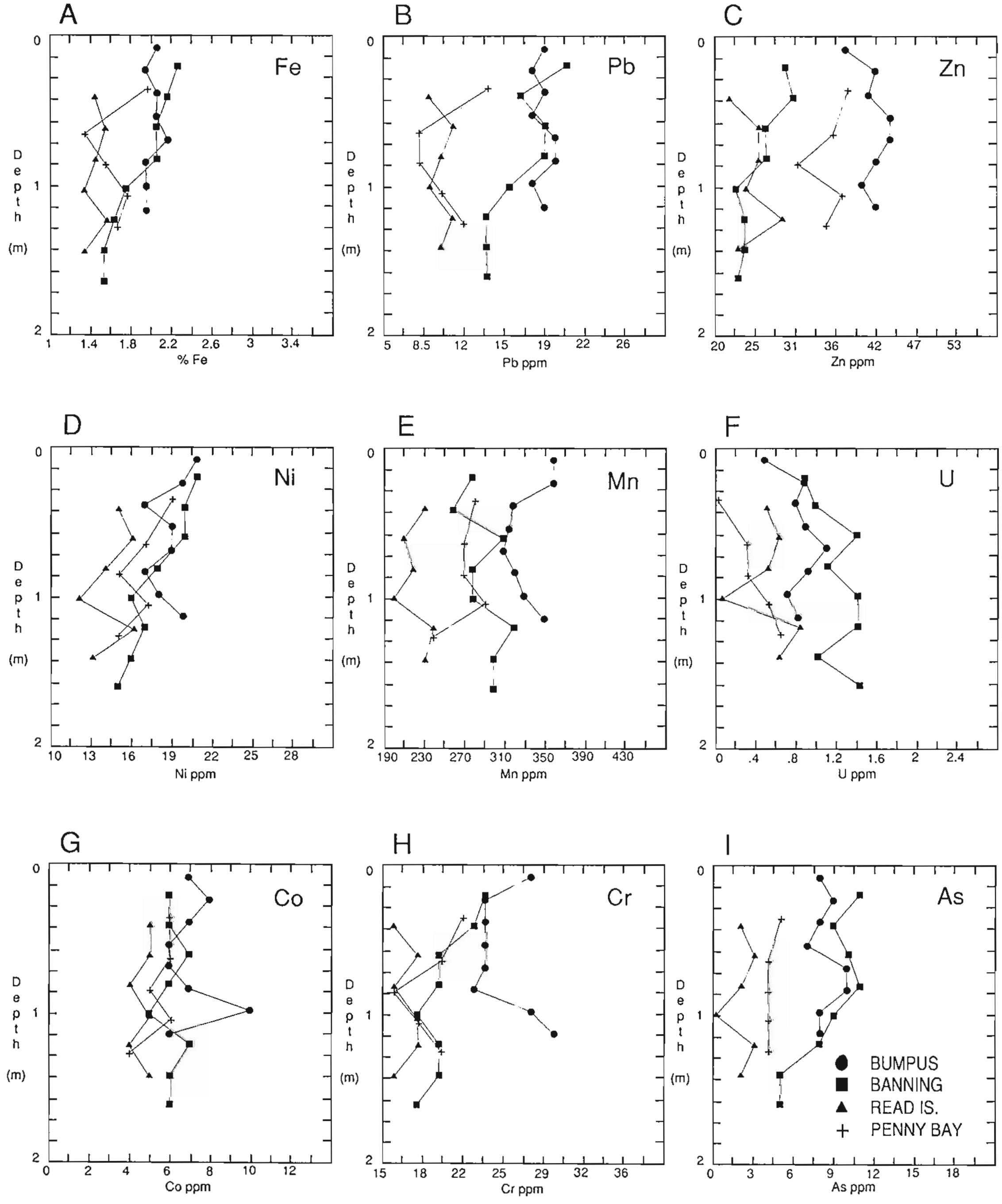


Figure 39. A-I. Trace elements values plotted with depth in soil pit; Fe, Pb, Zn, Ni, Mn have significant trends; U, Co, Cr, As show no significant trends (location map, Fig. 32).

the area. Such conditions result from present day mean annual temperatures less than -10°C and relatively snow-free (windswept) winters.

Our ability to reconstruct Quaternary environments depends on using evidence from periglacial landscapes. This includes developing an understanding of permafrost conditions such as ground temperature, permafrost extent, and active layer features. Important aspects of continuous permafrost conditions are the nature of ground ice and the presence of ice wedges, massive ice and pingos. The presence and distribution of ground ice can be partially assessed by mapping the pattern and extent of both relict and active thermokarst features. The most recognizable feature of permafrost terrain and periglacial landforms, principally patterned ground, is widespread on Victoria Island. We can therefore map surficial sediments and make environmental inferences, in part, by deciphering the relationship between permafrost conditions (patterned ground), drainage, and soils.

Permafrost conditions

Ground temperature

Few data exist concerning ground temperatures on Victoria Island and Wollaston Peninsula. Ground temperature data may vary on the same day: a temperature of 1.7°C at 0.9 m for one site on Wollaston Peninsula compares to a temperature of -5.3°C at 0.8 m (Table 5) in silty soil at another site east of the study area (E.B.A. Engineering Consultants Ltd., 1981).

Permafrost extent

The extent of permafrost is known from indirect indicators such as periglacial landforms and ground ice estimates.

Victoria Island lies well within the zone of continuous permafrost (ACGR, 1988). Ice wedges polygons are ubiquitous and form rapidly on modern floodplains and in shallow lakes. Permafrost thicknesses are unknown for Victoria Island although other Arctic islands have permafrost thicknesses ranging from 340-660 m on Melville Island and 335-600 m on Bathurst, Cornwallis, and Devon islands (Taylor, 1988), all beyond the margin of the Laurentide Ice Sheet. Within the Laurentide margin, on Russell Island, 200 km northeast of Victoria Island, ice-bonded permafrost extends to 300 m, based on resistivity in a borehole through Paleozoic rocks from a surface elevation of 114 m (Hardy and Associates, 1984).

Active layer conditions

Active layer thicknesses were measured directly in the field at campsites and in test pits or soil pits. The active layer is the surface layer of ground subject to annual thawing and

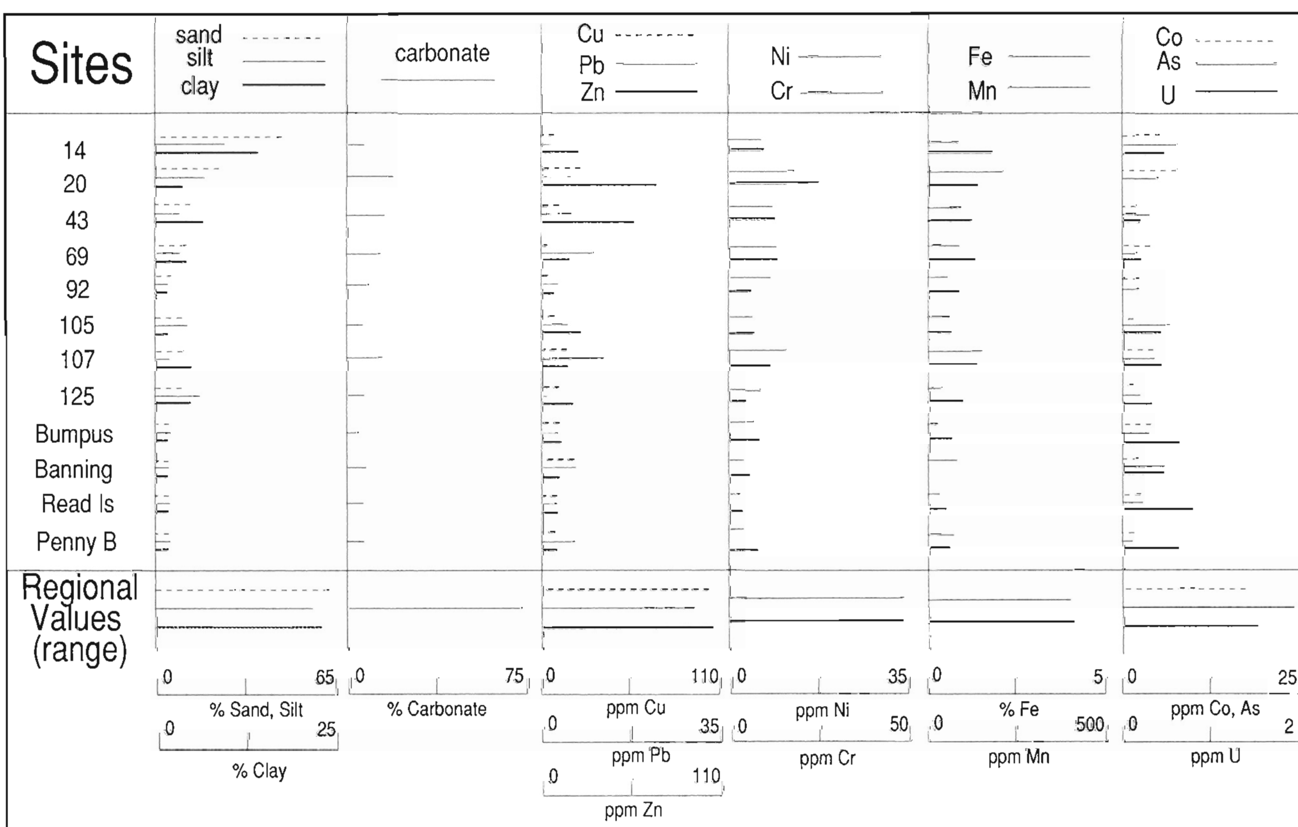


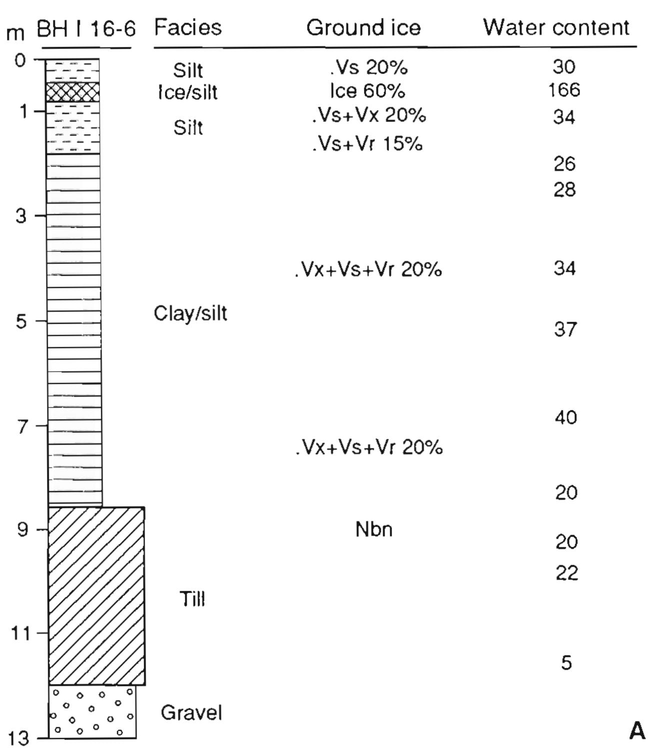
Figure 40. Variability of texture, carbonates, and trace metals in soil pits, Wollaston Peninsula by site and region.

freezing in areas underlain by permafrost (ACGR, 1988). Measured depths provide only minimum values because most pits were dug in July, somewhat before the period of maximum thaw in August. Test pits dug July 9 (Kugaluk River) and July 15 (Mount Bumpus) 1982 recorded permafrost at 115 and 120 cm, respectively, in well drained, unvegetated, upland sites in till. Test pits in 1983 revealed active layer depths of 105, 100, and 115 cm in mid July for similar, unvegetated, upland sites just east of the study area. Another site showed an active layer 75 cm deep in early July.

Table 5. Ground temperature profile, Wollaston Peninsula

Depth (m)	Temperature (°C)
0.8	-5.3
1.5	-1.2
2.3	-11.2
3.05	-10.1
3.8	-8.0
4.6	-11.9
6.1	-12.0
7.6	-11.9
9.1	-10.6
12.2	-16.2

Site: Kagloryuak River (I 16-6)
Date: 10.8.1980
Air T (°C): 5.0
Source: E.B.A. Engineering Consultants Ltd., unpublished report 1981



This site shows oxidation to the maximum depth of the active layer. Active layer depths of 75-80 cm were measured in pits on siltier, slightly moister and better vegetated sites.

Data from boreholes drilled in August 1980 (E.B.A. Engineering Consultants Ltd., 1981) indicate active layer depths mainly between 60-80 cm on and close to Wollaston Peninsula. In places, values of 1.0 and 1.1 m were recorded as were shallow depths of 30 to 40 cm. Deeper values occurred on coarse sediment, till, or gravel. Shallower depths generally occurred below marine limit and on siltier soils, where greater vegetation cover may have had an insulating effect.

Nature of ground ice

Despite the widespread occurrence of periglacial landforms (Washburn, 1980) and the inference of widespread segregated ice (Mackay, 1971), little ground ice has been seen on Wollaston Peninsula. Borehole logs of a transect across the southern part of the area show low ice contents and little segregated ice in tills particularly on upland sites (Fig. 37). Although marine silt and clay contained higher ice contents, little ice occurred as thick lensing or wedges. For example, at one site no excess ice occurred in till to depths of 13 m whereas the overlying marine silt and clay contained up to 20% by volume; ice crystals, coatings, or oriented ice (Fig. 41A). Ice lenses 5 mm thick and thinner vertical sheets occurred sporadically in some holes (E.B.A. Engineering Consultants Ltd., 1981, unpublished report). Most holes had 20-25 cm intervals showing 10-25% by volume and a few thin ice lenses. One hole revealed ice-rich till containing 90% by volume. At some sites the ice-bonded sediment showed no visible ice. Fabric studies at a test site east of the area also had frozen sediment but

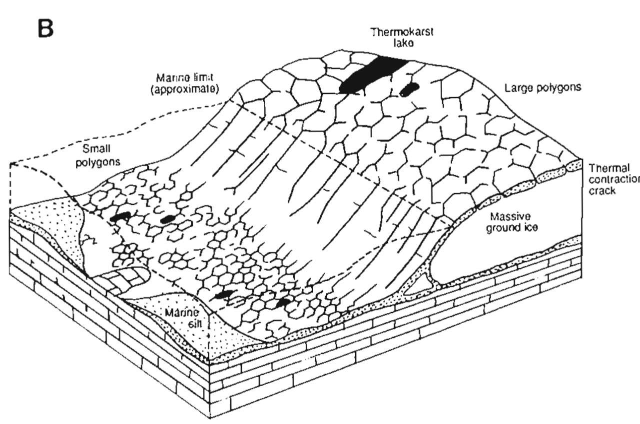


Figure 41A. Borehole geotechnical log from southern Wollaston Peninsula. **B**. Schematic model of ground ice occurrence related to large, polygonal, thermal contraction cracks and melt during high sea stands.

subsurface clast fabric had not been rearranged by ice action or frost wedging (Sharpe, 1992). This set of random observations indicates that segregated ice is not prominent in some settings.

Ice wedges

Ice wedges were not observed in the field except at sites over massive ground ice. The widespread occurrence of thermal contraction crack polygons suggests that ice wedges may be common but subsurface studies are necessary to verify their exact extent and nature.

Massive ice

Massive ground ice, observed at several sites, was only studied in detail at Ammalurtuq Lake. A 5 m high exposure of massive ground ice occurs within hummocky moraine (Fig. 22B). The ice occurs within an active thaw erosion scar 8-10 m high and 50 m wide and is capped by 1-2 m of diamicton with an abrupt contact. The exposed ice is 5 m high and 30-40 m wide. The ice is massive and relatively free of debris except for embedded, faceted boulders 30-40 cm in diameter. A few steeply dipping, debris-rich bands of ice were also found. In one location, a vertically oriented wedge of ice with vertical banding was found cutting across the massive ice. The massive ice has been interpreted to be of Pleistocene age based on regional geology, stratigraphic position, sediment character, contacts, and isotopic composition of the ice (Sharpe and Michel, submitted). The debris and clast content, banding and its regional setting within hummocky moraine suggest that the massive ice may have originated as glacier ice. Oxygen isotope analyses on the massive ice are not sufficient to support a glacial origin independent of stratigraphy; a segregated ice origin is also not clearly supported. The vertically oriented ice wedge is believed to represent younger, vein ice.

The presence of massive ground ice in hummocky moraine appears to correspond with the distribution of large (30-100 m), nonsorted polygons. This pattern, if verified, or valid on a regional basis, suggests widespread areas of ground ice, especially above marine limit (Fig. 9).

The following sketches a possible scenario of ground ice presence. Thick, massive ground ice occurs within hummocky moraine at sites of active thermokarst erosion (Sharpe, 1989). Past thermokarst erosion scars, common in this terrain, suggest possible widespread buried ice. Kettles and thermokarst lakes are common in hummocky moraine (Fig. 6B). Large polygonal patterns are commonly above marine limit (Fig. 9; Fig. 37) on hummocky moraine and end moraine. However, adjacent, washed moraine (below marine limit) has no such large widespread polygons and a very thin sediment cover (Fig. 9). This difference may relate to former melt of buried ice from terrain below marine limit (Fig. 41B). Large polygons may reflect thermal contraction cracking from massive buried ice (Mackay, 1984). Elsewhere, a thick cover of slumped diamicton protects the buried ice from melt except at exposed lake bluffs or similar positions of enhanced erosion. The corollary of this scenario (Fig. 41B) is that prominent moraines on Victoria Island are mainly ice-cored.

Pingos

Several relict or collapsed pingos on Wollaston Peninsula have been identified by Washburn (1947, 1980) and Fyles (1963). The pingos range in estimated size from tens to hundreds of metres across and from 5 m to more than 25 m high. They consist of a central depression or crater-like area surrounded by a large circular or arcuate ridge or rampart (Fig. 42). The ramparts (Mackay, 1987, 1988) are dissected in places by large gullies and by concentric cracks or fractures and, less commonly, by radial cracks. Some radial cracks may have formed as dilation cracks caused by ice-core expansion (Mackay, 1985) yet these appear continuous with large polygonal borders. The central depression in some lies level with the surrounding terrain and contains small ponds; in others the raised depression reveals its sedimentary character in eroded sections. One such section shows beds of stratified sand and silt containing moss (Fyles, 1963). These beds are the upthrust or domed sediments of glacial Lake Wollaston formed about 240 m a.s.l. All the pingos occur within such former lake bed sediments of Late Wisconsinan age. These pingos contained no ice and several appear as collapsed mounds of lacustrine sediment with slump scars.

Pingos formed in drained lake beds are considered to be closed-system pingos formed by ice growth that tapped groundwater under hydrostatic pressure (Mackay, 1979). Pingos provide clear indications of permafrost conditions and probable mean annual ground temperatures of -5°C and lower (Mackay, 1978). The Wollaston pingos appear to have formed under conditions different than present today. Their growth probably began immediately after glacial Lake Wollaston drained at about 10 500 years BP. French and Dutkiewicz (1976) reported the growth of pingos on Banks Island between 4500 and 7000 years BP.

Figure 42. Pingo in collapsed or degraded state. GSC 204766

Thermokarst activity

Many landforms and features produced by the melting of buried ice occur on Wollaston Peninsula. This activity, evident in the patterned ground and lake drainage features, is most clear in large areas of hummocky moraine. Models of hummocky moraine formation call upon episodes of ice melting (Clayton, 1964) during which thermokarst erosion developed. The nature of thermokarst activity is illustrated in the area around Ammalurtuq Lake (Fig. 43). In this area, active thaw erosion produces steep scarp headwalls and debris flow aprons. The terrain includes broad areas of previously disturbed slopes and sediment defined by relict scarps, scars, and debris flow aprons (Fig. 43). The melting of buried ice has also produced ice-block depressions, thermokarst lakes, and lakes drained by the melting of ground ice, which acted as a dam (Harry and French, 1988). The extent of previous thermokarst erosion covers up to 75% of the total area of hummocky moraine (Map 1650A).

Examination of present day thaw and flow processes provides the key to assessing the nature, extent, and timing of thaw erosion. Exposed ground ice melts during warm summers after the removal of a protective sediment cover. The presence of a thin (1-2 cm) debris cover helps to warm and melt the underlying ice. Removal of this debris uncovers new ice to melt, and slumping continues to increase the debris cover downslope. The ice face thus exposed has a 20-40° slope, which allows debris and meltwater to flow downslope and to produce an apron or levées beyond the exposed ice. Debris builds up in this fashion until it clogs the ice ramp and buries the ground ice. The thaw erosion at Ammalurtuq Lake has been active at least since 1958; a sharp erosion scarp is visible on the aerial photographs taken that year.

Stratigraphic sections adjacent to an active thaw erosion site record past melting and slumping events (Fig. 44). Measured sections comprise six main units: thick massive bouldery diamicton with striated clasts (units A, C, and F); interbedded sequence of sand, silt, clay with ice and organic material, and minor gravel (units B, D, and E); and interbeds of sand and clay with dated organics (units B and D). The whole sequence, horizontally bedded and showing little deformation, appears to consist of stacked units. Ice lenses occurring within clay-rich horizons (units A and E) appear to be segregated ice. Organic material from this section has been dated at 8300 ± 90 BP (Wat-1640) and 7960 ± 120 BP (Wat-1363) (Fig. 44). These results indicate repeated debris flow or slumping activity in immediate postglacial times (paraglacial sedimentation) followed by a long period of relative slope stability. The sequence may include more recent, reworked slump packages but further dating of these types of deposits would be necessary.

In summary, the widespread pattern of thaw erosion features, the apparent early postglacial age of much of the debris flow sediment, and the limited extent of present active thaw erosion suggest that thaw was more prominent in the past and that slopes have stabilized where thick sediment covers remain. Where this cover is removed during warm or wet intervals, extensive development of thaw erosion follows. The presence of thick massive ice bodies at some localities in this terrain, also raises the possibility that more extensive ice bodies exist. Whether this ice eventually proves to be of glacial origin or of segregated origin does not affect the fact that major areas of future erosion and subsidence could occur in morainal areas.

Periglacial landforms

The most common periglacial landform on Wollaston Peninsula is patterned ground. Nonsorted and sorted varieties range in diameter from tens of centimetres to 50 m. Large scale features consist of mass movement elements such as solifluction lobes and terraces, debris flows, and thermokarst depressions. Integrating information on pattern ground and large periglacial landforms helps in understanding the nature and distribution of ground ice.

Patterned ground

The most common patterned ground consists of nonsorted circles, polygons, and nets. Most forms are irregular circles or polygons (Washburn, 1980) that are about 2 m in diameter and commonly have slightly domed centres rising several centimetres above their borders. These forms are most clearly developed on diamicton (till) but they occur on silty marine and sandy or gravelly sediments. Nonsorted circles and polygons are usually bounded by depressions filled with vegetation (mainly *Dryas*). The central areas are relatively flat and often bare or poorly vegetated. On fine grained marine sediments, nonsorted patterns lack vegetation and are commonly dome shaped. These features have been called mud polygons (Washburn, 1947) and mud boils (Shilts, 1978). They have level, wet centres in low lying areas and central domes 10-20 cm high in well drained areas. Nonsorted circles and polygons vary from 0.5 to 3 m in diameter (average 1 m) in marine sediments.

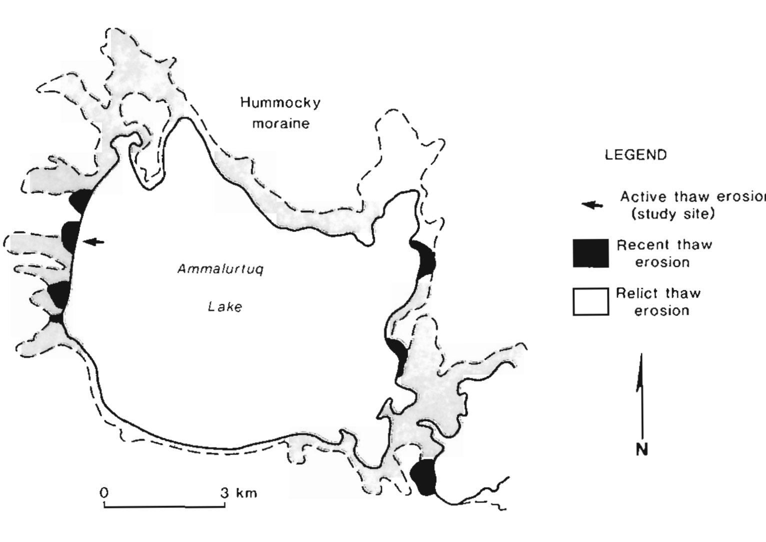


Figure 43. Map of thermokarst erosion scars around Ammalurtuq Lake.

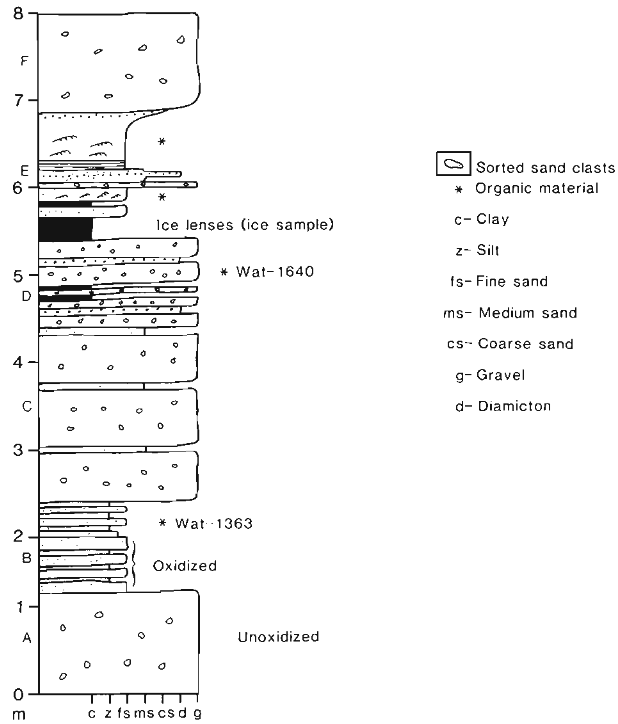


Figure 44. Sediment sequence in thermokarst erosion terrain at Ammalurtuq Lake.

Nonsorted patterns

The smallest nonsorted patterns are polygons 10-25 cm in diameter. They form miniature polygonal patterns within larger patterned forms. They are most common on fine grained sediments and have little relief. These forms are thought to be "desiccation" polygons produced by contraction caused by wetting and drying.

A second small form consists of tundra hummocks composed mainly of vegetation. Tundra hummocks are 15-25 cm high and 20-50 cm wide. They consist of a core of cryoturbated sand and organic debris covered by a mat of *Carex* (Western Ecological Services, 1981, unpublished report).

Large scale nonsorted patterned ground includes polygons (A in Fig. 37) with high centres, low centres, and fissures. These forms occur most commonly in ground moraine, hummocky moraine, and drumlin areas where diamicton covers the surface. They range in size from 10 to 50 m but are most commonly 15-20 m. Their borders are defined by surface cracks or depressions with slight to moderate cover of vegetation. Surface cracks may be open at the top and filled with organic rich sediments to a depth of 30-50 cm. These forms mainly occur on well drained sites (Fig. 37) and they are most prominent above high water marks such as marine limit and lacustrine limits. In fact this distribution is an aid to mapping marine limit in some areas (Fig. 9).

Nonsorted polygons with high centres or with degraded, irregular margins occur in selected low areas with fine grained soil. The forms may be 10-20 m across with bordering depressions of 2-3 m wide and 0.8-1.0 m deep. Depressions are vegetated whereas centres are bare. Depth of active layers have been measured at 65-72 cm in raised centres whereas 55-65 cm have been measured in depressions (Western Ecological Services, 1981, unpublished report). Large cracks associated with these forms appear to confirm the presence of ice wedges at depth.

Low-centre polygons occur with complete vegetation cover in low, moist areas and with bare centres in dry and perhaps wind deflated sites. These forms are 10-20 m in diameter with border fissures 10-20 cm deep. The fissures have a vegetated rim which may be raised 10-50 cm. Dry sites have lower relief, 10-30 cm, and bare centres. These sites have few stones and are found on marine silts. The active layer in low-centre forms is shallower than high-centre forms, as shallow as 25 cm. These forms are also related to ice wedges but no direct observations were recorded.

Coarse textured sediment found on deltaic and glaciofluvial outwash show large, nonsorted polygons from 10-40 m in diameter (Fig. 45A). Coarser gravel supports larger forms but most forms occur on level surfaces. Fissures 25-100 cm deep and 20-50 cm wide border these polygons. On delta or terrace fronts the forms become larger and stretch downslope.

Figure 45. **A**. Large polygons with fissures on deltaic sediment; GSC 204766-J; **B**. stone circles. GSC 204823-J

Nonsorted forms of patterned ground become stretched from circles, polygons, and nets on level ground to steps and stripes on slopes. For example, on flanks of drumlins well vegetated borders of unsorted circles, nets, and polygons at the crest become well vegetated furrows and stripes downslope. Stripes occur mainly on wet slopes beneath perennial or late-lying snowbanks on any landform. Steps occur most favourably on vegetated colluvial slopes that are moist but these slopes are gentler (<3°) than slopes containing stripes.

Sorted patterns

Patterned ground with sorted forms occur less commonly than nonsorted forms. The difference is defined by sorted borders that show a concentration of stones (Washburn, 1980). These borders are coarser than the interiors and they usually are not vegetated. Sorted forms are usually smaller, particularly for sorted polygons where 10 m is apparently maximum. They are most common on level surfaces. On Wollaston Peninsula the most prominent sorted forms occur as polygons on morainal ridges. The forms are 0.5-4.0 m in diameter and in places reach 10 m. On till surfaces the borders are defined by boulders or coarse gravel with clasts standing on end. In very coarse sediment, sorting produces "debris" islands separated by steeply inclined blocks.

Local occurrences of sorted stone circles (Fig. 45B) were found on moist outwash sediment. Sorted patterns occurred on very wet morainal slopes and produced stripes of wet bare soil in the centre with a combination of inclined stones and vegetation on the border.

Implication of patterned ground

The widespread distribution and variety of patterned forms on Wollaston Peninsula suggest extensive and continuous permafrost and frost induced processes. The exact nature and distribution of ground ice and ice wedges, however, requires clear documentation, which will allow the timing, age, and character of the pattern ground features to be recognized. For example, the large and extensive nonsorted polygons occur most prominently on diamicton. Several questions relate to their origin. Did these forms develop shortly after deglaciation and are they now relict or weakly active? Did they achieve an equilibrium size and do they now exist in a steady state? Did their position on well drained sites inhibit their activity after accumulated 'dry' sediment became a protective insulating cover? Did the presence of marine silt and clay prevent large polygons from developing below marine limit or is there another limiting condition (Fig. 9)? Does their distribution reflect the current distribution of buried ground ice? A model of ground ice distribution, linked to hummocky moraine and end moraine distribution and outlined in the section on *Nature of ground ice* (Fig. 41B), suggests large moraines on Victoria Island are ice-cored.

Mass movement features

Solifluction features, already well documented on eastern Victoria Island (Washburn, 1947), occur on Wollaston Peninsula particularly on morainal slopes. The best defined solifluction sheets or lobes have overrun raised shoreline features. In morainal areas a terrace or lobate solifluction form allows us to differentiate periglacial forms from ice contact features, in situ till sheets, or debris flow deposits. Presence of organic debris provides the best means of distinguishing solifluction debris from till. Solifluction is prominent in local areas as stepped and lobate forms. However, without extensive trenching it is hard to confirm the suspicion that broad areas of terrain are covered by solifluction debris. Dating of incorporated organics may help to determine when it was most active. Widespread solifluction appears to have been most active in immediate postglacial times based on the relative age of its forms.

Terrain disturbance and evaluation

Thaw erosion is part of slope adjustment in permafrost terrain and in terrain that contains buried glacial ice. Human activities in such areas may aggravate the problem of terrain disturbance resulting from thawing. The most likely possibility for such disturbance would come during any development; the specific example of pipeline development has been investigated (E.B.A. Engineering Consultants Ltd., 1980, 1981, unpublished report; Western Ecological Services, 1980, unpublished report) for the Polar Gas Project.

Limited test data show that low ice contents are common in many upland sites underlain by till and sandy sediments. These data are mainly from ground moraine or streamlined landforms. Thick ice bodies have been identified in areas of hummocky moraine that cover almost 40% of Wollaston Peninsula. Ice content and ice lenses and probably ice wedging is common in marine and lacustrine fine sediments. Design criteria for pipeline construction identify the need to minimize the disturbance of frozen soils (E.B.A. Engineering Consultants Ltd., 1981, unpublished report). The primary consideration is the depth of the active layer and the need to keep the system frozen because the pipe would be frozen and would carry gas below 0°C. Table 6 shows the minimum pipe burial depths for various soil conditions and terrain types. The ice content of soils in areas with high contents of ground ice is important. Soils with no excess moisture will be needed for backfill material to prevent thaw settlement from thermal erosion. In areas where large outwash terraces occur, such granular material is readily available. In areas where till is present, suitable granular fill may be difficult to find. The discovery of stratified sediments in some drumlins identifies a possible resource. Any prediction that other drumlins may contain stratified sediment (Sharpe, 1987) needs to be verified with boreholes. If proven, drumlin sediments would have clear importance for completing pipeline construction as cheaply as possible using nearby sources of fill. Hummocky moraine was also found to contain stratified sediment not predicted by some models of its formation.

Table 6. Recommended minimum depths for gas pipe burial in permafrost terrain on Wollaston Peninsula

Terrain type	Depth (m)
Bedrock	1.0
Ice-poor residual soils or till, well drained active layer, and slopes not exceeding 5°	1.2
Ice-rich fine grained soils, slopes not exceeding 2°	1.4
Ice-rich fine grained soils including till, slopes between 2 and 5°	1.6
All soils, slopes exceeding 5°	2.0
Stream beds	2.0
Minor and intermediate	Special design

Source: after E.B.A. Engineering Consultants Ltd., 1981, unpublished report.

Again nearby potential sources or granular fill make pipeline construction more feasible in areas of hummocky moraine than previously anticipated.

The widespread occurrence of patterned ground forms, mass movement landforms, and the possible broad extent of massive ground ice is to be expected in an area of continuous permafrost such as Wollaston Peninsula. Problems related to thermokarst erosion, thaw settlement, and active layer failure are obvious types of terrain disturbances that should be anticipated with future development.

QUATERNARY HISTORY

Events prior to last glaciation

Little is known of events predating the last glaciation of Wollaston Peninsula. Ice apparently covered all but northwest Victoria Island in Early Wisconsinan time (Vincent, 1989). Vincent (1982, 1984) initially suggested that last ice did not cover all of Wollaston Peninsula based on airphoto correlation with sediments from Banks Island. However, it appears more likely that Late Wisconsinan ice did not cover all of Diamond Jenness Peninsula to the north (Vincent, 1989) where Middle Wisconsinan or older deposits lie at the surface.

Fyles (1963) reported organic-bearing sediments underlying probable Late Wisconsinan till on adjacent Diamond Jenness Peninsula north of Wollaston Peninsula. The organics consist of matted leaves and herbaceous plants and were dated >32 400 BP (GSC-388, Blake, 1974), >37 000 BP (GSC-3613), and >38 000 BP (GSC-3592). The organics were considered to represent interstadial conditions (last interglacial age or older) based on their apparent similarities with climate typical of present conditions (Fyles, 1963). Vincent (1989) suggested that the organics may be Middle Wisconsinan based on identifying the underlying red till as Early Wisconsinan.

On Wollaston Peninsula at Kugaluk River, disseminated organics (small fragments of wood within sand at 95 m a.s.l. that underlies a surface till) have been dated at 45 100 BP (TO-95) by accelerator techniques (Table 7). Although this may indicate that nonglacial conditions were present on Wollaston Peninsula about 45 000 BP, the sandy sediments themselves may not have been deposited at that time. It is unlikely that shallow lacustrine or fluvial sediments would have been deposited in thick sequences 95 m a.s.l. during a nonglacial interval. It seems more likely that organic material was reworked during glaciofluvial erosion and thus redeposited prior to the glacial advance represented by the overlying diamicton, considered to be Late Wisconsinan till. Accelerator dates of this antiquity are considered suspect as real ages, they may represent minimum ages.

A second explanation emphasizes that the dated wood fragments are spruce. Spruce is a very unlikely species to find growing on Victoria Island during Pleistocene times (J. Matthews, personal communication, 1986). Neither organic beds from Diamond Jenness Peninsula nor the interglacial beds on Banks Island have yielded tree fragments (Matthews et al., 1986). Among several possible explanations of this anomaly, three seem particularly plausible; 1) Pre-Pleistocene organic beds occurring on Wollaston Peninsula, or up-ice of the area, have been glacially eroded and transported; 2) Spruce wood may have floated across Dolphin and Union Strait during a high sea stand that encroached upon Wollaston Peninsula; 3) Eolian transport during winter wind storms may have moved organic fragments during periods of little or no snow cover, prior to occupation by Late Wisconsinan ice. In any case, the underlying glacial diamicton that rests on bedrock at Kugaluk River (Fig. 17A) probably represents glacial conditions predating a nonglacial interval. Glacial deposits in a similar stratigraphic position to the Kugaluk River section occur within another section on a river near Cape Baring. Based on these two sections in western Wollaston Peninsula, evidence exists to suggest that glacial ice from the southeast covered all of Wollaston Peninsula at least once, and possibly twice. Evidence of three full glaciations is preserved (down ice-flow) on Banks Island (Vincent, 1989).

The glacial deposits above the dated organics have been traced by surface mapping and are clearly Late Wisconsinan in age (Sharpe, 1984). This mapping supports the concept that Late Wisconsinan ice covered all of Wollaston Peninsula to ice limits lying well beyond southwestern Victoria Island (Sharpe, 1984), perhaps at the west end of Amundsen Gulf as shown on the Glacial Map of Canada (Prest et al., 1968). Lower strata, depending on age of dated wood, may represent Early Wisconsinan ice cover as well.

Late Wisconsinan glacial activity

The most reliable discussion of the growth and limits of the last glacial maximum involves accurate ice limits, ice flow patterns related to ice build-up, and an understanding of deglaciation. The limits of last glacial activity on Victoria Island and the northwest margin of the Laurentide Ice Sheet are still in debate. Briefly, Vincent (1982, 1984, 1989) and Dyke et al. (1982) argued for restricted Late Wisconsinan ice on western Victoria Island; however, Sharpe (1984) and later Dyke (1987) argued for more extensive and full ice cover including ice cover of eastern Banks Island.

The spatial relationships of landforms outlined earlier helps to establish the limits of glacial activity during Late Wisconsinan time (Fig. 46). The continuous, gradational pattern of landforms seems to have formed beneath a single, former, large ice-stream that moved from east to west along Coronation Gulf and Dolphin and Union Strait (Sharpe, 1984, 1988a). Ice also occupied Prince Albert Sound but apparently produced no similar landform set because of strong topographic control from the bedrock scarps on the north side of Wollaston Peninsula. Alternatively, portions of the landform set may be submerged in the sound. The strongly shaped topography of the Kagloryuak River valley suggests ice flow similar to that to the south. Therefore two ice streams apparently split around the central plateau. Thus, topography and orientation of the major ocean troughs (Coronation Gulf, Dolphin and Union Strait, and Prince Albert Sound), controlled ice advance and build-up with an east-west alignment, which altered general ice advance from the southeast. No support was found for major east to west flow across Victoria Island as proposed by Dyke (1984).

The glacial limit during Late Wisconsinan time is based on the concept of full ice cover over Wollaston Peninsula (Sharpe, 1984). A 12 000 BP ice position is inferred to have occurred well into Amundsen Gulf (Fig. 46) but its exact position is difficult to define from information on Wollaston Peninsula alone. Landform patterns from landscapes south of Dolphin and Union Strait were used (Sharpe, 1984; St-Onge, 1988). The marine limit at Cape Baring (115 m) implies an approximate ice thickness of 350 m (based on rock-ice density ratios of 3:1 and no eustatic effect, Andrews, 1970). If the ice profile were parabolic (0.3 m/km), its position would fall close to the minimum limit of Vincent (1989). A lower ice profile (0.1 m/km), possibly occurring as an ice shelf or a surged ice margin, would have extended somewhat beyond that shown in Figure 46. Hodgson and Vincent (1984) proposed the development of a late glacial ice shelf in Viscount Melville Sound adjacent to northern Victoria Island. Ice shelves are generally subtended by polar or cold-based glaciers (Meirer and Post, 1987) rather than by the temperate or warm-based glaciers that traversed Wollaston Peninsula. Streamlined landforms and warm-based conditions were dominant on Wollaston Peninsula during at least late-glacial time. For this reason extensive ice shelves are not portrayed off Wollaston Peninsula.

An ice limit of >500 m a.s.l. was suggested for the Melville Hills region on the mainland southwest of the study area (Sharpe, 1984). This limit was based on the distribution of sets of streamlined landforms, hummocky drift distribution, and ice-marginal drainage features that appear similar to the landform set on Victoria Island (Sharpe, 1988). This limit has been supported by the work of St-Onge (1988; St-Onge and McMartin, 1987) but dating control is still required to confirm the ice limits as Late Wisconsinan.

The major reasons for full ice cover during last glacial ice activity are summarized from Sharpe (1984) as follows:

1) Projected glacial profiles from the highest, fresh (Late Wisconsinan) landforms (elevations close to 400 m a.s.l. in eastern Wollaston Peninsula) indicate full ice cover where the main peninsula is about 200 m a.s.l. (Fig. 4A).
2) The lack of significant ice-marginal accumulation of glacial drift or lacustrine deltaic sediments on the Wollaston plateau suggest no prolonged minimum ice margin.
3) The occurrence of large outwash (alluvial) fans rather than deltas indicates free drainage occurred during and following ice retreat rather than large-scale ponding required by minimum ice cover (Fig. 47C and Sharpe, 1984).
4) The deglacial features on central Wollaston Peninsula, considered to be Early Wisconsinan by Vincent (1984), are thin deposits and landforms on level carbonate terrain rather than subdued glacial terrain that is "old" in appearance (Fig. 4A).
5) One rather than two marine limits occur on western Wollaston Peninsula.
6) Soil data show no significant difference in properties within and outside the surfaces considered to be older and younger.
7) Drumlins that cross-cut hummocky moraine near Penny Bay (Map 1650A) require ice cover of central Wollaston Peninsula.

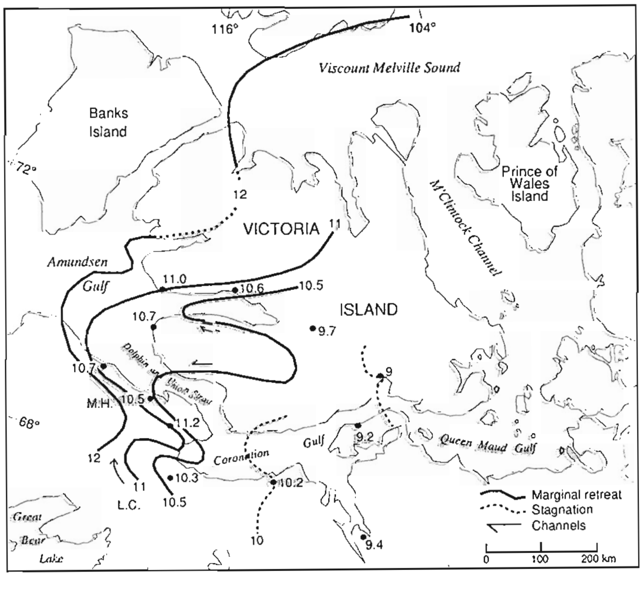


Figure 46. Approximate ice-marginal positions of southwestern Victoria Island during marginal retreat (solid lines). Dashed lines are very vague ice margins during regional stagnation. Time lines approximate in 1000 or 500 years BP.

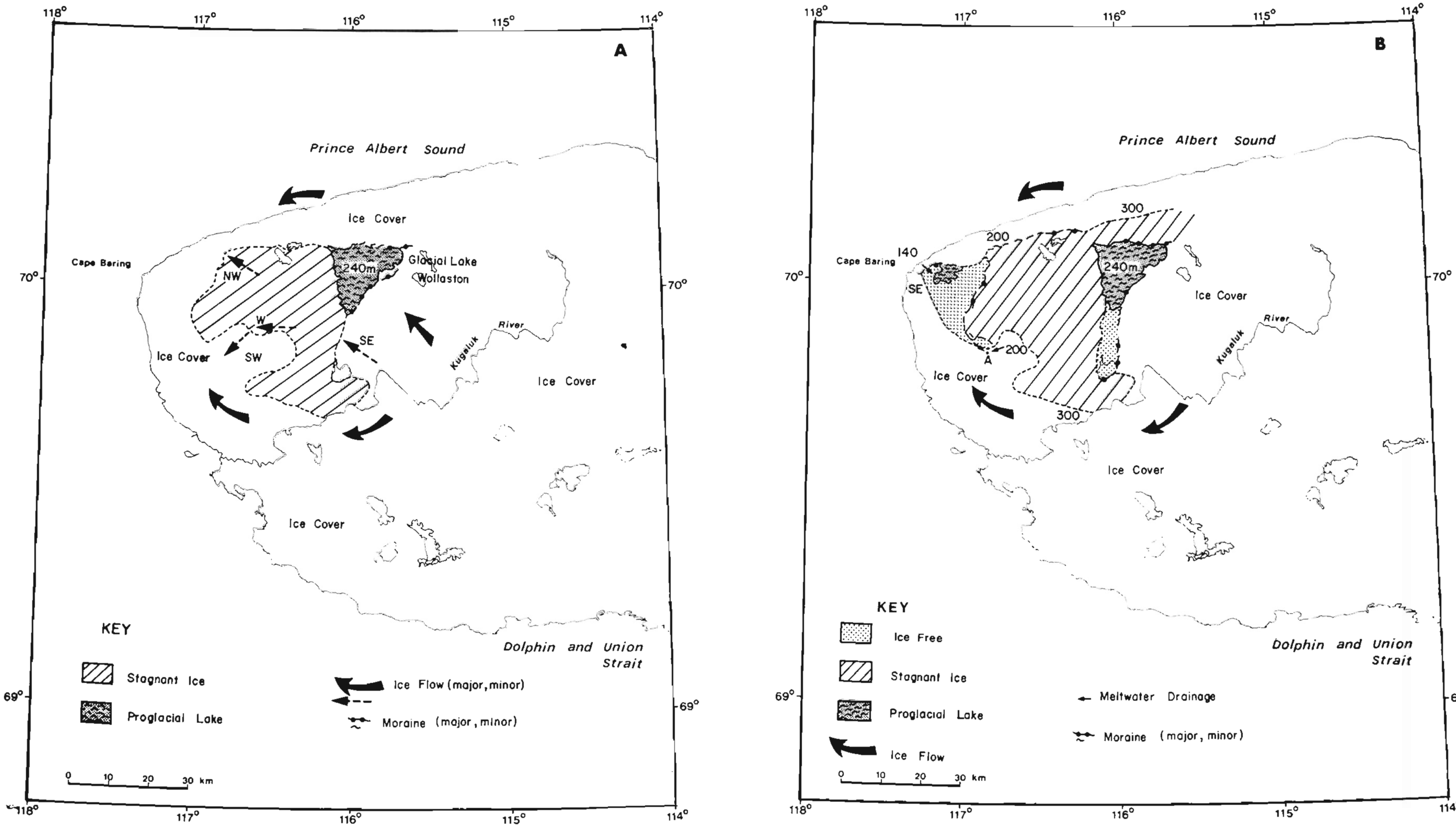


Figure 47. Ice-marginal positions at Wollaston Peninsula: **A**. Phase 1 (ponding) — ice margins and conditions during formation of glacial Lake Wollaston. **B**. Phase 2 (ponds to streams) — ice conditions during formation of southeast-sloping glaciofluvial terrace sequence at Cape Baring. **C**. Phase 3 (ice-marginal streams) — development of large meltwater drainage systems with ice margin positioned east of central Kugaluk River. **D**. Phase 4 (outwash fans) — development of large alluvial fans and extensive meltwater drainage system.

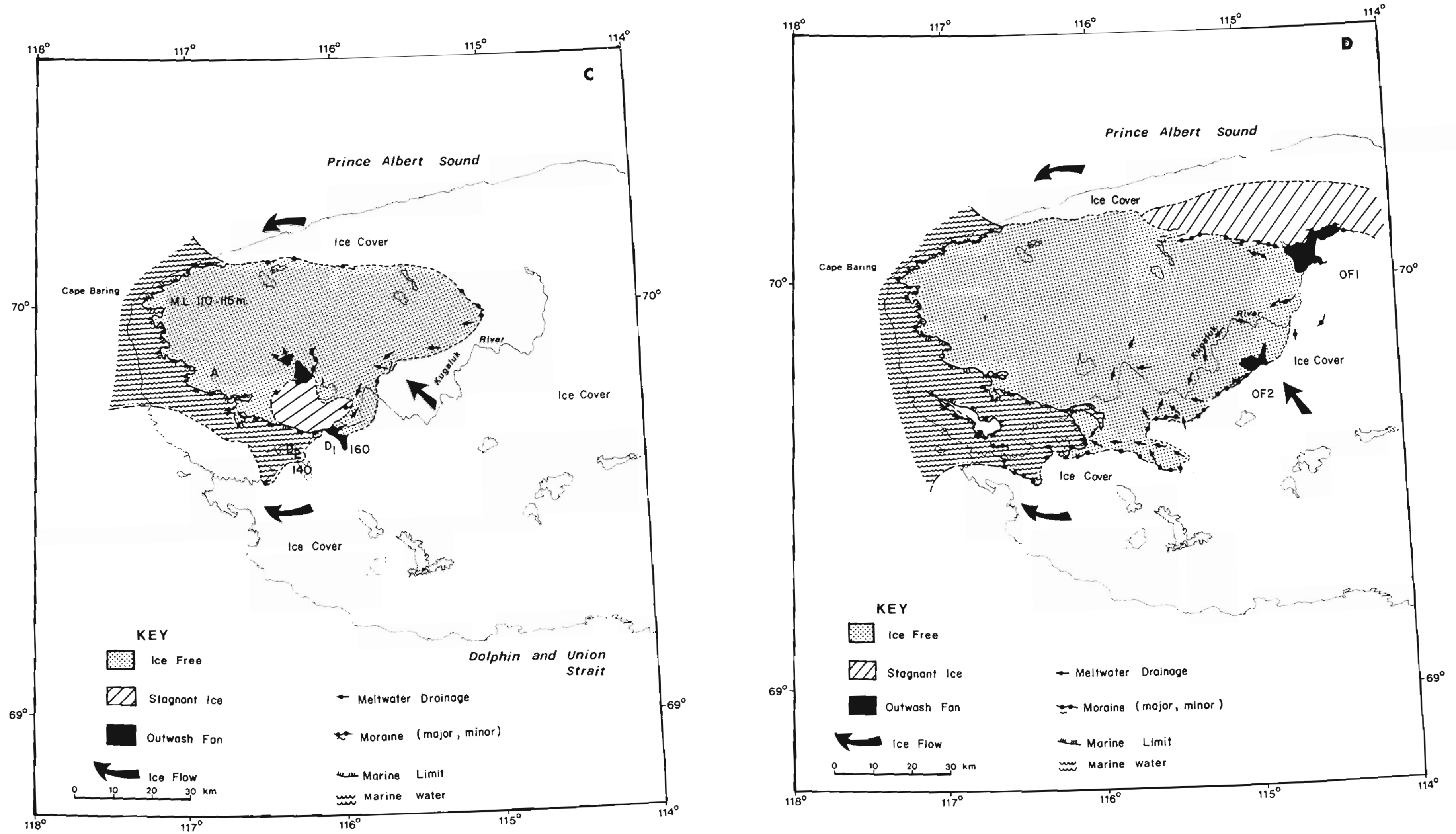


Figure 47 (cont.)

8) The glaciological model proposed by Sharpe (1988a) provides an explanation in terms of landform zonation for surfaces that appear to be old.

Ice flow indicators allow us to infer the pattern of ice build-up, from drift dispersal trends, regional flow patterns, strandline trends, landforms, and striations. Landform patterns and, to some extent, striations may be a product of ice-flow during deglaciation, although their patterns may be reasonable models for initial ice flow. Few striation data remain because of solution weathering in carbonate bedrock. Streamlined landforms preserved on Victoria Island are considered to be late events formed during the waning stages of glaciation rather than formed as initial late glacial flow patterns (Fyles, 1963; Sharpe, 1985, 1988; Hodgson, 1987) on Victoria Island.

Drift dispersal patterns based on the distribution of Precambrian erratics show that ice flowed from southeast to northwest. Local dispersal patterns of carbonate (carbonate "shadow" or zone of low values, in the lee of Precambrian inliers) also show a southeast to northwest trend. This pattern presumably reflects an ice dispersal centre from the Keewatin Ice Divide (Lee, 1959; Prest et al., 1968; Prest, 1984).

Fyles (1963) suggested a dominant southeast to northwest movement of the last glacial ice across Victoria Island based on indicators of regional ice flow. He supported this ice flow history by reference to the general northwest to southeast pattern of deglaciation and increasing elevation of raised marine features related to postglacial emergence. Deleveling trends (south of Wollaston Peninsula) also indicate a predominant northwest flow pattern (Andrews, 1987).

A predominant east to west ice flow pattern was later portrayed by Dyke (1984) as part of his hypothesis for an ice centre or dome in M'Clintock Channel. He based this suggestion on an anomalous pattern of isobases and a west to east ice flow pattern across Prince of Wales Island to Boothia Peninsula. Dyke proposed ice flow (of long duration) trending westward from his proposed M'Clintock dome and crossing Victoria Island, based on the presence of westward oriented ice flow features (streamlined forms) on Victoria Island. Dyke (1984) considered these westward flow features to be older (based on apparent cross-cutting relationships) than northward to northwestward flow patterns. He assigned them to the buildup of the last glacial episode. By contrast, Dyke considered the northwest flow patterns to be ice flow during deglaciation. The need for the M'Clintock dome is based, in part, on inferred flow patterns from M'Clintock

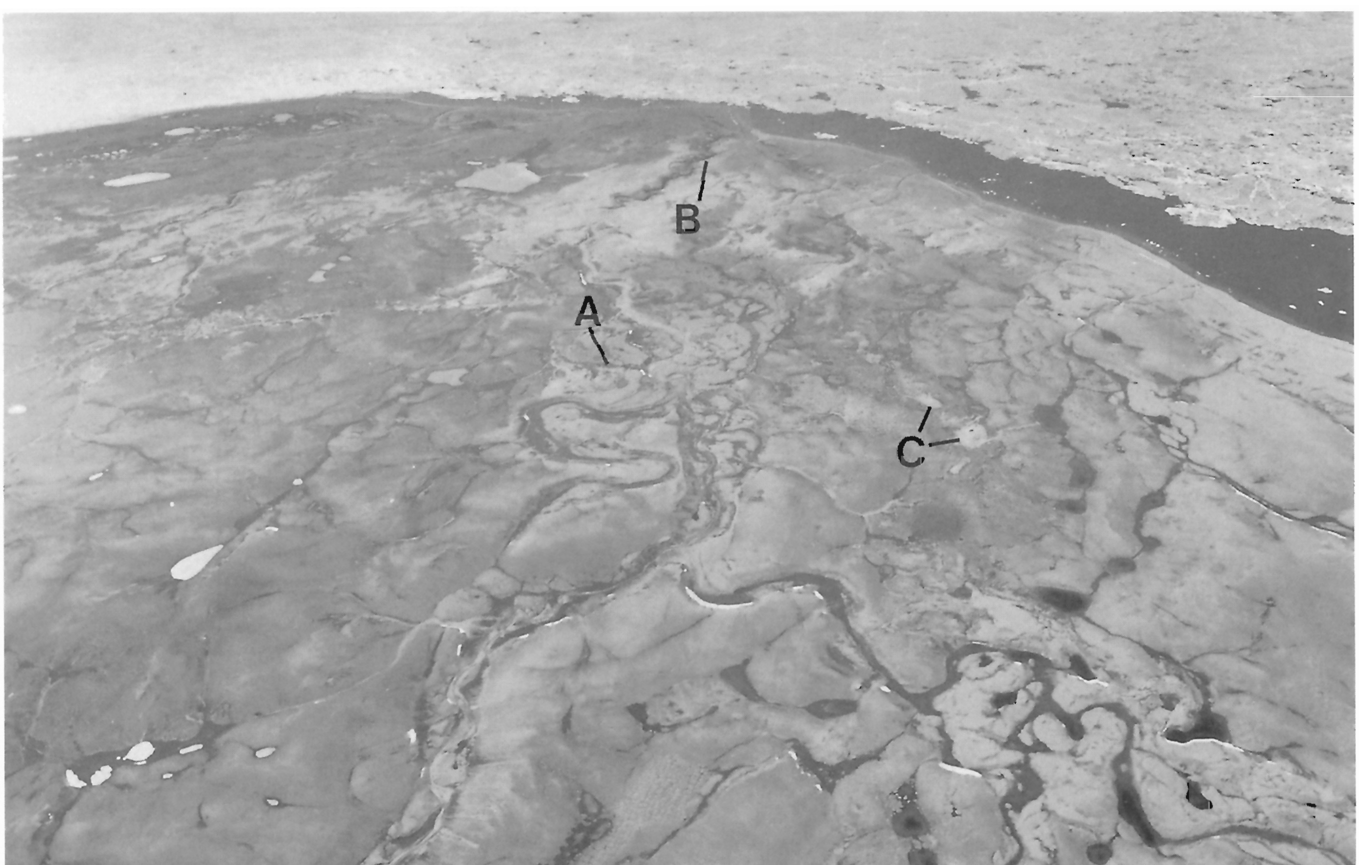


Figure 48. View northwest to Cape Baring indicating area of southwest-flowing glacial meltwater (A) establishing ice limits at Phase 2. Terraces (B) indicate flow to the northwest after ice retreated after esker-delta (C) formed. NAPL T345R-73

Table 7. Radiocarbon age determinations, Wollaston Peninsula and adjacent areas

Location map	Sample (Map #)	GSC #	^{14}C Date years (BP)	Location	Elevation (m)	Material	Comments
1	82-SBB-SH34	3566	10 700 ± 100	Cape Baring	91	shells	May date marine limit (115-120 m) and deglaciation of northwest Wollaston Peninsula
2	82-SBB-SH 11A	3580	9 150 ± 120	Lindaluk Island	84	shells	Dates marine limit and deglaciation at east extent of Wollaston Peninsula
3	83-NJ-0040	3719	1 150 ± 60	Cape Back	4	wood	Dates sea level at 4 m above present sea level; wood buried in beach gravel
4	83-NJ-0035	3725	8 980 ± 80	N. Wollaston	47	shells	Dates related to shells in littoral sediment and therefore date on sea level at or about 47 m a.s.l.
5	82-SBB-SH56 (894)	3727	10 600 ± 100	Cape Baring	105	shells	Dates marine limit and deglaciation as sample found 5-10 m below marine limit; supports GSC-3566
6	52-SBB-SH37 (1005)	4011	9 240 ± 150	E of Cape Back	77	shells	Appears to be too young; may be slightly contaminated by encrustation
7	82-SBB-SH37 (1005)	4012	10 200 ± 280	E of Cape Back	77	shells	Dates appear to be good estimate of age of marine limit (115-120 m a.s.l.)
8	82-SBB-27 (877)	TO-95	45 100	Kugaluk River	100	detrital	Dates from ice free period on Wollaston[1]
9	83-NJ-0039	S-2687	8 565 ± 220	Cape Back	28	whalebone	Date appears to date sea level at 28 m a.s.l.
10	83-NJ-0039	S-2686	9 780 ± 220	E Cape Back	40	whalebone	Date appears to be too old
11	83-NJ-0002	4114	7 660 ± 70	Forsyth Bay	40	shells	Dates formation of beach ridge at 40 m a.s.l.
12	82-SBB-SH-43 (774)	4134	9 290 ± 170	S of Mount Bumpus	93	shells	Date provides minimum estimate of marine limit and deglaciation
13	82-SBB-SH-75 (794)	4160	8 800 ± 130	S coast	33	shells	Date is too old for this surface and probably relates to closer to marine limit ~130 m a.s.l.
14	82-SBB-SH-50	4203	10 600 ± 90	S Cape Baring	80	shells	Date corroborates GSC-3566 and GSC-3727
15	82-NJ-0038	4293	10 400 ± 120	E of Cape Back	71	shells	Date relates to marine limit of about 120 m a.s.l.
16	87-NJ-15f	4504	740 ± 50	Point Caen	3	wood	Date provides age of low level sea
17	87-NJ-2f	4519	9 380 ± 120	Point Caen	69	shells	Dates marine limit at >100 m a.s.l.
18	87-NJ-2f	4537	9 280 ± 80	Point Caen	46	shells	Dates sea level closer to marine limit at >100 m a.s.l.
19	87-NJ-26f	4579	744 ± 90	Point Caen	15	shells	Dates a higher sea level than 15 m a.s.l.
20	87-NJ-22f	4643	7 350 ± 90	Point Caen	19	shells	Dates a higher sea level than 19 m a.s.l.
21	87-NJ-10f	4608	9 020 ± 80	Point Caen	56	shells	Dates sea level close to get above 56 m and possibly close to marine limit
22	87-NJ-12f	4616	8 840 ± 100	Point Caen	36	shells	Dates surface higher than 36 m a.s.l.
23	87-NJ-18f	4622	9 360 ± 110	Point Caen	100	wood	Dates slump event in hummocky moraine above marine limit at time following deglaciation i.e., minimum date on deglaciation and plant colonization
24	87-NJ-7f	4648	460 ± 50	Point Caen	27	wood	Date on wood that has been moved (compare GSC-4504)
25	87-NJ-8f	S-2993	9 190 ± 135	Point Caen	51	whalebone	Date relates to higher sea level than 51 m a.s.l.
26	87-NJ-14f	S-2995	1 390 ± 70	Point Caen	4	whalebone	Date provides estimate of low level sea; possibly moved
27	87-NJ-9f	S-2994	9 600 ± 146	Point Caen	57	whalebone	Date marine limit and deglaciation

[1]Dated at Isotrace, University of Toronto by mass accelerator.

Channel westward onto Victoria Island and the inference that the east to west flow was long-term, and, based on anomalous isobase patterns.

Deglacial features and landforms may be sparse in an area and so a model of how initial ice built up would be preserved by landforms related to that buildup. But it is also possible that ice retreat and melt produced the majority of landforms and deposits. Fyles (1963) considered that the complex pattern of streamlined landforms on Victoria Island related to late changes of ice flow direction during thinning (or retreat) of the ice sheet. This view was supported by studies of cross-cutting landform relationships in northwestern Victoria Island (Hodgson, 1987) and in eastern and southwestern Victoria Island (Sharpe, 1985, 1988a). Dyke and Morris (1988) propose multiple ages for streamlined flow patterns on Prince of Wales Island to the east (Fig. 18).

The concept of long-term, last glacial ice flow in an east to west corridor from M'Clintock Channel as proposed by Dyke (1984) and Dyke and Prest (1987) does not fit geological evidence from Victoria Island. 1) Sustained flow from M'Clintock Channel does not allow for the widespread

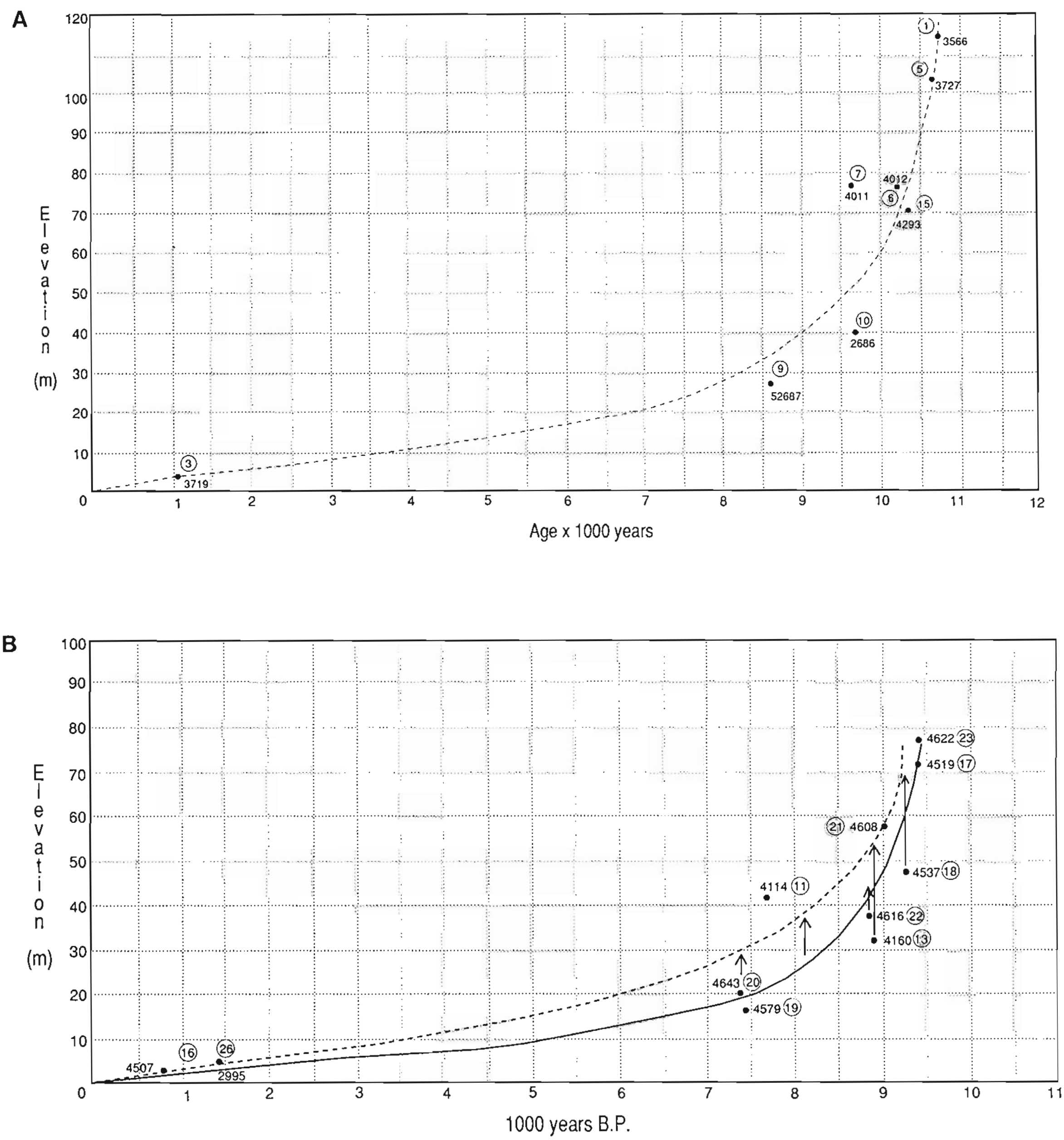


Figure 49. Preliminary emergence curves from Wollaston Peninsula: **A.** Cape Back-Cape Baring; **B.** Point Caen.

distribution of Precambrian erratics that cover most of Victoria Island unless recycled from earlier advances. 2) East to west flow patterns in Prince Albert Sound originated from ice streaming around Wollaston Peninsula, derived from flow across Kent Peninsula (Keewatin Ice Divide). 3) East to west flow patterns on eastern Victoria Island resulted from late flow of thick ice that resided in the marine troughs. Such late flow patterns derived from similar thick ice masses situated in Coronation Gulf and Dolphin and Union Strait (Fig. 16A). 4) Almost all surface landforms (streamlined forms) appear to be related to late deglacial flows either from ice streaming or possibility late glacial floods (Sharpe, 1985, 1987). 5) High elevations of postglacial emergence in the Bathurst Inlet – Kent Peninsula area relate to the presence of thick ice in marine troughs (that in part straddled Coronation Gulf) rather than to early encroachment of the sea as proposed by Dyke and Dredge (1989).

Deglaciation

Landforms on Wollaston Peninsula, important for determining ice limits, also allow a pattern of last or Late Wisconsinan deglaciation ice retreat to be mapped. The pattern of deglaciation for Wollaston Peninsula is clearly traced (Fig. 47A-D, 48) and summarized (Fig. 46) illustrating its relationship with adjacent areas. This history of deglaciation from full ice cover is supported by Vincent (1989) although earlier (1984) he had suggested incomplete ice cover of Wollaston Peninsula.

The pattern and style of deglaciation on Wollaston Peninsula are marked by initial ice-marginal retreat, followed by marginal stagnation, surging, and regional stagnation. Several available lines of evidence suggest this pattern in addition to the arrangement and mapping of the landforms themselves. The age relationships of the landforms on Wollaston Peninsula indicate that they represent formation within Late Wisconsinan time as defined by the date of marine submergence at about 11 000 years (e.g., 10 700 ± 100 BP, GSC-3566) of northwestern Wollaston (Cape Baring) and a minimum date (9360 ± 110, GSC-4622) on the Colville moraines.

Deglaciation was underway prior to 11 000 BP as indicated by the marine shell dates at Holman on adjacent Diamond Jenness Peninsula. Wollaston Peninsula was deglaciated by at least 11 000 BP as indicated by marine shells close to marine limit dated (GSC-35666) near Cape Baring (Sharpe, 1984). Prior to this and for 1000 years or more following 11 000 BP, ice marginal ponds were common on Wollaston Peninsula (Fig. 47A). At the same time (11 000-10 500 BP) Glacial Lake Coppermine and a series of smaller lakes in the Richardson River valley on the mainland south of Coronation Gulf were created by ice occupying Dolphin and Union Strait and Coronation Gulf (St-Onge and Bruneau, 1982; Mercier, 1984).

Shortly after 11 000 BP, ice marginal retreat across Wollaston Peninsula was underway. Extensive ice-marginal channels suggest that abundant discharge of meltwater along the ice margin accompanied retreat (Fig. 47B, C, D). At about the same time meltwater overflowed to the sea from glacial Lake Coppermine to the south (St-Onge, 1987 and Fig. 46). The ice margin was in contact with the sea and water was also apparently accumulating at the ice base along Dolphin and Union Strait. This inferred stored water apparently helped produce rapid movement in the ice stream in Dolphin and Union Strait. This ice configuration and development apparently led to compressive flow and to the formation of hummocky and shear moraines (Sharpe, 1988a). The shear moraines are complex and their development may imply several closely spaced, rapid (surge) events. These rapid flow events may also have produced cross-cutting of adjacent streamlined forms yet the pattern of cross-cuts indicates one complex flow. The rapid flow events are attributed to the action of former ice streams enhanced by subglacial water (Hughes et al., 1985).

It is further speculated that large floods may have followed surging flow and produced the array of streamlined landforms (Sharpe, 1988a). This interpretation is based on the internal structure of some drumlins (Read Island), meltwater erosion forms on bedrock (including rock drumlins), and tunnel valleys cross-cutting the streamlined forms.

The most significant deglaciation feature relates to the formation of the Colville moraine system that encircles Wollaston Peninsula. These moraines have not be directly dated (few marine limit sediments), but their formation can be attributed to glaciological, dynamic, and structural control (Sharpe, 1988a) in addition to climatic control (as proposed for other large arctic moraines, e.g., Dyke, 1984 and Dyke and Dredge, 1989).

After glacial surge and possible large post-surge flood events (e.g. Kamb et al., 1985), the ice became so extended and thin in profile that the role of active ice on Wollaston Peninsula effectively ended. The lack of ice-marginal landforms, deposits, and drainage systems suggests that remaining ice apparently melted in place. The hypothetical ice-marginal position (Fig. 46) shown at 10 000 BP refers only to the minimum time of marine incursion and does not imply an active ice front. The structure of large, open-channel eskers in the area shows a predominance of low-energy sediments including common stacked rippled sands. Ice flow during this interval appears to have originated from southeast of Kent Peninsula probably from the Keewatin Ice Divide (Lee, 1959; Fyles, 1963) based on regional ice-flow indicators (Prest et al., 1968), such as striae, drift dispersal trends, and patterns of land emergence.

Marine limit

Marine limit on Wollaston Peninsula, as in other areas, is variable and time transgressive, because ice applied a variable load to the crust and melted irregularly during regional stagnation. Marine limit, as traced on Map 1650A, rises to the southeast, reflecting the dominant ice movement either from the southeast or from the Bathurst Inlet area. The Bathurst Inlet area is also a region of high marine limit (Dyke, 1984). It seems reasonable that the Bathurst Inlet area represents an area of thick ice accumulation and possibly forms an extension of the Keewatin Ice Divide recognized to the south (Prest et al., 1968). Alternatively, the Bathurst Inlet area has been interpreted as an area of rapid initial marine incursion rather than an area of ice loading (Dyke and Dredge, 1989). Neither the history of ice retreat for southern Victoria Island presented here nor that for south of Coronation Gulf (St-Onge, 1987), appear to support this latter interpretation, because ice occupied the Coronation Gulf and Dolphin Union area in late glacial time as indicated by late landward flow. The sea appears to have entered the area in an erratic fashion; restrained rebound occurred in areas where melting ice masses prevented the sea from entering in an orderly and regular west to east manner.

Postglacial emergence

The pattern of postglacial emergence is defined on Wollaston Peninsula by dating marine deposits at various altitudes (Table 7, Fig. 49, 50). Dating of these events however, is incomplete, and only preliminary emergence curves are presented (Fig. 49A, B). The more tightly controlled curve (Fig. 49B) represents the one for a small valley in southwestern Wollaston Peninsula at Point Caen. This emergence curve has a form similar to the preliminary emergence curve for Holman on Diamond Jenness Peninsula to the north. These curves are comparable to a family of curves compiled for south central Arctic (Dyke and Dredge, 1989).

The curves appear to represent normal areas of glacioisostatic emergence depicting relaxation of the earth's crust to the size, thickness, and duration of the applied glacial load (e.g. Blake, 1975). For example, early on, sea level rose rapidly in response to ice removal. The curves flatten rapidly below 30 m or for the last 8000-9000 years. The curves are nested and indicate the earlier deglaciation of Cape Back relative to Point Caen. The curve for the Bathurst Inlet area to the south is nested inside the Wollaston curves and suggests continued normal emergence in that area.

The lower portions of the Wollaston curves do not have data to test for possible ice forbulge effects. In such areas land may have been undergoing submergence since middle Holocene time. A wood date on low beach terraces near Cape Back may relate to the emergence of a zone formerly submerged during Holocene times (Table 7). The curve is drawn, however, as a function showing a direct exponential decay, because no submerged geomorphological features have been observed to support this interpretation. The dated

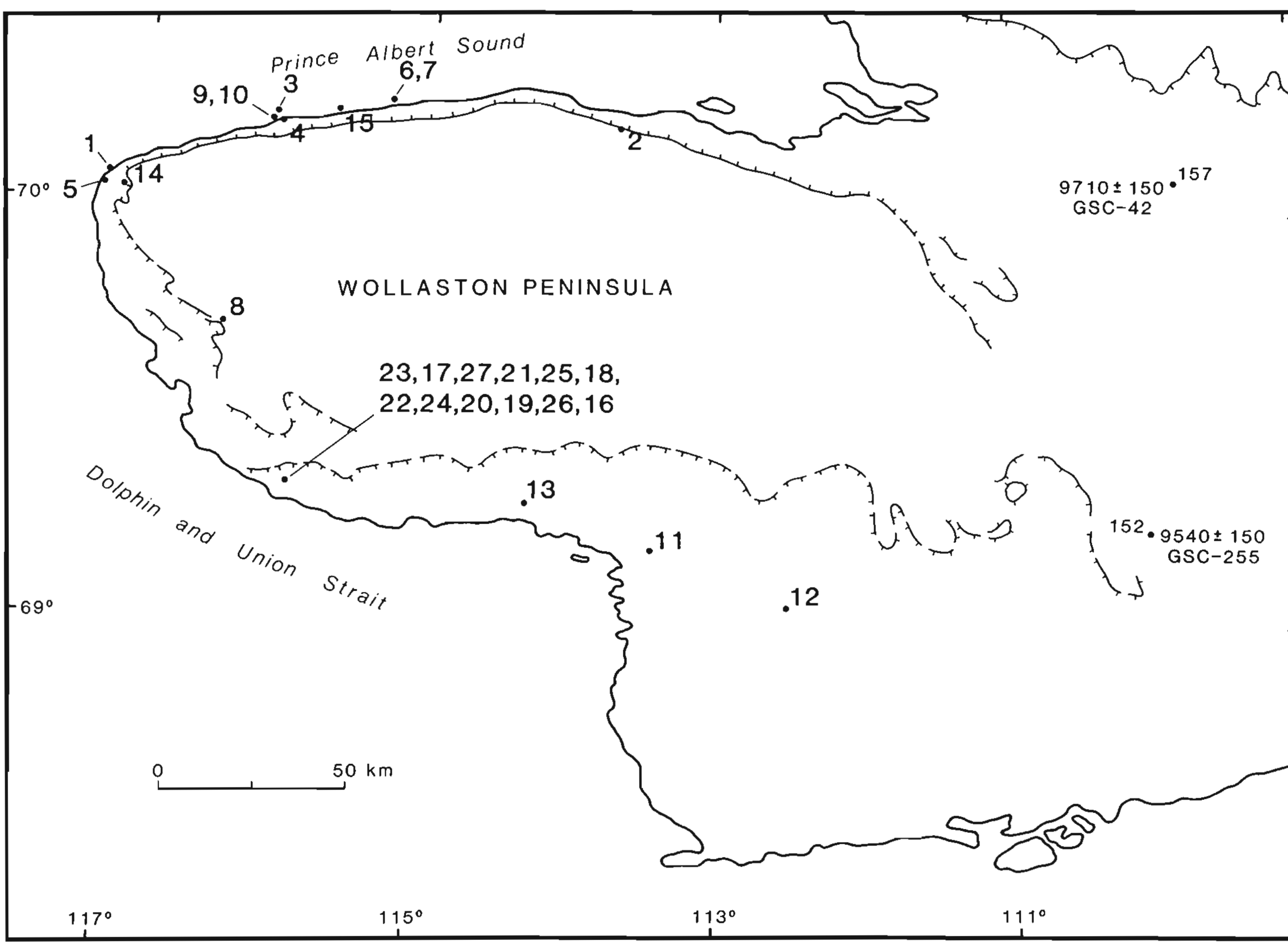


Figure 50. Location of radiocarbon date sites on Wollaston Peninsula. Numbers correspond to Table 7. Ticked line = marine limit. Numbers 152 and 157 are elevations (m) of dated sites from Fyles (1963).

wood may also have drifted across the sea from the mainland and, hence, it may only provide a maximum age for the sea level feature itself.

Extrapolation of the Point Caen curve to marine limit in the order of 100 m a.s.l. predicts deglaciation at about 9700 BP. This age provides an interesting comparison with organic remains found in morainal sediments near Point Caen. Wood found there dated at 9360 ± 110 BP (GSC-4622), which points to early colonization by plants adjacent to the recently departed ice sheet.

Emergence curves in the adjacent Bathurst Inlet area predict deglaciation in southeastern Victoria Island area prior to 8000 BP, which agrees with preliminary data from north of Cambridge Bay. More detailed surveys may further resolve the curves and interpret ice-loading events in the area.

ACKNOWLEDGMENTS

I thank J-S. Vincent for organizing and establishing the considerable logistics for fieldwork before my arrival at the Geological Survey of Canada and on Victoria Island in late June 1982. F.M. Nixon was masterful at helping me make the transition to arctic fieldwork during 1982 and 1983 field seasons. François Mainville, Chris Borowiecki (both 1983), and Ted Holden (1987) provided fine field assistance.

Staff of Polar Continental Shelf Project (George Hobson, Frank Hunt, and Barry Hough) provided invaluable support during arctic field operations. I thank J. Fyles, D. Long, G. Young, and many colleagues at the Geological Survey of Canada for enlightening discussion on various aspects of Wollaston Peninsula and regional geology. I thank Dr. Charles Tarnocai, Agriculture Canada, for reading the section on soils. Roger Frost and Lin Ho flew and navigated safely under all helicopter flying conditions. W.W. Shilts, D. Hodgson, J. Fyles, D. Harry, and J. Buckley made helpful comments to improve the structure and clarity of the report. D. Finley, T. Barry and M. Wecke did computer graphics for many of the diagrams.

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APPENDIX 1

Till sample and surface data, Wollaston Peninsula

Identification			Location		Grain size					Geochemistry										
Sample		site	latitude	longitude	gravel	sand	silt	clay	carbonate	Cu	Pb	Zn	Co	Ni	Cr	Mn	U	As	Fe	Munsell
82NJ 301	*@	761	69°47'	115°46'	61.5	53.5	34.7	11.8	77.1	22	8	21	3	10	10	200	0.4	3	0.7	10YR8/2
82SBB 21CN		761	69°47'	115°46'	36.2	56.2	32.2	11.8	73.8	22	6	16	4	7	9	130	0.5	2	0.5	10YR8/2
82NJ 305	*@	764	69°29'	111°34'	23.9	45.9	38.1	16.0	57.8	34	19	42	8	20	24	330	0.9	7	2.0	5YR7/3
82NJ 314	*@	765	70°13'	114°10'	48.0	88.2	10.2	1.6	74.2	30	35	53	12	29	32	460	0.7	23	2.4	2.5YR6/2
82NJ 315	*@	766	70°06'	113°10'	33.1	49.6	43.2	7.2	60.7	50	36	57	10	25	36	330	0.8	20	3.2	10YR7/3
82NJ 317	*@	767	70°06'	112°38'	25.1	43.8	44.5	11.7	61.7	45	30	45	9	23	29	340	0.5	16	2.5	10YR7/4
82NJ 318	*@	768	70°03'	112°16'	28.1	51.7	36.4	11.9	76.5	26	27	22	4	10	12	210	0.9	15	1.2	2.5YR8/2
82NJ 316	*@	769	70°00'	113°25'	13.6	48.1	36.7	15.2	51.8	48	26	62	12	27	37	410	0.9	13	3.1	10YR7/4
82NJ 320	*@	771	70°14'	115°13'	56.1	57.6	38.7	3.7	77.0	50	39	126	12	36	40	530	0.8	25	3.6	10YR7/3
82NJ 321	*@	772	69°47'	112°23'	35.8	50.8	34.2	15.1	42.8	39	19	54	10	26	33	430	0.5	6	2.7	7.5YR7/4
82NJ 322	*@	772	69°47'	112°23'	19.7	46.4	40.8	12.8	44.2	46	18	54	9	25	32	380	0.5	6	2.5	5YR7/3
82NJ 323	*@	773	69°47'	112°29'	52.9	71.0	20.3	8.7	44.5	49	22	56	13	28	32	470	0.9	10	2.6	5YR7/3
82NJ 324	*@	774	69°15'	112°20'	12.2	44.6	40.5	14.9	61.2	32	20	32	9	18	20	400	0.6	12	2.0	10YR7/4
82NJ 325	*@	775	69°04'	112°27'	17.3	47.3	36.7	16.0	47.8	49	17	45	8	23	30	330	1.1	7	2.5	7.5YR7/4
82NJ 326	*@	775	69°04'	112°27'	12.0	47.2	42.2	10.6	44.2	53	15	51	9	24	32	355	0.7	7	2.7	5YR7/3
82NJ 327	*@	776	69°04'	112°20'	22.3	52.3	34.7	13.0	52.6	49	12	43	6	23	28	330	0.5	5	2.2	5YR7/3
82NJ 328	*@	777	69°02'	111°49'	18.0	54.3	37.2	8.5	38.7	58	17	61	12	35	40	440	0.3	9	3.6	7.5YR6/4
82NJ 329	*@	778	68°43'	111°41'	7.3	29.3	65.2	5.5	31.8	120	14	54	11	34	35	380	0.7	10	3.3	10YR8/3
82NJ 330	*@	779	68°45'	111°34'	26.7	45.7	40.2	14.1	13.4	45	19	70	20	39	50	640	0.7	10	4.2	7.5YR7/2
82NJ 331	*@	779	68°45'	111°34'	45.4	68.2	26.6	5.2	25.7	78	16	57	16	33	34	620	0.3	15	3.3	10YR7/2
82NJ 332	*@	780	68°43'	111°19'	16.3	58.2	30.3	11.5	27.5	52	14	48	11	32	34	380	0.5	7	3.4	5YR7/3
82NJ 333	*@	781	68°42'	110°51'	36.9	50.7	37.4	11.9	15.9	61	19	64	17	38	45	495	0.7	9	4.5	5YR7/2
82NJ 334	*@	782	68°40'	110°27'	14.9	40.3	35.9	23.8	17.9	68	14	85	13	41	58	365	1.4	7	4.2	5YR6/2
82NJ 335	*@	783	68°38'	110°24'	20.7	53.2	37.2	9.6	22.9	73	13	63	11	35	42	320	0.8	7	4.2	5YR7/4
82NJ 336	*@	783	68°38'	110°24'	35.0	58.9	34.3	6.8	18.2	83	16	67	16	37	46	335	0.7	10	4.8	5YR7/3
82NJ 337	*@	784	68°59'	111°04'	26.2	46.8	43.7	9.5	42.9	69	17	55	11	33	38	380	0.5	9	3.3	5YR7/3
82NJ 339	*@	786	69°47'	117°04'	22.7	32.4	40.2	27.3	62.0	32	16	44	7	22	28	330	0.5	8	2.3	7.5YR8/2
82NJ 340	*@	787	69°37'	116°34'	31.2	37.1	39.1	23.8	65.1	27	14	39	8	20	27	320	0.3	6	2.0	5YR8/2
82NJ 341	*@	787	69°37'	116°34'	23.5	34.6	46.7	18.8	65.2	26	14	39	5	19	24	315	0.3	6	1.9	5YR8/2
82NJ 342	*@	788	69°27'	116°20'	29.2	64.7	28.6	6.7	58.4	34	13	67	11	30	38	335	0.0	11	3.0	10YR7/3
82NJ 343	*@	789	69°31'	115°55'	25.0	35.7	48.5	15.8	64.8	27	11	31	4	17	24	260	0.0	6	1.6	7.5YR8/4
82NJ 353	*	790	69°32'	115°20'	40.0	45.5	35.9	18.5	50.6	52	19	66	13	39	48	400	0.5	11	3.7	5YR7/3
82NJ 344	*	790	69°32'	115°20'	25.2	41.8	38.2	20.0	50.3	51	15	64	11	34	45	420	0.3	10	3.5	5YR7/3
82NJ 345	*@	791	69°31'	115°17'	28.8	56.6	36.9	6.4	51.9	66	27	89	13	38	50	390	0.7	17	4.6	10YR7/3
82NJ 346	*@	792	69°29'	115°14'	31.6	44.9	42.6	12.5	60.0	36	16	36	9	23	26	350	0.3	7	2.1	5YR7/2
82NJ 347	*@	793	69°21'	114°32'	18.9	43.1	39.1	17.8	63.3	26	15	25	3	13	18	270	0.3	5	1.4	5YR8/2
82NJ 348	*@	794	69°19'	114°17'	28.2	56.7	32.6	10.7	54.6	37	16	58	9	25	40	290	0.5	13	2.9	2.5YR7/3
82NJ 349	*@	794	69°19'	114°17'	17.6	37.6	42.5	19.9	60.2	30	15	34	7	18	24	285	0.2	4	1.9	5YR8/3
82NJ 350	*@	795	69°21'	114°16'	18.2	41.1	40.6	18.2	66.1	23	11	28	8	19	20	290	0.2	6	1.5	7.5YR8/2
82NJ 351	*@	796	69°43'	114°05'	80.2	50.7	41.8	7.5	54.9	47	21	85	11	39	42	310	0.3	13	4.0	10YR7/3
82NJ 352	*@	797	69°47'	114°13'	27.3	47.7	45.9	6.4	54.5	49	25	80	16	42	50	460	0.0	15	4.3	10YR7/4
82NJ 354	*@	799	70°04'	110°49'	35.1	66.8	27.5	5.7	67.2	26	24	24	5	19	20	280	0.5	13	1.9	10YR7/3
82NJ 355	*@	900	70°04'	110°39'	18.5	47.6	37.0	15.4	68.6	22	20	22	4	15	16	260	0.6	9	1.6	10YR8/3
82NJ 356	*@	801	69°55'	111°37'	23.5	49.4	39.4	11.2	61.2	41	20	39	8	27	30	300	0.4	14	2.4	10YR7/3
82NJ 357	*@	802	69°50'	111°27'	14.8	23.7	51.2	25.2	42.9	39	18	53		28	36	400	0.6	8	2.9	5YR8/3

- *=data used for plotting, @=sample part of formal design (Nixon, 1988), gravel as % of whole sample, sand/silt/clay as % of <2mm fraction
- carbonate is % expressed as $CaCO^3$ equivalent, iron is %, all other elements ppm in <2 micron fraction, 0=below
- Munsell colour of dried sample under fluorescent light, colour in comments is field observation

Colour — Surface features — Pit observations								Comments
%veg	%stns	%gr	%bs	dr	st	ox	org	
40	55	<2	<1	W	VM	X		till plain
30	55	3	5	W	M	X	X	hill top
10	85	2	5	W	M	X		moraine ridge
30	25	6	6	W	M	X	X	small moraine remnant, 20% erratic clasts
60	30			I	M	X	X	moraine, mud boils, 15% erratics
40	40			W	M		X	drumlin, veneer of silty sand
80	15	4	10	I	N	X	X	till plain, weak polygons, 20% erratic boulders
15	50			W	M	X		moraine
30			10		M	X	X	moraine, 15 m polygons
20	75		10	I	M		X	moraine, polygons, 73% carbonate boulders, 14% red siltstone
35	55			W		X	X	upland, 10 m polygons with 1 m relief
55	10			W	M	X	X	drumlin crest, 2 m polygons, 10% boulders
75	15			W	M	X		drumlin crest, shells, <1% boulders
85	10			W	M	X		drumlin flank
80	15			I	M	X	X	2-3 m polygons, 10-15 cm relief, shells
75	20			W	V		X	drumlin, boils, <5% boulders
80	10				N	X	X	40% outcrop, <1% boulders, pink quartzite common
80				I	M		X	veneer, 30 cm/rock, 75% of erratics are pink quartzite
80	15			W	V	X	X	veneer/rock, 30% quartzite erratics
85	15		10	W	M	X	X	<10% boulders, 70% carb., 20% quartzite, 10% granitic
85	10			I	M		X	30 cm veneer, 1-2% boulders, 70% carbonates, 20% quartzite
95	2			W	M			veneer
80	15	10	4	W	N		X	colluvial slope, striped, overlain by sand
90	5	20	4	I-W	N	X		colluvial slope, 5 deg., boils, pebble lith. 40% carb., 20% basic, 25% q., 25% s.s.
80	20			I-W	M	X	X	low ridge, veneer, 40 cm/rock, 5% boulders, boils
40	40	10	10	I	M	X	X	gently undulating, washed, 10 m polygons, 20% erratics
25	70	9	7	W	M	X	X	moraine ridge, weak polygons, 16% erratics
20	75			I	M	X	X	moraine, 2 m polygons with low relief
60	30	8	2	W	M	X	X	till plain, veneer/rock, near esker, 20% erratics
40	25			I	M	X		ribbed till plain, 15% erratic boulders, boils
15	70	5	9	W	V	X	X	hummocky moraine, 1 m polygons with 30 cm relief, 20% erratic clasts
25	65			W	V	X		moraine ridge
10	85	5	10	W	V	X		kame, 1 to 3 m polygons to stripes, 25% boulders, 15% erratic
20	75	8	16	W	M	X	X	small moraine ridge, 25% erratic clasts
70	15			W	M	X	X	drumlin, 2-5 deg. slope, 5 m polygons
70	25	4	12	W	M	X	X	drumlin, beached, 2-3 m polygons, 16% erratic clasts
		2	13	W	M	X	X	drumlin, beached, 2-3 m polygons, 15% erratic clasts
				W	V	X	X	small drumlin, 5 deg. slope, 1 m polygons, compact till
25	50	2	2	W	M	X	X	moraine, stone stripes, mud boils, 5% erratic clasts
45	40	5	25	W	M	X	X	till plain, small mud boils, 30% erratic clasts
50	35	4	18	W	M	X	X	drumlins, 2-5 deg. slope, 10 m polygons, 22% erratic clasts
40	40	5	19	W	M	X	X	ground moraine, 10 m polygons, mud boils, 24% erratic clasts
50	40	12	18	W	M	X	X	upland, 20% boulders, 30% erratic clasts
25	60	5	20	I	N	X	X	small moraine ridge, 5 m high, 3 m polygons, stripes, 25% erratic clasts

- °veg and %stns = estimate of percent vegetation and stone cover on site surfaces
- %gr and %bs = granitic and basic igneous clasts in the stone cover (% or MR=moderately rare, R=rare, VR=very rare)
- dr represents drainage; (W)ell drained, (I)ntermediate and (P)oor
- st represents stoniness; (V)ery stony, (M)oderately stony, and (N)ot stony
- ox and org are columns for presence of oxidation and organics denoted by (X)

Appenidx 1 (cont'd.)

Identification			Location		Grain size					Geochemistry										
Sample		site	latitude	longitude	gravel	sand	silt	clay	carbonate	Cu	Pb	Zn	Co	Ni	Cr	Mn	U	As	Fe	Munsell
82NJ 358	*@	803	69°21'	110°26'	26.8	58.4	31.2	10.5	63.4	57	29	46	11	26	31	360	0.7	17	2.9	10YR7/3
82NJ 359	*@	804	69°26'	111°20'	39.3	49.8	40.1	10.1	60.2	53	16	60	10	25	36	275	0.9	10	2.6	10YR6/2
82NJ 360	*@	805	69°15'	110°41'	33.0	48.4	37.3	14.3	61.3	30	27	58	15	38	32	320	1.0	20	3.5	2.5Y7/4
82NJ 361	*@	805	69°15'	110°41'	36.1	43.1	45.8	11.1	66.3	29	33	53	12	31	28	360	0.9	18	3.6	2.5Y7/4
82NJ 362	*@	806	69°15'	110°33'	27.6	40.7	44.2	15.1	69.1	34	26	24	10	19	20	355	0.5	14	2.0	10YR8/3
82NJ 363	*@	807	69°07'	110°19'	11.9	43.3	47.2	9.5	59.2	68	22	33	14	24	26	420	0.9	13	2.2	10YR8/3
82NJ 364	*@	808	69°18'	110°11'	27.1	51.9	38.2	9.8	56.6	58	30	51	14	33	36	350	0.7	21	3.2	2.5Y8/4
82NJ 365	*@	809	69°24'	110°34'	28.3	43.0	42.8	14.2	72.5	31	28	47	10	28	21	345	0.7	18	2.4	2.5Y7/4
82NJ 366	*@	810	69°28'	112°44'	21.4	48.3	42.1	9.6	58.6	41	17	43	9	22	30	340	0.6	9	2.2	10YR7/3
82NJ 367	*@	811	69°36'	112°51'	26.1	50.7	40.7	8.6	61.2	43	19	39	9	23	32	280	0.5	9	2.3	10YR8/3
83NJ 402	@	813	69°14'	113°12'	20.3	50.0	39.8	10.2	54.7	46	13	39	8	23	30	210	0.3	5	2.2	7.5YR7/6
83NJ 370A	@	817	69°53'	110°56'	26.4	44.0	40.1	15.9	62.2	32	21	28	7	18	23	290	1.0	12	2.1	10YR7/3
83NJ 370B	@	817	69°53'	110°56'	14.5	42.0	41.8	16.2	61.7	30	20	24	5	17	20	260	1.0	9	2.0	10YR7/3
83NJ 371	@	819	69°53'	110°48'	15.3	39.0	42.2	18.7	70.2	22	14	20	4	14	16	240	0.9	8	1.5	10YR7/3
83NJ 372	@	820	69°50'	110°33'	16.8	36.9	44.5	18.6	66.2	24	17	21	5	16	16	240	1.6	9	1.7	10YR7/3
83NJ 373		821	69°53'	110°56'	8.7	43.0	40.4	16.6	61.4	34	21	30	6	21	24	280	0.9	11	2.2	10YR7/4
83NJ 374		821	69°53'	110°56'	13.4	41.5	41.5	17.0	61.8	32	17	31	6	20	23	260	1.0	9	2.1	10YR7/4
83NJ 375		821	69°53'	110°56'	23.0	41.0	42.0	17.0	64.3	31	19	27	7	20	20	310	1.4	10	2.0	10YR7/3
83NJ 376		821	69°53'	110°56'	17.6	42.9	40.8	16.3	62.4	32	19	27	6	18	20	280	1.1	11	2.0	10YR7/3
83NJ 377		821	69°53'	110°56'	20.3	40.1	42.7	17.2	66.4	25	16	23	5	16	18	280	1.4	9	1.7	10YR7/3
83NJ 378		821	69°53'	110°56'	26.4	39.6	43.0	17.4	64.6	22	14	24	7	17	20	320	1.4	8	1.6	10YR7/3
83NJ 379		821	69°53'	110°56'	35.5	42.8	39.8	17.4	64.0	18	14	24	6	16	20	300	1.0	5	1.5	10YR7/2
83NJ 380		821	69°53'	110°56'	37.2	41.5	41.3	17.2	66.3	18	14	23	6	15	18	300	1.4	5	1.5	10YR7/2
83NJ 383	@	823	69°20'	113°05'	22.5	47.9	34.8	17.3	26.3	30	10	46	14	29	34	380	0.9	4	2.9	5YR6/3
83NJ 384	@	823	69°20'	113°05'	10.1	50.3	34.6	15.1	40.5	31	14	42	10	26	32	320	1.4	5	2.7	7.5YR6/4
83NJ 385	@	824	69°22'	113°06'	24.7	42.7	40.6	16.7	55.0	18	16	26	6	16	18	300	0.6	6	1.7	10YR7/3
83NJ 386	@	825	69°38'	113°39'	34.1	51.5	34.8	13.7	52.2	42	16	42	10	26	28	380	0.0	5	2.4	7.5YR7/4
83NJ 387	@	826	69°58'	115°53'	27.0	50.0	34.6	15.4	45.0	39	12	53	11	34	42	380	0.9	3	2.8	10YR6/3
83NJ 388	@	827	70°04'	115°46'	7.5	43.9	47.8	8.3	60.2	24	15	54	7	22	26	270	0.8	6	2.3	10YR6/4
83NJ 389	@	827	70°04'	115°46'	25.8	51.1	39.7	9.2	68.9	29	17	46	7	23	27	270	0.6	8	2.4	2.5Y7/4
83NJ 390	@	829	70°08'	115°54'	28.1	43.8	42.3	13.9	84.9	20	19	26	4	15	16	200	0.0	0	1.5	10YR7/3
83NJ 391		830	69°12'	113°22'	17.2	46.1	37.0	16.9	62.9	26	9	22	5	15	16	230	0.5	2	1.4	7.5YR7/4
83NJ 392		830	69°12'	113°22'	26.0	46.[illegible]		16.4	60.9	30	11	26	5	16	18	210	0.6	3	1.5	7.5YR7/4
83NJ 393		830	69°12'	113°22'	19.6	46.9	35.9	17.2	61.8	26	10	26	4	14	16	220	0.5	2	1.4	7.5YR7/4
83NJ 394		830	69°12'	113°22'	23.1	45.4	37.5	17.1	63.1	24	9	24	5	12	18	200	0.0	0	1.3	7.5YR7/4
83NJ 395		830	69°12'	113°22'	26.0	44.2	38.4	17.4	63.3	30	11	29	4	16	18	240	0.8	3	1.5	7.5YR7/4
83NJ 396		830	69°12'	113°22'	27.6	45.5	37.3	17.2	64.3	22	10	23	5	13	16	230	0.6	2	1.3	5YR7/3
82SBBI10-1	*	831	68°54'	112°05'					47.0	80	20	63	12	32	38	420	1.1	10	3.0	10YR7/3
82SBBI10-2		832	68°52'	112°13'					42.3											7.5YR7/2
82SBBI10-3	*@	833	68°49'	112°18'					42.2	86	16	67	15	32	44	400	1.1	10	3.4	7.5YR7/2
82SBBI11-3	*	834	68°57'	112°00'					45.8	64	22	57	16	32	40	460	0.9	6	3.0	7.5YR6/4
82SBBI14-1		835	69°55'	111°21'					65.8											10YR7/2
82SBBI14-2	*	836	69°48'	111°21'					63.0	31	24	36	10	23	26	400	0.7	11	2.0	10YR7/3
82SBBI14-4A		837	69°42'	111°20'					63.9	81	21	68	12	28	28	420	0.8	10	2.0	10YR7/3
82SBBI14-4B		837	69°42'	111°20'					61.3											10YR7/3

- *=data used for plotting, @=sample part of formal design (Nixon, 1988), gravel as % of whole sample, sand/silt/clay as % of <2mm fraction
- carbonate is % expressed as CaCO^3 equivalent, iron is %, all other elements ppm in <2 micron fraction, 0=below
- Munsell colour of dried sample under fluorescent light, colour in comments is field observation

Colour — Surface features — Pit observations								Comments
%veg	%stns	%gr	%bs	dr	st	ox	org	
60	25	2	8	W	V	X	X	3 deg. slope, no polygons, near glaciofluvial features, <10% erratic clasts
30	50	2	7	I	M	X	X	till plain, mud boils, 25% boulders, 18% erratics
90	5	15	20	W	V	X	X	till veneer/rock, mud boils, 5% boulders, 35% erratic clasts
75	15			I	M	X	X	till plain, veneer/rock
70	15	3	13	I	M	X		till plain, sorted mud boils, 16% erratic clasts
70	15	4	20	W	M	X	X	drumlin ridge in lake, boils, outcrop, 24% erratic clasts
70	20	2	7	W	M	X	X	fluted plain, 10 m polygons, mud boils, 10% erratic clasts
65	25	7	7	W	V	X	X	drumlin ridge, mud boils & stripes, 14% erratic clasts
40	50	3	15	W	M	X		low moraine ridge, 10 m weak polygons, 18% erratic clasts
45	45	7	19	W	M	X	X	moraine ridge, 10 m polygons, 26% erratic clasts
80	10			P	M	X	X	swale between drumlin ridges
60	35	0	5		M	X		drumlin top, gentle slope, mud boils
30	60	0	2		M	X		drumlin top, gentle slope, mud boils
60	20	0	R	IW	M	X	X	plain, veneer/rock?, weak 5 m polygons
				W	M	X		drumlin crest
90	5			I	M	X	X	till plain
65	30			W	V	X	X	veneer/rock platform
10	85			W	V	X	X	moraine, hummocky, 5 m polygons
25	65			W	V	X	X	moraine ridge
65	45			I	N	X	X	plain
5	85			W	V	X	X	hummocky moraine
				W	M	X	X	drumlin crest, washed, shell fragments
								Polar gas samples (E.B.A. Consultants Ltd., Edmonton, unpublished report, Nov. 1980.

- *veg and %stns = estimate of percent vegetation and stone cover on site surfaces
- %gr and %bs = granitic and basic igneous clasts in the stone cover (% or MR=moderately rare, R=rare, VR=very rare)
- dr represents drainage; (W)ell drained, (I)ntermediate and (P)oor
- st represents stoniness; (V)ery stony, (M)oderately stony, and (N)ot stony
- ox and org are columns for presence of oxidation and organics denoted by (X)

Appenidx 1 (cont'd.)

Identification			Location		Grain size					Geochemistry										
Sample		site	latitude	longitude	gravel	sand	silt	clay	carbonate	Cu	Pb	Zn	Co	Ni	Cr	Mn	U	As	Fe	Munsell
82SBBI15-2	•	838	70°09'	111°24'					71.6	18	20	22	5	12	16	310	0.6	6	1.2	10YR7/3
82SBBI16-4		839	70°21'	111°25'					76.6											10YR7/2
82SBBI17-2		840	70°40'	111°57'	9.0	32.9	59.0	8.1												10YR7/2
82SBBI17-4B		841	70°32'	111°42'					66.0											10YR7/3
82SBBI18-3		842	70°48'	112°12'	3.0	36.1	57.1	6.8												10YR7/3
82SBBI21-1		843	71°36'	113°42'	12.0	39.8	51.1	9.1												7.5YR7/2
82SBBI21-4		844	71°22'	113°29'																10YR6/3
82SBBI23-1A		845	73°06'	114°30'	19.0	44.4	48.2	7.4	70.1	57	25	62	19	34	34	800	0.7	12	2.8	10YR7/2
82SBB 1	•	846	69°40'	116°11'	26.3	58.9	27.5	13.6	75.3	24	10	29	5	11	16	220	0.6	5	1.4	7.5YR7/2
82SBB 3	•	848	69°37'	116°08'	37.5	70.6	23.0	6.4	66.8	66	17	69	12	26	37	420	0.8	15	3.0	10YR7/3
82SBB 6C	•	851	69°38'	116°29'	45.8	52.7	33.3	14.0	79.3	16	6	21	4	6	10	180	0.9	3	0.7	
82SBB 14B1		860	69°36'	116°22'	34.4	57.4	34.4	8.2	57.2	45	17	84	17	28	41	535	0.9	14	3.0	10YR7/3
82SBB 124B2		860	69°36'	116°22'	9.4	12.6	65.4	22.0	55.0	38	15	60	12	22	32	370	0.5	6	2.4	7.5YR7/4
82SBB 14C	•	860	69°36'	116°22'	24.6	48.2	42.6	9.2	60.6	45	14	64	12	21	32	390	0.7	10	2.3	10YR7/3
82SBB 20B2		865	69°47'	115°47'	37.6	51.3	42.2	6.5	55.8	51	18	109	16	33	44	600	0.5	13	3.6	10YR7/4
82SBB 20COX	•	865	69°47'	115°47'	58.7	73.9	23.5	2.6	74.2	28	12	38	8	21	20	425	0.5	8	1.6	10YR8/3
82SBB 23	•	868	69°43'	115°53'	30.3	50.5	34.6	14.9	65.3	20	7	28	4	11	16	240	0.5	4	1.1	10YR7/2
82SBB 25		870	69°43'	115°56'	20.2	45.0	39.2	15.8	72.1	16	8	21	3	5	11	178	0.4	3	0.8	10YR8/2
82SBB 26B1		871	69°42'	116°25'	16.5	39.9	44.7	15.4	66.6	22	7	30	6	10	16	290	0.7	4	1.3	7.5YR7/2
82SBB 26B2	•	871	69°42'	116°25'	27.9	39.0	46.1	14.9	62.9	26	9	31	6	9	19	285	0.9	13	1.7	5YR7/2
82SBB 27IIIX		872	69°42'	116°25'	27.7	44.1	42.1	13.8	57.4	41	11	67	11	24	35	370	1.4	8	2.4	7.5YR7/4
82SBB 27IIIZ		872	69°42'	116°25'					65.8	30	9	38	6	12	22	320	1.1	5	1.4	7.5YR7/2
82SBB 43AB		887	69°44'	116°03'	18.6	46.9	45.2	7.9	61.0	22	10	67	6	14	22	270	0.4	5	1.6	7.5YR6/2
82SBB 43B		887	69°44'	116°03'	14.3	40.2	47.4	12.4	58.7	21	7	39	4	12	18	215	0.4	5	1.4	10YR7/2
82SBB 43COX	•	887	69°44'	116°03'	21.8	49.4	40.8	9.8	66.1	24	10	37	6	13	19	230	0.3	8	1.4	10YR7/2
82SBB 43CN		887	69°44'	116°03'	22.5	38.9	46.9	14.1	73.0	16	5	19	4	6	10	165	0.2	4	0.8	10YR8/2
82SBB 46	•	890	69°23'	111°56'	23.7	46.2	42.8	11.0	62.5	30	13	35	8	12	20	355	0.7	10	1.4	10YR7/3
82SBB 58	•	902	69°24'	111°47'	27.6	35.3	42.1	22.6	62.5	26	8	33	6	11	18	280	0.7	4	1.3	7.5YR7/4
82SBB 69B	•	913	69°21'	112°00'	9.6	37.5	48.9	13.6	57.7	27	19	41	11	22	28	400	1.1	8	2.2	7.5YR7/4
82SBB 69CN		913	69°21'	112°00'	28.9	45.9	43.3	10.8	68.9	28	10	27	7	10	15	280	0.9	6	1.4	7.5YR7/2
82SBB 92B		936	69°38'	112°00'	15.1	49.0	40.4	10.7	45.7	38	11	54	12	23	30	425	0.7	8	2.3	5YR7/3
82SBB 92CN	•	936	69°38'	112°00'	19.0	45.6	42.9	11.5	53.3	36	8	47	9	15	25	340	0.7	5	1.9	5YR7/3
82SBB105AB		949	69°29'	[illegible]47'	27.7	51.6	39.8	8.6	61.8	26	12	65	8	12	20	370	0.3	10	1.8	10YR5/2
82SBB105COX		949	69°29'	111°47'	25.5	54.2	36.2	9.6	57.2	30	17	48	9	16	25	350	0.9	17	2.3	7.5YR7/4
82SBB105CN		949	69°29'	111°47'	18.4	45.7	43.8	10.4	58.8	32	12	42	9	15	25	320	0.7	12	2.0	10YR7/3
82NJ 302	•@	949	69°29'	111°47'	26.2	46.6	39.0	14.4	60.8	30	18	44	8	15	24	335	1.1	12	2.2	7.5YR6/4
82SBB107AB		951	69°28'	111°42'	21.4	48.2	37.8	14.1	64.0	26	12	51	8	12	20	260	0.5	11	1.5	10YR7/2
82SBB107B		951	69°28'	111°42'	8.4	44.4	39.9	15.7	55.7	39	25	69	13	22	30	395	1.0	15	2.9	10YR7/4
82SBB107C		951	69°28'	111°42'	36.6	52.2	35.6	12.2	66.2	31	14	39	10	11	20	310	0.5	10	1.6	10YR7/3
82NJ 303	•@	951	69°28'	111°42'	40.3	52.9	35.1	12.0	66.5	31	19	36	7	8	18	300	0.9	11	1.7	10YR8/3
82NJ 304	•@	951	69°28'	111°42'	42.0	52.5	35.7	11.8	67.2	34	20	36	5	19	21	270	0.8	13	1.8	10YR8/3
82SBB114	•@	958	69°33'	112°23'	27.0	51.8	40.1	8.1	60.3	44	23	51	10	26	26	350	1.0	14	2.5	7.5YR7/4
82NJ 306		969	69°29'	112°05'	24.4	45.8	40.6	13.6	62.8	35	18	42	8	20	24	360	0.9	9	1.9	7.5YR7/4
82NJ 307		969	69°29'	112°05'	18.9	46.0	40.5	13.5	62.5	35	19	41	7	17	24	320	0.8	8	2.0	10YR7/3
82NJ 308	•	969	69°29'	112°05'	22.2	45.1	41.2	13.7	62.0	36	18	44	6	19	24	315	0.9	7	2.0	10YR7/3

- •=data used for plotting, @=sample part of formal design (Nixon, 1988), gravel as % of whole sample, sand/silt/clay as % of <2mm fraction
- carbonate is % expressed as $CaCO^3$ equivalent, iron is %, all other elements ppm in <2 micron fraction, 0=below
- Munsell colour of dried sample under fluorescent light, colour in comments is field observation

Colour — Surface features — Pit observations								Comments
%veg	%stns	%gr	%bs	dr	st	ox	org	
		4	1	W	M	X		exposure at Boffa Lake
25	65	<1	2	W	M	X		hummocky moraine; soil pit
		9	7	W				exposure in small moraine, Kugaluk River; 20% erratics
20	80			W	M			hill side soil pit
20		1	1					soil pit; eolian input?
25	60	2	2					fluted plain; soil pit; oxidized C (2.5 YR 716)
		4	3					
		9	12	W	M			exposure; Kugaluk River
570	75							soil pit at camp 1982; permafrost at 115 cm
		2	6	W	M	X		thaw flow scar on Colville moraine
20%	70				VM			exposure in Colville moraine; 18% erratic boulders
80	10	3	5	W	M	X		fluted plain; soil pit
40	40	5	5					
75	15	<1	5	W	MN	X	X	till plain soil profile
60	20	2	5	W	M	X	X	fluted plain
10	40	2	2					
35	50	5	5	W	MN			knoll at base of moraine

- *veg and %stns = estimate of percent vegetation and stone cover on site surfaces
- %gr and %bs = granitic and basic igneous clasts in the stone cover (% or MR=moderately rare, R=rare, VR=very rare)
- dr represents drainage; (W)ell drained, (I)ntermediate and (P)oor
- st represents stoniness; (V)ery stony, (M)oderately stony, and (N)ot stony
- ox and org are columns for presence of oxidation and organics denoted by (X)

Appenidx 1 (cont'd.)

Identification			Location		Grain size					Geochemistry										
Sample		site	latitude	longitude	gravel	sand	silt	clay	carbonate	Cu	Pb	Zn	Co	Ni	Cr	Mn	U	As	Fe	Munsell
82NJ 309		969	69°29'	112°05'	18.9	47.0	39.0	14.0	62.2	38	20	44	6	19	24	310	1.1	10	2.1	10YR7/3
82NJ 310		969	69°29'	112°05'	23.8	45.0	40.7	14.2	61.5	35	20	42	7	17	23	320	0.9	10	1.9	10YR7/3
82NJ 311		969	69°29'	112°05'	14.9	46.1	39.8	14.1	62.7	38	18	40	10	18	28	330	0.7	8	1.9	10YR7/3
82NJ 312		969	69°29'	112°05'	12.1	46.5	39.2	14.3	61.3	37	19	42	6	20	30	350	0.8	8	1.9	10YR7/3
82NJ 313		969	69°29'	112°05'	14.5	45.6	40.3	14.1		33	19	38	7	21	28	360	0.5	8	2.0	10YR7/3
82SBB125A		969	69°29'	112°05'	35.8	61.9	30.9	7.2	58.1	24	17	57	9	25	28	405	0.8	10	1.8	10YR6/2
82SBB125B		969	69°29'	112°05'	12.6	44.6	44.9	10.5	61.3	34	16	39	8	22	28	340	0.8	8	2.0	10YR7/3
82SBB125COX		969	69°29'	112°05'	15.6	45.1	44.8	10.1	60.8	35	16	39	8	23	29	310	1.0	9	2.0	10YR7/3
82SBB125CN		969	69°29'	112°05'	14.7	44.4	45.0	10.6	0	34	17	43	8	20	28	360	0.9	8	1.8	7.5YR7/2
82SBBH 6	*	975	70°11'	113°09'	31.8	30.1	55.2	14.6	75.5	26	26	42	9	18	26	300	1.2	14	2.0	10YR8/2
82SBBH 7AB		976	70°01'	112°46'	18.8	51.1	40.4	8.5	50.6	39	19	63	12	27	34	320	0.8	10	2.4	7.5YR5/2
82SBBH 8	*	977	70°04'	112°44'	13.6	37.5	47.1	15.4	57.5	46	23	56	11	26	40	330	1.0	18	2.8	10YR7/3
82SBBH12		981	70°09'	112°31'	32.9	45.4	47.7	6.9	70.0	42	29	46	6	20	22	215	1.5	13	1.4	10YR7/2
82SBBH15	*	984	70°11'	112°15'	29.0	86.0	10.6	3.4	69.3	20	37	62	15	27	44	420	1.1	36	2.8	10YR7/4
82SBBH16	*	985	70°13'	112°11'	23.9	40.8	47.4	11.8	74.7	18	17	20	5	12	16	270	1.2	10	1.2	10YR7/3
82SBBH25	*	993	70°03'	117°04'	17.7	34.5	51.4	14.1	65.7	36	21	70	10	25	33	420	1.0	15	2.7	10YR7/3
82SBBH32C1		1000	70°01'	117°14'	13.1	35.1	53.8	11.1	79.2	16	16	29	5	13	18	270	1.1	8	1.2	10YR7/2
82SBBH32G		1000	70°01'	117°14'	28.7	27.3	60.8	11.9	55.0	50	23	84	13	35	36	525	0.3	18	3.4	10YR7/3
82SBBH32B	*	1000	70°01'	117°14'	8.3	9.3	79.7	11.0	28.7	75	33	160	21	44	47	540	1.9	20	5.3	2.5YR7/2
82SBBH33A	*	1001	70°02'	117°16'	11.9	31.4	53.5	15.1	69.0	28	14	47	7	20	26	330	0.3	8	1.8	7.5YR8/2
82SBBH33B		1001	70°02'	117°16'	29.3	40.3	46.6	13.0	84.3	14	14	20	2	7	8	200	0.3	6	0.7	10YR8/2
82SBBH38	*	1006	69°49'	113°31'	10.0	51.7	42.7	3.6	57.0	43	21	54	10	25	33	320	0.5	10	2.6	10YR7/4
82SBBH39	*	1007	69°47'	112°55'	20.6	43.6	41.7	14.7	54.4	48	25	52	10	27	34	430	0.7	11	2.8	10YR7/3
82SBBH40	*	1008	69°47'	112°35'	29.2	48.5	40.7	11.8	45.5	45	16	54	9	24	34	415	0.8	10	2.7	7.5YR7/4
82SBBH42	*	1010	69°13'	112°04'	14.8	41.6	41.0	17.4	60.3	36	20	36	9	23	22	400	1.0	11	1.8	7.5YR7/4
82SBBH47		1015	68°53'	110°54'	30.4	50.0	37.4	12.6	33.7	70	20	91	19	37	41	640	0.7	14	3.6	7.5YR6/4
82SBBH56	*@	1024	69°55'	117°09'	22.5	43.1	40.3	16.6	64.0	34	14	49	9	19	24	370	0.7	7	1.9	10YR7/2
82SBBH57	*	1025	69°46'	117°59'	24.4	45.6	37.4	16.9	65.8	30	12	43	8	17	22	330	0.5	7	1.8	7.5YR7/2
82SBBH60		1028	69°25'	116°23'	15.0	19.0	50.3	30.7	60.7	25	11	40	7	17	24	330	0.8	8	1.9	5YR7/3
82SBBH62		1030	69°30'	116°03'	40.3	51.3	37.2	11.5		36	14	46	8	23	28	380	0.5	7	2.2	
82SB3H66		1034	69°23'	115°50'	38.3	68.7	23.0	8.3		28	13	40	6	14	18	310	0.3	7	1.5	
82SBBH71AB		1039	69°32'	115°20'	40.3	56.6	36.8	6.6	53.4	40	16	77	15	33	44	520	0.7	9	3.3	7.5YR6/2
82SBBH71B		1039	69°32'	115°20'	37.8	74.5	21.6	3.9	52.2	55	19	65	14	32	41	580	0.5	14	3.2	7.5YR7/4
82SBBH77	*@	1045	69°58'	114°56'	24.1	48.7	42.5	8.8	61.1	41	19	47	10	30	32	360	0.5	10	2.5	10YR7/3
82SBBH78	*	1046	70°03'	115°21'	23.3	48.2	34.4	17.5	51.7	35	14	65	12	27	40	340	0.7	8	2.6	7.5YR7/4
82SBBH82	*	1050	70°05'	112°44'	34.3	43.0	48.3	8.7	69.2	60	32	40	7	23	23	275	0.9	27	2.5	10YR7/3
82SBBH86	*	1054	69°22'	111°36'	46.0	58.0	30.5	11.5	69.0	60	32	40	7	23	23	275	0.9	14	2.5	10YR7/4
82SBBH88	*	1056	69°20'	111°24'	47.6	62.1	28.6	9.3	67.2	36	26	51	9	24	28	350	1.1	17	2.4	7.5YR7/4
82SBBH91	*	1059	69°24'	110°25'	20.1	47.2	39.0	13.7	57.6	34	25	45	9	22	28	325	0.9	18	2.6	7.5YR7/4
83SBB 2		1061	69°54	110°56'	19.7	40.3	42.2	17.5	67.3	18	13	19	4	15	14	250	1.0	6	1.2	10YR7/3
83SBB 15		1074	69°52	111°05'	33.9	45.7	38.9	15.4	61.7	28	16	27	7	19	19	290	1.0	7	1.7	10YR7/4
83SBB 21		1080	69°45'	111°03'	15.2	26.5	44.6	28.9	56.1	31	17	35	8	22	24	330	1.0	10	2.2	7.5YR6/4
83SBB 64		1124	69°46'	115°41'	27.6	51.3	37.3	11.4	45.3	51	15	74	13	44	44	350	1.0	8	3.6	10YR6/4
83SBB 69		1129	69°44'	115°10'	35.0	81.5	12.0	6.5	45.9	35	15	38	9	31	30	340	0.8	6	2.2	10YR6/3
83SBB 73		1133	69°45'	115°13'	28.3	52.3	36.5	11.2	48.9	48	13	60	14	38	40	540	0.8	5	3.0	10YR6/3

- *=data used for plotting, @=sample part of formal design (Nixon, 1988), gravel as % of whole sample, sand/silt/clay as % of <2mm fraction
- carbonate is % expressed as CaCO^3 equivalent, iron is %, all other elements ppm in <2 micron fraction, 0=below
- Munsell colour of dried sample under fluorescent light, colour in comments is field observation

Colour — Surface features — Pit observations								Comments
%veg	%stns	%gr	%bs	dr	st	ox	org	
25	65							soil pit camp 2, 1982; permafrost at 125 cm
								10% Precambrian erratic clasts
								moraine ridge
								ribbed moraine crest

- *veg and %stns = estimate of percent vegetation and stone cover on site surfaces
- %gr and %bs = granitic and basic igneous clasts in the stone cover (% or MR=moderately rare, R=rare, VR=very rare)
- dr represents drainage; (W)ell drained, (I)ntermediate and (P)oor
- st represents stoniness; (V)ery stony, (M)oderately stony, and (N)ot stony
- ox and org are columns for presence of oxidation and organics denoted by (X)

Appenidx 1 (cont'd.)

Identification			Location		Grain size					Geochemistry										
Sample		site	latitude	longitude	gravel	sand	silt	clay	carbonate	Cu	Pb	Zn	Co	Ni	Cr	Mn	U	As	Fe	Munsell
83SBB 94		1154	69°53'	110°56'	7.7	60.1	30.8	9.1	51.1	31	8	31	8	19	20	300	1.0	3	1.7	7.5YR6/4
83SBB 97A		1157	70°07'	116°42'	18.2	35.9	47.2	17.2	74.3	13	11	22	4	14	14	200	1.1	3	1.0	10YR7/2
83SBB105		1165	69°11'	113°17'	28.5	47.3	38.4	14.3	47.3	41	14	45	11	30	29	390	1.1	4	2.4	10YR6/3
83SBB123-3A		1183	70°08'	116°46'	1.4	14.2	65.6	20.3	77.3	20	17	32	6	17	17	230	0.9	4	1.5	10YR7/3
83SBB127		1187	69°34'	114°54'	26.6	45.8	35.9	18.3	51.7	36	12	46	9	27	32	320	0.9	0	2.4	7.5YR6/4
83SBB129A		1189	69°35'	114°18'	25.5	45.9	37.5	16.6	59.0	26	11	34	8	22	23	280	0.9	2	1.6	10YR6/3
83NJ 019		1224	69°50'	116°40'	27.0	39.2	41.6	19.2	62.4	35	12	40	5	17	20	280	0.9	6	1.7	10YR7/2
83NJ 029		1229	69°47'	116°48'	21.5	47.0	36.2	16.8	65.0	32	11	33	4	17	20	220	0.6	4	1.7	10YR7/3
83NJ 033		1230	69°48'	116°39'	28.3	47.9	36.3	15.8	63.3	28	8	35	6	17	21	270	0.8	3	1.7	10YR7/3
83NJ 397		1234	69°49'	116°41'	25.3	43.2	39.3	17.5	60.8	26	12	35	4	15	20	240	0.6	4	1.6	10YR7/2
83NJ 398		1234	69°49'	116°41'	22.8	44.1	39.0	16.9	60.4	28	10	37	6	17	18	290	0.5	4	1.7	10YR7/3
83NJ 399		1234	69°49'	116°41'	26.1	43.5	39.6	16.9	61.7	24	8	31	5	15	16	270	0.3	4	1.5	10YR7/3
83NJ 400		1234	69°49'	116°41'	28.1	42.7	41.0	16.3	63.0	28	8	36	6	17	20	270	0.3	4	1.3	10YR7/3
83NJ 401		1234	69°49'	116°41'	24.9	43.5	39.4	17.1	64.5	28	14	38	6	19	22	280	0.0	5	1.9	10YR7/3
83NJ 403	@	1235	69°39'	114°46'	56.6	61.1	30.0	8.9	60.3	54	17	46	12	32	30	460	0.3	8	2.5	10YR7/4

- *=data used for plotting, @=sample part of formal design (Nixon, 1988), gravel as % of whole sample, sand/silt/clay as % of <2mm fraction
- carbonate is % expressed as $CaCO^3$ equivalent, iron is %, all other elements ppm in <2 micron fraction, 0=below
- Munsell colour of dried sample under fluorescent light, colour in comments is field observation

Colour — Surface features — Pit observations								Comments
%veg	%stns	%gr	%bs	dr	st	ox	org	
15	60			W	V	X	X	gentle slope
20	60	10	8	M	M	X		low drumlin crest
20	60	4	8	W	M			hummocky moraine, level, irregular frost cracks
15	65			W	M	X		outwash terrace, polygons, till showing through

- •veg and %stns = estimate of percent vegetation and stone cover on site surfaces
- %gr and %bs = granitic and basic igneous clasts in the stone cover (% or MR=moderately rare, R=rare, VR=very rare)
- dr represents drainage; (W)ell drained, (I)ntermediate and (P)oor
- st represents stoniness; (V)ery stony, (M)oderately stony, and (N)ot stony
- ox and org are columns for presence of oxidation and organics denoted by (X)

APPENDIX 2

Contoured geochemical plots of non-significant elements