c. 2

# COASTAL CLASSIFICATION OF THE PLACENTIA BAY SHORE

N.R. CATTO[1], M.R. ANDERSON[2], D.A. SCRUTON[2] AND U.P. WILLIAMS[2]

[1]Department of Geography
Memorial University of Newfoundland
St. John's, Newfoundland A1A 1A2

[2]Science Branch
Department of Fisheries and Oceans
P.O. Box 5667
St. John's Newfoundland A1C 5X1



October 1997

Canadian Technical Report of Fisheries and Aquatic Sciences
No. 2186

# COASTAL CLASSIFICATION OF THE PLACENTIA BAY SHORE

N.R. CATTO[1], M.R. ANDERSON[2], D.A. SCRUTON[2] AND U.P. WILLIAMS[2]

[1]Department of Geography
Memorial University of Newfoundland
St. John's, Newfoundland
A1A 1A2

[2]Fisheries and Oceans Canada
P.O. Box 5667
St. John's Newfoundland
A1C 5X1

October 1997

**Canadian Technical Report**
**of Fisheries and Aquatic Sciences No. 2186**

Canadian Technical Report
of Fisheries and Aquatic Sciences No. 2186

1997

# COASTAL CLASSIFICATION OF THE PLACENTIA BAY SHORE

by

N.R. Catto[1], M.R. Anderson[2], D.A. Scruton[2] AND U.P. Williams[2]

[2]Science Branch
Department of Fisheries and Oceans
P.O. Box 5667
St. John's Newfoundland
A1C 5X1

[1]Department of Geography, St. John's, Newfoundland A1A 1A2
[2]Science Branch, P.O. Box 5667, St. John's Newfoundland A1C 5X1

Cat No. XXXX_XXXXXXX ISSN 0706-XXXX

Correct citation for this publication:

Catto, N.R., M.R. Anderson, D.A. Scruton and U.P. Williams. 1997. Coastal Classification of the Placentia Bay Shore. Can. Tech, Rept. Fish. Aquatic. Sci. No. 2186: v + 48 p.

CONTENTS

# ABSTRACT

Catto, N.R., M.R. Anderson, D.A. Scruton and U.P. Williams. 1997. Coastal Classification of the Placentia Bay Shore. Can. Tech, Rept. Fish. Aquatic. Sci. No. 2186: v + 48 p.

This report classifies the shorelines surrounding Placentia Bay, based on study of the 1981 videotape survey held by the Department of Fisheries.-and Oceans, aerial photograph analysis, and site visits. The coast is dominated by coarse-grained gently to steeply sloping gravel-dominated beaches, and by cliffed shores. Mixed sand-and-gravel beaches are less common, and sand dominated systems are rare. Low tidal ranges, unsuitable bathymetry, and a scarcity of fine sediments largely preclude the development of tidal flats.

Seasonal and yearly variability is characteristic of most of the beach systems studied along Placentia Bay since 1989, and is evident in comparison of the 1981 videotape observations with aerial photographs taken during other years. This variability hinders effective classification of these systems based on a single time of observation. Textural and morphological fluctuations lead to different classifications of the same system in different years, or at different seasons.

Beaches are dominated by onshore-offshore transport of sediment, with shore-parallel transport playing a limited to locally non-existent role. Sediments and contaminants thus potentially have long residence times within individual coves and embayments. The majority of the beaches are marked by substantial onshore transport throughout much of the year, with swash wave energies far in excess of backwash energies.

Sea levels have varied in the region since deglaciation, in response to glacioisostatic factors. A general transgression, with minor regressive events, has been ongoing since the mid-Holocene, c. 3400 years ago. Recently, transgression has apparently accelerated, approximating a rate of sea level rise of at least 3 millimetres per year.

Future research should focus on particular shoreline systems, and on the impact of seasonal fluctuations and human activities upon individual biological species. Research along the Cape Shore has demonstrated the necessity of systematic, periodic beach visitation and monitoring. Comparative studies and monitoring of additional beach systems would be desirable.

# RÉSUMÉ

Catto, N.R., M.R. Anderson, D.A. Scruton and U.P. Williams. 1997. Coastal Classification of the Placentia Bay Shore. Can. Tech, Rept. Fish. Aquatic. Sci. No. 2186: v + 48 p.

Dans ce rapport on classe les lignes de rivage entourant la baie Placentia d'après l'étude de l'enregistrement sur bande magnétoscopique effectué dans le cadre du levé exécuté en 1981 par le ministère des Pêches et Océans, d'après l'analyse de photographies aériennes et d'après des visites d'emplacements. La côte est dominée par des plages de gravier à grain grossier faiblement à fortement inclinées et par des falaises. Les plages de sable et gravier mélangées sont moins communes et les systèmes dans lesquels le sable domine sont rares. De faibles amplitudes des marées, une bathymétrie inappropriée et la rareté des sédiments fins préviennent en grande partie la formation de larges estrans.

La variabilité saisonnière et annuelle caractérise la plupart des systèmes de plages étudiés autour de la baie Placentia depuis 1989 et ressort de manière évidente lorsque les observations enregistrées sur bande magnétoscopique en 1981 sont comparées aux photographies aériennes prises pendant d'autres années. Cette variabilité gêne une efficace classification de ces systèmes d'après des observations effectuées à une seule époque. Des fluctuations texturales et morphologiques mènent à des classifications différentes d'un même système observé en des années ou des saisons différentes.

Les plages sont dominées par le transport des sédiments vers le rivage-vers le large et le transport parallèlement au rivage ne joue, le cas échéant, qu'un rôle local. Les sédiments et les contaminants peuvent ainsi séjourner longtemps dans des anses et des indentations individuelles. La majorité des plages sont marquées par un substantiel transport vers le rivage pendant une bonne partie de l'année, puisque le jet de rive des vagues présente une énergie beaucoup plus grande que celle du flot de retour.

Depuis la déglaciation le niveau de la mer a varié dans cette région en réponse à des facteurs glacioisostatiques. Il y a transgression générale, avec de mineures régressions, depuis le milieu de l'Holocène il y a 3400 ans. Récemment, la transgression s'est apparemment accélérée pour engendrer une vitesse approximative d'élévation du niveau de la mer d'au moins 3 millimètres par année.

Les recherches futures devraient être axées sur des systèmes littoraux particuliers et sur l'incidence des fluctuations saisonnières ainsi que des activités de l'homme sur des espèces biologiques individuelles. Les recherches le long du Cape Shore ont démontré la nécessité de visites et d'une surveillance systématiques et à intervalles réguliers des plages. Des études comparatives et la surveillance de systèmes de plages additionnels seraient souhaitables.

## INTRODUCTION

In the late 1980's there was growing public concern for the marine environment especially in light of the accidents associated with the barge *Nestucca* and the oil tanker *Exxon Valdez*. One of the responses to this concern was the appointment in June 1989 by the Prime Minister of Canada, of a Public Review Panel on Tanker Safety Spills Response Capability. The mandate of the Panel was to review and evaluate - i) the measures currently in place to ensure the safe movement of oil and chemicals through Canadian waters, ii) Canada's ability to respond to marine spills of these products, iii) provisions for compensation for damages resulting from spills of oil and chemicals, and iv) Canadian legislation and international conventions which regulate the movement of vessels transporting oil and chemicals.

A major regional need in response planning for the marine environmental emergencies is the provision of detailed sensitivity mapping for areas with high potential for such emergencies. One of these areas identified during the Public Review Panel on Tanker Safety Spills Response Capability as an area with a high potential for an oil-related environmental accident was Placentia Bay, Newfoundland. This elevated risk was due to the presence of an oil refinery at Come-by-Chance. Subsequent to the Panel Report, it has been decided that oil from both the Hibernia and Terra Nova oil fields will be shipped through a new transshipment facility at Whiffen Head, Placentia Bay. It is anticipated that, at peak production, there will be in excess of 350 tanker movements per year in Placentia Bay.

The Panel had found that there was a paucity of sound environmental data in Placenta Bay and recommended that a sensitivity map be prepared. In October 1991, a Treasury Board submission for "Response to Marine Environmental Emergencies (Brander-Smith) was approved and DFO was funded to develop the map. One of the required products from this initiative was the establishment of a coastal classification system for Placentia Bay.

This report classifies the shorelines surrounding Placentia Bay, based upon geomorphological and sedimentological criteria. Classification was accomplished utilizing the videotaped record of a survey of the coastline, conducted in July 1981, which is currently held by the Department of Fisheries and Oceans. Additional data assisting in classification was provided by aerial photography of the Placentia Bay coast, previously conducted by the Governments of Canada and Newfoundland and Labrador, and by military organizations of Canada and the United States.

Following the initial (and continuing) investigations of the Atlantic Geosciences Centre (e.g. Forbes 1984, Shaw and Forbes 1987), on-site investigations ("ground truth") have been conducted at several coastal locations along the Placentia Bay shore by Catto since August 1989, and by students under his direction. These data provide important confirmation of the classifications based on remotely sensed data, allow assessment of hourly, diurnal, seasonal, and year-to-year variations in the morphology and texture of particular beaches, and provide information regarding small- and medium-scale sedimentary features and structures which cannot be viewed from a distance. Integration of the data collected on-site with that obtained from aerial surveys and photography thus completes the spatial and temporal pictures of these shorelines.

# MATERIALS AND METHODS

## VIDEO/AIRPHOTO INTERPRETATION

The shoreline classification of Placentia Bay is based on the analysis of videotapes from a 1981 aerial survey, interpretation of airphotos, and data gathered from site visits. In order to achieve an appreciation for the potential seasonal, yearly, and storm generated variations in classifications the 1981 video footage has been compared to aerial photographs taken in 1966, and to information gathered from foot surveys in 1993. These comparisons provide compensation for the lack of aerial video data from other seasons and years.

## AERIAL VIDEO INFORMATION

In early July of 1981 a series of aerial video surveys were recorded over a period of several days. The tapes were recorded from a fixed wing aircraft under good weather conditions and with good visibility. The average aircraft elevation was 945 ft. aasl with the extremes ranging between a low of 660 ft. asal and a high of 1500 ft. asal.

The recordings consist of a set of low-altitude, aerial colour videotapes that document the exact shore-zone character of Placentia Bay. The tapes were a main source of data for the maps presented in this report. The original 3/4" tapes were recorded by Woodward-Clyde Consultants for Mobile Oil Canada Ltd.

## AIRPHOTO INFORMATION

In order to better determine an accurate shoreline classification for Placentia Bay the videotapes were interpreted in conjunction with a series of aerial photographs. Airphotos used were borrowed from Memorial University Map Library and include all maps required to give complete coverage of Placentia Bay. The airphotos were taken at an elevation of 8,600 ft. aasl and the entire series of photos were taken in 1996. The scale of the photos is 1:15,840 (1 in: 1320 ft.).

## FOOT SURVEY INFORMATION

The foot surveys were conducted by Dr. Norm Catto (Department of Geography, Memorial University of Newfoundland) in the summer of 1993. Foot surveys were very important in this shoreline classification project as they provided a level of detail unattainable from videotape and air photo analysis alone.

## CLASSIFICATION SCHEME

In order to ensure that shoreline descriptions are clear and accurate an accepted standard classification system for describing substrate sediment, width, slope, and type of shoreline is required.

The classification system used in this report follows that used by DFO in other regions of Newfoundland and Canada. This system is based on the model proposed by John Harper for the Pacific Coast of Canada, and by SeaConsult Ltd. for the west coast of Newfoundland.

Adoption of any classification system creates potential problems for users. The main problems with the system used in this report are:

- Classification is based on a single aerial observation of the coast, implying that conditions do not vary substantially over the seasons or from year-to-year. This implication is not valid, especially in Placentia Bay, where the degree of beach modification through time is considerable. Some compensation has been made for this problem by providing descriptions in the text of changes caused by weather, and also, by the use of compound symbols on the maps to indicate where shoreline classifications change significantly as a result of extreme weather or seasonal variation;

- Individual classes within the system encompass a range of morphology and sediment texture. To compensate, textural classifications are accompanied where possible by discussion of the relative proportions of the grades of gravel and sand.

Anthropogenic modification of the shoreline is not explicitly considered as a classification unit in this system. Where it is an issue, enough information exists to establish the character of the shoreline prior to disturbance, and thus assess the impact of anthropogenic activity.

Detailed descriptions of each shoreline classification type are provided in the text along with examples of each type within Placentia Bay. Videotape references are provided where applicable. Clear distinctions are made between each shoreline type, especially where differentiation may be subtle. Seasonal changes or changes due to storm action are described.

## REGIONAL SETTING

Placentia Bay separates the Avalon Peninsula on the east from the Burin Peninsula on the west. The coastline can be divided into several segments, based partially on human convention and settlement patterns and partially on geomorphological signature. The shoreline from Point Lance at the southeastern limit of the bay to Argentia is termed the "Cape Shore". Other distinct segments include the northeastern shore, from Argentia north to Arnold's Cove; the bay head area from Arnold's Cove to Woody Island; the northwestern shore, from Woody Island southwest to D'Argent Bay, including Paradise Sound; the Burin Peninsula shore, from D'Argent Bay to Point Crewe; and Merasheen Island, Long Island, and Red Island in the north-central part of the bay.

Physiographically, the region is classified within the Atlantic Uplands of Newfoundland (Bostock 1970), a part of Appalachia. Maximum relief in the area is approximately 300 m, and sea cliffs in excess of 60 m height are common along the Cape Shore and Paradise Sound. The interior areas are marked by rolling hills, short rivers (many of them cascades), and blanket bogs and felsenmeer in exposed zones.

The climate of the region is classified as mid-boreal (Köppen Dfb) (Environment Canada 1981, Banfield 1981, Damman 1983). Daily mean temperatures in Placentia are -4° C in January and 16° C in July. Mean annual precipitation is approximately 1400 mm, of which 15-20 % falls as snow.

Snow cover persists for approximately 140 days in wooded areas, but snow is removed rapidly from exposed coastal zones. Fog is common, and Argentia averages 206 days per year with at least 1 hour of fog. Ice foot development commonly occurs in the winter.

Wind patterns vary seasonally, with easterly winds prevailing during the summer at Placentia and southwesterlies dominating during the winter. In the western parts of the bay, southwesterly winds are more prevalent throughout the year. Throughout the bay, however, winds may originate from any point of the compass at any time of the year. The southwesterly winds generally bring warm, moist air to the region from the surface of the Gulf Stream, but are also associated with many of the major storms during the summer and autumn. Northeasterly winds, which are responsible for much of the storm modification of beaches along Conception and Trinity Bays and the open Atlantic Southern Shore of the Avalon Peninsula, are generally ineffective agents of shoreline modification in Placentia Bay. Diurnal onshore and offshore winds are common in most embayments.

Currents within the bay generally follow a counter-clockwise circulation pattern, but much local variation exists. The currents in the vicinities of the larger islands are particularly influenced by the local bathymetry. Some coves are dominated by shore-parallel transport, whereas in others onshore-offshore sediment movement essentially normal to the beach dominates. In many coves, current patterns shift in response to changes of wind direction and storms. Anthropogenic and natural debris accumulates on all the beaches, but is especially evident along the Cape Shore. On these beaches, natural debris derived from shorelines south of Cape Hatteras, such as fragments of cypress wood *(Taxodium distichum)* and pumice, indicates that shore-parallel currents have been partially fed by the Gulf Stream. Such debris is very rarely encountered north of Placentia. Although pumice from Icelandic sources has been reported along arctic Canadian shorelines (e.g. Blake 1970), the absence of volcanic detritus from the shores of Conception Bay and the Atlantic coastline of the Avalon Peninsula suggests that the pumice was transported northwards by the Gulf Stream.

Vegetation throughout the region is dominated by coniferous boreal forests, with *Abies balsamea, Picea mariana, and Larix laricina* (Damman 1983). Scattered coastal areas contain patches of tuckamore *Picea glauca.* Plateaux and plains in exposed locations overlooking the shore, especially along the southern Cape Shore and in the offshore islands, are dominated by *Rhacomitrium moss, Empetrum nigrum, and Vaccinium sp.*

The entire shoreline of Placentia Bay was glaciated during the Quaternary period (Henderson 1972, Grant 1989). Distinct ice caps developed over several source areas in the Avalon Peninsula and Isthmus, and in the Middle Ridge area to the northwest. Ice from the Middle Ridge area flowed southward to the extremities of the Burin Peninsula, and eastward across the northernmost areas of Placentia Bay to Trinity Bay. Areas south of Southern Harbour were glaciated by local ice caps generated on the Avalon Isthmus and Peninsula, and were apparently never inundated by the main Newfoundland glaciers.

Some researchers have suggested that an additional- ice dome -developed southeast of the Burin Peninsula (Grant 1989), during a period of lower sea level induced by glacial growth, and that this. glacier flowed north onto the Burin Peninsula in the Lawn - St. Lawrence area. Evidence for this glacial event is uncertain, however, and re-investigation of the glacial sediments of the Burin Peninsula appears to be necessary. Glacial ice withdrew from the coastlines of Placentia Bay c. 12,000 - 11,000 B.P.

The distribution of Quaternary sediments surrounding Placentia Bay has most recently been been mapped by Vanderveer in 1977 (Point Crewe to Come-by-Chance) and by Catto between 1990 and 1992 (Come-by-Chance to Point Lance) at 1:50,000 scale. Mapping of Merasheen Island, Long Island, and Red Island on this scale has as yet not been completed, but these areas were mapped at a scale of 1:1,000,000 during compilation of the surficial geology map of Insular Newfoundland (Liverman and Taylor 1990). Dominantly, the Quaternary sediments along the coasts are coarse-grained diamictons.

## CLASSIFICATION SYSTEM

The classification system used in this report follows that used by the Department of Fisheries and Oceans in other regions of Newfoundland and Canada. This system is based on the schemes proposed by John Harper for the Pacific Coast of Canada, and by SeaConsult Ltd. for the west coast of Newfoundland. The classification system is outlined in Table 1. Although difficulties have been observed in the application of this scheme to Placentia Bay, it has been retained in the interests of regional consistency and to facilitate comparisons with other. similarly mapped shores.

Adoption of any classification system creates potential problems for users. This system assumes that classification will be based on a single observation of the coast (e.g. during an aerial survey operation, such as that conducted in July 1981 for Placentia Bay), and that conditions will not vary substantially throughout the seasons or from year-to-year. Observations of beach systems along the Placentia Bay coast indicate that the assumption of relatively constant sediment textures and shoreline morphology are not valid for many shores in this region. Transitions, both spatially and temporally, are common. In some areas, the changes are significant enough to entirely change the shoreline classifications that would be determined at different times. These shorelines are designated with compound symbols in this report (e.g. 13 / 16).

A second problem is that the individual classes within the system encompass different ranges of variability of morphology and sediment texture. Class 23 (estuary and fringing lagoonal) and Class 24 (bouldery tidal flat) shorelines, for example, incorporate many small zones varying in texture and morphology. such- as individual tidal channels, fluvial bars, areas of bank erosion and deposition, and vegetated and unvegetated zones. In contrast, steep beaches (Classes 15, 18, and 21) show much greater homogeneity.

Similar problems are encountered when cross-shore variations are considered. Although the classification scheme is designed primarily to reflect conditions at the water's edge, in many instances cross-shore variability is important when considering sediment supply, seasonal changes, and overall stability of the segment of shoreline. In this report, the impacts of cross-shore successions are considered in the discussion of individual shoreline classes and specific examples. Detailed analysis of the impact of cross-shore variations would require intensive study of individual beach segments.

Cliffed shorelines are assumed to be dominated by bedrock cliffs in the classification scheme. Although local areas of steep sediment bluffs are encountered along Placentia Bay, no provision for such areas has been made. The number of localities involved is small, however, and individual examples such as the shorelines at Little Barasway and Big Barasway are discussed in this report.

The definitions of textural subdivisions pose a potential problem to users of the system. In geological or sedimentological terms, "gravel" is defined as all materials of granule size or coarser, ranging from 2 mm diameter to the largest boulders, following the Wentworth-Udden textural classification system of 1898 - 1922. Clasts between 2 mm and 1 / 16 mm (0.0625 mm) are defined as "sand". Thus, a "gravel" beach could theoretically be composed entirely of granules, or entirely of boulders, or have a textural assemblage of a variety of gravel classes. A beach, in order to be considered as a sand-dominated system, must have a volumetric majority of clasts of grain diameter < 2 mm. Many beaches considered suitable for capelin spawning, such as Middle Cove or Gooseberry Cove, are thus classified as gravel beaches and contain very small proportions of sand (especially after storm events). The number of true sand beaches, therefore, is perhaps lower from the sedimentologist's perspective than from that of other users.

In this report, textural classifications are accompanied where possible by discussion of the relative proportions of the grades of gravel and sand. Following the standard Wentworth-Udden classification, gravels are subdivided into "granules" (2 - 4 mm diameter), "pebbles" (4 - 64 mm in diameter), "cobbles" (64 - 256 mm in diameter), and "boulders" (> 256 mm in diameter). Pebbles and cobbles may be further subdivided into fine, medium, and coarse grades. Sand is subdivided into "coarse" (0.5 mm - 2 mm in diameter), "medium" (0.25 - 0.5 mm in diameter), and "fine" (0.0625 - 0.25 mm in diameter) grades. Clasts between 0.0039 mm and 0.0625 mm in diameter are considered as "silt", and those less than 0.0039 mm in diameter are "clay". The term "mud" encompasses both silt and clay.

Anthropogenic modification of the shoreline is not explicitly considered as a classification unit in this system. In the Placentia Bay area, significant modification of the shoreline by direct human intervention is limited -to the harbour areas of fishing communities, areas where groynes have been constructed to retard sediment erosion and beach-parallel transport (such as Placentia town), and two industrially-disturbed regions, at Long Harbour and Argentia. In all cases, enough information exists (such as pre-development photographs of the Long Harbour area) to establish the character of the shoreline prior to disturbance, and thus to assess the impact of anthropogenic activity.

# COASTAL CLASSIFICATION ZONES

## CLASS 1 -- WIDE ROCK PLATFORM

The wide rock platform class is defined as a bedrock platform, largely or totally devoid of sediment, which slopes seaward at a shallow angle and is in excess of approximately 30 m in width. In other coastal regions of Atlantic Canada, such platforms are generally associated with gently dipping sedimentary or extrusive volcanic strata, in areas with limited sediment cover inland. Broad platforms are frequently associated with upper mesotidal or macrotidal regimes, often coupled with seasonal ice activity (as along parts of the west coast of Newfoundland, segments of the east coast of Grand Manan Island, N.B., and parts of the north coast of Prince Edward Island). In areas marked by mesotidal or microtidal conditions, such as Placentia Bay, sediment fluxes from either landward or seaward sources would have to remain low to keep the platform exposed.

The combination of steeply dipping bedrock, locally high sediment fluxes, and microtidal conditions throughout most of Placentia Bay effectively preclude development of this style of coast in most areas. The only examples of class 1 areas are located on the northwest shore of Copper Island, south of Port Elizabeth (Jude Island map-sheet). Copper Island has not been previously inhabited, and was not overflown during the 1981 survey. The regions are small, and are intermixed with sand and gravel-covered zones (classes 7 and 8). The lateral extent of the exposed rock platforms has varied throughout the 1980's and to 1993, with the degree of sediment cover ranging from approximately 20% to 50%. Variations can be attributed to influx and removal of sediment by storms driven by southwesterly winds, as no local supply of sediment exists on the island. The distribution of these zones thus can be expected to shift sporadically, dependent upon the direction and intensity of storm activity.

## CLASS 2 -- NARROW ROCK PLATFORM

The narrow rock platform class is defined as a bedrock platform, largely or totally devoid of sediment, which slopes seaward at a shallow angle and is less than 30 m in width. Such platforms may develop in areas of moderately to steeply dipping sedimentary or volcanic bedrock, in areas of metasedimentary bedrock, or in areas characterised by pronounced fluctuations in sea level. Inland areas are frequently marked by limited sediment cover, but the narrowness of the platform facilitates removal of sediment by marine processes, and hence more sediment may be present inland than is the case for Class 1 shores. Sediment fluxes, however, are generally low. Narrow rock platforms develop in all tidal regimes, and under a variety of sea ice conditions.

Narrow rock platforms occur along several segments of the Placentia Bay coastline. In the vicinity of Winging Head and White Point (Sound Island map-sheet, tape reference 2321 -- 2340), rock platforms interspersed with gravel beaches occur along a 5.5 km length of the east shore of North Harbour. Videotape records and aerial photographs from the summer months during the past decade indicate that approximately 10-16 % of the shoreline is marked by rock platforms devoid of sediment. Observation of the shoreline during February of 1992, however, suggests that much of the thin veneer of sediment which covers other platforms along the shore is removed periodically during the autumn equinoxial storms, leaving as much as 60 % of the shoreline devoid of sediment cover. The sediment is replenished by influxes from the land during spring, resulting from snowmelt runoff and enhanced freeze-thaw activity. Direct sediment transport by rivers plays a relatively minor role at Winging Head and north of Sail the Maid Island, and is not involved in beach development in the White Point area. Landward movement of sediment during storm events can result in changes of width of the area of sediment cover, thus changing the width classification of some zones.

The available data suggest that the classification which would result from a series of winter observations might differ from that based on summer records in the Winging Point area. Similar problems are apparent in other rock platform regions, such as those in the vicinity of Butler Head, Southern Harbour (tape reference 1940), Cousin Head (tape reference 4206), and probably on Coat Island (tape reference 741). Areas where such seasonal transitions occur are designated 2 / 4 and 2 / 5 on the maps.

A second example of a narrow rock platform zone is located along a 1.1 km expanse of shore east of Taylor's Bay Point (tape reference 4058 - 4064). In this region, the supply of sediment from the shore is diverted away from the rock platform zones along two minor streams, leaving the intervening class 2 zones relatively deficient in sediment supply. These areas thus appear to be more consistent in nature throughout the year than is the Winging Head area. Even along this shore, however, isolated surfaces are covered with thin discontinuous mantles of gravel on a seasonal basis.

Additional areas of class 2 shoreline are located at Lannon Point (tape reference 4205), Pump Cove (tape reference 4046), Shoal Cove (tape reference 4868), north of Sandy Point, Sound Island (tape reference 2515), and in several other locations.

**CLASS 3 -- ROCK CLIFF**

Rock cliffs are a ubiquitous feature of the Placentia Bay shoreline, occurring along virtually all segments of the coast. Cliff heights vary greatly, from low cliffs of 5 - 10 m in the Taylor's Bay Point area (tape reference 4066) to cliffs exceeding 80 m in height at Cape St. Mary's (tape reference 4290) and the western shore of Paradise Sound (tape reference 3100 - 3165). High cliffs also mark segments of the shore between Big Head and Gripe Cove (3690 3757), the southeastern shore of Merasheen Island (730 - 940), and the Cape Shore between Patrick's Cove and Big Barasway (4425 - 4467), among many other areas. Along the shores of the St. Bride's map area, high cliffs represent approximately 65 % of the shoreline length, and they represent in excess of 90 % of the length of the Paradise Sound coast, an area marked by a major bedrock fault.

All cliffed areas, regardless of cliff height, supply large quantities of sediment to the marine system as a result of frost wedging. Frost action is the dominant weathering process along the entire Placentia Bay coast. The rate of frost wedging is contingent upon the tensile strength of the rock units and the number of fluctuations about $0^{o}C$. The jointed, fractured, and bedded nature of much of the bedrock facilitates wedging, and the repetitive temperature fluctuations about the $0^{o}C$ mark characteristic of the winter and spring climate of the region facilitate rapid breakdown of the rock. Typically, the tensile strengths of unfractured basalts and Hadrynian argillites and sandstones which crop out along the Cape Shore are on the order of 10 - 20 % of the 1.4 x $10^6$ kg / $m^2$ stress imparted during the process of ice crystallization, and thus even unfractured bedrock is unable to resist frost wedging. Scattered observations of frost wedging activity in several coastal sites along the Avalon Peninsula, including Mount Arlington Heights and Placentia, suggest that weathering rates between January 1990 and April 1993 approximate 2 - 6 cm per year. Wedging by roots, and biochemical activity along the root surfaces, further accentuate weathering. Weathering by all other mechanical and chemical processes is insignificant by comparison, a consequence of the bedrock geology and boreal climate of the Placentia Bay coast.

Mechanical erosion of the cliffs also contributes substantial quantities of sediment to the marine system. Most erosion is accomplished directly by running water, with sea ice scour playing an insignificant role along all but the most friable coasts. Wave action has relatively little direct erosive impact on the cliffs, and notches are uncommon, but spray thrown against the cliffs by breaking waves contributes substantially to frost weathering upon freezing. Direct weathering and erosion through crystallization of salts in fractures is not effective along the Placentia Bay coast. In contrast to frost wedging, erosion due to salt crystallization is inversely dependent on the number of crystallization cycles per unit time involved. Along a boreal coastline, frequent inputs of seaspray and the moist climate effectively dissolve the salt crystals before they are able to reach sizes capable of causing erosion.

Anthropogenic activity also contributes to cliff erosion along some segments of the Placentia Bay coastline. Along the Cape Shore, sheep are responsible for denuding vegetation from many cliff edges, causing enhanced runoff and frost wedging and thus generating large quantities of sediment. This material, washed down the cliffs and streams and into the bay, is thus available for transport along the shore and re-sedimentation along sand and sand-and-gravel beaches. Sheep-derived sediments appear to be important components of several beaches along the Cape Shore, such as those at Cuslett's Cove (tape reference 4360) and Patrick's Cove (tape reference 4425). In recently urbanized areas of the Avalon Peninsula, such as Topsail Beach (Conception Bay), changing land use from sheep rearing to suburban development since 1945 have resulted in a shortage of sand supply to the beaches, thus changing their textural character. . Similar changes, involving a coarsening of beach sediments accompanied by enhanced rates of erosion, possibly could be responsible for modifying beaches downcurrent of the anthropogenically-disturbed areas of Argentia and Long Harbour, such as Ship Harbour Point (tape reference 205), Big Seal Cove (tape reference 209), and Crawley Island (tape reference 233).

## CLASS 4 -- GRAVEL BEACH ON WIDE ROCK PLATFORM

Class 4 shores are defined as those which have a gravel beach, composed primarily of pebbles, cobbles, and / or boulders, superimposed on a wide, gently sloping bedrock platform. The morphology of the beach is predominantly controlled by the bedrock. Where investigated in the field, the gravel forms a patchy veneer over the bedrock surface, and outcrops of bare rock are commonly present. Frequently, the beaches accumulate over the widest areas of the platforms, which are the areas of the bedrock that have the gentlest slopes. Intervening marginally steeper-sloped. areas commonly lack gravel cover, and hence patterns with alternating zones of Classes 4 and 2 are common.

The western shore of Long Island south of Port Royal Cove (tape reference 422) is an example of a Class 4 shoreline. Gently sloping sandstone and metasedimentary bedrock of the Conception Group is overlain by a thin, discontinuous sheet of gravel, dominated by medium to coarse pebbles and cobbles. The proportion of the platform covered by the gravel has been high since July of 1981, but variations throughout the past 13 years are evident in successive photographs. Such variations are created by differential sediment fluxes generated by individual storm events. As discussed above, the same segment of shoreline may be classed as either Class 2 or Class 4, depending upon the season or year when it is observed. In the case of this segment of shoreline, however, the gravel cover is sufficiently persistent to assign it simply to Class 4.

A second example of a Class 4 shoreline is located at Lannon Cove (tape reference 4200), near the westernmost extremity of the study area at Point Crewe. In this area, the bedrock platform is composed of fine sandstone and shale of Cambrian age. The gravel overlying this platform is dominated by fine to medium pebbles, with a small proportion of granules and sand. The differences in grain size between the Lannon Cove and Long Island beaches reflect the greater availability of finer sediments along the southwestern shore of the Burin Peninsula, coupled with the tendency of the bedrock to disaggregate into finer particles, rather than reflecting differences in energy level between the sites. The Lannon Cove and Lannon Point areas represent somewhat higher energy environments than the Port Royal area, but the greater sediment flux and differences in source texture keep the Lannon beaches supplied with finer gravels.

Other Class 4 beaches are dominated by coarse cobbles (e.g. Maggotty Cove, Sound Island, tape reference 2502) and by mixed assemblages of gravel of all grades (e.g. southeastern shore of King Island south-southeast of Tacks Beach, tape reference 1225). Seasonal fluctuations in texture, in particular involving removal and replacement of granules, pebbles, and even fine cobbles, and burial and exhumation of coarse cobbles and boulders, are evident in many Class 4 environments.

**CLASS 5 -- GRAVEL BEACH ON NARROW ROCK PLATFORM**

Class 5 shores differ from Class 4 in that they are developed on narrow rock platforms, generally marked by slightly greater slopes. The two classes form in similar situations, and may grade laterally into each other. In high mesotidal or macrotidal environments, the status of the tide may affect classification if it is attempted on the basis of only a single observation, but microtidal and low mesotidal shorelines such as those of Placentia Bay pose no difficulties in this regard. Individual Class 5 shores viewed by direct observation and on photographs taken at different times showed little variation attributable to tidal status, but seasonal variations similar to those discussed above for Class 2 and Class 4 shorelines were observed at some sites dominated by finer grades of gravel.

Four short segments of Class 5 shoreline are located at Lears Cove (tape reference 4296 - 4301), north of Cape St. Mary's. The rock platforms upon which these beaches are developed represent the lowest of a series of low, narrow benches which extend to approximately 6 m above sea level. These benches appear to be wave-cut platforms, and thus represent former high stands of sea level. At present, their age is controversial. Grant (1989) considered the terraces to be c. 100,000 a B.P. (Sangamonian), based primarily on his estimates of sea level fluctuations and chronology for Point Verde, Little

Barasway, and other sites to the north along the Cape Shore, and on his suggestion that the Cape St. Mary's area was not glaciated during the most recent (Late Wisconsinan) glaciation, c. 28,000 - 11,000 a B.P. Henderson (1972) and Catto (1992) recognized glacial deposits, landforms, and erosional features in the Cape St. Mary's area, however, and thus consider the region to have been ice-covered. At present, no evidence for assigning any of the several glacial phases recognized on the Avalon Peninsula to pre-Late Wisconsinan activity exists. The benches are not striated, and show no signs of glacial erosion, although glacial features are found to seaward. Together with the ongoing revision of the sea level history of the central and northern Cape Shore, this suggests that the benches may post-date the most recent glaciation, and hence that they may represent postglacial sea level positions. Further research, in particular dating of the expcsure surfaces using cosmogenic isotope concentrations (c.f. Phillips, 1994 *in press),* will be necessary to resolve this question.

The modern beaches are composed primarily of medium to coarse cobbles, with lesser amounts of boulders and pebbles. Infrequent observations since August 1989 suggest that the texture of these beaches has remained constant during this period. Platform cover beaches dominated by coarser cobbles and boulders exhibit less seasonal variation than finer textured beaches. In part, this indicates the relict character of much of the coarsest sediment. The coarser sediments were commonly initially supplied to the beach areas by glaciofluvial discharges, when glacial ice stood some distance offshore in Placentia Bay. When the ice retreated, and the beaches began to form along the new shoreline when sea level was established at approximately its current position, wave and current energy levels proved insufficient to move or modify the largest clasts. Many of the coarsest clasts on narrow rock platform beaches show no sign of marine transport, and some retain glacial striations and other glacial erosional features on their surfaces.

Class 5 shorelines dominated by finer cobbles and pebbles, such as Little Brule at the northern tip of Merasheen Island (tape reference 545), are more susceptible to modification by storm activity. Several of these shorelines show seasonal and year-to-year transitions in the volume and texture of sediment cover, and may alternate between Class 5 and Class 2.

## CLASS 6 -- GRAVEL BEACH WITH ROCK CLIFF

Class 6 shorelines are defined as those with small, fringing, steeply-sloping gravel beaches backed by rock cliffs. Frequently, the beaches are also flanked by rock cliffs, and are developed in small coves or clefts in the rock. These are generally referred to as "pocket beaches".

Pocket beaches are common along shorelines dominated by rock cliffs. They represent the accumulation areas for sediment derived from local frost wedging and other erosive processes of the rocks surrounding the cove, as well as areas where coarse sediment transported by wave and storm activity accumulates. Pocket beaches range in length from 1 metre (in areas where narrow,' steeply-dipping or vertical fractures reach sea level) to 10's of metres (where the beaches are developed in small coves). Steep gravel beaches in excess of 100 m in length are assigned to shore Class 15 in this report. In plan view, most pocket beaches have a gently to sharply concave sea front.

The width of pocket beaches varies from less than 1 metre to approximately 10 m. Widths tend to vary along the longer pocket beaches, with the greatest widths associated either with an area of stream discharge or on the downcurrent sides of the larger coves.

Slope angles vary with the texture of the sediment, the degree of reworking by storm and wave activity, and the configuration of the backing and flanking cliffs. Slope angles are generally directly proportional to the dominant grain size involved. On short, narrow beaches formed at the base of steep, high cliffs, where there is no significant channelized stream flow from land, clasts lie at or dose to the critical angle of repose for dry sediment, ranging from $20^0$ - $25^0$ for pebbles up to $40^0$ - $45^0$ for coarse boulders. These beaches tend to have planar or gently concave surface profiles, with the steepest slopes aligned perpendicular to the trend of the beach front. Accumulation of the sediment proceeds largely by mass movement, and the internal structures of the beaches may resemble those of terrestrial talus cones.

Storm reworking of these beaches is infrequent, and most commonly results in removal of finer pebbles and cobbles, creating instabilities in the beach system and triggering small mass movements on the beach surfaces. These disturbances alter the concave profiles of the beaches, producing temporary surfaces marked by alternating zones of convex and concave slopes. Characteristically, these irregularities are gradually eliminated as further material is provided to the beach, usually within a few weeks if no subsequent storms intervene. Examples of such short, narrow pocket beaches are common in areas such as the western shore of Paradise Sound (tape reference 3145 - 3170), and along the Cape Shore between Ship Cove and Big Barasway (tape reference 4463).

In areas where the cliffs are less enclosing and the cove is wider than ± 20 m, a different style of pocket beach develops. Such beaches usually are fed in part by streams, and hence have a more texturally varied (and often more consistent) sediment supply. The sediment texture of these beaches tends to be finer than that of the tightly enclosed pocket beaches. Under these circumstances, the beach tends to have a gentler surface slope, ranging from 10 - $15^0$ for pebble beaches to 27 - $35^0$ for cobbles and boulder beaches. The surface profiles tend to be slightly to strongly concave. Cuspate structures are present during the spring and summer months on some of the more lengthy pebbly beaches. The steepest slopes tend to be aligned at sharp acute angles ($60^0$ - $85^0$) to the trend of the beach front, facing the direction of the prevalent waves. In some coves, different parts of the beach slope at different angles and trends, indicating differing wave strengths and angles of attack in consequence of the local bathymetry.

Storm reworking of these beaches occurs relatively infrequently, but is more common in more exposed situations. Storm waves lead to the formation of cuspate structures on the beach, causing temporary irregularities in the profiles. The resulting profiles are made up of several superimposed concave cusps, giving a somewhat scalloped appearance to the overall concave shape. These irregularities may persist until the next storm season. Along many of these beaches, the net effect of storm activity is accretion, as sediment from the length of the cliffed shoreline is focused in the cove area. Examples of this style of Class 6 beach are located in LaPlante Cove (tape reference 2589) and in Cooper's Cove, Long Island (tape reference 554).

Fringing gravel beaches, where rock cliffs back the shore but do not confine the beach laterally, are relatively uncommon. The beaches develop where underwater obstructions serve to focus the sediment in a similar fashion to the exposed flanking cliffs of the pocket beaches. These beaches tend to be steep, narrow, and relatively unstable, and many undergo complete or severe degradation during storm events. Examples of this type of Class 6 shoreline are found along the north coast of Long Island, northeast of Jude Island (Baine Harbour map-sheet, not surveyed in 1981), and north of Buffett Head (tape reference 452).

## CLASS 7 -- SAND & GRAVEL BEACH ON WIDE ROCK PLATFORM

Class 7 shorelines are differentiated from Class 4 shorelines on the basis of texture. In this report, a Class 7 shoreline is defined as a beach which contains between 30 % and 70 % sand (determined either from visual estimates or *in* situ sampling), and is developed on a wide rock platform. Most of the Class 7 beaches investigated in this region contain more gravel than sand, and the sand is predominantly coarse-grained. Yearly, seasonal, and daily variations in texture are evident on many of the beaches, and should be expected on all. The beaches studied, however, do not appear to have contained substantial amounts of medium- or fine-grained sand at any time since c 1966-1970. Slopes on the beaches range from $10^0$ - $25^0$, and the angle of slope is generally proportional to the dominant clast size.

Class 7 shorelines are relatively uncommon in the Placentia Bay region, primarily because there are relatively few broad rock platforms and few areas where sand-sized material can accumulate in these settings. Examples are found on the southeastern shore of Woody Island (tape reference 2540), on the southern and western shores of Davis and Flat Islands (tape reference 3466 - 3485), and in the Goose Cove - North Harbour area (tape reference 2346 2352).

The morphology of Class 7 beaches is predominantly controlled by the bedrock. The sediments form a veneer or blanket over the bedrock, patches of which are infrequently exposed. The extent of sediment cover is generally greater than for a Class 4 or 5 shoreline, but seasonal variations and topographic irregularities can produce areas of exposed bedrock platform flanked by sediment-covered segments. The beaches accumulate over the widest areas of the platforms, produced by shorelines marked by alternating zones of Classes 7 and 2, as is evident along the southeastern shore of Woody Island.

The differences in grain size between the Class 7 beaches predominantly reflect the relative availability of sand, rather than indicating differences in energy level between the sites. The Davis Island and Flat Island beaches appear to contain more sand the those along Woody Island. The beaches in the Goose Cove area vary seasonally in texture. The summer and early autumn are marked by accumulations of sand, which tend to be removed during the late autumn and early spring.

## CLASS 8 -- SAND & GRAVEL BEACH ON NARROW ROCK PLATFORM

Class 8 beaches resemble those of Class 7, except that they are developed on narrow rock platforms with moderate slopes. Lateral gradation between the these two classes occurs on Copper Island, and southeast of Harbour Buffett (tape reference 422 - 425). Class 8 shorelines in the Placentia Bay area are associated with microtidal and low mesotidal regimes.

Class 8 beaches at Coffin Cove and Dicks Island (tape reference 428 - 434) are composed primarily of medium to coarse pebbles, with lesser amounts of cobbles and sand. Sand appears to comprise less than half of the sediment. The beaches slope with concave profiles at angles between $15^0$ and $27^0$. Seasonal variations in slope and texture appear to be relatively minor.

Class 8 shorelines along the Coachman Islands (south of Davis Island) and at Northeast Cove, Long Island (tape reference 335) are dominated by fine pebbles, granules, and sand, with lesser amounts of coarse pebbles and few cobbles. These beaches slope with very gently concave profiles at angles between $8^0$ and $20^0$. Seasonal variations in slope and texture appear to be more frequent along these shores than for the coarser Class 8 regions.

**CLASS 9 -- SAND & GRAVEL BEACH WITH ROCK CLIFF**

Class 9 beaches differ from those of Class 6 by containing substantial quantities of sand, between 30 % - 70 %. Lengths and widths are generally similar to those of Class 6, and these beaches can also be considered as "pocket beaches". Steep mixed sediment beaches in excess of 100 m in length are assigned to shore Class 18 in this report.

Mixed sediment beaches develop at the base of steep cliffs where the frostwedged clasts (which are generally coarse) are joined by finer sediment derived from other sources. Along Placentia Bay, sand originates from overlying Quaternary surficial deposits (glacial till, other diamictons, or glaciofluvial sands and gravels), fluvial systems, bluffs of Quaternary deposits up-current that are prone to slope failure, and from focusing of deposition of sand derived from distal up-current locations or from nearby offshore sources. The generally thin and discontinuous Quaternary sediment cover, especially in coastal regions, limits the formation of Class 9 shorelines, and as a result these are much less common than the coarser pocket beaches of Class 6. Examples of Class 9 shores can be found at Coffin Cove (tape reference 432), Red Land Cove (tape reference 3555), Dough Ball Cove (tape reference 1041), Maurice Poole Cove (tape reference 4670), Silver Bay (tape references 3943 -3946), and Maricot Island Cove (south of Great Paradise, tape reference 3095), among other areas.

Class 9 shores are marked by lesser slopes than those of Class 6, generally between $6^0$ (sand contents > 60 %) and $25^0$ (sand contents < 40 %). The surface profiles tend to be slightly to moderately concave. Cuspate features develop rarely, and when produced are generally poorly formed and ephemeral. The steepest slopes are aligned at sharply acute angles ($60^0$- $90^0$) to the trend of the beach front. Divergence of slopes along the shoreline may occur, but is less common than is evident on gravel pocket beaches.

Storm reworking results in temporary modification of these beaches, but the changes do not appear to be long-lasting. Coarse-textured sediment is frequently exhumed by storms, but rapid re-burial by finer clasts commonly occurs. Much of the sand fraction appears to move cyclically within individual coves, subsequently being swept offshore during backwash from storm surges and then returning to the beach. The beaches thus will appear to maintain a relatively consistent texture, unless they are photographed or visited within approximately 2 - 4 weeks of a major storm.

The laterally restricted nature of the harbours where the majority of Class 9 beaches are located precludes most forms of anthropogenic development and modification. Extraction of sand from these beaches would probably cause initial degradation, but offshore sediment sources and / or Quaternary sediments onshore would be able to re-supply the beaches with sand. Substantial modification would only result if the sediment supplies were truncated or currents were diverted from the beach sites.

## CLASS 10 -- SAND BEACH ON WIDE ROCK PLATFORM

Beaches with sand concentrations in excess of 70 % are uncommon along the Placentia Bay shore, and are completely absent from long reaches of the coast. The lithology of the bedrock units, the prevalence of frost weathering, the scarcity of fine-grained Quaternary sedimentary deposits onshore, the steep slopes, and the high energy environments characteristic of much of the shoreline effectively limit the opportunities for developing sandy beaches. These factors are especially evident in locations where the bedrock comprises a substantial element of the shoreline. Consequently, examples of sand beaches associated with rock platforms or cliffs are rare along Placentia Bay.

The only example of a Class 10 zone observed along the Placentia Bay shore is located along the eastern side of Lance Cove (tape reference 4212 4225). This zone grades laterally to the south into a sandy beach on a narrower rock platform (Class 11 beach). To the west, the zone grades into an open sand flat (Class 19).

The Class 10 zone extends for approximately 50 m along the shore, and is 30 - 40 m wide at low tide. The sand in this area consists of moderately sorted, medium and fine-grained, subrounded discose clasts. Quartz, feldspar, argillite, slate, shale, hornblende, biotite, and other heavy minerals are present. The sand is derived from aeolian dome dunes which back the main sand flat to the west, and is transported to the rock platform area by beachparallel drift, recycling from offshore areas, and rarely by northwesterly winds that rework the dunefield and move sand directly to the platform area. Minor aeolian reworking also occurs over the supratidal areas.

Sand flux is high in all seasons except mid- to late winter, when an ice foot develops over part of the sand flat and the remaining terrain is largely frozen. Reworking of the dunal sand, and consequently supply to the beach, is facilitated as a result of sheep grazing on the dunes, and of the use of all-terrain vehicles by the local shepherds to herd the animals twice daily.

The beach is marked by a gentle slope (2° - 8°) with a planar to very gently concave profile. Small areas with convex slopes are occasionally present between the high tide and mean sea level marks. Cuspate structures are not developed, but irregular zones of very fine swash-and-backwash scour patterns, produced by minute low-energy vortex currents within the incoming and outgoing water masses are present during calm periods. The scours form a hachured pattern, with linear swash scours 0.1 - 0.3 cm deep oriented easterly truncated by backwash-produced linear or very gently curved scours 0.3 - 0.5 cm deep oriented southwesterly. The scours are separated by flat-crested ridges 0.7 -

1.5 cm in width. The angles between the swash and backwash features vary from $35^0$ to $70^0$. Swash oriented parallel to the shore face tends to produce backwash oriented at $35^0$ - $45^0$ to the shore, and generally occurs during low to moderately low energy conditions. In contrast, very low energy conditions permit beach drift to become more effective, and the resulting backwash scours are oriented at shallower angles ($50^0$ - $70^0$) with respect to the swash. Throughout this segment of shoreline, however, the acute angles between swash and backwash indicate that transport of particles approximately perpendicular to the shore (onshore offshore movement) is dominant over beach-parallel drift. These features are highly ephemeral, frequently lasting only until the next large swash wave destroys the old pattern and begins designing a new one.

Ripples are also developed under low energy conditions. Characteristically, only swash produces ripples. The ripples are straight-crested, in phase, with sharp crests and distinctive stoss slopes (angles of 10 - $15^0$) and lee slopes (angles of $22^0$ - $26^0$). Typical crest-trough heights (amplitudes) are 2 - 4 cm, and typical wavelengths are 8 - 15 cm. Wavelength / amplitude ratios (ripple index of Tanner, 1967) range between 4 and 7, representing typical values for low-energy ripples produced under essentially unidirectional water flow. The internal structures are marked by fine planar lee-side laminations defined by heavy mineral monolayers and dilayers, spaced at 0.1 - 0.2 cm intervals. Stoss-side structures are not preserved. Preservation of the ripples is rare.

When the beach is subject to moderate energy waves, diffuse sand sheet and grain flow activity is constant. Sedimentary structures produced during low energy events are not preserved, and the sheeting and grain flows do not generate sedimentary structures which are recognizable after activity ceases. Sediment below the surface of the beach is internally structureless, indicating that reworking during moderate energy periods is common. Bioturbation has not been observed on the beach surface.

Although individual structures and features are very ephemeral, the beach retains its basic character and gross morphology throughout the year. The relative lateral extent of the Class 10, Class 11, and Class 19 shores shift marginally throughout the seasons, and between years, but the basic character of this part of Lance Cove has changed little since 1981. This beach will most probably remain stable, if the sediment supply can be maintained.

## CLASS 11 -- SAND BEACH ON NARROW ROCK PLATFORM

Class 11 beaches differ from those of Class 10 in that they are developed -on narrow rock platforms. In addition to the beach flanking the Class 10 shore at Lance Cove (discussed above), additional Class 11 shorelines are present at the western-most extremity of Lance Cove, along the western shore of Woodly Island south of Jeans Cove (tape reference 2558), along part of the north shore of Barred Island (tape reference 4084), and at Three Sticks Cove, Little Lawn Harbour (tape reference 3967). The shorelines at the latter three localities differ from the Lance Cove system in that the sand is supplied primarily by beach parallel drift sediments derived from the erosion of coastal bluffs and other beach deposits, rather than being derived from aeolian sediments. Consequently, the sediments are dominantly coarse sand and granules at these localities.

The beach at Barred Island is typical of these Class 11 shorelines. Moderately sorted coarse sand and granules dominate a gently sloping beach ($2^0$- $6^0$), flanked laterally by sand and gravel flats (shore classes 16 and 17). The shore is marked by low energy conditions at most times, and the area serves as a temporary and permanent repository for sand following beach-parallel currents around Barred Island and across to the mainland at Land Hummock. Cuspate structures have not been observed on this beach.

The coarse sand and granule texture of the beach effectively precludes almost all ripple development. The dominant sedimentary structures are discontinuous planar parallel sand laminae, dipping seaward at $2^0$ - $6^0$. Frequent reworking results in destruction of these laminations. Bioturbation and aeolian modification of the sediments are not apparent.

The Class 11 beaches at Barred Island and similar localities appear to undergo more seasonal and year-to-year variation than does the Class 10 beach at Lance Cove, but the beaches still maintain their essential character at all times. At Lance Cove, the Class 11 beaches have remained essentially constant in character throughout the period since July 1981.

## CLASS 12 -- SAND BEACH WITH ROCK CLIFF

Sand beaches backed by rock cliffs are uncommon along the Placentia Bay shoreline. Genesis of Class 12 shorelines requires bedrock which is dominantly sandstone, or weathers to sand-sized particles, along with low to moderate energy conditions. Cliff heights are generally less than 15 m. In most "pocket beach" situations, focusing of wave energy during storm events results in the removal of sand-sized material, and frost weathering produces larger clasts. Terrestrial sediment input from streams is generally minimal in steep cliff areas. The Class 12 shorelines are thus much more areally restricted than are those of Classes 6 and 9. Examples in the Placentia Bay area include Murphy's Cove, Little Lawn Harbour (tape reference 3963), segments of shoreline west and south of Dock Point, D'Argent Bay (tape reference 3570), and two segments of shoreline along the southern margins of Flat Island, south and west of Roche Peak (tape reference 3480). All of these shores are backed by friable rock cliffs 10 m or less in height.

The Flat Island shores are typical of -those of Class 12. The beaches exposed to storm waves during the autumn equinoxial gales, resulting in erosion of the cliffs by wave action and a consequent supply of coarse sand and granules for the beaches. During the spring and summer months, generally lower energy conditions (particularly in Flat Island Harbour) permit the sand to remain largely undisturbed and unaltered on the beaches. Beach slopes are low (estimated at $\pm$ $5^0$). Aerial reconnaissance indicates that the beaches are not marked by conspicuous cuspate features, suggesting that wave reworking during the summer is generally at a minimum. Small patches of vegetation also indicate that significant reworking does not occur during the summer. The beaches would thus remain similar in character from year to year, unless subjected to a direct attack by an anomalously large storm. In most areas of Class 12 shoreline, the configuration of the coastline and the local bathymetry act to deflect wave activity away from the beaches.

**CLASS 13 -- WIDE GRAVEL FLAT**

Class 13 shores are defined as those with gravel-dominated flats (less than 30 % sand component) which have maximum widths in excess of 30 m. Along the Placentia Bay coast, most Class 13 shores contain less than 10 % sand-sized particles, and widths commonly exceed 50 m. Wide gravel flat areas are associated with many fishing communities, such as Placentia (tape reference 0001), Gooseberry Cove (tape reference 4452), Haystack Harbour (tape reference 313), and Arnold's Cove (tape reference 2100). Many of these communities were initially established because the wide gravel flats were suitable areas for drying fish for preservation and export.

The Class 13 shores vary substantially in sediment texture, small- and large-scale sedimentary structures, overall morphology, and genesis. Textural assemblages range across the entire spectrum of gravel deposits, from boulder and coarse cobble-dominated assemblages, representing essentially relict sedimentary deposits formed during deglaciation (north part of Big Barasway, tape reference 4474), to assemblages dominated by fine pebbles and granules during the late summer months (Gooseberry Cove, tape reference 4452). Sorting varies from good to extremely poor. On some beaches, seasonal shifts in texture are ubiquitous (Gooseberry Cove), whereas on others the textural shifts are less pronounced and less predictable (Ship Cove, tape reference 4457; Arnold's Cove), and on still others little textural change with the seasons is observed (Angel's Cove, tape reference 4374). Individual segments of complex, lengthy beaches such as Big Barasway and Green Point-Point Verde-Placentia Roads (tape reference 4520-4535) show differing patterns of textural variation along their lengths, both seasonally and in response to individual storm events.

Textural shifts cannot be generalized between adjacent beaches, or from segment to segment of the same beach. For example, the effect of Hurricane Bob (summer 1991) on the texture of central Cape Shore beaches was negligible on Angel's Cove and the southwestern part of the Point Verde- system; very limited on Patrick's Cove, most of Big Barasway, and the central and southern parts of Point Verde; evident on Gooseberry Cove, Ship Cove, and the outlet area of Big Barasway; and extremely pronounced (involving removal of almost all of the granules and medium pebbles, coupled with substantial erosion) on the eastern part of the Point Verde system. Fluctuations in the morphology of the Cape Shore beaches were evident after large storms in October 1991, late December 1991, and March-April 1992, but the storms of early October 1992 had virtually no impact on this shore (although they significantly modified many of the Conception Bay beaches which faced into the predominantly northeasterly winds). Similar differences are evident when textures are compared between beaches on seasonal or yearly bases.

Sedimentary structures, both small- and large-scale, show similar ranges of spatial and temporal variability. Most beaches are too coarse to permit the formation of ripples, and the development of small-scale sedimentary structures is confined to short periods of relative quiescence. Swash bar complexes, small cuspate features, and viscous grain flow cones, fans, and sheets mark some pebble-dominated beaches during the early summer months. Such features are ephemeral, being destroyed and re-formed on a daily basis, and few survive the intense reworking characteristic of the late summer and autumn along most shores.

Ripples are present only in granule-dominated zones (such as the lower energy portions of Gooseberry Cove). Most are marked by in-phase development with low sinuosity, narrow (1 cm) crestal platforms, stoss and lee slopes of $3^0$- $5^0$ and $12^0$- $20^0$ respectively, and ripple indices (Tanner 1967) ranging between 3 and 9. These characteristics indicate that the ripples formed under higher energy regimes than those evident on sandy beaches (e.g. Class 10), but that the energy levels are still relatively low. The ripples are generally developed by the incoming waves, and are best preserved on inter-channel 'bars' in zones marked by undulating shallow bathymetry. Incoming waves attack the shoreline along a quasi-linear front, producing ripples along their lengths. The outgoing waves are generally focused in shallow channels, especially in areas where the shore is marked by cuspate features developed during periods of higher energy. The outgoing waves succeed in destroying the ripples in the channel areas, but frequently leave the intervening bars relatively unaltered. Such ripples, however, are ephemeral in nature, and individual systems seldom survive more than 10 12 incoming - outgoing wave events. After storms (and in some cases after high tides) the entire ripple system has been destroyed.

Large-scale sedimentary structures are present on most Class 13 systems at various times during the year, and may persist throughout an entire year in some zones. Sheets and lenses of gravel, produced by rapid-flowing shallow swash and washover bores triggered by anomalously high waves or storm events, are present on some finer-grained gravel beaches, but are very ephemeral. The most common feature is the gravel cuspate structure, formed by wave activity. Gravel cusps give the beach a scalloped appearance, and are marked by bowl-like hollows open at the seaward margins, separated by sharp points of gravel. The scale of the cusps varies from minimum breadths (along shore) of ± 10 centimetres to maximums in excess of 10 m. The widths (perpendicular to shore) range from < 10 cm to 1.5 m, and the depths (crown to base of hollow) range from 2 cm (one clast thickness) to > 1.5 m. Slope angles within the hollows may exceed $45^0$, but are generally between $12^0$ and $25^0$. The overall shape of the hollows varies from essentially circular, with a deep central depression, steep back slopes, and a lip at the seaward edge; to shallow depressions, with widths much less than breadths, and no seaward lip; to elongate depressions, with breadths ≤ widths, that gradually slope landward without a seaward lip. These morphological differences reflect differing wave energy conditions, durations of wave events, the relative importance of onshore-offshore transport *versus* shore-parallel transport, and the relative energies and erosive strengths of the incoming and outgoing water. For example, shallow, breadth >> width structures represent conditions marked by significant shore-parallel transport, whereas circular structures with strongly concave cross-sections represent very dominant onshore-offshore movement. Storm waves which overtop the back-beach areas usually produce elongate, linearly-sloping depressions, with width > breadth, as the waves overtop the barrier and disperse landward forming washover channels, rather than returning as backwash. A seaward lip is produced where the largest materials are initially dislodged from the back wall of the cusp, but are too large to be transported seaward under wave power alone. The cobbles move to the base of the cusp under gravity, but then accumulate on the seaward lip as the water diffuses through them without being able to transport the clasts.

Where the cusps are formed by waves which strike the shore parallel to its trend, and where shore-parallel transport of sediment is negligible, the slopes bordering the depressions are symmetrical and have similar angles with respect to the trend of the shoreline. More commonly, however, the depression and slopes are asymmetrical, with the degree of skewness reflecting the angle of wave attack on the shore and the impact of some longshore transport.

The morphology and pattern of cuspate development thus is highly dependent on local, temporally-varying wave conditions. Cuspate morphology commonly differs throughout the length of any particular Class 13 shore, differs throughout the seasons or in response to individual storm events (e.g. Hurricane Bob of summer 1991, the equinoxial gales of early October 1991, and the late winter storms of 1992). Differences also are attributable to elevation above sea level, as different waves strike the shore at different elevations. and so produce different styles of cusps. Stacked sequences of cusps, reflecting different wave regimes, are common on many gravel beaches along the Avalon Peninsula. Systematic observation of several beaches along the Cape Shore, as well as other areas along the Avalon Coast, indicate that some cusps may remain unaltered for several years. These large features, therefore, reflect particularly intense storms, and their presence is not a reliable guide to the most recent sedimentation -history of the beach.

Variations in overall morphology of these beaches are also common. Many beaches undergo periodic cycles of erosion and deposition throughout the year, leading to changes in slope angle, development of temporary shore-parallel spits and bars, and collapse of oversteepened fronts. Variations are also evident between years. The central Cape Shore beaches generally suffered from a deficiency of sediment in 1992, leading to erosion of different magnitudes along the shore (e.g. minor at Ship Cove, moderate at Gooseberry Cove, extensive at Big Barasway). The previous two years were marked generally by a net excess of deposition. The spring of 1993 was marked by a small net deposition at most of these systems, but erosion appears to have continued at others (e.g. Patrick's Cove and parts of Big Barasway). In contrast, the beaches north of Long Harbour showed relatively little change in sediment supply between 1991 and 1992, but all have been marked by some erosion during the spring of 1993. Early summer 1993 appears to be marked by erosion of most systems, but at a lesser rate than that evident in 1992. Similar variations since 1966 are evident through comparison of aerial photography of many of the gravel beaches throughout Placentia Bay.

Shifts in the quantity and texture of material supplied to the beach by streams, and seasonal fluctuations in stream volume, also lead to alteration of the beach morphology. Many broad gravel flats are associated with steep gravel beaches (shore Class 15), and the changes in slope angle throughout the seasons (or from year-to-year) are significant enough to change the designation between these two classifications. Typically, gravel beaches show modal slopes as low as $3^0$ - $4^0$ in the late summer, especially where finer pebbles and granules are important constituents of the beach (e.g. Gooseberry Cove). In contrast, storm activity and seasonal fluctuations may combine to produce slopes in excess of $25^0$ during the late autumn and early winter. The beach thus varies seasonally between a broad gravel flat and a complex dominated by one or more steep gravel beaches (shore Class 15). Such beaches are designated as 13 / 15 zones. Changes in width of the gravel flats over time (from Class 13 to Class 14) are relatively uncommon in the Placentia Bay region.

The degrees of variation between the shorelines grouped together within Class 13, and the spatial and temporal variations within individual Class 13 systems, are therefore considerable. Generalizing among Class 13 systems is difficult, and a thoroughly comprehensive approach would necessitate monitoring individual beaches over a period of several years. Along the Placentia Bay shore, detailed monitoring of Big Barasway and Ship Cove has been conducted between 1989 and 1993 (Boger and Catto 1992, 1993a, 1993b, and *in preparation;* Boger 1994), and monitoring of Gooseberry Cove has been conducted since 1990 (Moss *in preparation;* and unpublished research by Catto). Other Class 13 beaches along the shoreline which have been investigated and are currently being monitored by Catto include Angel's Cove, Patrick's Cove, Green Point-Point Verde-Placentia Roads, Southe-Harbour, and Arnold's Cove.

**CLASS 14 -- NARROW GRAVEL FLAT**

Class 14 shorelines differ from Class 13 in that the width of the gravel flat is less than 30 m. These shores develop either where steep bathymetry precludes the genesis of a Class 13 shore, or where a bluff of Quaternary sediment provides an ample source of coarse material along a relatively straight, non-embayed, segment of coastline. As for Class 13 shorelines, textural variation within the classification is considerable, and shorelines may be dominated by any grade of gravel, from granules to boulders. Most Class 14 shores along Placentia Bay are composed predominantly of coarse pebbles and cobbles. Sedimentary structures resemble those of the wider gravel flats. Typical examples are located at Little Barasway (tape reference 4496) and Southern Harbour (tape reference 1935).

The shore at Little Barasway is typical of this class. The gravel strand varies along its length and seasonally from 8 m to 25 m at low tide. The modal slope has varied from a low of $3^0$ (after maximum summer deposition in early September 1990) to a maximum of $29^0$ (after severe erosion resulting trom the storms of late December 1992). Typically, the shore slopes seaward with a gently concave profile, with maximum slopes of $8^0$-$10^0$. Cuspate structures are infrequently present, and are generally shallow with breadth >> width, suggesting significant shore-parallel transport. The lack of pronounced embayments along this segment of coast limits the focusing of offshore waves. Texture varies with position and season, but most of the beach is composed of coarse pebbles and cobbles (slightly finer at the low tide line). Textural and morphological variations, such as cusp asymmetry (when present) indicate a northward sediment transport direction.

Sediment supply to the beach is high. The beach is fed by a stream laden with sediment from the sheep-rearing area to the east. Bluff failures are common, especially during storm events, and these provide a mixed textural assemblage ranging from f-me and medium sand (derived from capping loess deposits) to coarse cobbles and boulders (derived from glaciomarine diamictons and glaciofluvial gravels). Cliff recession rates locally have exceeded 1 m 1 a since autumn 1989, and individual blocks representing more than 1 m in depth from the cliff edge commonly fall from the bluff face. Sheep disturbance of the cliff edge sediments also contributes material to the beach. In addition, the shore-parallel current transports sediments derived from the Quaternary bluffs at the north end of Big Barasway, to the south-southwest. Consequently, Little Barasway is currently enjoying a period of net. sediment accretion, and the beach has been steadily growing since autumn1989. Storm activity results in short-term sediment removal, but input of new materials from the bluffs and shore-parallel currents quickly repair any damage. In addition, much sediment which is washed to sea during storms returns to the beach at later times. Chunks of terrestrial peat, derived from the Quaternary bluffs, are commonly observed arriving at the beach front from seaward for days after major storms (such as Hurricane Bob).

The constancy of sediment supply allows the Little Barasway system to recover rapidly after storms, regaining its basic profile within weeks (days, after lesser storms). Class 14 shores which are less exposed, but also have a less readily available source of sediment, are both less frequently disturbed during storms and are slower to recover. The shores at Southern Harbour exhibit these effects. Recent local construction in the Southern Harbour area has disturbed some of the Quaternary sediment bluffs (by removal of vegetation), and the sediment supply to the system has increased between 1990 and 1992. This increase appears to be causing stabilization of the area, as it was not severely disturbed during any of the most recent storms, and may eventually lead to progradation and the development of a Class 13 shore in this area.

## CLASS 15 -- STEEP GRAVEL BEACH

Steep gravel beaches commonly exhibit a wide range of texture and morphology from season to season, and among locations. As discussed above, Class 13 / 15 transitional assemblages (such as Big Barasway) are very common along the Placentia Bay shore. Class 14 / 15 transitional assemblages are less common, but do occur in some places, such as the southern side of Margery Cove Point, Red Island (tape reference 759). Textures on Class 15 beaches range from granules to boulders, but cobble-dominated systems are most common. Seasonal and/ or yearly variations in classification between gravel and sand-and-gravel beaches (Classes 15 and 18) occur in some areas, such as Scrape Cove, Merasheen Island (tape reference 941), the north shore of Arnold's Cove (tape reference 2101-2110), and Little St. Lawrence (tape reference 4792).

Examples of steep gravel beaches not associated with extensive progradational beach ridge complexes or gravel flat development are present at Fox Harbour (tape reference 175-184, 4667-4668). These beaches generally exhibit a strongly concave pattern marked by one or more tiers of cuspate structures where undisturbed by human activity (as surrounding Bottom Barasway and The Neck, in the Fox Harbour area). The slopes generally range between $10^0$ and $22^0$, with significant seasonal variability. Cuspate structures are commonly present, giving the beaches a scalloped cross-section. Textures vary from pebble- to cobble-dominated.

Many tombolos are associated with this style of shoreline. In addition to The Neck, gravel-dominated tombolos are present at Little Gallows Harbour (tape reference 3276), St. Joseph's (tape reference 3291), and Haystack Harbour (tape reference 313). Other tombolos show seasonal textural variations between gravel and mixed sand and gravel, as at Little St. Lawrence (tape reference 4792).

Tombolos may form by several mechanisms, including landward growth of hooked spits attached to the island, accumulation of debris in the lee of the island through shadowing, seaward progradation of a single barachoix or hooked spit, seaward progradation of a cuspate spit or of converging spits, or by one or more of these mechanisms combined with sea level regression. The gravel-dominated tombolo systems of Placentia Bay were fed predominantly (e.g. Haystack Harbour) or exclusively (e.g. The Neck) by sediment derived from the land. Most of the gravelly tombolos are marked by well-developed steep linear beaches, with beach widths and distance across the tombolo relatively constant. This geomorphology suggests that the tombolos developed by seaward progradation of individual linear barachoix or spits. The presence of isolated lagoons of linear or irregular shapes (as at Haystack Harbour) supports this conclusion. Tombolos created by the progradation of cuspate spits usually contain a triangular central lagoon or depression, marking the area intermediate between the converging currents.

The role of sea level regression in the formation of these tombolos appears to have been relatively minor. Although sea level has regressed throughout northwestern and eastern Placentia Bay since the post-glacial maximum stand, recent rises in sea level have been recorded along the entire length of the coast (Grant 1989; D. Forbes, Atlantic Geoscience Centre, personal communication; and data collected by Catto from Cape Shore sites and Biscay Bay). Rates of sea level rise over the most recent 270 years, suggested by tidal gauge data and the archaeological excavations of Fort Frederick, Placentia, are on the order of at least 3 mmper year. The recent history of sea level change, therefore, is somewhat unfavourable to tombolo development and preservation, especially in situations where gravel tombolos join bedrock outcrops (as at The Neck).

Storm activity appears to have little permanent effect on these tombolos. Although exceptional waves may overtop the tombolo and temporarily isolate the island from the main shore, as overwash fan patterns on The Neck, and aerial photograph analysis of the St. Joseph system suggest, no evidence of truncation or breaching of the tombolos is apparent.

## CLASS 16 -- WIDE SAND & GRAVEL FLAT

Class 16 shorelines are differentiated from those of Class 13 on the basis of texture. A Class 16 shoreline is defined as a wide flat which contains between 30% and 70 % sand, as determined either from visual estimates or *in situ* sampling. Class 16 beaches investigated in this region are generally dominated by fine pebbles and granules, and the sand proportion is usually 30- 40 %. The sand is generally coarse-grained. Many sand and gravel flats undergo textural modification throughout the year, and from year-to-year. Beaches where such textural modification is considerable are designated as 13 / 16 (e.g. Southwest Cove, Long Island, tape reference 342). Along other beaches, seasonal or yearly changes result in shorelines alternating between Classes 16 and 17 (narrow sand and gravel flat). Examples of this style of shoreline are located on Red Island (e.g. Wild Cove, tape reference 750) and King Island (Tack's Beach, tape reference 1253). Seasonal and/or yearly changes in sand and gravel shorelines, similar to those which affect gravel flats, also cause some areas to alternate between sand and gravel flat status and Class 18 (Steep Sand and Gravel Beach). Examples of this type of shoreline are located at Butler Island (tape reference 606), Burin Bay Arm (tape reference 3035), and other areas.

Sand and gravel flats which have remained unaltered (in terms of the classification used in this report) are much less common than gravel flats. Moll Point, Argentia (tape reference 4560-4570), Cochrane Cove, Red Island (tape reference 780), and Taylor's Bay, Burin Peninsula (tape reference 4068) all serve as examples of Class 16 beaches. Moll Point, however, has undergone both direct anthropogenic modification and changes as a result of human activity to the southeast (Freshwater area), and thus, as all the beaches of the Argentia Peninsula, is not in a natural state.

The beaches of both Cochrane Cove and Taylor's Bay are marked by gentle seaward slopes ($2^0$-$8^0$), with limited or no cuspate feature development. At Cochrane Cove, a river system entering from the west provides a source of medium and coarse sand, which allows the beach to maintain its relatively fine texture. The cove is sheltered, and reworking appears to be minimal. The east-facing aspect of the cove protects it from the effects of southwesterly winds, the most prevalent and effective storm winds in the Red Island area. This beach, therefore, is essentially quiescent at the present.

At Taylor's Bay, the texture of the beach is due to reworking of Quaternary sediment from the surrounding area, as well as direct river input. Taylor's Bay is more influenced by currents than is Cochrane Cove, and sediment is generally carried counter-clockwise in the bay head area (from east to west). The flats widen progressively to the west, from 5 m at the eastern extremity of the embayment head (Class 17 shore) to > 70 m at some low neap tides in the central and western areas. The texture generally fines from east to west, the combined result of shore-parallel currents and the input of fine sediment from a stream which debauches into the embayment after passing through a back-barrier lagoon (and thereby loses much of its coarsest load). This pattern is repeated at other embayments along the southern Burin shore, most notably at Lansey Back Cove (tape reference 4017, 4027) where river input and westward currents combine to create a westward progression from a graveldominated (± 70-75 %) mixed sediment beach (Class 16) to a sand-dominated flat with < 10 % gravel (Class 19) at the western extremity.

Reworking of the Burin Peninsula systems during storm events is more extensive than is the case in Cochrane Cove. The Burin systems are open to the prevailing winds, and funneling of the waves in the embayments is common. Steep beaches form seasonally in several areas, and small segments created during storms persist in some places, especially where backed by lagoons (as at Taylor's Bay). Supply of sediment from the land, however, quickly re-establishes the textural pattern and basic morphology after storm events.

Several of the Burin Peninsula beaches were subject to tsunami attack as a result of the Grand Banks Earthquake of 1929. Taylor's Bay sustained considerable damage at that time, but no traces of the tsunami remain evident on the surface today, despite attempts to recognize its effect in the geomorphic and sedimentary record (D. Liverman, Department of Mines and Energy, personal communication). Further investigations in the Burin Peninsula region are planned in an attempt to assess the long-term geological signature of the tsunami event.

## CLASS 17 -- NARROW SAND & GRAVEL FLAT

Class 17 beaches are defined as those dominated by mixed populations of sand and gravel, that are less than 30 m in width. Many Class 17 zones are transitional, spatially and over the short and long term, to broad sand and gravel flats (Class 16), to steep sand and gravel beaches (Class 18: examples include Creephole Point, Jean de Baie, tape reference 3569; and the north shore of Burnt Island, Nonsuch Inlet, tape reference 3238), and to steep gravel beaches of Class 15 (e.g. Bittern Cove, tape reference

2591). These transitions reflect changes wrought by seasonal events, shifts or temporary truncations of sediment supply, and isolated major storms.

Two examples of Class 17 beaches are located at Fair Haven (tape reference 1490) and Mooring Cove (tape reference 3650). Both these beaches are gently to moderately sloping in the summer months (slopes $3^0$ -$14^0$), and have little cuspate development. Slopes begin to steepen in late summer, a process which is accelerated by the equinoxial gales. February slopes as high as $25^0$-$30^0$ have been observed at Mooring Cove (1992). Decline of the slope angles begins in the early spring (apparently earlier at Mooring Cove than at Fair Haven). The Mooring Cove beach appears to be more subject to attack than the beach at Fair Haven, and consequently exhibits a greater seasonal variation in morphology. Small-scale sedimentary structures are rare at both sites, being confined to scattered ephemeral ripples of low sinuosity with narrow crestal platforms. Sediment preserved in the beaches is generally structureless and moderately to poorly sorted. The beach sediment at Fair Haven is coarser (modal 60% pebble gravel and 30 % coarse sand) than that at Mooring Cove (modal 40 % pebble gravel and 40 - 50 % coarse and medium sand), but both areas have been modified somewhat by anthropogenic activity.

## CLASS 18 -- STEEP SAND & GRAVEL BEACH

Steep sand and gravel beaches develop both seasonally in association with sand and gravel flats (e.g. Arnold's Cove, tape reference 2101) or gravel beaches (e.g. Hogan Cove, Merasheen Island; Scrape Cove, Merasheen, tape reference 941), and independently (e.g. Cross Point, Merasheen Island, tape reference 950). Class 18 beaches are involved in many tombolo, spit, and barachoix features, especially on the major islands.

As is the case for the Class 15 systems. seasonal variability is a hallmark of steep mixed sediment beaches. Slopes range from minima of $<5^0$ to maxima of $> 25^0$. Profiles are strongly concave on the coarser systems, but may be almost planar on sand-dominated beaches. Textural assemblages span the range of possibilities, from cobble beaches with lesser amounts of coarse sand (Hogan Cove) to granule- and coarse sand-dominated systems (parts of the Cross Point shoreline). Cuspate structures are present on the coarsest beaches in all years, but may be absent from finer beaches at most times. Stacked tiers of cusps are evident on photographs of several Merasheen systems, but are generally absent from Cross Point and Arnold's Cove.

Tombolos associated with Class 18 beaches (such as that at Cross Point) appear to have developed primarily from seaward progradation of individual barachoix or linear spits, rather than from converging rip currents or cuspate spits. In several cases, however, two barachoix or linear spits have prograded independently from the mainland, forming a doubly-tied island. These independently-developed tombolos usually are texturally different. At Whitesail Head, for example, the northern tombolo system, across Beckford Cove, Presque Harbour (tape reference 3044) is a mixed sediment feature, with apparently approximately equal proportions of sand and gravel in July 1981. The southern tombolo, across Long Beach (tape reference 3068), was a Class 15 shoreline in July 1981, dominated by coarse pebble and cobble gravel. These textural distinctions have remained in evidence on aerial photographs taken subsequently. Evidence of overtopping is not present on most of the tombolo systems, and none appears to have been breached recently. Small washover channels are relatively ephemeral features, however, and hence some minor overtopping may have occurred without leaving definitive traces in the geomorphic or sedimentological record. Sea level change does not appear to have substantially modified these features.

## CLASS 19 -- WIDE SAND FLAT

Sand flats are defined here as containing less than 30 % gravel of all grades, including granules. Seasonal variations locally cause classifications to alternate between sand and gravel-dominated and sand-dominated zones (e.g. 16 / 19, Flat Island Harbour, tape reference 3466; Salt Cove, tape reference 4872). Associations of wide and narrow sand flats (Class 20) and steep sand beaches (Class 21) are also present.

The generally coarse texture of the Quaternary sediment, the high energy levels of most of the Placentia Bay shoreline, the shortness and steepness of the streams carrying sediment to the shore, the steep bathymetry, the low mesotidal to microtidal regime, and the prevalence of frost wedging all combine to limit the supply of sand to the coast of Placentia Bay. Sand-dominated systems can only develop in a few isolated regions, where some of these factors are locally not involved. Commonly, sand has accumulated in the coastal zone through other, terrestrial processes (such as aeolian activity), rather than having been carried to the sites by marine currents.

One of the largest sand flats along the Placentia Bay shore is located at Lance Cove (tape reference 4225). This Class 19 shore grades laterally to the east into a Class 10 environment (as discussed above), and grades westerly into a Class 11 shoreline (Sand flat on narrow rock platform). The sediment consists of medium to fine-grained, moderately sorted, discose sand clasts of quartz, feldspar, argillite, slate, shale, hornblende, biotite, and other heavy minerals.

Sand accumulated at Lance Cove from reworking of glaciofluvial deposits during early postglacial time. Following marine regression during the early and mid-Holocene, this sand was further reworked into a complex of low dome dunes, sand sheets, and patches of coarse loess. A $^{14}C$ date obtained from peat buried by dune material and subsequently exhumed by fluvial erosion suggests that dune building prograded to the shore area c. 5380 ± 60 B.P. (GSC-5572). This dunal sediment is actively undergoing reworking at present, as the result of coastal onshore winds, fluvial erosion, storm waves, and anthropogenic-induced deflation resulting from overgrazing by sheep and disturbance from all-terrain vehicles. Sand flux to the beach, therefore, is high at present from early spring to mid-winter. Seasonal icing during mid and late winter effectively precludes sediment movement at these times.

The sand flat is marked by an extremely gentle slope ($<1^0$ - $4^0$). Storm activity results in small areas of undercutting at the dune margins and along the course of the stream which crosses the beach, but these seldom exceed 0.5 m in height and are quickly smoothed by subsequent reworking. Most storm waves appear to travel over the surface of the sand flat without causing significant erosion, and the energy is focused at the dune field margin. Sediment eroded from the dunes is laid down during backwash as a thin, planar, gently dipping stratum. Repetitive swash events destroy the stratification imparted during each backwash period, and thus the storm deposits are characteristically structureless.

During normal wave activity, swash-and-backwash scour patterns and low energy ripples are produced, similar to those which characterise the Class 10 shore (as described above). Bioturbation is not in evidence.

The stream which flows across the beach also produces sedimentary structures. This area, thus, is one of a very few on the Placentia Bay shore where non-marine sedimentary structures are preserved. Fluctuating energy levels and water volumes in the stream allow production of various styles of ripples, planar beds (resulting from migration of small diffuse sand sheets and sediment clusters), internally structureless fan-shaped deposits (resulting from viscous grain flows induced by bank undercutting and collapse), and rarely antidunes, formed by upstream migration of oversteepened wave fronts. All of these features are small-scale structures, and all are ephemeral. Exposures of sediment in the beach show that, below the surface, sediments are generally structureless or planar-bedded, reflecting reworking during storm events.

Other wide sand flats are present along the lower reach of the Piper's Hole River (tape reference 2347-2367), at Flat Island Cove (tape reference 3474), in the Cow Head area (tape reference 3658), north of Red Head (tape reference 4036), and at Point May Pond (tape reference 4176). All are characterised by very gentle slopes, and are located in areas of abundant sand supply. Aerial photograph analysis indicates that all of these zones are marked by relatively stable conditions, and that the characters of these beaches have changed little in recent years. Beaches such as those at Cow Head and north of Red Head, where aeolian sedimentation is less significant than fluvial input, are generally coarser than the system at Lance Cove. At Flat Island Cove, the sand flat is laterally transitional into a mixed sand and gravel flat, and is associated with tombolo development. Here, the textural character of some zones along the beach changes seasonally, coarsening in the late autumn and gradually acquiring finer sediments throughout spring and summer.

**CLASS 20-- NARROW SAND FLAT**

Narrow sand flat systems are uncommon along the Placentia Bay shore. Examples occur at Swift Current (tape reference 2450 - 2470), Cow Head (tape reference 3658), along the eastern side of Burin Bay Arm (tape reference 3842), on Patricks Island, south of Oderin Island (not surveyed in July 1981), and at the heads of some elongate embayments such as Bay de I'Eau and North Harbour (Capelin Cove, tape reference 2336). Gradation among shorelines of Classes 19, 20, and 21 is common.

Narrow sand flats resemble the broader flats of Class 19 in most respects. Sediments are generally somewhat coarser, but much of this textural differentiatation can be attributed to the available sand supply rather than to factors inherent to the flats. The narrow sand flats are all in regions where sediment is derived primarily from fluvial and marine processes, rather than from aeolian deposits. Consequently, the sand supplied to theses beaches is generally moderately sorted, medium- to coarse-grained discose clasts. Sedimentary structures are rarely preserved, and planar laminations sloping parallel to the general slope of the beaches ($2^0$-$7^0$) are commonly intercalated vertically and laterally with structureless deposits. The beaches appear to have retained their general character throughout the period under observation and analysis.

## CLASS 21-- STEEP SAND BEACH

Steep sand beaches develop both in association with sand flats (e.g. Burin Bay Arm, tape reference 3482; Lansey Back Cove, tape reference 4017), and independently of sand flats, grading laterally (and seasonally) into mixed sand and gravel flats (e.g. southwest shore of Woody Island, tape reference 2550). Modal grain sizes are generally in the coarse sand range. Slope angles vary from $< 3^0$- $15^0$, with most slopes approximating 5 - $8^0$. Profiles are linear to slightly concave.

Seasonal variability is less apparent on the Class 21 shores than on steep beaches with large concentrations of gravel (Classes 15 and 18). The beach front trends are gently concave to linear. Cuspate structures are not apparent at most times, but may persist for short periods following storms. Where developed, cusps are shallow and have breadths >> widths, with no seaward lips. Cuspate lines of sand particles, often only one or two clasts thick, form during low energy swash-and-backwash periods. Characteristically, the cuspate lines are asymmetrical, indicating the existence of shore-parallel transport. Ripples are rarely present, and are ephemeral.

At Lansey Back Cove, the sand-dominated beach is present on the downcurrent side of the mouth of a small stream. The sandy sediment for this beach is supplied largely by the stream, and hence the downcurrent beach is finer in texture than that located on the eastern, upcurrent side of the stream mouth. At Burin Bay Arm, the sandy beaches develop in the vicinity of the head of the arm (near Salt Pond), and grade into coarser sand and gravel beaches southward, corresponding to increased energy levels and winnowing along the seaward trend. In both areas, therefore, the transition between sand-dominated and sand-and-gravel-dominated beaches is evidently a function of local sediment supply, from essentially point sources. Along the southwest Woody Island shore, the situation is somewhat more complex, with multiple sources and a serrated coast creating areas of net positive sand influx and other areas marked by deficits and erosion of sand, and coarser mixed sediment beaches. The Woody Island shorelines are thus somewhat more susceptible to seasonal and year-to-year variations than are those at Lansey Back Cove and Burin Bay Arm.

Sandy systems in the Placentia Bay region thus appear to be generally more stable than those dominated by mixed sediments or gravel. This conclusion, however, is biased by the very small number of sand-dominated shorelines present, and their tendency to occur only under very restricted circumstances, commonly in low-energy locations. Changes in sandy shorelines which escape detection through aerial photograph or videotape analysis may be revealed through field research.

## CLASS 22 -- MUDFLAT

Mudflat areas are defined as those shores with a slope $< 2^0$, little or no permanent vegetation cover, surface sediment composed of $< 50$ % total sand and gravel, and few or no boulders. The majority of the sediment may be either silt, day, or a combination of both. Mudflats are generally associated with tidal activity in most regions of Atlantic Canada, but this is not a necessary component of the classification. Estuarine deposits formed predominantly by fluvial action, those occupied in whole or large part by any form of vegetation, and those with boulders on the surface are excluded from this classification.

The prototypical mudflats in Atlantic Canada are located on the margins of the Bay of Fundy, and in Malpeque Bay and other regions of the coast of Prince Edward Island. These flats are marked by generally silt-dominated textural assemblages, with sand components of 30 - 40 % not uncommon (several 'mudflats' in these areas contain more sand than silt and -clay combined). Sedimentary structures are uncommon on many of these mudflats, except in channelized areas, and are confined to horizontal laminations, bioturbation features, rare dessication cracks and dewatering features, and aeolian ripples produced during low tides. Such flats develop under mesotidal and macrotidal regimes, in areas with an abundant supply of fine sediment.

The coastline of Placentia Bay is not suited for the development of these features. Sediment supply is limited in many areas, and coarse materials predominate. Tidal regimes are microtidal and low mesotidal, and tides are insignificant compared to waves in shaping almost all segments of the shore. The development of many tidal flats and associated salt-water marshes is related to slowly rising sea level (e.g. Allen 1990), rather than being characteristic of the relatively rapid rise evident on parts of the Placentia coast within the past 270 years. Regions where tidal flats have developed under conditions of rapidly rising sea level (e.g. Chezzatcook Inlet, Carter *et al.* 1989) are also marked by abundant sediment supply.

The only area where a true 'mudflat' exists is in the vicinity of Calmer, on Point May Pond (tape reference 4176). In this area, small mudflats are associated with sandier zones (Class 19) and lagoonal margins marked by mixed sediment and organic matter (Class 23). This region is classified as a compound shore, 23 / 22 / 19, with the order reflecting the relative importance of each shoreline type. Adjacent zones are dominated by partially vegetated lagoonal margin sand flats (23 / 19), and by similar flats marked by spasmodic vegetation expansion and contraction (23 / 19 u).

Analysis of the tapes and aerial photographs suggests that the small Calmer mudflats have slopes of $1^0$ or less. The dominant texture appears to be silt, with more sand than clay. The flats appear to be eroding at a very small rate, as indicated by successive aerial photographs. This erosion may reflect rising sea levels along the southern Burin Peninsula shore, but could also be attributable simply to occasional breaches of the Point May - Calmer Point barrier system during individual storms. Detailed analysis of this region would require multiple cores in the mudflat zones.

## CLASS 23 -- ESTUARY AND FRINGING LAGOONAL

Estuary and fringing lagoonal areas are defined as those where estuarine conditions prevail, together with marginal areas marked by organic sediments, aquatic or marsh vegetation, or near-stagnant lagoonal waters. Lagoons associated with the back-beach areas of barachoix, tombolos, and similar features are excluded from this classification.

Along the margins of Placentia Bay, estuaries are developed by many of the major streams entering the western side of the bay, such as at North Harbour (tape reference 2338), Black River (tape reference 2426), Swift Current (tape reference 2440), Cape Roger Bay (tape reference 3265), and Bay de I'Eau (tape reference 3355). Lesser streams at Salt Pond (tape reference 3847) and Point May Pond (tape reference 4176) have also created small estuarine / fringing marsh areas. Along the eastern shore of Placentia Bay, the steep cliffs, shallow coves, and short rivers limit the scope for estuary development. Examples are present at Ship Harbour (tape reference 198), Northeast Brook (tape reference 153) and Long Harbour (tape reference 217). Modification of the sediment flux and fluvial systems entering the latter two of these estuaries by anthropogenic activity has been extensive, however (especially at Long Harbour), resulting in destabilization of the estuarine system which has of yet not been rectified.

The definition of an 'estuary' is a troublesome matter for sedimentologists and geomorphologists. In this report, an 'estuary' is defined as an embayment marked by interchange of initially distinct populations of fresh terrestrial water with saline marine water. In a boreal climate, this definition raises the theoretical difficulty that some embayments may cease to qualify as estuaries during the winter months, when stream inflow drops to such low levels that the fresh water mass fails to retain its identity. Most streams, however, flow with sufficient volume throughout the year to allow the estuary to maintain its status.

A greater climatically-based concern comes when trying to classify a boreal estuary. Numerous schemes have been developed for estuarine classification, but most sedimentologically- or dynamically-based attempts relate the ratio of the velocity of surface water : basal water to the ratio of surface salinity : basal salinity. Seasonal fluctuations in stream flow frequently result in major changes of character of the estuary throughout the year. In cases where surface ice develops over part of the estuary, mixing and wind shear are impeded, often resulting in changes in the near-surface salinity and velocity. Such estuaries may change in classification several times throughout the course of the year.

Precise classification of an estuarine system thus requires numerous measurements of surface and basal velocity and salinity throughout the year (and preferably, for several years to eliminate weather fluctuations). In the absence of such measurements, classification of the estuary becomes a matter of speculation. Tentative classification may be based partially upon knowledge of the volume and consistency of the fluvial inflow and of the local climate, which enables an estimate of the likelihood of formation of a fresh surface water layer or the existence of a plunging cold density or turbidity current. A tentative estimate also partially depends on knowledge of the nearshore bathymetry, especially at the mouth of the estuary. This enables an estimate of the relative velocity of the basal and surface waters to be made, and permits assessment of the potential for underwater obstructions to flow and the consequent development of semi-stagnant, high salinity basal zones.

In the estuarine systems around the margins of Placentia Bay, fresh water influx is low compared to the marine water mass. Fresh waters tend to rise to the surface, because of their lesser density (controlled by differential temperatures) and their relatively low sediment loads (especially after the water has progressed ± 100 - 200 m offshore. Mixing on the surface would be ubiquitous, due both to current and wind activity.

Estuarine systems along Placentia Bay are not obstructed at their seaward margins by large moraines or bedrock sills. Over-deepening by glacially induced erosion, a common feature of the fjordal estuaries of the South Coast and the Bonne Bay / Portland Creek areas of Newfoundland, has not occurred or is not significant in most of these embayments. Consequently, the most common estuarine condition would be expected to involve mixing of surface fresh water with saline waters, and hence low salinity gradients from surface to depth, coupled with high relative velocities of basal water with respect to surface water.

These estuaries, therefore, would generally be categorized by well-mixed conditions during most of the year. Salt-water wedge systems would only exist during periods of anomalously high fresh water influx (e.g. for short periods following spring break~up). Partially mixed systems could only develop where bathymetric obstructions precluded rapid flow of basal water. Local partially mixed zones could develop in the lees of small obstructions. Surface layer mixed estuaries would not develop in the Placentia Bay area, partially due to the lack of underwater obstructions and partially due to seasonal ice cover, which curtails mixing during the winter and early spring.

The fringing marsh / organic-rich zones associated with several of these estuaries serve as sediment traps and holding areas, primarily for sand and coarse silt. Much of the sediment impounded in these areas remains within the system, contributing to shoreline progradation. Most of these areas currently lie entirely above mean high tide, and thus cannot be considered either as 'mudflats' or true salt-water marshes. Recent rising sea levels may result in the eventual erosion and re-mobilization of much of this sediment.

## CLASS 24 -- BOULDERY TIDAL FLAT COMPLEX

Bouldery tidal flat areas are distinguished from mudflats (Class 22) by the presence of boulders scattered across the entire surface of the tidally affected area. The surface texture of bouldery tidal flats varies greatly throughout the system, but the overall sediment assemblage is dominated by sand, granules, and pebbles. Vegetated areas are commonly interspersed throughout the flat. Slopes of bouldery tidal flat areas are generally very gentle, approximately $1^0$ - $1.5\ ^0$ except where cut by tidal channels.

The only example of a bouldery tidal flat complex along the Placentia Bay shore is located at the head of Come-by-Chance (tape reference 2240-2305). This complex represents a tidal flat conditioned by glaciofluvial sedimentation (Catto 1991). The boulders, cobbles, and the majority of the coarse and medium pebbles present are too large to be moved by the tidal currents or even the storm waves which affect this coast today. Consequently, the tidal flat has developed as a result of superficial reworking of the previously deposited glaciofluvial fan. The sediment assemblage present (particularly in textural terms) thus reflects primarily the latest Wisconsinan glaciofluvial environment, and is a relict assemblage.

The tidal flat is marked by meandering and anastomosing tidal channels, small washover fans, bank collapse sequences, and sedimentary successions resembling those of coarse-sediment oxbow lakes in abandoned channels. The tidal flat is bounded at its seaward margin by a cobble-dominated steep mid-bay barrier beach. At present, marine transgression is permitting enhanced reworking of the cobble gravel barrier, and local breaching and overwashing of the barrier has led to an increase in marine energy levels, evident in the uppermost sediments of the tidal flat succession.

## SUMMARIAL DISTRIBUTION OF SHORE CLASSES

Shorelines along Placentia Bay are dominated by coarse-grained gravel deposits (Classes 6, 13, 14, and 15) and cliffed areas (Class 3). Areas with mixed sand and gravel deposits (Classes 9, 16, 17, and 18) are less common than gravelly zones, but dominate some areas of the shoreline, in particular the northeastern shore (Fair Haven -Arnold's Cove), parts of Merasheen and Long Islands, and the Burin Peninsula shore southeast of D'Argent Bay. Exposed rock platform areas (Classes 1 and 2) are relatively uncommon, but rock platforms partially covered by coarse sediment (Classes 4, 5, 7, and 8) occur more frequently. Sand-dominated shorelines (Classes 10, 11, 12, 19, 20, and 21) are rare, reflecting the paucity of sand particles in the region. Most are confined to restricted areas, such as Lance Cove, Flat Island, and Woody Island. Estuaries (Class 23) are developed at the heads of most of the deep embayments along the northeastern and northwestern areas of the shore. The microtidal - low mesotidal conditions prevailing in the bay effectively preclude the development of tidal mudflats (Class 22) and bouldery tidal flats (Class 24), and only a single example of each was observed. The characteristics of the shorelines with sediment components are summarized in Table 2.

The majority of the beaches along the Placentia Bay shore are marked by energy levels of swash waves that are much greater than that of the outgoing backwash. The majority are also marked by dominantly onshore-offshore sediment transport, with shore-parallel transport playing a lesser (in many cases, a non-existent) role. This pattern of sediment transport implies that sediments and contaminants, once introduced into a beach-cove system, will remain within that system for a considerable period, and are somewhat less likely to migrate laterally along the shore. This sedimentation pattern is best developed in enclosed or semi-enclosed coarse-grained sediment areas, and is least likely to be developed along open, sand-dominated beaches. Some sand-dominated systems (such as Lance Cove) are marked by shore-parallel transport.

Beaches throughout the Placentia Bay region are marked by seasonal and yearly changes in morphology and texture, limiting the value of single-observation classification. Although all beaches along coastlines everywhere undergo modification over time, the degree of fluctuation in the Placentia Bay region, especially when considering coarse-grained or mixed sediment population shores, is exceptional. Stability is not a hallmark of most of these shores.

## SEA LEVEL HISTORY AND RECENT COASTAL MODIFICATION

Sea levels in Placentia Bay have undergone a series of changes since deglaciation, c. 12,000 - 11,000 B.P. Initially, sea levels were higher than present around the bay, due to the effects of glacioisostatic depression emanating from the much larger Laurentide inlandsis to the northwest. Higher sea levels carved erosional benches and deposited gravel terraces at elevations between 5 m and 20 m above sea level, with the northwestern shore suffering the most inundation and the southern tips the least.

Subsequently, sea level fell around the coast, dropping below present during the early Holocene (Grant 1989, Shaw and Forbes 1990). The presence of submerged estuarine and deltaic sediments southeast of Swift Current (John Shaw, Atlantic Geoscience Centre. Bedford Institute of Oceanography, personal communication) indicate that sea levels stood as much as 20 m below present levels in the northern part of the bay. Along the Cape Shore, $^{14}C$ dated terrestrial peat deposits from Patrick's Cove (7660 ± 90, GSC-5414), Point Verde (6130 ± 80, GSC - 5158), Little Barasway (5600 ± 60, GSC-5580), Fox Harbour (5150 ± 80, GSC - 5169), and Big Barasway (3480 ± 60, GSC - 5319) indicate that sea levels were at or below present throughout the midHolocene. All of these sites represent exposed seacoast locations, where trees are currently unable to grow and peat cannot form or accumulate. Simultaneously, dune progradation was occurring at Lance Cove (5380 ± 60, GSC - 5572), also suggesting that marine regression had exposed fresh sand deposits there. The decline in sea level can be attributed to a reaction from glacioisostatic over-compensation.

During the past 1300 years, sea levels have continued to fluctuate, in response to ongoing isostatic adjustment. At Ship Cove, a $^{14}C$ date from terrestrial sediment overlain by marine silt indicates that sea level rose to at least ± 1 m above present c. 1340 ± 70 B.P. (GSC - 5306). Drowned forests and peat at Biscay Bay Brook (east of Trepassey) and at numerous locations on the Burin Peninsula (Grant 1989) indicate that sea levels have risen in the past 1000 years (e.g. GSC - 5414, 750 ± 90 B.P., Biscay Bay Brook). Further investigations are being conducted by D. Liverman (Newfoundland & Labrador Department of Mines and Energy) and by Catto to attempt to define the chronology of these late Holocene events more precisely.

Archaeological evidence from Fort Frederick in Placentia (Royce Gaines, personal communication, 1993), and evidence from elsewhere along the Avalon Peninsula coast suggests a rate of sea level rise on the order of 3 mm per year during the past 270 years. Evidence of enhanced erosion along many Placentia Bay beaches suggests that transgression is currently occurring.

## RECOMMENDATIONS FOR FURTHER RESEARCH

1. One or more critical areas of the shoreline west of Come-by~Chance should be targeted and intensely monitored over approximately a two-year cycle. The data obtained from studies of this type previously conducted along the Cape Shore and northeastern Placentia Bay have demonstrated the variability of these systems, and the need for repetitive visitation and monitoring.

2. Critical biological species should be targeted, and an assessment of the nature and variability of local nearshore / beach habitats and its influence on these species should be conducted.

3. Estuarine systems in the region are as yet poorly known. Additional research, especially periodic sampling of water mass parameters, would be valuable in understanding these systems.

4. Regions slated for coastal development should be assessed prior to development activity. This area, however, also affords the opportunity to study the "restoration time" or the time required to establish a quasi-equilibrium in beach areas formerly disturbed by human activity and now left

to natural forces. Several of the abandoned communities on Merasheen, Long, Woody, and / or Red Island could be selected for such study.

5. Comparative studies should be conducted on other segments of the Newfoundland coastline, including Conception Bay, Trinity Bay, Bonavista Bay, Notre Dame Bay - Hamilton Sound, the Southern Shore of the Avalon Peninsula, and the southwestern shore from Burgeo to Port-aux-Basques, building upon studies underway at the Atlantic Geosciences Centre.

## REFERENCES

Allen, J.R.L., 1990. Salt-marsh growth and Stratification: a numerical model with special reference to the Severn Estuary, southwest Britain. Marine Geology, 95: 77-96.

Banfield, C., 1981. The Climatic Environment of Newfoundland. In Macpherson, A.C. and Macpherson, J.B., eds., The Natural Environment of Newfoundland Past and Present. Memorial University, St. John's, 83-153.

Blake, W., 1970. Studies of glacial history in Arctic Canada. 1. Pumice, radiocarbon dates, and differential postglacial uplift in the eastern Queen Elizabeth Islands. Canadian journal of Earth Sciences, 7: 634-664.

Boger, R., 1994. Sedimentology, Geomorphology, and Evolution of two Gravel Barachoix Systems, Placentia Bay. M.Sc. thesis, Department of Geography, Memorial University, St. John's.

Boger, R., and Catto, N.R., 1992. Sedimentology, Geomorphology, and Evolution of Gravel Barachoix Systems, Placentia Bay. Geological Association of Canada Conference, Abstracts, Wolfville, Nova Scotia.

Boger, R., and Catto, N.R., 1993a. Recent Coastal Evolution of Gravel Barachoix, Placentia Bay, Newfoundland. In Hall, J., and Wadleigh, M., eds., The Scientific Challenge of Our Changing Environment, Canadian Global Change Program, Incidental Report Series IR 93-2, Royal Society of Canada, 42-43.

Boger, R., and Catto, N.R., 1993b. Morphology, Sedimentology, and Evolution of Gravel Barachoix, Placentia Bay, Newfoundland. Canadian Association of Geographers, Abstracts with Proceedings, Ottawa, Ontario, p. 93.

Bostock, H., 1970. Physiography of Canada. In Douglas, R.J.W., ed. Geology of Canada, Geological Survey of Canada, Economic Geology Report 1: 3-29.

Carter, R.W.G., Forbes, D.L., Jennings, S.C., Orford, J.D., Shaw, J., and Taylor, R.B., 1989. Barrier and lagoon coast evolution under differing relative sealevel regimes: examples from Ireland and eastern Canada. Marine Geology, 88: 221-242.

Catto, N.R., 1991. Gravel-dominated tidal flat, Come-by-Chance, Newfoundland: A coastline conditioned by Glaciofluvial Sedimentation. Canadian Quaternary Association, Abstracts, Fredericton, N.B., p. 20.

Catto, N.R., 1992. Quaternary Geological Mapping, southwestern Avalon Peninsula. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 92-1: 23-26.

Catto, N.R., 1993. Sea level Variation in Newfoundland and Labrador -Clacio-isostatic, Climatic, and Anthropogenic. In Hall, J., and Wadleigh, M., eds., The Scientific Challenge of Our Changing Environment, Canadian Global Change Program, Incidental Report Series IR 93-2, Royal Society of Canada, 40-41.

Damman, W.H., 1983. An ecological subdivision of the island of Newfoundland. W. Junk, The Hague, 648 p.

Environment Canada, 1981. Canadian Climate Normals. Atmospheric Environment Service, Ottawa.

Forbes, D.L., 1984. Coastal Geomorphology and sediments of Newfoundland. Geological Survey of Canada, Paper 84-1B: 11-24.

Grant, D.R., 1989. Quaternary geology of the Atlantic Appalachian region of Canada. In Fulton, R.J., ed., Quaternary Geology of Canada and Greenland. Geological Survey of Canada, Geology of Canada 1: 393-440.

Henderson, E.P., 1972. Surficial geology of Avalon Peninsula, Newfoundland. Geological Survey of Canada, Memoir 368: 121 p.

King, A. F., 1988. Geology of the Avalon Peninsula, Newfoundland. Newfoundland Department of Mines and Energy, Map 88-1.

Liverman, D.G.E., and Taylor, D., 1990. Surficial Geology of Insular Newfoundland, Preliminary Version. Newfoundland and Labrador Department of Mines and Energy, Map 90-08.

Moss, G., in preparation. Geomorphology of Gooseberry Cove. Honours B.Sc. thesis, Department of Geography, Memorial University.

Phillips, F., 1995. Cosmogenic $^{36}$Cl Accumulation. In Rutter, N. W. and Catto, N.R., eds., Dating Methods for Quaternary Deposits , Geoscience Canada, 61 -66.

Shaw, J., and Forbes, D., 1987. Coastal barrier and beach-ridge sedimentation in Newfoundland. Proceedings, Canadian Coastal Conference 87, Québec. National Research Council of Canada, 437-454.

Shaw, J., and Forbes, D., 1990. Short- and long-term relative sea-level trends in Atlantic Canada. Canadian Coastal Conference Proceedings, National Research Council of Canada, 291-305.

Tanner, W.F., 1967. Ripple mark indices and their uses. Sedimentology, 9: 89-104.

**Table 1: Shoreline Classification Scheme for Placentia Bay**

| Class | Substrate | Sediment | Width | Slope | Type | Examples |
|---|---|---|---|---|---|---|
| 1 | Rock | None | Wide | Flat | Wide Rock Platform | Copper I. |
| 2 | Rock | None | Narrow | Flat | Narrow Rock Platform | Winging Head, Taylor's Bay |
| 3 | Rock | None | Narrow | Steep | Rock Cliff | Cape St. Mary's, Paradise Sound, & numerous others |
| 4 | Rock & Sediment | Gravel | Wide | Flat | Gravel Beach on Wide Rock Platform | Port Royal Cove, Lannon Cove |
| 5 | Rock & Sediment | Gravel | Narrow | Flat | Gravel Beach on Narrow Rock Platform | Lear's Cove, Little Brule |
| 6 | Rock & Sediment | Gravel | Narrow | Steep | Gravel Beach with Rock Cliff | LaPlante Cove, Cape Shore n. of Ship Cove, Numerous Others |
| 7 | Rock & Sediment | Gravel & Sand | Wide | Flat | S & G Beach on Wide Rock Platform | Woody Island, Davis Island |
| 8 | Rock & Sediment | Gravel & Sand | Narrow | Flat | S & G Beach on Narrow Rock Platform | Dicks Cove, Coffin |
| 9 | Rock & Sediment | Gravel & Sand | Narrow | Steep | S & G Beach with Rock Cliff | Red Land Cove, Marticot Cove |
| 10 | Rock & Sediment | Sand | Wide | Flat | Sand Beach on Wide Rock Platform | E. Lance Cove |
| 11 | Rock & Sediment | Sand | Narrow | Flat | Sand Beach on Narrow Rock Platform | Woody Island<br>Barred Island |
| 12 | Rock & Sediment | Sand | Narrow | Steep | Sand Beach with Rock Cliff | Flat I. Harbour |

**Table 1 (continued) : Shoreline Classification Scheme for Placentia Bay**

| Class | Substrate | Sediment | Width | Slope | Type | Examples |
|---|---|---|---|---|---|---|
| 13 | Sediment | Gravel | Wide | Flat | Wide Gravel Flat | Gooseberry Cove, Haystack Harbour |
| 14 | Sediment | Gravel | Narrow | Flat | Narrow Gravel Flat | Little Barasway, Southern Harbour |
| 15 | Sediment | Gravel | Narrow | Steep | Steep Gravel Beach | Ship Cove, Big Seal Cove |
| 16 | Sediment | Gravel & Sand | Wide | Flat | Wide Sand & Gravel Flat | Moll Point, Cochrane Cove |
| 17 | Sediment | Gravel & Sand | Narrow | Flat | Narrow Sand & Gravel Flat | Fair Haven, Mooring Cove |
| 18 | Sediment | Gravel & Sand | Narrow | Steep | Steep Sand & Gravel Beach | Arnold's Cove, Cross Point |
| 19 | Sediment | Sand | Wide | Flat | Wide Sand Flat | Lance Cove, Flat Island Cove |
| 20 | Sediment | Sand | Narrow | Flat | Narrow Sand Flat | Swift Current, Cow Head |
| 21 | Sediment | Sand | Narrow | Steep | Steep Sand Beach | Woody Island |
| 22 | Sediment | Mud | Wide | Flat | Mudflat | Calmer |
| 23 | Sediment | Organics & Mixed Clastics | Wide | Flat | Estuary & Fringing Lagoonal | Swift Current, Bay de L'Eau |
| 24 | Sediment | Mixed | Wide | Flat | Bouldery Tidal Flat | Come-by-Chance |

**Table 2: Summary of Beach System Characteristics**

| Sedimentary Structures and Features | | | | | |
|---|---|---|---|---|---|
| **Class** | **Texture** | **Beach Slope** | **Small Scale** | **Large Scale** | **Stability** |
| 4 | Gravel | 2° - 6° | None | Rare Cusps | Moderately Stable |
| 5 | Coarse Gravel | 4° - 10° | None | None | Stable |
| 6 | Enclosed Pocket Beach<br>Coarse Gravel | 20° - 45° | None | None | Stable |
| | Open Pocket Beach<br>Fine Gravel | 10° - 35° | None | Cusps | Moderately Stable |
| | Fringing Gravel Beach<br>Gravel | 10° - 30° | None | Cusps | Unstable |
| 7 | Gravel > Sand<br>Coarse Sand | 10° - 25° | None | Rare Cusps | Moderately Stable |
| 8 | Gravel ≥ Sand | 15° - 27° | None | Rare Cusps | Stable - Moderately Stable |
| | Sand Gravel | 8° - 20° | None | Rare Cusps | Moderately Stable - Unstable |
| 9 | Gravel > Sand | 6° - 25° | None | Rare Cusps | Moderately Stable |
| 10 | Medium - Fine Sand | 2° - 8° | Swash-backwash Scours<br>Straight-crested Ripples | Sand Sheets | Stable |
| 11 | Coarse Sand - Granules | 2° - 6° | Planer Parallel Laminae | None | Moderately Stable |
| 12 | Coarse Sand - Granules | ± 5° | None | None | Moderately Stable |

**Table 2 (continued): Summary of Beach System Characteristics**

| Sedimentary Structures and Features | | | | | |
|---|---|---|---|---|---|
| **Class** | **Texture** | **Beach Slope** | **Small Scale** | **Large Scale** | **Stability** |
| 13 | Coarse Gravel | 4° - 45° | None | Cusps | Unstable |
| | Fine Gravel | 3° - 30° | Swash Bars; Small Cusps; Rare Granule Ripples | Cusps Gravel Sheets | Unstable |
| 14 | Gravel | 3° - 29° | None | Cusps | Unstable |
| 15 | Gravel | 10°- 22° modal (max. 45°) | None | Cusps | Unstable |
| 16 | Gravel > Sand | 2° - 20° | None | Rare or No Cusps | Unstable |
| 17 | Gravel ≥ Sand | 3° - 30° | Ephemeral Ripples | Generally None | Unstable |
| 18 | Gravel ≥ Sand | 5° - 28° | None | Cusps | Unstable |
| | Sand ≥ Gravel | 5° - 20° | None | Generally None | Unstable |
| 19 | Medium - Fine Sand | <1° - 4° | Planer Parallel Laminae<br>Swash and Backwash Scour<br>Straight Crested Ripples<br>Small Fluvial Structures | Sand Sheets | Stable - Unstable |
| 20 | Coarse Sand | 2° - 7° | Planer Parallel Laminae | Sand Sheets | Moderately Stable |
| 21 | Coarse Sand | <3° - 15° | Rare Ripples; Cuspate Lines | Rare Cusps | Moderately Stable |
| 22 | Silt; Sand > Clay | ≤ 1° | None Evident | None Evident | Stable |
| 24 | Mixed | 1° - 1.5° | Fluvial and Tidal Channel Features | Tidal Channels Bank Collapse | Moderately Stable |

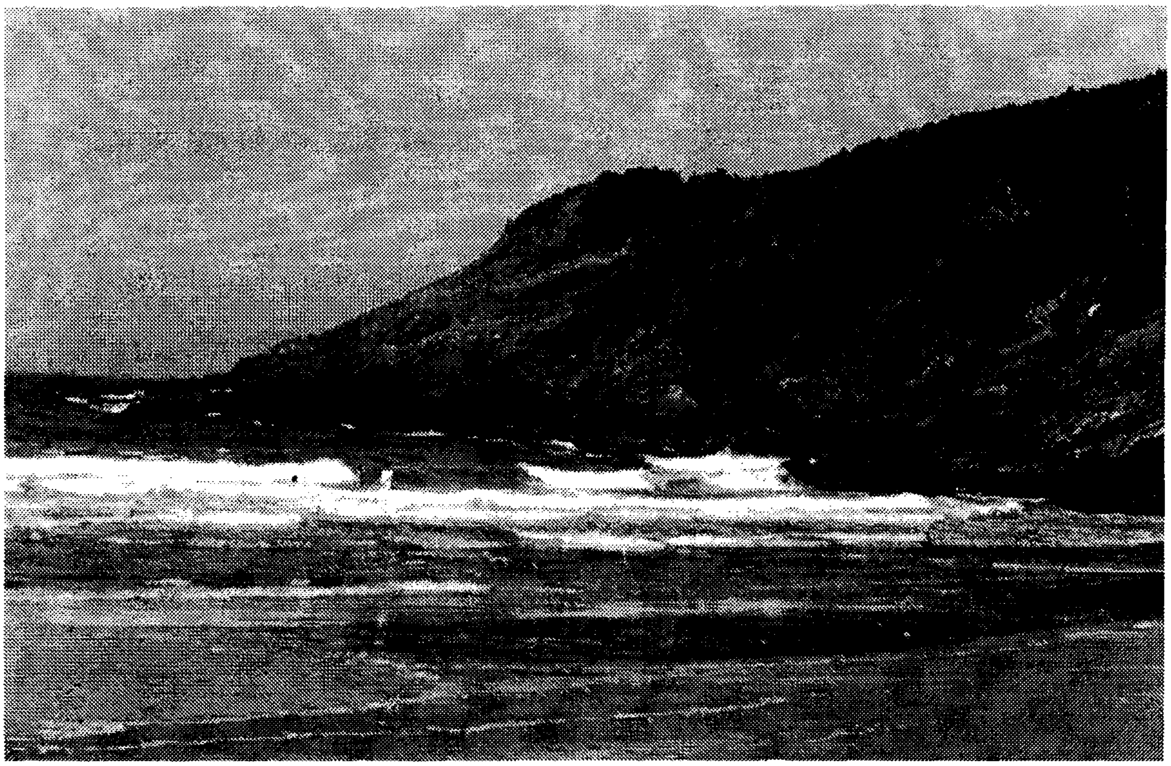

Illustration 1. Gooseberry Cove, Placentia Bay: Class 13, Wide Gravel Flat. Shoreline with gravel-dominated flats (<30% sand) with maximum widths of 30 m.

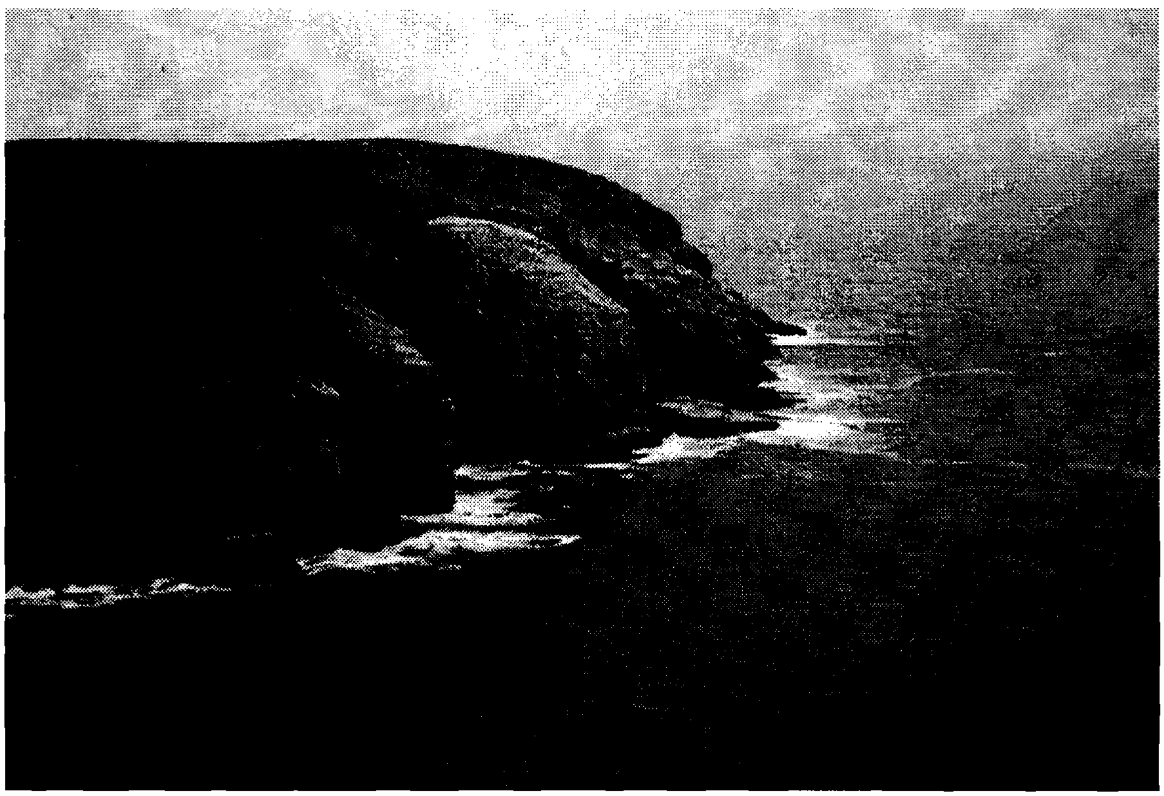

Illustration 2. Cape St. Mary's: Class 3, Rock Cliff

Illustration 3. Burin, Class 2 (Narrow Rock Platform)

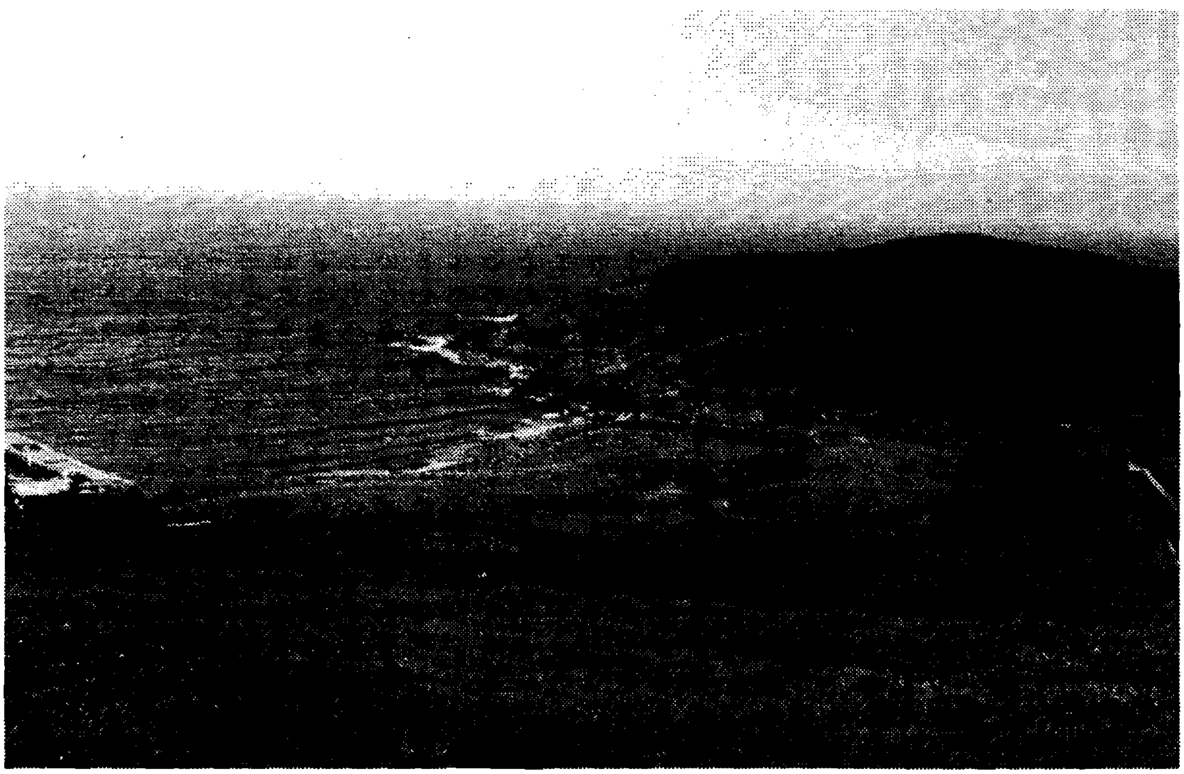

Illustration 4. Angel's Cove (Gravel Flat with Gravel Beach)

Illustration 5. Big Barasway (Steep Gravel Head & Gravel Flat)

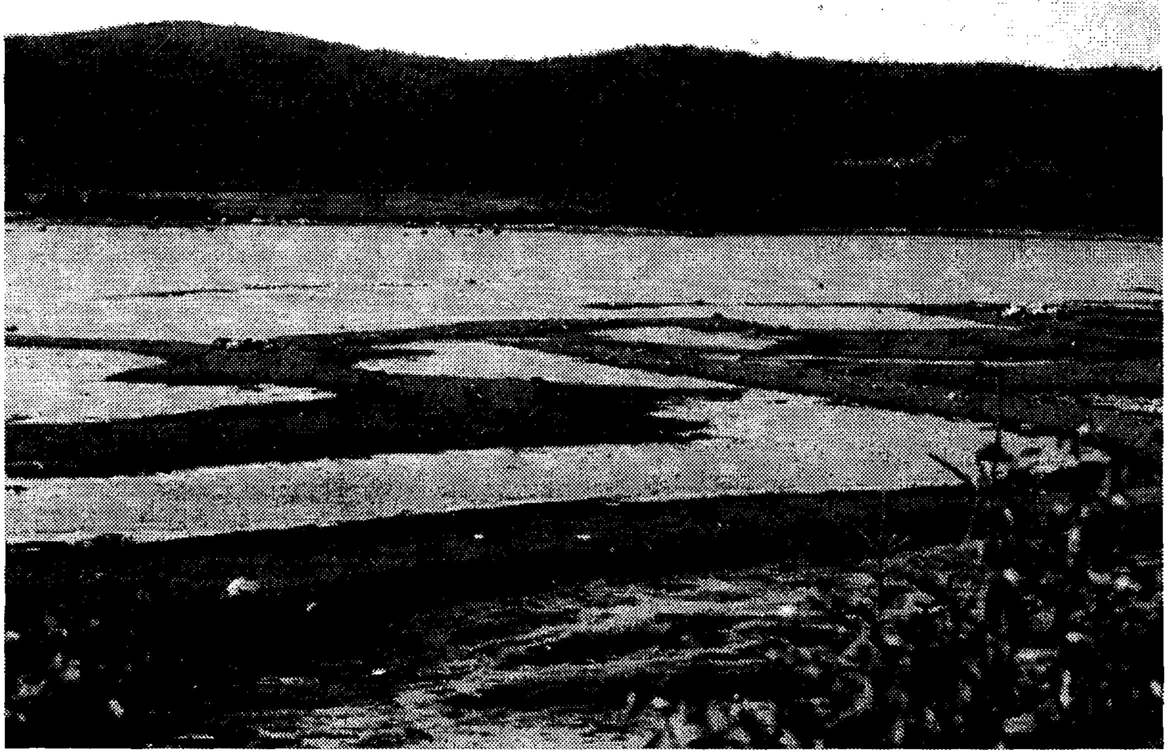

Illustration 6. Come-by-Chance, Class 24 (Bouldry Tidal Flat)

Illustration 7. Lance Cove (Modification of Dome Dunes)

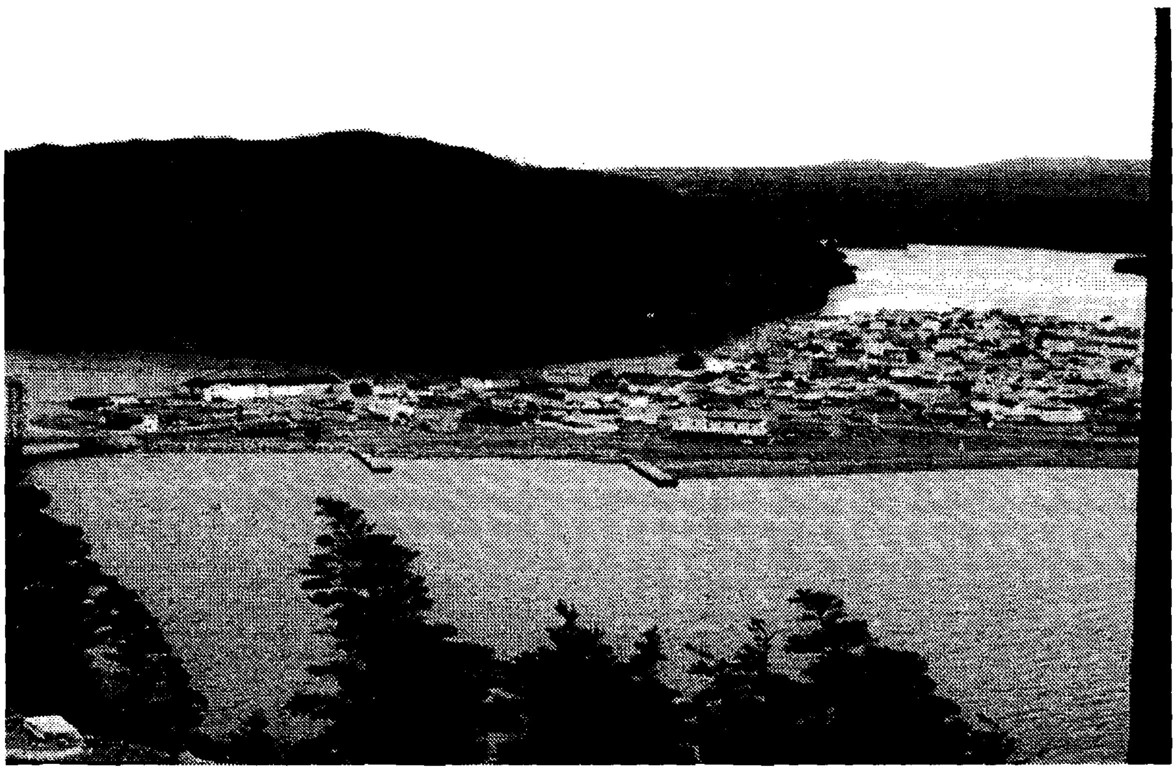

Illustration 8. Placentia

Illustration 9. Ship Cove (Steep Gravel Beach)

Illustration 10. Lance Cove (Ripples Developed on Sand Beach)

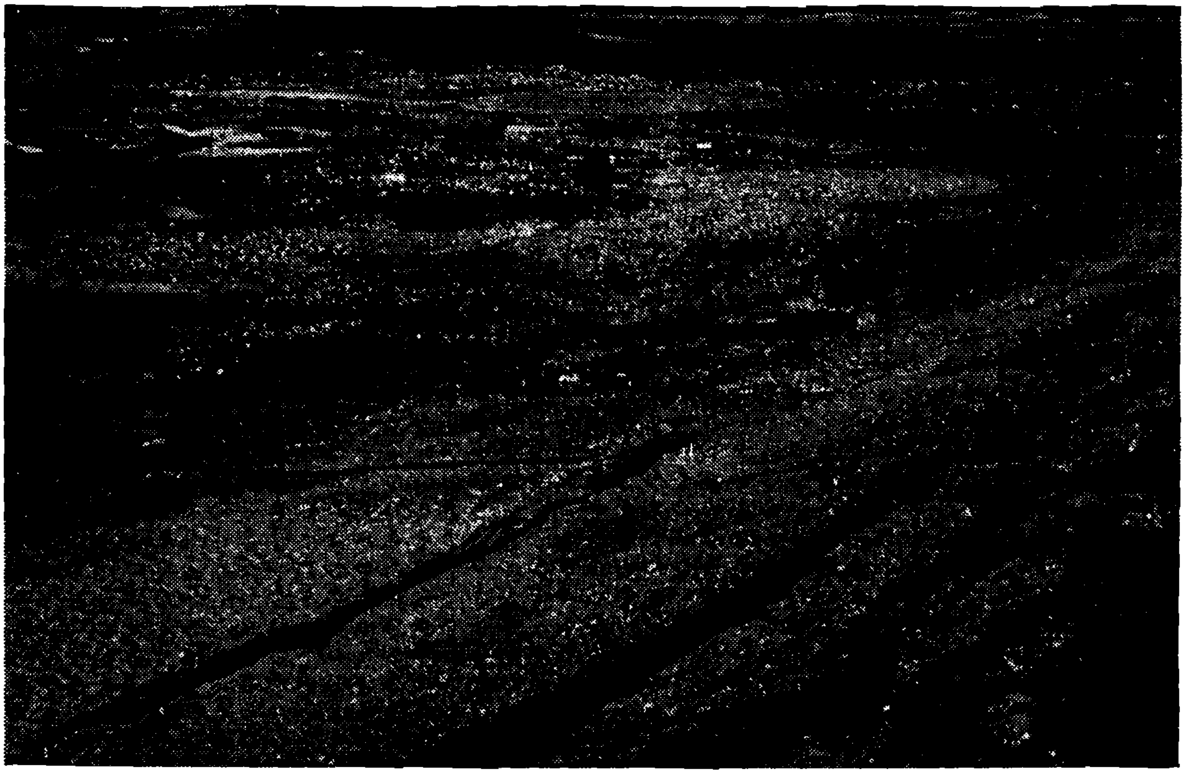

Illustration 11. Rock Platform

Illustration 12. Sand & Gravel Beach on Narrow Rock Platform

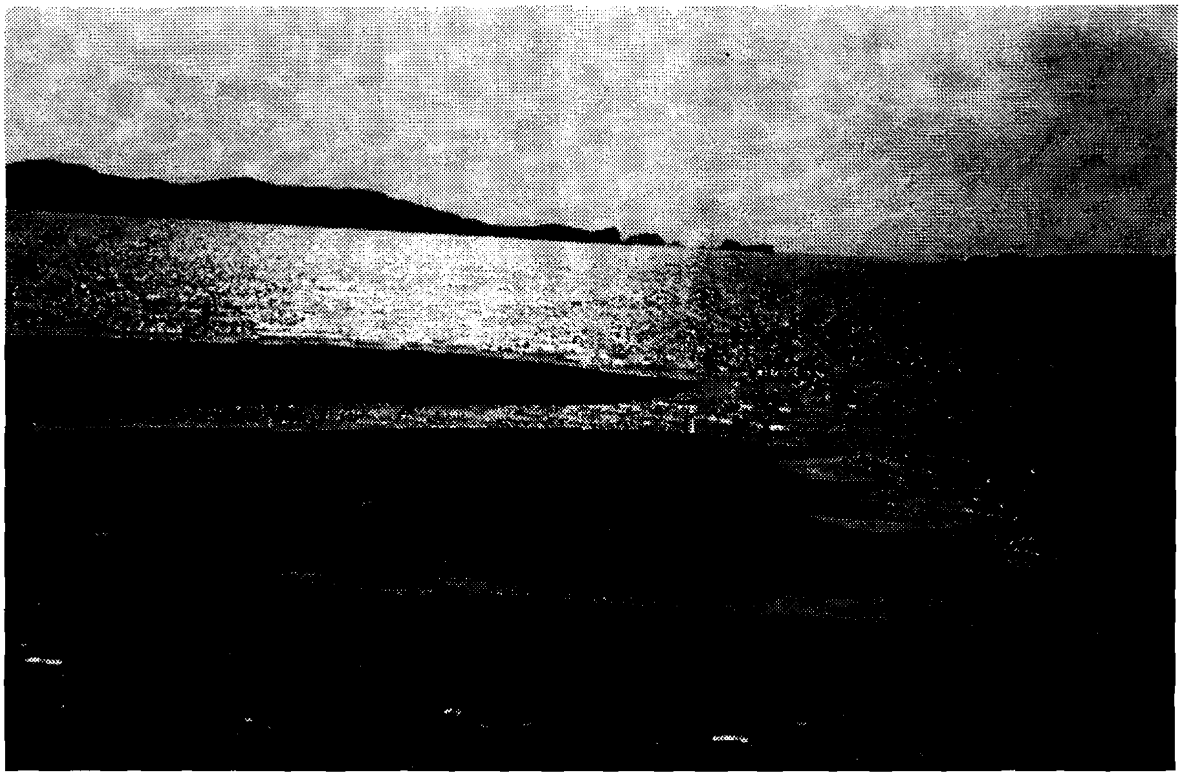

Illustration 13. Southern Harbour, Placentia Bay, Class 14

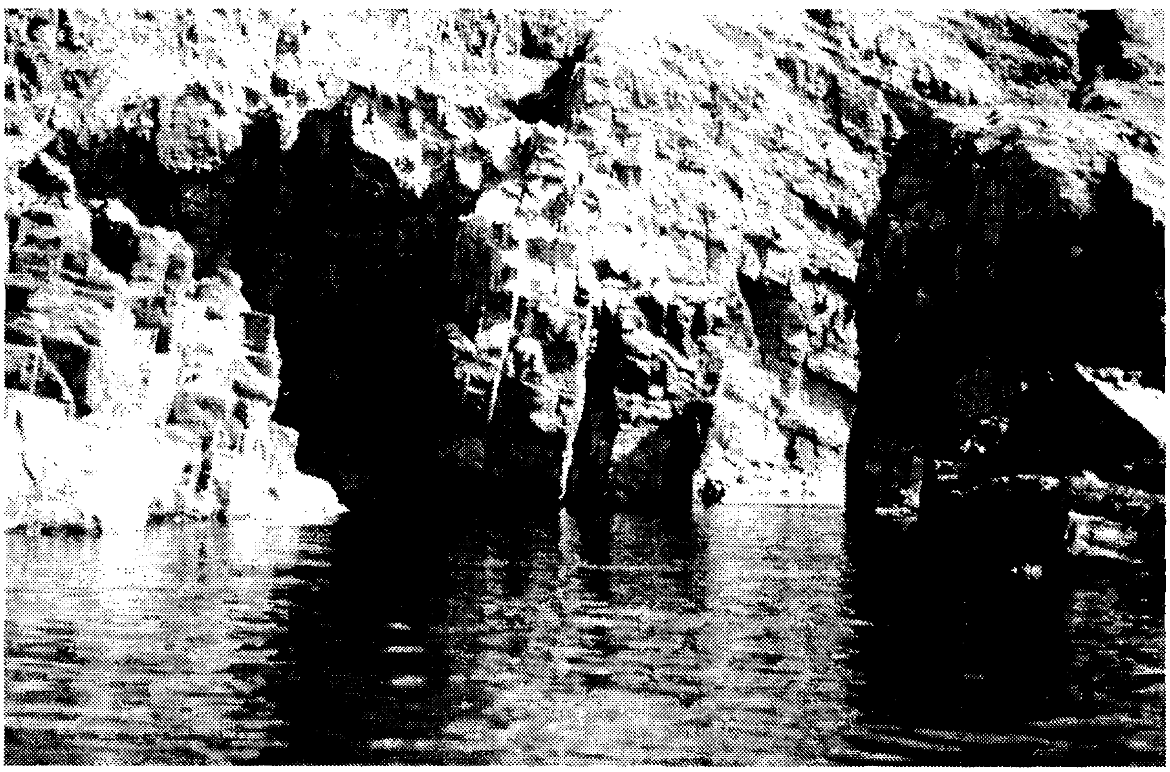

Illustration 14: Site Located Between Big Barrasway & Ship Cove, Class 3 (Rock Cliff)

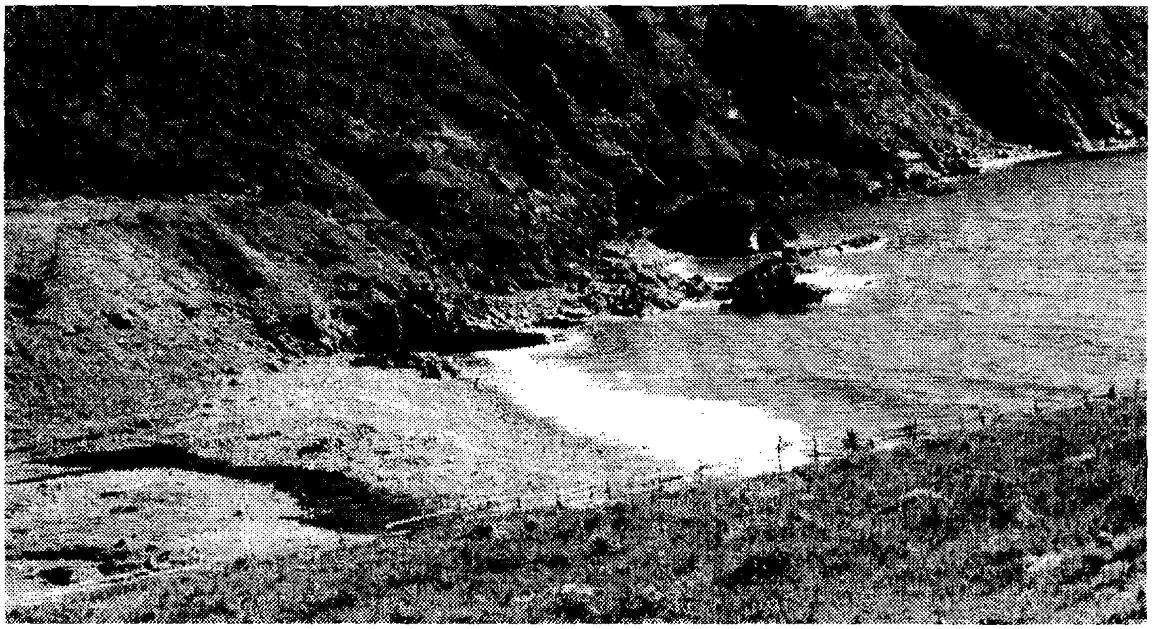

Illustration 15. Sand & Gravel Beach with Rock Cliff