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Coastal Environments Oil Spills and Clean-up Programs in the Bay of Fundy

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February, 1977

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COASTAL ENVIRONMENTS, OIL SPILLS AND CLEAN-UP PROGRAMMES IN THE BAY OF FUNDY

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A Report Submitted to:

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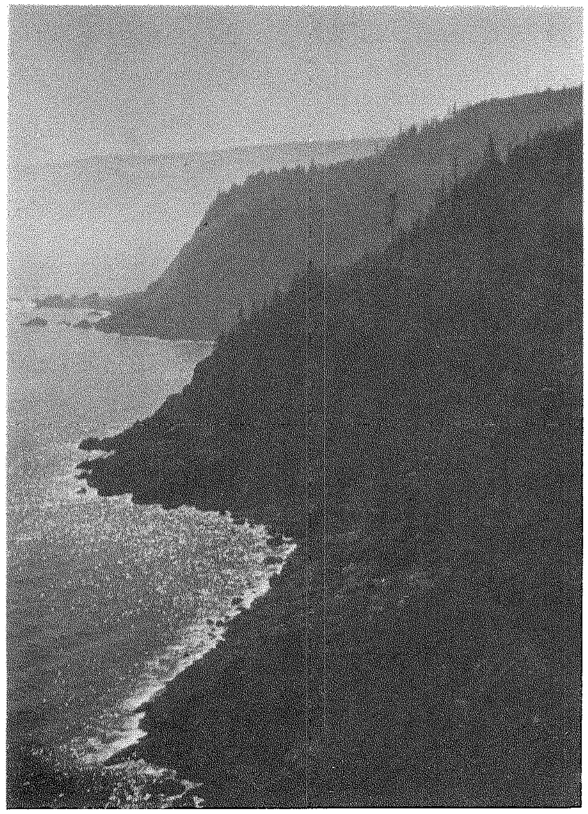

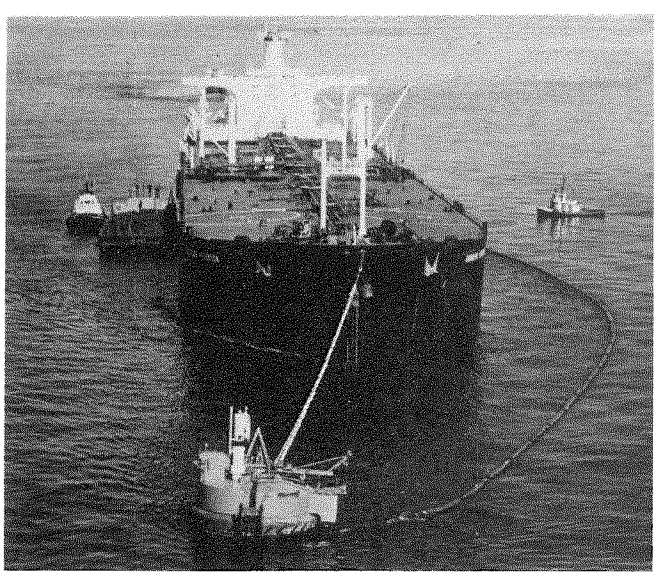

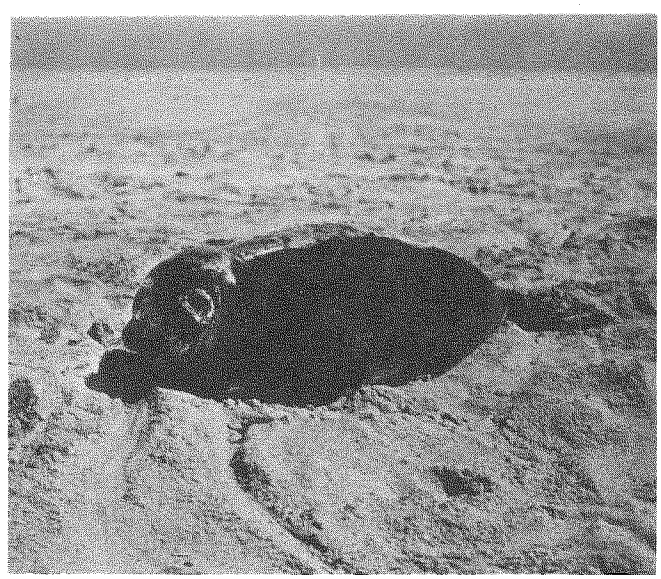

ABSTRACT

The Bay of Fundy has a coastline of approximately 1400 km. Within this region, there is a great variety of coastal features; six major coastal environments and twelve major shoreline types have been identified following a reconnaissance survey. The coasts of the Bay of Fundy are characterized by high tidal ranges and by the predominantly rocky nature of the shore zone. Tidal range exceeds 10 m in the Minas Basin and Chignecto Bay, where wide intertidal mudflats or sand flats and marshes are characteristic of the shore zone. This information on coastal features and shoreline processes is applied to an assessment of the expected impact and persistence of oil on the shore for each of the shoreline types. Guidelines and recommendations for protection and clean-up of the shores of the Bay of Fundy are presented and are related to the nature of the shoreline, the sediments, the shoreline processes, and the effectiveness of available techniques.

RESUME

La ligne de côtes de la baie de Fundy mesure approximativement 1400 km et son modelé varie beaucoup. Un levé de reconnaissance a, en effet, permis d'identifier six principaux environnements côtiers et douze principaux types de ligne de virage. Les côtes de la baie de Fundy se caractérisent par un fort marnage, et la nature surtout rocheuse de la zone littorale. Dans le bassin des Mines et la baie Chignectou, dont la zone littorale se caractérise par des sèches de vase ou de sable et des marais, le marnage dépasse 10 m. Toutes ces informations servent à l'évaluation des conséquences et de la persistance des hydrocarbures sur chacun des types de lignes de rivage. On offre des lignes directrices et des recommandations concernant la protection et le nettoyage des rives de la baie de Fundy, selon la nature de la ligne de côte, les sédiments, les processus se déroulant sur le rivage et l'efficacité des techniques disponibles.

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PART 1 - FOREWORD

1.1 INTRODUCTION

The distribution and persistence of oil residues on the shoreline following a major spill are dependent upon the type and volume of the spill, the climatic, meteorologic and oceanographic conditions at the time of the spill, the littoral zone energy characteristics, and the nature of the coastal sediments. Effective contingency planning for clean-up operations of contaminated coasts requires accurate estimates of the probable effects of a major coastal spill but, as the nature of the contamination problem will vary depending on the characteristics of a particular coastal environment, contingency plans for a variety of environments are necessary. With this in mind, the Environmental Protection Service of Environment Canada commenced preparation of a contingency plan for the Bay of Fundy in spring 1976. One aspect of the plan required a survey of the coast of the Bay of Fundy and preparation of a report that would outline the expected impact of a coastal oil spill in the different coastal environments that occur in this region. As a result this report was prepared to consider the geological variability of the Bay of Fundy coast and to determine the expected distribution and persistence of oil-spill residues in the coastal zone.

A 3-day aerial reconnaissance of the Bay of Fundy coastline provided base-line information on the nature and variability of coastal environments along this section of coast. The reconnaissance was carried out in cooperation with Dr. F.C. Duerden of the Environmental Protection Service in Halifax and the Canadian Coast Guard, who provided helicopter support for the survey.

1.2 OBJECTIVES

The primary objectives of this report were as follows:

1. to define the major coastal environments of the Bay of Fundy,
2. to outline the significant geological characteristics and processes in each environment,
3. to discuss the expected nature and behaviour of oil residues in the different environments,
4. to discuss the expected distribution of oil residues in the littoral environment,
5. to discuss the expected persistence of oil residues in each environment,
6. to assess the available clean-up techniques in terms of their applicability and effectiveness in the Bay of Fundy,
7. to present guidelines for the implementation of the most suitable clean-up techniques in each coastal environment, and
8. to provide a short bibliography of relevant geological and clean-up information sources.

The report was prepared from (1) information gathered during an aerial reconnaissance of the Bay of Fundy coast, (2) experience gained by studies associated with previous major oil spills in the coastal zone, (3) literature surveys of the effects of previous spills in different coastal environments, and (4) discussions with other workers who have been involved with coastal oil spills or clean-up programmes.

1.3 FORMAT

Each major topic outlined in the objectives is treated independently and can be used without reference to other parts of the report. The coastal geomorphology and process characteristics are discussed initially at the regional scale (Part 2). The Bay is then subdivided into 6 major coastal environments that are defined as distinct units on the basis of variations in either process or the morphological characteristics (Part 3). At the most detailed scale the major shoreline types are defined and discussed (Part 4). Whereas definition of the coastal environments provides information on the character of a section of coast, the identification and description of shoreline types is concerned with details of the shore at specific sites. By using this approach that deals with the coastal zone at different scales, it is possible to present detailed information within the context of more general regional characteristics.

From this basis an assessment of the expected impact of a spill in the Bay of Fundy is discussed with reference to the different coastal environments and the different shoreline types (Part 5). This section includes an assessment of the applicability and effectiveness of available clean-up techniques, with accompanying guidelines for the most suitable response in each coastal environment. The major points of this section are summarized in a series of tables that provides a reference guide to the more detailed text.

Appendices following the main text provide (A) a location diagram of places referred to in the text, and (B) a definition of terms.

PART 2 - THE BAY OF FUNDY

2.1 INTRODUCTION

The Bay of Fundy is a large embayment of the Gulf of Maine on the east coast of Canada (Fig. 1). The coastline of the Bay, from Brier Island in the southwest to the United States border in the northwest is approximately 1400 km in length (E.J. Cooper, pers. comm., 1971) The dominant characteristic of the coastal environment is the large tidal range (Photo 1) which everywhere exceeds 5 m and reaches a maximum of 15 m in parts of the Minas Basin. Maximum tidal ranges of 21 m have been reported under storm conditions (Ganong, 1903).

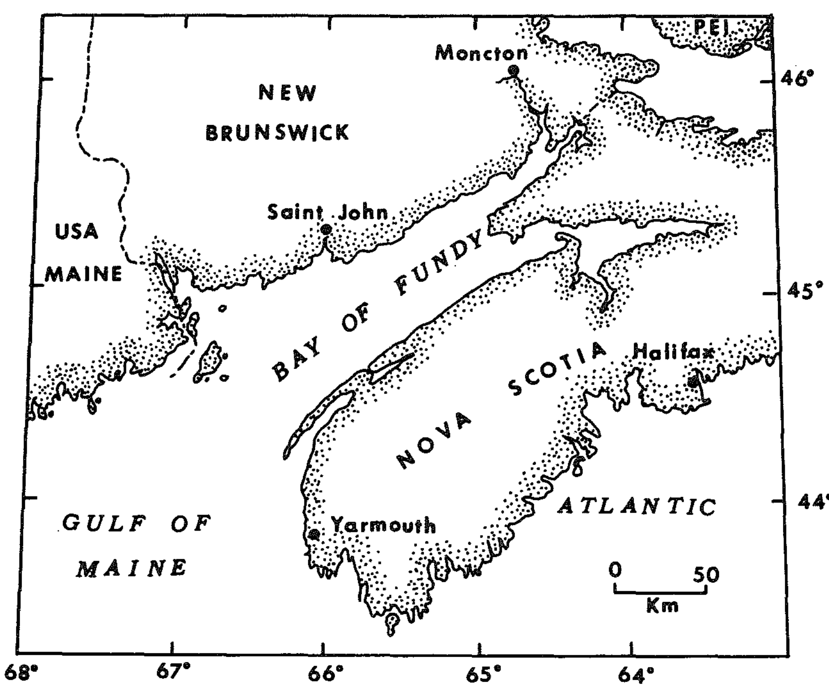
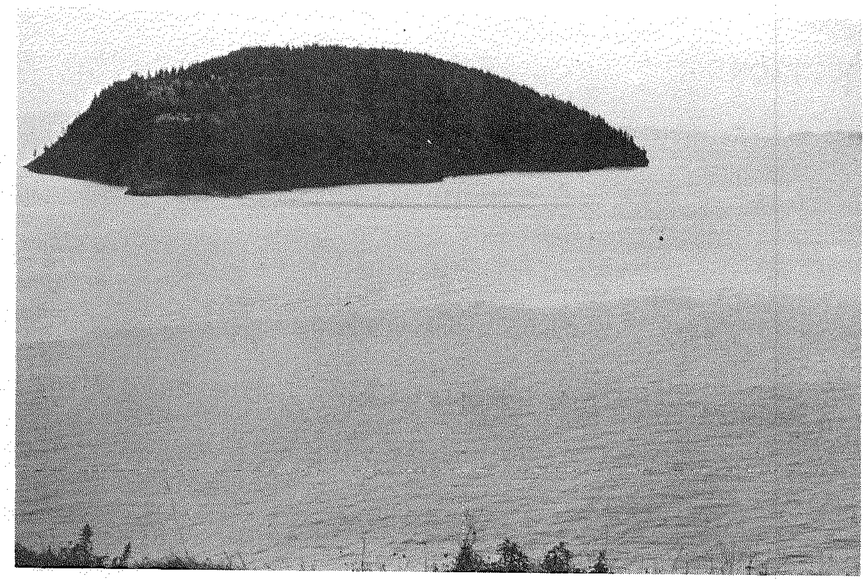


Figure 1. Location of the Bay of Fundy.



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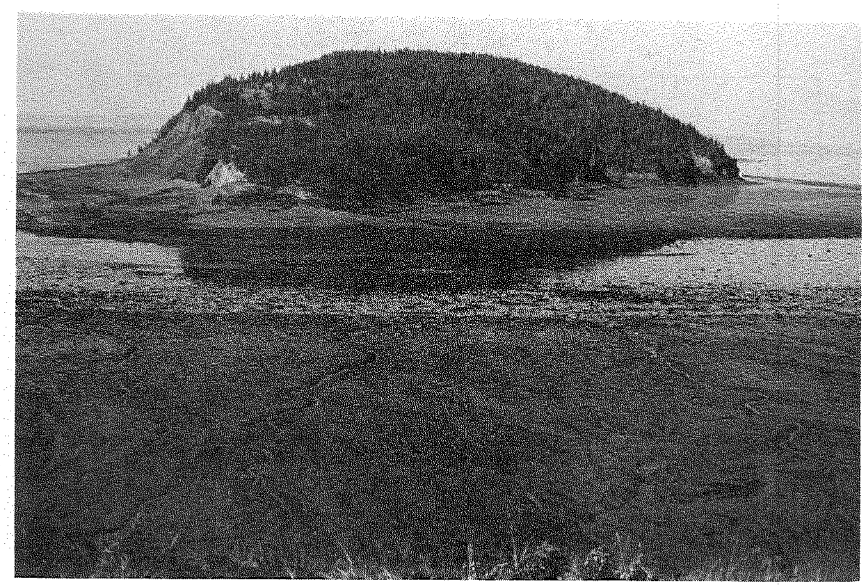

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Photo 1. Five Islands, Nova Scotia at high tide (upper photograph) and low tide (lower photograph). The mean tidal range at this location on the north shore of the Minas Basin is 11.6 m.

The Bay is sheltered from the Atlantic, so that wave energy levels are lower than on the outer coast of Nova Scotia or on the coast of Maine. A large proportion of the shoreline comprises rock outcrops, with wide mud or sand intertidal flats and extensive marshes in the upper reaches of the Bay (Chignecto Bay and Minas Basin).

2.2 WINDS

There is a distinct seasonal variability in the wind patterns of this region, although the dominant and prevailing winds are out of the westerly quadrant throughout the year. In summer, winds are generally out of the south-southwest while in winter months velocities are higher and the prevailing winds are out of the west-northwest (Fig. 2, Table 1).

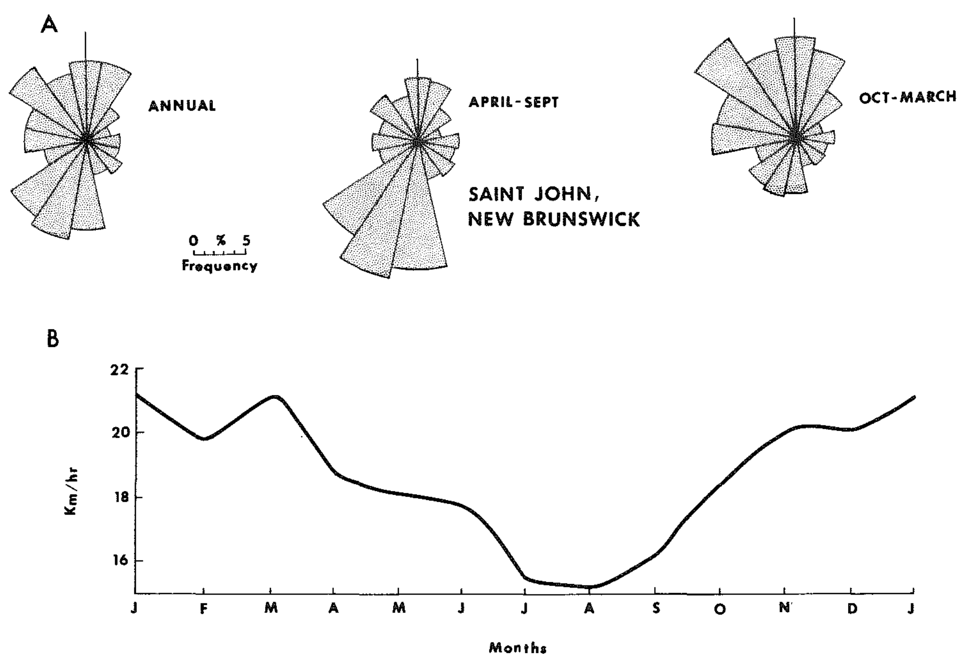


Figure 2. Wind direction (A) and velocities (B) for Saint John, N.B. (Source: Canada, Department of Transport, 1968).

TABLE 1. Meteorological Data - Bay of Fundy

a. Prevailing wind direction
b. Mean monthly wind velocity (km/hr)
c. Mean daily temperature (°C)

LOCATION		JAN.	FEB.	MARCH	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR
	a.	N	NW	NW	NNE	SSW	SSW	S	SSW	SSW	SSW	NW	NW	SSW
Saint John	b.	21.1	19.8	21.1	18.7	18.0	17.7	15.4	15.1	16.1	18.3	20.1	20.0	18.5
	c.	-12.4	-11.9	- 6.3	- 0.6	4.0	8.1	11.5	11.7	8.7	3.8	-0.9	- 8.8	0.6
	a.	WSW	WSW	WSW	WSW	SW	SW	SW	SW	WSW	WSW	WSW	WSW	WSW
Moncton	b.	22.7	21.6	22.5	20.9	20.0	19.3	17.2	17.4	18.3	19.6	20.6	21.2	20.1
	c.	-13.6	-13.6	- 8.1	- 2.0	3.2	8.3	11.8	10.7	6.4	1.7	- 2.3	-10.2	- 0.6
	a.	W	W	W	W	W	W	W	W	W	W	W	W	W
Truro	b.	16.7	15.6	16.9	15.8	15.0	13.2	11.6	12.4	12.1	14.0	14.8	15.6	14.5
	c.	-10.7	-11.3	- 7.0	- 2.0	2.6	7.2	11.3	10.6	6.3	2.1	- 1.1	- 7.8	0.0
	a.	WNW	WNW	WNW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WNW	WNW	WSW
Greenwood	b.	19.8	18.3	19.8	17.2	15.8	14.8	12.6	12.9	13.2	15.5	17.2	18.0	16.3
	c.	- 9.1	- 9.9	- 5.2	- 0.4	4.4	9.4	12.8	12.1	8.1	3.7	0.0	- 6.3	1.6

The local wind and weather patterns of the Bay of Fundy are directly related to the west to east passage of low-pressure systems across the region. These cyclonic storms are more frequent and more intense during the period October to April than in summer months.

2.3 WAVES

The importance of waves generated in the North Atlantic Ocean diminishes rapidly from west to east in the Bay of Fundy due to the narrow shape of the Bay. The entrance is exposed to the full force of North Atlantic swell and storm waves, but within the Bay itself and in the upper parts of the Bay, locally-generated wind waves are of greater importance. The Bay is oriented approximately east-west, and as this coincides with the prevailing wind direction, waves can be generated over relatively long fetches (q.v. Appendix p. 170). The intensity of wave activity at a given time on any particular section of coast varies considerably depending primarily on the shoreline orientation, fetch distances, wind velocity, and wind direction. In Minas Basin, for example, which is cut off from the main body of the Bay, fetch distances do not exceed 50 km and wave heights are rarely greater than 2 m (Knight and Dalrymple, 1976). For the main area of the Bay, Swift _et al_,(1973) state that wave heights are usually greater than 1 m for 50% of the time, but only greater than 4 m for 10% of the time. The most exposed sections of coast within the Bay, in terms of wave energy levels, are Salisbury Bay, Cape Chignecto, Advocate Bay and Scots Bay. These locations are west-facing coasts that are oriented perpendicular to the maximum fetch direction.

2.4 TIDES

Tides and tide-generated currents are the dominant littoral and nearshore processes in the Bay of Fundy. The mean tidal range is everywhere greater than 5 m, increasing eastwards from the entrance of the Bay to greater than 10 m in Chignecto Bay and Minas Basin (Fig. 3, Table 2). The tides

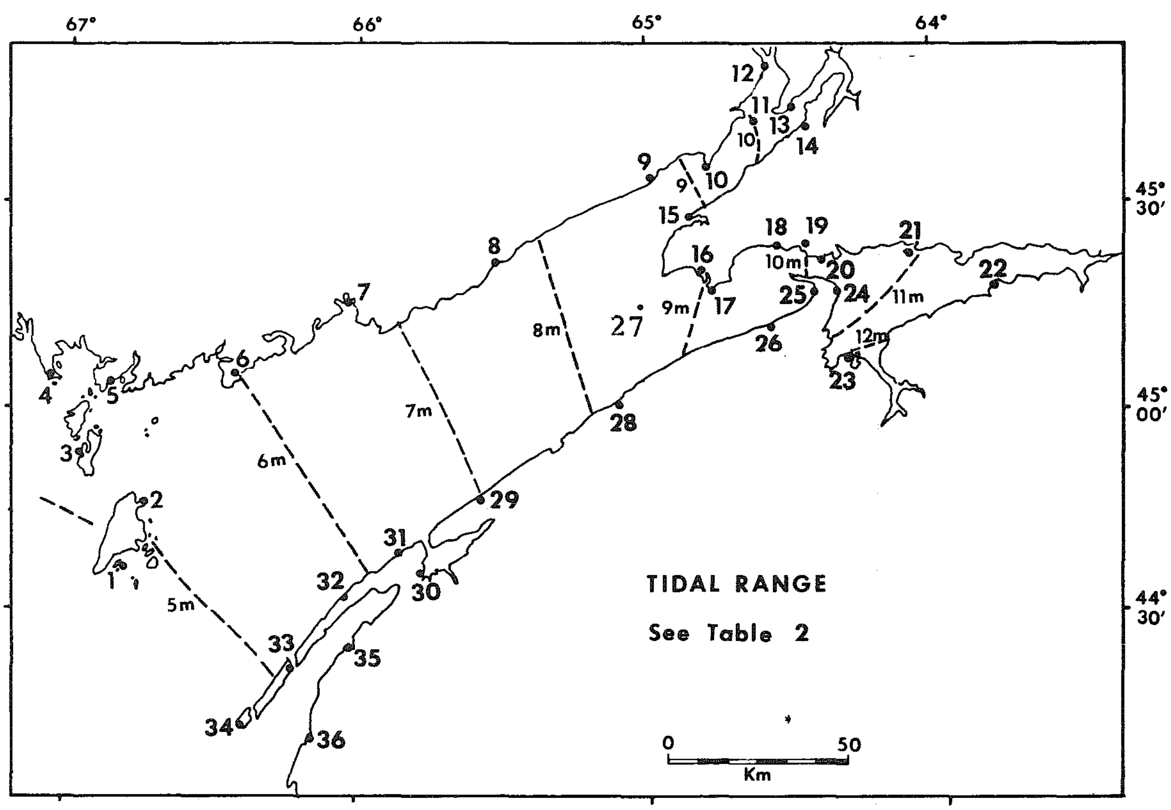


Figure 3. Tidal range in the Bay of Fundy. Locations referred to in Table 2 are indicated by the the numbers 1-36.

TABLE 2. Tidal Ranges in the Bay of Fundy

	LOCATION	MEAN TIDAL RANGE	LARGE TIDAL RANGE		LOCATION	MEAN TIDAL RANGE	LARGE TIDAL RANGE
1	Wood Island	4.4m	6.0m	19	Diligent R.	10.4m	14.2m
2	North Head	5.5	7.3	20	Cape Sharp	10.2	13.8
3	Welshpool	5.6	7.5	21	Five Islands	11.6	15.8
4	St. Andrews	6.0	8.3	22	Burncoat Head	11.9	16.0
5	Back Bay	5.5	7.8	23	Avonport	12.0	15.5
6	West Dipper	6.2	8.6	24	Cape Blomidon	10.7	14.4
7	Saint John	6.7	9.1	25	Scots Bay	9.9	13.5
8	St. Martins	8.0	11.2	26	Baxters Harbor	9.9	13.8
9	Herring Cove	8.8	11.9	27	Ile Haut	9.0	12.8
10	Cape Enragé	9.5	13.2	28	Margaretsville	8.4	11.5
11	Grindstone Is.	10.2	14.2	29	Parkers Cove	7.1	9.8
12	Hopewell Cape	10.7	14.7	30	Digby	6.8	9.3
13	Pecks Point	10.2	14.4	31	Deep Cove	6.4	8.7
14	Joggins	10.3	13.7	32	Centreville	5.8	8.2
15	Cape Capstan	8.9	12.0	33	Tiverton	5.2	7.2
16	West Advocate	8.8	12.2	34	Lighthouse Cove	4.8	6.5
17	Cape d'Or	9.3	12.8	35	Weymouth	4.7	6.6
18	Port Greville	9.9	13.3	36	Meteghan	4.5	6.2

(Source: Canadian Hydrographic Service, 1975) are semi-diurnal and there are considerable differences (up to 3 m) in the height of the tides and the tidal range between the spring and neap phases (Fig. 4). Due to the large volume

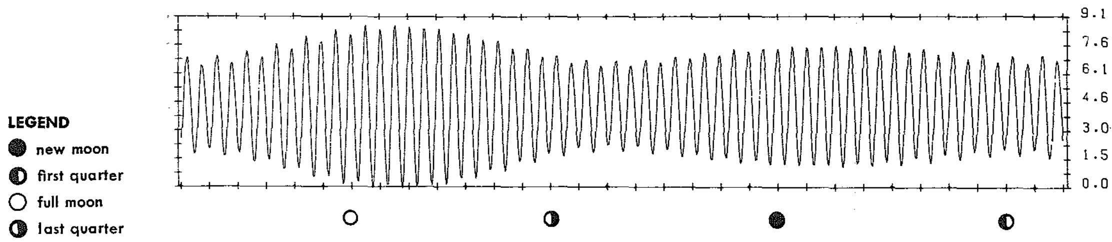


Figure 4. Typical tidal curve for Saint John, N.B. for one month (from Canadian Hydrographic Service, 1975).

of water entering and leaving the Bay with each 13-hour tidal cycle, currents are in the order of 0.75 m/s to 1.0 m/s, with maximum velocities >5 m/s in Minas Passage. The tidal currents are generally parallel to the axis at the Bay and the residual currents indicate a counter-clockwise pattern (Swift et al, 1973) (Fig. 5). In the intertidal zone, current velocities range from 0 to 1.5 m/s (Knight and Dalrymple, 1976).

One important aspect of the large tidal range is that wave energy is dissipated over a considerable vertical height. This means that rarely is wave energy concentrated at one particular height or location on a beach.

2.5 ICE

Ice plays an important role in coastal processes from December through to early April when air temperatures are below freezing (Fig. 6, Table 1). Ice forms on the beaches and in the intertidal zone as shorefast ice or on the water surface

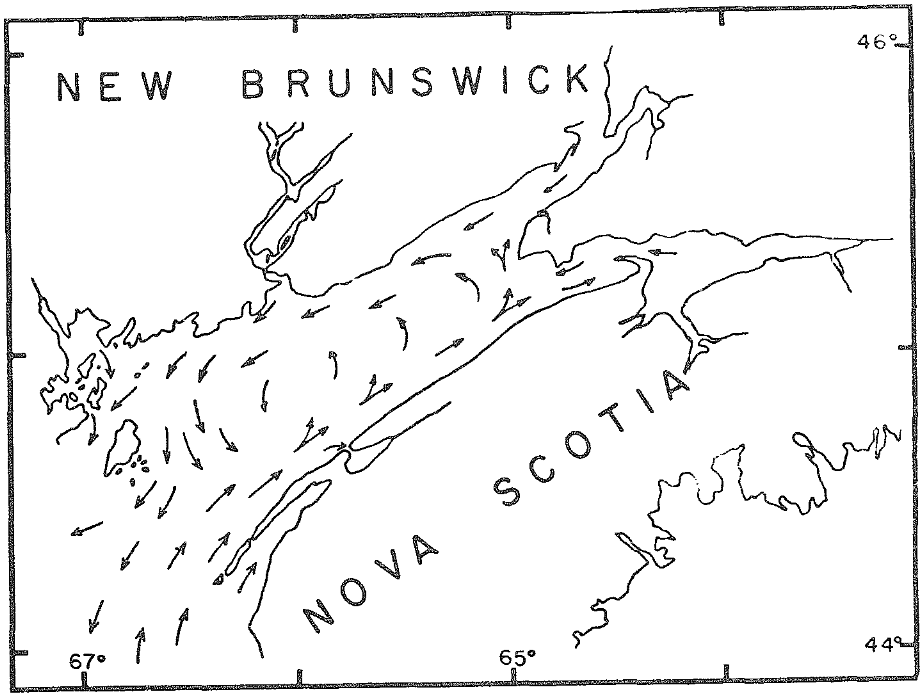


Figure 5. Residual tidal currents in the Bay of Fundy (from Pelletier, 1974).

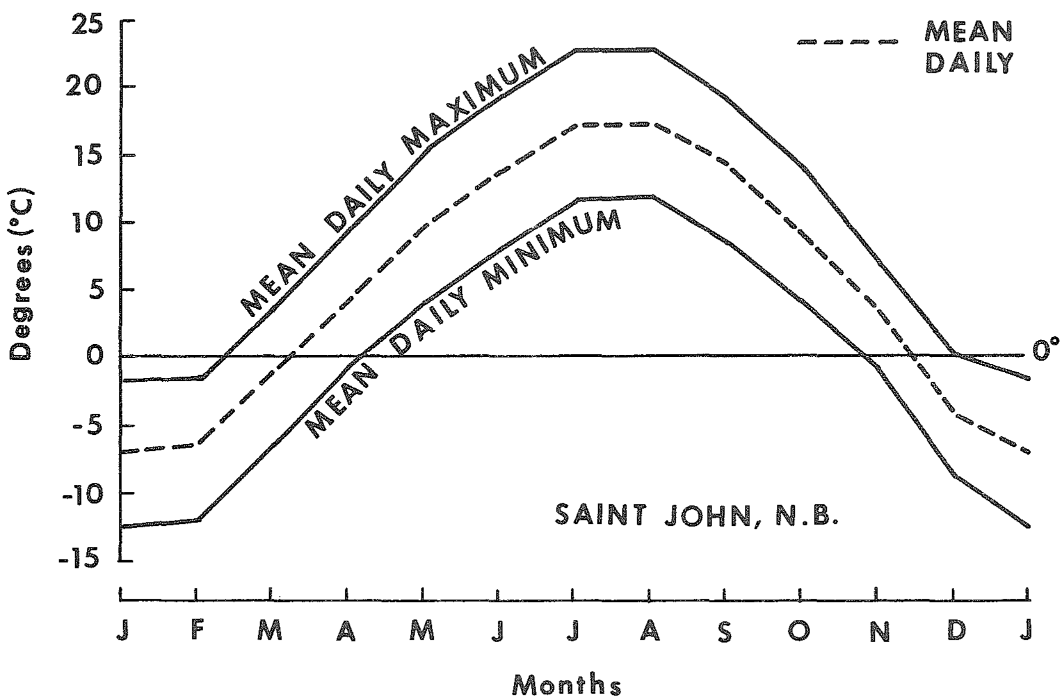


Figure 6. Mean monthly air temperature data for Saint John, N.B.

as drifting ice floes. Ice is important in (1) limiting wave generation, (2) dampening existing waves, and (3) protecting the beach/nearshore zone from wave activity, thereby preventing any redistribution or longshore transport of sediments. Ice foot features vary in size from 1 or 2 m high on gently sloping beaches, to heights of 9 m on steep rocky coasts (Knight and Dalrymple, 1976). The pack ice cover is always broken, due to the effects of wind action and the strong tidal currents.

2.6 GEOLOGY

The Bay of Fundy is located in part of the Appalachian region, an area of deformed sedimentary and volcanic rocks (Fig. 7). These rocks range from very resistant basalts to

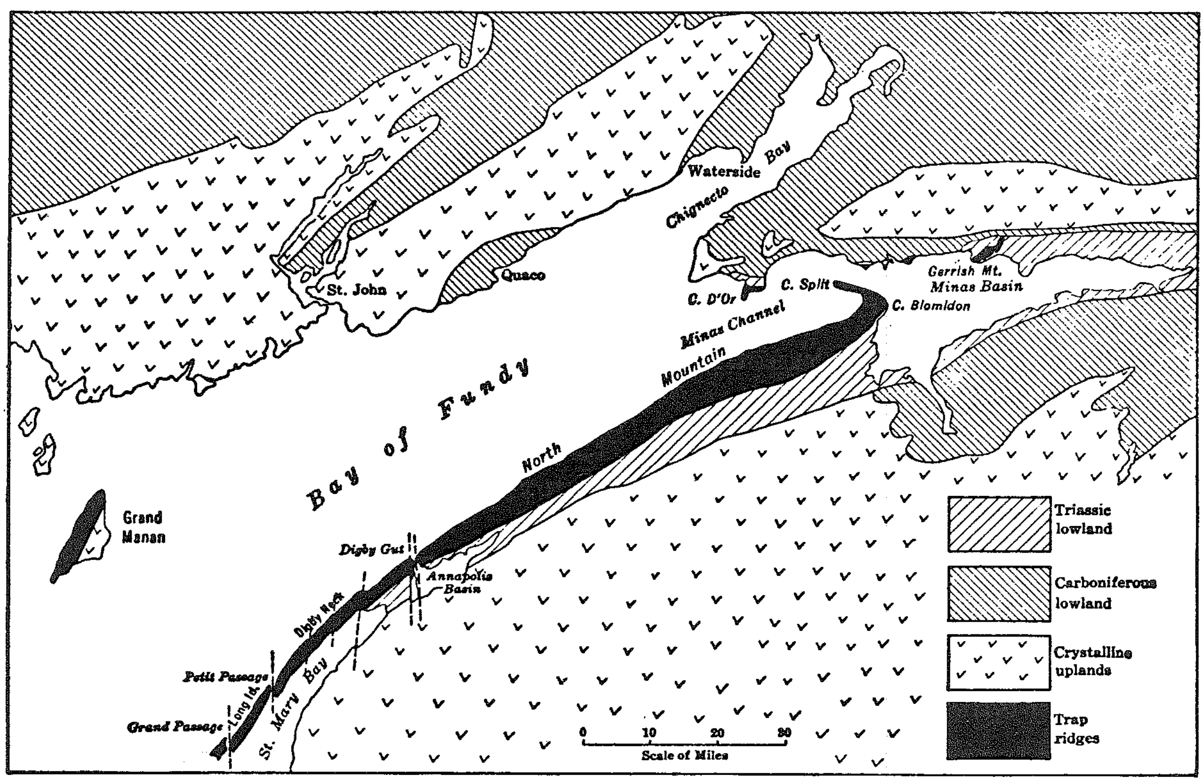


Figure 7. Geology of the Bay of Fundy region (from Johnson, 1925).

unresistant sandstones and shales. Glacial erosion of the area caused a smoothing of the topography and sand and sand-pebble-boulder material was deposited in certain areas. Where these unconsolidated glacial deposits are present along the coast, erosion rates can reach up to 2 m/year (Churchill, 1924).

The funnel shape of the Bay of Fundy is a result of fluvial and glacial erosion along the southwest-northeast structural trends of the region. This is particularly evident along the south coast of the Bay from Brier Island to Cape Split where resistant volcanic rocks were intruded along a structural weakness. In the upper Bay two embayments have been formed where the resistant upland area of the Cobequid Hills separates Chignecto Bay from the Minas Basin.

There is a great variety in local relief throughout this region as a result of the effects of glacial and fluvial erosion and the differing resistances of the rock outcrops. Some coasts are very low with farmland adjacent to the beaches. Other areas are characterized by vertical cliffs up to 200 m in height. Maximum relief in the coastal zone is in the order of 300 m.

PART 3 - COASTAL ENVIRONMENTS

3.1 INTRODUCTION

The coastline is subdivided into 6 units (Fig. 8, Table 3), based on variations in shoreline type that are controlled by the local geology and by littoral processes. Although considerable variation of shoreline types may occur within each environment, there is sufficient homogeneity of the processes and form at the regional scale to define these distinct environments.

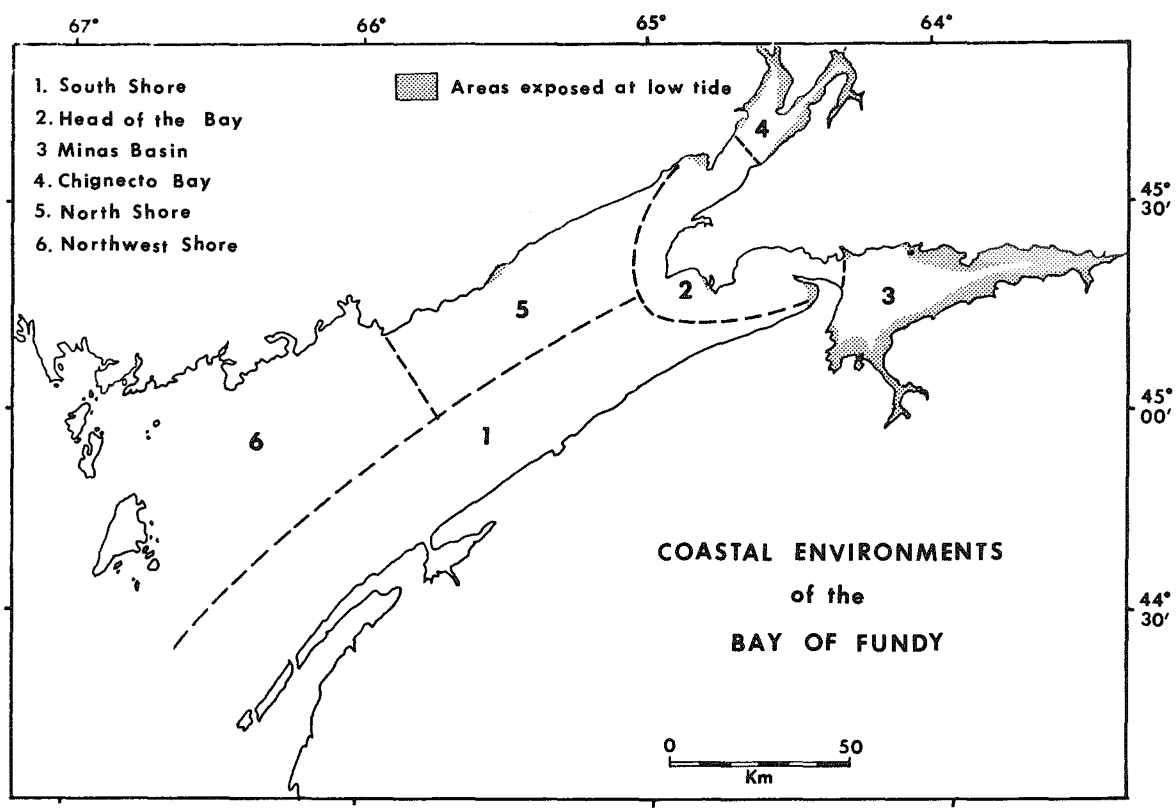


Figure 8. Subdivision of the Bay of Fundy into six coastal environments (see Table 3).

TABLE 3. Characteristics of the Coastal Environments of the Bay of Fundy (see Fig. 8)

	SUBDIVISION	GEOLOGICAL CHARACTER	BACKSHORE RELIEF	BEACH CHARACTER	FETCH AND WAVE EXPOSURE	MEAN TIDAL RANGE	SEDIMENT AVAILABILITY
1.	SOUTH SHORE	resistant basalt dyke parallels coast	low rocky coast or cliffs up to 30m	absent or narrow cobble beach at high water mark, with wide intertidal platform	sheltered (50 km)	6 - 10m	very sparse
2.	HEAD OF THE BAY	resistant rocks; basalts or granites	cliffed coast, up to 200m	absent or large pocket beaches of peb/cob on beachface and mud overlying coarse seds in intertidal zone	exposed (50-100 km)	10m	sparse, but locally abundant
3.	MINAS BASIN	sandstone and shales, or unconsolidated glacial deposits	cliffs, up to 30m	wide intertidal mud or sand flats on rock platform, peb/cob beach at h.w.m.; marshes in sheltered areas	very sheltered (<50 km)	>10m	abundant
4.	CHIGNECTO BAY	sandstones and shales	cliffs, up to 20m	wide intertidal mud flats on rock platform, peb/cob beach at h.w.m.; extensive marshes in sheltered areas	very sheltered (<50 km)	>10m	abundant
5.	NORTH SHORE	resistant rocks, sedimentary rocks and intrusives, thin till cover	cliffs (west, 5-60m; east, >100m)	absent or coarse-grained pocket beaches	sheltered (<50 km)	6 - 10m	very sparse
6.	NORTHWEST SHORE	resistant rocks, thin till cover	low rocky coast or cliffs, 5-30m	absent or coarse-grained and narrow	outer coast exposed, rest sheltered (<50 km)	6m	sparse

Contingency planning for oil spill clean-up requires information on the variability of coastal environments and shoreline types so that the basic response plan can be adapted to suit each different locality where necessary. This discussion of the major coastal environments and the following one on shoreline types (Part 4) provides a comprehensive assessment of the coastal zone of the Bay of Fundy at both the regional and local scales.

3.2 SOUTH SHORE

This unit is a straight, rocky coast that follows the exposure of a southwest-northeast trending resistant basalt dyke or trap (q.v.). The western section of the dyke is a thin peninsula that has been segmented by north-south faults, with Brier Island and Long Island slightly offset to the north (Fig. 7). The peninsula results from erosion of sedimentary rocks that outcrop immediately north and south of the dyke. The erosion of the unresistant rocks that outcrop in the Annapolis Valley, between the dyke and the resistant rocks to the south, has resulted in the formation of St. Mary's Bay and the Annapolis Basin. The region was glaciated by ice that moved across the region to the southeast. Glacial deposits exposed along the coast are predominantly reddish-brown stoney tills (q.v.).

Mean tidal range of the semi-diurnal tides increases from 4.7 m on Brier Island at the entrance of the Bay to 9.9 m at Baxters Harbour at the eastern limit of this unit (with spring tidal ranges of 6.5 m and 13.7 m respectively). Strong tidal currents (2 to 3 m/s occur between Long Island and Brier Island, between Digby Neck and Long Island, and in Digby Gut). The importance of waves generated in the Atlantic decreases to the east but, as the prevailing winds are out of the westerly quadrant (Fig. 2, Table 1), this coast is exposed to locally-generated waves throughout the year. Swift et al, (1973) indicate that in the Bay wave heights are >3.6 m in summer and >4.0 m in winter for 10% of the time. The major limiting factor on the effectiveness of wave action in the littoral zone is the large vertical range over which the wave energy is dissipated. Sea ice is present from January to April, but the Bay is never frozen over and in some years, little ice forms at all, so that wave action is not severely limited during winter months. Beach-fast ice or an ice foot may develop but may not be present throughout the winter, freezing and thawing periodically.

The coastal geomorphology of the shore west of Digby Gut is characterized by a low rocky coast. Occasional pocket beaches have acted as sediment traps and have small well-developed beaches of medium- and coarse-grained material, but otherwise the coast is largely devoid of sediments. East of Digby

Gut a wide rocky intertidal platform is backed by vertical cliffs up to 30 m in height (Photo 2). The upper intertidal zone has a discontinuous cover of coarse sediments (pebble-cobble-boulder).

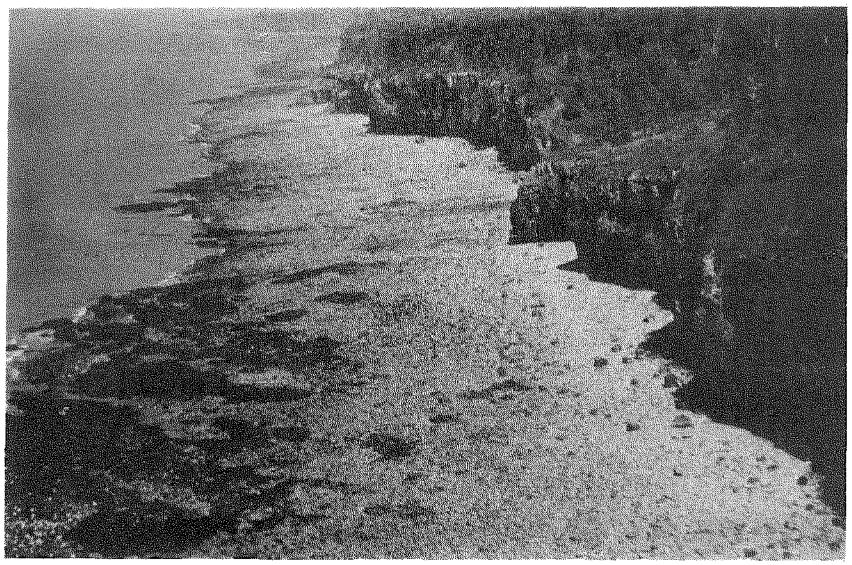


Photo 2. Cliffed coast east of Digby Gut on the south shore. The cliffs are cut into resistant Triassic basalt, the wide (approx. 150 m) intertidal wave-cut platform is partially covered by pebble-cobble sediments. Photograph at low tide.

Sediment transport directions are primarily to the north-east as waves approach predominantly out of the westerly quadrant. This is a straight rocky coast and no marshes or dunes are present on the open coast. However, in the sheltered Annapolis Basin, extensive marsh development has occurred in this area of wide intertidal sand and mud deposits. On the open coast where there is no sediment cover the intertidal rock platforms are covered with seaweeds, primarily *Fucoids* and *Laminaria*.

3.3 HEAD OF THE BAY

This section of coast is considered a distinct unit on the basis of its exposed location with respect to waves generated along the axis of the Bay. Although primarily a coast of high resistant cliffs, this upland coast is also characterized by three large southwest-facing embayments (Fig. 9). In the

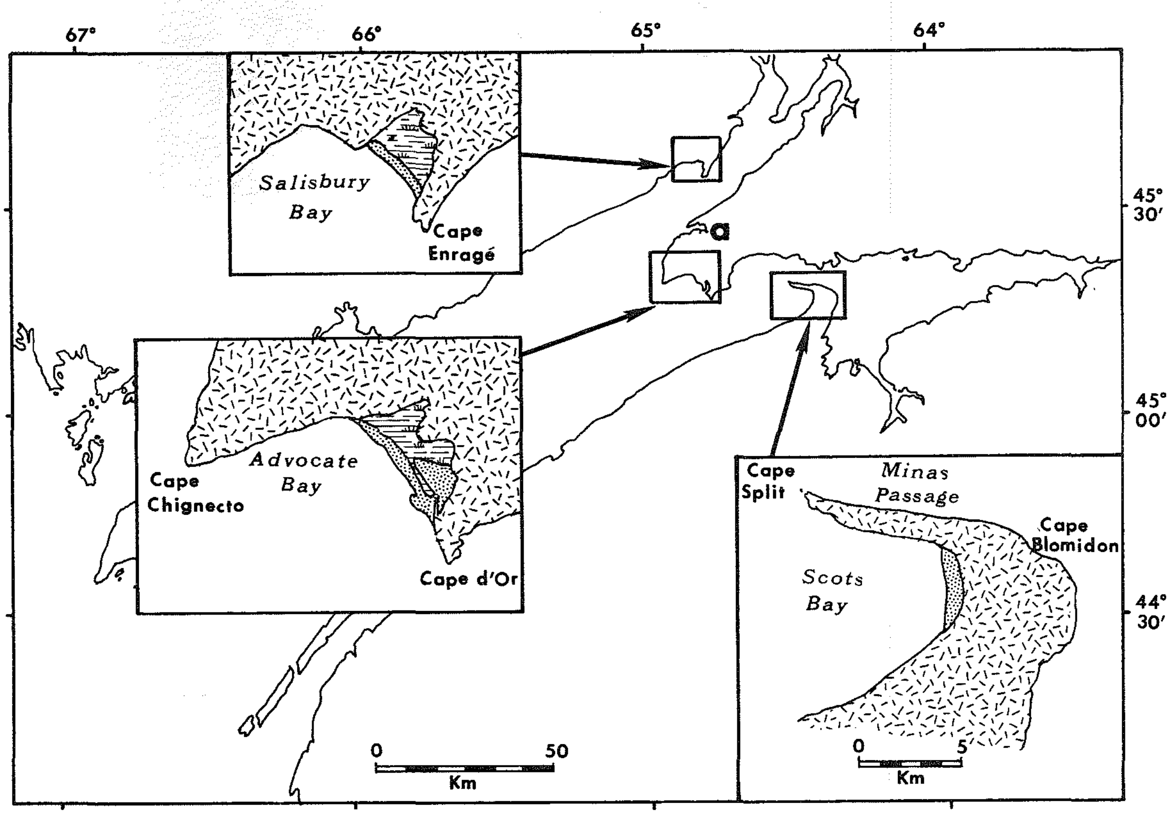


Figure 9. Details of the three large embayments in the Head of the Bay. Beaches are indicated by the dot pattern. The Apple River-Cape Capstan embayment is located by **a**.

southeast part of this unit the curved shape of the Cape Blomidon-Cape Split headland is a result of the exposure of the eastern end of the basalt dyke (Fig. 7). In the central area that separates Minas Basin and Minas Channel from Chignecto Bay (the Cobequid Uplands),a zone of metamorphic and igneous rocks gives way north to unresistant sedimentary rocks. The western extremity of this upland area is the resistant granite outcrop of Cape Chignecto (Fig. 7). Southeast of Cape Chignecto an extension of the Cape Split dyke forms a major headland at Cap d'Or. Between these two resistant headlands, sedimentary rocks have been eroded to form the large embayment of Advocate Harbour. In the northern section of this unit, the generally straight coast is interrupted by a major headland at Cape Enragé that is an outcrop of resistant, vertically-dipping conglomerates. Erosion along a northeast-southwest trending fault has produced the large embayment of Salisbury Bay by offsetting Cape Enragé from the otherwise straight coast. A fourth smaller embayment at Cape Capstan has resulted from erosion by the Apple River along a structural weakness. As a result of either structural control or the nature and location of resistant outcrops, these large southwest-facing embayments have developed at the head of the Bay of Fundy.

In each case, these embayments are bounded by headlands or coasts of high cliffs and rocky intertidal platforms and act as large sediment traps for any material that is supplied to the littoral zone either by local erosion or by longshore transport. The Scots Bay-Cape Split embayment traps sediment that is moved to the northeast along the straight South Shore unit. Material is supplied to the Advocate Harbour embayment by erosion and reworking of the local sedimentary rocks and glaciofluvial or fluviomarine sediments. The Cape Capstan embayment traps sediment that is moved along the south shore of Chignecto Bay and a mid-bay bar constricts the mouth of the Apple River. In the Salisbury Bay-Cape Enragé embayment sediments have accumulated by the trapping of material transported alongshore to the northeast and by the erosion of local unresistant sedimentary rocks.

Relief in the area is generally high with maximum cliff heights of 80 m at Cape Split, 180 m at Cape Blomidon, 150 m at Cap d'Or, 210 m at Cape Chignecto and 35 m at Cape Enragé.

Mean and spring tidal ranges in this unit vary between 8.8 and 12.2 m at West Advocate, 9.5 and 13.2 m at Cape Enragé, and 10.7 and 14.4 m at Cape Blomidon (Fig. 3). Currents generated by the semi-diurnal tides are strong in the offshore zone (>1 m/s) with little decrease in velocity with depth. Currents reach velocities in excess of 5 m/s in the Minas Passage area (Cameron, 1961). Prevailing and dominant winds are out of the westerly quadrant, coinciding with the direction of maximum fetch, that is, along the axis of the Bay, so that the shoreline in this unit is exposed to the highest levels of wave energy in the Bay. As in all macro-tidal environments, however, this energy is expended over a wide vertical range.

The coastal geomorphology of this unit is characterized by high (>20 m) resistant cliffs, with occasional wide intertidal rock platforms or small pocket beaches (Photos 3 and 4). Large embayments (Salisbury Bay, the Apple River estuary, Advocate Harbour and Scots Bay) are sediment traps exposed to maximum fetch directions and have well-developed beaches with wide (1-2 km), mud low-tide terraces and steep pebble-cobble beach faces that are backed by storm ridges and by marshes (Fig. 10). Coarse-grained beaches occur at the base of the cliffs where talus deposits are reworked by littoral processes.

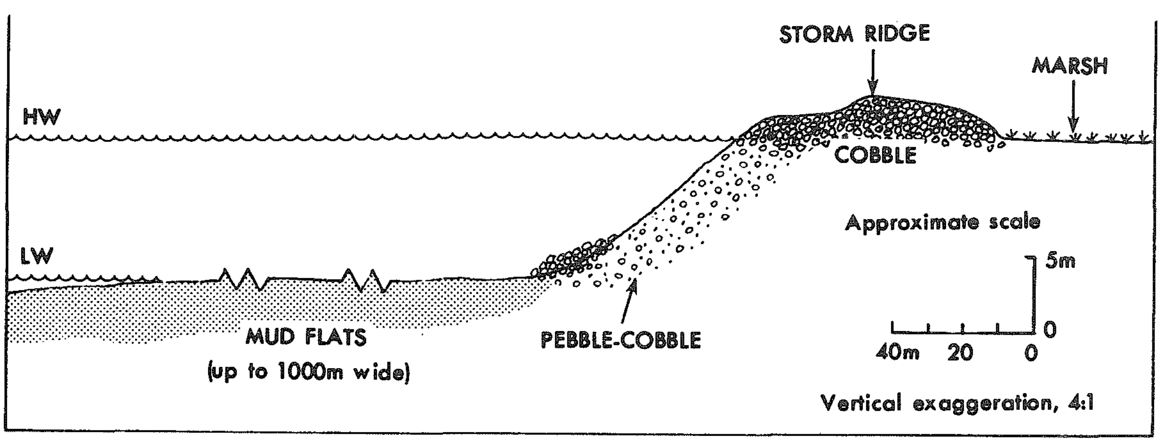


Figure 10. Idealized morphology and distribution of sediments on a profile across an exposed, large pocket beach. (c.f. Photo 22, p.58).

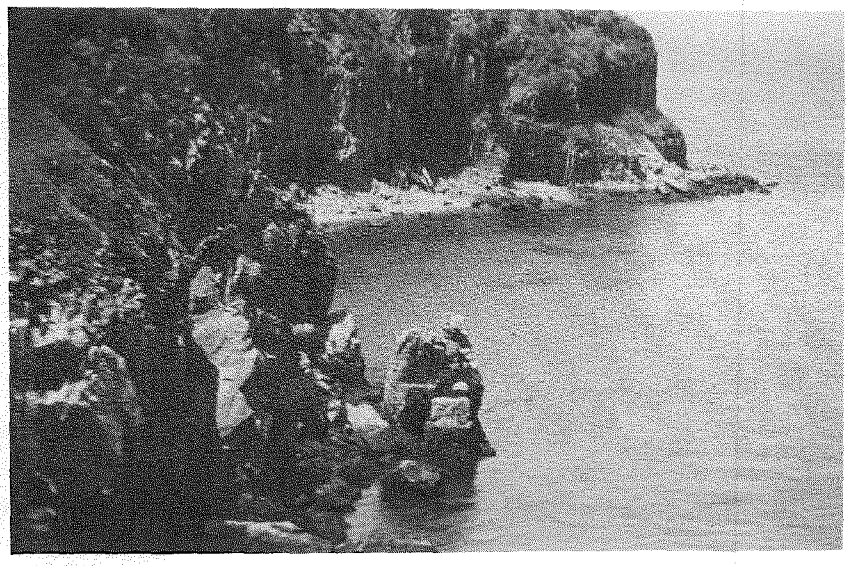


Photo 3. Cliffed coast near Cap d'Or. The basalt cliffs are approximately 50 m high and are interrupted by occasional pockets.

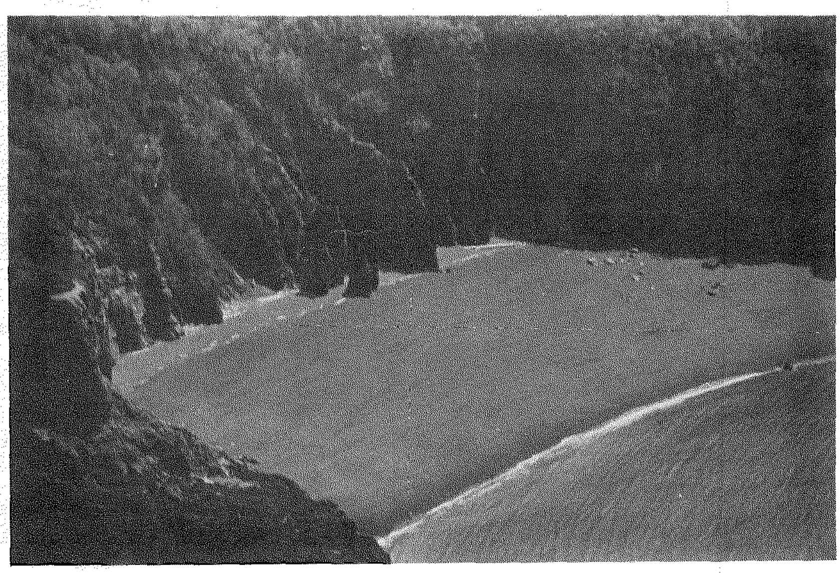


Photo 4. Pocket beach northeast of Cape Chignecto. The pebble-cobble beach is approximately 60 m wide at low tide and is bounded on both sides by high resistant cliffs.

3.4 MINAS BASIN

Minas Basin is an extension of the Bay of Fundy that trends east-west due to erosion along the Cobequid Fault that defines the north shore of the Basin. The rocks that outcrop around the Basin are unresistant red or grey sedimentary rocks. A few small outcrops of basalt occur in the Five Islands area along the north shore. The bedrock is overlain by glacial and fluvioglacial deposits, usually <10 m thick, that occur mainly in bedrock lows along the shore (Swift and Borns, 1967). Where the unresistant rocks or glacial deposits are exposed along the shore, erosion rates up to 2-3 m/year have been reported (Churchill, 1924).

Sediment in the Minas Basin is derived largely from coastal erosion of the unresistant sedimentary rocks and the glacial deposits (Dalrymple _et al_, 1975). Major intertidal sand bodies occur along the south and northeast margins of the Basin. Two major bodies in the south and east are located at the Avon River and at the head of Cobequid Bay (Swift and McMullen, 1968). On the north shore two large sand bodies are located in the areas of Economy Point and Five Islands (Photo 1b) (Klein, 1970). These sand bodies rest on till and/or bedrock, are up to 25 m thick and are often exposed in the intertidal zone (Dalrymple _et al_, 1975).

Tidal range in the Minas Basin reaches a maximum in the vicinity of Burncoat Head, where the mean and large ranges are given as 11.9 and 16.3 m respectively (Canadian Hydrographic Service, 1975). Everywhere within the Basin the mean tidal range of the semi-diurnal tides is greater than 10 m. This leads to the generation of strong intertidal currents that reach velocities in the order of 2 m/s (Knight and Dalrymple, 1976). The Basin is oriented east-west so that the maximum fetch direction coincides with the prevailing and dominant winds out of the westerly quadrant. Wave heights in summer are usually in the order of 0.5 to 1 m, with occasional storm waves reaching 2 m in height (Knight and Dalrymple, 1976). Littoral processes are dominated by tide-generated currents.

Ice plays an important role in limiting tidal and wave action from late December to early April. Although the sea ice does not form a solid sheet the ice cover is 70 to 90% (Knight and Dalrymple, 1976). On the coast an ice-foot develops that is 1-2 m high and 10-30 m wide on gently-sloping intertidal zones but can reach 9 m in height on steeply-sloping bedrock coasts (Knight and Dalrymple, 1976). Considerable quantities of sediment are redistributed by ice-rafting as broken sea-ice grounds and is refloated by the semi-diurnal tides.

The coastal geomorphology of this unit is characterized by large intertidal sand or mud deposits. The characteristic sequence (Fig. 11a) has a pebble-cobble beach near the high water mark that gives way seaward to a gravel lag deposit that

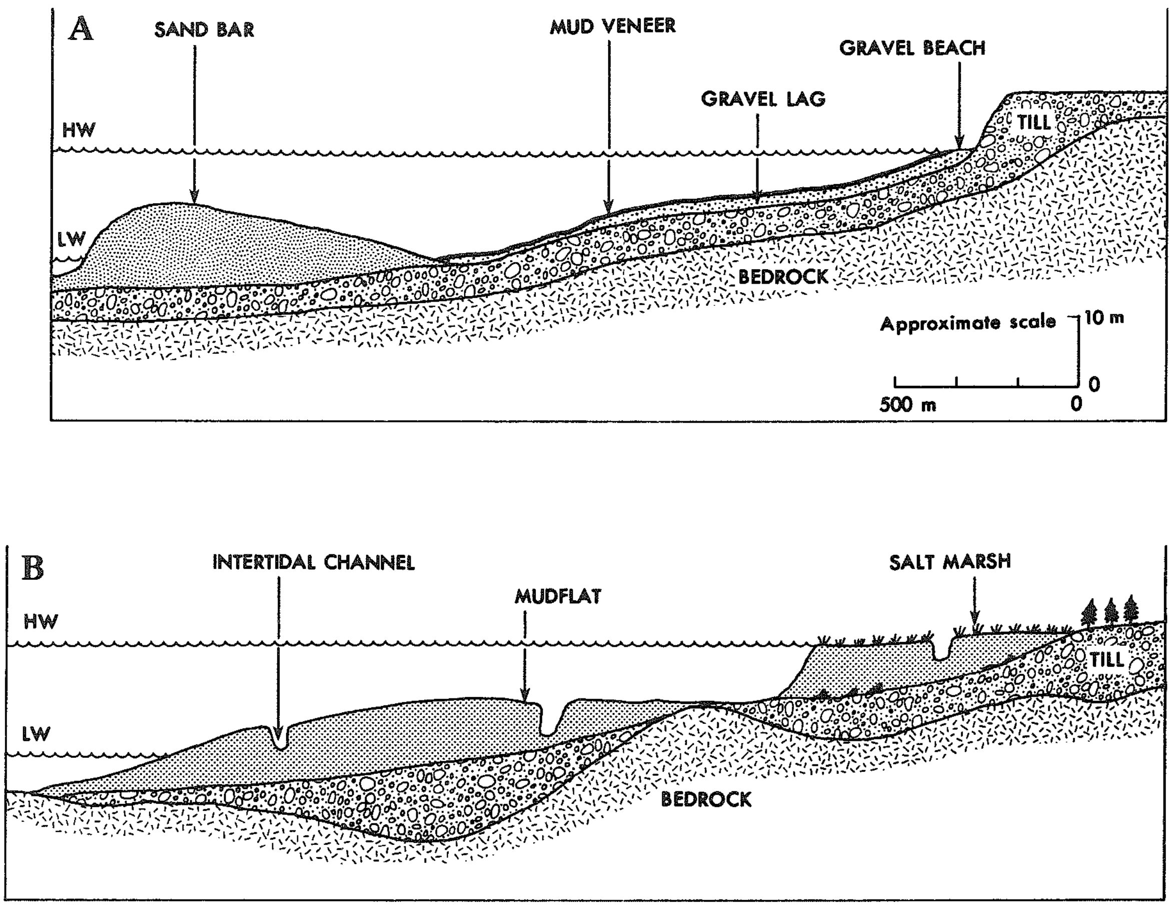


Figure 11. Idealized profiles across two of the major shoreline types that occur in the Minas Basin.

(A) Intertidal sand flats with a gravel beach at the high-water mark backed by an unresistant till cliff,

(B) Intertidal mudflats that give way to salt marshes above the high-water mark.

(Adapted from (A) Dalrymple et al, 1975 and (B) Swift et al, 1973).

has a thin (15 cm) mud veneer. This in turn is replaced by a large sand deposit, up to 5 km wide, in the middle and lower intertidal zone (Dalrymple et al, 1975). The sand flats are characterized by surface sand waves and megaripples that are formed by the high-velocity tidal currents. Towards the east and in areas sheltered from the strong tidal currents (bays and estuaries) the intertidal sand is replaced by mudflats (Fig. 11b), as fine-grained sediments are deposited by a decrease in tidal current velocities. The backshore is either bedrock cliffs, that can reach 30 m in height, Pleistocene deposits, or salt marsh. The marshes are particularly extensive in the eastern section of Cobequid Bay and are incised by deep creeks that have little or no vegetation on their banks. The cliffed sections of this coast usually have a beach of reworked talus deposits with sediments in the sand to boulder-size range.

3.5 CHIGNECTO BAY

Erosion along southwest-northeast structural trends has produced this northern arm of the inner Bay of Fundy. The bedrock is unresistant sedimentary rocks that form cliffs up to 20 m high along the coast. Following deglaciation the area was inundated by the sea so that at the head of Cumberland Basin a strait linked the southern Gulf of St. Lawrence with the Bay of Fundy in an area which is largely marsh deposits today. Erosion of coastal outcrops of glacial deposits and the unresistant sedimentary rocks provides sediment directly to the littoral zone for reworking and redistribution. The intertidal sediments in this unit are mainly muds, as compared to the large volumes of sand on the exposed intertidal flats of the Minas Basin. Beaches of coarse sediments (pebble-cobble-boulder) occur in the upper part of the intertidal zone.

The semi-diurnal tides are everywhere greater than 10 m and reach a maximum at the heads of Shepody Bay and Cumberland Basin with mean ranges of 11.8 m and large ranges of 14.5 m (Canadian Hydrographic Service, 1975). This is a sheltered wave environment except for waves generated locally by winds out of the southwest, which is the maximum fetch direction. As in the Minas Basin, wave heights are rarely greater than 2 m and the available wave energy is dissipated over a considerable vertical range, so that littoral processes are dominated by the effects of the tides. Sea and beach-fast ice are present from December to early April. The sea-ice cover is less than in the Minas Basin, as Chignecto Bay is more open and ice floes are moved easily into the main body of the Bay of Fundy by the ebbing tide and by winds out of the northeast. Ice plays an important role in redistributing sediments and vegetation by rafting during winter months, particularly in the upper part of the Bay.

The coastal geomorphology of this unit is characterized by wide (up to 2 km) intertidal rock platforms, backed by unresistant cliffs. The platforms are covered by extensive mud deposits dissected by tidal channels (Photo 5) that, in sheltered areas, give way to extensive marshes. The marsh sediments are red inorganic muds that contain little or no riverborne material but result from deposition during spring tides and storm surges (Ganong, 1903). The marshes are not flooded by ordinary tides and Ganong describes them as the "flood plains of tidal rivers". The most extensive marshes are at the head of Cumberland Basin (Tantramar-Aulac; Missaquash; and La Planche). Other large marshes are in Shepody Bay (Memramcook River, Petitcodiac River and Shepody River). Most of the marshes have been dyked during historical times so that only some 4,000 hectares remain in their natural condition.

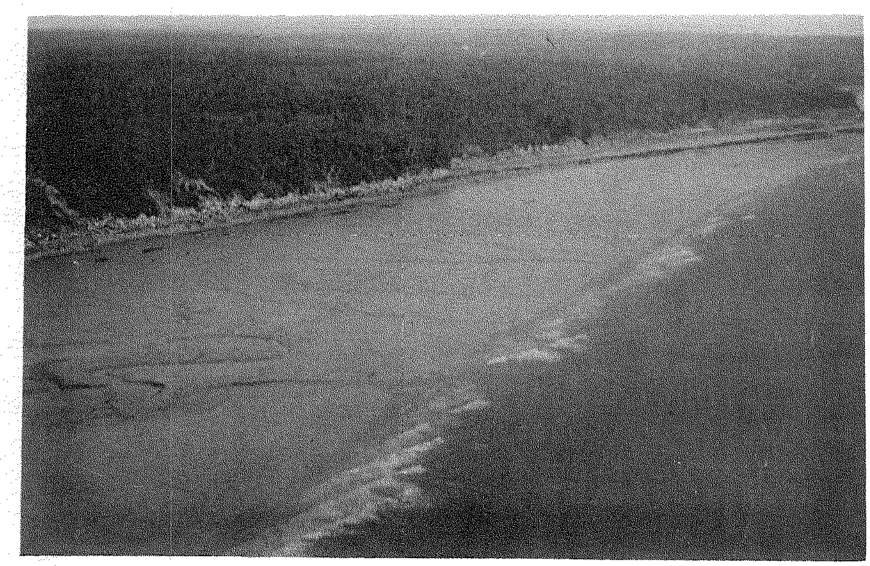


Photo 5. Wide mud flats exposed at low tide on the north shore of Cumberland Basin. The flat intertidal zone is dissected by tidal creeks and gives way landward to a pebble-cobble beach.

3.6 NORTH SHORE

This straight section along the north-central coast is a fault-line scarp shoreline (Johnson, 1925) between crystalline rocks to the north, and the unresistant, sedimentary rocks that underlay the offshore area. Structural trends throughout the region are northeast-southwest (Hayes and Howell, 1937). Mean tidal range increases from 6.7 m at Saint John to 9.0 m near Salisbury Bay (Fig. 3), with spring tidal ranges increasing from 9.1 m to 11.9 m. The coast is exposed to winds and locally-generated waves out of the south and southwest, but wave heights rarely exceed 4 m. Ice is present in the littoral zone and on the adjacent nearshore areas during winter months, but the beach-fast ice may thaw and refreeze periodically.

The coastal geomorphology of the straight resistant upland coast east of Quaco Head is characterized by cliffs over 100 m in height (see frontispiece). The homogeneity of this section is occasionally interrupted by indentations where littoral processes or rivers have eroded along secondary faults. In these indentations small pocket beaches have accumulated. West of Quaco Head, sedimentary and intrusive rocks have been eroded to form a crenulate shoreline with cliffs varying in height from 15 to 60 m.

The character of the coast is determined primarily by the geologic and physiographic parameters, little sediment is available for reworking and redistribution and the only major accumulations are at the Alma River, Martin Head and in Quaco Bay. Elsewhere the narrow, high-tide beaches are of coarse-grained sediments (pebble-cobble-boulder).

3.7 NORTHWEST SHORE

The drowning of this lowlying region has produced a complex shoreline of bays, inlets and islands. The rocks are resistant and small outcrops of basalt occur on north Grand Manan and at Point Lepreau. Structural trends are southwest to northeast and this has a noticeable influence on local shoreline configuration. The west and southeast shores of Grand Manan are fault-line coasts. Cliffs on the west-facing coasts of Grand Manan reach 60 m in height, but elsewhere in this unit cliff heights rarely exceed 15 m. Surficial sediments on land are usually thin (<10 m) but occasional thick deposits occur locally, for example, at Point Lepreau. Littoral sediments are generally scarce, as little material is supplied to the coast from erosion of the resistant cliffs or of the scarce coastal outcrops of glacial sediments.

The outer coasts are exposed to waves entering the Bay of Fundy from the Gulf of Maine. However, due to the complex shoreline, much of this unit is characterized by sheltered low-energy wave environments. Tidal ranges are in the order of 5 to 7 m (Fig. 3), so that even on the exposed coasts this is still a tide-dominated, macro-tidal environment. Residual tidal currents parallel the coast from northeast to the southwest

(Fig. 5), following the main direction of the ebb currents (Swift et al, 1973). Tidal currents are particularly strong in Grand Manan Channel (up to 2 m/s) (Canadian Hydrographic Service, 1975) and at the entrance to Passamaquoddy Bay (>1 m/s) (Pelletier, 1974). In winter months, sea-ice develops and is present in the bays and inlets for up to 4 months each year.

The coastal geomorphology of the eastern half of this unit is characterized by an indented coast with the sheltered embayments of Saint John's Harbour, Lorneville Harbour, Musquash Harbour and Maces Bay separated by the exposed, low, resistant headlands (up to 30 m in height) of Lorneville, Seely Point and Point Lepreau (Photo 6). Sediment accumulates in the embayments to give wide mudflats in the intertidal zone that have a pebble-cobble beach at the high-water mark, backed by marshes. Beaches are generally narrow with coarse sediments in the gravel and boulder size range. West of Maces Bay, the large re-entrant of Passamaquoddy Bay is a complex rocky coast of islands and bays (Photo 7). The entrance to Passamaquoddy Bay is partially closed by Campobello Island and Deer Island, to give a sheltered low-energy wave environment. Few beaches occur in this section and little marsh development has occurred due to the lack of fine-grained sediments. Grand Manan Island lies 11 km off the mainland coast and is an upland area of resistant intrusive rocks. The northwest coast is a fault scarp whereas the east coast has become a small archipelago of low rocky islands with the recent submergence of this region. The east coast of the island has some well-developed sand beaches that are separated by rocky cliffs.

Photo 6. Resistant, exposed rocky coast at the eastern entrance of Passamaquoddy Bay.

Photo 7. Sheltered, lowlying coast in Passamaquoddy Bay (west Deer Island).

PART 4 - SHORELINE TYPES

4.1 INTRODUCTION

The coastline of the Bay of Fundy is extremely varied. It is not possible, therefore, to simply categorize shoreline types to account for every variation, as the complexity of the coast would give an unwieldy number of related but distinct units. Rather than attempting to deal with each of the many shoreline features, 12 major shoreline types will be described, along with some of the major variations. For example, a wave-cut rock platform is a major shoreline type, but because of local variations it can be either (1) devoid of sediments, (2) have a pebble-cobble beach at the high-water line, or (3) be covered by coarse sediments. By simplifying the total variability in this manner each shoreline type can be described more accurately.

When applying this information to field situations it must be remembered that this is a method of describing and explaining major shoreline types rather than an attempt to define every single type of shoreline that occurs in the Bay of Fundy. In using the information it may be necessary to refer to more than one part of this section in order to relate the shoreline types to a specific field situation. For example, if a pocket beach is backed by marsh it would be necessary to refer to unit 7 (pocket beaches) and unit 12 (marshes).

To facilitate the discussion the shoreline types have been grouped into 4 categories: rock or cliff shorelines;

shorelines with beaches; shorelines with intertidal sediments; and shorelines with vegetation. The complete list of shorelines is given in Table 4.

4.2 ROCK OR CLIFF COASTS

1. Exposed resistant coast with low backshore or cliffs:

1a. With no beach or intertidal platform - Resistant rocky coasts undergo very little change over short time periods. The term resistance in this context refers to the durability of the rock to withstand the forces of waves and weathering. In the case of the latter, frost action in winter months and the chemical effects of wave spray are important. Although these are coasts of erosion, the rates at which the shoreline retreats are barely perceptible over decades or even centuries.

On rocky coasts that have no beach or intertidal wave-cut platform (Photo 8) the morphology of the shoreline is controlled

Photo 8. Exposed rocky coast with no intertidal wave-cut platform and no littoral sediments; south shore of East Wolf Island (see also Photos 3 and 6).

TABLE 4. Shoreline Types

ROCK OF CLIFF SHORELINES:

1. Exposed resistant coast with low backshore or cliffs:

   a. with no beach or intertidal platform
   b. with wave-cut platform devoid of sediments
   c. with wave-cut platform and beach at high-water line
   d. with wave-cut platform and intertidal sediments (see 9).

2. Sheltered resistant coasts.

3. Exposed unresistant cliffs.

4. Sheltered unresistant cliffs.

SHORELINES WITH BEACHES:

5. Cobble or mixed-sediment beaches:

   a. with beach at base of cliff
   b. with beach with overwash
   c. with beach with inlet and/or lagoon.

6. Sand beaches.

7. Pocket beaches:

   a. on rocky coasts
   b. in a large embayment.

8. Beaches in sheltered environments.

SHORELINES WITH INTERTIDAL SEDIMENTS:

9. Coarse sediments on a wave-cut platform.

10. Intertidal mud.

11. Intertidal sand.

SHORELINES WITH VEGETATION:

12. Marshes.

by the nature of the rock and the overall gradient across the coast. Local erosion leads to the formation of headlands and bays but the overall form of the shoreline (i.e., the presence or absence of cliffs) results from the topography adjacent to the coast. In the lowlying areas of Passamaquoddy Bay, the rock is simply exposed in the foreshore and gives way landward to vegetation. This is in a relatively sheltered wave environment with resistant rocks, so that waves have not been able to erode with any degree of success. In an area of greater backshore relief, cliffs will develop as either the resistance of the rocks decreases or the level of wave energy increases. Thus at Cape Chignecto, the very resistant granite outcrop is exposed to the full force of waves generated along the axis of the Bay, local relief inland is high, and vertical cliffs up to 250 m in height have been formed (see Photo 3).

1b. <u>With wave-cut platform devoid of sediments</u> - Wave-cut rock platforms (Photos 9 and 10) develop in the intertidal zone where littoral processes are able to erode the upper foreshore and backshore. In an area of high tidal ranges this is a slow process as wave energy is dissipated over a large vertical area. Wave energy is only concentrated at one level for approximately two hours during the turn of the tide, as the water level varies little during that period. Thus, erosion at the high-and low-water levels is only possible for four hours each day. However, this concentration of wave attack frequently

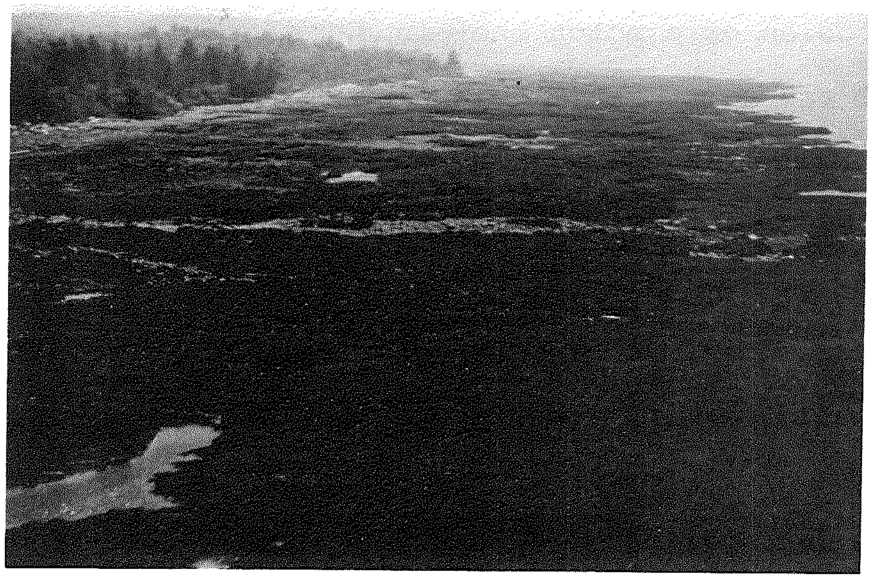


Photo 9. Very wide (c. 150 m) wave-cut rock platform exposed at low tide near Parker's Cove on the south shore, east of Digby Gut. The platform is cut into resistant basalts and is largely devoid of sediment. The rock surface is almost completely covered by algae.

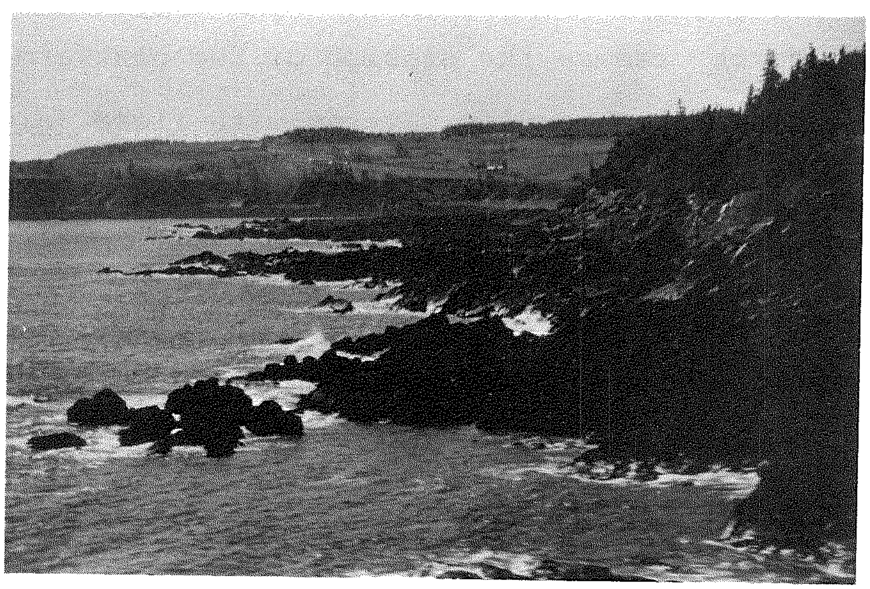


Photo 10. Narrow rocky platform to the west of Quaco Bay on the north shore.

leads to erosion of a notch that is cut into cliffs at the high-water level and to a small erosion scarp at the low-water level that marks the seaward limit of the rock platform.

Notches are the result of abrasion by wave-moved cobbles or pebbles that are used basically as cutting tools, particularly during periods of storm-wave activity. They are, therefore, usually associated with the presence of coarse material near the high-water level. Erosion of the notch will eventually lead to a rock fall once the cliff face becomes unstable. In this way, the cliff retreats and sediment is supplied to the littoral zone.

Rarely is a wave-cut platform completely devoid of sediment as the products of erosion usually collect in depressions or hollows, where they are used as abrasives to further erode the rock. The main feature of this type of shoreline is that sediments do not form a protective layer on the surface of the platform and thereby reduce the erosion of the platform. Intertidal rock platforms are usually covered with flora (algae or "seaweed") and fauna, and frequently have isolated pools of water that cannot drain as the water levels fall during an ebbing tide. The algae gives the intertidal zone a dark colour that is often in contrast to the light-coloured supra-tidal rocks.

1c. With wave-cut platform and beach at high-water line - If sufficient material is eroded from the platform or the upper foreshore, it may accumulate near the high-water level to form a beach (Photo 11). In the Bay of Fundy such beaches are usually of coarse (pebble-cobble-boulder) sediments. These beaches have steep beach-face slopes (q.v.) and a storm berm. Further information on them is given in shoreline type 5a.

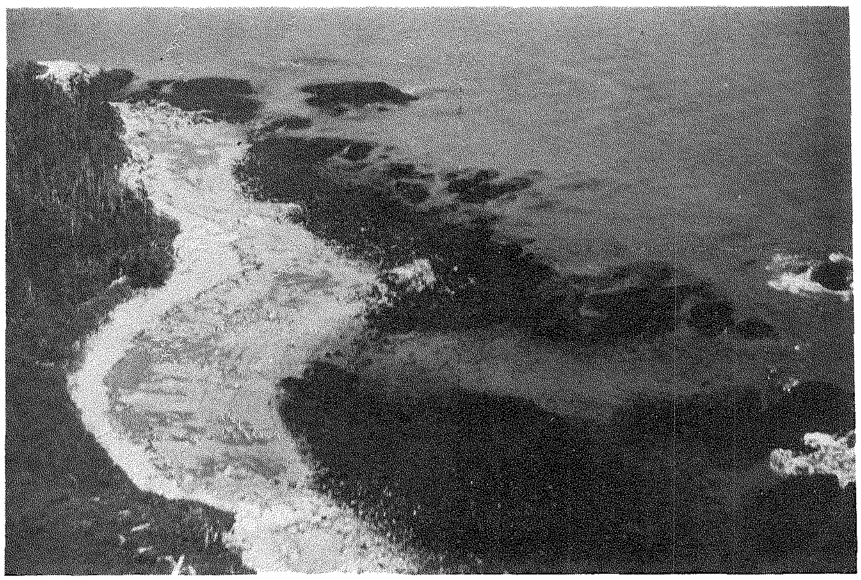


Photo 11. Rock platform and pebble-cobble beach in the upper intertidal zone, near Point Lepreau.

1d. Wave-cut platform and intertidal sediments - Discussion of intertidal sediments that completely cover wave-cut platforms is presented in section 9 (page 64).

2. Sheltered resistant coasts:

Resistant rocky coasts that are sheltered from wave- and tide-induced processes rarely have well-developed wide intertidal platforms or steep cliffs (see Photo 7). The intertidal zone is usually covered with algae, has numerous rock pools at low tide, and only occasionally is a beach or a notch formed at the high-water level. High cliffs are rare in sheltered areas, as these are usually drowned lowlying areas with low backshore relief.

3. Exposed unresistant cliffs:

Where sedimentary rocks or unconsolidated glacial deposits outcrop in the shore zone, rates of erosion are relatively high (up to a maximum of 2 m/year), depending on the exact nature of the rocks or deposits and on the exposure to littoral processes. On unresistant rock coasts, such as the sandstone cliffs of the Minas Basin, retreat can result from erosion of a notch at the high-water level that is followed by a rock fall once an unstable situation is created. Erosion also results from weathering, and frost action in winter is particularly important on this type of rock. Water in the rocks expands as it freezes and then contracts during a thaw. Numerous freeze-thaw cycles readily lead to fragmentation and rock falls on the cliff face. In areas of very unresistant rocks or unconsolidated deposits, vertical cliffs are uncommon. Cliff retreat results primarily from landslips (slumping or sliding), particularly following heavy rains or a storm. Wide intertidal wave-cut platforms are common on unresistant coasts and are usually covered with sediment that is supplied by local erosion (Photo 12) (see section 9).

4. Sheltered unresistant cliffs:

These cliffs erode in the same manner as those on exposed coasts, but rates of retreat are much slower and intertidal platforms are much narrower. As sheltered areas are usually drowned lowlands, backshore relief is not high and cliff heights are consequently low (Photo 13).

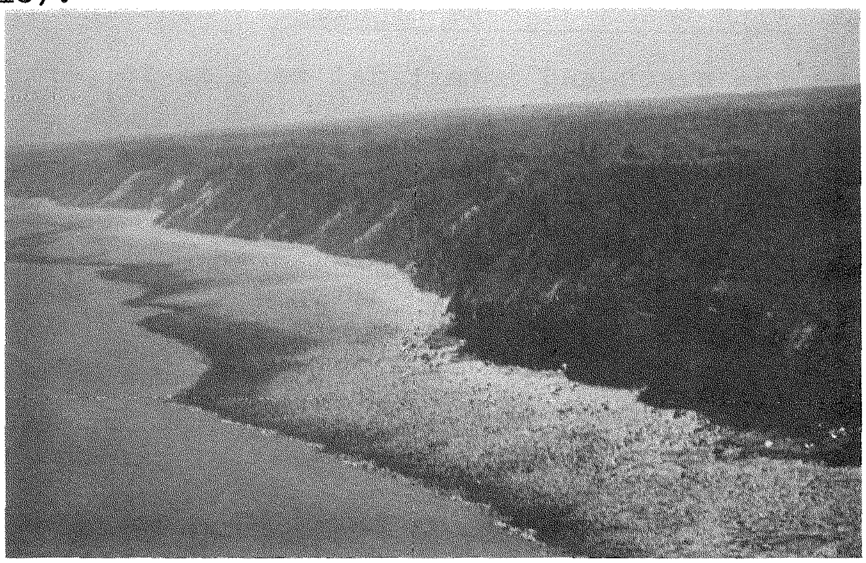


Photo 12. Resistant basalt cliffs, near right margin give way east (to the left) to unresistant cliffs of glacial deposits. Note that the platform is wider to the east as waves have been able to erode the unresistant cliffs more rapidly than the basalt cliffs.

Photo 13. Unresistant cliff of glacial sediments in a sheltered environment, Saint John's Harbour. Note the variety of sediment sizes, ranging from boulder to sand.

4.3 SHORELINES WITH BEACHES

5. Cobble or mixed-sediment beaches:

5a. With beach at base of cliff - Sediment that is supplied to the beach and intertidal zone is in part derived from the weathering and erosion of cliffs along the shore. Rates of erosion, the volume of sediment supplied, and the size of the sediment supplied are controlled by the nature of the rocks exposed in the cliff. Resistant igneous and metamorphic rocks yield little material, usually coarse (pebble-cobble-boulder) sediments. Unresistant sandstones provide large volumes of sand-sized sediments. Erosion of glacial deposits is rapid in exposed locations and gives very large volumes of sediment whose size varies according to the type of deposit, providing material from mud to boulders. Commonly weathering and erosion provide a mixture of sediment sizes. The beaches at the base of cliffs in this region usually consist of a mixture of pebble-cobble-material, with some sand and boulders (Photos 14 and 15).

These beaches, that are primarily reworked talus (q.v.) deposits, occur in the upper foreshore and above the high-water line (Photos 16 and 17). During storm-wave activity the whole beach is reworked and sediment is moved seaward into the intertidal zone. This is the mechanism by which sediment that falls down the cliff face onto the backshore is transported into the littoral zone, and is subsequently transported alongshore or to

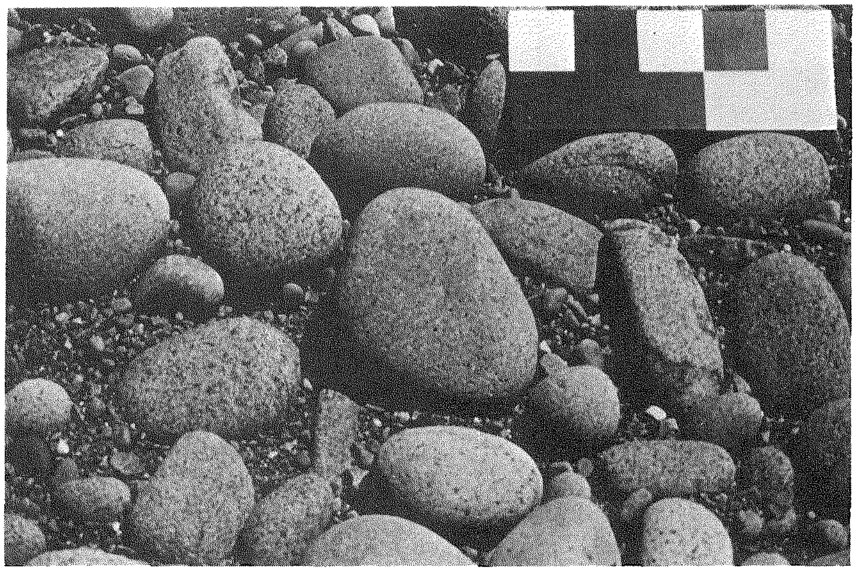


Photo 14. Mixed sand, pebble, cobble sediments on a beach on the south shore. The scale is graduated in 5 cm squares.

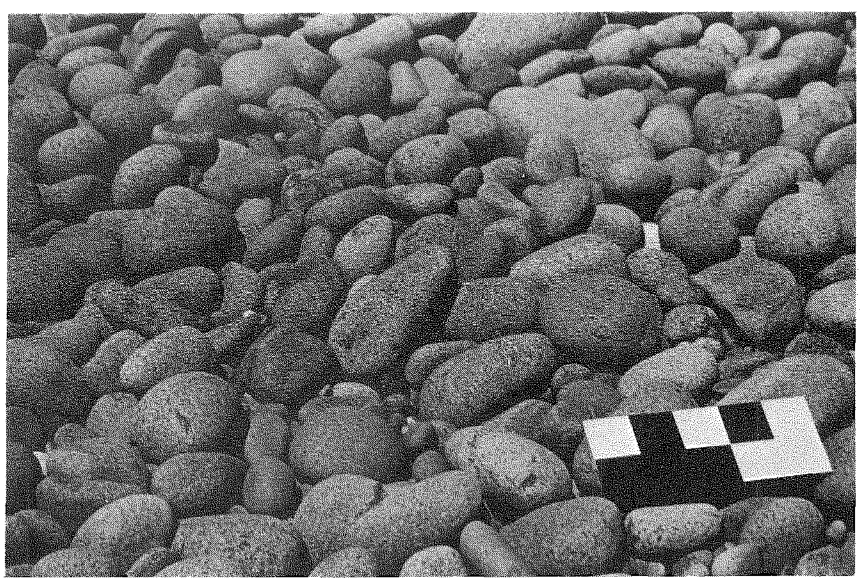


Photo 15. Cobble beach with no sand or pebble fraction: south shore.

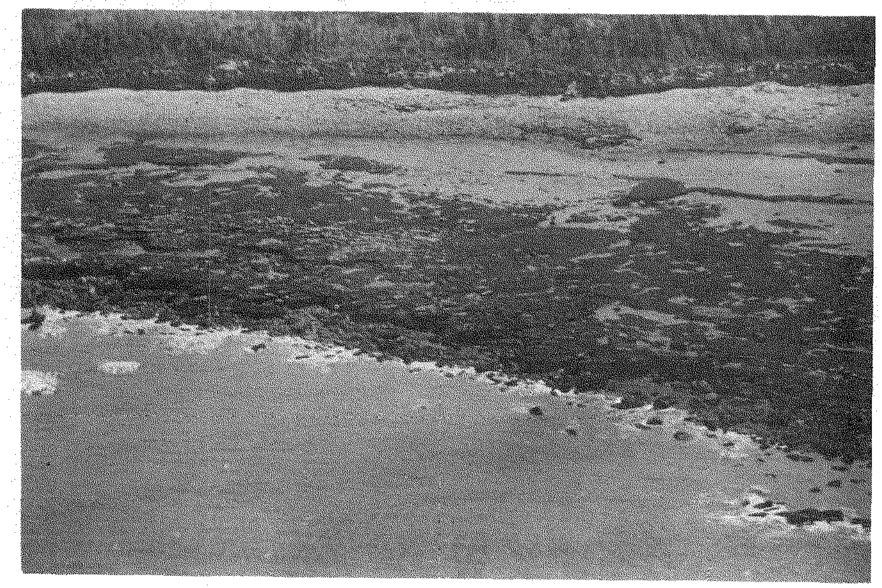


Photo 16. Rocky coast with wave-cut platform and a pebble-cobble beach at the base of the eroding cliffs, south shore Chignecto Bay.

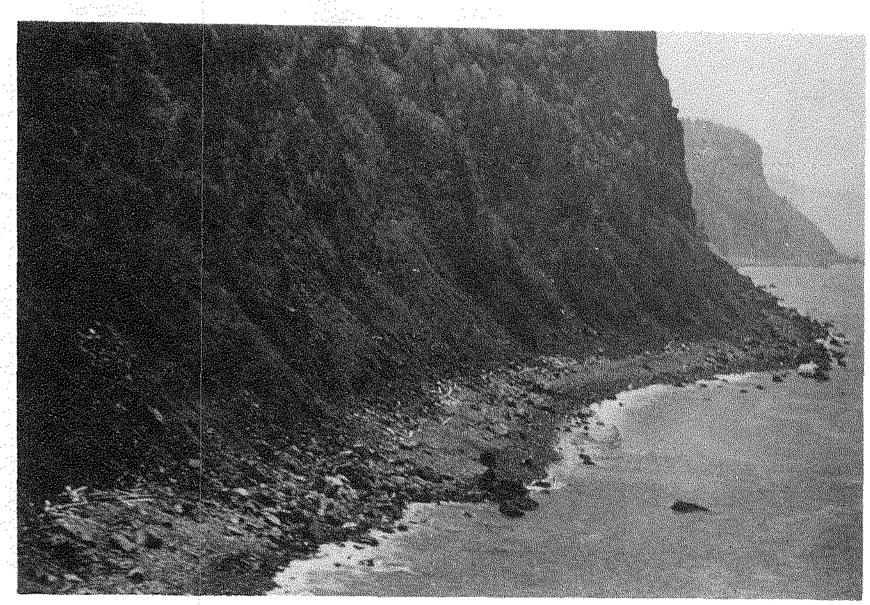


Photo 17. Reworked talus deposits and beach at the base of cliffs on the west coast of Grand Manan Island.

other parts of the intertidal zone by waves and/or tides. Removal of the material from the backshore during storms exposes the base of the cliff, which is then attacked and eroded by the waves, supplying more material to the littoral zone. Following the storm, further sediment accumulates in the backshore as the cliff face is weathered and material falls from the cliff downslope. This material is then reworked and redistributed by the next storm.

5b. With beach with overwash - Where sediments accumulate in the upper foreshore in areas without cliffs, waves push material above the high-water line into the backshore during storms. This creates a storm-ridge and a berm (q.v.) (Fig. 10 and Photos 18 and 19). During non-storm periods the waves create a flat, sloping beach face which is in equilibrium with the normal prevailing waves. Storm waves erode the beach face and (1) comb down the sediments to deposit them in the lower foreshore, and (2) push coarse material into the backshore. With the return to normal waves the sediment in the lower foreshore is transported back into the beach face to re-establish the equilibrium, but the sediment that was pushed above the high-water line remains where it was deposited. Unless material is supplied to the beach from alongshore transport to replace that which was lost during the storm, the beach will migrate landwards with successive storms. In most parts of the Bay of Fundy sediments are available for replacement and in the short-term (1-10 years) the beaches are relatively stable.

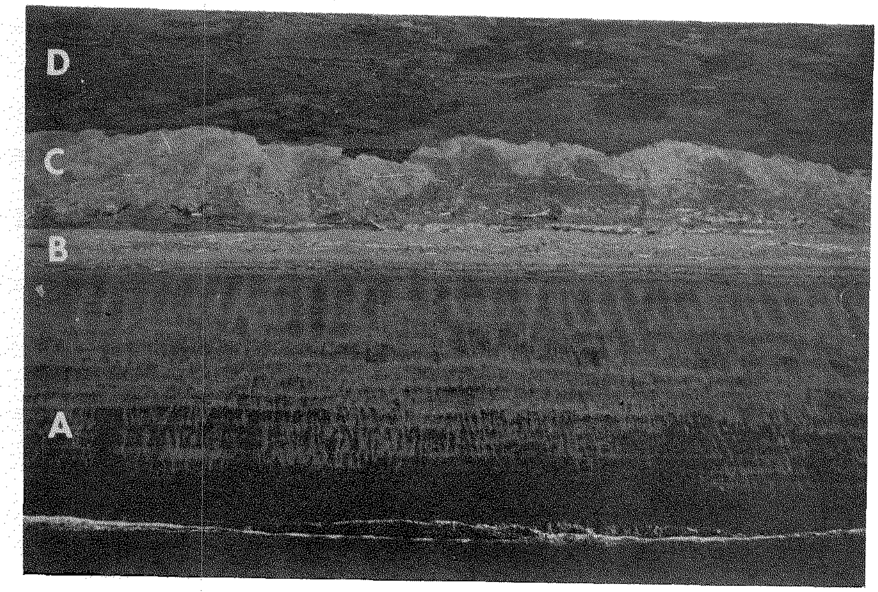


Photo 18. View landward of (A) intertidal beach, (B) berm and storm ridge, (c) overwash, and (D) marshes, Advocate Harbour. The photograph covers a 150 m section of beach, and the intertidal zone, from the berm to the water line is approximately 50 m wide. Photograph was taken at mid-tide, the mud flats in the lower intertidal zone are below the water level.

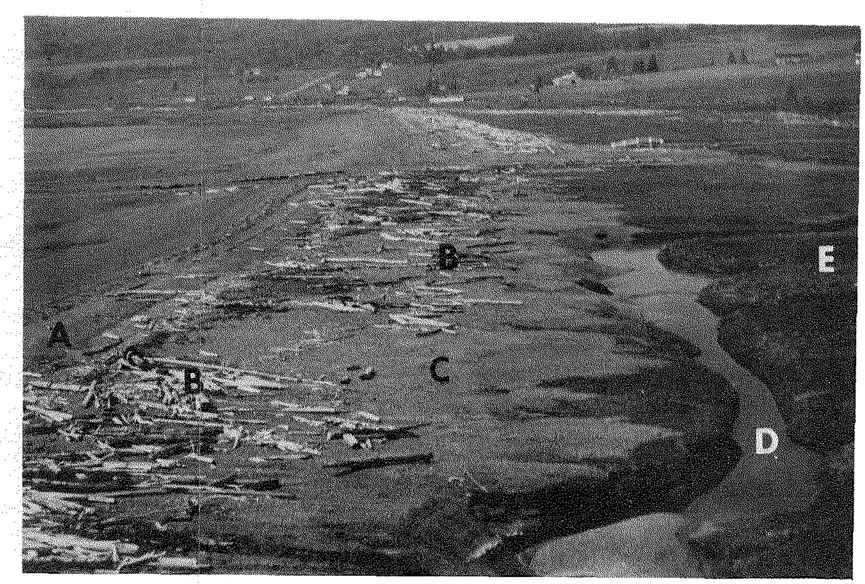


Photo 19. View alongshore at Scots Bay. (A) berm and storm ridge, (B) debris lines, (C) overwash, (D) tidal creek, and (E)marsh.

During storms, waves wash over the storm ridge, pushing material landwards. This process, called overwash, causes burial of the land, or marsh, landward of the backshore zone (Photos 18 and 19). The upper limit of storm-wave activity is marked by a line of debris (wood, logs, garbage, etc.) that normally accumulates at the high-water line and is then carried to a higher level by the storm waves. These debris lines are a useful indicator of the maximum limits of wave activity by individual storms, and often several lines can be identified until a very large storm moves them.

The beach face is a zone of continuous wave activity as the tide rises and falls. During the ebbing tide a variety of small ridges, either straight or wave-like, are formed parallel to the water line (Photo 18). With a rising tide these small features are destroyed as waves rework the sediments. The backshore area is only affected by the infrequent storm waves. Sediments are usually coarse (pebble-cobble) and often covered with debris accumulations (Photo 19).

5c. With beach with inlet and/or lagoon - Essentially the same processes occur on this type of beach as on those described above except where (1) a lagoon or marsh is connected to the sea by a tidal inlet that breaches the beach, or (2) the beach is backed by a closed lagoon or pond.

Inlets primarily occur where rivers or streams exit from the adjacent land area. In the Fundy region the inlets are generally small due to the small size of the drainage basins. In addition to acting as river exits, the inlets also drain tidal marshes or lagoons in the backshore. As rivers and streams are small, and the tidal range is so large the inlets are usually dry at low tide.

The actual location of an inlet can change, often as a result of storm waves breaching a low point in the beach ridge and sealing the former inlet. A pattern that frequently reoccurs is one in which, under normal wave conditions, an inlet will form on the downdrift end of a beach (i.e., if the prevailing direction of longshore sediment transport is from east to west, the inlet will occur at the west end of the beach). If a storm breaches the inlet at the updrift end (in this example, the east end) the former inlet is closed. Subsequently, sediment brought into the area from alongshore closes the new inlet and the former inlet is reopened.

Due to strong tidal currents, that result from the large volumes of water passing through an inlet during each tidal cycle, sediment is continuously moved in and out of the inlet during flood and ebb tides. This causes deposition of a small fan of sediments on the seaward margin of the inlet that protrudes from the beach. This deposit (called an "ebb-tidal delta") is often exposed at low tides (Photo 20).

In the inlet itself sediments are reworked and redistributed by the tidal currents and considerable changes can take place

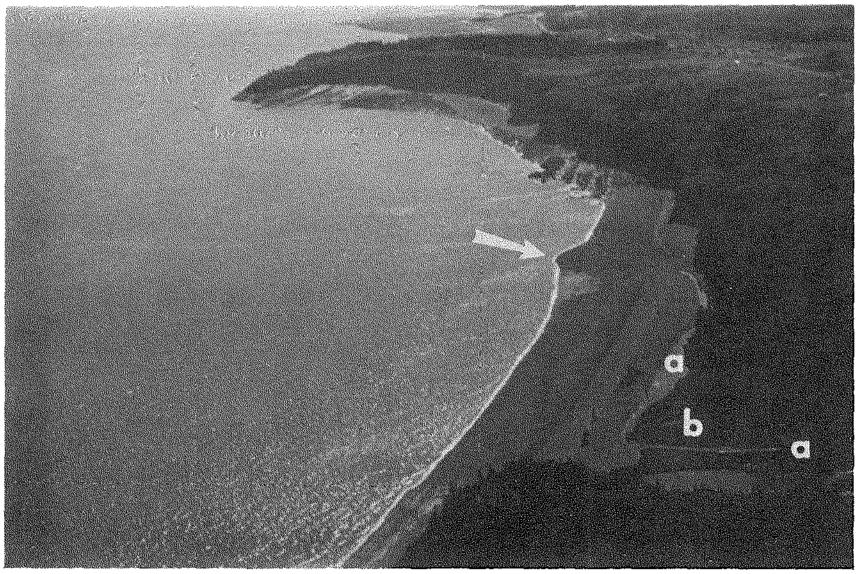


Photo 20. Small ebb-tidal delta (located by arrow) at an inlet just east of Quaco Head. The pebble-cobble beach is backed by a small river(a) and marshes(b).

within one or two tidal cycles. Sediments are buried, exposed and then eroded and redeposited as the exact location of the channel or channels within the inlet changes. Inlets are, therefore, one of the most variable environments in the littoral zone. Although generally stable in position, movement of sediment within the inlets by the ebb and flood tidal currents results in continual changes of morphology.

Lagoons that are drained by inlets have muddy intertidal zones and are discussed in section 10; marshes are discussed in section 12.

Where a closed lagoon or pond is present behind a beach, overwash deposition leads to gradual infilling. Changes in the water level, that result from runoff from the adjacent land areas, give debris lines that mark the upper limit of the water level. Usually the lagoons or pond are small so that no significant waves are generated and these are essentially areas of low energy and little change.

6. Sand beaches:

Sand beaches are governed by the same processes as a cobble or mixed-sediment beach and have a similar form, except that a storm ridge rarely develops. During storms, waves wash sand over the berm to produce a flat backshore berm. This difference is a result of the inability of the swash (q.v.) to infiltrate the beach. On a cobble beach the swash pushes sediment onto the berm and the swash then percolates rapidly into the beach, depositing the sediment at the limit of the uprush. On sand beaches the swash cannot percolate into the beach as rapidly and the swash continues its uprush farther and usually right across the berm.

The berm may become colonized by salt-tolerant plants that initiate small dune systems by trapping wind-blown sand. If the vegetation withstands subsequent storm-wave activity a dune system will slowly develop. Sand beaches are rare in the Fundy region and only small dunes have been able to form due to the lack of sand-sized material in the upper beach face.

7. Pocket beaches:

Sediments in the littoral zone are usually transported alongshore by waves and tides. In most cases sediment is fed into a beach (from the updrift direction), passes alongshore through the beach, and then leaves at the other (downdrift) end. This normal situation can be interrupted if sediment cannot leave the system, for example, if a rock headland interrupts the coast (Photo 20). In this event sediments will accumulate on the downdrift section to form a wide beach. Another situation can occur where the beach has rock headlands at either end. In this environment, sediments are not fed into the system from alongshore nor can they leave the system. A beach that has rock outcrops that define its limits to give an isolated feature (Photo 21) is referred to as a pocket beach.

Photo 21. Pocket beach of pebble-cobble-boulder sediments at Cape Split. The intertidal zone is approximately 50 m wide. Photograph taken at low water.

7a. <u>On rocky coasts</u> - The same processes that operate on cobble or mixed-sediment beaches (type 5) characterize the beaches of this unit. The only major variable is the lack of sediment input to the system, which means that if sediment is removed from the beach, naturally or by man, there is insufficient material available to replace that which is lost, and the beach will retreat landwards.

Where a pocket beach forms in a small bay or re-entrant on a rocky coast (Photos 21 and 22) these are essentially closed systems (i.e., isolated "pockets" of sediment that are trapped in a small bay). As this type of shoreline usually occurs on a rocky coast the beach is frequently backed by cliffs. The storm ridge, that is often covered by debris, consists largely

Photo 22. Pocket beach of pebble-cobble sediments with mud flats on a rock platform in the lower intertidal zone; west of McCoy Head on the north shore.

of cobble sediments whereas the beach face is a sand-pebble-cobble mixture. The lower intertidal zone is a wide mudflat (Photo 22) that may sometimes have cobble or pebble-cobble sediments in isolated patches.

Figure 12 is a sketch of a small pocket beach at Point Wolfe in the Fundy National Park. The beach, that is set back in the embayment, is composed of cobble-sized sediments and is

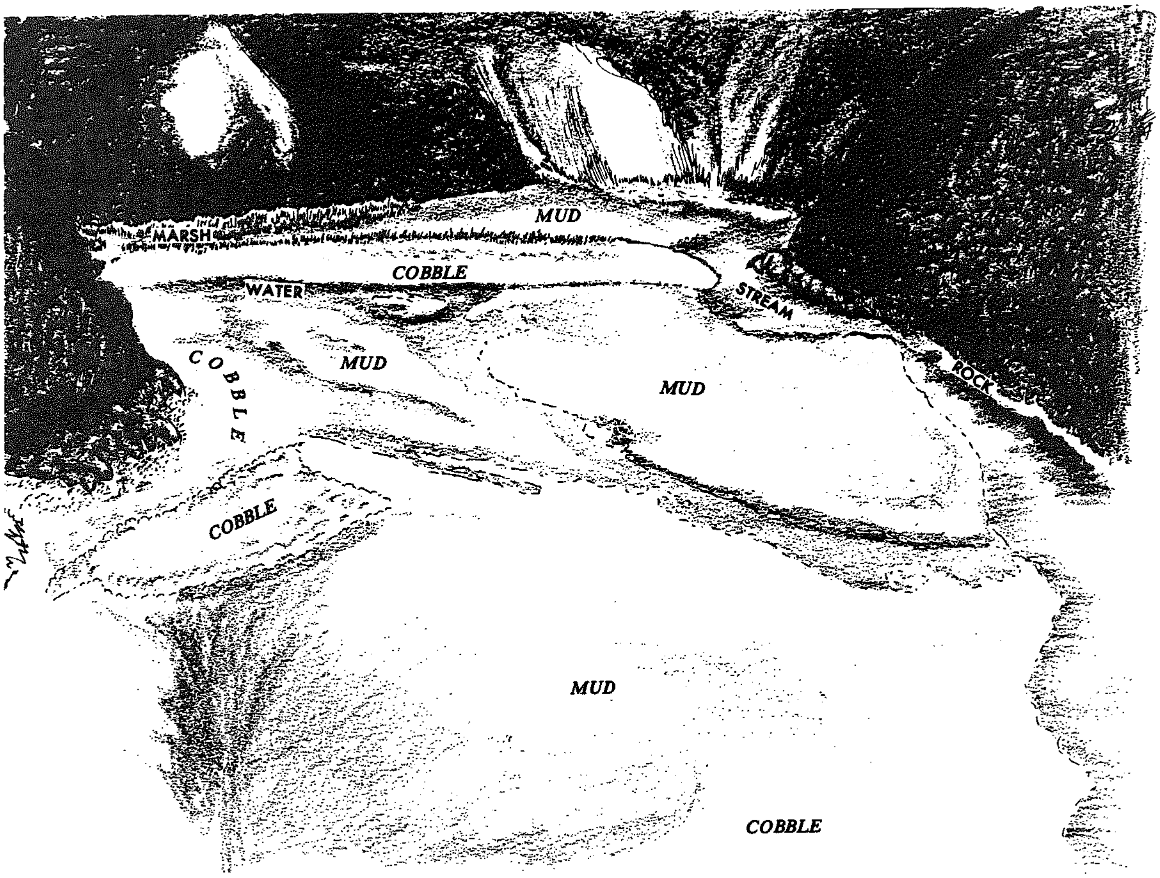


Figure 12. Sketch of a small embayment with a pocket beach at Point Wolfe on the north shore in Fundy National Park.

backed by mudflats and a small marsh. On the seaward side of the beach the intertidal zone is a mixture of mud and cobble sediments, with rock outcrops on the margin of the embayments. This is a small bay, sheltered from wave action, and the intertidal sediments are poorly sorted. By contrast, in an area of higher wave energy, at Cape Enragé (Fig. 13) the small pocket beach has a distinct zonation of sediments from mud in the lower intertidal zone to cobbles on the beach face and above the high-water mark. Sorting and zonation of sediments is generally better as levels of wave energy increase.

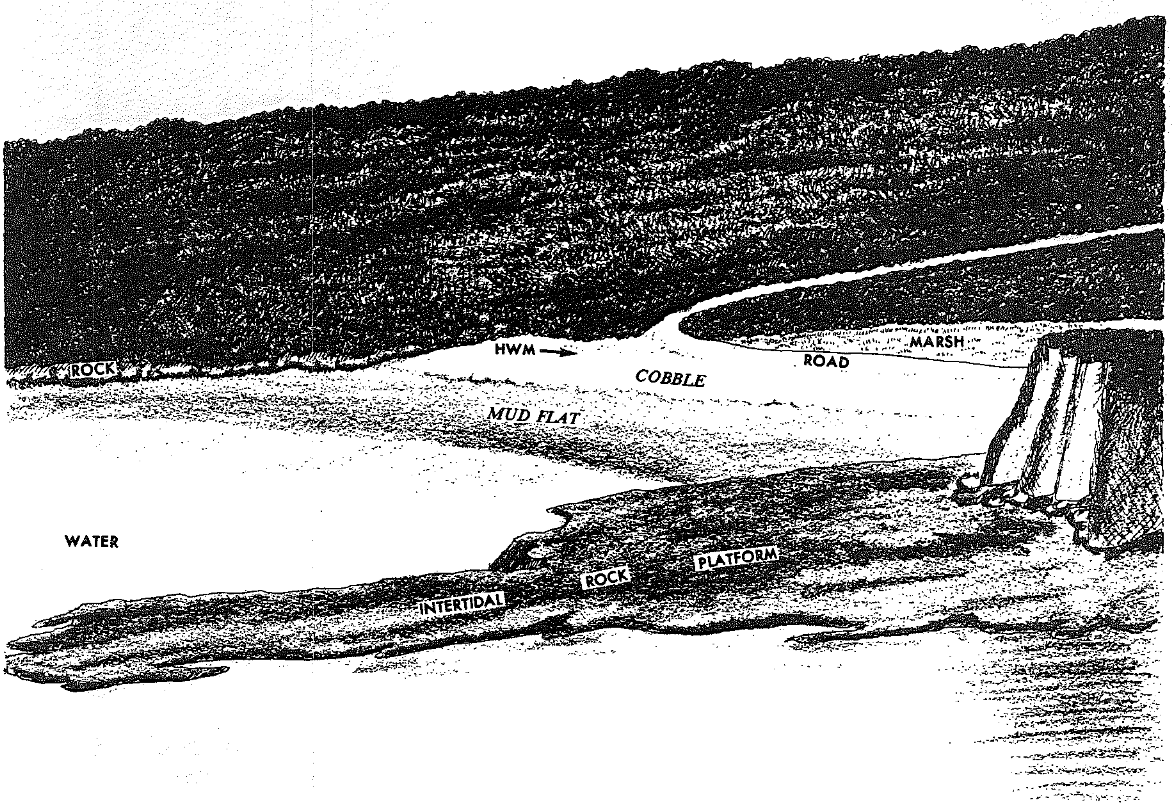


Figure 13. Sketch of an exposed pocket beach at Cape Enragé. By contrast to Figure 12, the intertidal sediments have a distinct zonation due to higher levels of wave energy at this site (c.f. Fig. 10 and Photo 22).

7b. In a large embayment - The development of large beaches in the embayments of Salisbury Bay, Advocate Bay and Scots Bay represent a type of shoreline peculiar to the Bay of Fundy. Each of these major embayments acts as a large trap at the end-point of a longshore sediment transport system (Fig. 9). In each case the tidal range is in the order of 9 m and a steep, wide beach face of sand-pebble-cobble sediments gives way to a wide (up to 1 km) mudflat in the lower intertidal zone (Figs. 10 and 14). The beaches are backed by salt marshes that are slowly being buried by overwash in sections adjacent to the storm ridge (Photos 18 and 19)

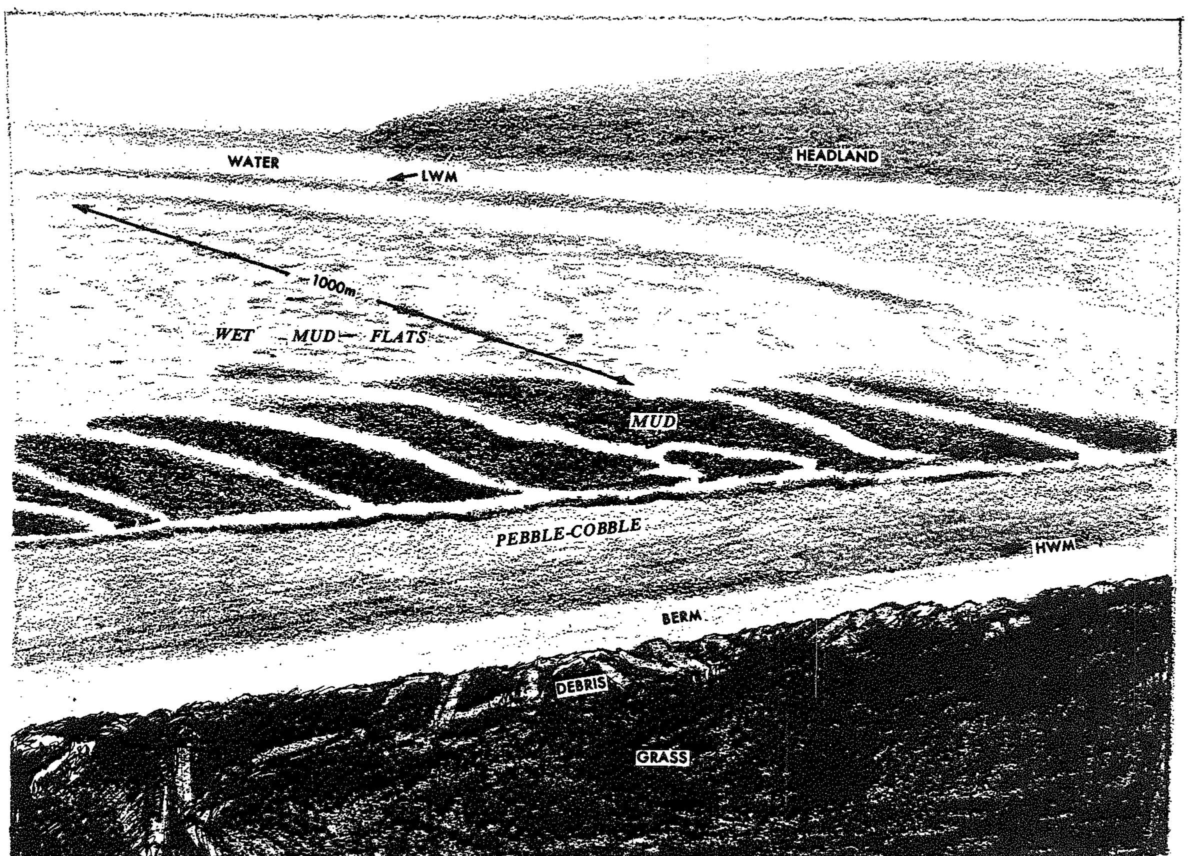


Figure 14. Sketch looking seaward of the Scots Bay embayment. At low tide the pebble-cobble beach face and berm give way seaward to a wide mudflat (c.f. Fig. 10).

8. Beaches in sheltered environments:

Beaches that are exposed to wave action have a well-defined sequence of a mudflat, beach face, and storm ridge (Fig. 10) that results from the sorting of the sediments. Where beaches are sheltered from wave action, the sorting processes are less effective. Mud or sand deposits are still common in the intertidal zone, but the beach face is less steep, the berm is lower and usually there is no storm ridge. The degree to which a beach is sheltered varies between localities, so that there is a transition rather than a distinct difference between exposed and sheltered beaches. Photograph 23 is of a beach in Saint John's Harbour that is sheltered from waves out of the southwest, but that is still subject to wave action and sediment sorting (see also Photo 13). Photograph 24, taken in Annapolis Basin, shows a very sheltered environment and a beach with no berm or storm ridge. In this example, the debris lines indicate maximum water levels and the limits of wave uprush, these are only slightly higher than the mean high-water level. As exposure decreases, the ability of waves to sort the sediments also decreases, and the rates of sediment movement and, therefore, longshore sediment transport also decrease.

Photo 23. Sheltered pebble-cobble beach in Saint John's Harbour.

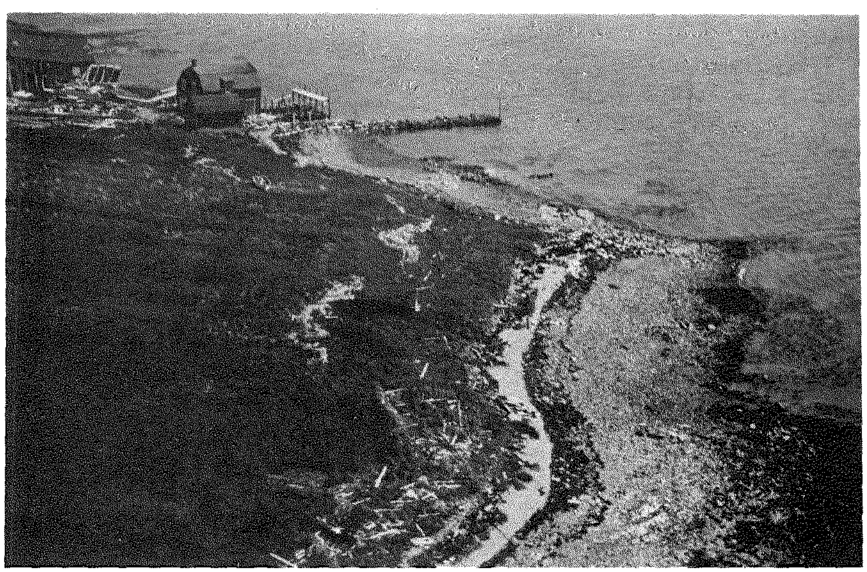


Photo 24. Very sheltered beach in Annapolis Basin.

4.4 SHORELINES WITH INTERTIDAL SEDIMENTS

The most significant characteristic of the Bay of Fundy coastline is the high tidal range. In areas of low relief or unresistant, eroding cliffs this creates extensive intertidal areas that are exposed at low tide. In Chignecto Bay and Minas Basin the width of the exposed intertidal areas reaches as much as 5 km (Fig. 8). In these two sheltered coastal environments the till or bedrock surfaces are covered by thick mud or sand deposits (Photos 1 and 5). By contrast, in areas of the Bay that are more exposed to wave activity, the wave-cut platforms are covered with pebble-cobble sediments (Photo 2).

9. <u>Coarse sediments on a wave-cut platform:</u> Sediments on a wave-cut platform can act as either a protective apron or as an abrasive tool, depending on the thickness of the sediment cover. A thick cover (e.g., Photo 12) protects the rock surface from abrasion, so that wave erosion of rock outcrops is restricted to the notch at the high-water level and to the step at the low-water level (see 1b). Where the sediment cover is incomplete or thin (Photos 2 and 25) waves and/or tidal currents move the coarse sediments which then abrade the rock surface. Most of the intertidal sediments are in the pebble-cobble size range and can be moved by wave action on coasts exposed to high wave energy levels. As sediment size increases (i.e., to the boulder size range) or wave energy levels decrease, the rates of sediment movement and, therefore, of

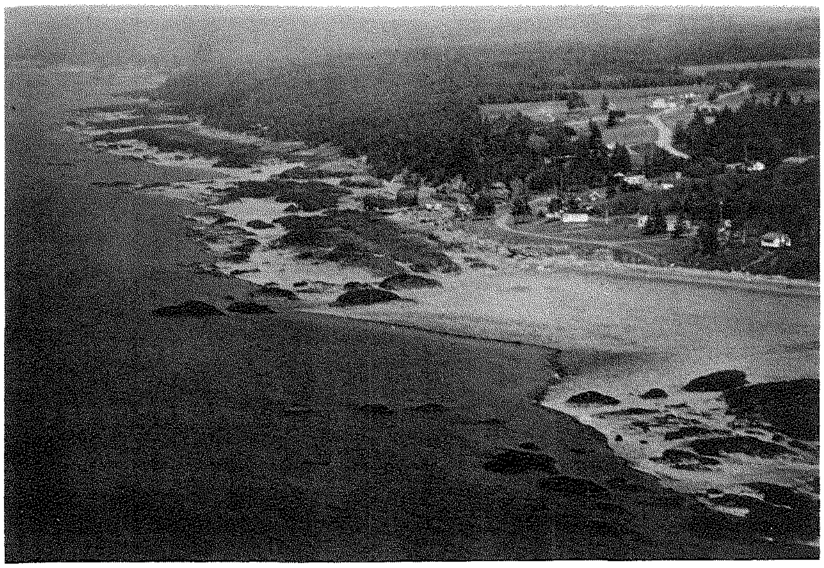


Photo 25. Wave-cut platform on the south shore near Margaretsville, an area with only a partial sediment cover in the intertidal zone.

abrasion decrease. As high wave energy levels are necessary to erode the rock cliffs and thereby form wide platforms, this type of shoreline is usually found only in exposed sections of the Fundy coast.

10. Intertidal mud:

Intertidal mud deposits occur primarily in areas sheltered from wave activity. The mud flats can be extensive features, for example in the Avon River estuary, the Economy Point area, and in Shepody Bay (Photos 1b and 5; Fig. 11b), or they may be restricted to the lower intertidal zone of pocket beaches (Photo 22; Figs. 10 and 14). In the latter case, the mud deposits slope very gently seawards and are only exposed during the lowest stage of the ebb-tidal cycle.

In Minas Basin and Chignecto Bay the extensive mud deposits are dissected by a network of deep tidal creeks that greatly hinder access. These creeks are steep-sided and may be up to 3 m deep. The flood tide travels rapidly across the gently sloping flats and care must be exercised in these areas to avoid being caught by the rising water level. In sheltered areas the mudflats give way to marshes above the high-water level (Photo 26).

Photo 26. Intertidal mud deposits on the sheltered north shore of Annapolis Basin. The mudflats, shown here at mid-tide, give way landward directly to marsh deposits that have been reclaimed by dyke construction.

Even at low tide the mud deposits are usually covered by a thin film of water that cannot drain through the closely-packed sediments. Where muds are saturated with water they tend (1) to be very unstable, leading to slumps on the banks of the tidal creeks, and (2) to have a low bearing capacity, that is often insufficient to support the weight of a person.

Except for the complex system of entrenched tidal creeks, the mud deposits have a generally flat surface. Occasional shallow depressions are evident at low tide, appearing as pools of standing water. Morphological changes in the mudflats result primarily from migration of the tidal creeks, causing erosion and deposition as the creek meanders across the flats. Other changes, that result from either deposition during the slack water at high tide or from scour by tidal currents, may change the elevation of the surface but do not alter the basically flat surface morphology.

Minor surface features, ripples that are in the order of only a few centimeters high, can occur if the muds are unsaturated. These ripples migrate under the effects of the tidal currents and tend to be more common in the upper parts of the intertidal zone where the sediments are more easily drained or where there is a mixture of find sand and coarse mud sediments.

11. Intertidal sand:

Extensive sand deposits occur in Minas Basin, Chignecto Bay and Annapolis Basin. These sand flats are exposed at low tide but are completely covered by the flood tide. The sands are in a state of constant motion as a result of the strong tidal currents that can reach velocities up to 1.5 m/s (Knight and Dalrymple, 1976). The sediments move basically as a series of sand waves or giant ripples that may have wave lengths of as much as 20 m and may be up to 1.5 m high (Photo 27). The sand flats usually have a complex surface topography of ripples and sand waves of all sizes that changes with each tidal cycle as the currents scour, erode, transport and deposit the sediments.

Photograph 27 shows a typical sand flat in the Minas Basin, on the south shore just east of the Avon River estuary. It can be seen that the form and orientation of the sand waves can vary over very short distances and that more than one type of sand wave can occur at the same locality. In the case shown in this photograph, a series of small ripples occur in the troughs between the larger sand waves. The troughs frequently contain standing water when the flats are exposed at low tide (see also Photo 28).

4.5 SHORELINES WITH VEGETATION

12. Marshes:

The tidal marshes of the Fundy region are found in the sheltered eastern areas of the Bay and in areas that are sheltered from wave activity. They occur in Passamaquoddy Bay and the Annapolis Basin (Photo 26) but reach their maximum extent in the

Photo 27. Sand waves exposed at low tide on the wide intertidal flats east of the Avon River estuary in the Minas Basin. These sand waves are up to 1 m high, are spaced approximately 5 m apart, and are migrating from left to right on this photograph.

Photo 28. Intertidal sand flats on the south shore of Annapolis Basin. Scale is given by the two people in the middle distance.

eastern sections of Minas Basin and Chignecto Bay. The marshes are submerged only by spring tides (q.v.) or by high-water levels associated with storms that pile water up against the coast.

Many of the marshes have been reclaimed for agriculture by construction of dykes that prevent salt water from inundating the backshore areas (e.g., Photo 26). Where the marsh has not been reclaimed by man the typical sequence is one that has a wide mudflat in the intertidal zone which gives way directly to the marsh with no beach or accumulation of coarse sediment at the high-water mark (Fig. 15). The marsh may colonize the highest parts of the mudflats, if it is an area of mud deposition; or the edge of the marsh may erode as waves attack the edge of the vegetation at high tide (as is the case illustrated in Fig. 15).

The marshes are dissected by steep-sided, deep, tidal creeks. These creeks are bare of vegetation and slowly change their course by erosion of the banks and deposition in sections sheltered from the strong tidal currents. The tidal channels are filled with water by flood tides but, as noted above, the water only overflows into the marshes at times of high water levels.

The unreclaimed marshes have a flat surface interrupted only by the tidal creeks. The vegetation is primarily a species of cord grass *(Spartina alterniflora* or *Spartina patens)*.

The dyked marshes tend to have a slightly lower elevation than the natural marshes due to improved drainage, compaction of the sediments, and the absence of sediment that would otherwise be deposited at times of high water levels. The dykes are rarely breached and, therefore, the reclaimed areas are rarely flooded by salt water.

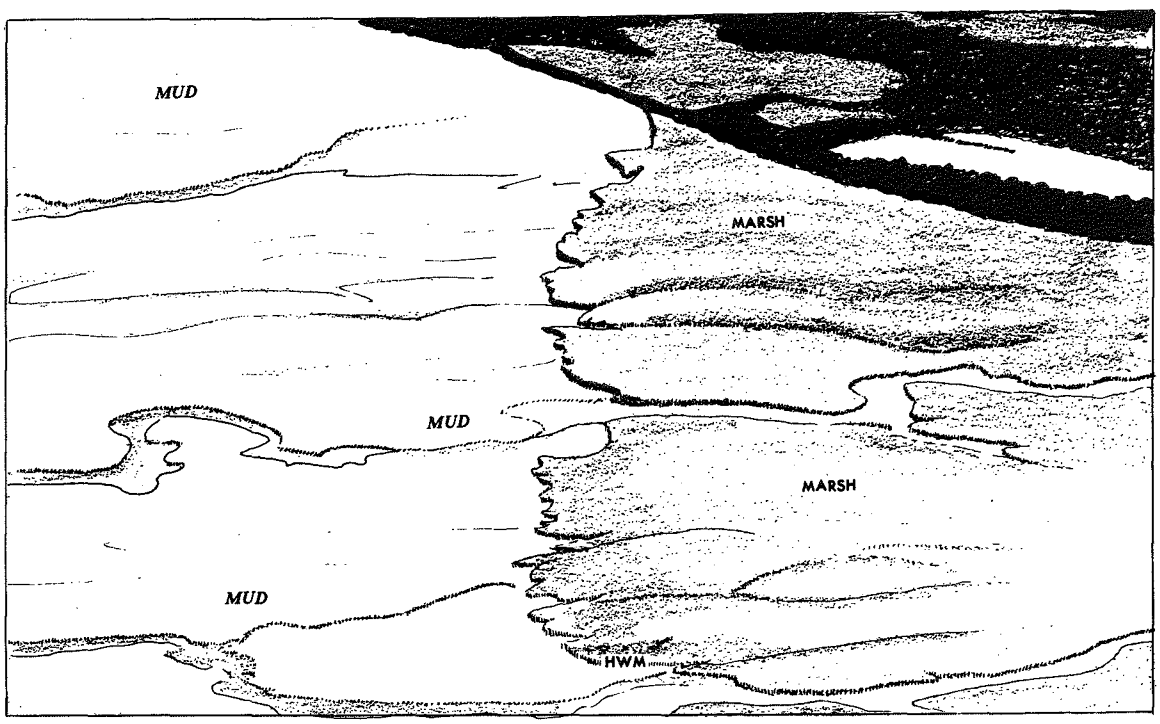


Figure 15. Sketch of marsh and mudflats on the south shore of the Minas Basin. The junction of the marsh and the mud is marked by a low (<1 m) erosional scarp.

4.6 SUMMARY

The coasts of the Bay of Fundy are extremely varied. This outline of the major shoreline types isolates the primary components in order to simplify the large number of combinations that occur in nature. As the emphasis has been placed on the most important features and processes in each type of shoreline, the discussion has necessarily been simplified and has not included a detailed rationale or explanation of the processes themselves. This would be superfluous as the prime objective of this report is to present a description of the character of the Fundy coast in terms of shoreline types as well as the most important factors that control the nature of the sediments and the topography in the shore zone.

No attempt has been made to present a map that shows the actual distribution of each of the 22 shoreline types discussed above, but a generalized indication is given by Figure 16 that was prepared from an interpretation of aerial photography by Welsted (1974). This map is included only as a guide as no detailed maps of the shoreline types of the Fundy coast have been prepared to date. The broad categories used by Welsted in Figure 16 correspond generally to the shoreline types discussed in this section. However, it must be pointed out that the unit referred to as "Mudflats" is somewhat misleading as many of the locations indicated on the map are, in fact, areas of extensive sand deposits.

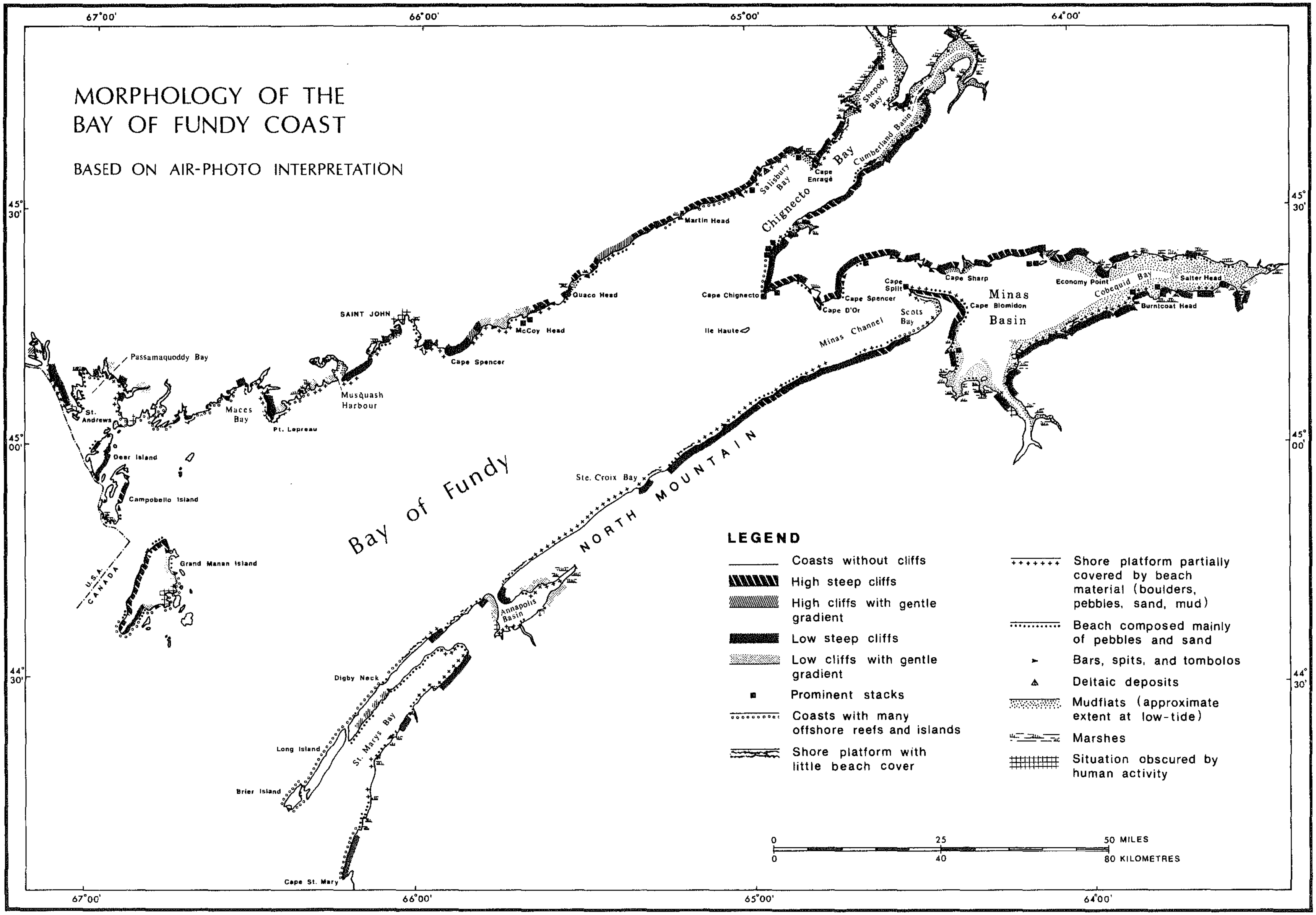


Figure 16. Morphology of the Bay of Fundy based on Air-Photo Interpretation (Welsted,1974).

PART 5 - EXPECTED IMPACT OF A SPILL

5.1 INTRODUCTION

The major factors that determine the effects of a spill on a coast are:

(a) the volume of oil in the spill,

(b) the type of oil involved,

(c) the climatic and meteorologic conditions at the time of the spill,

(d) the shoreline energy conditions (waves and tides),

(e) the morphology and sediments of the shore zone.

The first three factors are extremely difficult to predict even for a high-risk area, because of the large number of variables and the large number of possible combinations of conditions involved. The last two factors can be predetermined with some confidence and may be used as the basis for regional and local contingency plans by providing estimates of:

1. how and where the oil would be deposited,
2. the persistence of the oil,
3. the suitability of available clean-up techniques to a particular area,
4. the effectiveness of those techniques,
5. guidelines for the clean-up operations.

Oil spill response and countermeasures for coastline areas require consideration of:

i. surveillance and monitoring of the oil on the open sea to determine likely impact locations,

ii. protection of the coast by containment of the oil on the open sea if possible,

iii. onshore protection to minimize effects of the spill,

iv. criteria for decisions on the requirements and necessity for a clean-up operation,

v. availability, effectiveness and cost of such an operation,

vi. guidelines for the operations to minimize possible adverse actions that may lead to more damage than caused by the spill itself, and

vii. transfer and disposal of the oil and/or contaminated material.

This report is concerned with items iii, v, and vi, and this section considers these aspects of a potential spill in terms of each of the six coastal environments and 22 shoreline types discussed in Parts 3 and 4.

Even though knowledge of how to cope with the problem has increased considerably since the first major clean-up operation that followed the spill from the *TORREY CANYON* in 1967, many gaps exist in our ability to predict the impact of a spill on the shoreline. For example, few studies have been carried out on muddy coasts (which are a major shoreline type in the Fundy region). However, from a knowledge of oil behaviour and of coastal processes it is possible to estimate the expected distribution and persistence of oil on the shoreline. Undoubtebly, improvements to these estimates will be made as further experience is gained from research, spills and clean-up operations in the future. This discussion, therefore, represents a state-of-the-art viewpoint rather than a definitive analysis.

The two basic approaches for contingency planning related to oil on the coast are geographic or thematic. In the geographic approach, shoreline types are mapped and operational criteria are related to defined sections of the coast (e.g., Yates, 1975). This involves detailed initial mapping of the coast to define the distribution and location of particular shoreline types.

The thematic approach presented below (sections 5.4 to 5.7) for the Bay of Fundy region is to (a) discuss the various aspects of a spill on different types of shorelines and to (b) summarize the major points in a series of tables (one for each of the shoreline types).

This approach differs from the geographic method in that the shoreline types and the operational considerations are discussed without reference to specific coastal locations. By this method the necessity for detailed mapping is avoided and shoreline types can be defined by a less expensive and less time-consuming reconnaissance of the coast. Geographic factors are considered briefly (section 5.3) in order to outline the major variability of the impact of oil on the shore but the emphasis is focussed primarily on the individual shoreline components (sections 5.4 to 5.7)

This thematic approach provides the basis for contingency planning and for field clean-up operations in this region. It is important to remember, however, that it is not possible to cover local details of shoreline process and morphology. On-site advice and guidance for specific locations or environmental conditions remains a critical element in the effectiveness of response and countermeasures.

5.2 GENERAL CONSIDERATIONS

Before dealing directly with the impact of a spill on the shore it is useful to outline some basic points concerning the behaviour of oil. Therefore, this section briefly considers: the size of spills; the type of oil; persistence (or degradation) of oils; climatic and meteorological conditions; and sediment types.

The *size of spill* can be defined according to a wide variety of criteria. For this report spills are considered in three groups as outlined in Table 5. These groups are not intended to have fixed limits but rather provide an indication of the magnitude of the spill for discussion purposes.

TABLE 5

	TONS	BARRELS	IMPERIAL GALLONS	LITRES
Small spill	< 1	< 7	< 250	< 1,110
Medium spill	1 - 50	7 - 350	250 - 12,500	1,110 - 55,000
Large spill	> 50	> 350	> 12,500	> 55,000

*Note: These are only approximate equivalent volumes.

The *types of oil* vary considerably from aviation gas to tar lumps. Even crude oils vary in their composition and viscosity. Louisiana crude is very light, whereas, Arabian or Venezualan crudes are generally heavy and sometimes almost asphaltic.

For this discussion, oil types have been grouped into three major categories: (1) liquid or free-flowing oils: These include unweathered light crudes, diesel fuels and most other refined oils. These thin or light-grade oils tend to evaporate rapidly on exposure and rarely form thick or solid residues. (2) very viscuous oils: This group includes heavy crude oils and weathered crude, such as bunker fuels, Bunker C ("residual" oils). This type of oil would include emulsions such as "chocolate mousse", a water-in-oil emulsion. (3) semi-solid or tarry oils: These are primarily oils that have been at sea for some time and have been weathered. They are heavy, tend to coagulate into lumps, and have lost most of the light fractions.

The *persistence of oil* is a function of the rate at which the oil weathers or ages. Weathering occurs as a result of photo-oxidation, biodegradation (microbial oxidation), dissolution, evaporation and emulsification. In general, the bunker fuels and viscous oils (refined oils) are less readily biodegraded as the light fractions have already been removed, consequently these oils are more persistent than the lighter grades.

Biodegradation and evaporation are partially controlled by temperature so that rates of degradation and fractionization are higher as air and water temperatures increase. Water salinity is an important factor in dissolution. The lower the levels of salinity, the more soluble is the oil, so that in fresh water areas (such as estuaries or river mouths) the oil is more readily diluted and thinned. The heavier grades are the least soluble in water. All biodegradation and chemical degradation processes increase as energy levels increase. Therefore, in areas of high wave activity more energy is available to break up the oil; more oxygen is available for chemical breakdown; and rates of microbial attack increase.

The *climatic and meteorological conditions* at the time of the spill, and while the oil is on the water or the shore, greatly affect the behaviour of the oil. As mentioned above, with cold air or water temperatures, weathering rates decrease. Strong winds and rough seas increase evaporation rates and tend to break up slicks into smaller individual patches of oil. If water levels against the shore are high, due to a storm-induced surge or to spring high tides, oil will be deposited above the limit of normal wave activity, and consequently not be subject to dispersion or dissolution, except during subsequent high water levels.

The *size of the sediments* affects the depth to which stranded oil can penetrate, although this also varies depending on the viscosity of the oil. Light grade oils can permeate all except the finest-grain sediments, such as muds. In this latter case, the spaces between particles are extremely small and are usually filled with water. Heavy oils do not usually penetrate sand more than a few centimeters, except where air temperatures are high and the oil has been on the beach for some time. In this case, as the viscosity is reduced, the oil will permeate the surface sediments under the influence of gravity. Once again, the influence of water is important. If the sand is saturated with water, the spaces between the particles are filled, thus making it more difficult for oil to penetrate the surface of a sand beach.

On pebble or cobble beaches where the space between the particles is not filled with smaller-sized sediments (e.g., Photo 15) even the semi-solid and tarry oils can penetrate the beach. In Chedabucto Bay, weathered Bunker C oil was observed to have penetrated as much as 1.5 m below the surface of a pebble-cobble beach.

Sediment size has an important effect on rates of weathering. If oil is buried in mud the anaerobic conditions (the absence of oxygen) prevent any chemical or microbial degradation. In sand or pebble-cobble beaches the burial of the oil also retards weathering. Physical abrasion and redistribution is limited so that the oil remains in a static position and does not benefit from the incorporation of oxygen, thus again slowing down chemical and biodegradation.

Some general principles related to clean-up operations are:

1. Cleaning procedures should not be initiated until all danger of recontamination from the source or from adjacent shorelines is over,
2. Natural self-cleaning is usually effective, although rates of oil degradation vary considerably depending on the type and volume of the oil and on local energy conditions.

From this brief summary it can be seen that a considerable number of factors exist that can occur in a wide variety of combinations to affect the nature, behaviour and persistence of oils that impact on the shore zone. For a clean-up operation these factors only become critical when decisions are required for (i) the necessity of removal of the oil, (ii) selection of the most suitable techniques for onshore protection, or (iii) the removal operation itself. A basic knowledge of the nature and behaviour of oils on water and on the shore then provides a better understanding of how the oil is likely to be deposited and how long it will persist on the shore.

5.3 GEOGRAPHIC ASPECTS OF A COASTAL SPILL

This section discusses some of the regional environmental controls on the impact of a spill on the coast. These general comments are organized with reference to each of the six coastal environments discussed in Part 3 (see Fig. 8 and Table 3). They serve as an introduction to and provide background information for the more detailed account of the estimated impact on the shore itself that is given below in sections 5.4 to 5.7.

SOUTH SHORE:

A coastal spill on the sea in this part of the Bay of Fundy would probably be moved alongshore from west to east, the direction of the prevailing and dominant winds (Fig. 2) and of the residual tidal currents (Fig. 5). Slicks that pass through the channels between Brier Island and Long Island, between Long Island and the mainland, and the entrance to the Annapolis Basin would be fragmented by the strong and turbulent tidal currents in these narrow passages.

Oil deposited in the intertidal zone would be subject to wave action but levels of wave energy decrease somewhat from southwest to northeast so that rates of physical abrasion and weathering would decrease correspondingly. This alongshore variation in wave energy levels is, however, of a lower magnitude than the difference in energy levels between this unit and the very sheltered units of Minas Basin and Chignecto Bay.

Oil from a large spill would probably coat much of the intertidal vegetation on the wave-cut platforms that lack a sediment cover (Photo 9). This presents a problem in terms of choosing between removal of the contaminated vegetation or leaving the oil there to degrade naturally. Removal of contaminated algae is a difficult procedure, whereas if no action is taken there is always the danger that oil would seep out of the algae and would be released to contaminate adjacent areas over a long time period.

Settlements along the coast in the western sections of this unit tend to be located in coves and/or pocket beaches. Here oil would collect and would persist longer than on the open coast, as these are sheltered areas.

In eastern sections, where settlements occur on coasts characterized by coarse sediments in the upper intertidal zone, rates of longshore sediment transport and, therefore, rates of abrasion associated with the movement of sediments, are relatively high. This factor would assist in the weathering and degradation of beach oil.

Annapolis Basin presents an anamolous situation in this coastal environment. If oil enters the Basin it would be deposited in a very sheltered, low energy environment that is characterized by mud or sand flats and marshes. In this area rates of natural degradation would be low, migrating sand waves would tend to bury the oil on the intertidal flats, and the reclaimed marshes would be protected from contamination by the dykes.

HEAD OF THE BAY:

The most important consideration in this unit is the probability that oil on the sea could be moved into the three large embayments of Scots Bay, Advocate Bay, and Salisbury Bay (Fig. 9), and into the Apple River estuary. These embayments face the southwest and winds out of the west or southwest, the prevailing and dominant wind direction, could drive slicks directly into the bays. Once oil enters these large bays, it could well be trapped there and contaminate the large bay beaches. A secondary and more favourable point is that these bays are exposed to waves generated along the axis of the Bay of Fundy (i.e., along the maximum fetch) so that reworking, abrasion, and weathering of oil on the shore would be encouraged by the relatively high wave energy levels.

Oil trapped in rock pools above the high-water mark on the coasts adjacent to the bay beaches, would be a potential source of recontamination during times of subsequent high water levels.

Elsewhere in this predominantly rocky, cliffed coastal environment, the shore zone is largely inaccessible so that clean-up operations of these sections could not be considered. Contingency planning would, therefore, focus on shorelines adjacent to the settlements that occur in sheltered bays or at river mouths.

MINAS BASIN:

The strong, turbulent currents in Minas Passage (up to 5 m/s: 10 kts) would fragment any oil slicks entering Minas Basin from the Bay of Fundy. Within the Basin, slicks moved by tidal or wind-driven surface currents into sheltered areas would be deposited in very low energy environments, thus rates of degradation would be slow. Oil deposited on the mud or, more particularly on the sand flats at low tide, would be subject to burial within several, or even one, tidal cycle. Major problems on these flats would be accessibility, because of the deep tidal channels or creeks; the generally low bearing capacity of the muds; the limited time during which the flats are exposed; and the rapidity with which the rising tide floods the flats.

Many of the marsh areas in the Minas Basin have been reclaimed and would be protected from contamination by the dykes. Elsewhere, unreclaimed marshes would be contaminated if the oil were to be deposited at a time of high water levels.

This coastal environment could be considered a low risk area for coastal spills, as few ships enter these waters and oil spilt in the Bay itself could only enter the Minas Basin through the narrow passage to the north of Cape Split. However, should oil enter or be spilt in the Basin, the problems of clean-up would be considerable on many of the shorelines.

CHIGNECTO BAY:

Most of the points discussed above in relation to the Minas Basin are directly applicable to this similar coastal environment. This Bay is not protected by a narrow entrance, so that the risk of a slick entering this area from the main part of the Bay of Fundy is somewhat greater than for the Minas Basin.

NORTH SHORE:

Few sections of this rocky, cliffed coast could be considered for clean-up operations as the shore zone is largely inaccessible and uninhabited.

Of particular importance, however, would be the shores of the Fundy National Park which are a major recreational attraction in this region. Figure 15 is a sketch of one cove in the National Park and illustrates the complexity of even a small local clean-up programme in this area. Rock outcrops are fronted by mixed mud and/or cobble deposits in the intertidal zone, with mud and marshes in the sheltered sections behind the cobble beach.

The movement of oil on the water in this region is difficult to predict as winds are generally out of the west, but the strong ebb-tidal currents would tend to move oil towards the west along this shore (Fig. 5). This coast is exposed to waves generated along the axis of the Bay and the relatively high levels of wave energy would assist degradation of oil in the shore zone.

NORTHWEST SHORE:

This region is the highest risk area for a coastal spill in the Bay of Fundy. Saint John is a major port of eastern Canada and handles tankers as well as cargo traffic. Oil on the water would tend to move west along the coast from Saint John, towards the sheltered areas of Passamaquoddy Bay, where it would come ashore in any of the numerous small bays or coves. In the event of future development of an oil terminal at Eastport, Maine, the risk of a major spill would increase considerably. This port is located at a site that would involve navigation through a narrow channel, bound on both sides by rocky coasts, in an area of strong tidal currents.

On the exposed sections of this coast, the oil would be subject to high wave energy conditions. In the sheltered locations that are protected from the open sea, the persistence time of the oil in the shore zone would be much longer. Strong tidal currents, for example, in Grand Manan Channel, would fragment a slick and cause rapid dispersal of oil on the water.

SUMMARY:

1. Climatically, this is a region of cold air and water temperatures. Therefore, rates of weathering and degradation of oil on the water and on the shore are relatively low.

2. In winter months, ice on the shoreline would prevent contamination of the intertidal zone (Photo 29).

Photo 29. Ice in the intertidal zone of pebble-cobble beach in Chedabucto Bay. The ice completely covers the intertidal area and would prevent oil contamination of those sections of beach in the event of a spill.

3. Winds are primarily out of the west, and would tend to drive slicks eastward into the more sheltered parts of the Bay. On the north coast, this could be offset by surface tidal currents that would move slicks towards the west (Fig. 5).

4. Strong tidal currents would rapidly disperse slicks and, in many parts of the Bay, would break up the slicks before they travelled very far from the source of the spill.

This is particularly true where the tides are constricted between islands and/or headlands.

5. There is a wide variation in both wave and tidal energy levels within this region. Wave energy levels decrease from west to east, whereas tidal energy levels increase from west to east.

6. There is a great variety of shoreline types, ranging from steep rock cliffs to wide intertidal sand or mudflats. Sediments in the shore zone range in size from boulders to mud.

7. Few sections of the coastal zone are inhabited or are used for recreational purposes.

8. The highest risk area for a spill is the northwest coast of the Bay, and, in particular, the area adjacent to Saint John, New Brunswick. This area has the greatest ship traffic and the harbour of Saint John handles tankers as well as cargo vessels. This coast is also the area of greatest population density in the Bay of Fundy.

9. Few sections of the Fundy coast would be easily accessible. The most common shoreline types (rock coasts, sand or mud-flats, pebble-cobble beaches) are also the most difficult to clean. Recent efforts have been largely focussed on the development of clean-up techniques for sand beaches, but sand beaches account for less than 1% of the Fundy coastline.

5.4 ROCK OR CLIFF SHORELINES

1. Exposed resistant coast with low backshore or cliffs:

1a. With no beach or intertidal platform.

IMPACT OF OIL: This shoreline type occurs in areas of high wave energy levels so that slicks would usually be dispersed or broken up before reaching the shoreline. Waves are reflected from steep rock coasts, and this tends to keep oil away from the shoreline in all except calm conditions.

Oil coats rocky coasts if the rock surface is dry and if the wave conditions are calm. As oil adheres more easily to dry surfaces, this can affect the nature of the contamination, particularly in the intertidal zone. Oil would more likely be deposited in the upper intertidal zone and at the high-water level, because these zones have more time to dry out during the low-tide period than the lower sections of the intertidal zone. Rocky intertidal zones are often covered with algae which adsorb or physically trap the oil.

As a general rule, as the steepness of the rock coast increases, then the amounts of oil deposited decrease. On lower-angle cliffed coasts there is a greater likelihood of oil being

FOOTNOTE: Use of sections 5.4 to 5.7 to relate the expected impact of a spill on different shorelines in a specific field situation would require reference to more than one shoreline type. For example, a pocket beach can be backed by either marshes or a cliff, therefore, reference to these separate sections is necessary.

trapped in crevices or rock pools. On a vertical cliff, much of the oil will flow or fall down the cliff during the low tides. This oil could then cover clean rock surfaces and, if these are dry, the oil would not be refloated by the rising tide.

PERSISTENCE OF OIL: These exposed coasts are characterized by relatively high wave energy levels, so that dispersion by the hydraulic action of waves is effective in removing oil from the rock surfaces. Thomas (1973) reported that severely oiled rocky shores in Chedabucto Bay showed only small amounts of oil after a period of one year.

Limiting factors on the rates of natural self-cleaning in this shoreline type are: (i) the tidal range, and (ii) the deposition of oil above the normal limit of wave activity. As the tidal range increases, so available wave energy is spread over a greater vertical range. This reduces the amount of energy that is concentrated at a particular level, especially when compared to a non-tidal environment where all wave energy is concentrated at a single level. Tidal range is important in determining persistence times if large volumes of heavy oil coat the rock surfaces. This is the case in the Bay of Fundy where the tidal range is 5 m at the entrance to the Bay and increases to 15 m at the eastern end. It should be expected that in the areas of highest tidal range, the persistence of oil would be greatest.

The likelihood of oil being deposited in large volumes above the normal wave activity is low, as oil deposition is prevented during periods of storm waves by reflection of the waves from the rocks. Some oil may be splashed on the rocks above high water as breaking waves mechanically "throw" oil above the zone of normal wave activity.

Wave energy is concentrated at the low and high-water levels, as the water level is constant during the 2-hour slack periods at the turn of the tides. Oil would therefore be more rapidly dispersed by wave action at these levels.

ONSHORE PROTECTION: There is no method of protecting a cliff from contamination if no beach is present, except by offshore techniques such as booms and skimmers. On rock coasts with low angle surfaces, protection could be provided if necessary by spreading sorbent on the rock before the oil is washed ashore. Removal of the oil/sorbent mixture would be easier than removal of the oil directly from the rock surface or algae. If there is a beach at the base of a cliff, mechanical equipment can be used to build a dyke to prevent oil washing onto backshore areas (see 5, page 113).

CLEAN-UP TECHNIQUES: Hydraulic, steam-cleaning or sandblasting techniques could be used to disperse the oil from the rock surfaces where accessibility allows. There is a danger, however, that the intertidal flora and fauna would be damaged by these techniques. Results from a clean-up programme, following a spill of No. 6 fuel oil in Casco Bay, Maine, indicate conflicting effects of dispersion by high-pressure hot water techniques. In the upper intertidal zone, recolonization was slower on rocks that were cleaned when compared to rocks that were not cleaned; however, in the lower intertidal zone, repopulation was aided by this technique (Eidam et al, 1975). Unless cleaning is necessary it is recommended that the oil be left to natural dispersive processes.

If oil collects in rock crevices or hollows it can be removed by manual techniques such as pumps, buckets or cans. These techniques are recommended if clean-up is required in order to prevent redistribution of the oil to adjacent areas.

If algae in the intertidal zone is contaminated it can be cropped, but it has been reported (Eidam et al, 1975) that recovery of the algae is faster if left to natural cleaning. The primary reason for cropping would be to remove the oil in order to prevent contamination of adjacent shorelines.

CLEAN-UP GUIDELINES: Unless cleaning is necessary it is recommended that no action be taken. If cleaning is required, manual removal of oil from pools etc., is the most effective technique in terms of collecting the greatest volumes of oil in the shortest time period. This should be carried out as soon as possible after the oil reaches the shore, before it is dispersed by subsequent tides (providing that there is no danger of subsequent recontamination).

On steep, cliffed coasts care should be exercised if dispersion techniques are used in order to avoid creating a rock fall, particularly if high-pressure hoses are used. Natural cliff erosion occurs by waves undercutting the cliff until it becomes unstable and collapses. Erosion could be induced if high-pressure hoses accelerate the process during a clean-up of the rock surface, particularly in the area of the wave-cut notch near the high-water level. In the unlikely event that this could occur, it would probably lead to injury of clean-up personnel.

Manual clean-up of these rocky shores is made difficult in the intertidal zone by the usually slippery nature of the rock surfaces. Again, dangers are related, not to shoreline damage, but to the safety of clean-up personnel.

There is always a danger to flora and fauna in any clean-up technique and before dispersal techniques or cropping are implemented, the potential hazards should be assessed by biologists or ecologists.

1b. Wave-cut platform devoid of sediment.

IMPACT OF OIL: Intertidal platforms can be contaminated if the oil is on the surface of the water during an ebbing tide. As water drains from the platform, oil on the water would drain downslope, but as the surface of a platform is invariably irregular, some oil would collect and be trapped in depressions or intertidal pools. This usually would occur only under moderate or calm wave conditions.

With a rising tide, much of the oil that is trapped in depressions or tidal pools would be refloated and redistributed towards the high-water level. There it would be deposited at the slack period during the turn of the tide. On an ebbing tide, oil in the intertidal zone would be carried seawards.

PERSISTENCE OF OIL: On these exposed coasts, oil near the shore is dispersed by wave activity. As wave energy levels are usually high, this type of shoreline is self-cleaning.

The persistence time depends primarily on the type and volume of the oil and on wave energy levels following contamination. With a large volume of asphalt-rich oil, low wave energy conditions, and low air and water temperatures, the persistence time of the oil would be greatest.

ONSHORE PROTECTION: As in the case of 1a, the spreading of sorbents on the platform before the oil washes ashore would partially protect the rock surface. However, in areas where the rock platform is very wide (Photo 9), this is impractical.

CLEAN-UP TECHNIQUES: Dispersion by hydraulic, steam-cleaning or sand-blasting would remove oil from the rock surfaces. As on all rocky coasts in this region, there is at least a partial cover of algae in the intertidal zone and this could be damaged by these techniques. No action is recommended unless necessary.

Manual techniques can be used to remove oil from depressions and from tidal pools. This is recommended if action is necessary and should be initiated as soon as possible after the oil has been deposited (provided that there is no danger from recontamination), as tidal or wave activity would rapidly redistribute the oil elsewhere. Pumps, buckets, cans, or hand-operated vacuum-skimmers (Berry and Wolfe, 1975) could be used for the removal.

Oil-seaweed mixtures could be removed by cropping. However, this should be avoided unless necessary as the algae recovers more rapidly under natural conditions than if cropped (Eidam et al, 1975).

CLEAN-UP GUIDELINES: Unless cleaning is necessary it is recommended that no action be taken. If cleaning is necessary, manual removal techniques are more effective than dispersion. Removal of the oil should be carried out as soon as possible after the oil has stopped contaminating the shore. Vacuum-skimmers, either powered by hand or by machine pumps, would be particularly applicable to this type of clean-up, as the platforms are frequently very wide and the time available for clean-up before the tide floods over them is very short.

1c. Wave-cut platform and beach at high-water line.

The impact and persistence of oil on this type of shoreline are discussed separately elsewhere under 1b (page 95) and under 5 (page 104). However, the following points directly related to this shoreline type are considered here briefly.

CLEAN-UP TECHNIQUES: These techniques would be the same as discussed in the sections noted above with two additional comments.

(i) There would be little damage caused by removal of sediment from the base of a cliff if such action is necessary. The primary reason for avoiding sediment removal on beaches is to prevent overwashing of a beach by storm waves as this would result in inundation of backshore areas and landward migration of the beach system (erosion). Where a beach is at the base of a cliff, this danger would not exist, and removal of sediment contaminated by oil would, therefore, have no adverse effects.

(ii) A more desirable alternative to removal would be to redistribute the contaminated sediments from the high-water zone onto the intertidal platform, if machinery can be used. Wave action would then eventually return the material back to the base of the cliff, but in doing so it would abrade oil from the surface of the sediments and from the rock surfaces. The oil would be dispersed, and rates of weathering and degradation would be greatly increased.

CLEAN-UP GUIDELINES: It is recommended that no action be taken unless it is necessary to prevent contamination of adjacent coastal sections. Degradation of oil on sediments near the high-water mark could be accelerated if these sediments can be moved by machines onto lower parts of the intertidal zone.

1d. Wave-cut platform covered by intertidal sediments.

The impact, persistence and clean-up aspects of this shoreline type are discussed in 5.6 (page 131).

2. Sheltered resistant coasts:

IMPACT OF OIL: Oil on the sea tends to collect in sheltered environments. These coasts are protected to varying degrees from wave activity so that there is a higher probability that oil will be deposited on this type of shoreline. In very sheltered environments, such as parts of Passamaquoddy Bay where there is little or no wave reflection, the oil would simply coat the rock surfaces throughout the intertidal zone. It would collect in rock pools as the tide falls, and would be refloated and redistributed by the flooding tide. Oil would be adsorbed and trapped by the algae that generally covers the intertidal zone.

The degree of contamination depends primarily on the volume of oil in the spill. In Chedabucto Bay, oiling of rocky coasts was less severe farther away from the source, but occasionally local concentrations would be severe where an unbroken slick was washed ashore. The most severely contaminated coasts were sheltered areas directly adjacent to the source of the oil.

PERSISTENCE OF OIL: Rates of weathering and degradation would be slower in sheltered environments due to the overall lowering of energy levels. In Chedabucto Bay, oil still coated rock surfaces in sheltered intertidal zones three years after the shore was oiled (see Owens and Rashid, 1976 - Fig. 16).

Hydraulic dispersion by wave activity is greatly reduced, and this results in a reduction of oil break-up and lower rates of chemical degradation. In addition, the thickness of the oil on the rock surfaces is greater than on exposed coasts, consequently less surface area of the oil would be exposed to degradation.

ONSHORE PROTECTION: Other than the prevention of oil reaching the coasts, little can be done to protect these sheltered shorelines except for spreading of sorbents on the rock before the oil washes ashore.

CLEAN-UP TECHNIQUES: These are the same as would be implemented on exposed resistant coasts (page 93). Clean-up would often be easier in this shoreline type as the wave-cut platforms are generally narrow, but this would be offset by the higher degree of contamination that would likely occur in the sheltered locations.

CLEAN-UP GUIDELINES: Unless cleaning is necessary it is recommended that no action be taken. If cleaning is required, manual operations to remove the oil from pools and depressions (using pumps, buckets, etc.) are effective, though often time-consuming methods. As noted earlier, algae recovers from oil contamination more rapidly if left to clean naturally than if it is cropped. Dispersal techniques, such as high-pressure hoses and steam-cleaning, can also have more of an adverse effect on intertidal flora and fauna than if they are left to recover naturally.

Clean-up should be initiated only after the danger of recontamination is past.

3. Exposed unresistant cliffs:

IMPACT OF OIL: These cliffs are usually protected by a platform and/or beach, so that oil would only be deposited above the beach by storm waves. Where no beach or platform is present, the oil would be washed ashore in the same manner as discussed above for resistant coasts (page 91).

PERSISTENCE OF OIL: These cliffs are eroded by weathering, rock falls or landslips at rates that may reach 2 m/year. As the cliffs recede, any oil on the cliff face would be eroded and deposited in the littoral zone or as talus. If the oil is deposited above the active beach zone or buried, it would degrade slowly. If the oil is moved into the intertidal zone, degradation would be relatively rapid.

ONSHORE PROTECTION: There are no methods of protecting cliffs from contamination if there is no beach, except by offshore protection and only if this is practical and necessary.

Sorbent can be spread on the cliffs before the oil is washed ashore and this would facilitate any necessary clean-up.

CLEAN-UP TECHNIQUES: Erosion of the cliffs and the subsequent natural cleaning is an effective and relatively rapid process. Dispersal techniques could be applied if necessary, and these would be more efficient than on resistant coasts, as the unresistant rock surface would be partially removed with the oil.

Collection of oil from rock pools, crevices or hollows by manual techniques can remove oil that may otherwise be redistributed to adjacent shorelines. On cliffs of unconsolidated material, shovels or rakes could be used to remove oil from the cliff face.

CLEAN-UP GUIDELINES: No action is recommended as this shoreline type will clean itself naturally, usually within a relatively short (1 to 2 years, depending on the type and volume of oil) period of time.

Unresistant cliffs are basically unstable, so that care must be taken to insure that cliff stability is not disturbed by clean-up procedures. If a beach is present at the base of an exposed, unresistant cliff, it acts as a buffer and protects the base of the cliff from wave attack. Removal of the beach sediments should be avoided as this would reduce the level of the protection, expose the cliff to waves, and probably increase the rate of cliff erosion until a new beach deposit could accumulate.

Removal or excavation of oiled sediments from the lower sections of a cliff of unconsolidated sediments would change the slope at the base of the cliff. This would probably cause sliding or slumping, most probably during the first period of heavy rainfall following the operation.

Unresistant bedrock cliffs could be cleaned, if necessary, by dispersal techniques. Unless the requirement to clean the rock faces is immediate, they should be left to natural dispersive processes, which would take longer but would be equally effective. If dispersal techniques are used, in particular high-pressure hoses, the dangers of creating a rock fall or landslide by inducing an instability at the base of the cliff must be considered. This could cause a serious hazard to clean-up personnel.

4. Sheltered unresistant cliffs:

IMPACT OF OIL: Sheltered environments near a spill site are high risk areas. Oil collects in bays and coves protected from wave activity and coats the intertidal shoreline. The cliffs are rarely contaminated, except where a beach is absent or during times of high water levels.

PERSISTENCE OF OIL: Should oil be deposited on unresistant cliffs, it would be degraded slowly. The cliffs are above the limit of normal wave activity so that the dispersive effects of waves, which would otherwise increase degradation rates, are absent.

ONSHORE PROTECTION: As on all cliffed coasts, little can be done except to prevent the oil from reaching the shore or to spread sorbents before it is washed ashore.

CLEAN-UP TECHNIQUES: Dispersion or manual removal techniques can be applied to remove oil from the cliff face if necessary.

CLEAN-UP GUIDELINES: No action is recommended unless clean-up is necessary. Although the cliffs would rarely be contaminated, clean-up of the beaches at the base of the cliff by sediment removal or removal of material from the lower parts of the cliff, could affect stability. As noted in the previous section (page 102), cliff stability should not be disturbed as this could lead to rock falls or landslips.

On cliffs of unconsolidated material in sheltered environments (e.g., Photo 13), removal of beach sediments from the base of a cliff is particularly critical. This removal would expose the base of the cliff to waves and could lead to acceleration of cliff retreat in an area where erosion rates are usually very low (Photo 30).

5.5 SHORELINES WITH BEACHES

5. Cobble or mixed-sediment beaches:

IMPACT OF OIL: The primary factors controlling the impact of oil on a cobble or mixed-sediment beach are: (1) the type of oil, (2) the volume of oil, (3) the sediment type and, (4) the energy environment. On beaches that have wide spaces

Photo 30. Cliff of unconsolidated sediments in a sheltered environment at Arichat, northern Chedabucto Bay, April 1970. The intertidal sediments and the base of the cliff were coated with oil. A bulldozer was in the process of removing the base of the cliff. The cut at the base of the cliff is marked by the arrow. This could have caused cliff instability, but action was taken to prevent damage to the cliff before too much excavation had taken place.

between the individual pebbles or cobbles (Photo 15) virtually all oils can penetrate into the beach. On the cobble beaches at Chedabucto Bay, the heavy Bunker C oil penetrated as much as 1.5 m (about 4 feet) within 3 to 4 weeks after deposition. As the spaces between the individual particles decrease in size or are filled with finer sediments (Photo 14), only the lighter oils penetrate. If heavy oil is deposited on a beach in summer months, high temperatures would decrease the viscosity of the oil on the beach surface and cause it to penetrate deeper into the sediments.

On sheltered beaches if oil comes ashore in large volumes, it coats the entire intertidal zone (Photo 31). In more exposed locations, it tends to be deposited at the high-water mark but

Photo 31. Sheltered pebble-cobble beaches in northern Chedabucto Bay, May 1970. The intertidal sediments are completely covered with a thick (5-10 cm) layer of Bunker C. This oil had immobilized the sediments to produce an asphalt-like beach that had not recovered by August 1973.

has also been observed in the lower foreshore at the base of the beach face slope (on Fig. 10 this would be at the junction of the pebble-cobble sediments and the mudflats).

If the oil comes ashore during storm conditions, it will (1) coat the rock surfaces, if the beach is backed by cliffs, or (2) be deposited on the storm ridge above the high-water mark. During periods of very intense storms, when waves wash over the beach crest, it would then be carried over the storm ridge and onto the overwash deposits and marshes in the backshore.

Another important factor on the impact of oil is related to the beach conditions at the time the oil is washed ashore. This is more important on exposed coasts than in sheltered environments where the beach changes little. The normal beach cycle in the Bay of Fundy is erosion during storms and recovery in the post-storm period (page 51). If oil is deposited in the intertidal zone immediately following a storm, it will likely be buried by clean sediments, as material is moved back onto the beach in the post-storm recovery period. If oil is deposited on a beach that has previously recovered it will remain there (to be abraded by wave action) until a period of storm-wave erosion, at which time redistribution of sediments by wave attack will disperse the oil either seaward or onto the storm crest.

PERSISTENCE OF OIL: Rates of degradation are related directly to the type of oil and the energy levels in the littoral zone. Heavy oils will persist longest even in high energy environments. In the Fundy region, one factor that directly affects persistence is the large tidal ranges. Energy is spread over a wide, vertical range, even in areas exposed to high levels of wave activity. This reduces the amount of time that waves expend their energy on any part of the beach. The exceptions, however, are the high-and low-water zones where wave energy is concentrated at one level during the turn of the tides.

On exposed coasts where wave energy levels are high, dispersion of oil on the sediments in the intertidal zone is achieved by washing and abrasion. This accelerates rates of chemical weathering, and natural cleaning is often very rapid (i.e., a matter of weeks). If, however, the oil is deposited during storms and is above the normal limits of wave activity, it is subject to low energy conditions and degrades slowly. A similar situation occurs if the oil is deposited during a storm (Fig. 17a) and is then buried by material pushed onto the storm ridge by a subsequent storm (Figs. 17b and 17c). Although some of the oil is removed as waves cut into the beach, the majority of oil is buried. This may give the beach the false appearance of having been cleaned. Once oil is buried, it can persist over long periods of time, without chemical or physical change.

In Chedabucto Bay, where oil was deposited on some beaches at irregular intervals over a 4-month period, several layers of buried oil were exposed in the intertidal zone of some pebble-cobble beaches (Photo 32).

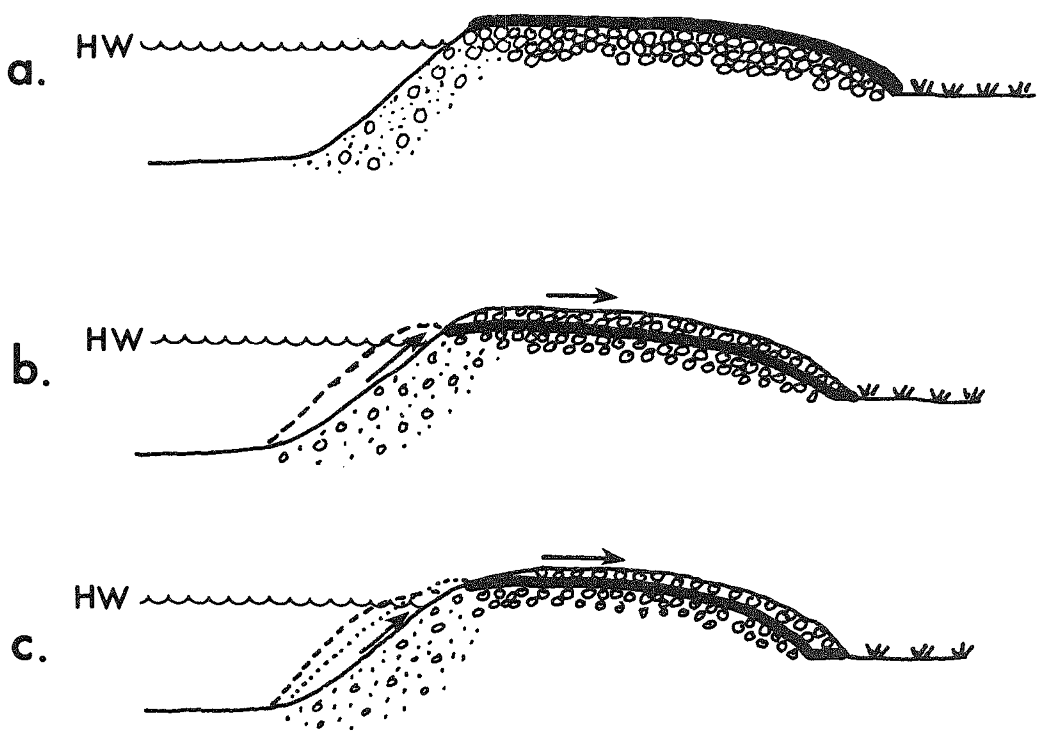


Figure 17. Schematic illustration of (a)oil deposited on top of a pebble-cobble beach during storm conditions. A second storm (b)erodes the beach face and material is thrown onto the berm and storm ridge to cover the oil layer. Part of the buried oil layer is exposed in the beach face (Photo 32). Another storm (c) continues this process of burial and exposure.

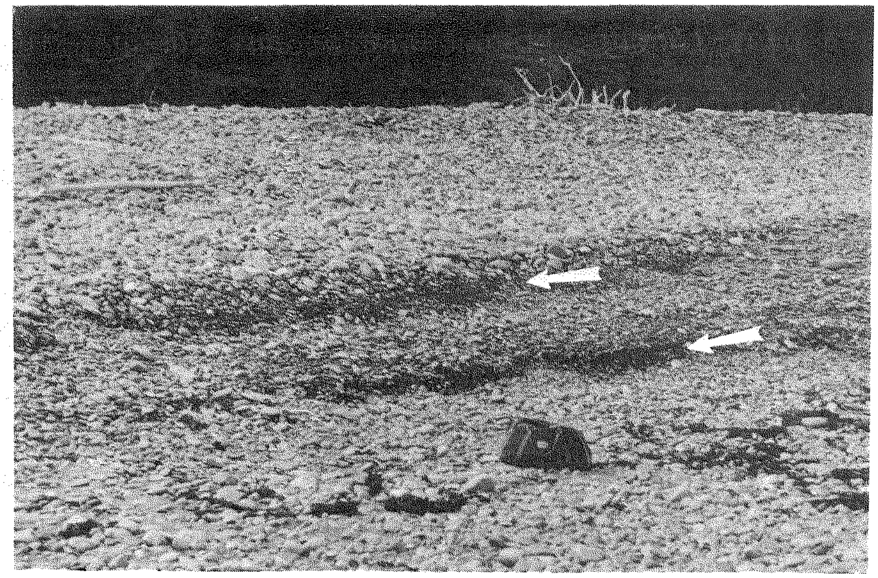


Photo 32. Hadleyville beach, Chedabucto Bay, June, 1970. The beach was contaminated on at least two occasions during periods of storms. Two layers of buried oil (indicated by the arrows) are exposed in the upper intertidal zone on this pebble-cobble beach.

Oil washed ashore in a sheltered environment may persist for a long time. On sheltered cobble beaches in north Chedabucto Bay, oil still filled the spaces between the sediments 3 years after the spill (Photo 33). As wave energy levels are low and the beaches are protected from intensive storm-wave activity, the sediments are rarely moved and the form of the beach remains constant. Where large volumes of heavy oil are washed ashore, the beach becomes immobilized and the oil acts to bind the sediments together. This reduces even further the ability of waves to move the sediments and abrade oil from the surface of the cobbles. In effect, the intertidal zone becomes an asphalt-like "pavement" rather than a beach.

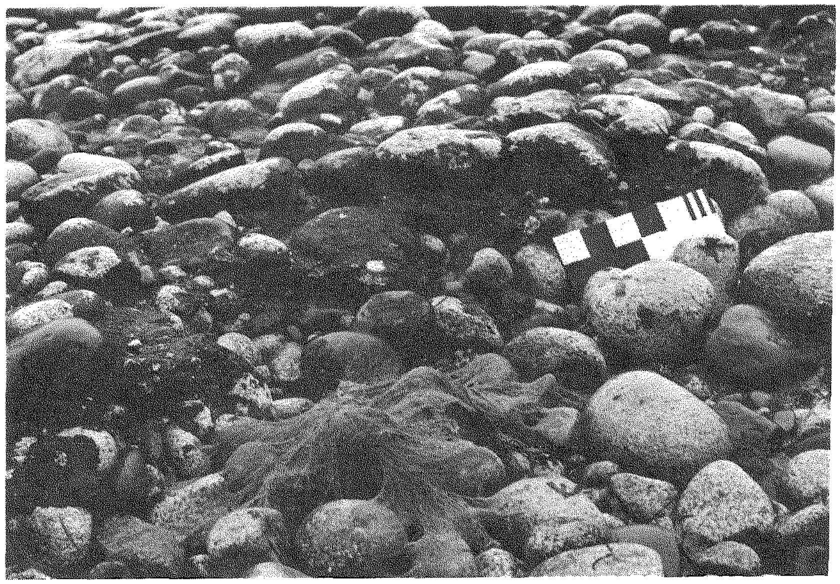


Photo 33. Sheltered cobble beach near Black Duck Cove, Nova Scotia. This beach was completely covered with oil from the "Arrow" in spring, 1970. By August, 1973 oil still remained between the sediments (upper left), but the "asphalt-beach" was being slowly broken up by wave action (lower right). The scale marks a small erosion scarp where waves had cut back into the "pavement" releasing the immobilized sediments and dispersing the heavy, weathered oil.

On some beaches, natural cleaning of oil-contaminated intertidal sediments can occur by the alongshore migration of rhythmic beach features. This type of beach form is shown in Photograph 34. Usually the features (known as beach cusps or rhythmic topography) migrate slowly alongshore in areas where there is longshore sediment transport in only one direction.

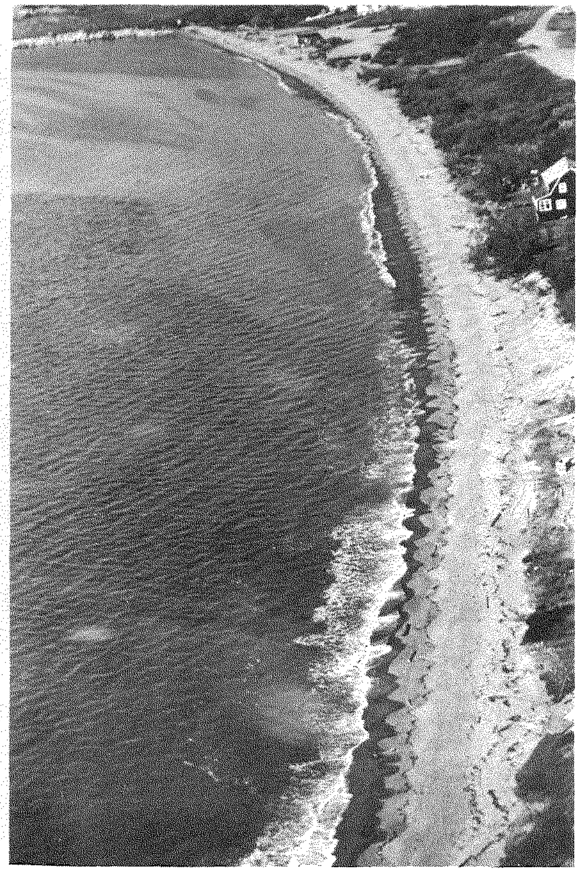


Photo 34. Sheltered pebble-cobble beach on the eastern shore of Saint John's harbour. The intertidal zone is characterized by small rhythmic features.

The effect of oil deposited at the high-water mark, as in Figure 18a, or in the intertidal zone is that the oil is eroded and dispersed. As the features migrate in one direction (Figs. 18b to 18d), some sections of the oil are gradually eroded, whereas others are buried. Eventually (Fig. 18e), once the feature has moved one wave-length alongshore, it is likely that all the oiled sediments would be mixed and abraded or dispersed, thus accelerating the degradation of oil.

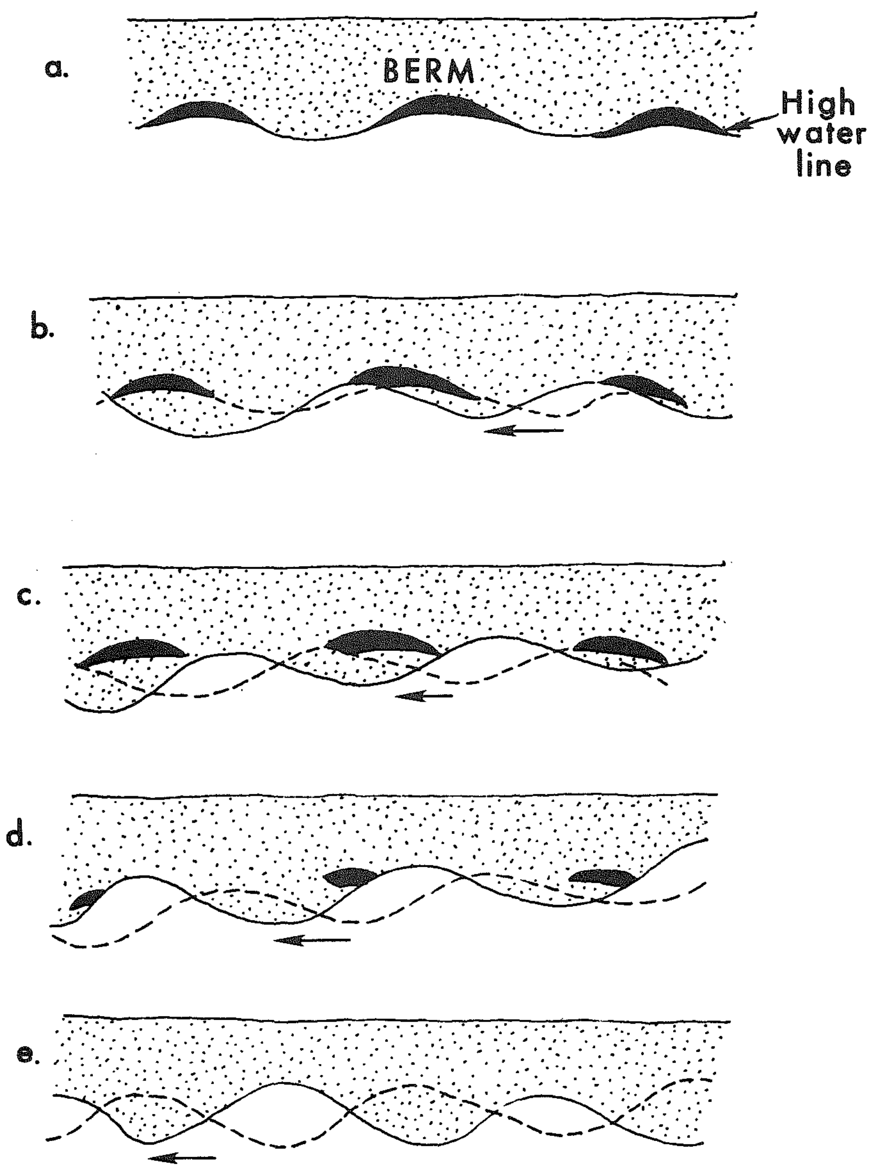


Figure 18. Plan view of effects of migrating rhythmic features on oil deposited at the high water level (see text).

ONSHORE PROTECTION: It would be difficult to protect the intertidal zone of cobble beaches as these are often very wide (up to 50-60 m) and usually the intertidal zone on exposed beaches self-cleans rapidly so that protection is not necessary.

Action to prevent oil from reaching the storm ridge or backshore marshes could be taken by using machinery to build a dyke on the berm. This would be achieved best by pushing material towards the berm from the backshore. This would not be completely effective as oil and water would infiltrate the dyke as waves wash into it, but it could be valuable if large volumes of oil are being washed ashore. In the case of light oils, these would be dispersed rapidly downwards into the beach, but at least would not affect the sensitive backshore marshes. If heavier oils are involved in the spill, these would also penetrate the dyke but the oil would be concentrated on the dyke rather than allowed to spread over the storm ridge and into the marshes.

CLEAN-UP TECHNIQUES: Should clean-up be necessary, oil on the surface of the beach can be removed manually using shovels and rakes, if amounts are small, or by use of wheeled front-end loaders for large-scale contamination. In the case of a large spill, no effective clean-up techniques are available so that mechanical removal rarely achieves the desired objectives.

Manual removal is time-consuming and may be expensive, but has proved in the past to be effective except for very large shoreline spills or for spills of light oils. In the latter case, the use of sorbents assists in the removal of these low viscosity oils.

Mechanical clean-up of this type of beach is difficult, because of the low traction afforded by these sediments and because of the depth to which oil penetrates the sediments. Further problems result if the oil has been buried. Then clean-up of oil becomes more a case of excavation rather than removal.

On exposed beaches self-cleaning is rapid in the intertidal zone but very slow above the limit of normal wave activity. In these cases, it would be more effective, and less costly, to use machinery to push the contaminated sediments from areas above the high-water mark or from the upper beach into the lower parts of the intertidal zone. Normal wave action will return the sediments back to the upper parts of the beach. In doing so, oil would be abraded from the surface of the cobbles, thus increasing the rates of dispersion and degradation.

CLEAN-UP GUIDELINES: Manual removal of oil or oil-coated sediments presents no problems with respect to beach stability, as little sediment is removed and no damage is caused to the beaches. Available mechanical techniques for clean-up operations on cobble beaches are not well-suited to the problem. This is a result of the low traction on a pebble-cobble beach and from the nature of the sediments that allow oil to penetrate into the beach. Machinery on the beach often causes mixing of clean and contaminated sediments and is not effective in removing all of the contaminated sediments.

It is rarely possible to use graders or elevated scrapers on this type of beach. From experience in Chedabucto Bay, the most efficient machine is a wheeled front-end loader (Photo 35). This equipment could operate on relatively steep cobble-slopes. Tracked vehicles used in the "Arrow" clean-up proved to have less traction. If oil is only on the beach surface and if a front-end loader is handled carefully, it is possible to remove the oil-covered sediment without removal of large quantities of clean beach material (Owens, 1971).

Photo 35. Wheeled front-end loader removing a wide (5 m), thick (10-20 cm) layer of oil deposited at the high-water level on a pebble-cobble beach in southern Chedabucto Bay, April 1970.

If oil penetrates the beach, then large volumes of material must be removed for relatively small amounts of oil. On one cobble beach in Chedabucto Bay at Hadleyville (Owens, 1971), sediments were excavated to a depth of 1 m as the oil had been buried by storm-wave activity following contamination (Photo 32).

Probably the most important aspect of large-scale mechanical clean-up on cobble beaches is concerned with the removal of sediment. Oil is often deposited in the high-water mark or berm areas. If this material is removed, then the backshore is more susceptible to overwash. The berm and storm ridge act as a natural dyke that is only breached by large storms. If this natural dyke is removed, then even small storms produce overwash and inundation of the backshore. In addition, the material that is pushed up the beach by storm waves is used to replace that which was removed. Several such storms would be required to rebuild the storm ridge. This has the effect of causing the whole beach to retreat. At Indian Cove in Chedabucto Bay, removal of sediment to depths up to 2 m from the upper intertidal zone resulted in retreat of the beach ridge by 20 m during the 12-month period following the completion of the clean-up programme (Owens and Drapeau, 1973).

This type of situation can be avoided by either pushing the contaminated material into the intertidal zone to increase the rate of dispersion and degradation, or by replacement of that material which is removed. The replacement material should be of the same size and type as the original beach material.

A third, as yet untried but a feasible approach, is to replace the removed sediments by clean overwash deposits taken from the backshore areas. These could be carried or pushed by machinery to the localities where contaminated sediments were removed. The overwash deposits are not an integral part of the active beach system, so that little or no damage would be caused by their transfer to the active sections of the beach.

If oil does not form a complete cover on the beach and if complete cleaning is not required, degradation of the oil can be accelerated by dispersal techniques. These include hydraulic action (high-pressure hoses), steam-cleaning, or machine-drawn rakes and hoes. In this approach, the oil is broken up and dispersed, and thereby larger surface areas of the oil are exposed to chemical degradation.

On very sheltered beaches, where the sediments are immobilized by the presence of large volumes of oil, the use of agricultural rakes or hoes to break up the oil cover would be of great benefit to increase rates of degradation. This is especially applicable where a thin beach deposit occurs at the base of, and protects, an unresistant cliff. In this case, sediment could be reworked, and degradation would be accelerated, without removal of sediment that could lead to cliff erosion.

5a. With beach at the base of cliff.

The only additional consideration not discussed above is that sediment removal does little damage in this type of environment (see page 98). This type of shoreline would rarely require cleaning, but should this be necessary, it is still preferable to push the contaminated material into the intertidal zone and allow waves to disperse the oil, rather than to remove the contaminated sediments from the beach.

5b. With beach with overwash.

All the relevant points for this shoreline type are discussed above. Should oil reach the backshore marshes, this presents a different kind of clean-up problem, that is discussed on pages 137 to 140.

5c. With beach with inlet and/or lagoon.

In the case of a beach backed by a closed lagoon (i.e., with no inlet), clean-up may be required if oil is washed over the beach onto the lagoon surface or the backbeach. This is a low-energy environment as only small waves are generated within the lagoon. Physical breakdown of the oil on the backshore is therefore slow, but can be accelerated by dispersal or mixing using rakes and hoes. In many situations, it may not be feasible to use mechanical methods to disperse or remove the oil on the backbeaches as they are frequently too steep for machinery.

Oil could be removed manually from the lagoon surface using buckets, small skimmers, etc., and from the backshore with shovels and rakes. The clean-up of these areas could be helped by spreading sorbents over the oil, as this is frequently easier than simply trying to remove the oil directly from the surfaces.

If an inlet is present in the beach, the areas within and adjacent to the inlet are very dynamic locations, subject to frequent changes. Dispersion of oil by waves and currents would therefore be rapid. The continual movement of sediments in the vicinity of the inlet would lead to alternate burial and exposure of oil on the intertidal sediments. Clean-up of intertidal, coarse sediments is discussed on page 131.

Where an inlet connects a lagoon or marsh to the open sea, oil often enters these sheltered areas through the inlet during the flooding tide. Protection for the marshes or lagoons could be achieved if it is possible to boom the inlet. The impact and clean-up of oil on intertidal mudflats (that are common in tidal lagoons) and on marshes are discussed on pages 133 and 137 respectively.

6. Sand beaches:

IMPACT OF OIL: Sand beaches are uncommon in the Bay of Fundy region. They usually occur in coves or small bays; sheltered locations where oil is likely to wash ashore. Only light or distillate oils would penetrate the beach sediments more than a few centimeters. The depth of penetration is greatly reduced if the sand grains are wet and if the sand is saturated. In the latter case because the spaces between the grains are filled with water.

If oil is deposited on the upper beach following a storm (Fig. 19b), it will frequently be covered by sand moving back onto the eroded beach (Figs. 19c to 19e). This would give the

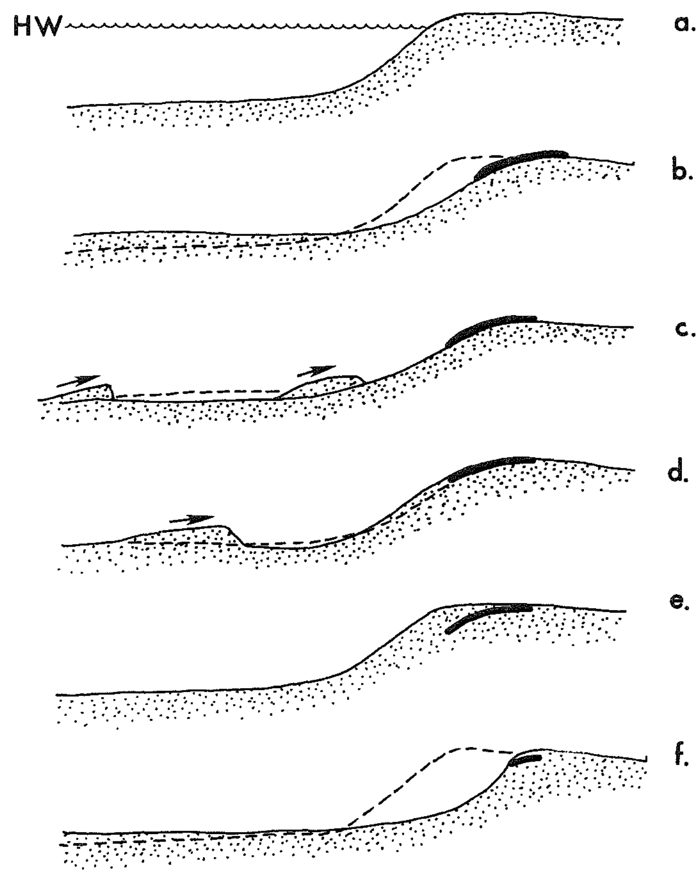


Figure 19. Effect of an erosion-deposition cycle on a sand beach after oil is deposited on the upper beach at the end of a period of storm erosion (b). As the beach recovers (c to e) from the erosion, sand is returned to the beach and buries the oil. The oil would then be exposed in the beach face (f) by the next period of storm wave erosion (Photo 36).

beach the appearance of having been cleaned naturally, whereas on the next storm the buried oil would be exposed in the beach face (Fig. 19f and Photo 36).

Photo 36. Buried oil exposed in the upper intertidal zone on a sand beach near Point Michaud, northern Chedabucto Bay, May 1970. This photograph corresponds to stage "f" in Figure 19.

PERSISTENCE OF OIL: If the oil is deposited within the limits of normal wave activity, it would be dispersed rapidly (within weeks), unless the oil cover is thick or unless the beach is in a very sheltered environment. If the beach is blanketed by oil, waves erode the seaward margin of the oil to produce a small scarp. Dispersal of the oil would be achieved as waves erode into the scarp, although very slowly. In a sheltered environment the oil could persist for a long time if wave energy is insufficient to break the oil cover.

ONSHORE PROTECTION: The berm and backshore sections of a sand beach can be protected by pushing sediment towards the high-water mark from the backshore to build a dyke. This could be achieved using machinery if the beach is accessible. The intertidal zones could not be protected in this manner due to the large tidal range. The dyke would have to be sufficiently high to prevent oil washing over the crest at high tide.

Sorbents could be used, to make clean-up easier, if placed on the intertidal beach at low water or on the berm, to mix with the oil as it washes ashore.

CLEAN-UP TECHNIQUES: As the sand beaches in the Fundy region are usually short (less than 1 km long), manual techniques would often be as effective and less costly than mechanical removal, unless there is a very thick oil cover. Machinery could be used to remove a thick oil cover by skimming material from the beach surface. If machinery is used, care should be taken to avoid removal of excessive amounts of clean sand, as this could lower the level of the beach and lead to overwash by storm waves.

An effective and tested method of cleaning sand beaches is to make windrows from passes by a bladed vehicle, such as a grader or a bulldozer with an angled blade. These windrows are then removed by front-end loaders or elevating scrapers. This technique is preferable to using bulldozers to simply push oil and sediment onto the berm for later removal, as it reduces the amount of mixing or spillage that can occur.

CLEAN-UP GUIDELINES: Sand beaches can be cleaned successfully, if required, and if proper techniques are used to prevent damage to the beach. For small spills or for short sections of beach, manual removal with rakes and shovels is recommended. If the coverage is thick and continuous over a large area, bladed vehicles are recommended to form windrows that are then removed directly into trucks by a front-end loader or an elevating scraper. Graders or scrapers are preferred over front-end loaders and bulldozers, but the latter may be more practical in some cases on the sand beaches of Fundy which are usually small in size and would leave little room for the larger-size vehicles to maneuver. In this instance, a front-end loader is preferred over a bulldozer.

The beaches should not be cleaned until the danger of recontamination is past. Care should be exercised to prevent removal of large volumes of material, and if this is necessary the material should be replaced.

If cleaning is not necessary, but it is desirable to disperse the oil, the sand on the upper parts of the beach could be pushed into the lower parts of the intertidal zone where it would be reworked, abraded, and eventually returned to its original position. This would greatly accelerate the rates of natural degradation. In sheltered environments where oil coats the intertidal zone, but a complete clean-up is not necessary, mixing of the sediments using mechanical rakes or hoes would break the oil cover, mix the beach deposits, and increase the rates of degradation.

7. Pocket beaches:

Most aspects of pocket beaches have been discussed above in the sections dealing with rock coasts and shorelines with beaches. Three points, however, should be emphasized.

(i) Pocket beaches, whether they are on rocky coasts or in large embayments (Photos 21 and 22; Figs. 13 and 14) tend to act as traps for oil. The beaches are usually set back from the general trend of the coast and are therefore often in a sheltered environment. This favours the deposition of oil. This also results in lower rates of degradation than on adjacent, more exposed sections of coast.

(ii) As pocket beaches have rock headlands and/or platforms on either side, there is a real danger of recontamination from oil trapped in rock pools. During the "Arrow" clean-up programme, a pocket beach at Indian Cove was cleaned, only to be reoiled twice within two days (Photo 37), due to the release of oil from adjacent rock headlands during spring tides (Owens, 1971).

(iii) Pocket beaches usually have a limited supply of sediment (page 57). Therefore, material removed during a

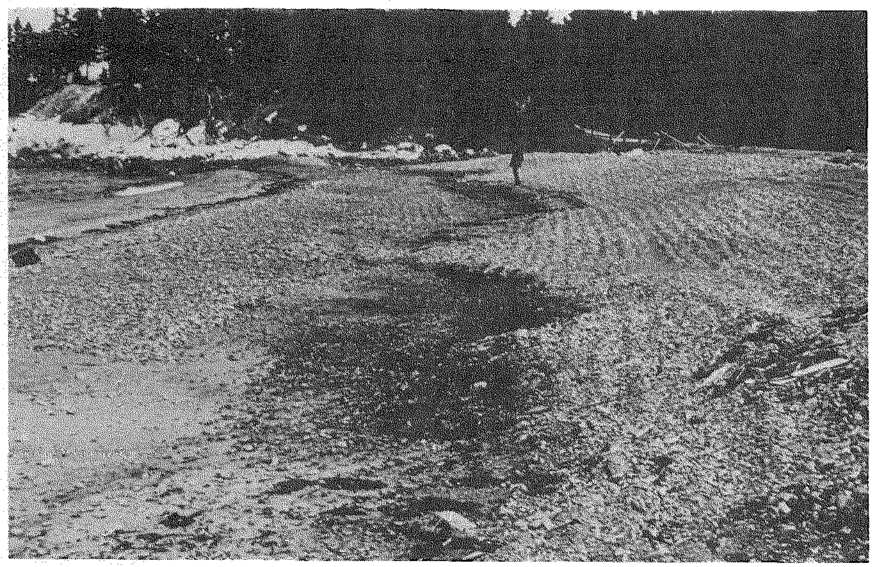


Photo 37. A pebble-cobble pocket beach at Indian Cove in Chedabucto Bay one day after the beach had been cleaned using mechanical equipment. Oil was released from pools in adjacent rock outcrops during spring tides. It was deposited at the high-water mark during the high tide slack period.

clean-up operation will be replaced naturally, only very slowly if at all. This was the case in the Indian Cove example during the "Arrow" clean-up (page 117). If a large amount of material is removed it should be replaced with similar material to avoid the danger of storm waves washing over the beach. As mentioned earlier (page 117), it is possible that overwash material from the backshore could be used as replacement sediment for material taken from the berm or from the storm ridge.

8. Beaches in sheltered environments:

IMPACT OF OIL: Typically, oil deposited on sheltered beaches completely coats the intertidal zone if the spill is large (Photos 30, 31, and 38). Oil tends to concentrate in these sheltered environments, and rates of dispersion and degradation are slow. The beach sediments in these low energy

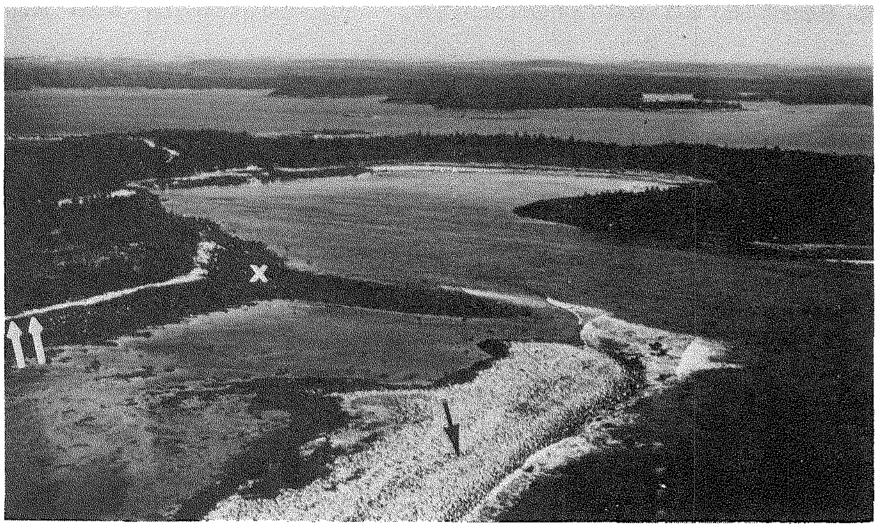
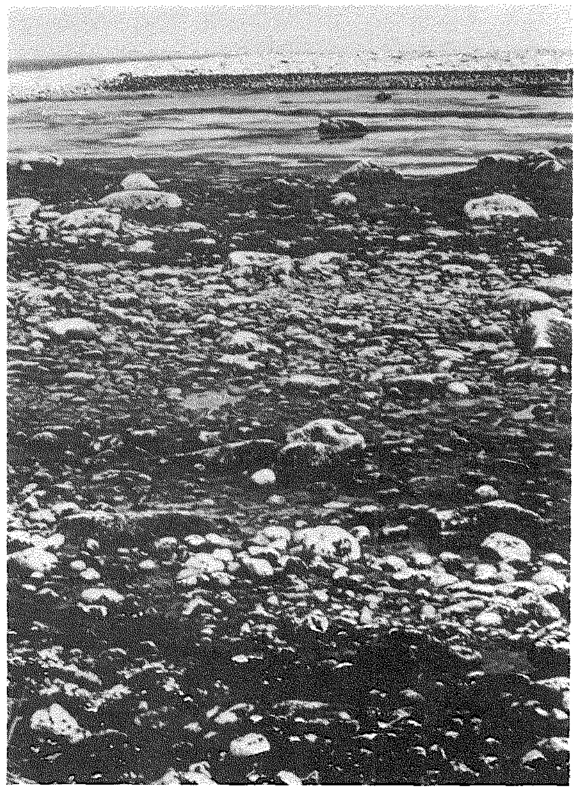


Photo 38. The contrast between the exposed and sheltered beaches following severe contamination of the pebble-cobble beaches at Black Duck Cove, N.S. is very evident in this low-tide aerial photograph, taken one month after the oil was washed ashore. Oil originally covered all of the intertidal zone but has been dispersed from the exposed beach and only traces remain at the high-water mark (located by the arrow). Double arrow indicates lagoon high-water mark.

environments are usually very poorly sorted so that penetration of the oil is limited, as the spaces between the pebbles or cobbles are usually filled with sand and/or mud. Unless the oil is deposited during storms or at times of high water levels, it is confined to the intertidal zone. This is evident in Photograph 38, where the sediments above the high-water mark on the lagoon beaches were untouched by the oil.

PERSISTENCE OF OIL: The rates of natural degradation are very low in sheltered environments. Photographs 39a and 39b illustrate a very sheltered section of beach (located on Photo 38), three years after the shoreline was contaminated by Bunker C oil from the tanker "Arrow". The oil was deposited as a thick (20 to 40 cm) layer over the entire intertidal zone in March, 1970 (Photo 38). By May, 1973 (Photo 39a), thick oil was still present over the intertidal zone in the sheltered lagoon and had only been abraded from the surfaces of the cobbles. Oil was still present as large pools, up to 30 cm deep, at some locations (Photo 39b) and had weathered little (Owens and Rashid, 1976).

The rate of weathering depends on the level of wave activity at a given location. The beaches described above are in a lagoon that is closed to all wave activity. Other, less sheltered, beaches in Chedabucto Bay did show varying degrees of self-cleaning depending on local exposure to waves. The oil spilt in Chedabucto Bay was Bunker C which initially has a low rate of weathering. The combination of large volumes of oil being washed ashore, a heavy type of oil, sheltered beaches, and cold air and water temperatures throughout most of the year means that this oil will probably persist for a considerable time in the future at Black Duck Cove. This would also be the case if a large volume of heavy oil were to be washed ashore in sheltered parts of the Bay of Fundy, such as Passamaquoddy Bay, Saint John's harbour, or the Annapolis Basin.



a

b

Photo 39. The intertidal zone in the lagoon at Black Duck Cove in May, 1973. The location of the photographs is marked by an X on Photograph 38.
(a) The intertidal zone looking across the lagoon. Oil on this beach and on the backshore of the outer beach still covers most of the intertidal zone.
(b) Concentrations of unweathered oil still persist in depressions in the lower intertidal zone.

ONSHORE PROTECTION: Little can be done in this shoreline environment except to spread sorbents in the intertidal zone at low tide before the oil is washed ashore. As the oil does not contaminate the upper parts of the beach unless water levels are high, there would be no advantage in building dykes on the berm.

CLEAN-UP TECHNIQUES: Manual clean-up would be effective if large amounts of oil are not washed ashore. If contamination is extensive and the oil deposits are thick, then mechanical equipment would be necessary if clean-up is required. As most beaches in sheltered environments are composed, at least in part, of coarse sediments, front-end loaders would be the most preferable equipment. If clean-up is not necessary, dispersion and increasing rates of weathering could be achieved by using equipment (such as rakes and hoes, mechanical shovels, or front-end loaders) to break up the oil cover. If this had been carried out on sections of the sheltered beaches of Chedabucto Bay it would, no doubt, have helped the natural cleaning of those beaches.

CLEAN-UP GUIDELINES: Unless clean-up is necessary no action is recommended. Mixing of the sediments and oil using rakes, etc., would do no damage to beach stability and would increase rates of natural weathering. Mechanical removal of sediments, if necessary, could cause the beach to be overwashed during storms and could lead to erosion. Any material removed from the beaches in sheltered environments should be replaced, as the beach deposits are usually not extensive and rates of natural sediment replacement are very slow.

5.6 SHORELINES WITH INTERTIDAL SEDIMENTS

9. Coarse sediments:

IMPACT OF OIL: Deposition of oil residues in the intertidal zone would probably be limited to heavy or tarry oil residues, as light-grade oils would be easily refloated by a flooding tide. Deposition would occur as the water level is lowered during the ebb stage and oil would collect in depressions and in the voids between individual cobbles or pebbles. Following the "Arrow" spill in 1970, many of the intertidal deposits of pebble-cobble material in exposed high-energy areas near the source of the spill were completely covered with Bunker C.

PERSISTENCE OF OIL: Even on exposed coasts, rates of dispersion can be low, as oil penetrates the surface of sediments and fills the spaces between cobbles and pebbles so that it is protected from waves or currents. Coarse sediments on an intertidal wave-cut platform are often stable and not moved by normal wave action. Deposition of heavy oils tends to produce an "asphalt pavement" and sediment redistribution is greatly reduced. Examples of this type of situation were observed on exposed intertidal areas in Chedabucto Bay 3 years after the initial contamination. Sand and pebbles had become incorporated in the surface of the oil to give the appearance of an asphalt road, and the cobble sediments had become completely immobilized.

Some break-up of the oil-sediment "pavement" was observed where cobble material had been moved by wave or current action. This movement of material provided an edge or small scarp which could be undercut by further wave activity. The scarp was then cut back further on an increasingly wider front. This type of erosion proceeds slowly, and in low energy environments, it would be barely perceptible.

Rates of weathering or dispersion are slow if an "asphalt pavement" is formed, as little of the oil is exposed. Where the oil deposits are less thick and the sediments are not immobilized, rates of degradation are higher. In this case, if the oil coats pebbles, cobbles or boulders, a large surface area is exposed to abrasion, dispersion and weathering.

ONSHORE PROTECTION: Little or nothing can be done to protect the intertidal zones, particularly where they are very wide (Photo 12).

CLEAN-UP TECHNIQUES: No effective or practical clean-up techniques are available for this type of environment. If the contamination is severe, machinery could be used to try to break up the oil cover and thereby help dispersion and weathering. For lesser amounts of oil, manual removal with shovels would be difficult but probably effective.

CLEAN-UP GUIDELINES: No action to clean the intertidal zone is recommended. Even if it is desirable, no effective methods are available. Dispersal techniques or machinery could be used to break up the oil cover. The time available for such work is limited and caution should be exercised to ensure that men and equipment are not caught by the rapidly rising flood tides, particularly where the intertidal zone is very wide.

10. Intertidal mud:

IMPACT OF OIL: All except the very light grades of oil would not penetrate even dry intertidal mud deposits. Heavy and tarry oil residues would be deposited on the surface of the mud by an ebbing tide and would remain there if they could not be refloated by flood tides. If tidal currents are sufficiently strong, they would sweep the residues from high areas and they would then collect in depressions. In areas of rapid sediment transport, the residues could become buried within one or two tidal cycles.

Mudflats are an important biological environment and the fauna in the intertidal muds are most susceptible to the possibility of smothering by blanketing of oil or death by toxic components.

PERSISTENCE OF OIL: Oil on the surface of the mudflats would be subject to degradation from energy supplied by currents in the intertidal zone. If buried, oxygen supplies would be cut off and degradation of the residues would cease. The oil would not degrade at all until subsequently uncovered by further movements of the sediments. Mud deposits are rarely static so that this environment may appear clean within a few weeks following a spill, although the residues may be buried rather than dispersed.

ONSHORE PROTECTION: Nothing can be done to protect this type of environment except in the case where the mud deposits are in a lagoon that is connected to the open sea by an inlet. In this case, if booms across the inlet are practical, they could be used to keep oil out of the lagoonal areas.

CLEAN-UP TECHNIQUES: No effective or practical clean-up techniques are available for this type of environment. Small amounts of oil can be removed manually, and larger accumulations could be cleaned by machinery if the sites are accessible.

CLEAN-UP GUIDELINES: No action is recommended and frequently none is possible. Mudflats often cannot support the weight of a person, let alone machinery. In areas that are accessible, extreme caution must be exercised to prevent men and equipment from becoming stuck in patches of soft mud. Where intertidal mudflats are wide (Photos 1b and 5; Fig. 14), the water rapidly covers the lower foreshore at the start of the flood tide. Mudflats are dissected by steep-sided, deep drainage channels which can also hinder access.

11. Intertidal sand:

IMPACT OF OIL: Light grade oils could penetrate unsaturated sands, but otherwise, oil residues would remain on the surface of intertidal sands. Due to the constant movement of sediments in this type of environment, any oil not refloated by flood tides would be subject to frequent burial and exposure as sand waves migrate over the intertidal flats (Photo 27 and Fig. 20). Large lumps of oil would probably be broken up into small balls, that would be rolled by the tidal currents. These would be coated with sand grains and would probably collect in the troughs and depressions between the sand waves.

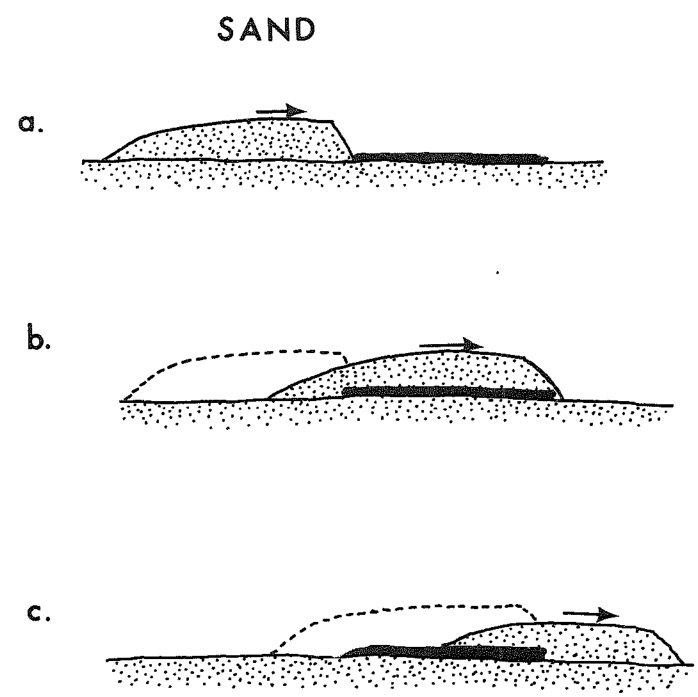


Figure 20. Sand waves in the intertidal zone frequently bury and re-expose oil deposited in this environment (Photos 27 & 28).

PERSISTENCE OF OIL: Tidal currents are strong, up to 2 m/s, so that unless the oil is buried, rates of dispersion and degradation would be rapid. If the oil is buried, no degradation would occur until it is re-exposed.

ONSHORE PROTECTION: No practical methods of protecting the intertidal areas are possible.

CLEAN-UP TECHNIQUES: If it necessary and practical to remove oil residues from intertidal sand deposits, small lumps can be easily removed with shovels and rakes, whereas larger amounts can be removed by machinery. In this type of environment, where the sands are rarely flat, a grader or elevating scraper would be impractical. The most efficient equipment would be a front-end loader.

CLEAN-UP GUIDELINES: On the open sand flats of the Minas Basin no action is recommended. In this environment, the rapidity with which the tide rises and the hazards of encountering patches of soft sand make unnecessary movement across the intertidal areas risky. Other areas of intertidal sand, such as the Annapolis Basin (Photo 28), are more accessible to men and machines. In this area, if clean-up is necessary, front-end loaders could be used to remove large patches of oil. Manual techniques would be effective for smaller deposits. In this environment no damage would result from removal of the intertidal sediments.

5.7 SHORELINES WITH VEGETATION

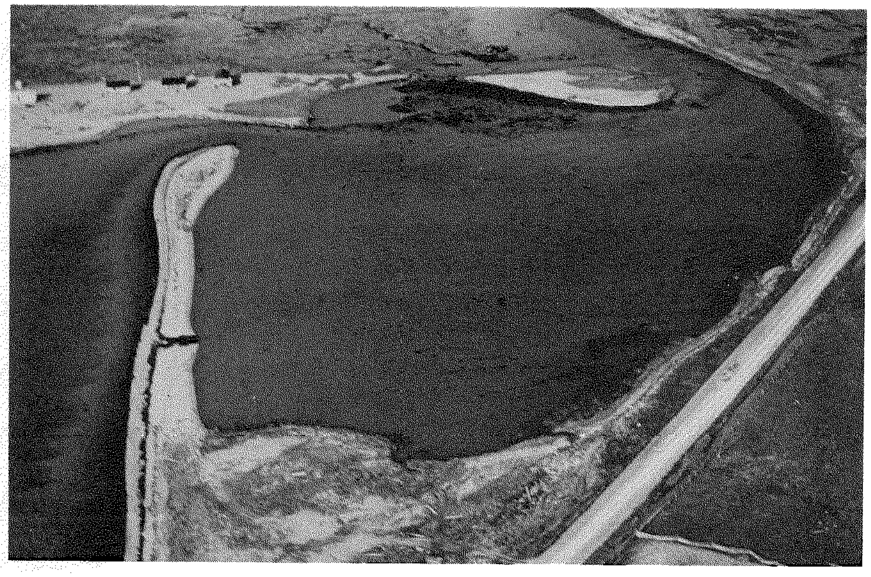
12. Marshes:

IMPACT OF OIL: Marshes develop in sheltered environments; areas that are very susceptible to oil deposition. The effect of a spill on a marsh depends primarily on the water level at the time that the oil reaches the area. If water covers the marsh surface, as would be the case during storm surges or the spring high tides, the oil would be deposited on the vegetation.

Many of the Fundy marshes have been reclaimed by dyke construction and these areas would be protected except during periods of exceptionally high water levels. If water levels do not exceed the normal high-water mark, the oil would be deposited only at the marsh edge and in the tidal creeks (Photo 40).

Marshes are the most fragile of the shoreline types in the Fundy region in terms of the ecological environment. The impact on the vegetation varies with the type of oil. Light grades tend to have a more adverse effect than heavy or tarry oils. Also, less damage is caused to marsh vegetation if contamination occurs during fall or winter (Cowell, 1971). It has been found that marshes recover from spill effects within 1 or 2 years (Cowell, 1971). Oil may be present, but it does not severely impede growth of perennial species.

PERSISTENCE OF OIL: Marshes are very active environments in terms of biochemical interaction. This leads to rapid degradation of all but the most asphaltic oil residues. If oil on the marsh surface is covered by sediments it will not degrade under these anaerobic conditions and may persist for many years.



a

b

Photo 40. Marshes in a sheltered lagoon on the north shore of the Baie de Chaleur, October 1974.
(a) Winds moved slicks onto the beach and into the lagoon where they accumulated at the shoreline.
(b) Oil also became trapped in tidal creeks (located by the arrow). Water levels were normal therefore the oil was only deposited on the edges of the marsh.

ONSHORE PROTECTION: The dykes that were constructed to reclaim marshes for farmland (Photo 26) protect those areas except during unusually high storm surges. Similar protection could be given to unreclaimed marshes; if it is necessary, if sufficient time is available to build small dykes at the high-water mark, if material for the dykes is readily available, and if sections of marsh that would require such protection are accessible. It is possible to give such protection and although it would be a costly procedure, action should be taken if possible as marshes are the most affected ecological shore-line environment in terms of oil contamination.

CLEAN-UP TECHNIQUES: Oil deposited on the edges of the marshes could be removed manually with rakes and shovels. If oil is trapped in creeks (Photo 40b), it can be skimmed off the surface at high tides. Where vegetation has been covered, it can be cropped if necessary. Baker (1971) points out that some plants actually benefit from cropping (e.g., *Spartina* and *Juncus*), as this increases the number of shoots on the plant.

Localized burning of the oil and grass has been recommended (Wardley-Smith, 1968) and has been shown to be effective as long as the lower stems and roots are not burnt.

CLEAN-UP GUIDELINES: Marshes are a sensitive and dynamic environment that may recover rapidly even from severe spills, however, the highest priority should be given to protection from contamination. Clean-up operations in this environment should only be undertaken if necessary and should be planned in consultation with biologists. Machinery should not be used as this can cause extensive damage. Burning, if it is necessary, should only be carried out in fall and winter months.

As marshes are often habitats for wildlife, particularly birds, it may be better to keep the birds away rather than to try to clean the marsh. This is particularly applicable during migration seasons when the marsh would only be a temporary stopover.

5.8 SUMMARY

Decisions to implement a protection or clean-up operation are based on a wide range of criteria that include: economic or recreational use of a shoreline; rates of natural cleaning; biological sensitivity; shoreline stability; possibilities of recontamination; effectiveness of available techniques, and accessibility.

The estimated effects of a spill in the Fundy region, the assessment of protection and clean-up techniques, and potential problems of a clean-up programme are summarized in Tables 6 to 9. These tables are intended only as an abridged version of the detailed discussions presented in sections 5.4 to 5.7. The tables are followed by a brief discussion of shoreline sensitivity (in terms of protection and clean-up) and of the applicability and effectiveness of clean-up techniques.

Impact, Persistence, Protection and Clean-Up

The synopsis given in Tables 6 to 9 is presented in the same sequence as the text discussion. In the event of a spill, particularly a major one, it is important to refer to the discussion of the processes and the shoreline types (Parts 2, 3, and 4) as well as the impact of oil on the different shoreline types.

The shoreline types, in the first column of these tables, follow the numbering used in the text of Parts 4 and 5 (as given on page 41).

TABLE 6. ROCK OR CLIFF SHORELINES

SHORELINE TYPE	IMPACT	PERSISTENCE	ONSHORE PROTECTION TECHNIQUES	CLEAN-UP TECHNIQUES	CLEAN-UP GUIDELINES
1a	*Oil deposited in calm conditions in intertidal zone if rock is dry: collects in pools & crevices: during storms, oil splashed above high-water mark.*	*Usually low, unless oil is deposited above normal limit of wave activity.*	*None effective: can spread sorbents to make oil removal easier.*	*Can disperse oil with hoses, steam, or sand blasting if necessary: can remove oil from pools & crevices manually: can crop oiled-algae.*	*No action recommended: if necessary, manual removal effective: dispersion can damage flora and fauna and could cause cliff instability.*
1b	*Oil collects in pools on ebbing tide and at the high-water mark on flood tide.*	*Natural dispersion rapid: but slow if in low energy area, cold temperatures and heavy oil.*	*None effective: sorbents assist if clean-up is planned.*	*Dispersion, manual removal or cropping could be effective.*	*No action recommended: intertidal zone only exposed for short periods of time.*
1c	*See* 1b *&* 5.	*See* 1b *&* 5.	*See* 1b *&* 5.	*Can remove sediments or push them into intertidal zone for reworking.*	*No action recommended: reworking preferable to removal.*
1d	*See* 9, 10 *&* 11 →			*See* 9, 10 *&* 11 →	

SHORELINE TYPE	IMPACT	PERSISTENCE	ONSHORE PROTECTION TECHNIQUES	CLEAN-UP TECHNIQUES	CLEAN-UP GUIDELINES
2	*Oil collects in sheltered areas: if oil volume is large, will coat intertidal zone: if storm waves, oil deposited above high water.*	*Degradation is slow, especially above the limit of normal wave action.*	*None effective: sorbents could assist if clean-up is planned.*	*Same as* 1a.	*No action recommended: manual removal can be effective.*
3	*Oil usually is deposited on the beach: the cliff is only contaminated during storms.*	*Natural erosion removes the oil.*	*None effective: sorbents could assist if clean-up is planned.*	*Dispersion or manual removal could be effective.*	*No action recommended: if necessary, manual removal effective: avoid inducing cliff instability.*
4	*Oil collects in sheltered areas: oil usually deposited on beach below cliff except during storms.*	*Degradation is slow, especially above the limit of normal wave action.*	*None effective: sorbents could assist if clean-up is planned.*	*Dispersion or manual removal could be effective.*	*No action recommended: if necessary, manual removal effective: avoid inducing cliff instability*

TABLE 7. SHORELINES WITH BEACHES

SHORELINE TYPE	IMPACT	PERSISTENCE	ONSHORE PROTECTION TECHNIQUES	CLEAN-UP TECHNIQUES	CLEAN-UP GUIDELINES
5	*Oil penetrates sediments: if large volume of oil, covers intertidal zone; otherwise, deposition primarily near high-water level or on backshore or marshes during storms. Oil on backshore may be buried by later storms.*	*Dispersion and weathering rapid in intertidal zone on exposed beaches: slow above intertidal zone and in sheltered areas. In sheltered areas, large volumes can produce an immobilized beach ("asphalt pavement").*	*None effective for intertidal zone because of high tidal ranges. Can protect backshore by dyke at high-water level.*	*Small spills: manual removal can be effective; sorbents useful for the lighter-grade oils. Large spills: mechanical clean-up using front-end loaders to push material into intertidal zone or break-up "asphalt pavement" and disperse oil.*	*If action is necessary, manual techniques recommended. For large spills, mechanical techniques can rework sediments or break-up immobilized beach. Wheeled front-end loader preferred to other machines. Sediment removed from upper beach should be replaced to prevent damage to beach stability.*
5a	*See* 1c.	*See* 1c.	*See* 1c.	*See* 1c.	*See* 1c.
5b	*See* 5.	*See* 5.	*See* 5.	*See* 5.	*See* 5.
5c	*Deposition in backshore intertidal areas.* *See also* 9, 10 *and* 12. →	*Degradation is slow on backshore beaches: rapid in inlets.*	*Backshore areas can be protected by dykes on the beach or booms in inlet.*	*Manual removal, dispersion or mixing can be effective.*	*Dispersion or break-up of oil cover increases degradation.*

SHORELINE TYPE	IMPACT	PERSISTENCE	ONSHORE PROTECTION TECHNIQUES	CLEAN-UP TECHNIQUES	CLEAN-UP GUIDELINES
6	*Only lighter oils penetrate beach. Oil deposited near high-water level unless large volume and/or calm conditions, then coats intertidal zone. During storms, oil deposited on backshore or marsh.*	*Low if oil is in zone of normal wave activity: high if buried or above high-water level.*	*Backshore areas can be protected by dyke at high-water level.*	*Small spills: manual removal effective. Large spills: machinery can skim oil & contaminated sediments from beach or can push oiled sediments into intertidal zone for reworking or can break-up oil cover.*	*Manual removal recommended. For large spills, front-end loader preferable and probably most effective in confined areas. Dispersal and mixing preferable to sediment removal.*
7	*Potential oil traps. Danger of recontamination from adjacent rock areas.*	*Usually sheltered, so degradation slow, except in large exposed embayments.*	*SEE RELEVANT SECTIONS.*		*Usually limited sediment replenishment so, replacement necessary for large volumes removed.*
8	*Oil collects in sheltered areas, will coat intertidal zone except during storms. "Asphalt pavement" with large volumes of oil.*	*Dispersion and degradation is slow (may be years).*	*None effective in intertidal zone; sorbents can assist if a clean-up is planned. Dykes would protect backshore.*	*Manual removal or machines to break-up the oil can be effective.*	*Mechanical sediment removal to be avoided. Mixing and dispersion could be effective. Manual removal recommended if action is necessary.*

TABLE 8. SHORELINES WITH INTERTIDAL SEDIMENTS

SHORELINE TYPE	IMPACT	PERSISTENCE	ONSHORE PROTECTION TECHNIQUES	CLEAN-UP TECHNIQUES	CLEAN-UP GUIDELINES
9	*Deposition in intertidal zone during ebb tide. Oil in sediment forms "asphalt pavement", even on exposed coasts if the spill is large.*	*"Asphalt pavement" very persistent, surface oil dispersed more rapidly.*	*None effective.*	*Small spills: can remove oil manually. Large spills: no effective techniques. Can break-up oil cover with machinery.*	*No action recommended: except to break up oil, if necessary, with machinery.*
10	*Light-grade oils dispersed, heavy oils can collect in depressions during ebb tide. Oil may be buried by sand waves.*	*Surface oils degrade rapidly, buried oil does not degrade.*	*None effective.*	*No practical or effective techniques except for small spill - in this case, can use manual or mechanical removal.*	*No action recommended: very difficult to clean because of access, soft mud, tidal creeks, and large tidal range.*
11	*Light-grade oils can penetrate sands; heavy oils collect in depressions during ebb tide. Frequent burial and reexposure.*	*Exposed oil would degrade rapidly. Buried oil does not degrade.*	*None effective.*	*Small spills could be removed manually; large spills could be cleaned by machinery if conditions permit.*	*No action recommended: only practical machine would be wheeled front-end loader, but it may get stuck. Small spills can be cleaned manually.*

TABLE 9. MARSHES

SHORELINE TYPE	IMPACT	PERSISTENCE	ONSHORE PROTECTION TECHNIQUES	CLEAN-UP TECHNIQUES	CLEAN-UP GUIDELINES
12	*Oil deposited on marsh edges and in creeks with normal tides. Oil deposited in marsh surface with high-water levels. Less damage if spill is in winter.*	*Degradation usually rapid except for tarry oils or if oil is buried.*	*Marsh should be protected if possible. Dykes effective at edge of marsh if feasible.*	*Manual removal or cropping of marsh. Manual removal in the creeks at high tides. Controlled burning may be possible.*	*Protection preferable to clean-up. No machinery. Manual removal recommended. Burning possible in fall or winter only.*

Shoreline Sensitivity

The major shoreline types or shoreline environments can be assigned a sensitivity ranking in terms of the impact of a spill. Group I (Table 10) is the most sensitive. These environments or shorelines would be afforded the highest priority for protection and clean-up. Not only is oil likely to collect in these sheltered areas, but it would also persist the longest.

Group II would be affected in a similar manner, but these environments are less sensitive in terms of the potential harmful impact on the flora and fauna of the shore zone. The shoreline environments of Group III are less likely to be severely impacted and degradation rates are higher. Group IV would generally not need protection or clean-up, and rates of dispersion and degradation are high.

ASSESSMENT OF CLEAN-UP TECHNIQUES

The applicability and effectiveness of a particular clean-up technique will vary considerably, depending on the type and volume of the oil, the nature of the shoreline, and the shoreline sediments. As a general guide, Table 11 indicates the applicability and effectiveness of nine clean-up techniques with reference to the shoreline types of the Bay of Fundy coast. Any attempt such as this one in Table 11 to recommend clean-up techniques for specific shoreline types,

TABLE 10. SHORELINE SENSITIVITY

DECREASING SENSITIVITY ↓

I	marshes lagoons
II	sheltered environments pocket beaches
III	exposed beaches mud flats sand flats
IV	exposed rock or cliff environments

TABLE 11. SHORELINE CLEAN-UP TECHNIQUES

	i	ii	iii	iv	v	vi	vii	viii	ix
1a	O?	O	X	X	NA	NA	+	O	X
1b	O?	O	X	X	NA	NA	+	O	X
1c	O?	O	X	X	+	O	+	O	X
2	O?	O	X	X	NA	NA	+	O	X
3	O?	O	X	X	NA	X	+	O	X
4	O?	O	X	X	NA	X	+	O	X
5	O?	O	X	X	+	O	+	O	X
5a	O?	O	X	X	+	O	+	O	X
5b	O?	O	NA	NA	+	O	+	O	X
5c	O?	O	NA	NA	+	O	+	O	X
6	O?	X	NA	NA	X	+	+	O	X
7a	O?	O	NA	NA	+	O	+	O	X
7b	O?	O	NA	NA	+	O	+	O	X
8	O?	O	NA	NA	+	O	+	O	X
9	X	O	NA	NA	O	O	+	O	X
10	X	NA	NA	NA	X	X	+	O	X
11	X	NA	NA	NA	X	O	+	O	X
12	O?	NA	NA	NA	X	X	+	NA	O

\+ Recommended O May be of use (depending on local conditions)
X Not Recommended NA Not applicable

Dispersion

i biodegradable
ii hydraulic
iii steam-cleaning
iv sand-blasting
v mixing

Removal

vi mechanical
vii manual
viii sorbents
ix burning

must necessarily be very generalized, and on-site decisions must take into account local conditions.

Dispersion: (i) Chemical dispersants have been banned by many agencies because of the toxic effects on flora and fauna. At present, progress in the development of a new generation of non-toxic biodegradable dispersants provides a positive approach that may be of great value in the near future (T. Whelan, III, pers. comm.). If acceptable biodegradable dispersants are developed in the near future these would be particularly applicable and effective on rocky shorelines and on coarse-sediment beaches.

(ii) Hydraulic dispersion can be used to wash oil from rock surfaces and cobble beaches. This has been found to be an effective method but on cobble beaches it merely washes the oil from the surface and into the sediments, rather than cleaning the beach.

(iii) Steam-cleaning removes oil from rock or boulders but leaves residual oil on the surfaces as a stain. This technique can be harmful to flora and fauna and is not recommended as it is more expensive and potentially more harmful than hydraulic dispersion.

(iv) Sand-blasting is a slow but effective technique for removal of oil from rock and boulder surfaces. The method is not recommended as it is slower, more expensive and potentially more harmful to the biota than hydraulic dispersion.

(v) Mixing of oil contaminated sediments promotes evaporation and weathering by exposing a large surface area of the oil to degradation. This is especially effective for light-grade oils that evaporate easily. Care must be exercised to avoid burial of the oil, as this reduces degradation.

Removal: (vi) Where large amounts of oil contaminate a beach, mechanical removal can prove effective if used correctly. On sand beaches, where oil does not penetrate, this technique is particularly effective as long as the equipment can remove the oil and sediment by skimming. This technique is more difficult on cobble or mixed-sediment beaches where oil penetrates deeper and traction is reduced. If large volumes of sediment are removed from the upper beach, they should be replaced to avoid damage to beach stability. Care must be exercised to avoid mixing clean and contaminated sediments. In this respect it is more effective to directly remove the sediment and load it into trucks, rather than to push the contaminated material onto the backbeach with bulldozers and then remove it. On sand beaches, graders are recommended if they can be used; if not, a wheeled front-end loader can be effective. On cobble or mixed-sediment beaches, a wheeled front-end loader has been found to be the most effective machine.

(vii) Manual removal is effective, particularly on rock coasts and on beaches where contamination is light. Manual techniques can be used in combination with mechanical removal and with sorbents.

(viii) Sorbents, such as straw, peat moss, or synthetic products, can be spread in the shore zone prior to oil being washed ashore. The sorbent collects oil and can prevent contamination of rock or boulder-cobble surfaces and can prevent penetration of oil on beaches of coarse sediments. The sorbent-oil mixture must be removed from the shore zone.

(ix) Burning of oil on the shore often requires additives to initiate ignition and maintain combustion. Frequently, residues remain after burning. On beaches, burning can cause penetration of the oil into the sediments. This technique is not recommended, except for marsh environments in fall or winter months where it can have beneficial effects.

In addition to these techniques, contemporary research into shoreline protection and sediment cleaning (see Bibliography, page 160) may yield useful results. In particular, low-cost degradable protective polymers that prevent adsorbtion and absorbtion of oil by sediments and rocks could become valuable tools in the protection of sensitive shorelines.

Manual removal techniques are the most generally applicable and the least damaging methods of cleaning shorelines, except where contamination is severe. Dispersion of oil may be effective for cleaning, but it releases oil that will be redistributed and redeposited elsewhere, unless it is collected and removed.

A major point to be remembered in implementing any clean-up technique is that the effectiveness can be immediately nullified if there is a danger of recontamination after a shoreline has been cleaned.

PART 6 - CONCLUSIONS

In the Bay of Fundy region, contingency plans for a coastal oil spill must allow for a wide range of shoreline types and a variety of coastal environments. A major spill would present many problems in this area. The rugged and inaccessible nature of much of this coast would preclude clean-up in many areas. Also, the large tidal range and the wide intertidal zone would present logistical problems at many sites. For many types of shoreline, the technology to remove all of the oil does not exist. This does not preclude clean-up operations: efforts to minimize the damage caused by a spill can reduce the detrimental effect on local communities and on shoreline flora and fauna. Care must be exercised as the application of unsuitable techniques may lead to more damage than would have been caused by the oil alone. Knowledge of the nature of the shoreline and of the shoreline processes provides a sound basis for the preparation of effective protection and clean-up plans for the rapid response necessary in the event of a major spill.

Oil persists for a long time in low energy (sheltered) environments, but degrades rapidly on exposed coasts. If the contamination does not damage shoreline areas and does not present economic or social problems, it is recommended that the oil be left to disperse and degrade naturally.

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APPENDIX A

LOCATIONS WITHIN THE BAY OF FUNDY

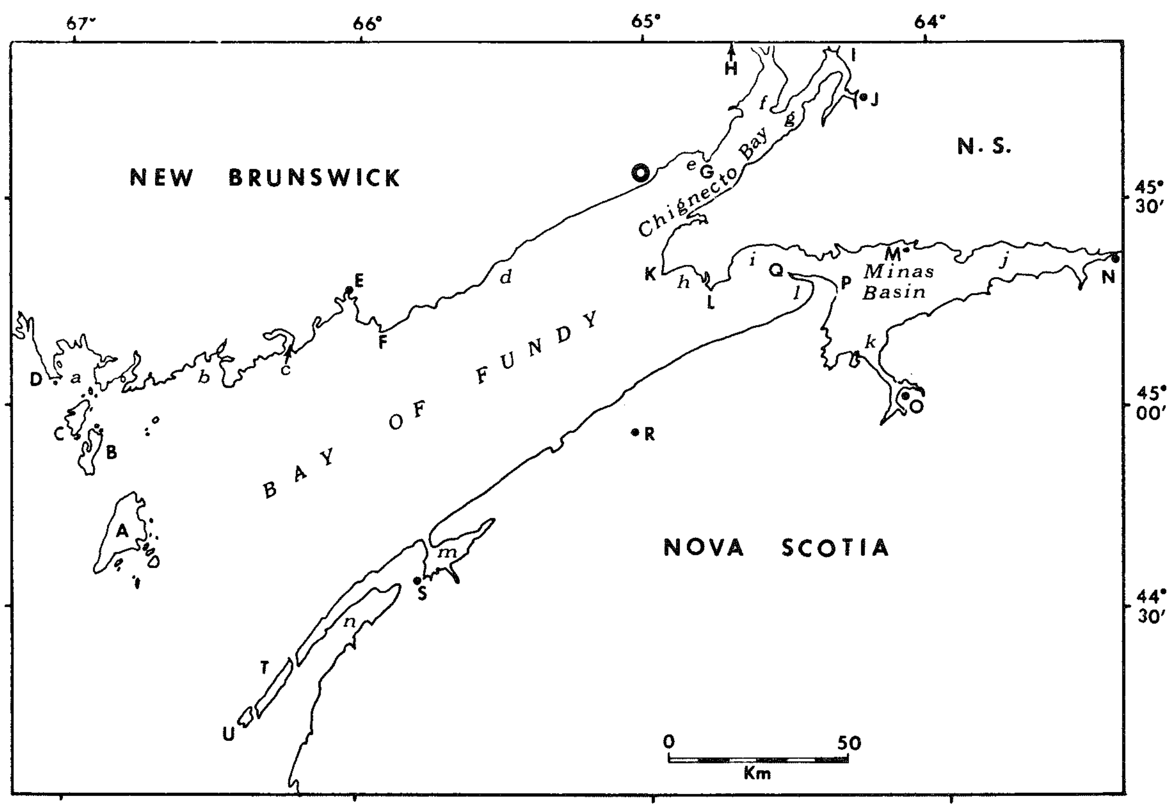

Figure 21. Locations within the Bay of Fundy.

LOCATION INDEX

a - Passamaquoddy Bay
b - Maces Bay
c - Musquash Harbour
d - Quaco Bay
e - Salisbury Bay (Rocher Bay)
f - Shepody Bay
g - Cumberland Basin
h - Advocate Bay
i - Greville Bay
j - Cobequid Bay
k - Avon River
l - Scots Bay
m - Annapolis Basin
n - St Marys Bay

A - Grand Manan Is
B - Campobello Is
C - Deer Is
D - St Andrews
E - Saint John
F - Cape Spencer
G - Cape Enragé
H - Moncton
I - Sackville
J - Amherst
K - Cape Chignecto
L - Cape d'Or
M - Five Islands
N - Truro
O - Wolfville
P - Cape Blomidon
Q - Cape Split
R - Greenwood
S - Digby
T - Long Is
U - Brier Is

⊙ - Fundy National Park

APPENDIX B

DEFINITION OF TERMS

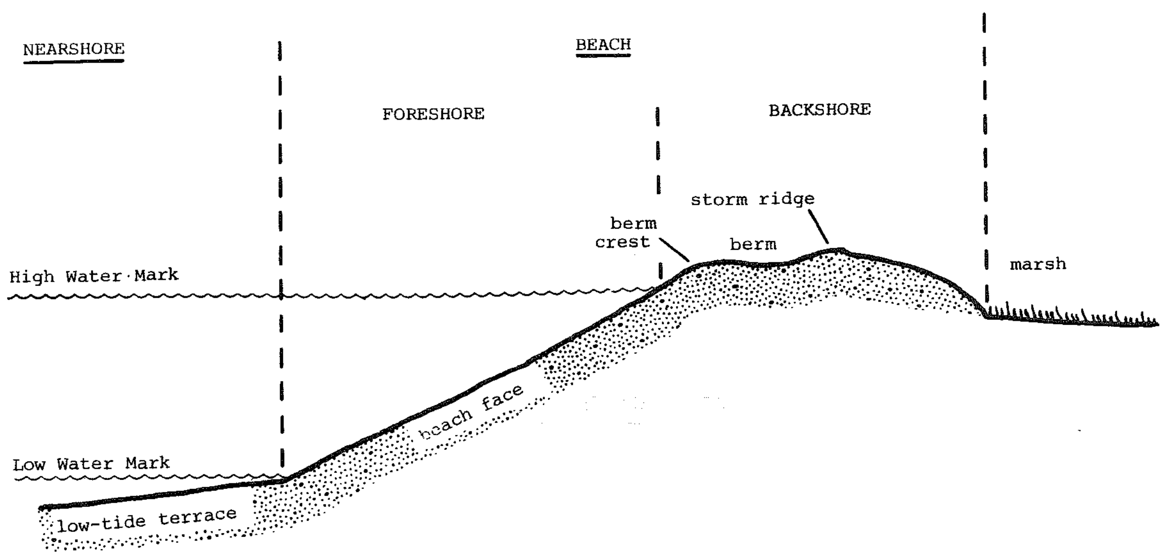

Figure 22. Beach features and subdivisions.

APPENDIX B

BACKSHORE: That part of a beach above the high-water mark that extends landward to the limit of storm-wave activity (see Fig. 22).

BACKWASH: The movement of water down the beach-face slope after a wave has broken and has surged up the beach face (see swash).

BASALT: A resistant volcanic rock that occurs either as a lava flow or as an intrusive dyke (q.v.).

BEACH: An environment of unconsolidated sediments in the coastal zone, between the low-water mark and the landward limit of storm-wave activity (see Fig. 22). The upper limit is usually marked by vegetation (such as dunes) or a cliff.

BEACH FACE: Upper part of the foreshore, between the low- and high-water marks. Usually the beach face has the steepest slopes (up to 40°) in the beach zone (see Figs. 10 and 22, Photo 18).

BERM: A zone above the beach face that is nearly horizontal and is above the limit of normal wave action (see Fig. 22, Photo 19).

BERM CREST: The seaward limit of the berm (see Fig. 22).

DYKE: A vertical or steeply-dipping sheet of igneous rock formed as molten rock was forced towards the earth's surface.

FETCH: The length of open water over which the wind can generate waves.

FORESHORE: That part of the beach between the low- and high-water marks (see Fig. 22).

GRANITE: (see Metamorphic Rocks).

HIGH-WATER MARK: The upper limit of the tidal water level. Mean high-water mark or the mean high-tide mark is the upper limit averaged over a time period. Spring high-water mark or spring high-tide mark is the upper limit of spring tides. Neap high-water mark is the upper limit of neap tides (see Fig. 22).

ICE FOOT: A feature that is formed at or above the high-water mark by the freezing of swash or wave-spray in winter months. The ice-foot is fixed to the beach and disappears either by wave abrasion or by melting in the spring (see Photo 29).

ICE RAFTING: The process by which sediment is incorporated or adheres to a piece of ice. The ice subsequently moves (e.g., by a rising tide) and this sediment is eventually deposited at a different site.

IGNEOUS ROCKS: Rocks that have solidified from molten rock. There are many types of igneous rock, most of which are resistant to erosion, depending on the conditions under which the molten material cooled and solidified.

INTRUSIVE ROCKS: Molten rocks that solidified before reaching the earth's surface. They are igneous rocks.

LITTORAL ZONE: Synonymous with "foreshore", used more as an adjective.

LONGSHORE SEDIMENT TRANSPORT: The mechanism by which material is moved parallel to the coast by wave- or tide-induced littoral processes.

LOW-TIDE TERRACE: The flat or gently sloping lower part of the foreshore at the base of the beach-face slope (see Fig. 22). All or part of the low-tide terrace may be exposed at low tide.

LOW-WATER MARK: The lower limit of tidal water level. Mean low-water mark or the mean low-tide mark is the lower limit averaged over a time period. Spring low-water mark or spring low-tide mark is the lower limit of spring tides. Neap low-water mark is the lower limit of neap tides (see Fig. 22).

MARSH (salt-marsh): A flat, vegetated area at or above the high-water mark that is flooded by spring tides or during storm surges.

MEAN LOW-WATER MARK: (see Low-Water Mark).

MEAN HIGH-WATER MARK: (see High-Water Mark).

MEGARIPPLES: Ripples of sand or mud that have crests spaced between 50 cm and 5 m apart (see Sand Wave).

METAMORPHIC ROCKS: Rocks that were originally igneous or sedimentary but have been changed due to the effects of heat and/or pressure. Frequently very resistant rocks (e.g., granite).

MUD: General term for fine-grained sediments in the silt-clay range.

NEAP TIDES: Those tides that occur twice a month when the gravitational pull of the sun and moon are at right-angles to each other. As a result of the opposing forces, high tides are lower than usual and low tides are higher than usual (see Fig. 4).

NEARSHORE: The zone, seaward of the low-water mark, that is affected by normal wave action. The nearshore zone gives way offshore where bottom sediments are not affected by waves.

POCKET BEACH: An isolated beach that is bounded on both sides by rock outcrops, cliffs or platforms, to form a discrete unit (see Photo 22).

ROCK PLATFORM (INTERTIDAL): On a rocky coast, a flat or gently sloping wave-eroded platform in the lower foreshore. Often has a small scarp at the seaward limit, which is usually the mean low-water mark. Initially, waves cut a notch (see Wave-Cut Notch) at the base of a cliff. As the cliff retreats, a platform of increasing width is formed (see Photo 2).

SAND WAVES: Regular spaced wave-like sand forms that have a crest-to-crest spacing greater than 5 m (see Photo 27).

SEDIMENT SIZE: Units are defined by the mean diameter of the particles:

boulder	250 mm
cobble	64-256 mm
pebble	4-64 mm
coarse sand	0.5-4 mm
medium sand	0.25-0.5 mm
fine sand	0.06-0.25 mm
silt	0.06 mm

(see also Mud)

SEDIMENTARY ROCKS: Rocks formed by the deposition of sediments in layers, by wind, river, ice or marine processes.

SPRING HIGH-WATER MARK: (See High-Water Mark).

SPRING TIDES: Tides that occur when the gravitational pull of the sun is in the same direction, and therefore reinforces, that of the moon. High tides are higher and low tides are lower than usual. Spring tides occur twice a month at the new and full moon (see Fig. 4). The highest spring tides occur twice a year at the spring and autumn equinoxes, when the sun is overhead at the equator.

STORM RIDGES: A ridge formed in the <u>backshore</u> above the high-water mark by wave action during storms. The ridge is changed only by subsequent storm waves (see Fig. 22).

STORM SURGE: During storms the water level can be raised above the normal high-water mark as water is piled against the coast by onshore winds.

SWASH: The motion of a wave as it breaks and surges up the beach-face slope (see Backwash).

TALUS: The accumulation at the base of a cliff that forms as the cliff face is weathered.

TIDAL CURRENTS: Water movements that result from the action of the tides. Ebb currents or flood currents often follow different paths in a channel. Residual tidal currents can be determined by comparing the ebb and flood currents to give the prevailing direction of water movement at a given location.

TIDAL FLAT: A wide, flat area, usually of sand or mud, in the lower foreshore, that is exposed at low-tide.

TIDAL RANGE: The vertical difference in water level between high and low tides. Mean tidal range is taken as the average between the tidal range during spring and neap tides.

TILL: An unconsolidated deposit of sediments that range from clay to boulders laid down by a retreating glacier or ice-sheet.

TOMBOLO: A beach or beaches that connect an island to the mainland or to another island.

TRAP: Synonymous for dyke.

WATER TABLE: The line between the dry unsaturated zone and the low saturated groundwater zone. The water table usually emerges in the lower foreshore just above the junction of the low-tide terrace and beach-face slope.

WAVE-CUT NOTCH: A notch at the base of a coastal cliff eroded at or near the high-water mark by waves.

WINDS (DOMINANT): Those winds which over a time period (usually a year) have the highest velocities. The direction of the dominant winds may differ from that of the prevailing winds.

WINDS (PREVAILING): Those winds which occur with the highest frequency.