GLACIAL, POST GLACIAL, PRESENT AND PROJECTED SEA LEVELS, BAY OF FUNDY

Prepared by

Gordon Fader
Atlantic Marine Geological Consulting Ltd.
2901 Parkdale Avenue
Halifax, Nova Scotia
B3L 3Z2

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Relative Sea level Change - the Bay of Fundy Region

In Maritime Canada former Quaternary shorelines have been identified at elevations as high as 75 m above present sea level and over 100 m below. The locations, elevations and the tilt of these shorelines appear to be controlled by two factors: 1) uptake of oceanic water in glaciers and its later release during ice melting, and 2) depression of the earth's crust from the weight of the continental glaciers and subsequent rise from melting ice. In contrast to the glacial and early post glacial history of sea level change, sea level appears to be rising in Maritime Canada today at a rate of between 20 and 30 cm/100 years. This has been attributed to long term climate change and crustal subsidence (Scott et al., 1995). A summary of the glacial history of the region over the past 100 ka provides an understanding of the relative sea level change and a perspective on future potential change. The sea level history of the region also controls to a large degree the characteristics of materials deposited in association with both high and low sea level stands and the intervening areas that have been transgressed and regressed.

Quaternary glaciers played a major role in sea level change and for Atlantic Canada there are two opposing glacial models termed maximum and minimum models. The maximum model suggests that ice extended across the entire region to the continental slope from a Laurentide ice centre in Quebec, (Goldthwait, 1924, Denton and Hughes, 1981, Shaw et al., in press). The minimum model suggests the presence of only local thin glaciers during the late Wisconsinan (Grant, 1977; Dyke and Prest, 1987). Through mapping of the glacial landforms and materials both on land and in the offshore, a more complex model of Wisconsinan glaciation (the last major ice advance in Atlantic Canada) has been developed and it appears to be closer to the maximum model. Figure 1 (Shaw et al., in press, 2005) shows the extent of ice in Atlantic Canada during the LGM (last glacial maximum) attained sometime shortly before 20 000 ybp.

This discussion is a summary of findings in Stea et al., 2001 and the results of mapping of sediments in the Bay (Fader et al., 1977, Fader, 1989) and adjacent coastal areas with an emphasis on the Bay of Fundy region.

Sea Levels During Previous Interglacial

A regional former sea level position prior to the Wisconsinan glaciation has been mapped and interpreted as an abrasion surface 4 – 6 m above present sea level in parts of Nova Scotia. It is overlain in places by peat and wood beyond the range of radiocarbon dating (Grant 1980). This rock platform has been interpreted as an erosional surface formed during the last interglacial period (marine isotope stage 5e) approximately 120 000 ybp. Grant interpreted that it represents an important former equilibrium position of sea level due to glacier melting and crustal subsidence after the previous major glacial episode. Marine sands have been found in both northern and southern Nova Scotia at elevations of 25 m and provide further evidence for higher sea levels.

The amount of relative sea level rise during the last interglacial is very important as it may be an indicator of present and future sea level rise in Maritime Canada. Based on the present rate of sea level rise, it would take approximately 2 ka from now to raise sea levels by 6 m (the height of the old abrasion platform). Such estimates are minimum as the rate of subsidence is expected to decrease exponentially (Pirazzoli, 1996).

Late Wisconsinan Sea Levels 20 – 10 KA

The earliest Wisconsinan phase of ice flow extended across the region to the continental slope and was grounded in over 300 m of water depth and perhaps as much as 800 m (Figure 1). Deglaciation began earliest in the southwest (outer Gulf of Maine in Northeast Channel) as early as 21 ka and progressed across the continental shelf in a time transgressive manner with the last ice remaining on the eastern Scotian Shelf. Ice retreated rapidly out of the Gulf of Maine and the Bay of Fundy because of their great depths and linear morphological connection to the ice centres. Figure 2 shows the location of ice in the region and the early opening of the Bay of Fundy at 14 000 ybp. By 13 000 ybp much of the coastal region of the Bay of Fundy was free of glacial ice (Figure 3). This removal isolated an ice mass on Nova Scotia (Scotian Ice Divide) that later became an active ice centre. The isolated ice cap was drawn into the deeper Bay of Fundy and formed outwash deltas, wave cut terraces and raised marine beaches. In the Bay of Fundy there is an anomalous northeast trend to lower marine limits from over 40 m at the mouth to 0 near the Bay head (Figure 4). The shorelines are tilted toward a local late ice centre, the source of the ice flow out of the Bay of Fundy. Stea (1982) suggested that shorelines around the Bay of Fundy are diachronous and the marine limit may not be a function of ice thickness but of protracted ice retreat to local ice centres. This may have prevented the formation of beaches in some areas. Widely varying ages on raised marine deposits from both sides of the Bay support this idea.

Relative Sea Level History of the Bay of Fundy

The relative sea level history in the Bay of Fundy is very complex with the lowstand shoreline shallowing from southwest to northeast (Fader, 1989, Fader et al., 1977). The following is a discussion of the high and low stand history of sea levels and new ideas resulting from the collection and interpretation of multibeam bathymetry in the Bay. Former high sea level stands are relatively easy to discover, interpret and map. Most are associated with rock platforms, beach sediments of well-sorted sand and rounded gravel, terraces and sometimes deltaic sediment deposits where rivers and streams entered the former sea. Lidar imagery and aerial photographs also show vegetation changes possibly related to textural properties of the sediments that affect water content and the presence of subtle terrace and beach morphological features. They are difficult to interpret from on-land field investigations alone.

Determining the position of former lowered sea level stands that are presently submerged is a much more difficult problem. Seabed features indicative of low sea level stands and subsequent transgressions include: terraces, erosional surfaces and unconformities, sediment textural characteristics of winnowing, absence of fine-grained sediment, erosion of glacial till and glaciomarine sediment, muted topography and relative greater exposures of bedrock. Dating these low sea level stands is also very difficult as material suitable for dating, such as marine shells, must be confirmed to have formed in situ in low stand deposits. With the advent of multibeam bathymetric mapping, subtle morphologic characteristics of low sea level stands are becoming easier to recognize and interpret. However, in areas of high energy, such as the Bay of Fundy, overprinting by modern sediment transport processes has resulted in the burial of low stand features making their recognition more difficult. The following is a summary of the low stand sea level evidence from the Bay of Fundy (Fader et al., 1977) and a discussion and interpretation of recent multibeam bathymetry.

The lowest position of sea level in post glacial time prior to the Holocene marine transgression is critical to the distribution of sediments, their stratigraphic relationships, sediment texture and seabed features such as exposed bedrock, former channels, etc. For the Scotian Shelf and outer Gulf of Maine, this position occurs at a depth of approximately 115 – 120 m in the offshore and 65 -70 m in the nearshore (Figure 4). It has been based on the identification of 1) terraces developed at this depth found on echograms and seismic reflection profiles; 2) textural dissimilarities between the surficial sediments above and below this level, 3) morphological differences above and below the low stand such as muted topography and greater erosion above, and 4) the presence of thick deposits of glacial material below and its general absence or modification above.

Within the Bay of Fundy, the low sea level stand has been interpreted to occur at a depth of between 40 to 60 m gradually decreasing in depth from 110 m near German Bank, Gulf of Maine to the southwest of Yarmouth. In the Fader et al. (1977) study, glacial till and glaciomarine sediments were found in the Bay of Fundy well-above the depth of occurrence of the low stand on the adjacent Scotian Shelf. At the entrance to the Bay of Fundy a noted increase in silt and clay component from sediment samples supports a decrease in the former sea level position. The grain shape of the gravels in the outer Bay of Fundy also supports this model. Transgressed gravel surfaces consist of well-rounded to rounded clasts and the gravels in the Bay well-above the 110 m transition on the Scotian Shelf, are angular to subangular in shape indicating occurrence below the low sea level stand.

Another indicator of the shallowing of the low sea level position from the Gulf of Maine to the Bay of Fundy was the discovery of Tertiary aged mudstone fragments in decreasing water depths to the north near the entrance of the Bay. These clasts could not have survived a marine transgression and their presence in shallow water depths provides additional information on the low sea level position.

Along the southwestern and southeastern coasts of Nova Scotia there is no evidence for a postglacial marine limit higher than the present shoreline. Studies by Goldthwait (1924), Hickox (1962), Bloom (1963), Swift and Borns (1967), Grant (1971) and others have found widespread raised marine strandlines and marine deposits in the area to the north of Yarmouth and along the south and north coasts of the Bay of Fundy and the Gulf of Maine. These features attest to late and post glacial significant rebound. In Nova Scotia the marine limit increases in elevation from a hinge line slightly north of Yarmouth and trends generally northeastward on land parallel to the geographic axis of the Bay of Fundy. Along the Nova Scotian side of the Bay, the highest marine limit is 45 m at Digby Gut (Grant 1971 and Stea et al., 2001). It occurs at 41 m at Sandy Cove on Digby Neck. A radiometric age on the marine limit in this area is 14 000 GSC #1259 determined from intertidal seaweed from Gilbert Cove where the marine limit is only 1 m above present sea level. In contrast, the height of the marine limit in New Brunswick is

73 m above present sea level (Gadd, 1973). A minimum age for this limit is 13 325 ybp. In central Maine the height of the marine limit is even higher at 135 m (Stuvier and Borns, 1975) and is dated at 13 000 ybp. This means that a tilt existed across the Bay of Fundy due to greater depression of the crust in New Brunswick and Maine as a result of closer approximation to the Laurentide ice centre. Although formed at the same time, there is approximately a 30 m difference in the present elevation of the marine limit in a line of section across the Bay of Fundy from Digby to Saint John (Figure 5).

Sea Level History Post Marine Limit Formation

The marine limit (highest level of marine water on land) formed some time after the ice retreated or is coequalivent with the timing of ice retreat. In some areas ice cover may have prevented the formation of raised marine features, hence, they are discontinuous. The early post glacial body of water that existed in the area of the Bay of Fundy has been termed the “DeGeer Sea” and was considerably larger than the present Bay extending up the Annapolis Valley and the St. John River Valley flooding large areas of present land.

After 13 500 ybp, isostatic rebound exceeded the rate of eustatic sea level rise resulting in a marine regression across the former sea bed (elevations presently to a maximum of 45 m) with a resulting emergence of the land. Using global sea level curves for the Wisconsinan period (Curray, 1960 and Fairbanks, 1989, Milliman and Emery, 1968) an estimate of the crustal rebound can be calculated. Sea level had returned by at least 20 m when the raised beaches were formed. These values combine to indicate an isostatic rebound of 168 m for the south coast of New Brunswick and 140 m for the south shore of the Bay of Fundy (Fader et al., 1977).

Through this process of rapid isostatic rebound, the relative sea level in the Bay of Fundy fell during the time period of 13 000 to approximately 9 500 ybp. Grant (1971) studied aggraded material in intertidal estuaries and estimated that sea level fell to a position 20 - 30 m below the present level. Recent studies in coastal and nearshore Maine by Belknap et al. (1989) show the presence of a widespread unconformity at a present water depth centered around 60 m. Studies of the surficial geology of Passamaquoddy Bay using seismic reflection profiles by Fader and Pecore 1991, also recognized a regional unconformity at a depth of 60 below Holocene pockmarked muds that was developed on glaciomarine sediments. As discussed earlier, Fader et al., (1977) recognized a widespread absence of till in the Bay of Fundy above depths of 37 m. Perhaps more indicative of the position of the low stand is the occurrence of well-rounded lag gravel deposits on till in depths shallow than approximately 40 m water depth and angular clasts below. Hundreds of grab samples were examined for their grain shape in the mapping of the surficial geology to support the interpretation that sea level fell to a depth of at least 40 m and perhaps as deep as 60 m in the Bay of Fundy from the time the glacial ice receded until 9 500 ybp. Recently collected multibeam bathymetry from several areas of the Bay of Fundy shows a variety of previously unrecognized seabed features such as iceberg furrows, fluted till and sub parallel transverse moraines in water depths greater than 60 m that are too delicate to have survived a marine transgression intact and support the interpretation of the low sea level position. Deltaic deposits have also been found in similar depths with high-resolution seismic reflection profiles.

After formation of the low sea level stand at approximately 9 500 ybp, relative sea level began to rise and transgressed areas above 60 m water depth continuing to the present shoreline. Transgressions can be very effective erosional mechanisms compared to regressions where sediments tend to be armoured and not undercut and are thus preserved. In the Bay of Fundy, tills and previously deposited glaciomarine sediments were eroded, armoured with lag gravels and the topography was smoothed and muted in this transgressed zone of between 60 m water depth and the present shoreline. Subsequent strong currents resulting from the development of high tides in the Bay of Fundy further armoured this surface and continue to do so at present.

Glacial and Post Glacial Sea Level History of the Whites Point Area, Digby Neck, Bay of Fundy

Based on the previous discussion it is possible to develop a site specific glacial and post glacial history of the Whites Point area, Digby Neck, that emphasises the sea level history, resulting processes and implications for sediment character. During the late Wisconsinan period from 22 – 18 ka ago the area was completely covered by glacial ice centered in New Brunswick and areas to the north and northeast. This thick ice crossed the Bay of Fundy and Nova Scotia and extended to the continental shelf edge in the region beyond Browns Bank. In the period of 18 -15 ka ago an ice divide termed the Scotian Ice Divide formed over the backbone of Nova Scotia (South Mountain Batholith) and ice was drawn down into the Bay of Fundy and the Laurentian Channel to the east by calving ice streams. Ice movement at this time over Digby Neck shifted from the northwest to ice from centres on South Mountain to the east. New multibeam bathymetric data from the floor of the Bay supports an interpretation of ice movement toward the mouth of the Bay of Fundy through the recognition of offshore aligned drumlin fields oriented southwest – northeast. By 13 000 to 12 500 ka ago the Bay of Fundy became ice free and as a result of isostatic depression. This area of Digby Neck was covered by marine waters to a height of 45 m. Areas above this height were subaerially exposed and have never been submerged below marine waters. Marine terraces were carved and till was reworked into well-sorted clean sands and gravels which remain in some areas today as raised marine beach deposits. At this time the area was also open to the Gulf of Maine and storms and high energy wave events would have been common. Following this period, relative sea level rapidly dropped until approximately 9 500 ybp. This resulted in a major regression of sea level across the landscape with further erosion of bedrock and glacial materials. The low stand occurred offshore in present water depths of between 40 and 60 m.

Following the maximum low relative position of the sea at approximately 9 500 ybp, relative sea level began to finally rise as the rate of eustatic sea level rise overtook that of isostatic rebound. This resulted in a transgression of the previously regressed surface and further modification of the seabed and associated materials. The transgression further eroded pre-existing materials which by this time had already been modified during the regression. In water depths above the 40 – 60 m low stand, a beach front progressively moved across the landscape. Such a high energy process largely eroded most till with the exception of material that was protected in channels and depressions. Boulders were liberated from the till and the fine-grained silts and clays were largely removed from the sediments and transported to deeper water.

Tidal amplification commenced around 6 000 ybp when the outer banks of the Gulf of Maine (Georges and Browns) were finally flooded and submerged (Grant 1970). As a result of the development of high tides, increased erosion of the seabed commenced. Fine-grained sands were redistributed and deposited over till and glaciomarine sediment particularly in the inner Bay of Fundy. Sand waves formed in localized fields covering 30% of the inner Bay of Fundy seabed. Former glacial till surfaces below the low sea level stand were subjected to stronger bottom flow and continued to be winnowed and armoured with lag gravels.

Short Term Relative Sea Level Trends in the Bay of Fundy

Tide gauge data from Atlantic Canada extends back almost 100 years and contains a strong signal of rising sea level (Shaw and Forbes, 1990). Grant (1970, 1975) cited rates of 46, 41 and 26 cm/century for St. John, N.B. Carrera and Vanieck gave rates of 31.4 cm/century for the time period 1966 – 1985 for Yarmouth, south of the entrance to the Bay of Fundy.

The sources for compiling tide gauge trends discussed in Shaw and Forbes, 1990, are Tidal Publication No. 30 published in 1951 by the Canadian Hydrographic service. They also used data obtained from Marine Environmental Data Services (MEDS), a branch of the Department of Fisheries and Oceans (Figure 6). The Yarmouth data set from MEDS sources includes some isolated values for 1900 and 1956 with the continuous set beginning in 1967. The rate for the period 1900 -1988 is 26.3 cm/century. Excluding the 1906 value, the rate is 26.8. For St. John, N.B. and the rate includes 24 values predating 1929, the first year of MEDS recordings. The record gives a rate of 21.2 cm/century. A regression using only data from 1929 onwards provides a rate of 28.4 cm/century.

From the above values it is clear that along with many areas in Atlantic Canada, the Bay of Fundy is experiencing a rise in relative sea level. Clearly the calculated rise does depend on the length of the record. The two most important causes of sea level rise are crustal subsidence and eustatic sea level rise. The fact that rates change regionally suggests regional variations in the crustal component. Grant (1975) also reached this conclusion. Although rigorously discussed in the scientific literature, it is difficult to detect a significant global climatic warming signal in the sea level rise.

Tidal Variations

Sea surface elevation records taken at Saint John, New Brunswick were analyzed by Godin (1992) who noted that the amplitude of the M2 tide was increasing at a rate of 10 -15 cm/century. He interpreted this to be the result of changes in resonance resulting from sea level rise or sediment redistribution at the Bay head. Scott and Greenberg (1983) estimated a 1.5% increase in tidal amplitude for each 1 m rise in sea level. This would only translate into a 1-2 cm/century increase based on the present knowledge of sea level rise. Greenberg (1979) suggested that such high increases in tidal amplitude as suggested by Godin could only occur with major tidal power installations and not changing sedimentation patterns. Greenberg and Petrie suggested that more study was required to sort out magnitudes and causes of changing amplitude of the M2 tide.

Summary of Sea Level History and Implications for the Marine Terminal and Quarry at Whites Point, Digby Neck

The history of relative sea level change in the Bay of Fundy has been complex, rapid at times, and is much different from that along the south and east coast of Nova Scotia where the marine limit is the present shoreline. In the Bay of Fundy and particularly along Digby Neck, Long Island and Brier Island, a former sea level position occurred as high as a present elevation of 45 m at the end of the last glaciation. Prior to 14 000 ybp, much of the area was covered by Wisconsinan ice that derived from centres both to the north and northwest. These ice centres later shifted to local positions on Nova Scotia with glaciers being drawn down into the deeper and linear Bay of Fundy and Gulf of Maine. As the ice receded, and as a result of lingering isostatic depression of the crust from the overlying ice, marine terraces, deltas and beach sediments were formed.

What follow was a rapid rebound of the land despite rising eustatic sea level, that together resulted in falling relative sea levels and a regression of sea level across the intervening areas. The relative sea level fell to a maximum of 60 m water depth in the Bay of Fundy and reached this low position at approximately 9 500 ybp. At this time the Bay of Fundy was much smaller. The evidence for a lowstand consists of unconformities, morphological features, textural differences, low stand deltas and exposed bedrock. At this time, rising sea level from the global melting of glaciers and a decrease in isostatic rebound, combined to result in a relative sea level rise that continued to the present shoreline. This was a time of marine transgression and pre-existing bedrock and surficial materials were further eroded, sorted and reworked. Fine-grained sediments were removed and transported to deeper water. The most recent understanding of present sea level change is that it is slowing but still rising at rates of between 20 and 30 cm/century.

This glacial and historical sea level knowledge has implications for both the marine terminal and on land quarry construction. Of utmost importance to the design of the marine terminal is to take into consideration the continued projected rise in sea level. Based on the knowledge of sea level change over the past 50 years, all facilities will be designed and constructed to anticipate a sea level rise of 30 cm/century with associated potential change in tidal heights and storm waves.

With regard to the design and construction of the land based quarry facilities, knowledge that former sea levels were as high as 45 m on Digby Neck will also be considered in the design and construction. These former and higher sea levels will have an effect on the potential generation of fine-grained silts and clays during construction. Most of these grain sizes have already been removed from the site during both the regressions and transgressions associated with changing sea level over the past 14 000 years. Large areas of the site also have thinner overburden as a result of erosive processes from sea level changes with more bedrock exposure than would normally be expected. These characteristics arise from the complex sea level history and indicate that minimal amounts of surficial materials will have to be removed and redistributed. Those that will be excavated are mostly well-sorted clean sands and gravels without a fine-grained silt and clay component. This considerably reduces the potential quantity of fine-grained particulates that could be produced from construction activity.

Figures

1) A map of the distribution of ice in Atlantic Canada at approximately 20 000 ybp during the Last Glacial Maximum (LGM) superimposed over a digital terrain model of the land at 13000 ybp. Ice divides are dashed and flow lines for ice streams are shown in solid thinner lines. From Shaw et al., in press (2005).

2) A map of the distribution of ice in Atlantic Canada at approximately 14 000 ybp. At this time ice has left the Bay of Fundy and icebergs are numerous in that area. From Shaw et al., in press (2005).

3) A map of the distribution of ice in Atlantic Canada at approximately 13 000 ybp. Areas around the Bay of Fundy coastal zone are ice free at this time and raised marine features are being formed. From Shaw et al., in press (2005).

4) Lines of equal emergence (isopleths) of elevations of the marine limit in Nova Scotia and New Brunswick. The marine limits are represented by wave-cut terraces, beaches and deltas. Former interglacial shorelines occur around Cape Breton Island and north of Yarmouth. In contrast, the low stand shoreline offshore east Nova Scotia at 65 m is shown. From Stea et al., 2001.

5) Profile across the Bay of Fundy in a line of section from Saint John to Digby showing the present sea level as well as the former sea level at approximately 13 000 ybp when the marine limit was formed. It illustrates the greater amount of rebound experienced by the New Brunswick coastline following formation of the high stand. From Fader et al., 1977.

6) Tidal records and rates of change for a) Charlottetown, P. E. I., b) Yarmouth, N. S., c) Saint John, N.B., and d) St. John’s, Newfoundland and Labrador. From Shaw and Forbes, 1990.

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Figure 1

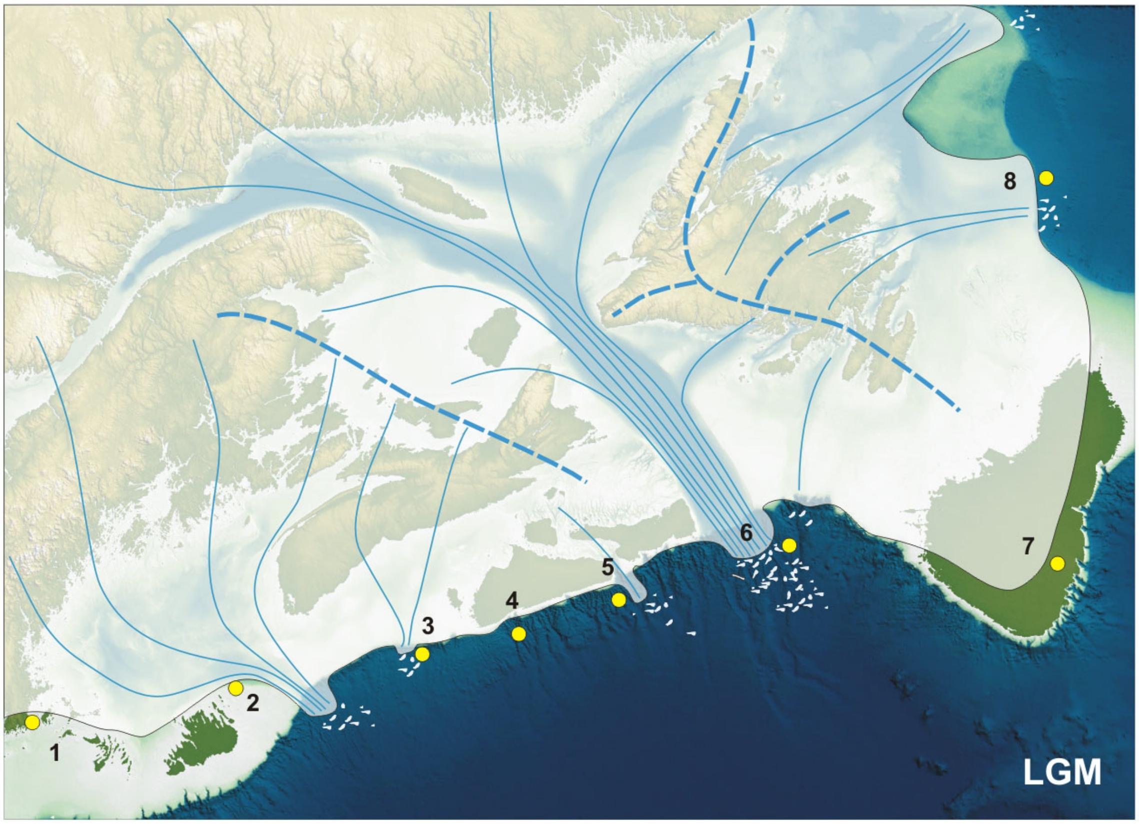


Figure 2

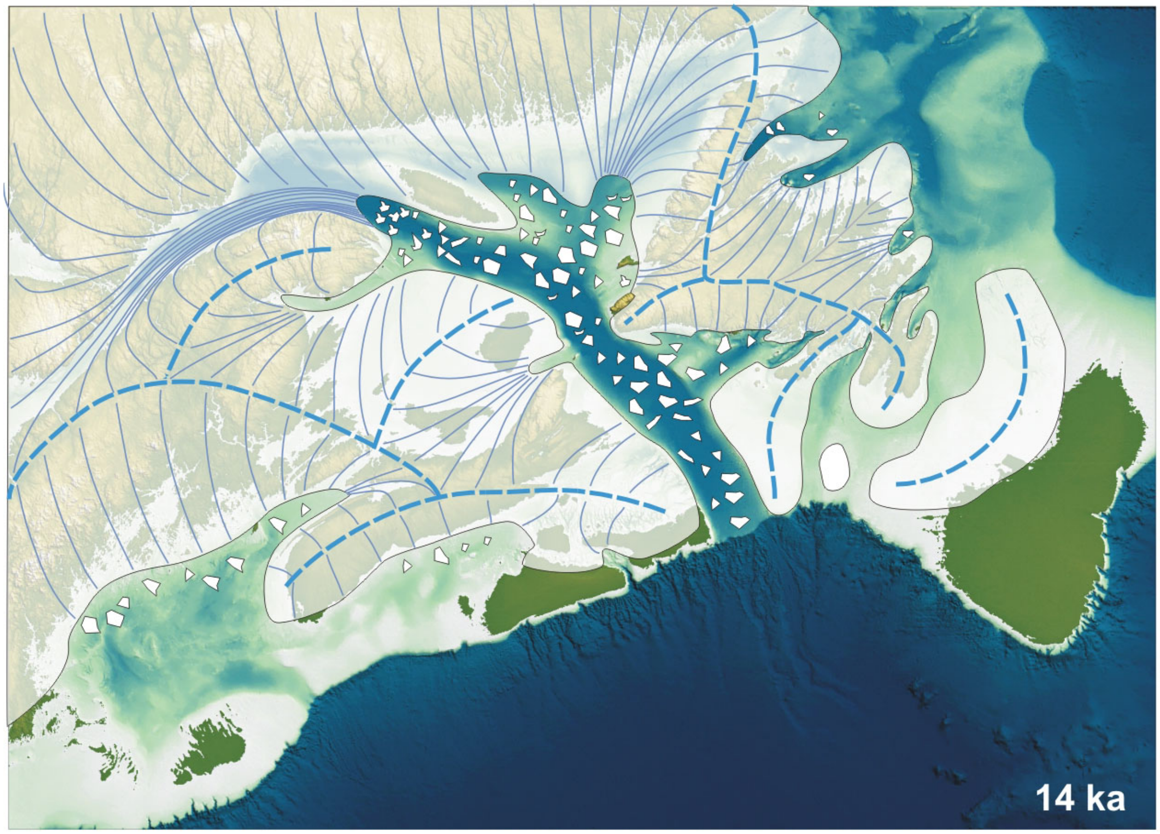
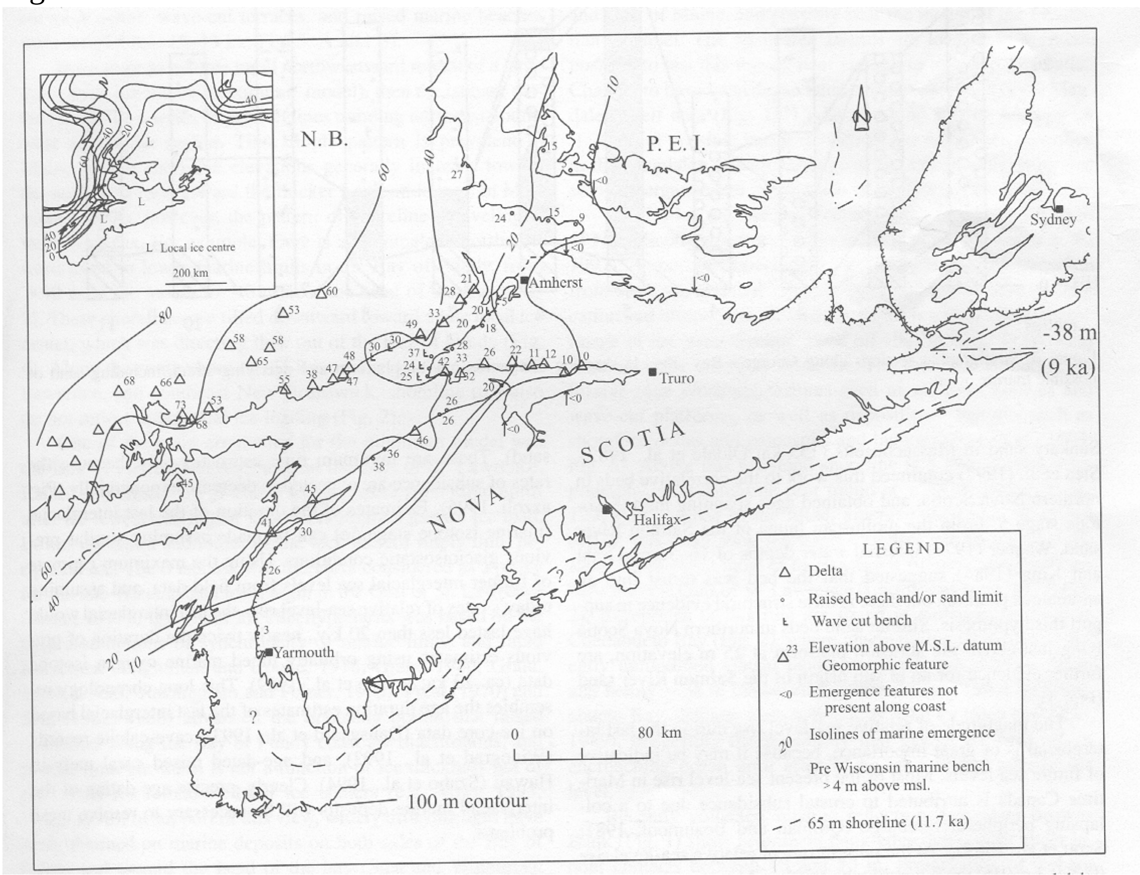


Figure 3

Figure 4



N. B.
P. E. I.
NOVA
SCOTIA
Amherst
Truro
Halifax
Yarmouth
Sydney
-38 m
(9 ka)
100 m contour
0
80 km
L Local ice centre
200 km
LEGEND
Delta
Raised beach and/or sand limit
Wave cut bench
Elevation above M.S.L. datum
Geomorphic feature
Emergence features not present along coast
Isolines of marine emergence
Pre Wisconsin marine bench > 4 m above msl.
65 m shoreline (11.7 ka)

Figure 5

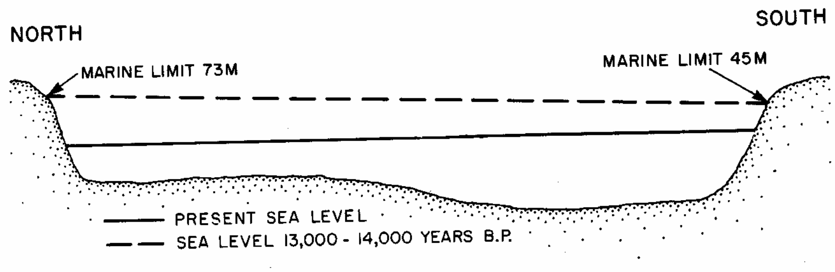
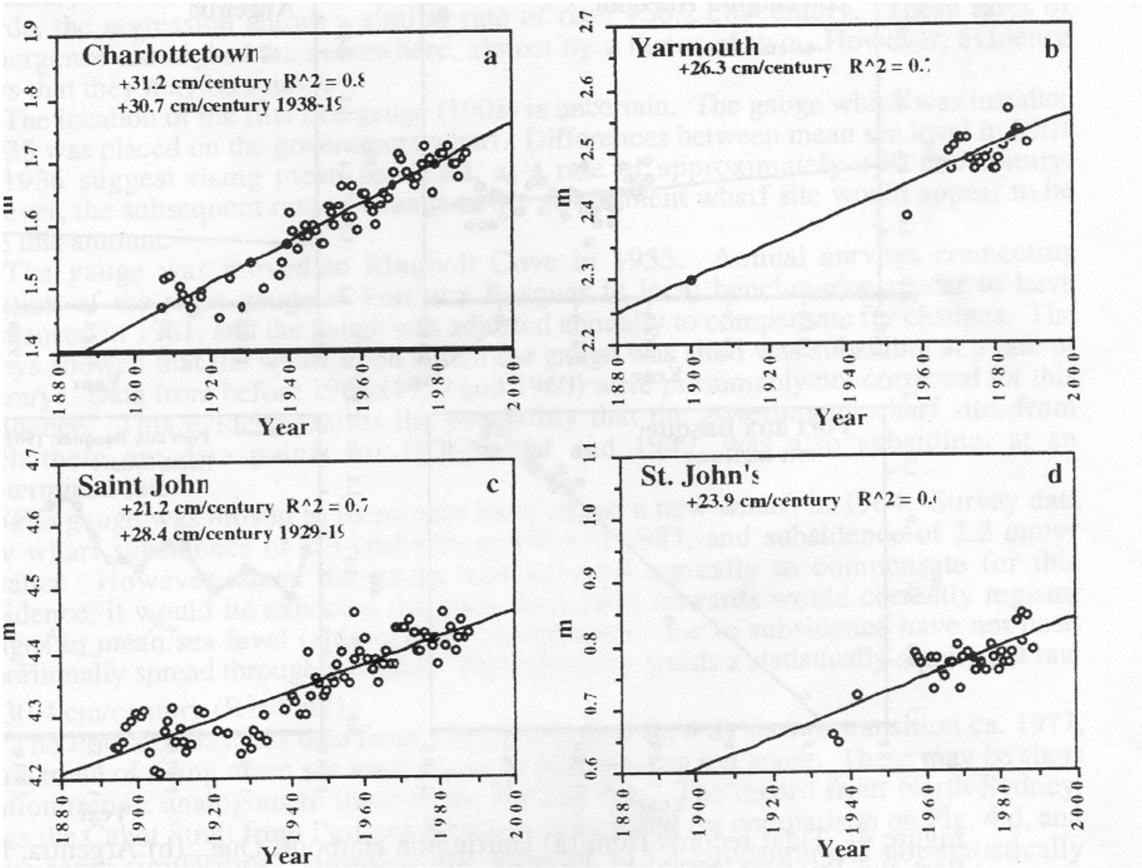

NORTH
SOUTH
MARINE LIMIT 73M
MARINE LIMIT 45M
PRESENT SEA LEVEL
SEA LEVEL 13,000 - 14,000 YEARS B.P.

Figure 6



Charlottetown
a
+31.2 cm/century R^2 = 0.8
+30.7 cm/century 1938-19
Yarmouth
b
+26.3 cm/century R^2 = 0.7
Saint John
c
+21.2 cm/century R^2 = 0.7
+28.4 cm/century 1929-19
St. John's
d
+23.9 cm/century R^2 = 0.
m
Year