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Dynamic Geomorphology of the Drumlin Coast of Southeast Cape Breton Island

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The southeastern coast of Cape Breton Island from Gabarus Bay to Framboise Cove has been investigated as a typical example of a drumlin coast. Landforms have been mapped from ground observations and air photographs. Time series of coastal profiles of both beaches and eroding drumlin cliffs have been measured. Nearshore sediment distribution has been mapped. An analysis has been made of wind and wave frequency and direction data.
Four coastal segments are distinguished: (1) the south coast of Gabarus Bay has rock-cored drumlins separated by small barrier beaches; (2) the coast around Winging Point has a relatively stable depositional tombolo coast; (3) Fourchu Bay and Framboise Cove are developed in an area of thick till drumlins, and consist of barrier bars backed by lagoons and drumlins; and (4) the Fourchu Head and Red Cape are rocky coastlines from which all till has been removed by marine erosion.
The geomorphological evolution is a consequence of the initial drumlin landscape, the availability of a wide range of sediment sizes, and the type and intensity of marine erosion processes including the effects of transgression. Two types of coast are developed: a) in irregular hilly areas, where the till is thin and occurs in rock-cored drumlins; and b) in valley areas, where thick till drumlins are found. In each of these types, three stages of coastal development are distinguished. These represent the effect of differing rate of maturation, dependent on the configuration of drumlins and varying type and intensity of marine erosion.

Depuis la baie de Gabarus jusqu'à l'anse Framboise, la côte sud-est de l'île du Cap-Breton a été étudiée en tant qu'exemple type d'une côte à drumlins. Les formes de relief ont été cartographiées à partir d'observations sur le terrain et de photographies aériennes. On a mesuré à différents intervalles de temps, des séries de profils côtiers comprenant des plages ainsi que des falaises de drumlins soumises à l'érosion. La distribution des sédiments littoraux a été cartographiée.

On distingue quatre environnements côtiers. Le littoral sud de la baie de Gabarus est caracterisé par des drumlins à noyau rocheux séparés par des plages barrières de faibles dimensions. La côte à tombolos qui entoure la pointe Winging est un environnement de déposition relativement plus stable. Dans les régions de la baie Fourchu et de l'anse Framboise, des drumlins constitués d'un till épais sont à l'origine d'une côte barrière appuyée par des langunes et des drumlins. Les côtes rocheuses du cap Fourchu et de Red Cape ont été dénudées de leur till par l'action érosive de la mer.

L'évolution géomorphologique de la côte ressort du paysage à drumlins original, de la disponibilité d'une vaste gamme de sédiments, ainsi que du type et de l'intensité des processus d'érosion marine, y compris les effets de la transgression. On reconnaît deux types de côtes: l'une caracterisée par un paysage semé de collines oùl'on retrouve un till mince associé à des drumlins à noyau rocheux; l'autre, que l'on retrouve dans les vallées, se distingue par d'épais drumlins constitués de till. Chacun de ces types de côtes se développe en trois étapes correspondant à des régimes de maturation différents qui dépendent de la configuration des drumlins ainsi que de l'intensité et du caractère particulier de l'érosion marine.

[Traduit par le journal]

INTRODUCTION

Drumlin coasts are widely distributed in Nova Scotia. The early work of Johnson (1925) and Goldthwait (1924) established Nova Scotia as a type area for this class of coast. This study examines 50 km of the southeastern coast of Cape Breton Island, from Gabarus Bay to Red Cape (Fig. 1). The area has attractive drumlin-coast scenery: there are many lakes and ponds along the shore, protected by gravel beaches and vege-

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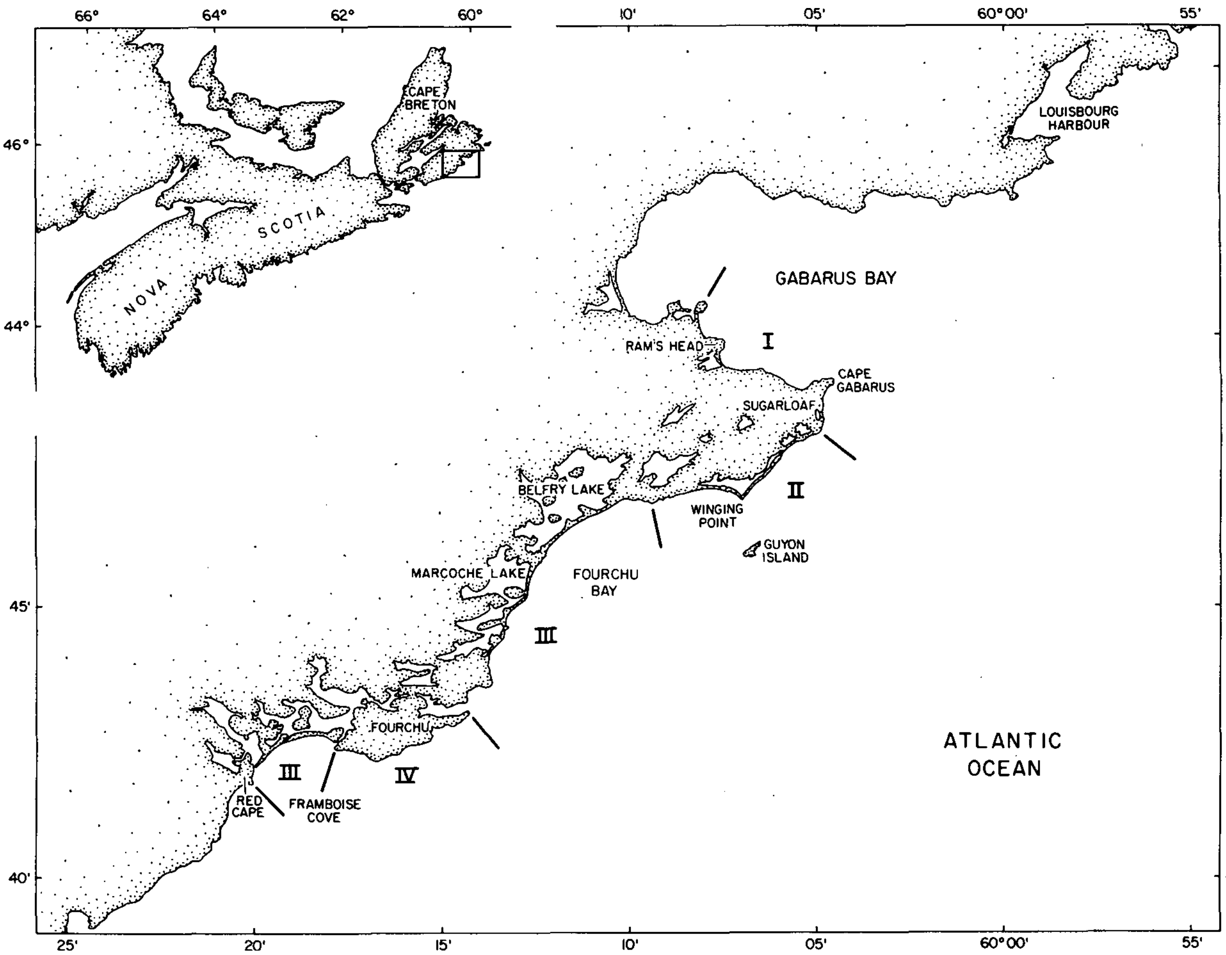

Fig. 1 - Map showing location of study area and division into four coastal segments.

tated drumlin islands. Rocky reefs are overlain by reddish clay till cliffs. We have studied the characteristics of this drumlin coast to develop a model describing the major processes of postglacial development of the coastline. No comparable study of coastal geomorphology has been made since the classic work of the early twentieth century. During the Holocene transgression, different parts of the coast were exposed to varying wave and current regimes, and were also under the control of the geological structure, lithological character, and original morphology of the land surface. As a result of these factors, different parts of the drumlin coast have different geomorphological features, reflecting different processes and evolution. These particularities exist even within short distances, such as from Cape Gabarus to Framboise Cove.

METHODS

A reconnaissance survey of the area was started in the spring of 1979 when observations were made at one-kilometre intervals along the coastline. On the basis of these observations, a coastal geomorphological map was made and the locations for 16 shore profiles were selected (Figs. 2 and 3). During November of 1979, the whole area was studied and photographed from a helicopter in cooperation with R. Taylor and D. Frobel from the Atlantic Geoscience Centre, Bedford Institute of Oceanography. Systematic field work was carried out between the summer of 1979 and the fall of 1980 in cooperation with R. Taylor

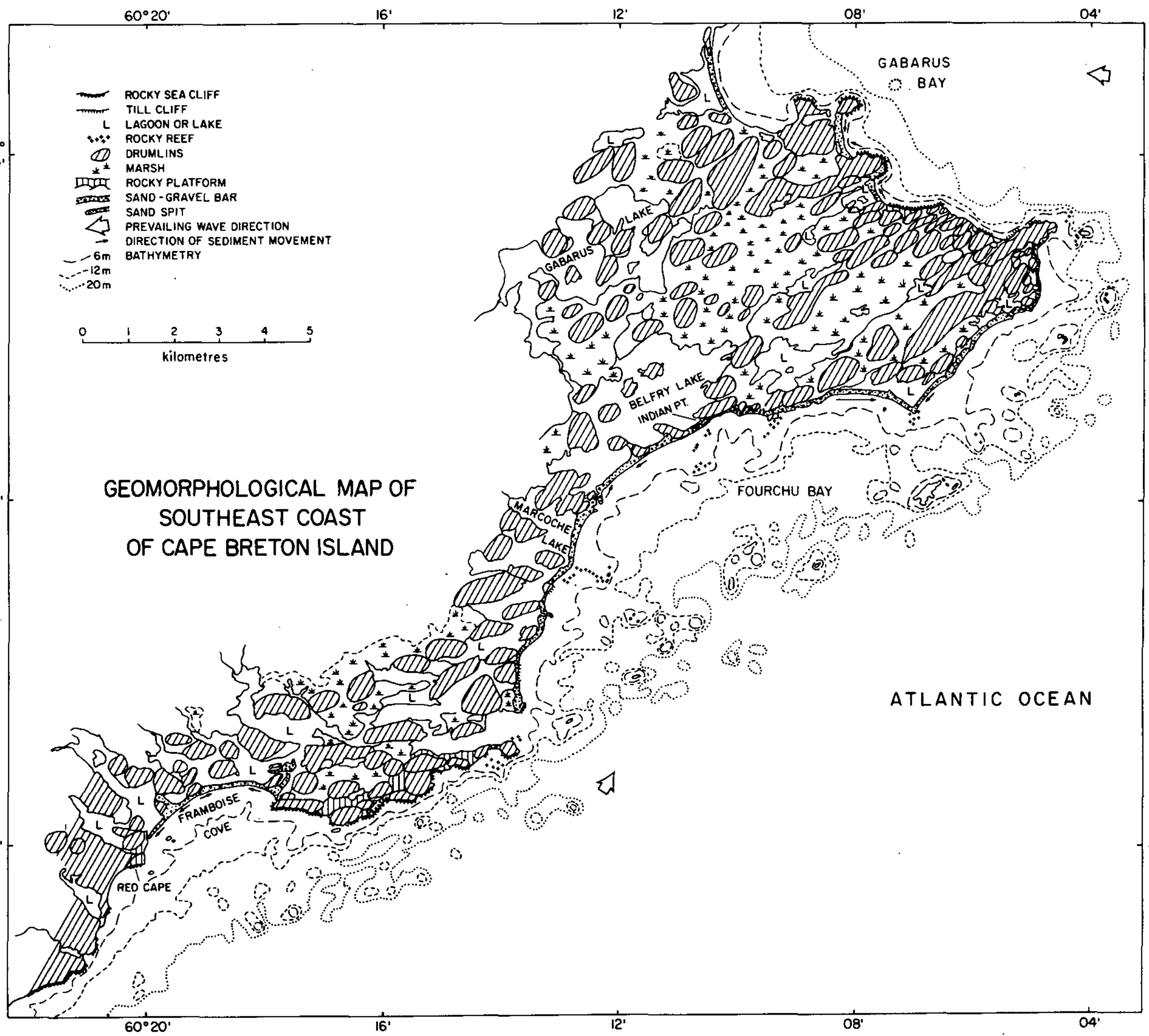

Fig. 2 - Detailed geomorphological map of the southeast coast of Cape Breton Island.

and D. Frobel. Profiles were surveyed using Emery poles (Emery, 1961) with the horizon for reference. Nearshore profiles were obtained from a 3.6-m ZODIAC, using a Raytheon DE-719 echo sounder. Offshore surveys were conducted from CSL TUDLIK using a Mini Ranger IV navigational system with Raytheon echo sounder and Klein side-scan sonar. Part of the sea floor was surveyed from a chartered fishing vessel, LONE ANGEL, with an over-the-side Ocean Research Equipment (ORE) acoustic profiling unit with a 3.5 kHz pinger-type source operating at 10 kW power, recorded on an EPC 48-cm analogue recorder with a 0.25-s sweep.

Sediment samples collected from sea shore and bottom were analyzed by standard methods (Carver 1971), according to the size of the sediment. The size distributions of sandy sediments were determined by sieve analysis and of finer sediment by pipette analysis. The mean size, standard deviation, skewness and kurtosis were computed for each sample. Folk's sediment nomenclature is used. Coarse samples of beach cobbles and pebbles were measured in the field by using a circle scale of Wadell (Krumbein and Pettijohn 1938). One hundred clasts per 0.25 m^2 area were measured to determine mean size, psephicity (roundness), flatness and sphericity of

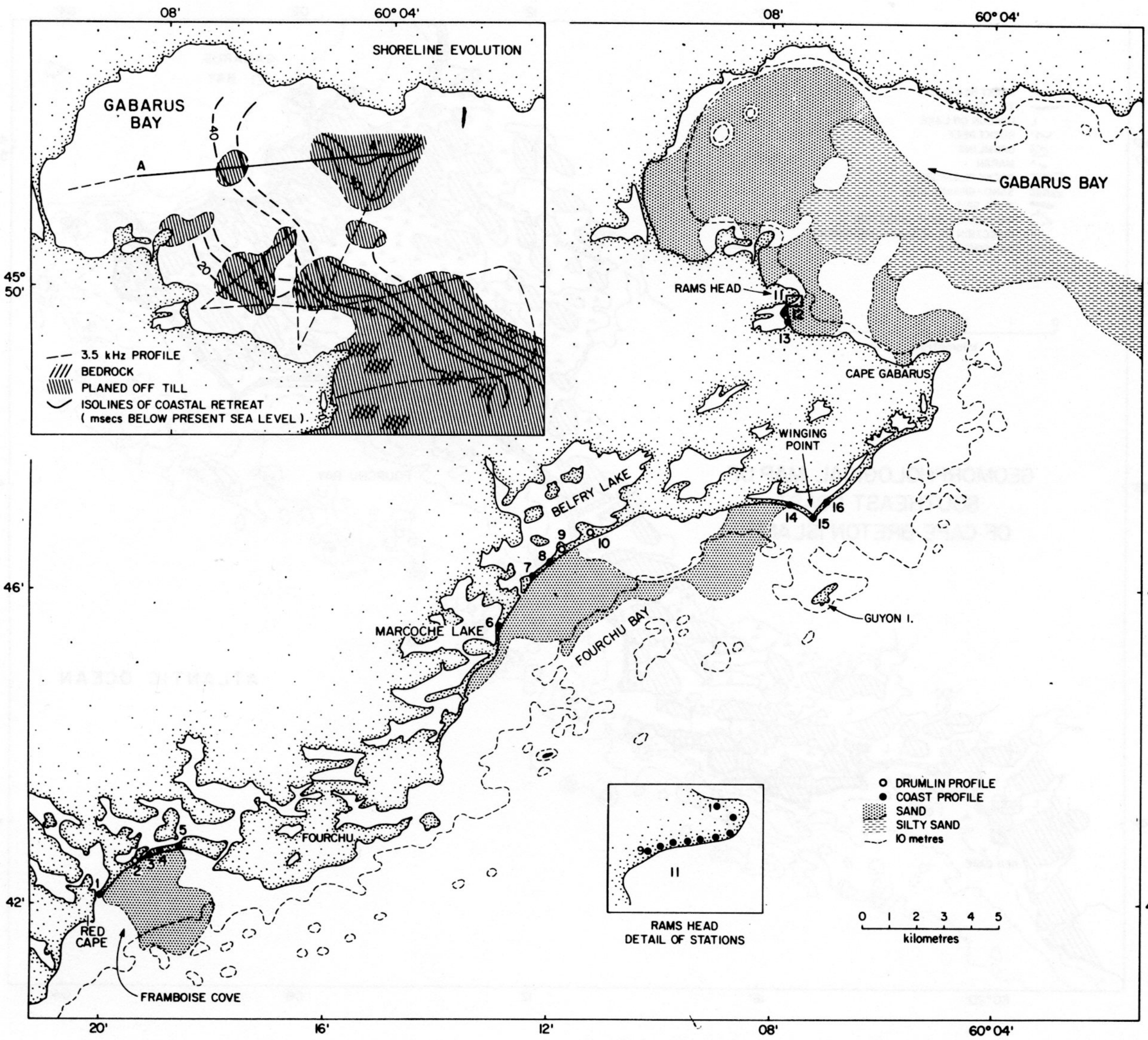

Fig. 3 - Southeast Cape Breton Island, showing (a) location of coast and drumlin profiles 1-16 (c.f. Fig. 7 and Table 6), (b) nearshore sediment distribution, based on 200 grab samples and 100 km 3.5kHz profile. Inset shows inferred development of Gabarus Bay with rising sea level: for further explanation, see text.

each sample (these parameters are defined in Table 1).

GEOGRAPHICAL AND GEOLOGICAL SETTING

The study area is located on the central part of the southeastern coast of Cape Breton Island. It extends from the large embayment of Gabarus Bay in the east to Red Cape, 50 km to the west-southwest. Relief at the coastline is relatively low, approximately 2-5 m; inland hills rise 60 m above sea level.

The bedrock belongs to the late Precambrian Fourchu Group (Weeks 1954; Cooke 1973), which is mainly volcanic in origin with rare interbedded sedimentary rocks. Dark green volcanic breccia or tuff is most common. Sedimentary rocks include shale, siltstone and rare sandstone or greywacke. The rocks have been sheared and metamorphosed to a low grade in most areas. The Fourchu Group is cut by intrusive igneous rocks, such as granite, especially around Gabarus Bay.

Table 1

DEFINITION OF CLAST PARAMETERS

a	Length
b	Breadth
c	Thickness
r	The radius of curvature of the most convex direction of the flattest developed face.
Mean Size:	$\sqrt[3]{abc}$
Flatness	$\frac{a + b}{2c}$
Psephicity	$\frac{2r}{a}$
Sphericity	$\sqrt[3]{\frac{abc}{a}}$

As a rule, it is difficult to determine the strike and dip of bedding of the Fourchu rocks. It is assumed that an anticlinal structure trends southwesterly across the Louisburg peninsula and Fourchu may be close to the anticlinal axis of these pyroclastic rocks. Shale and siltstone, although common, are not abundant. Narrow shale bands found in the Louisburg peninsula are also common extending northeastward from the mouth of Framboise River and to the north of Fourchu. At the mouth of Framboise River these rocks are associated with fine volcanic breccia or coarse tuffs.

The landforms of the exposed Precambrian rocks in the study area are variable. The north shore of Gabarus Bay is steep, the hills rising abruptly from the sea to a height of 60 m. From the south side of Gabarus Bay to Framboise, the land is much lower and irregular, with rocky lowland, fields of drumlins mostly 20 to 30 m high, and numerous bogs, ponds and lakes. The general trend of the land surface is probably a continuation of the peneplain of the northern tableland of Cape Breton, which dips southwards beneath the sea (Goldthwait 1924), but this has been substan

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tially modified by Quaternary glacial erosion (King 1972).

During the Wisconsinan glaciation, ice moved in three widely divergent directions (Grant 1972): first toward the east, then toward the northeast, and finally southwards in an offshore direction. Any weathered mantle of rock waste or soil was almost completely removed by the ice, in addition to a great deal of solid rock. The ice rounded or smoothed the hills and ridges, gliding over the obstructing summits or filling small depressions. In consequence, the hills took the form of arched mounds of glacial drift, known as drumlins (Goldthwait 1924). They commonly occur in groups or fields and may display a striking parallelism of arrangement.

The drumlin belt of Nova Scotia is one of the four major such belts in North America (Thornbury 1960). Drumlins are common in several areas along the Atlantic coast of Nova Scotia, but are most abundant and have been most studied in northern Queens and Lunenburg Counties (Flint 1971). East of Halifax drumlins are found at several places along the coast, and the southeastern coast of Cape Breton is one such drumlin district. The trend of the drumlin series is mainly northeasterly, parallel to one of the directions of the ice flow and also to the strike of the bedrock.

There are two kinds of drumlins in the study area: true drumlins that consist mainly of glacial debris and are oriented in the direction of ice movement; and rock-core drumlins, comprising bedrock with a veneer of glacial till on top, that are more or less oriented in the strike of the bedrock. Both are considered as drumlins in this report, because both are of glacial origin, occur in the same area, and are probably related to a single glacial event.

COASTAL PROCESSES

The classic work of Goldthwait (1924) and Johnson (1925), and more recent local studies by Bowen and Piper and their

Table 2

1980 WIND FREQUENCY BY DAILY PREVAILING DIRECTION, SYDNEY (46°10'N, 60°03'W)

Wind Direction	Monthly Frequency (percent)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
N	12.9		19.35		22.58	23.3		12.9	13.33		10.0	6.45
NNE		3.45	9.67		3.22		3.22			3.22		3.22
NE		3.45	6.45		6.44		3.22	3.22		6.44	10.0	
ENE			3.22	3.22	6.44			3.22			6.66	
E		3.45		6.66							3.33	3.22
ESE	6.45		3.22	3.32	3.22		9.67	3.22	3.33	3.22	3.33	9.67
SE	3.22		3.22	6.66	3.22	3.33	6.45			3.22		
SSE	3.22		3.22	10.0			6.45	9.678	3.33	3.22	3.33	6.45
S	6.45	10.34	6.45	13.3	6.44	13.33	19.35	3.22	23.3	19.35	10.0	
SSW	6.45		6.45	3.32	9.67	23.3		9.67	3.33	6.44	6.66	9.67
SW		17.24	6.45	10.0	3.22	20.0	29.03	16.12	13.33	22.58	6.66	6.45
WSW	9.67	6.89	3.22	3.32	6.44			25.8	13.33	3.22	3.33	16.12
W	45.2	24.13	16.12	3.32	16.13	16.6	12.9	3.22	16.6	19.35	20.0	32.25
WNW	3.22	3.45	3.22		3.22		6.45		3.33			3.22
NW	3.22	3.45	6.45	6.66	6.44			9.67	6.66	3.22	6.66	
NNW		6.89	3.22		3.22		3.22			6.44	10.0	3.22

students (Bowen 1975; Piper 1980), have defined some of the general processes by which the drumlin coast of Nova Scotia has developed.

The Atlantic coast of Nova Scotia is a coastline of submergence, on which sea level has risen by some 40 m in the last 10,000 years (Quinlan and Beaumont 1981). The earlier history of relative sea level is unclear, but there is no evidence of stands of sea level above the present level since late Wisconsinan deglaciation (Quinlan and Beaumont 1981). Tide gauge records (Grant 1970) suggest a present sea level rise as great as 4 mm per year.

Wave erosion causes retreat of drumlin cliffs, at rates in excess of one metre per year in exposed areas. Some of the eroded sediment is redeposited in barrier beaches of sand or pebbles between drumlin headlands. Rising sea level allows continuing coastal erosion, as the wave-cut platform submerges and ceases to significantly dissipate wave energy. Sediment supply is generally insufficient to permit beach progradation, and, as sea level rises, catastrophic breaching and landward beach retreat may occur (Bowen 1975). Substantial washover may be a precursor of actual breaching.

Coastal dynamic processes, especially those processes related to waves and currents, are very important factors in shoreline development. These processes control the movement of material along the coast. Because local climatic and oceanographic data are lacking observations from climatological stations and ships are used.

Winds and Waves

During the winter months there are frequent storms over southeastern Cape Breton. These storms bring cold air

Table 3

1980 AVERAGE DAILY WIND SPEED FREQUENCY, SYDNEY (46°10'N, 60°03'W)

Monthly Frequency %	Wind Speed (km/h) 7-12	13-19	20-30	31-40	41-50	51-60
January	6.45	22.58	38.7	25.8	6.45	
February	6.89	31.03	48.27	10.34	3.45	
March	6.45	19.35	48.38	16.12	9.67	
April	6.66	46.66	33.33	10.0	3.33	
May	9.67	32.25	51.61	3.22	3.22	
June	10.0	40.0	46.6	3.33		
July	22.58	61.29	16.12			
August	3.22	32.25	45.16	16.12	3.22	
September	6.66	40.00	53.33			
October	3.22	51.61	41.93	3.22		
November	3.33	6.66	20.0	53.33	6.66	10.0
December	12.90	32.45	41.93	12.9		

from the west, northwest, or southwest, i.e. basically from the continent. During summer months winds over the area are generally moderate, mainly from the south or southwest (Tables 2 and 3). The maximum hourly mean speed for this area is between 110 and 125 km hr^{-1} in winter and spring but in summer it is somewhat less (Thomas 1953).

These wind conditions have a great effect upon wave generation in the coastal area (Tables 4 and 5). Southwesterly and southerly waves are predominant from May to August. Northerly, westerly, and northeasterly waves prevail during October and November. During the other months the waves are mainly from the west, but northerly and southwesterly waves are also significant. Because of the orientation of the coastline, waves from the west and northwest do not have a significant effect on shore processes. Therefore, for the whole year the effective predominant wave and wind are southwesterly. More than two-thirds of storms occur in the winter months (December to February) and the remainder during the transition periods in spring and autumn. The modal wave height offshore is between 1.5 to 2.5 m from November to April and lower during the remainder of the year (Table 5).

Tropical hurricanes occur during late summer and early autumn. Although the annual occurrence rate in the northwest Atlantic Ocean is between 6 and 10, only 10 are recorded to have passed across Cape Breton Island between 1871 and 1977 (U.S. Department of Commerce, 1978). The wind speed in hurricanes can be in excess of 180 km hr^{-1}. Under these rare conditions, waves could become extremely high. Based on 1970 data, the 10-year maximum deep-water wave height for the coast of Nova Scotia, including the southeastern coast of Cape Breton, is 16 to 18 m (Neu 1971, 1976). The 100-year wave is between 22 and 24 m.

Waves are refracted upon moving to the coast. The speed of waves is reduced as a result of the decreasing water depth, so that wave fronts are bent while approaching the shoreline. Because of wave refraction, wave energy is concentrated around headlands, while wave action is dispersed in the bays.

Refraction diagrams for the 6-, 10-, and 14-s waves approaching Gabarus Bay from northeast, east and southeast are plotted in Fig. 5. All diagrams show that the wave energy gradually decreases in Gabarus Bay, but is concentrated around the headland of Cape Gabarus.

Refraction diagrams for 10-s waves approaching the Fourchu area, from the southwest, south, southeast, and east and for 6-s waves from the southwest are plotted in Fig. 6.

Table 4

WAVE DIRECTION FREQUENCY (1970 - 1972) FOR THE AREA OFFSHORE FROM S.E. CAPE BRETON ISLAND (Neu 1971, 1976)

Direction	Monthly Frequency (percent)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
N	14.59	12.94	12.69	15.08	5.9	5.11	6.45	3.76	10.0	20.96	18.3	13.97
NE	8.64	6.47	6.35	14.52	11.29	3.4	7.52	2.68	8.3	12.36	17.7	6.98
E	1.62	10.0	9.52	11.73	10.75	5.11	3.22	5.37	14.4	15.05	11.1	8.6
SE	2.16	5.88	3.70	6.70	11.29	5.68	5.37	9.67	8.3	2.68	6.66	5.3
S	5.94	14.1	8.46	6.70	20.43	30.11	26.88	23.12	124.4	9.14	9.44	5.9
SW	14.60	14.7	17.98	13.96	23.10	30.11	28.49	27.90	13.3	12.36	8.88	10.2
W	27.5	23.5	31.74	20.67	10.20	15.9	18.28	20.40	21.1	15.05	16.1	31.7
NW	24.86	12.3	9.52	10.61	6.98	4.54	3.76	6.99	10.0	12.36	11.6	17.2

Tide and Currents

Along the southeastern coast of Cape Breton the tide is mixed and propagates northwestwards from the open sea. The tidal range is not great: the mean range in Gabarus Cove is about 1.2 m, and spring range is about 1.5 m. In general, tidal currents are not important geomorphological agents in this area.

Currents along the coast are quite dependent upon the winds, and consequently are variable in speed and direction, but are constrained by local coastal morphology and bathymetry. The prevailing surface current often experienced about 5 km off this coast is 0.3 to 0.5 m/s to the west-southwest.

COASTAL TYPES

Drumlins dominate the morphology of the 50 km coastline from Gabarus to Red Cape along the southeastern coast of Cape Breton Island. The coast is transgressive, with embayments formed by flooding of valleys between drumlins. Sand and gravel deposits, derived mainly from the drumlins, accumulate in the embayments and enclose lagoons. Rounded or oval-shaped drumlins, either single or in a group, are drowned, forming dome-shaped islands or promontories.

Drumlin types, the relationships between the direction of the coastline and the drumlins, and topographical characteristics of the submarine coastal slopes all vary along the shore. Thus the action of different directions and intensities of waves and currents forms a variety of coastal morphologies, which can be considered as different developmental stages of the drumlin coast. The coast of the research area is divided into four sectors or subtypes, from north to south, each with a different developmental stage (Fig. 1). These four sectors are:

(1) South coast of Gabarus Bay (Rouse Point - Cape Gabarus - Sugar Loaf). This area is characterized by active marine erosion of drumlins, and the development of small embayments, some with barrier beaches, between headlands of bedrock or drumlins (Fig. 4 A).

(2) The Winging Point coast (Sugar Loaf - Winging Point - Indian Point). This is a coastline of marine deposition, with tombolos and barrier beaches backed by eroding drumlins and lagoons (Fig. 4 B).

(3) Framboise Cove and Fourchu Bay (Indian Point - Fourchu Head). This is a coastline of marine deposition with an extensive coastal barrier (Fig. 4 C).

(4) Fourchu Head to Red Cape. This is a low rocky coastline of marine erosion, from which drumlin tills have been largely removed by marine erosion (Fig. 4 D).

1. South Coast of Gabarus Bay

Table 5

SIGNIFICANT WAVE HEIGHT* FREQUENCY (1970 - 1972) FOR THE AREA OFFSHORE FROM SE CAPE BRETON ISLAND (Neu 1971, 1976)

Wave Height (m)	Monthly frequency of Wave Height (percent)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0 -0.5												
0.5-1.5	20.54	15.88	17.9	27.37	54.3	61.36	72.0	65.6	69.4	50.0	17.7	12.9
1.5-2.5	37.29	38.82	38.62	43.0	30.1	30.11	23.6	26.3	23.88	33.3	35.0	42.47
2.5-3.5	20.0	19.4	23.28	17.3	9.14	7.95	3.22	5.9	3.8	10.75	24.4	30.64
3.5-4.5	14.59	12.35	10.05	9.49	5.38	0.57	1.07	1.07	2.2	3.22	9.44	8.6
4.5-5.5	3.78	5.29	7.93	2.23	1.07					1.07	7.77	4.8
5.5-6.5	3.24	4.7		0.55				1.07	0.55	1.61	2.22	3.2
6.5-7.5	0.54	2.35	1.06								0.5	0.53
7.5-8.5		1.17	0.53								2.7	0.53
8.5-9.5			0.53									0.53
9.5-10.5												

* Where the 'significant wave height' is the mean height of the highest third of all the waves in a wave train.

a. General setting

This coastal type is located along the southern part of Gabarus Bay extending from Rouse Point to Cape Gabarus and then to Sugar Loaf, a total distance of about 11 km. The basic trend of the coastline is northwest to southeast, except between Gabarus Point and Sugar Loaf where it is north to south. Louisburg Peninsula and Scatarie Island protect the coastline from strong northerly waves. In this area, easterly and northeasterly waves with a large fetch prevail. The bedrock of this part of coast is mainly greyish, siliceous sandstone, shale, siltstone, or limestone. There are granite outcrops in coastal cliffs between Harris Lake and Gull Cove.

b. Drumlin cliffs

The drumlins along this coast are smaller than elsewhere in the study area but are closely spaced and trend northeasterly (060° to 080°). Along the coast they are seen to rest on an irregular rock platform 5 to 8 m above sea level, suggesting that this drumlin field originally developed on rocky, hilly ground; therefore, the drumlins are rock-cored and are covered with only a thin sheet of glacial till. For the most part, the till is 2 to 4 m thick, and is a yellowish sandy gravel.

The till is only 0.5 to 1.0 m thick on the granite hills west of Gull Cove, but more than 10 m thick between Gull Cove and Cape Gabarus.

The northeast-trending drumlins meet the coastline obliquely, and marine transgression has produced an eroded rocky embayment coast. The drumlin hills enter the sea to become headlands or islands. A 3- to 5-m high sea cliff forms an uneven rocky bench beneath the cliff, facing the sea obliquely. There are several pocket beaches and cliffs 10 m high in the area of granite bedrock.

Cape Gabarus projects seawards in a northeasterly direction. It consists of more than 10 m of greyish-yellow till that thins eastwards as the underlying polished bedrock surface rises to 8 m above sea level. Wave erosion at the base of the till has cut a cliff from which material frequently slumps, supplying sediment to the seashore. Despite the strong wave action, glacial striae are quite well-preserved on the bedrock surface. The top of the headland is a rocky platform 100 to 200 m wide. The

Table 6

MEASUREMENT OF DRUMLIN RETREAT BY USE OF STAKES

Stake No.	Location	1979.9.25 (m)	1979.11.21 (m)	1980.5.12 (m)	1980.8.6 (m)
4-100*	Framboise Cove area on the top of sand bar, 100 m east of profile 4	1.48		1.00	0.96
4-200**	200 m east of profile 4	2.00		1.74	1.74
4-300	300 m east of profile 4	2.30		2.27	2.27
4-400	400 m east of profile 4	2.44		2.44	2.44
2*	Framboise Cove area on the top of No. 2 drumlin	2.00		0.50	eroded
201***	30 m west of stake 2	2.30		2.00	2.2
202	30 m east of stake 2	2.05		1.40	1.40
203	Landward of stake 2	8.10		6.47	6.40
				1980.5.14	
900	Fourchu Bay area on the top of No. 9 drumlin	3.75		3.70	3.70
9002	30 m west of stake 9	2.55		2.45	2.45
9003	30 m east of stake 9	2.40		2.35	2.30
9004	Landward of stake 9	13.74		13.70	13.70
				1980.5.12	
10	Fourchu Bay area on top of No. 10 drumlin	1.30		1.0	1.0
1001	Landward of stake 10	6.30		6.0	6.0
		1979.9.16		1980.5.14	1980.8.10
1101	Harris Lake area on the top	2.0	1.95	1.90	1.90
1102	of Rams Head drumlin.	2.0	2.00	1.98	1.98
1103	1101 is on the northern	2.0	2.00	1.98	1.95
1104	edge of the drumlin.	2.0	2.00	2.00	1.95
1105	1102 is on the east side,	2.0	1.95	1.90	1.82
1106	and 1103 to 1109 are on	2.0		1.90	1.90
1107	the southern side of	2.0		1.90	1.90
1108	the drumlin (see Fig. 3)	2.0		2.00	2.00
1109		2.0		2.00	lost stake

* Framboise Cove, ** the distance from stake to the edge of dune scarp
*** all results show the distance between stake and the edge of drumlin cliff

platform appears to be wave-cut, because it cuts across the regional glaciated bedrock surface, leaving low cliffs and stacks. The platform marks the extent of erosional retreat of the headland at approximately present sea level, and this can be used as an index of the intensity of wave erosion.

Rams Head has a more sheltered location on the south side of Gabarus Bay. Like Cape Gabarus, it consists of till overlying a bedrock terrace a few metres above sea level. Retreat of the till cliff is more or less 0.1 m in a year according to the measurement of stakes on the top of the Rams Head drumlin (Table 6). The wave-cut platform is 40 m wide on the north, 75 m on the east, and 20 m on the south, suggesting much less rapid erosion than at Cape Gabarus.

c. Barrier beaches

Along this section of coast, small bays have developed between rocky headlands or drumlins, and have transgressed landward as sea level has risen. Some of these bays are less than a hundred metres wide. Clasts from the headlands have been deposited in the bays to form steep, narrow cobble or pebble bars which enclose lagoons.

Harris Lake is one of the largest embayments along this type of coast, with the total area of the bay being about 1.5 km^2. Four parallel strings of drumlins extend southwesterly through this area, with the outer two strings marking the edge of the lagoon, and the inner smaller strings forming small islands in the lagoon. The bar at Harris Lake is 750 m long. Its northern end is protected by Rams Head, and in the wave shadow of northeast waves the bar is low and wide (135 m) (Fig. 7, profile 12). It consists of pebbles and coarse sand, the mean size of the pebbles increasing from 25 mm at the bar crest in the north to 35 mm in the middle and 50 mm at the southern end as exposure to waves driven by the northeast winds increases. The bar profile at the southern end is narrower (70 m), higher, and steeper, with a storm beach berm (Fig. 7, Profile 13). The material of the bar appears to have come from the eroded headlands along both sides of the bay. Cobbles, pebbles, and coarse sand accumulate on the bar, while fine sand and silt are deposited on the sea floor offshore (Fig. 3). Mean pebble psephicity at the drumlins on Rams Head is 0.2, which increases to 0.3 to 0.4 on the bar, still a low value reflecting the local sources of the material and the short distance of sediment transport (Fig. 8).

The variation in morphology and grain size of the bar within a single bay results from differences in wave intensity related to the varying coastal exposure. This morphological analysis indicates that waves from the northeast and east are most effective in modifying the coast along Harris Lake.

Two shore profiles (Fig. 7) at the northern (12) and southern (13) ends of the bar illustrate these effects. Profile 12 is located along the northern part of the bay protected by Rams Head. The sediment is coarse sand and pebbles. In 1980, seasonal changes in the beach profile were mainly around mean high tide level but below extreme high tide level. Sediment accumulated in the spring and summer during times of low wave activity, but eroded during the time of strong northeasterly and easterly winter waves. The backshore adjacent to the lagoon receives little sediment.

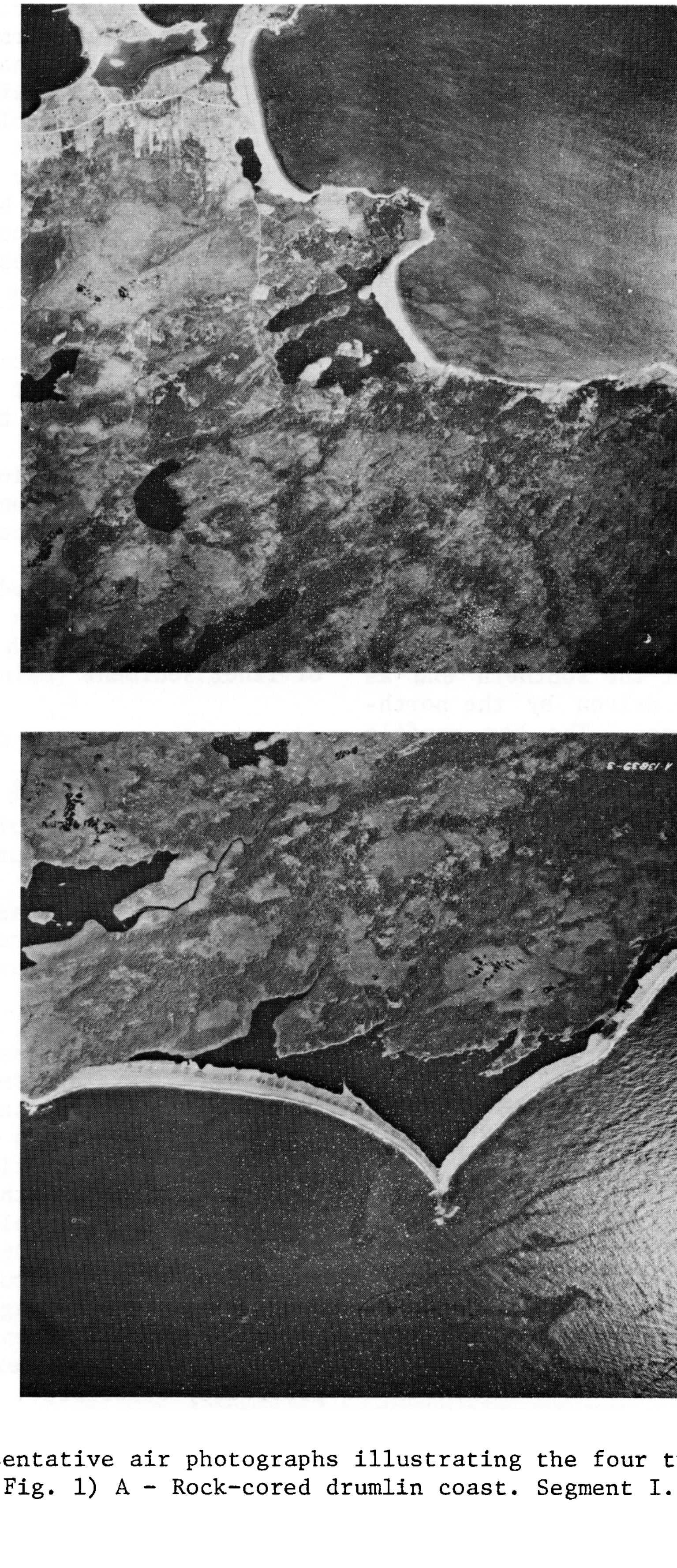
Profile 13 is located on the narrow, higher southern part of the bar. The cobbles at this end of the bar are moved mainly during storms; average waves do not change the profile significantly. The upper foreshore consists of cobbles and pebbles that accumulated during winter and late fall, when the northeast waves predominated. Only the lower part of the foreshore profile changed during the summer, with the accumulation of finer sediment (mainly coarse sand).

2. The Winging Point Coast

a. General setting

A depositional tombolo coast is found from Sugar Loaf southward to Winging Point, then westward to Indian Point. The total length of coastline is 9.5 km. The drumlins in this region are closely spaced, have rocky cores, and at the coast rest on rocky platforms. The drumlins trend 060° to 080°, almost parallel with the coastline. Offshore there are several small islands and reefs following the same trend, which are probably remains of old drumlins and protect the coastline from waves. The main feature of this coast is well developed double tombolo or bi-tie-bar islands (Zenkovich 1967) enclosing lagoons. Most of the drumlins are separated from the sea by lagoons and barrier beaches. Thus the scenery of this type of coast is quite different from the one previously described.

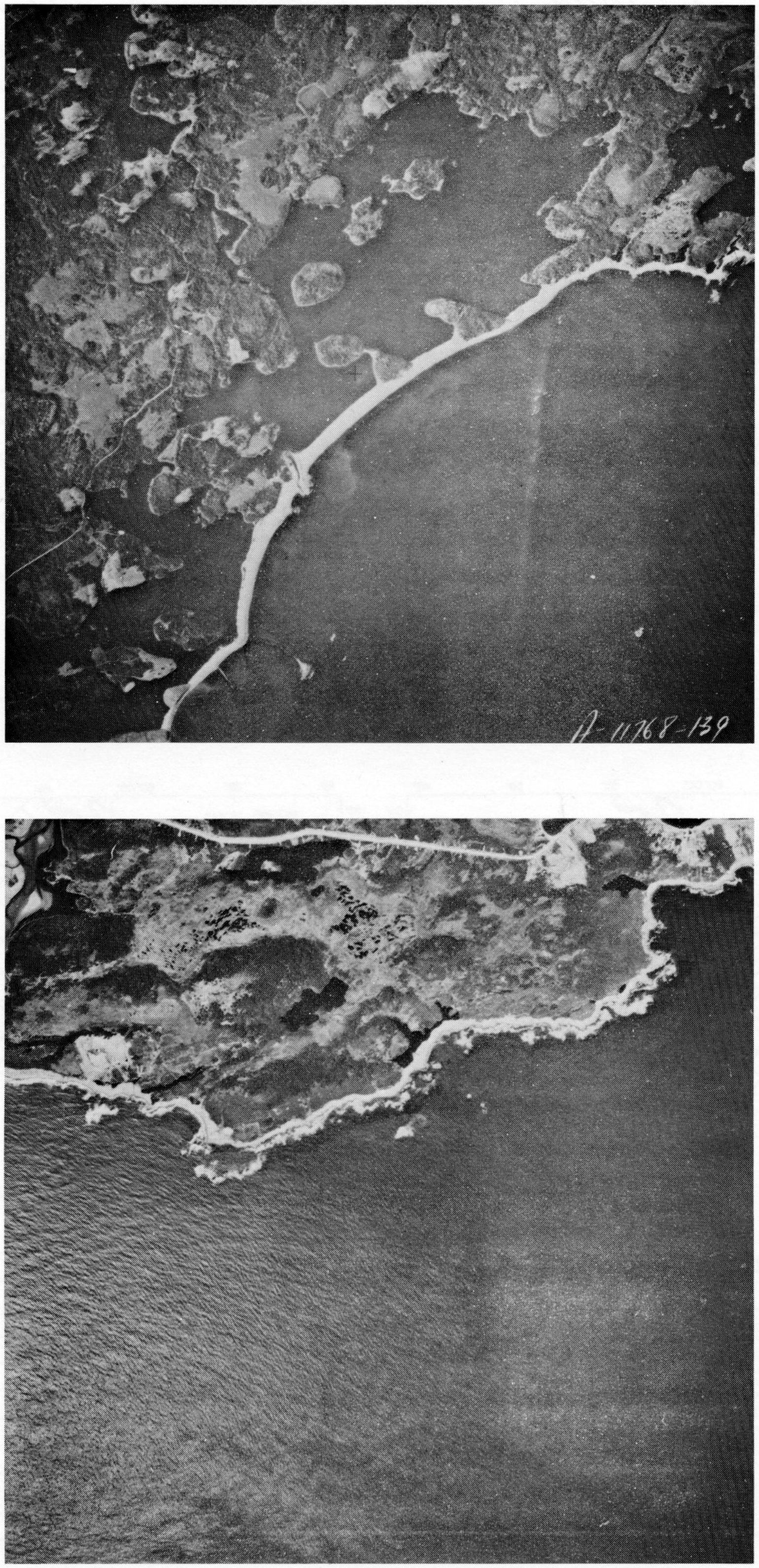
This coast is exposed to the open sea, including long-fetch southerly waves. The prevailing waves are southwesterly



A

B

Fig. 4 - Representative air photographs illustrating the four types of coastal sediment (c.f. Fig. 1) A - Rock-cored drumlin coast. Segment I. South coast of



C

D

Gabarus Bay; B - Double-tombolo drumlin coast. Segment II. Winging Point; C - Valley drumlin coast. Segment III. Coast of Fourchu Bay; D - Eroded low rocky coast. Segment IV. Fourchu Head.

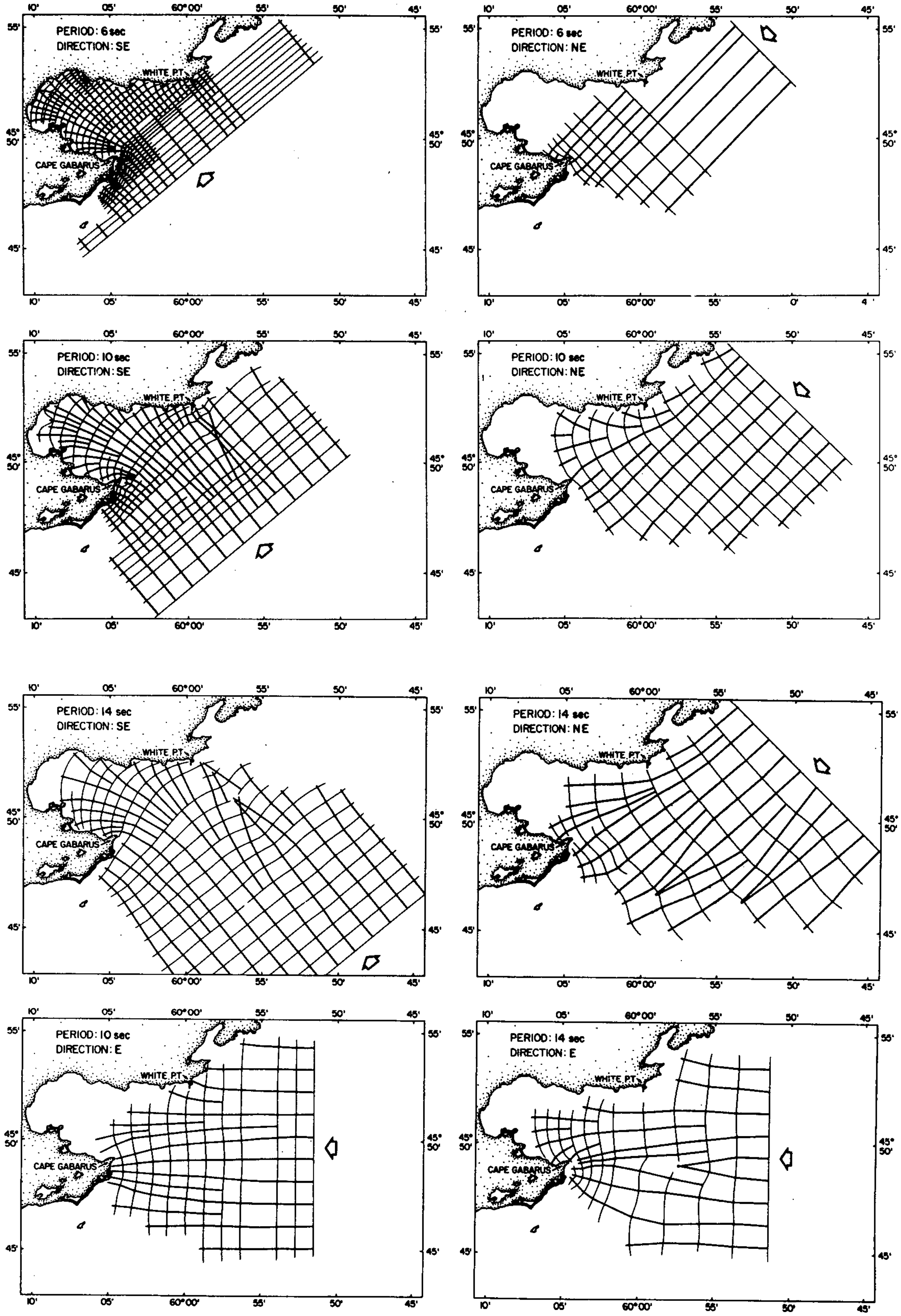


Fig. 5 - Wave refraction diagrams for Gabarus Bay, showing effects of varying direction and period of waves.

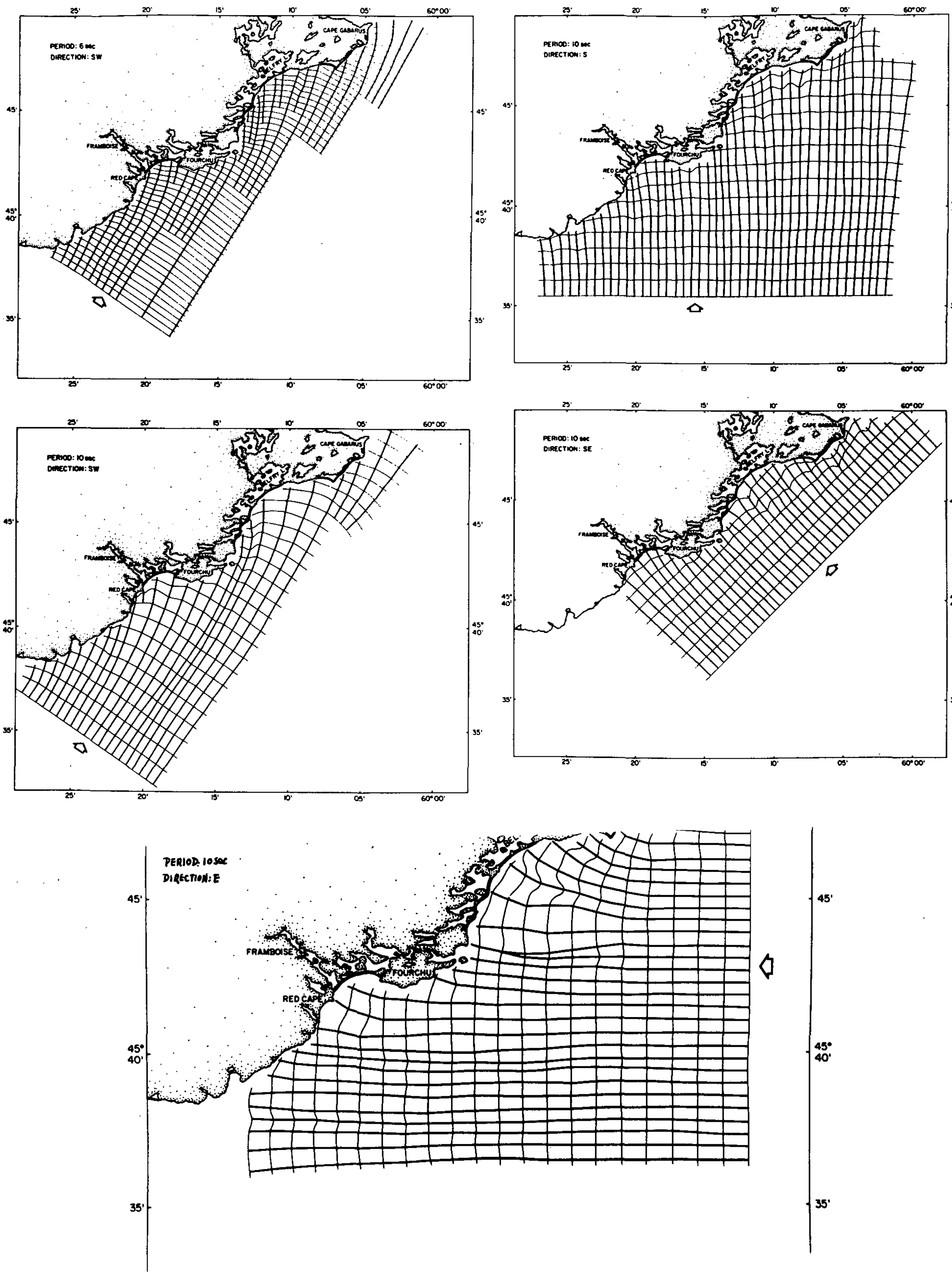


Fig. 6 - Wave refraction diagrams for Fourchu and Framboise Bays, showing effects of varying direction and period of waves.

for much of the year, except in winter and spring when the northeasterly waves are strongest. Allong this coast wave current and wind action are also stronger than in southern Gabarus Bay. Strong marine erosion that accompanied the post-glacial sea level rise has caused erosion and submergence of former drumlins, which become a series of oval-shaped islands or reefs offshore. These eroded drumlins have supplied sufficient sediment to the coast to develop extensive tie bars behind islands or reefs.

b. Winging Point

Winging Point, located at the centre of this segment of the coast, is a typical symmetrical or double tombolo. It is therefore used as an example to describe the coastal development. Winging Point is a rocky reef tied to the coast to the east and west by pebble bars. The reef is the remnant of a rock-cored drumlin, and is exposed during extreme low tide. It consists of Cambrian metasediments striking 055° with a 50°NW dip. The trend of this drumlin was northeast - southwest, and other rock ledges nearby also show this orientation. A second reef is located 100 m offshore from Winging Point, and Guyon Island is located 1.5 km off these two reefs. The reefs and islands protect the coast from wave erosion by refracting waves (Fig. 6) and causing the development of the two bars from east and west that connect Winging Point reef to the coast.

The eastern bar is 1.5 km long, and the western bar 2.2 km, the latter being 0.5 to 1.0 m higher than the shorter eastern bar. The entire bar consists of sand and gravel, with coarse sand deposited at the apex immediately north of the reef. Sand dunes are stabilized by grass and occur along the entire western bar, but only on part of the more exposed eastern bar.

Longshore sediment transport controlled by prevailing winds moves sediment toward the bar apex without any noticeable material exchange between the two bays. The bars prevent coastal erosion of drumlins from occurring and supplying significant amounts of sediment. The main direction of sediment movement along this coast is thus normal to the shoreline, reworking old coastal deposits or glacial till.

The east bar at Winging Point (Fig. 7, Profile 16) appears to undergo periodic washover and is getting lower. Waves have eroded the top of the bar and moved the material from the top to the lower slopes of both sides of the bar. This situation reflects the lack of sediment supply to this part of the coastal zone. Washover has resulted in little vegetation being established. In contrast the seaward progradation of dune grass and the evidence of sequential beach profiles show that the western bar is slowly accumulating sediment.

During winter and spring, under the prevailing northeast winds, the east bar is affected by wave erosion and the height decreases (Fig. 7, Profiles 16 and 15-1). The western bar is protected from the northwest waves by Winging Point so that, during the winter, this bar tends to grow (Fig. 7, Profile 14). During the summer southwest waves prevail so that the eastern bar is accumulating while the western bar undergoes wave erosion. During the autumn, both western and eastern bars are eroded because of the changing direction of the approaching waves.

Because of different coastline orientation and exposure, waves cause different seasonal changes of the beach profile. The sediments show no apparent seasonal changes, and on the whole both bars are relatively stable, showing only slight accumulation in the west and erosion in the east.

c. The southwest part of Winging Point coast

The trend of coastline is perpendicular to the trend of the drumlins, so that the shoreline consists of headlands and small embayments. The rock cores of drumlins consist of gneiss and slightly metamorphosed sandstone and slate (strike

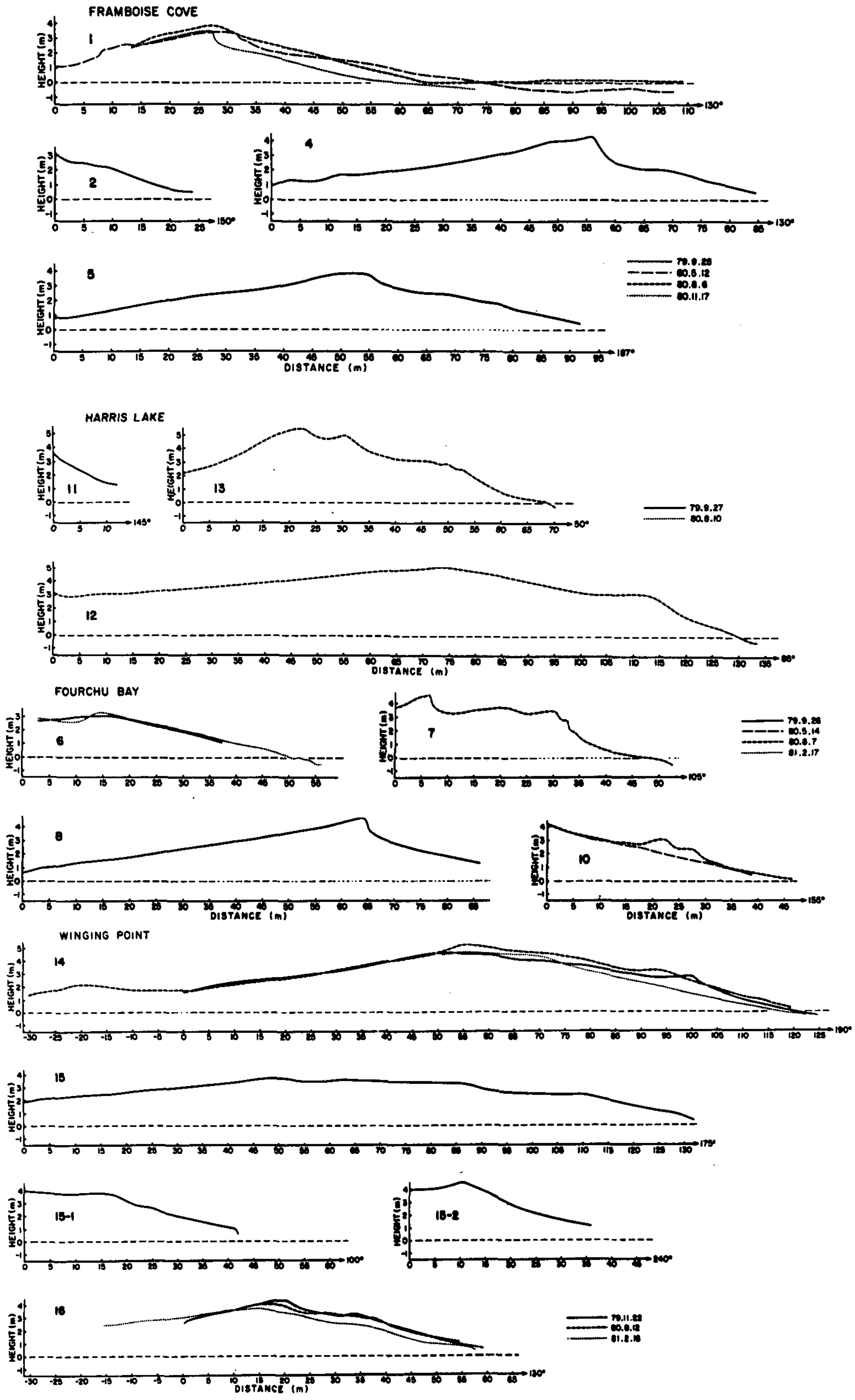


Fig. 7 - Representative coast profiles of southeast Cape Breton; profiles located in Figure 3.

040°, dip 20° to 60°SE). Drumlin rock cores form a platform 4 to 5 m above sea level, such as at Rock Point, which is affected by storm waves. Rock benches are covered by cobbles and pebbles forming beaches with crests reaching 6 to 7 m above sea level. Sediment has been deposited in small bays or behind the shoals to form bay-head bars of coarse sand and fine pebbles. There are also several tie-bars (Fig. 4C), such as at Rock Point, where two bars consisting of coarse sand and fine pebbles enclose a small lagoon. The west bar is larger than the east bar, but the east bar contains storm beach berms. Accumulation forms and flag-shaped pine trees both show that southwesterly winds and waves prevail.

Little material appears to be supplied to this coast by coastal erosion or longshore transport. The bars appear to have a stable morphology. Submerged drumlins lying offshore refract the approaching waves, leading to the formation of tie-bars. This part of the coast is in a relatively stable state, without either severe erosion or fast deposition.

3. Fourchu Bay and Framboise Cove

a. General setting

The coast of Fourchu Bay and Framboise Cove consists of barrier bars, backed by lagoons and series of drumlins. The total length of coastline is about 12.5 km and follows the same general northeasterly (065° to 080°) trend as most of the drumlins. A few drumlins trending 105° were probably formed by an early easterly ice flow. Along this type of coast drumlins were developed in the original depressions or valleys, and formed elliptic or dome-shaped till hills. The till in the drumlins is 10 to 15 m thick and consists of yellowish-brown silty and sandy gravel. The drumlins are widely spaced, lack rock cores and bedrock occurs only at their base. They are thus quite different from the thin rock-cored drumlins developed on the hilly ground farther east. Since the retreat of the ice-sheet, the drumlins exposed to the sea have been completely cut away, leaving elliptical shoals offshore. There are at least four northeast-trending lines of drumlin remnants visible on bathymetric charts and seismic profiles (Fig. 3, Fig. 9) of this area. Along the shoreline, exposed parts of drumlins have been eroded, forming 10- to 15-m high bare till cliffs. Spits trail from their submerged ends and sand bars tie them together in parts. In Fourchu Bay and Framboise Cove, sandbars have united to form an extensive barrier bar that has, in places, built out in front of the drumlin cliffs, thereby reducing the effectiveness of wave attack on the cliffs. Thus, on this drumlin coast, complete, unmodified drumlins are found in the lagoons, eroding drumlins at the coastline, and relict drumlins occur offshore, showing all stages of the coastal development.

The nearshore sediment of Fourchu Bay consists of pebbles near Winging Point, the drumlin shoals, and around the headlands; and fine sand occurs in deeper water.

b. Drumlin cliffs

There are 11 drumlins in this area that have been truncated and form coastal cliffs of till (Fig. 2). Measurements on the top of the drumlin cliffs show that most of these cliffs are still being modified and retreat slightly during storms. A few typical examples are described.

Number 2 drumlin is a 5-m high and 75-m long drumlin located near the middle part of Framboise Bay. The slope of the drumlin cliff is from 54° to 60°. The till is greyish-yellow, sandy gravel. Between September 1979 and September 1980 the cliff retreated 0.3 to 2.0 m with the middle part retreating most rapidly (Table 6). Drumlin No. 10 is a 10-m high accumulation of silty gravel located in the middle part of Fourchu Bay bar. There is a pine forest on the top of the drumlin but only dead trees on the edge of the cliff. The cliff retreated 0.3 m in one year.

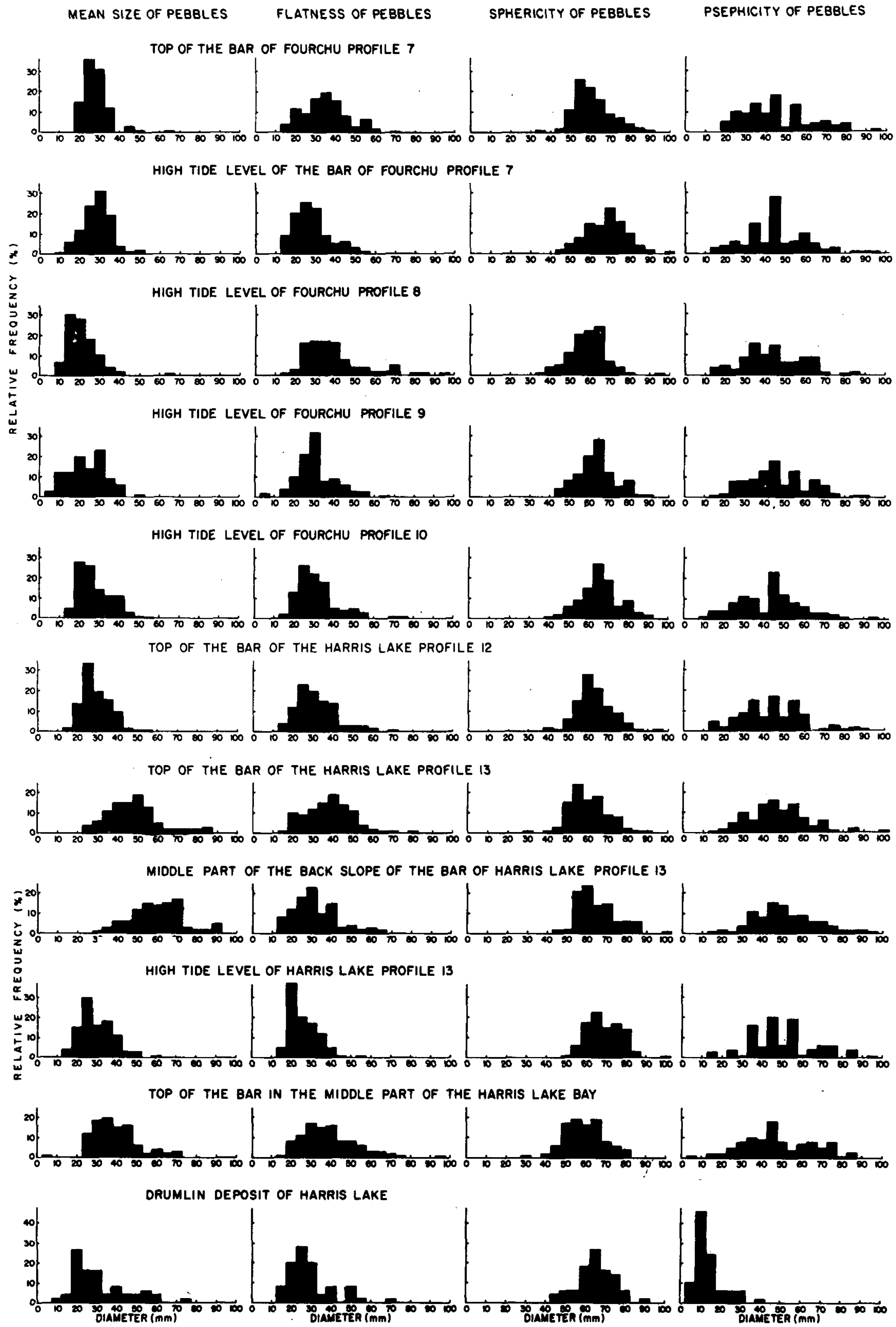
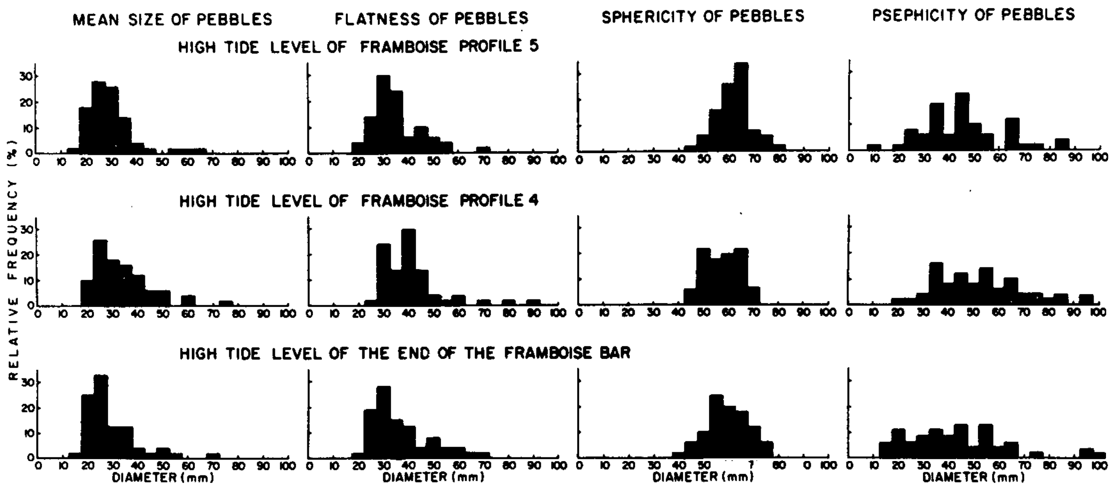


Fig. 8 - Histograms showing properties of pebbles at Harris Lake, Fourchu and Framboise; for locations see Figures 3 and 7. Definition of parameters in Table 1.



Drumlin cliffs appear to retreat faster in Framboise Cove than in Gabarus Bay. The rate of retreat depends on the fetch of the prevailing waves. However, the sections of the coast that are being eroded are far shorter than the depositional sections, so that only a small portion of the sand-bar sediment can have been derived from recently eroded parts of the coast.

c. Fourchu Bay

In Fourchu Bay the sand bar is 3.9 km long and 140 m wide, extending from Indian Point in the east to Belfry Head toward the southwest. Belfry Head is a 10-m high, dome-shaped headland of sandstone and slate, with three groups of nearly vertical joints (striking 160°, 260°, 290°) that control the morphology of the cliff and uneven rocky beach. At the south side of the headland is a small tidal inlet. A sand causeway has been built several times by local people, but this has been breached in storms and kept open by strong currents. Across the Belfry tidal inlet, the bar extends southward for 2.2 km to a new inlet at Marcoche Lake; from here it continues south with small bay bars toward Fourchu Harbour.

The sand bar of Fourchu Bay consists of coarse sand and pebbles. Pebble or cobble bars appear at the base of till cliffs or near rock headlands. Fourchu Bay bar is a bayhead bar consisting of a series of bayhead beaches: the formation of this united large bar enclosed the lagoon and small bays, changing what was originally a curved and embayed coastline to a flat and straight depositional sand-bar coast. The lithology of the beach pebbles is similar to those in the drumlin tills, consisting mainly of sandstone, slate and limestone, with little granite and gneiss. In the process of transport from the drumlins, the pebbles have been changed to form rounded or flat beach pebbles. The psephicity of the bar pebbles is 0.4, considerably higher than drumlin tills (0.11) (Fig. 8) suggesting that the pebbles are stored and reworked in the nearshore zone.

The morphology of the sand bar varies along different parts of the coast:

(i) Symmetric foreshore and backshore - This occurs where the bar is between the drumlins and in front of a lagoon (e.g. Indian Point, and Profile 8, Fig. 7). Near Indian Point the bar consists of coarse sand and pebbles, ranging in diameter from 40 - 100 mm at the upper part of the bar to 20 mm on the lower part. The bar suffers only slight erosion and both sides of the slope are still symmetrical.

At Profile 8, the sediment size ranges from medium sand at low tide level to gravelly sand at high tide level. The sediments are poorly sorted because the material is supplied locally without extensive transport. The bar faces the open sea and its top retreated 2 m in the winter of 1979 - 80. Thus the profile is slightly asymmetric, with a one-metre high scarp along the top edge of the bar (Fig. 7, Profile 8). This part of the bar consists of coarse sand with fine wind-blown sand on the top.

(ii) Asymmetric foreshore and backshore-Profile No. 7 is an example of this morphology. The bar here is narrow, steep and with several beach berms (Fig. 7, Profile 7). Because it is located near Belfry Head, the bar consists mainly of sandstone pebbles, 20 to 40 mm in diameter, derived from the adjacent headland. Roundness and flatness are low, only about 0.45 and 0.3 (Fig. 8). Sediment at low tide level is poorly sorted coarse sand. There are pronounced seasonal changes in Profile 7. Pebbles accumulate during winter storms, but are removed from the middle part of the beach face in summer and are deposited on the lower part of the beach.

(iii) A single foreshore - Profile 10 is an example of an inclined beach with a single slope (Zenkovich 1962) at the base of the drumlin cliff (Fig. 7, Profile 10). The swash reaches the foot of the cliff, and all of the water thrown up is incorporated in the backwash. There are mainly pebbles on the upper beach, and granules and medium sand on the lower beach. The profile is accumulating as the drumlin cliff retreats. Because there are no systematic changes in sediment grain size along the beach, there is unlikely to be major longshore movement of the littoral sediment.

As the beach sediment is largely fine sand and most of the pebbles are well-rounded, it is unlikely that much of the sediment is derived directly from drumlin erosion. A long period of sediment reworking is indicated in the nearshore, where sediment from erosion of former drumlin tills accumulates. Only a part of the beach sediments is supplied by modern marine erosion of drumlin cliffs or headlands.

In this part of Fourchu Bay, both drumlin cliffs and pebble bars show limited erosional retreat, so that there is only a limited supply of sediment on this coast. However, wave energy is decreased considerably because the approaching waves are refracted by relict drumlin islands and shoals. Under these circumstances, the coastline is relatively stable.

To the south of Belfry, along the outer coast of Marcoche Lake, the coastline stretches from north to south, and is exposed to the open sea to the east. Because of the large fetch, the easterly waves are quite strong. As a result, extensive overwash transport of sediment occurs, resulting in a relatively flat bar profile (Fig. 7, Profile 6). Waves transport gravel from nearshore landwards and because the sediment supply is plentiful and the bar is growing, the material is excavated for construction by local people. The bar sediment is well sorted fine sand mixed with granules. Because of the artificial influence of the excavation, the beach profile does not show the natural state.

From Marcoche Lake to the south there are two small drumlin cliffs, about 100 m long and 5 m high. At the foot of the cliffs there are almost bare clayey beaches, partly covered with a thin layer of coarse sand. The beach slope is 7° at the clay beach and 4° at the sandy part. Farther to the south a small river mouth separates the two drumlins from a third drumlin, which also has a trend of 060°. This river mouth or tidal inlet is new. A bar here has been washed out by strong currents, probably by flood currents, because the tails of sand bars at both sides of the inlet point landward. The abandoned inlet was at the south side of the third drumlin, now occupied by a new crescentic pebble bar. The bar is asymmetric with two slopes, and about 3 m above sea level. The bar is very new and bare of vegetative cover. Beneath the crescentic bar well packed boulders make a smooth bed, formed by strong and fast-running currents, apparently the result of an abandoned tidal channel.

d. Framboise Cove

Framboise Cove bar is 3.5 km long, extending westward from the east drumlin headland of the cove. It can be divided into three parts: (1) end of the bar, (2) base of the drumlin cliff, and (3) normal beach. A tidal inlet to Bagnell Lake separated the bar from the west drumlin headland of Framboise Cove. The Framboise River discharges into Bagnell Lake 10 km inland, so there are no apparent river mouth features at the bar.

Profile 1 (Fig. 7) is located at the west end of the Framboise Cove bar, and shows a complete profile with two slopes. The material consists of medium sand mixed with 20 to 30 mm pebbles (Fig. 8). The bar is low and flat. Beach profile measurement does not show seasonal changes, perhaps because of the excavation of the sand material.

Profile 2 (Fig. 7) is an inclined beach at the foot of No. 2 drumlin cliff. The beach sediment is mainly sandy gravel with positive skewness and poor sorting, because of mixing with a large amount of slumped mass from the retreating cliff. Profile measurements show that material accretes here, especially during the winter, presumably because winter storms have eroded the cliff and supplied the material to the beach. During the summer moderate waves remove beach sediments to the sea, so that the beach face is slightly decreased.

Profiles 4 and 5 (Fig. 7) are located in the middle part of the Framboise Cove bar. Here the bar faces the open sea and, because it is far from a drumlin cliff, it should result from sediment processes acting on the bar alone. The bar consists of a complete profile with two slopes. The backshore slope, adjacent to the lagoon, is gentle and has a cover of grass: the foreshore slope is shorter with a 0.5 m scarp on the top, resulting from wave erosion.

Along this part of the bar the sediment below high tide level consists of fine sand. Around the high tide level there are pebbles in Profile 5, but pebbles with medium sand in Profile 4. Coarse sand with pebbles occurs at the top of the bar. This type of sediment distribution with coarse sediment on the upper part of the bar, gradually becoming finer downslope, indicates that the sediments were transported by waves. Very fine sand is deposited on the sea bottom in the bay. Littoral sediment distribution, especially the pebble size distribution, suggests that there is a longshore transport from both headlands toward the centre of the bay. The mean size of sediments decreases from both ends of the bar toward the middle, so that sediment at Profile 4 is finer than at any of the other profiles. The psephicity and flatness of the pebbles in Profile No. 4 are also higher and they are mixed with well sorted sand (Fig. 8, Table 7). Although the top of the bar is eroded by waves to form scarps, shore profile measurements show that only slight seasonal changes take place. The bar seems to be stable or slightly accumulative.

e. Summary

Fourchu Bay and Framboise Cove have a double coastline. The curved inner coastline of drumlins is enclosed by barrier bars of sand, gravel and pebbles which form an outer straight coastline. Between these two coastlines are large lagoons containing small drumlin islands. There is no significant river sediment supply, neither is very much sediment supplied by the coastal erosion. The coastal sediment originates mainly from the submarine coastal slope of old deposits of the residual material of eroded drumlins. This source of sediment is limited. The coast faces the open sea, but several groups of relict drumlin reefs influence the waves approaching the coastline. Under this condition, the coastline of Fourchu Bay and Framboise Cove is considered dynmically stable over periods for which sea level change is negligible.

4. Fourchu Head to Red Cape

This type of coast dominates from Fourchu Head to Red Cape. The original land was a rocky platform or a series of small hills that developed small rock-core drumlins. The thin till of those drumlins rests on the rock platform some 5 or 10 m above sea level. The trend of drumlins is 055° to 070°, and the coastline is nearly parallel with the drumlin axis. Here the coast faces the open sea to the southeast. Due to the large fetch and wave refraction on this projecting stretch of coast, wave energy is high. The powerful waves cut the sandstone and slate to form a very irregularly eroded rocky coast. Uneven rocky beaches with frequent cobbles are common along the protected part of the coastline. Wave-cut beaches in some parts are more than 400 m wide. For example, the width of the submarine wave-cut beach from Fourchu Head to Framboise east headland is 700 m. Along this coast strong waves have swept away the drumlin tills and inhibited the growth of coastal vegetation.

GEOLOGY OF NEARSHORE AREAS

a. Gabarus Bay

The 3.5 kHz seismic profiles of Gabarus Bay show three types of sea floor (Fig. 9):

(1) small areas of bedrock (with a rough, highly irregular reflective surface);

(2) relatively flat areas of till, locally with thin sand or gravel patches; and

(3) areas of thick (up to 30 msec) sediments overlying an undulating hard surface, presumed to be till.

The bedrock outcrops east of Cape Gabarus and in northeasterly Gabarus Bay are a continuation of prominent lines of isolated rocky islands or reefs. In both trend and distribution they appear to be the cores of rock-cored drumlins from which the till cover has been stripped during marine transgression.

The flat till surfaces are most probably the result of coastal retreat of till cliffs, planed-off to a wave-cut platform. Isobaths of this till surface thus represent successive positions of the drumlin cliff coastline during the Holocene transgression (Fig. 3). The deepest flat till surfaces are about 50 m below present sea level.

In contrast, the undulating till surfaces preserved beneath sediment have not experienced wave erosion, and have maintained their original form. They occur in water depths greater than 50 m, suggesting that the maximum early Holocene lowering of sea level was about -50 m. They are also widespread in many shallower areas of southwestern Gabarus Bay. In these areas the drumlins were probably submerged in lagoons (as is at present happening in Harris Lake), protected from the open sea by barrier beaches. These beaches presumably linked drumlin headlands, so that their former positions can also be approximately located (Fig. 3).

Since the early Holocene, till cliffs at Cape Gabarus have retreated about 5 km in a westerly direction. The isolines of retreat suggest that perhaps half of this sediment would have been

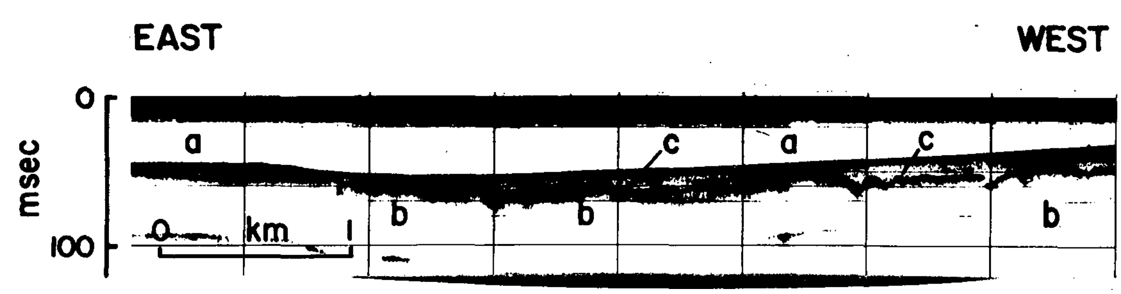


Fig. 9 - 3.5 kHz profile in northern Gabarus Bay, showing planed-off till drumlins (a); buried drumlins (b); and overlying lagoonal and shallow marine sediments (c); profile located A-A' in Figure 3 inset.

transported by longshore drift toward Gabarus Bay and half southwestward toward Fourchu Bay. Assuming the till cliffs were 5 m high, some 1×10^8 m^3 till has been eroded from this area, and a further 0.2×10^8 m^3 from within Gabarus Bay.

b. Fourchu Bay and Framboise Cove

The geological history of the coast off Fourchu Bay and Framboise Cove is less easily interpreted. Rocky shoals, perhaps the cores of drumlins, are common. Between these shoals, the seabed sediment comprises sand and pebbles, and thick, accoustically transparent sediment sequences are not seen.

If the drumlins that are widespread on land originally extended at least 4 km seawards, then during Holocene transgression large amounts of till would have been eroded and supplied to the coastal zone.

COASTAL DEVELOPMENT

Most drumlin coasts are in areas of submergence in mid to high latitudes. The origin of a drumlin coast is related closely to glacial processes. Drumlin fields were formed during glaciation and the drumlin coast developed during the ensuing Holocene sea level rise. Drumlin coasts typically consist of small bays and myriads of islands. The sediment size in till varies from boulders to clay, and bars consist mainly of sand and gravel. As a result of the different coastal processes, the drumlin coast eventually becomes flat and straight.

The dynamic processes of a drumlin coast depend on the original types of drumlin, the morphology of the bedrock surface on which they rest, coastline orientation and exposure, and topographic features of the submarine coastal slope. These factors influence both the coastal sediment supply and the intensity and characteristics of waves.

Sediment supply from rivers is minor. River processes in high latitude, glaciated uplands are not as important as in middle and lower latitudes, because numerous glaciated lakes have trapped sediment in the drainage area. Because of the moist climate, the ground is covered with a luxuriant growth of grass and bushes, thereby retarding erosion. In mainland Nova Scotia and Cape Breton Island very little sediment is supplied by rivers (Piper and Keen 1976).

The sediment of a drumlin coast is supplied directly or indirectly by drumlin till, either from till cliffs or old coastal sediment on the sea bottom that originally came from drumlin till. Drumlin till is poorly sorted and drumlin coasts also include all sizes of sediment. Along the southeast coast of Cape Breton, the sediment comprises mainly cobbles, pebbles, sand and coarse silt.

Within the study area there are two contrasting developments of till. In irregular hilly areas, till is thin, and occurs in rock-cored drumlins. In valley areas bedrock is low-lying and thick till drumlins occur. These two types of till morphology have very different effects on coastal geomorphology. We can examine this by studying the stages by which the drumlin coast evolves (Fig. 10). In this analysis, we assume that a slow rate of marine transgression took place.

1. Hilly coast with rock-cored drumlins

(i) Initial stage - this is where rising sea level in the early Holocene begins to drown and erode the drumlin coastline. At first there are a series of drumlin headlands and small embayments. With time, rocky headlands and residual till cliffs form on each side of the bays. Cobble and pebble bars gradually enclose the bays to form small lagoons. During this stage marine erosion is the leading process and the sediments originate from headlands. The inferred early Holocene coast east of Cape Gabarus would have shown this type of development, and the present coastline from Cape Gabarus south toward Sugar Loaf is an example of this stage.

(ii) Mature stage - As marine erosion

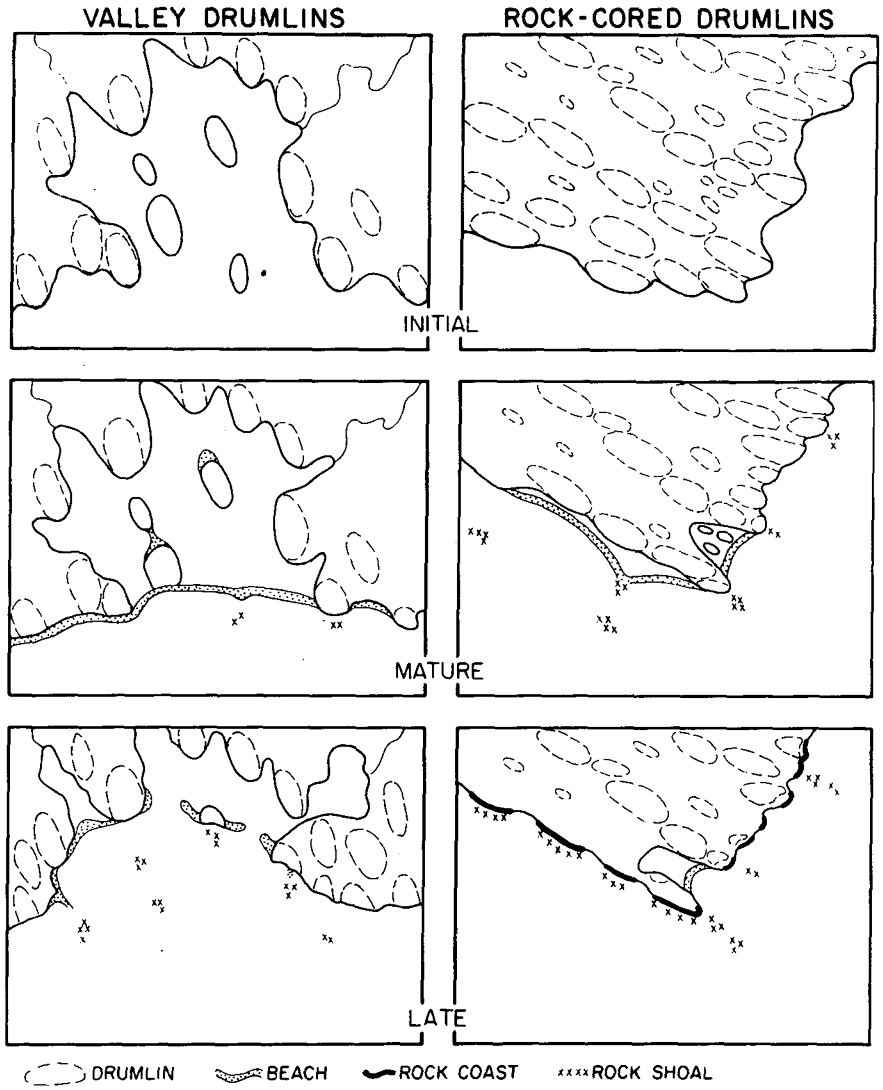


Fig. 10 - Cartoons illustrating stages of coastal geomorphic evolution of (a) hilly rock-cored drumlin areas, and (b) valley thick drumlin till areas.

progresses, where the trend of the drumlin is oblique or normal to the coastline, two or more small bays may combine to form a large bay. The single bar becomes longer but is still protected by two rocky headlands at the sides of the bay. The sediments come both directly from the headland and through the nearshore, as for example in Harris Lake Bay.

Where the coastline is parallel with the general direction of drumlins, marine erosion and sea level rise caused the coastline to retreat and form a series of small islands or relict drumlins. Sediments are deposited in the wave shadow area of islands or reefs to form well-developed tombolos or tie bars. Thus, the original coast is enclosed by tie bars or tombolo systems. At this stage, strong marine erosion is not a leading process, because waves are refracted by eroded island sand reefs. The coast has reached a relative dynamic equilibrium, except for the rise of sea level. The coast of Winging Point is an example of the stage.

(iii) Late stage - This stage of drumlin coast is developed only where it faces open ocean and where there is a very steep coastal slope. Drumlins have nearly disappeared due to marine erosion, and have formed an irregular curved and eroded rocky lowland coast; for example, the coast westward of Fourchu Head.

2. Valley areas with thick till drumlins

(i) Initial stage - Valley areas, because they are low-lying, form deep bays and inlets during early transgression. They are thus relatively sheltered from open ocean waves. The flooded drumlins form dome-shaped forested islands.

With the start of marine erosion, pine trees are removed, exposing a glacial till cliff. Gravel and coarser material, derived from the eroded till, is carried along the coast and deposited mainly at the landward side of drumlin islands to form a tie bar or a small spit. Finer materials however are carried to the sea. This stage of the drumlin coast type is very short-lived, because marine erosion is rapid on coasts of unconsolidated sediment. This type of coast can be seen in the inner parts of lagoons or where there are long narrow bays, such as in the lagoon of Fourchu Bay and Framboise Cove.

(ii) Mature stage - As the coastline irregularities retreat and more sediment accumulates because of drumlin erosion, extensive bars develop, which enclose a series of lagoons and drumlin till cliffs. There are several islands and drumlin shoals offshore. Most sediment is reworked from the nearshore and very little is supplied by contemporary marine erosion. Thus, the stage of coastal evolution such as in Fourchu and Framboise Bays is also in a state of dynamic equilibrium.

During this stage, both erosional and depositional processes transform the coastal geomorphology. Either process may dominate at any given time, or the two may proceed in cycles that are related to seasons or longer-term dynamics, including rates of sea level change.

(iii) Late stage - This stage of development is seen only where the coast faces open ocean. Drumlin tills are eroded and swept off, leaving only the bedrock base of the drumlins close to the water surface. In extreme cases, all the drumlin islands and reefs have been eroded and have disappeared, leaving fragments of tie bars, which always meet the coastline at right angles. As the erosion continues by wave action, these residual bars also disappear. Only boulders are left along the coast at random locations. At this stage also, there may be crescentic till cliffs and well-developed tie bars or tombolos in the inner parts of the more sheltered bays. The southeastern coast of Cape Breton Island has not reached this stage. However, analogies exist in the Yarmouth area, at Shag Harbour, and Three Fathom Harbour, on the mainland coast of Nova Scotia.

SUMMARY

Two fundamental types of drumlin coast are distinguished: hilly coasts with rock-cored drumlins, and valley coasts with thick till drumlins. Their development can be described in terms of three stages. These stages do not express different coastal age, because all three stages may be seen in the same area, and coastal processes of all drumlin coasts here started at much the same time, at the beginning of the Holocene transgression. The stage reflects differences in the speed of coastal development, determined by the intensity of wave action and availability of sediment supply. However, these factors are governed by the original landform and coastline configuration.

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