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LATE HOLOCENE SEA-LEVEL CHANGES, EASTERN NEWFOUNDLAND

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ABSTRACT

Investigation and ^{14}*C dating of tree stumps inundated by rising marine waters at Mobile, Ship Harbour, and Port de Grave, in combination with research at The Beaches archaeological site and other previous investigations, have established that the sea level has risen along the coastline of eastern Newfoundland during the late Holocene. The estimated rates of sea-level rise vary between the localities, from a minimum value of 1 mm/a to a maximum in excess of 6.5 mm/a. The available data suggest that the rate of sea-level rise may have accelerated within the past 400 years.*

INTRODUCTION

THE PATTERN OF SEA-LEVEL FLUCTUATIONS IN EASTERN NEWFOUNDLAND

During the Quaternary glaciation, large volumes of water were frozen in the major Laurentide glacier complex centred in Labrador. As a direct result, the sea level was lower than at present, along the eastern Newfoundland coastline. The thickness and extent of the St. Mary's Bay glacier, and the other smaller glaciers on the Avalon Peninsula (Catto, 1998a) were not sufficient to overcome the glacio-isostatic distortion induced by the much larger Laurentide ice sheet (Grant, 1989; Liverman, 1994, 1998).

As deglaciation began, sea level rose throughout eastern Newfoundland. The isostatic depression of the land surface allowed marine waters to reach up to 55 m asl at St. Veronicas, 35 m asl at the head of Hermitage Bay, 25 m asl at McCallum and Rencontre East, and 15 m asl at English Harbour West and Pass Island (*see* Leckie and McCann, 1983; Grant, 1989; Shaw and Forbes, 1995; Catto, 1997). All areas of the south coast were subject to marine inundation. Similar elevated sea levels are recorded along Bonavista, Trinity, and Conception bays. Sea levels up to 35 m above the present shoreline are recorded by terraces at Eastport, Traytown, and Little Sandy Cove, Bonavista Bay; and by erosional benches at Charlottetown (Sommerville, 1997). At St. Chad's, north of Eastport, shells of the marine mollusc *Hiatella arctica* indicate that the sea stood about 14 m above its present elevation ca. 12 400 BP (Liverman, 1994). Near Port Blandford, marine clays preserved in coastal bluffs also indicate higher sea levels (Sommerville, 1997).

Around the shoreline of Conception and Trinity bays, higher sea levels carved erosional benches and deposited gravel terraces at elevations between 5 and 20 m above sea level, with the northwestern shore having the greatest inundation and the southern tips the least (Catto and Thistle, 1993; Catto, 1994b; Liverman, 1994). A similar picture is evident along the east shore of Placentia Bay north of St. Brides, and along the western shore north of Marystown. After the initial latest Wisconsinan deglaciation, sea level varied from its present elevation near St. Brides and Marystown, to 20 m asl at Swift Current (Shaw and Forbes, 1995; Catto, 1998b).

Earliest Holocene sea-level history was substantially different on the southernmost part of the Burin Peninsula, and along the open Atlantic coastline south of Cape St. Francis, where raised marine features have not been recognized. Cores taken from St. John's Harbour indicate that a freshwater lake occupied the present harbour shortly after deglaciation, ca. 11 000 BP (Lewis *et al.,* 1987). This suggests that sea level at the time was at least 14 m below present, the elevation of the controlling sill in The Narrows. Marine transgression is recognized by a transition from a brackish thecamoebian (*Centropyxis aculeata*) to a marine foraminiferal assemblage, ca. 9900 BP.

Sea level in St. John's Harbour appears to have remained below present throughout the Holocene. No raised marine deposits have been encountered in excavations in

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[1] Port de Grave, Newfoundland

downtown St. John's, although marine deposits at elevations to 5 m above sea level are present along the southern shore of Conception Bay at Portugal Cove, St. Philips, and Conception Bay South (Brückner, 1969; Catto and Thistle, 1993; Catto and St. Croix, 1997).

Following the postglacial maximum, sea level fell around most of the eastern Newfoundland coastline. The decline in sea level is attributed to a reaction from glacio-isostatic over-compensation, following the "Type B" model proposed by Quinlan and Beaumont (1981, 1982) and modified by Liverman (1994, 1998). Shaw and Forbes (1995) documented sea-level minimum positions around Newfoundland. Although the sea-level minimums were not synchronous in all localities, all date from the early to mid-Holocene. In areas without raised marine features, such as St. John's Harbour and the tip of the Burin Peninsula, early Holocene sea levels were lower than the present 0 m asl contour.

The pattern of the postglacial lowstand in eastern Newfoundland is a series of concentric loops, centred on the Middle Ridge area west of Terra Nova National Park (Shaw and Forbes, 1995). This pattern indicates that the Newfoundland-centred glacier had a greater influence on postglacial sea-level history than was the case for the preceding pattern of glacially related marine maxima. The upper marine limits were produced by the glacio-isostatic influence of the Laurentide Ice Sheet in Labrador, whereas the lower marine limits along the shoreline appear to be the products of glacio-isostatic deformation associated with Middle Ridge glaciation. Glacio-isostatic influences of the postulated glaciers developed on the offshore banks (Miller and Fader, 1995) are not apparent in the pattern of sea-level minima on the south coast, or in Fortune and Placentia bays.

Along northwestern Placentia Bay, the presence of submerged estuarine and deltaic sediments southeast of Swift Current indicates that sea levels stood approximately 8 m below present levels in the northernmost part of the bay. Other submerged deltas are located at −13.9 m in Paradise Sound and −18.9 m at Long Harbour (Shaw and Forbes, 1995). Wave-cut terraces, offshore of Argentia and Ship Cove, are submerged to depths of 19.6 m. In addition, along the Cape Shore and St. Mary's Bay, ^{14}C dated terrestrial peat indicate that sea levels were at, or below, the present level throughout the mid-Holocene (Catto, 1994b; Catto *et al.*, 1997). All of these sites represent exposed coastal locations subject to erosion, high winds, and salt spray, where trees are currently unable to grow and peat currently cannot form or accumulate.

Offshore of the Conception Bay coast, submerged shoreline features have not yet been located. Extrapolation from the data available for northeastern Placentia Bay and western Trinity Bay suggests that sea levels fell to between 10 and 25 m below present during the early Holocene (Grant, 1989; Shaw and Forbes, 1990, 1995; Liverman, 1994). The available data from Trinity Bay is restricted to Random Sound, where terraces offshore of the mouths of Shoal Harbour River, Little Shoal Harbour River, and Northwest Brook lie at –9.7 m asl (Shaw and Forbes, 1995).

Following the lowstand in the mid-Holocene, ca. 6000 years ago, the sea level has risen steadily to its present position. The eastern Newfoundland coastline is currently submerging, in common with all of coastal Newfoundland south of St. Barbe and Hare Bay on the Northern Peninsula.

Previously documented evidence (Catto, 1994b, 1995) indicates that the sea level around the Avalon Peninsula has continued to fluctuate, in response to ongoing isostatic adjustment for the past 3000 years. At Ship Cove, south of Placentia, a ^{14}C date from terrestrial sediment overlain by marine silt suggests that the sea level rose to at least ± 1 m above present ca. 1340 ± 70 BP (GSC - 5306). Drowned forests and peat at numerous locations on the Burin Peninsula (Grant, 1989) indicate that sea levels have risen in the past 3000 years. At Biscay Bay Brook (east of Trepassey), a spruce stump found rooted in forest peat below the high tide line was ^{14}C dated at 750 ± 90 BP (GSC - 5414). Building foundations uncovered by archaeological excavations at Ferryland and Placentia suggest that sea level may have been ± 3 m lower than present in the early 1600s.

Evidence of enhanced erosion along many Avalon, Burin, and South coast beaches suggests that marine transgression is presently occurring. Terrestrial peat deposits have been destroyed or partially inundated by rising marine waters at Patrick's Cove (Placentia Bay), Ship Harbour (Placentia Bay), Dog Cove (St. Mary's Bay), Biscay Bay, and Mobile (Southern Shore), among other sites. Coastal erosion accelerated by rising sea levels has occurred at several localities, notably in Conception Bay South (Taylor, 1994).

This contribution discusses three Avalon Peninsula sites where additional evidence of sea-level fluctuations during the latest Quaternary has recently been documented and dated through ^{14}C analysis. Recent geological investigations have revealed evidence for sea-level rise during the late Quaternary at three locations: Mobile, Ship Harbour, and Port de Grave (Figure 1).

RESULTS

MOBILE

Investigation of the embayment at Mobile, south of St. John's, began in 1991 as part of a regional mapping project (Catto, 1994a). Further investigations were carried out in 1994 and 1995 by Jones (1995) and Catto (1995), and work has continued at the site from 1995 through October 1999.

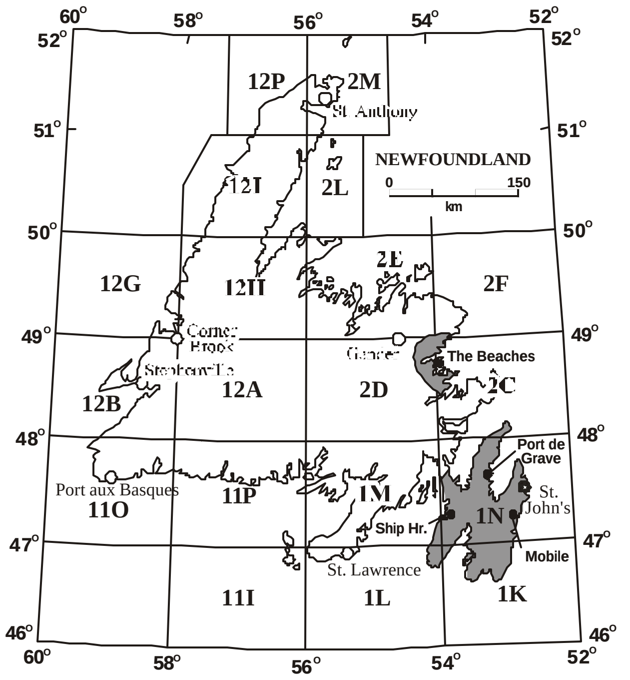

Figure 1. *Location map.*

An 160-m-long cobble–gravel beach forms a concave arc at the head of Mobile Harbour (Jones, 1995). The southernmost part of the beach, adjacent to Mobile Brook, is a gently sloping planar surface, with slope angles of <2° at the high tide line (Plate 1). In the backshore area, slopes are reversed, inland toward Mobile Brook. Overwash features, including fans, are common, and a stratigraphy of overwash fans infills the northern part of the Mobile Brook valley. The oldest of these overwash features was produced by a storm in January 1966, that damaged a stage and wharf, formerly located here. The ruined infrastructure was later dismantled. The sediment texture in this area is dominantly granules and fine pebbles containing coarse sand. Much of this sediment was carried to the shore as bedload by Mobile Brook. During periods of minimal flow in the brook, the beach system laterally aggrades across the outlet, partially or completely blocking it and hindering the migration of brown trout to Mobile Big Pond. During these events, fine to medium pebbles dominate this area of the beach.

The central part of the beach is marked by stacked tiers of cusps. The cusps vary in form along the breadth of the beach, with the largest at the southern part of the central segment being symmetrical, bowl-shaped, and having seaward lips, indicating formation by shore-normal transport in reflective environments. Smaller cusps are strongly asymmetrical, indicating longshore transport along the beach front. In the more northerly part of the central segment, all cusps tend to be asymmetrical, indicating transport toward the north. The pattern of cusp morphology, together with the grain-size distribution (fining toward the north on the northern 70 percent of the beach), suggests that the beach sediment is moved along the shoreline to the north by local currents.

At the northernmost part of the beach, a former outlet of Mobile Brook has been impounded by storm overwash sediment. This outlet had previously been abandoned by Mobile Brook when the stream was diverted for hydroelectric power production and road construction prior to 1966. The 1966 storm infilled the former outlet with overwashed coarse pebbles and fine cobbles. Medium to coarse sand, deposited by the stream channel prior to its abandonment has remained in the beach system, and is periodically exhumed and covered by migrating pebbles and cobbles (Jones, 1995). In this area, the uppermost cusps are chute-like, indicating that overwashing has occurred, and the barrier crest is as much as 2 m lower here than along the south–central part of the system. The lower tiers of cusps are shallow and asymmetrical indicating transport parallel to the shore, toward the northeast. To the north of the abandoned channel, bedrock of the Renews Head Formation (King, 1988) is exposed along the shore. Mobile Beach is affected by all major storms, including southwesterly hurricanes as well as easterlies. Erosional and depositional episodes succeed each other.

Along the northern half of the beach system, a submerged group of Picea (spruce) stumps rooted in terrestrial peat was exhumed as a result of storm action in 1994 (Jones, 1995). Subsequent storms have eroded the peat, causing some stumps to be removed, and have periodically exposed and buried others in sediment. At least 16 stumps have been identified so far, with about ten remaining in life position. The exposed bases of the stumps extend to 700 cm below low tide level (approximately 1.5 m below mean sea level), and two were exposed at low tide along the beach between April and October 1999 (Plate 2). In at least one instance, a rooted stump was subsequently used to secure a vessel. This evidence of human usage, combined with the presence of the remains of the old stage at the southern end of the beach, requires caution in the assessment of upright wood at Mobile Beach. Upright pieces of wood cannot be assumed to represent *in situ* ‘trunks' unless the stump can be thoroughly excavated, demonstrating that an exposed upright piece is actually a rooted stump and not a pole driven into the sediment by human hands.

The substrate in which the erect stumps are found represents further evidence of their *in situ* position. Rooted stumps along the northern half of the shoreline are underlain and partially buried by forest fibric peat, containing spruce cones and needles and lacking rockweed, kelp, and other marine organic detritus. Typically, the peat extends to the low tide limit, where it is erosionally overlain by recent marine pebble and granule gravel with admixed coarse sand.

The peat contains no cobbles or pebbles. Sand and granules together represent less than 5 percent of the peat strata by volume and are not concentrated in distinct horizons. Thin horizons of manganese and iron-oxide staining are present to depths of 500 cm below the mean low tide level. The thickest accumulation of peat measured by excavation extends approximately 700 cm below low tide level, where it overlies large granitic boulders and other erratics associated with the local glaciogenic diamicton (Catto, 1994a, 1998a). The peat thus represents *in situ* terrestrial accumulation of organic debris above the prevalent sea level at the time of formation. In contrast, poles of the former stage at the southern end of the beach have been driven into pebble gravel. Peat is not present along the shoreline at the southern end of Mobile Beach.

Plate 1. *Mobile Beach, looking north, April 1999. Stumps are located below high tide line.*

Plate 2. Picea *rooted stump recovered from 1.5 m below mean sea level, subsequently ^{14}C dated to 310 ± 50 BP (GSC-5836).*

Carbon (^{14}C) dating of the outer rings of one rooted stump, excavated to verify its rooted and *in situ* character, indicated an age of 310 ± 50 BP (GSC-5836). Dendrochronological investigation suggests that the spruce reached maximum ages of 40 to 50 years at the times of their demise. There is no dendrochronological evidence to suggest that the trees died as a result of blowdown, a catastrophic storm, or a single flooding event. Individual rings show that the trees were stressed by onshore winds, forming a branching habit with the majority of the branches to the leeward side (*cf*. Robertson, 1984). Comparison of the fossil tree rings with those of spruce trees presently growing at Mobile Beach indicates that wind stresses were similar to those of the present ca. 310 BP.

Plate 3. *Big Seal Cove, Ship Harbour, looking east, April 1999. Stumps are located offshore of exposed sand beach.*

In the modern environment, the roots of spruce trees are confined to elevations in excess of 2 m asl. As spruce cannot survive if their roots encounter salt water, the presence of the rooted stumps indicates that sea level was at least 2 m lower than present when the now submerged spruce were growing. Although the spruce could have grown at elevations greater than 2 m asl, the minimum value of sea-level rise since 310 ± 50 BP is thus ca. 2 m, if the ^{14}C date from Mobile is valid.

Conversion of a ^{14}C date to an actual 'calendar' date requires assessment of the relationship between an actual 'calendar' year and a ^{14}C 'year'. Carbon (^{14}C) dates are arbitrarily calculated assuming a zero year of 1950 AD (a choice dictated by the advent of nuclear bomb testing following World War II). A further complication is that the rate of ^{14}C concentration in the atmosphere has not been constant throughout the late Quaternary, making linear correlation between ^{14}C and calendar years impossible. Recently, however, precise 14C dating of the dendrochronological record provided by oak fossils in Germany has allowed a year-by-year calibration of ^{14}C years to calendar years, extending more than 11 000 calendar years back from the present (*see* Stuiver *et al.,* 1998; Friedrich *et al.,* 1999). Within the limits of analytical error, therefore, the ^{14}C age of a fossil can be calibrated, and an estimate of its age in calendar years determined.

Analysis of the German oak dendrochronological record suggests that the *Picea* stump at Mobile, ^{14}C dated at 310 ± 50 BP, has an age of 300 to 400 years (1600 to 1700 AD) in calendar years. Thus, sea level has risen at this site along the Atlantic shoreline of the Avalon Peninsula at a rate between approximately 4 mm/a and 6.5 mm/a, values similar in order of magnitude to that inferred from the archaeological data at Ferryland. However, these rates are substantially higher than those reported or inferred for other areas of Atlantic Canada throughout the late Holocene (e.g., Shaw and Forbes, 1995).

SHIP HARBOUR

Additional submerged forest sites have recently been discovered along the Avalon Peninsula. At Ship Harbour, Placentia Bay, approximately 50 *Picea* tree stumps (Plate 3) are preserved along the sheltered north-facing shoreline of Big Seal Cove (Griffiths, 1999). The stumps (Plate 4) are rooted in forest soil and fibric peat, and are overlain by marine medium sand and fine pebbles. The zone with stumps and peat extends seaward for a minimum of 15 m, and at mean low tide the most distal stumps are covered with 1.5 m of seawater; all stumps are inundated at high tide. Preliminary dendrochronological observations indicate that the stumps represent trees that were subject to wind stress from prevailing offshore winds, and that individual trees survived for approximately 50 years.

The southern margin of Big Seal Cove is protected from the open waters of Placentia Bay by virtue of its orientation, and also by the presence of Fox Island, offshore to the west-southwest. Consequently, this part of the cove is a low-energy dissipative environment. Fine pebbles are the dominant texture of the beach sediments, with granules and medium sand in the offshore areas. Cusps are not developed on the single berm, and no features of storm washover or disturbance have been observed in contrast to the more open environment of Ship Harbour Point to the southwest.

Plate 4. Picea *stump, Big Seal Cove, subsequently ^{14}C dated at 2260 ± 60 BP (Beta-132317).*

The south shore of Big Seal Cove is backed by an eroding bluff of marine gravel overlying diamicton, that in turn overlies jointed siltstone (Catto, 1992). The surface of the gravel supports a tuckamore (krummholz) spruce assemblage. Although the presence of vegetation has long been known to stabilize slopes (e.g., Wu *et al.*, 1979; Riestenberg and Sovonick-Dunford, 1983), tuckamore white spruce at cliff-top sites may actually accentuate erosion under conditions of rising sea level. Block failure of unconsolidated sediment bluffs, and of badly jointed bedrock is accelerated where tuckamore, killed by salt spray, is present. The tuckamore roots act to wedge the substrate apart, reducing cohesion and promoting frost wedging, and the dead tree acts as a top-heavy obstruction to onshore winds. Sites with dead tuckamore cover erode more rapidly than sites covered with grass and *Empetrum* headland herb assemblages (*see* Damman, 1983; Thannheiser, 1984), or boreal forests with upright trees. A similar effect is evident where a bluff-top fringe of coastal trees is subject to erosional pressure, as at Topsail United Church. At Big Seal Cove, active erosion of the bluff has resulted in the collapse of rooted masses of tuckamore, leaving irregularly oriented clumps of stumps and roots across the upper part of the beach. These recent features, however, are readily distinguished from the rooted stumps offshore, as they are not oriented in growth position and sit on, and in, marine pebble gravel.

A part of one stump from Big Seal Cove yielded a ^{14}C date of 2260 ± 60 BP (Beta-132317). This ^{14}C date is correlative to a calendar age between 405 BC and 180 BC (2355 to 2130 years ago). As the base of the rooted stump was located 2 m below modern mean sea level, the minimum rate of sea-level rise here is 1.0 mm/a. A greater rate of sea-level change could have occurred, as the trees may have died before seawater inundated their location. In the modern environment, trees do not grow at elevations less than 2 m asl. If the stump was killed when sea level was 2 m below its elevation of –2 m asl, the rate of sea-level rise would be approximately 2 mm/a over the past ca. 2200 to 2300 years.

PORT DE GRAVE

At Port de Grave, dredging to deepen the harbour in May and June 1999, resulted in the recovery of numerous (more than 100) large fragments of tree stumps (Plate 5). Individual stumps exceeded 50 cm in diameter, with attached root systems in excess of 2 m. Stumps were dominantly *Picea glauca* (white spruce) and *Picea mariana* (black spruce), but stumps of *Abies balsamea* (balsam fir), *Betula papyrifera* (white birch), and *Betula alleghenensis* (yellow birch) were also recovered. The largest stumps indicate tree lifespans in excess of 70 years. Dendrochronological investigations suggest that the trees were growing in a non-stressed environment, without being subjected to strong coastal winds. The presence of *Betula alleghensis*, currently confined to sheltered localities in the central Avalon Peninsula (Damman, 1983), also indicates that the coastal environment was not subject to strong winds or salt spray. Some fragments of wood display bite marks from gnawing rodents.

Peaty material ranging from very fibrous to mesic-humic, containing spruce, fir, and larch (*Larix laricina*) cones and twigs, was also dredged from the harbour bottom. Many stumps had fibrous peat adhering to their roots and bark.

The material was recovered during harbour-dredging operations, rather than as a result of targeted geological investigation. Consequently, the stratigraphic succession

Plate 5. *Dredged spoil, Port de Grave, May 1999. Large stumps and fragments of trees are visible on the surface of the spoil pile.*

was not preserved, and the fossils were simply dumped as dredged spoil. The initial depth of the harbour floor prior to the commencement of dredging was 6 m below modern sea level. Materials brought to the surface thus potentially included fossils of several ages. The presence of modern bones of moose (*Alces alces*), domestic dog (*Canis familiaris*), and seal (*Phoca*) indicates that modern material was also dumped or transported to the harbour floor. Consequently, concern was expressed that the tree stumps could have been transported to the harbour floor by natural or anthropogenic processes. However, inspection of the stumps did not reveal any evidence of transportation, as many still had adhering bark. In the community of Port de Grave, large stumps were commonly burned as winter fuel, and thus stumps would not be discarded into the harbour. Stumps were inspected to determine if axe marks or other signs of human influence were present, but were not observed. The presence of the fibric and mesic–humic peat associated with the stumps, sediment distinct from the marine pebble gravel and granules that currently line the harbour margin in undisturbed areas, indicates that the harbour bottom was occupied by forested terrain.

Wood submitted for ^{14}C dating yielded an age determination of 2630 ± 60 BP (Beta-132316). This age indicates that the stumps were not anthropogenically transported to the harbour. Comparison with the ^{14}C calibrated German oak dendrochronological record (Stuiver *et al.*, 1998; Friedrich *et al.*, 1999) indicates a calendar age of 2845-2720 years, (equivalent to 895 to 770 BC), allowing 2 standard deviations.

As the elevation of the dated stump can only be estimated at a minimum of approximately 6 m below modern sea level, the estimated rate of sea-level rise is only an approximate value. An additional complication is provided by the local bathymetry. The floor of Port de Grave Harbour was partially isolated from the open waters of Conception Bay by a gravel ridge, developed earlier in the Holocene under lower sea-level conditions. Although this ridge has been lowered by wave action during sea-level rise, and was subsequently pierced and dredged to improve draught in the harbour entrance channel, it would have temporarily served to block access of sea water into the depression in the harbour floor. However, the permeable gravel would not have served as an effective barrier to sea-level rise for a significant period. In addition, the absence of wind stress recorded in the rings of the stumps indicates that the growth habit of the trees was not influenced by strong coastal winds or salt spray, suggesting an inland position.

If the base of the stump was no higher than 6 m asl, the minimum rate of sea-level rise was 2.1 mm/a over the past 2845 years. Alternatively, assuming that the stump was at a depth of 2 m and considering a minimum age of 2720 years, this produces a rate of sea-level rise of ca. 3 mm/a; hence an estimate of between 2 to 3 mm/a thus appears appropriate for sea-level rise over the past 2800 years in Port de Grave Harbour.

BEACHES ARCHAEOLOGICAL SITE

Data concerning recent sea-level changes is lacking for the Trinity Bay shoreline. Investigation of the ‘Straight Shore' to the northwest of Bonavista Bay suggests that sea level has risen only slightly (± 70 cm) in the past 3000 years (Shaw and Forbes, 1990). However, sea-level rise is partly responsible for coastal erosion of The Beaches archaeological site north of Burnside (Plate 6), where a tombolo is actively undergoing submergence. Protective measures have proven necessary to protect the site from further erosion as archaeological excavation proceeds, and some parts of the site are below present mean sea level. Interpolation among results from the Avalon Peninsula (Catto, 1994b, 1995; Catto *et al.*, 1999; Catto and Thistle, 1993), those from the Straight Shore (Shaw and Forbes, 1990), and the observations from The Beaches, suggests that sea-level rise along the northern part of the Trinity Bay shoreline (southern Bonavista Peninsula) currently approximates 2 mm/a.

Plate 6. *Beaches archaeological site, 1995, showing protective measures against coastal erosion.*

DISCUSSION

Exact quantification of the rates of sea-level rise over short periods (decades to hundreds of years) is complicated by many factors, including local subsidence (*cf.* Belpeiro, 1993), confusion of storm and tsunami deposits with those associated with modal marine conditions (Foster *et al.*, 1991), and erosion induced above mean high water (e.g., Bryan and Stephens, 1993). A further complication is induced by landward migration of barachoix and other coastal features (examples are discussed in detail by Shaw and Forbes, 1987; Forbes *et al.*, 1995). More dated sites are required throughout eastern Newfoundland before a definite statement concerning the precise rate of sea-level rise is possible. Although the exact rate of change is uncertain, and although the relative importance of anthropogenic and natural factors contributing to sea-level rise on a continent-wide scale (*cf.* Kemp, 1991) and the nature of regional climate change (Pocklington *et al.*, 1994; Morgan and Pocklington, 1996) are also unclear, sea level is rising along the eastern Newfoundland shoreline. The data from the sites at Port de Grave, Ship Harbour, and Mobile, combined with that obtained previously (Boger, 1994; Catto, 1994b; Catto *et al.*, 1997) from Biscay Bay Brook, Big Barasway and Ship Cove (Placentia Bay), and archaeological investigations at Ferryland and Placentia, indicate that sea-level rise is continuing. The calculated rates of rise, however, differ from a minimum of 1 mm/a (the lowest estimate at Ship Harbour) to a maximum in excess of 6.5 mm/a (the highest estimate at Mobile). At Port de Grave and Biscay Bay Brook, sea-level rise is estimated to be ca. 2-3 mm/a during the late Holocene. A similar rate is tentatively estimated for The Beaches site.

At Ship Cove, the presence of marine sediments at 1 m asl, overlying terrestrial peat dated at 1340 ± 70 BP (GSC - 5306), suggests that marine waters exceeded modern sea level in the late Holocene. Coastal erosion at Big Barasway and Ship Cove indicates that sea level currently is rising. The occurrence of terrestrial forest peat in an exposed location at Big Barasway dated at 3480 ± 60 BP (GSC - 5319) demonstrates that mid-Holocene sea level was lower than at present (Boger, 1994; Catto, 1994b). Although the Ship Cove site suggests that local fluctuations can occur, possibly related to storm activity, the overall pattern for the coastline of eastern Newfoundland is one of progressive submergence through the mid- to late Holocene.

The differences in the estimated rates of sea-level rise reflect the uncertainties involved in calculating numerical values from inundated stumps. However, the similarity of the rates for the latest Holocene estimated from Mobile, and those suggested from the archaeological investigations, may indicate that the rate of sea-level rise has accelerated in the most recent phase of the Holocene.

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REFERENCES

Belpeiro, A.P.
1993: Land subsidence and sea level rise in the Port Adelaide estuary: Implications for monitoring the greenhouse effect. Australian Journal of Earth Sciences, Volume 40, pages 359- 368.

Boger, R.
1994: Morphology, sedimentology, and evolution of two Gravel Barachoix Systems, Placentia Bay. M.Sc. thesis, Department of Geography, Memorial University of Newfoundland, St. John's, Newfoundland, 174 pages.

Brückner, W.
1969: Post-glacial geomorphic features in Newfoundland, eastern Canada. Ecologae Geologicae Helvetiae, Volume 62, pages 417-441.

Bryan, W.B. and Stephens, R.S.
1993: Coastal bench formation at Hanauma Bay, Oahu, Hawaii. Geological Society of America Bulletin, Volume 105, pages 377-386.

Catto, N.R.
1992: Surficial geology and landform classification, southwest Avalon Peninsula. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File 2186.

1994a: Surficial geology and landform classification, eastern Avalon Peninsula. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File 001 N/536.

1994b: Coastal evolution and sea level variation, Avalon Peninsula, Newfoundland: geomorphic, climatic, and anthropogenic variation. *In* Coastal Zone Canada 1994, Co-operation in the Coastal Zone. *Edited by* P.G. Wells and P.J. Ricketts. Bedford Institute of Oceanography, Volume 4, pages 1785-1803.

1995: Field Trip Guidebook, Eastern Avalon Peninsula. Canadian Quaternary Association (CANQUA) Congress, St. John's, Newfoundland, June 1995, EC 1-EC 9.

1997: Geomorphological and sedimentological classification of the Bay D'Espoir- Hermitage Bay - Connaigre Bay - western Fortune Bay coastline. Technical Report, Coast of Bays Corporation, St. Alban's, Newfoundland.

1998a: The pattern of glaciation on the Avalon Peninsula of Newfoundland. Géographie physique et Quaternaire. Volume 52, pages 23-45.

1998b: Surficial geological mapping, Merasheen-Harbour Buffett-Sound Island map-areas: an update. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 98-1, pages 173-177.

Catto, N.R., Anderson, M.R., Scruton, D.A. and Williams, U.P.
1997: Coastal classification of the Placentia Bay shoreline. Canadian Technical Report of Fisheries and Aquatic Sciences, page 2186.

Catto, N.R., Anderson, M.R., Scruton, D.A., Meade, J.D. and Williams, U.P.
1999: Shoreline classification of Conception Bay and adjacent areas. Canadian Technical Report of Fisheries and Aquatic Sciences, page 2274.

Catto, N.R. and St. Croix, L.
1997: Urban geology of St. John's, Newfoundland. *In* Urban Geology of Canadian Cities. *Edited by* P.F. Karrow and O.L. White. Geoscience Canada, pages 445-462.

Catto, N.R. and Thistle, G.
1993: Geomorphology of Newfoundland. International Geomorphological Congress, Guidebook A-7.

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

Forbes, D.L., Orford, J.D., Carter R.W.G., Shaw, J. and Jennings, S.C.
1995: Morphodynamic evolution, self-organisation, and instability of coarse-clastic barriers on paraglacial coasts. Marine Geology, Volume 126, pages 63-85.

Foster I.D.L., Albon A.J., Bardell, K.M., Fletcher, J.L., Mothers, R.J., Pritchard, M.A. and Turner, S.E.
1991: High energy coastal sedimentary deposits; an evaluation of depositional processes in southwest England. Earth Surface Processes and Landforms, Volume 16, pages 341-356.

Friedrich, M., Kromer, B., Spurk, M., Hoffman, J. and Kaiser, K.F.
1999: Paleo-environment and radiocarbon calibration as derived from Late glacial/Early Holocene tree-ring chronologies. Quaternary International, Volume 61.

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

Griffiths, H.
1999: Coastal geomorphology and sedimentology, Whiffen Head-Ship Harbour area, Placentia Bay. M. Env. Sc. Thesis, Department of Geography, Memorial University of Newfoundland, St. John's, Newfoundland, 93 pages.

Jones, S.E.
1995: A study of the morphology and sedimentology of a coastal beach in Mobile Harbour, Newfoundland, in conjunction with shoreline evolution and sea level rise. Honours B.Sc. Thesis, Department of Geography, Memorial University, St. John's.

Kemp, D.
1991: The Greenhouse Effect and Global Warming: a Canadian Perspective. Geography 1991, pages 121-130.

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

Leckie, D.A. and McCann, S.B.
1983: Late Quaternary glacial history of the Hermitage area of southern Newfoundland. Canadian Journal of Earth Sciences, Volume 20, pages 399-408.

Lewis, C.F.M., Macpherson, J.B. and Scott, D.B.
1987: Early sea level transgression, eastern Newfoundland. INQUA 1987, Programme with Abstracts, page 210.

Liverman, D.G.E.
1994: Relative sea-level history and isostatic rebound in Newfoundland, Canada. Boreas, Volume 23, pages 217-230.

1998: Relative sea level history and isostatic rebound in Atlantic Canada; based on radiocarbon dated marine molluscs and regional geomorphology. Abstract Volume, Joint meeting GAC, MAC, APGGQ, IAH, CGU, May 18-20, 1998, Québec.

Miller, A.A.L. and Fader, G.B.J.
1995: A Late Pleistocene-early Holocene local independent ice cap on the Tail of the Grand Banks: foraminiferal evidence. CANQUA abstracts CA 33, CANQUA/CGRG 95, St. John's, Newfoundland.

Morgan, M.R. and Pocklington, R.
1996: The chilling aspects of global warming in Atlantic Canada. *In* Climate Change and Climate Variability in Atlantic Canada. *Edited by* R.W. Shaw. Environment Canada, Atlantic Region, Occasional Paper 9, pages 184-194.

Pocklington, R., Morgan, R. and Drinkwater, K.
1994: Why we should not expect 'greenhouse warming' to be a significant factor in the Eastern Canadian coastal zone in the near future. *In* Coastal Zone Canada 1994, Co-operation in the Coastal Zone. *Edited by* P.G. Wells and P.J. Ricketts. Bedford Institute of Oceanography, Volume 4, pages 1824-1830.

Quinlan, G. and Beaumont, C.
1981: A comparison of observed and theoretical postglacial relative sea levels in Atlantic Canada. Canadian Journal of Earth Sciences, Volume 18, pages 1146-1163.

1982: The deglaciation of Atlantic Canada as reconstructed from the postglacial relative sea-level record. Canadian Journal of Earth Sciences, Volume 19, pages 2232-2246.

Riestenberg, M.M. and Sovonick-Dunford, S.
1983: The role of woody vegetation in stabilizing slopes in the Cincinnati area, Ohio. Geological Society of America, Bulletin 94, pages 505-518.

Robertson, A.W.
1984: Tamarack (*Larix laricina* (Du Roi) K. Koch) as a bilogical indicator of wind. M.Sc. Thesis, Department of Geography, Memorial University of Newfoundland, St. John's, 174 pages.

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

1990: Short- and long-term relative sea-level trends in Atlantic Canada. Proceedings, Canadian Coastal Conference 90, Kingston. National Research Council of Canada, pages 291-305.

1995: The postglacial relative sea-level lowstand in Newfoundland. Canadian Journal of Earth Sciences, Volume 32, pages 1308-1330.

Sommerville, A.A.
1997: The late Quaternary history of Terra Nova National Park and vicinity, northeast Newfoundland. M.Sc. Thesis, Department of Geography, Memorial University of Newfoundland, St. John's, 152 pages.

Stuiver, M., Reimer, P.J., Bard, E., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., Plicht, J. and Spurk, M.
1998: INTCAL98 Radiocarbon Age Calibration. Radiocarbon, Volume 40 (3).

Taylor, T.
1994: Coastal Land Management, Town of Conception Bay South. Honours B.A. Thesis, Department of Geography, Memorial University of Newfoundland, St. John's.

Thannheiser, D.
1984: The coastal vegetation of eastern Canada. Department of Biology, Memorial University of Newfoundland, St. John's.

Wu, T.H., McKinnell, W.P. III and Swanston, D.N.
1979: Strength of tree roots in a landslide on Prince of Wales Island, Alaska. Canadian Geotechnical Journal, Volume 16, pages 19-33.