Journal of Coastal Research	7	2	477–488	Fort Lauderdale, Florida	Spring 1991

Gravel Barrier Migration and Sea Level Rise: Some Observations From Story Head, Nova Scotia, Canada

J.D. Orford[†], R.W.G. Carter[‡] and D.L. Forbes*

[†]School of Geosciences
Queen's University
Belfast BT7 1NN Northern Ireland

[‡]Department of Environmental Studies
University of Ulster
Coleraine BT52 1SA, Northern Ireland

*Atlantic Geosciences Centre
Geological Survey of Canada
Bedford Institute of Oceanography
Box 1006
Dartmouth, Nova Scotia B2Y 4A2, Canada

ABSTRACT

ORFORD, J.D.; CARTER, R.W.G. and FORBES, D.L., 1990. Gravel barrier migration and sea-level rise: Some observations from Story Head, Nova Scotia, Canada. *Journal of Coastal Research*, 7(2), 477–488. Fort Lauderdale (Florida). ISSN 0749-0208.

The migratory response of swash-aligned gravel-dominated barriers to sea-level rise is a relatively little-studied process. Story Head barrier, on the Atlantic coast of Nova Scotia, is swash-aligned and experiencing contemporary landward migration (6m a^{-1}) via storm-generated crest overtopping and overwashing. Barrier migration rates are presented for the period 1945 to 1982. Landward migration of the seaward barrier shoreline is linearly proportional to both the 5-year smoothed rate of sea-level change ($r = +0.91$) and the annual sea-level change rate ($r = +0.69$), although the back-barrier migration rate is not related significantly to these rates of sea-level change. This difference between front and back-barrier migration response to sea-level rise reflects the intervening role of storm intensity (frequency and magnitude) superimposed on sea-level rise. Story Head barrier fluctuates between dominance of barrier crest build-up by overtopping run-up and crest breakdown by overwashing flow. The balance between these two mechanisms, which controls the rate of onshore barrier migration, depends on both storm intensity and the rate of sea-level rise.

ADDITIONAL INDEX WORDS: *Gravel-dominated barriers, barrier migration, sea-level change, storm activity.*

INTRODUCTION

The relationship between sea-level rise and shoreline change is both a vexed and a strategic debate for coastal geomorphology in view of the projected global rise in sea-level over the next few decades (TITUS, 1986). Although a relationship between sea-level rise and shoreline recession has been proposed for fine-grained clastic beaches (BRUUN, 1962; SCHWARTZ, 1967; BRUUN, 1988), it is far from an empirical certainty that gravel beaches respond to sea-level rise in the manner suggested by the Bruun Rule (ORFORD, 1987; FORBES *et al.*, 1989), despite Bruun's advocacy of the universality of his rule for all grain sizes (BRUUN; *pers. com.* 1986). The virtual absence of any published data on gravel barrier migration in relation to observed sea-level rise only serves to underline the hitherto hypothetical basis of attempts to rationalize this process.

8907 received 28 November 1989; accepted in revision 6 August 1990.

This paper examines the relationship between sea-level rise and the migration of the swash-aligned gravel-dominated Story Head barrier, on the Eastern Shore of Nova Scotia (Canada), between 1945 and 1982 (Figure 1). The Eastern Shore exhibits contemporary development of gravel barriers in response to continuing erosion of Pleistocene glaciogenic deposits at the coast. Many of the barriers experience onshore migration in association with high rates of sea-level rise.

GRAVEL BARRIER RESPONSE TO SEA-LEVEL RISE

Sea-level rise *per se* is not a mechanism directly influencing gravel barrier migration. Clearly, sea level is the passive plane upon which mechanisms occur and in turn generate the dynamic processes of barrier alteration.

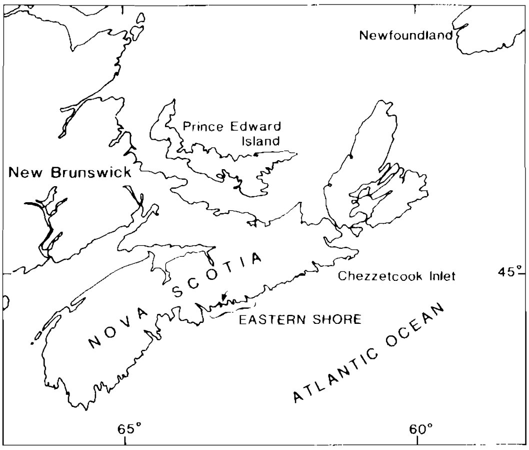

Figure 1. Location of Chezzetcook Inlet on the Eastern Shore, Nova Scotia.

Existing evidence for gravel barrier response to sea-level rise points mainly toward onshore migration. Much of this evidence comes from southern England (HARDY, 1964; CARR and BLACKLEY, 1974) and Ireland (CARTER and ORFORD, 1981), which in general have experienced little, if any, sea-level rise in the last 1–2ka (CARTER *et al.*, 1989a). Therefore the proposition of relationships between barrier migration and sea-level change has been structured by inference rather than on direct evidence.

The dominant process by which gravel barriers migrate is through rollover. Beachface sediment is passed over the barrier crest by storm-wave activity. It then remains passively on the back slope before burial by subsequent storm-generated washover sediment. In this way the barrier shifts landward, so that in time the back-barrier sediments will emerge through the beach face to be incorporated once more in the overpassing cycle. Coarse clastic barriers show a major difference from fine clastic barriers in this respect. In general, the capacity for sediment return to the seaward face of a gravel system, by other than exhumation, is radically below that of a sand system, where tidally maintained breaches in the barrier are common and effective in cross-barrier sediment recycling (CARTER *et al.*, 1989b).

Barrier migration by rollover was advocated by HARDY (1964) for the origin of Loe Bar, Cornwall. Here, flint in the gravel barrier which bars the Helston estuary could only have been derived from an offshore source and incorporated into the barrier during onshore movement under a rising sea level. CARR and BLACKLEY (1974) suggested that the evolution of the largest gravel barrier on the south coast of England, the Chesil Bank, was by continual barrier overtopping under a rising sea-level, so that the feature has rolled onshore.

The balance between barrier crest build-up due to wave overtopping and crest breakdown by wave overwashing dictates the rate of rollover and migration. The rate of barrier migration is therefore dependent on that part of the spectrum of run-up volume that crosses the barrier crest. We recognize a series of distinctive responses to the volume of run-up reaching, overtopping and overwashing a gravel barrier crest (Figure 2: ORFORD and CARTER; 1982). As run-up elevation (R) increases relative to barrier crest height (B) and as run-up volume (Qw) increases, crest-top deposition (overtopping) gives way to crest removal at discrete positions (discrete overwash). Further increases in the washover volume lead to complete crestal displacement (sluicing overwash) and may finally cause barrier breakdown (barrier dislocation) as the entire barrier crest is demolished by surge-like swash flow. Shoreward displaced sediment accretes on the back-barrier area to act as a foundation for later barrier positions.

The differential response of migrating seaward barrier and back-barrier shorelines is a measure of barrier volume change (per unit length of barrier) related to barrier elevation changes. If the barrier's seaward shoreline retreats at a faster rate than the back-barrier shoreline then the barrier must be building up with crestal elevations rising through concentrated overtopping (Figure 3). The reverse situation with the back-barrier edge migrating faster than the seaward face indicates that the barrier crest must be falling with overwash predominating. When migration rates are equal then crestal elevation is held despite migration. These implications, drawn from differential barrier shoreline migration, depend on there being zero longshore sediment transport. This condition is more likely to be met when barriers are swash-aligned than drift-aligned.

The balance between overtopping and over-

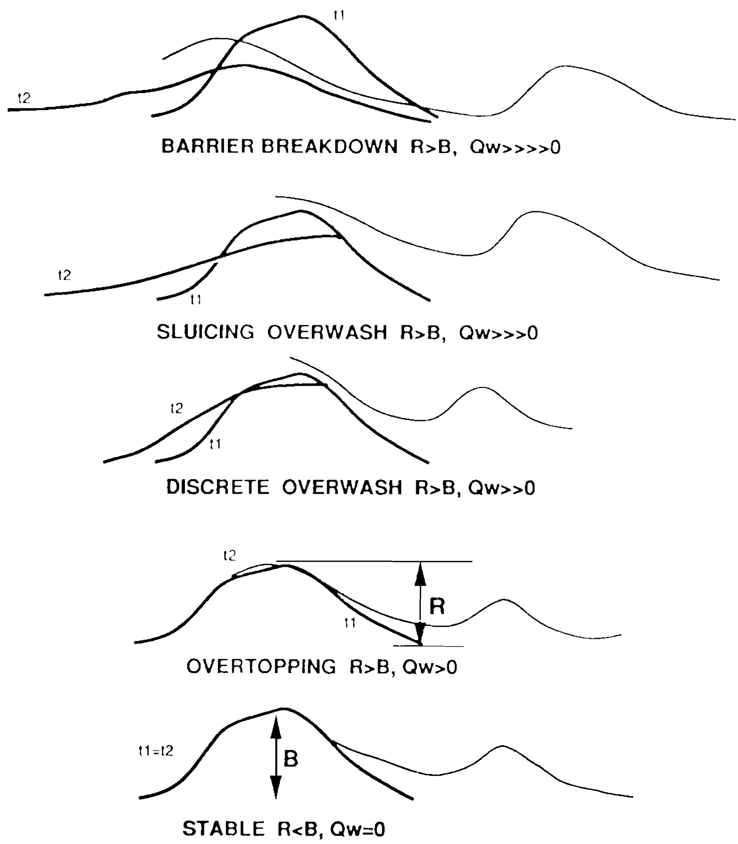

Figure 2. The continuum of overtopping and overwashing modes by which gravel barrier crest migration may occur; t1 and t2 are crestal profiles before and after storm generated overtopping and/or overwashing run-up.

washing is dictated by the frequency and magnitude of storms. As the overall storm intensity rises, the rate of crestal overwashing and hence crestal lowering is likely to increase. As storm intensity drops, overwashing diminishes and overtopping with crestal build-up increases. The overall migration of a gravel barrier is dependent on the rate of overwashing, which leads to barrier rollover, rather than overtopping, which allows the shoreline edge to retreat but is unlikely to effect back-barrier migration.

Storm intensity operates independently of sea-level change. However, the effects of storm intensity change may be noticeable in the mean sea-level record through barometric pressure and geostrophic set-up. These are most likely to be statistically noticeable when storm frequency rises over a prolonged period, though barometric and geostrophic induced set-up from one event could add marginally to the statistical evaluation of a mean annual sea-level value.

The balance of overtopping to overwashing may be altered by the rate of sea-level change assuming that the storm intensity remains constant. Any increase in mean sea-level will change the overtopping/overwashing ratio toward overwashing. This ratio can only be held constant under rising sea level by the provision of sediment to build the crest up. As DILLON (1971) noted, an increasing volume of sediment is required to build up a stable barrier crest. On swash-aligned barriers, this volume can only be found from existing material on the beachface. It is likely with high rates of sea-level rise that overwashing will predominate, causing a reduction in the barrier crest elevation and an increase in the back-barrier migration rate.

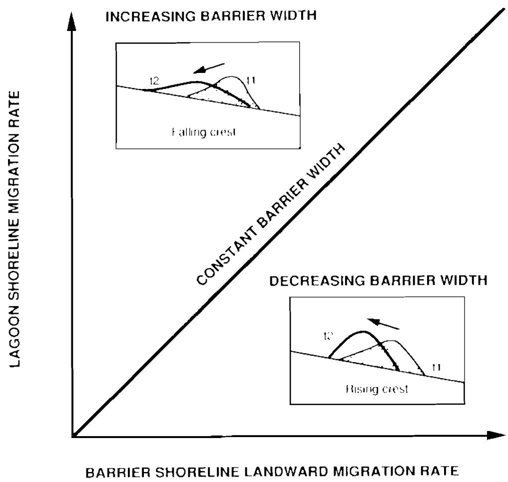

Figure 3. Schematic view of barrier crestal stability domains as a function of seaward and back-barrier shoreline migration.

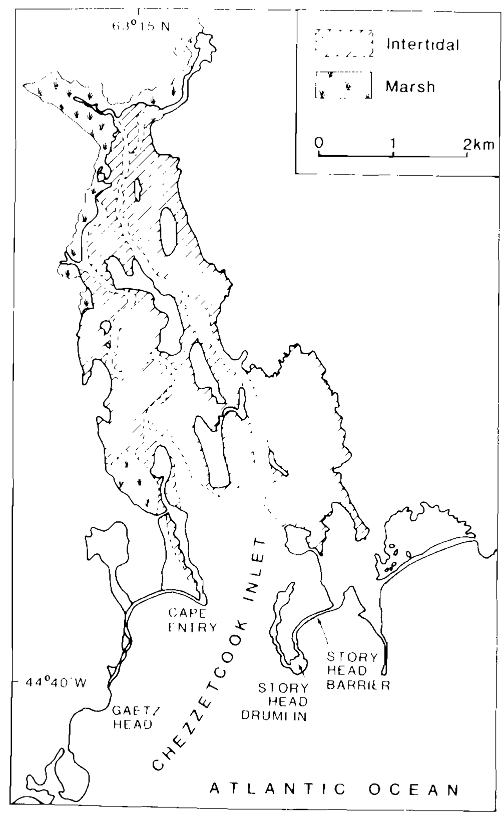

Figure 4. Location of Story Head barrier at the entrance to Chezzetcook Inlet.

The slower the rise in sea level the more likely it is that the coherence of the crest can be maintained. The relationship between back-barrier migration and sea-level change rate will not be so well-defined under these circumstances. Where sea level is stationary the rollover process must be increasingly spasmodic, depending on the occurrence of increasingly low-frequency, high-magnitude storm events whose extension of the run-up spectrum allows further onshore displacement of crestal material. This process and hence barrier migration must cease over time as the fetch-limiting storm event is approached asymptotically. The extensive, gravel-dominated barriers of southeast Ireland fall into this last category (CARTER and ORFORD, 1981; ORFORD and CARTER, 1982, 1984).

SITE CHARACTERISTICS

The western part of the Eastern Shore of Nova Scotia (Figure 1) comprises a series of irregular-shaped estuaries etched into a metasedimentary rock basement covered with a variable thickness of glacial diamict. Much of this cover is in the form of drumlins. The diamict sediment is heterogeneous containing up to 20% coarser than -4.0ϕ (pebbles to boulders; SONNICHSON, 1984). The erosion of drumlins exposes large volumes of transportable gravels that are concentrated into barriers by longshore drift. Sediment sources and drift volumes in the transport system are highly variable. Both drift-aligned and swash-aligned barrier systems are observed, often with drumlins acting as anchors for refraction-hinge positions (CARTER *et al.*, 1989b; FORBES *et al.*, 1990). BOYD *et al.* (1987) suggested a model for Eastern Shore coastal deposition, by which post-glacial sea level rise has generated episodic beach and barrier building related to a wave-generated erosional front passing across the area. Episodic sediment movement and deposition through periods of barrier accretion and then destruction are engendered as drumlins are eroded progressively.

Story Head barrier is a swash-aligned, gravel barrier that is tied to the remnants of Story Head, a drumlin at the eastern side of Chezzetcook Inlet (Figure 4). In 1987 the barrier crest extended laterally for 800 m. The barrier was 40 to 60 m wide and up to 3.8 m high with a datum (NAD, 1927) set at 0.23 m below mean sea level at this site, and had a cross-sectional volume of about 120 $m^3 m^{-1}$ barrier length. The barrier was composed predominantly of pebbles and cobbles with some sand and boulders.

Story Head barrier is progressively moving landward due to storm activity which forces a rollover process (FORBES *et al.*, in press). Evidence of barrier migration due to overwash can be seen in the washover fans on the back-barrier margin (Figure 5). SCOTT (1980) noted a rapid, landward migration of the barrier between 1945 and 1974. The difference in barrier position from the first hydrographic survey in 1854 and the topographic survey of 1917 shows a relatively stable barrier moving landward at less than 1 m a^{-1}. FORBES *et al.* (in press) have shown that the present Story Head barrier is a remnant of a larger barrier which split in the 1950s, leaving a remnant of the barrier's basement material on the shoreface as a drowned feature. The still active element of the Story Head barrier is now migrating over the back-barrier intertidal area at about 6 m a^{-1} (field measurements between 1985 and 1988). There are statistically significant differences in clast morphology between samples from the Story Head drumlin-flank barrier and samples from the swash-aligned barrier now dominated by overwash. There are also statistically significant differences in clast lithologies between these same two barrier sections. These clast differences have been interpreted (CARTER *et al.*, in press) as indicating that the central portion of the barrier is probably inherited from an older barrier element which was captured by Story Head drumlin, acting as a hinge point, during an earlier retreat phase.

The Eastern Shore of Nova Scotia experiences a seasonal wave regime, with relatively low waves dominating in summer. Most wave activity results from west to east tracking cyclonic activity moving both north and south of the study area. Modal deepwater wave heights are in the order of 1.5 to 2 m, with modal wave periods about 8 to 10 s. Annual deepwater significant wave heights of 7–8 m have been reported by NEU (1982) for the Scotian Shelf. Significant wave heights of 3–4 m with peak periods in the 10–12 s range are common during winter storms over the inner shelf (FORBES and DRAPEAU, 1989). However, these deepwater statistics obscure the fact that inshore wave regimes are spatially highly variable, due both to the complex bathymetry and the intricate coastal configuration (CARTER *et al.*, 1990). These result in changes in wave height and wave-approach angle over only a few tens of metres in places. The coast is mesotidal, with a spring range of just over 2 m recorded at Halifax Harbour.

RECENT SEA-LEVEL CHANGE

The Holocene history of relative sea-level change in Nova Scotia has been considered by GRANT (1970, 1977), QUINLAN and BEAUMONT (1981, 1982), SCOTT *et al.* (1987) and SHAW and FORBES (1990) among others. Sea level was around 10 m below present sea level 3500 years ago, and has been rising more or less consistently since then. Sea-level changes between 1920 and 1988 (Figure 6) are available from the Halifax Harbour tide gauge (Marine Environmental Data Service, Department of Fisheries and Oceans, Ottawa). The data are for mean annual water levels measured on a datum with zero set at 1.33 m above the pre-1986 Halifax Harbour chart datum. A linear least-squares function fitted to the raw data ($r = +0.90$) indicates a mean rate of sea-level rise of 3.59 mm a^{-1}. A 19-year smoothing function (unweighted) to adjust for the longest-term tidal periodicity identifies a near-linear ($r = +0.98$) trend of 3.79 mm a^{-1} (1929–1979). It is against this background of rapidly rising relative sea-level that the migration of Story Head barrier must be considered.

METHODS

Vertical air-photography of Story Head barrier started in 1945 with eight subsequent runs being available up to 1982. Photograph scales varied between 1:10000 and 1:36000. All photographs were enlarged using a plan variograph to an arbitrary scale of 1:4121. The position of the barrier's seaward and back-barrier shoreline was obtained from each photograph. The back-barrier shoreline was defined, for the purpose of this study, by the edge of the gravels where they transgressed over the lagoon's sands and muds. The seaward shoreline edge is taken as the junction between the actively mov-

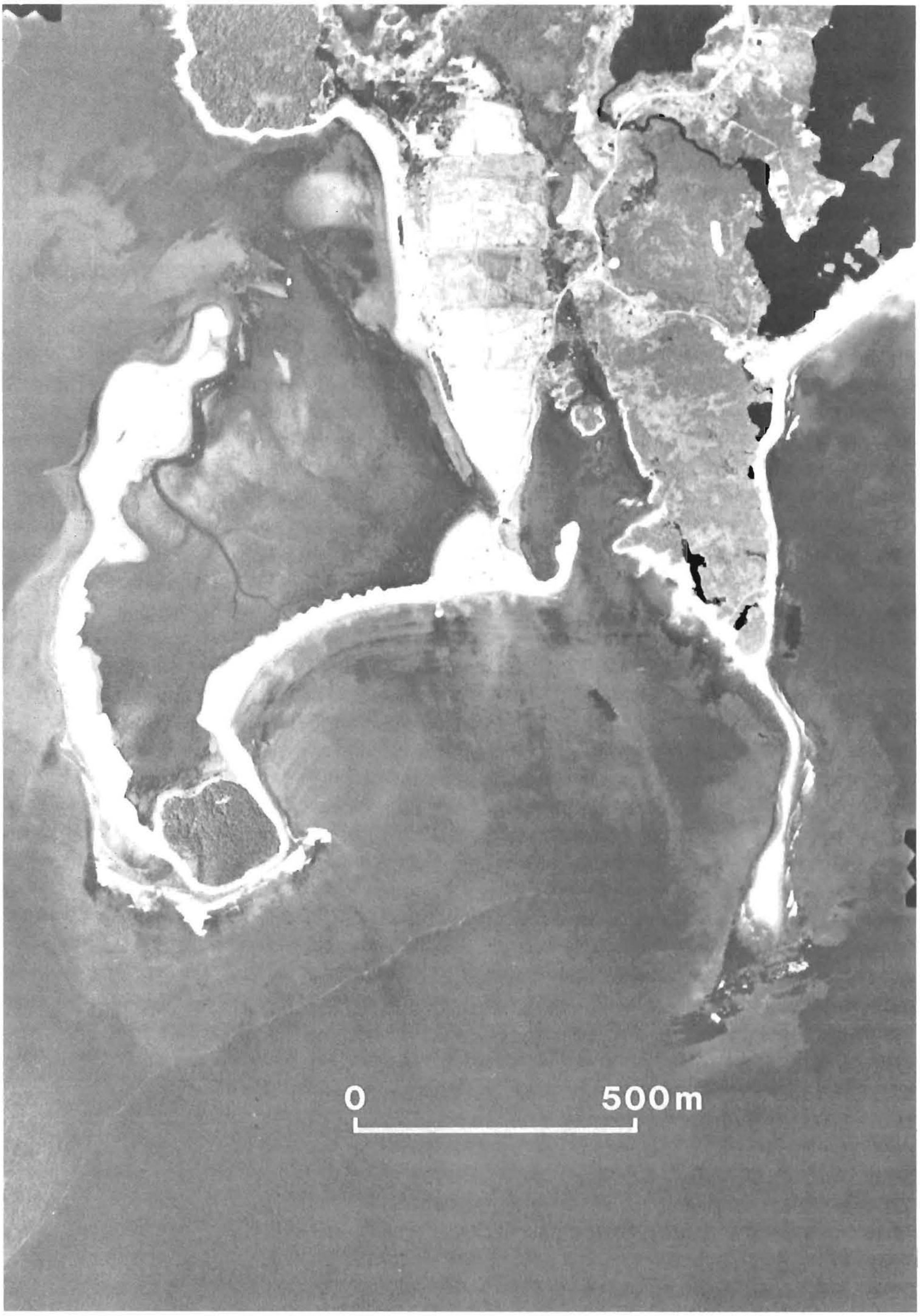

Figure 5. Story Head barrier showing washover fans indicating the mode of barrier migration. (Airphotograph A14288–149, ©Her Majesty the Queen in Right of Canada, reproduced from the collection of the National Air Photo Library with permission of Energy, Mines and Resources Canada.)

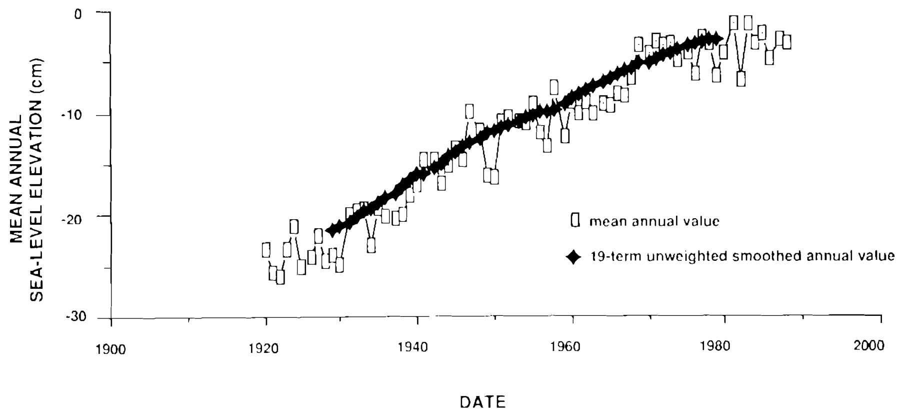

Figure 6. The relative sea-level curve based on the annual mean sea-levels recorded at the Halifax Harbour tide gauge for 1920–1988. An unweighted 19-year smoothed sea-level curve is also shown.

ing gravel plus associated sand and the underlying basement of truncated lagoon mud and lag boulders. In both situations the differential reflective qualities of the materials aided shoreline location. Unknown variable tidal levels at the time of photography may have increased any error term related to the position of the seaward barrier shoreline. Superimposition of the barrier shoreline allowed measurement of barrier migration distance for eight inter-photograph periods. The distances between successive seaward barrier shorelines and successive back-barrier shorelines were measured along a transect line chosen at random on the central segment of the barrier subject to most rapid migration. Migration rates were calculated from displacement distances divided by the number of years between dates of photography (Table 1). As exact photograph dates were unavailable, calculation of mean migration rates based on integer years between photographs will have introduced some imprecision.

Despite the long-term linearity of sea-level change recorded at Halifax Harbour, it is evident that considerable annual variation exists. Short-term variation, usually associated with a mix of meteorological and oceanographic forcing, is superimposed on sea-level rise of a global or regional nature. There is likely to be debate as to what measure of sea-level rise should be used in evaluating the effect on barrier migration. In this case a 5-year weighted smoothing function has been applied to the Halifax data (Figure 7). The sea-level curve for Halifax Harbour was divided into eight time periods based on photograph dates. The sea-level change for each time period was calculated as the difference between the value of the 5-year running-mean sea-level curve at the beginning and end of each time interval. The rate of sea-level

Table 1: *Sea-level change and barrier migration data for Story Head barrier.*

Period	Annual SLC rate mm a^{-1}	5-yr SLC rate mm a^{-1}	Seaward barrier edge migration rate m a^{-1}	Back-barrier edge migration rate m a^{-1}
1945-54	2.78	4.54	4.24	1.07
1954-60	3.33	−0.57	3.18	8.08
1960-64	−0.50	2.35	11.28	8.48
1964-66	5.10	3.44	9.81	4.44
1966-67	−3.00	9.43	21.26	24.23
1967-68	18.00	16.45	26.17	12.27
1968-74	2.67	3.12	7.63	9.96
1974-82	−2.37	0.96	7.77	9.09

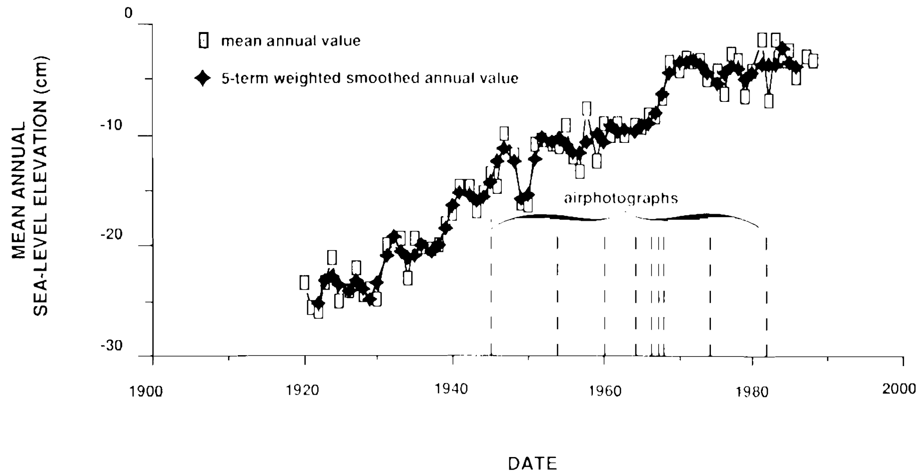

Figure 7. The relative sea-level curve based on the annual mean sea-levels recorded at the Halifax Harbour tide gauge for 1920–1988. A weighted 5-year smoothed sea-level curve is also shown. The vertical dotted lines indicate availability of migration data for Story Head barrier.

change was taken as the difference in sea-level divided by the number of years between photographs (Table 1). The same operation was used for deriving a rate of sea-level change based on the raw annual data. Although an average barrier retreat rate of 1.32 m a^{-1} is available for the period 1917–1945 (based on map and photo evidence), the equivalent sea-level rise rate is unavailable so this period has been excluded from the correlation analysis.

RESULTS

The migration data (rates of the seaward and back-barrier shoreline positions) as well as the sea-level rise rates for the eight observation intervals are given in Table 1. A visual indication of barrier migration can be found by comparing the 1945, 1954, 1966 and 1982 shoreline positions (Figure 8). The intervening known barrier positions have been omitted for clarity. The shoreface ridge feature on the 1974 photograph, discussed by FORBES *et al.* (in press), is also plotted and shows a correspondence with the position of the 1945 barrier.

The general plan form of the barrier has remained constant during the retreat stage. The most marked difference is the lengthening of the barrier segment along the flank of Story Head drumlin. CARTER *et al.* (in press) estimated that the overall barrier length has extended by some 35% over the thirty-seven years between the earliest and latest photograph.

The variable rates of barrier migration are observable (Figure 9) when the actual migration distances from the 1945 datum position are plotted for both the seaward and lagoon shoreline positions. Using the pre-1945 migration rate (1.32 m a^{-1}) as a basis for comparison, there are three phases of migration post-1945: (a) 1945–1960 with migration rate three to four times the pre-1945 rate; (b) 1960–1968 with a period of very rapid migration (up to 25 m a^{-1}); and (c) 1968–1982 with a period of decelerating migration, but still over five times the pre-1945 rate (7 to 8 m a^{-1}).

The migration rate of the barrier's seaward shoreline shows a significant relationship ($r = +0.69$; $p > 0.05$) with the rate of mean annual sea-level change. The correlation between barrier migration rate and sea-level change rate rises significantly when the 5-year smoothed data are used (Figure 10; $r = +0.91$; $p > 0.002$). This last relationship predicts the barrier's seaward shoreline migration rate in metres increasing by 1.356 times for each millimetre per year increase in the sea-level rise rate. Note that the linear function in both cases indicates the possibility of minor onshore barrier migration even with falling sea-level. The migration rate of the back-barrier margin with

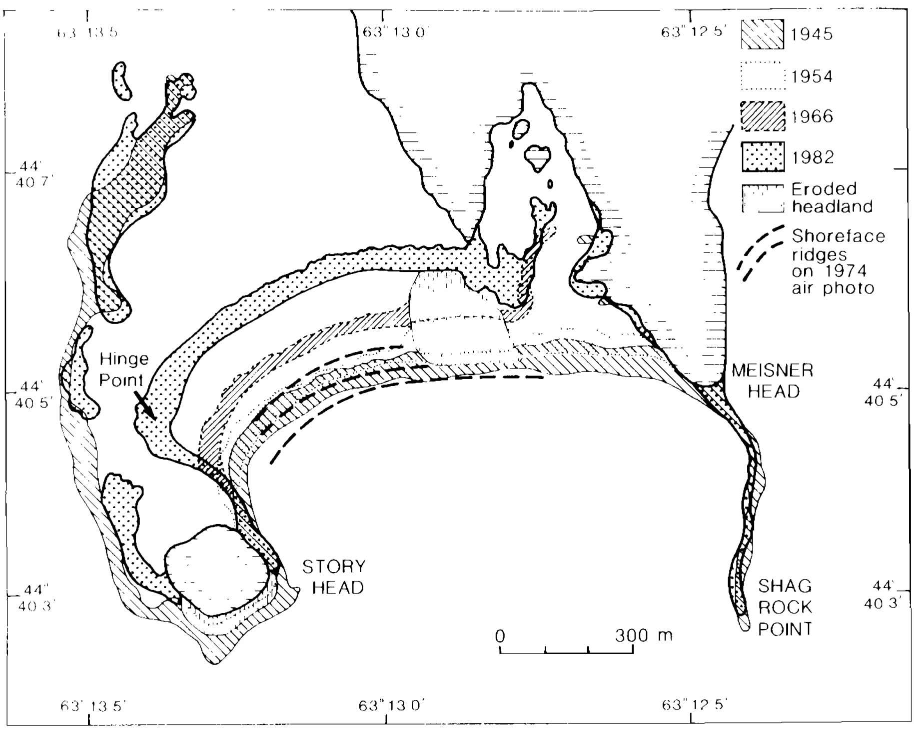

Figure 8. Four stages of Story Head barrier migration between 1945 and 1982 from vertical air photography.

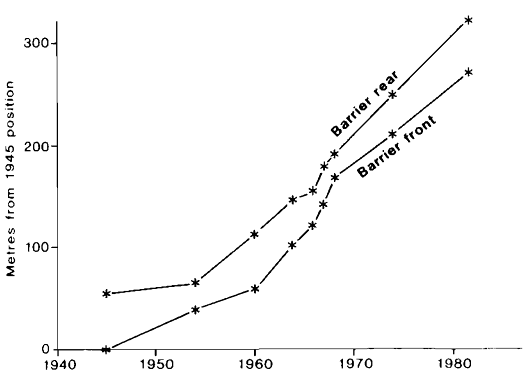

Figure 9. Migration positions of seaward and back-barrier edge shorelines of Story Head barrier between 1945 and 1982.

the annual rate of sea-level change is inverse ($r = -0.17$) and non-significant. The relationship is reversed with the smoothed sea-level change rate ($r = +0.40$) but is still non-significant. The linear relationship between seaward and back-barrier shoreline retreat rates is not well defined ($r = +0.69$; $p > 0.05$) with less than half the variance of the back-barrier shoreline retreat explainable solely in terms of seaward shoreline retreat ($r^2 = 0.476$).

Story Head barrier moved between the two domains of crest build-up and crest reduction during the period 1945–1982 (Figure 11). A movement sequence between these domains can be recognized, though no periodicity is evident in these moves. Superimposed on Figure 11 are the contours of a linear surface of sea-level rise rate (fitted by a least squares method). Over 85% of sea-level data can be related statistically to the joint seaward and back-barrier migration rates of the barrier.

DISCUSSION

The positive relationship between barrier seaward edge migration and rate of sea-level rise appears to support Bruun's thesis. However, two points need to be considered which

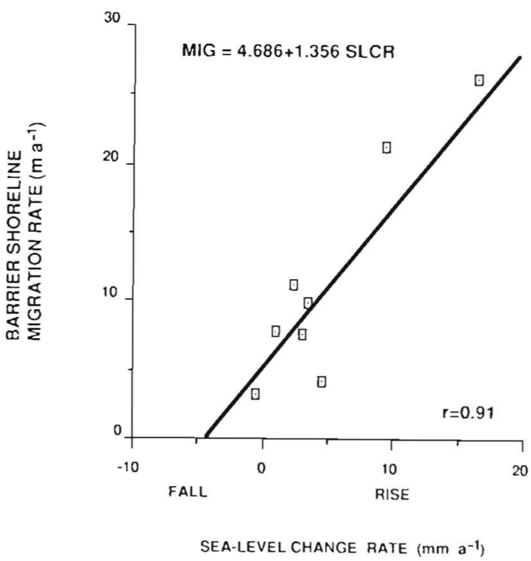

Figure 10. The linear relationship between barrier seaward shoreline migration rate (1945 to 1982) and smoothed (weighted 5-year) sea-level rise rate for Story Head barrier.

may affect the validity of this relationship where gravel barriers are concerned: (a) barrier migration is not related solely to sea-level rise and (b) the extent to which Story Head barrier migration rate may be representative of a particular type of gravel-based barrier.

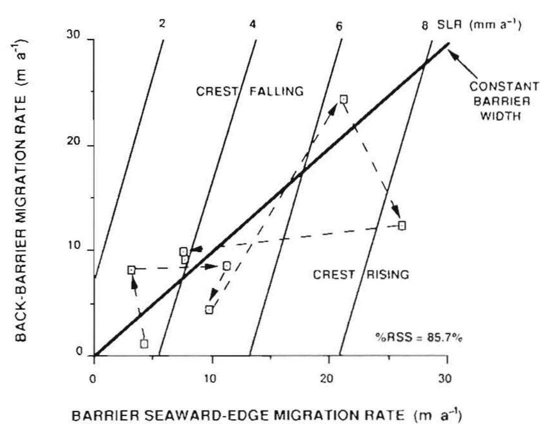

Figure 11. The relationship between migration rates (1945–1982) of the seaward and back-barrier edge shorelines for Story Head barrier as a function of sea-level rise rate. The secular movement of the barrier through domains of crest rise and crest fall is plotted by the dashed line.

Barrier Migration Related To Storm Activity

Story Head barrier has switched between domains of crest build-up and crest breakdown. Although any one of these domain switches may be solely an artefact of the last most significant storm event prior to the photograph, rather than to conditions prevailing throughout the period, it does underline the point that barrier migration is a function of storm and sea-level rise interaction.

The failure of the barrier's seaward-edge and back-barrier migration rates to be linked directly stresses the nature and importance of the intermediary role of barrier processes causing crest build-up and crest breakdown. It is these latter storm-related processes which control back-barrier migration rate rather than sea-level rate *per se*. However, because they are storm-related it is likely that any variation in the frequency and intensity of coastal storms could be reflected in changes recorded in mean sea-level and hence the association between migration and sea-level.

The period of relatively slow barrier migration (1917–1945) at Story Head could reflect a slow sea-level rise rate and only a marginal breakdown of crest stability. However, the long-term rate of sea-level rise prior to 1945 was not significantly different from that operating after 1945 (Figure 6). Any prolonged period of crest build-up and slow migration would, therefore, imply reduced storm activity, so that overwashing would be diminished in favour of overtopping. Storm incidence and intensity in the North Atlantic (after BROWN *et al.*, 1986; CRY and HAGGARD, 1962) have changed over the period 1900 to 1980, with post-1930 storm incidence, measured over 5-year intervals, rising by about 75%. Storm data for the 1950s and later show a period of extreme cyclonic activity on the Scotian Shelf (Figure 12). Concomitant increases in wave activity may account for the increases in barrier migration rates in recent decades, though the exact timing of storm intensity and increased migration rates is not well-defined.

To What Extent Is Story Head Barrier Typical?

FORBES *et al.* (1990) have shown that Story Head barrier is one of a set of contrasting

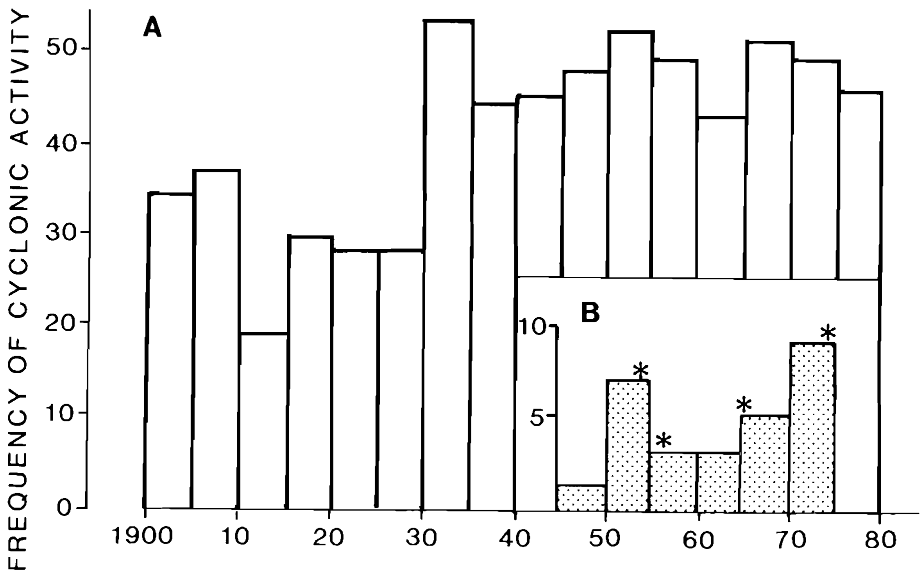

Figure 12. Incidence of cyclonic activity and severe storms over the North Atlantic Ocean. (A) after Cry and Haggard (1962). (B) The thirty most extreme storms on the Scotian Shelf (Brown *et al.*, 1986). *Severe storms impinging on the Nova Scotian coast (Deiure, 1983).

gravel-dominated barriers found along the Atlantic coast of Nova Scotia. Story Head barrier is classified as a low, washover-dominated, rapidly migrating barrier (type 3), while high, stable barriers (type 2) which have experienced a similar sea-level and storm-wave regime to Story Head, occur in adjacent bays.

FORBES *et al.* (in press) argue that Story Head barrier most likely entered a phase of instability promoting rapid migration sometime in the mid-1950s. This may have been due to the occurrence of an extreme event, like the 1954 severe storm that DEIURE (1983) noted, exceeding a threshold of local sea-level rise and wave activity, causing the barrier to experience something akin to sluicing-overwash. FORBES *et al.* (in press) suggest that barrier breakdown resulted in the barrier's crestal superstructure being detached and translated landward, leaving drowned remnants of the barrier's foundation in its wake. Subsequent storm activity generated a phase of active rollover of the remaining active barrier superstructure. The rapid migration rate of Story Head barrier in recent decades may have been affected by a reduction in the barrier's cross-sectional volume relative to its pre-1950s volume. Although the cross-sectional barrier volume may have been reduced as a consequence of barrier lengthening, the detachment of the barrier's crestal superstructure from the barrier shoreface substructure would also have reduced barrier sediment volume which in turn would allow faster barrier rollover rate.

The recent rapid migration rate of Story Head barrier therefore might be regarded as a product of a relaxation episode following a major phase of instability. Future migration rates may well be conditional on the stretching and break-up of the barrier arc (this has already occurred at the north-west corner, which was breached in December 1986). If the migration rate is being monitored in a relaxation phase, then these results may be representative only of a single 'snap-shot' of barrier behaviour limited to a time window when sediment supply is minimized and the barrier is receptive increasingly to climatic forcing. This would serve to accentuate the rate of migration but not necessarily change the positive relationship between migration and sea-level change rate.

CONCLUSION

The 1945–1982 migration rates, obtained from air-photography, for the gravel-dominated Story Head barrier appear directly proportional to short-term smoothed sea-level change rates, despite barrier migration being achieved through the activity of storms overtopping and overwashing the barrier crest.

The data from Story Head indicate that the response of barriers may be more sensitive to short-term fluctuations in sea-level rate than hitherto recognized. The use of a 5-year smoothing function on tide gauge data highlights the importance of short-term sea-surface fluctuations related to meteorological forcing that can be regarded as useful in monitoring barrier migration. The use of long-term smoothed sea-level curves may mask important low-order forcing of shoreline migration.

The limited data set from Story Head does not allow us to carry this debate further at this stage. These results and the interpretations made from them should only be considered as a first approximation. It should be borne in mind that the barrier volume at Story Head is small and further data on larger barriers should be obtained in order to consider the relative contributions of overtopping and overwashing to barrier development as well as the relationship between barrier migration rate and sea-level rise rate.

ACKNOWLEDGEMENTS

Acquisition of the data was under NATO Grant 016/84. We acknowledge the support of NERC Grant GR3/7711. We also acknowledge the Geology Survey of Canada for allowing us access to air photography, maps, and charts of Story Head. The critical comments of Dr. Simon Jennings were greatly appreciated. We wish to thank Bob Taylor for assistance and Maura Pringle for drawing some of the figures. This paper forms a contribution to IGCP 274. (GSC contribution no. 26190).

LITERATURE CITED

BOYD, R.; BOWEN, A.J., and HALL, R.K., 1987. An evolutionary model for transgressive sedimentation on the Eastern shore of Nova Scotia. *In*: D. FITZGERALD and P. ROSEN, (eds.), *Glaciated Coasts*. San Diego: Academic Press, pp. 87–114.

BROWN, R.D.; ROEBBER, P., and WALSH, K., 1986. Climatology of severe storms affecting coastal areas of eastern Canada: Ottawa, Environmental Studies Revolving Funds, *Report 020*, 230p.

BRUUN, P., 1962. Sea-level rise as a cause of shore erosion. *Journal of Waterways Harbours Division. American Society of Civil Engineers*, 88, 117–130.

BRUUN, P., 1988. The Bruun rule of erosion by sea-level rise: a discussion on large scale two and three dimensional usages. *Journal of Coastal Research*, 4, 627–648.

CARR, A.P. and BLACKLEY, M.W.L., 1974. Ideas on the origin and development of Chesil Beach, Dorset. *Proceedings of the Dorset Natural History and Archaeology*, 95, 9–17.

CARTER, R.W.G. and ORFORD, J.D., 1981. Overwash processes along a gravel beach in southeast Ireland. *Earth Surface Processes and Landforms*, 6, 413–426.

CARTER, R.W.G.; ORFORD, J.D.; FORBES, D.L., and TAYLOR, R.B., 1987. Gravel barriers, headlands and lagoons: an evolutionary model. *Coastal Sediments '87*, American Society of Civil Engineers Specialty Conference, New Orleans, 2, 1776–1792.

CARTER, R.W.G.; DEVOY, R.J.N., and SHAW, J., 1989a. Late Holocene sea levels in Ireland. *Journal of Quaternary Science*, 4, 7–24.

CARTER, R.W.G.; FORBES, D.L.; JENNINGS, S.C.; ORFORD, J.D.; SHAW, J., and TAYLOR, R.B., 1989b. Barrier and lagoon coast evolution under differing relative sea-level regimes: examples from Ireland and Nova Scotia. *Marine Geology*, 88, 221–242.

CARTER, R.W.G.; JENNINGS, S.C., and ORFORD, J.D., 1990. Headland erosion by waves. *Journal of Coastal Research*, 6, 517–529.

CARTER, R.W.G.; ORFORD, J.D.; FORBES, D.L., and TAYLOR, R.B., 1990. Morphosedimentary development of drumlin flank barriers in a zone of rapidly rising sea-level: Story Head, Nova Scotia. *Sedimentary Geology*, (in press).

CRY, G.W. and HAGGARD, W.H., 1962. North Atlantic tropical cyclone activity, 1901–1960. *Monthly Weather Review*, 90, 341–349.

DEIURE, A.M., 1983. The Effect of Storms on Sediments in Halifax Harbour. M.Sc. Dissertation. (unpubl.), Dalhousie University, Halifax, 216p.

DILLON, W.P., 1971. Submergence effects on a Rhode Island barrier and lagoon and inference on barrier migration. *Journal of Geology*, 78, 94–106.

FORBES, D.L. and DRAPEAU, G., 1989. Near-bottom currents and sediment transport over the inner Scotian Shelf; sea-floor response to winter storms during CASP. *Atmosphere-Oceans*, 27, 258–278.

FORBES, D.L.; TAYLOR, R.B., and SHAW, J., 1989. Shorelines and rising sea-levels in eastern Canada. *Episodes*, 12, 23–28.

FORBES, D.L.; TAYLOR, R.B.; SHAW, J.; ORFORD, J.D., and CARTER, R.W.G., 1990. Development and instability of barrier beaches on the Atlantic coast of Nova Scotia. *Proceedings of the Canadian Coastal Conference 1990* (Kingston, Ontario), pp. 83–98.

FORBES, D.L.; TAYLOR, R.B.; ORFORD, J.D.; CARTER, R.W.G., and SHAW, J., 1990. Gravel barrier migration and overstepping. *Marine Geology*, (in press).

GRANT, D.R., 1970. Recent coastal submergence of the Maritime provinces. *Canadian Journal of Earth Sciences*, 7, 676–689.

GRANT, D.R., 1977. Glacial style and ice limits, the Quaternary stratigraphic record and changes of land and ocean level in the Atlantic Provinces, Canada. *Geographie Physique et Quaternaire*, 31, 247–260.

HARDY, J.R., 1964. Sources of some beach shingles in England. *20th International Geographical Congress*, Paper 1651 (abs.), pp. 112–113.

NEU, H.J.A., 1982. 11-year deep-water wave climate of Canadian Atlantic waters. *Canadian Technical Report of Hydrography and Ocean Sciences*, No. 13, 41p.

ORFORD, J.D., 1987. Coastal processes: the coastal response to sea-level variation. *In*: R.J.N. DEVOY, (ed.), *Sea Surface Studies*. London: Croom Helm, pp. 415–463.

ORFORD, J.D. and CARTER, R.W.G., 1982. Crestal overtop and washover sedimentation on a fringing sandy gravel barrier coast, Carnsore Point, Southeast Ireland. *Journal of Sedimentary Petrology*, 52, 265–278.

ORFORD, J.D. and CARTER, R.W.G., 1984. Mechanisms to account for the longshore spacing of overwash throats on a coarse clastic barrier in southeast Ireland. *Marine Geology*, 56, 207–226.

QUINLAN, G. and BEAUMONT, C., 1981. A comparison of observed and theoretical post-glacial sea-levels in Atlantic Canada. *Canadian Journal of Earth Sciences*, 18, 1146–1163.

QUINLAN, G. and BEAUMONT, C., 1982. The deglaciation of Atlantic Canada as reconstructed from the postglacial relative sea-level record. *Canadian Journal of Earth Sciences*, 19, 2232–2246.

SCHWARTZ, M.L., 1967. The Bruun theory of sea-level rise as a cause of shore erosion. *Journal of Geology*, 75, 76–92.

SCOTT, D.B., 1980. Morphological changes in an estuary: a historical and stratigraphic comparison. *In*: S.B. McCANN, (ed.), *The Coastline of Canada*, Geological Survey of Canada, Paper 80-10, pp. 199–205.

SCOTT, D.B.; BOYD, D.R., and MEDIOLI, F.S., 1987. Relative sea-level changes in Atlantic Canada: observed level and sedimentological changes vs. theoretical models. *In*: D. NUMMEDAL, O.H. PILKEY, and J.D. HOWARD, (eds.), *Sea-level Fluctuations and Coastal Evolution*. Tulsa: SEPM, Special Publication. No. 41, pp. 87–96.

SHAW, J. and FORBES, D.L., 1990. Long- and short-term trends of relative sea-level in Atlantic Canada. *Proceedings of the Canadian Coastal Conference 1990* (Kingston, Ontario), pp. 291–305.

SONNICHSON, G., 1984. The Relationship of Coastal Drumlins to Barrier Beach Formation Along the Eastern Shore of Nova Scotia. B.Sc.Hons Thesis, Geology Department, Dalhousie University, Halifax, Nova Scotia.

TITUS, J.G., 1986. The causes and effects of sea-level rise. *In: Effects of Changes in Stratospheric Ozone and Global Climate*. Washington, DC: US Environmental Protection Agency, Vol. 1, pp. 219–248.

ZUSAMMENFASSUNG

Das Wanderungsverhalten von Stradwällen, die durch auflaufende Wellen bedingt sind und vorwiegend aus Schottern bestehen, infolge eines Meeresspiegelanstiegs ist ein relativ wenig untersuchter Prozeβ. Der Strandwall von Story Head an der Atlantikküste Nova Scotias ist durch auflaufende Wellen bedingt und erlebt z.Z. durch strumbedingtes Abtragen der Krone und durch Überspülen eine landwärtige Wanderung von 6 m/Jahr. Die Wanderungsgeschwindigkeiten werden für de Zeitraum zwischen 1945 und 1982 angegeben. Die landwärtige Wanderung der meerwärtigen Strandlinie des Strandwalls ist linear proportional sowohl zu der für jeweils 5 Jahre geglätteten Rate der Meeresspiegeländerungen (r = +0,91) als auch zu der jährlichen (r = +0,69), ohwohl die Wanderungsrate des landwärtigen Strandwallteils nicht signifikant mit diesen Meeresspiegelschankungsraten verknüpft ist. Dieser Unterschied in der Reaktion auf den Meeresspiegelanstieg zwischen meer- und landwärtigem Teil des Strandwalls spiegelt die Bedeutung des Faktors Sturmintesität (Häufigkeit und Stärke) wieder, der den Meeresspiegelanstieg überlagert. Der Strandwall von Story Head schwankt zwischen einer Dominanz des Aufbaus der Strandwallkrone durch auflaufende Wellen und des Abbaus der Krone durch Überspülen. Das Gleichgewicht zwischen diesen beiden Mechanismen, die die Rate der landeinwärtigen Strandwallwanderung bestimmt, hängt sowohl von der Sturmintesität als auch von der Geschwindigkeit des Meeresspiegelanstiegs ab.—*Helmut Brückner, Geographisches Institut, Universität Düsseldorf, F.R.G.*

RESUMEN

La respuesta migratoria de las barreras litorales de gravas alineadas con la rompiente, ante el ascenso del nivel medio del mar, es un proceso poco estudiado. La barrera de Story Head, en la costa Atlàntica de Nova Scotia, està alineada con la rompiente y ha experimentado en èpocas contemporàneas una migraciòn hacia tierra de 6 m/año mediante el rebase en los temporales. Se presentan las migraciones de la barrera en el periodo desde 1945 hasta 1982. La migraciòn hacia tierra de la lìnea de costa definida por el lado del mar de la barrera es linealmente proporcional a: 1) la tasa de variaciòn del nivel medio del mar, suavizada en promedios de 5 años (r = 0.91) y 2) la tasa anual de variaciòn del nivel medio del mar (r = 0.69). Sin embargo, la tasa de migraciòn del la lìnea de costa del lado de tierra no se correlaciona de una manera significativa con estas tasas de variaciòn del nivel medio del mar. esta diferencia de respuesta ante entre las migraciones de la parte frontal y posterior de la barrera ante las variaciones del nivel medio del mar refleja el papel que representa la intensidad de los temporales (frecuencia y magnitud) superpuesto al ascenso del nivel del mar. La barrera de Story Head oscila entre el dominio de la construcciòn de la barrera mediante el ascenso y ligero rebase de la coronaciòn y la rotura de la cresta debido al flujo de rebase en temporales. El balance entre estos dos mecanismos que controlan la velocidad de migraciòn hacia tierra de la barrera, depende de la intensidad de los temporales y de la tasa de ascenso del nivel medio del mar.—*Department of Water Sciences, University of Santander, Cantabria, Spain.*