SEDIMENT BYPASSING AT MIXED ENERGY TIDAL INLETS

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ABSTRACT

Inlet sediment bypassing, through the previously recognized mechanisms of stable inlet processes and ebb-tidal delta breaching, has been documented at six mixed energy (tide-dominated) coasts around the world including the coasts of: central South Carolina, Virginia, southern New Jersey, New England, the East Friesian Islands, and the Copper River Delta in Alaska. Regardless of the mechanism, the end product of the bypassing process is the formation of a large bar complex that migrates onshore and attaches to the downdrift inlet shoreline. Thus sediment bypassing is a discontinuous process at mixed energy tidal inlets.

The morphology of the bar complexes is highly variable with widths ranging from 40-300m and lengths from 300 to over 1500m. Generally, the size of the bar complexes increases as inlet size increases and as the rate of longshore sediment transport increases. The frequency of bar welding events at mixed energy inlets varies from 3-7 years. The location where the bars attach to the downdrift beach and length of shoreline that is affected by the bar welding process is dependent on inlet size, orientation of the main ebb channel and wave versus tide dominance of the shoreline.

INTRODUCTION

Tidal inlets represent an interruption in the longshore sediment transport system. The manner in which inlets bypass sand on their ebb-tidal shoals controls the rate and location of sand nourishment to the downdrift barrier island. This paper will discuss how sediment moves past non-structured tidal inlets and the factors that influence this process along mixed energy (tide-dominated) depositional shorelines (Hayes, 1979; Nummedal and Fischer, 1978). Mixed energy coasts, as Hayes (1979) has described, are characterized by short stubby barrier islands, numerous tidal inlets with well developed ebb-tidal deltas, and a marsh and tidal creek system that separates the barriers from the mainland. The central South Carolina coast (Fig. 1) which has a 1.5m mean tidal range and 0.6m average wave height, is an example of such a coast. Other mixed energy (tide-dominated) shorelines that will be discussed in this paper are listed in Table 1. The wave and tidal energies of these coastlines are shown graphically in Figure 2.

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Figure 1. Mixed energy (tide-dominated) coast of central South Carolina coast showing Dewees Island in the foreground and Bull Island in the background.

Table 1. Mixed Energy (tide-dominated) Shorelines

1.	Central South Carolina Coast	FitzGerald et al, 1978; Nummedal et al, 1977; Hubbard et al, 1979
2.	Georgia Coast	Oertel, 1975; 1977; Oertel and Howard, 1972
3.	New Jersey and Virginia Coasts	Halsey, 1979; Rice et al, 1976; FitzGerald, 1981, 1982
4.	New England Coast	Hine, 1975; Hubbard, 1975; Magee and FitzGerald, 1980; FitzGerald and Fink, 1981
5.	Gulf of Alaska Coast	Hayes et al, 1976
6.	German Friesian Island Coast	Luck, 1976; Nummedal and Penland, 1981; FitzGerald et al, 1982
7.	Netherland Friesian Island Coast	Bruun and Gerritsen, 1959; Bruun, 1966

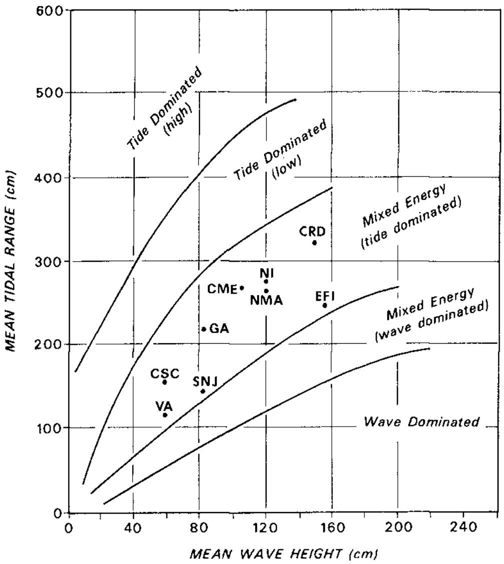


Figure 2. Coastal classification (after Hayes, 1979; Nummedal and Fischer, 1978). Mixed energy (tide-dominated) inlet shorelines where bar complexes weld to beach include: CRD - Copper River Delta, Alaska; EFI - East Friesian Islands, West Germany; NI - New Inlet, Massachusetts; NMA - northern Massachusetts, CME - central Maine; GA - Georgia (note that bar complexes do weld to these inlet shorelines as they do in other mixed energy coasts); CSC - central South Carolina; SNJ - southern New Jersey; VA - Virginia.

INLET SEDIMENT BYPASSING

Inlet sediment bypassing is defined as a process whereby sand is transported from the updrift side of the tidal inlet shoreline to the downdrift side. In a pioneering paper by Bruun and Gerritsen (1959) they described three methods by which sand moves past tidal inlets: 1) through wave induced sand transport along the periphery of the ebb delta (terminal lobe), 2) through the transport of sand in channels by tidal currents, and 3) by the migration of tidal channels and sand bars. They also showed that the type of bypassing process that occurs at an inlet could be determined using the following expression:

$$r = M_{mean}/Q_{max} \qquad (1)$$

where: (r) equals the ratio between the longshore sediment transport rate (M_{mean} in cubic yards per year) and the maximum discharge at the inlet under spring tidal conditions (Q_{max} in cubic yards per second). Inlets with high ratios (r>200-300) bypass sand by wave action along the terminal lobe and inlets with low values (r<10-20) bypass sand by the other two methods.

FitzGerald et al (1978) in a study of central South Carolina tidal inlet processes found that sediment bypassing occurs by the migration of tidal channels and/or sand bars (method #3). They presented two models which detailed the mechanics of sand bypassing at non-migrating inlets: bypassing by stable inlet processes and by ebb-tidal delta breaching (Fig. 3). The r values for these inlets range between 50 and 150 and thus it would seem that Bruun and Gerritsen's (1959) third method of inlet sediment bypassing may not be characteristic of tide-dominated inlets but rather a process that occurs at mixed energy inlets. In later papers by FitzGerald and Hayes (1980) and FitzGerald (1982) the models depicted in Figure 3 were shown to be applicable to other mixed energy tidal inlets (Table 1).

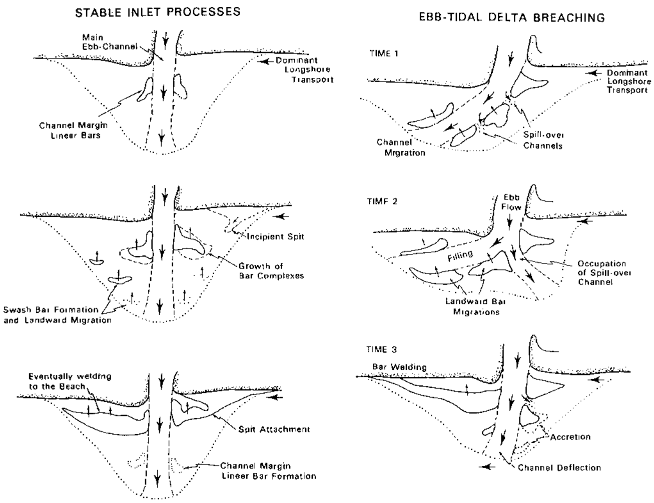


Figure 3. Models for inlet sediment bypassing at mixed energy (tide-dominated) coasts (from FitzGerald et al, 1978). Note that large bar complexes migrate onshore along the downdrift inlet shoreline in both cases.

Stable Inlet Processes

Stable inlets are defined as having a stable inlet throat (non-migrating) and a stable main ebb channel position through the ebb-tidal delta (Fig. 3). The pattern of sand circulation at mixed energy inlets has been described by a number of researchers including Oertel (1972), Hine (1975), FitzGerald et al (1976), Davis and Fox (1980) and Nummedal and Penland (1981).

The bypassing of sand at these inlets occurs through the formation, landward migration and attachment of large bar complexes to the downdrift inlet shoreline. The development of the bar complexes results from the stacking and coalescing of swash bars on the ebb tidal delta platform. Swash bars are wave built accumulations of sand (Hine, 1975) that form in the distal portion of the ebb delta from sand that is transported seaward in the main ebb channel. The swash bars move onshore due to the dominance of landward flow over the swash platform. As illustrated in Figure 4 waves breaking across the terminal lobe create bores of water that retard the ebb-tidal currents but that enhance the flood-tidal currents. Thus, there exists a net landward transport of sand on both sides of the main ebb channel. The net movement of sand onshore has also been attributed to increased wave suspension during the flood cycle than during the ebb cycle (Oertel, 1972; Hubbard et al, 1977; FitzGerald and Levin, 1981).

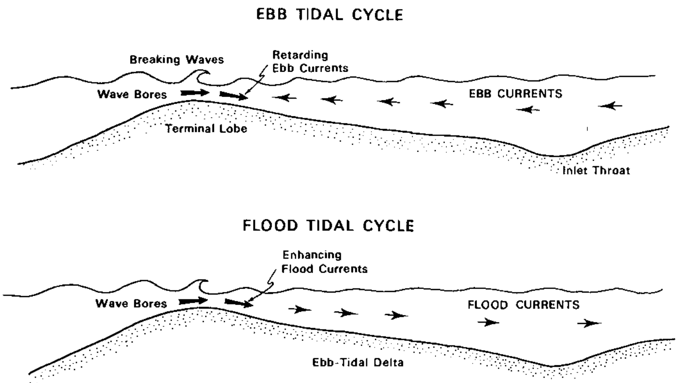


Figure 4. Wave swash model. Wave bores retard ebb tidal currents on the swash platform while they enhance the flood tidal currents. Net landward sediment transport results on both sides of the main ebb channel.

The stacking and coalescing of swash bars results from a decrease in the rate of their onshore migration. As swash bars migrate up the shoreface they gain a greater and greater intertidal exposure and thus wave swash, which causes their onshore movement, operates over an increasingly shorter period of the tidal cycle (Fig. 5). This developmental process is exemplified in the sequential sketches made of Price Inlet, South Carolina from aerial photographs taken between

1973 and 1977 (Fig 6). A photograph taken of the bar complex welding to the downdrift shoreline at Price Inlet in 1977 is shown in Figure 7.

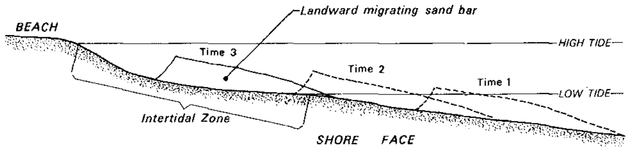


Figure 5. Model of bar migration up the shoreface. Note that the bar attains a greater intertidal exposure as it moves closer to shore. This will cause an increasingly shorter period of the tidal cycle in which wave swash operates. Thus onshore bar migration slows with time resulting in a stacking of swash bars.

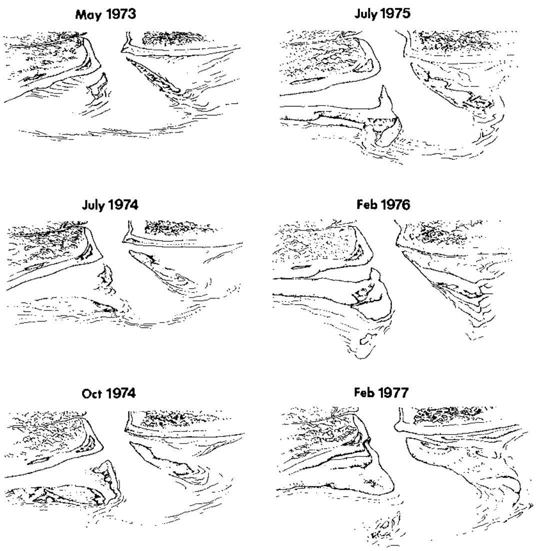


Figure 6. Sequential sketches of Price Inlet, South Carolina, drawn from aerial photographs. Note the bar complex development and its onshore migration.

Figure 7. Oblique aerial photograph of Price Inlet, South Carolina showing a bar welding event. Downdrift shoreline is in the foreground.

Ebb-Tidal Delta Breaching

Inlets that bypass sand through ebb-tidal delta breaching have stable inlet throat positions but their main ebb channels migrate (Fig. 3). The dominant direction of longshore sediment causes preferential deposition on the updrift side of the ebb-tidal delta. This results in a downdrift migration of the main ebb channel such that it will tend to parallel the downdrift inlet shoreline (Bruun and Gerritsen, 1959). This channel configuration produces a circuitous pathway for tidal exchange between the ocean and backbarrier area. Consequently, ebb flow in the main channel will breach a new channel through the ebb delta. This process may occur gradually during a six to twelve month period or it may happen catastropically during a single storm when tidal currents are stronger. A 1963 vertical aerial photograph of Breaches Inlet, South Carolina (Fig. 8) shows the breaching process in a stage of near completion. The old channel position is being abandoned.

Once the breaching process is completed, most of the water entering and leaving the inlet flows through the new channel. Because of the smaller volume of flow in the abandoned channel, scour by tidal currents decreases and the channel is gradually filled with sediment. The processes that cause this infilling include ebb and flood-tidal currents, wave induced sediment transport on the swash platform and finally the landward migration of swash bars.

Ebb-tidal delta breaching results in the bypassing of a large proportion of the ebb delta sand. Some of this sand fills the abandoned channel while the rest forms a large bar complex similar to the bar complex described in the stable inlet processes section. These bars migrate onshore and attach to the landward beach. An example of a large bar complex that formed after delta breaching at Breaches Inlet, South Carolina is shown in Figure 9.

Figure 8. Vertical aerial photograph of Breaches Inlet, South Carolina showing that a new channel has recently been breached through the ebb-tidal delta. The abandoned channel is being filled with sediment at this time.

Figure 9. Oblique aerial photograph of the downdrift shoreline of Breaches Inlet, South Carolina. The large bar that has partially attached to the Isle of Palms formed after the ebb-tidal delta had been breached.

BAR MORPHOLOGY AND BEHAVIOR

Along mixed energy (tide-dominated) coastlines (Table 1) regardless of how sand bypasses the inlet, whether it be through stable inlet processes or ebb-tidal delta breaching, the end product is the formation of a large bar complex. These bars have been recognized and measured at many tidal inlets too numerous to mention. They are normally aligned parallel to shore and are cuspate in shape. Their lengths and widths are highly variable but an average range would be: length = 300-1500m and width = 40-300m. They are fronted by a .5 to 1.5m high slipface. Bar complexes associated with inlet sediment passing should not be confused with ridge and runnel systems that have been described by Hayes and Boothroyd (1969) and Davis and Fox (1972). They are normally much larger features and add a much greater volume of sand when they weld to the beach than do ridge and runnel systems.

As the bars migrate onshore they gain a larger and larger intertidal exposure. This is due to a combination of the bar's moving up the shore face and the continued welding of swash bars to its seaward side. The rate of landward migration of bar complexes is dependent on tidal range, wave energy and height of the bar with respect to mean low water. Bar migration rates have been measured at Price Inlet, South Carolina to be 110m/yr (FitzGerald, 1976) while in the East Friesian Islands, West Germany they migrate over 400m/yr (Nummedal and Penland, 1981). The greater migration rate in the Friesian Islands compared to that of Price Inlet is due to greater wave energy along the German coast (Fig. 2). Larger waves produce stronger wave swash and thus, a greater onshore sediment transport rate. Tidal range affects bar migration rates by controlling the period of time in which wave swash will be an active process.

When the bar welds to the intertidal beach its cuspate nature usually results in a small ponded water region being formed in front of the bar. The rate of migration of the bar up the beach is slow and highly dependent on the high tide level and wave energy. Migration is the greatest when spring tides coincide with large wave heights. The rate of migration also increases during moderate storms. During these events, although some of the lower bar sands may be eroded and move along shore or offshore, the large waves and storm surge cause increased wave swash and higher portions of the beach to be affected by this process. The final welding of the bar to the beach above mean high water occurs during a large spring tide with high wave activity. It could also happen during a storm.

OCCURRENCE OF BAR COMPLEXES

Remarkably similar shoreline morphologies found among mixed energy (tide-dominated) coasts throughout the world (Table 1), which presumeably is the result of similar ratios between wave and tidal energies (Fig. 2), would suggest that inlets along these shorelines should exhibit similar sand bypassing mechanisms. One indication that this is true is the documentation of landward migrating bar complexes along most of these coastlines. Examples from five regions around the world will be used to corroborate this.

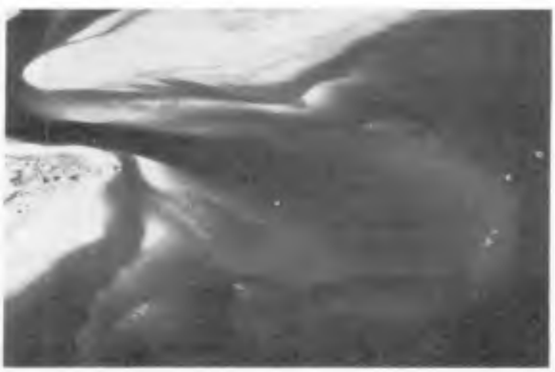
It has already been demonstrated that inlet sediment bypassing at central South Carolina inlets occurs through the attachment of large bar complexes to the downdrift beaches (Figs. 7 and 9) and therefore, further evidence will not be supplied. However, for a more detailed discussion of sand bypassing along this coast consult FitzGerald et al (1978) and Sexton and Hayes (1982).

On the New England coast, mixed energy barrier systems exist along parts of Cape Cod, Massachusetts, along a 30km stretch of shoreline between Boars Head, New Hampshire and Cape Ann, Massachusetts, and along sections of the central and southern coast of Maine. For the barriers north of Cape Ann northeast storms cause a net southerly longshore transport direction along the coast. Inlets of this region bypass sand by ebb-tidal delta breaching (Parker River Inlet, Fig. 10) and through stable inlet processes (Essex River Inlet, Fig. 11). In Figure 11A note that a bar has recently welded to the high beach and that another bar is developing on the swash platform. Nauset Inlet located on outer Cape Cod transfers sand to the south by both bypassing processes (Fig. 12).

Figure 10. Oblique aerial photograph of Parker River Inlet, Massachusetts. Note that the main ebb channel abuts the downdrift beach and that the bulge in the downdrift shoreline coincides with bar welding.

Along the central Maine coast most of the beaches occur in pockets between protective headlands or they are found at mouths of major river systems. The sand comprising the barriers in the latter setting are believed to have been derived from sediment that was discharging out of the rivers during deglaciation. The sand circulation pattern at one of these localities is illustrated in a diagram of the Popham Beach-Kennebec River system (Fig. 13). FitzGerald and Fink (1981) have described the exchange of sand between the beach and river as follows. Sand is transported seaward in the channel between Wood and Pond Islands by dominant ebb-tidal currents. It is deposited in the shallow water region between the

a



b

Figure 11a. 1978 Vertical aerial photograph of Essex River Inlet, Massachusetts.

11b. Oblique photograph showing bar development in 1980.

Figure 12. 1978 Oblique aerial photograph of Nauset Inlet, Massachusetts.

6 and 12 foot contours. Wave attack coming from a southeasterly direction drives the accumulating sand in an onshore direction toward Fox Island. Swash bars stack at this location, forming a large landward migrating bar complex over 1.5km in length. A bar complex welds to Popham Beach at a frequency of about once every five to seven years. An example of one of these bars is shown in Figure 14. As the bar migrates onshore it extends toward the Kennebec River and thus when it attaches to the shore a large portion of Popham Beach is affected. The sediment gyre is completed by flood and wave-generated currents that transport sand east along the beach and into the Kennebec River channel.

Along the southern New Jersey coast the transfer of sediment past inlets has been reported by Halsey et al (1981) and FitzGerald (1981; 1982). The dominant direction of longshore sediment transport on this coast is to the south. The updrift inlet shorelines are commonly formed by southerly accreting spits. The southerly downdrift inlet shorelines are sites of deposition. At Absecon Inlet and Great Egg Inlet on the New Jersey coast the dominant mechanism for inlet sediment bypassing is through ebb-tidal delta breaching. As a consequence of this process bars measuring between 500-1500m have moved onshore to the downdrift inlet shorelines of Atlantic City Beach and Ocean City Beach, respectively (FitzGerald, 1981; 1982). Two sequential U.S. Coast and Geodetic Survey bathymetric maps of Absecon Inlet illustrate the breaching process (Fig. 15). Note the deflection of the main ebb channel in 1864 and its straight seaward course in 1881. The sand that was bypassed during the delta breaching process moved onshore and had formed a large bar that had partially attached to the Atlantic City shoreline by 1881.

Inlet sediment bypassing on the Virginia coast has been discussed by Rice et al (1976) and FitzGerald (1982). Rice and others have described the historical migration of channels and the formation

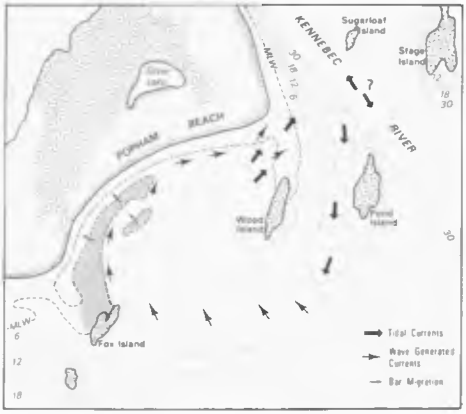


Figure 13. Sand circulation at Popham Beach, Maine (from FitzGerald and Fink, 1981). A sediment gyre is developed by: seaward transport by ebb-tidal currents, onshore transport by wave action, and northeast sand movement by flood-tidal and wave-generated currents. Bar complexes along this shore are over 1km long and weld to the beach every five to seven years.

Figure 14. Oblique aerial photograph of Popham Beach, Maine illustrating a bar welding event (photograph by Fink).

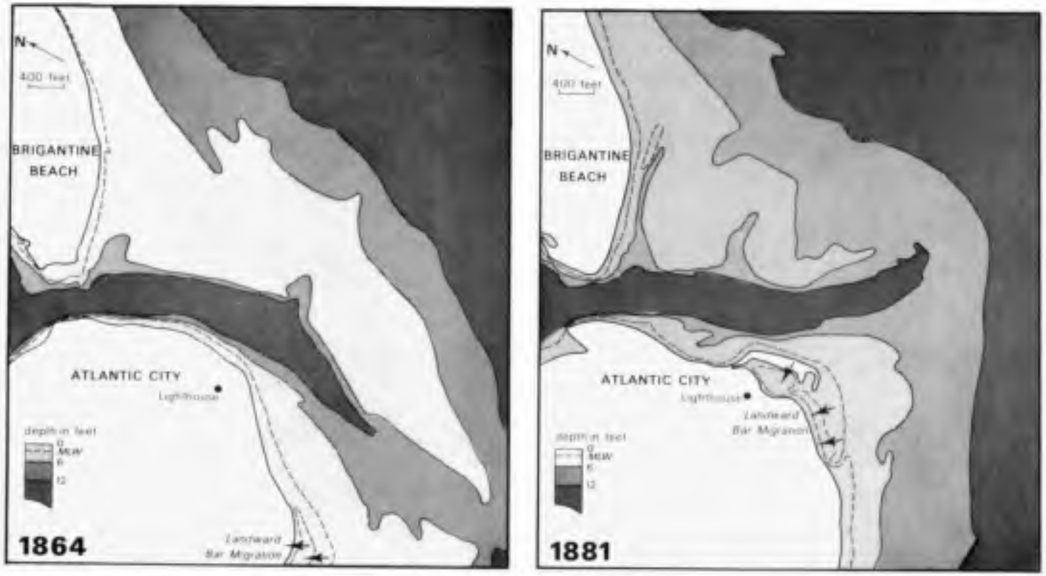


Figure 15. Bathymetric maps of Absecon Inlet, New Jersey redrawn from the 1864 U.S. Army Corps of Engineers survey and the 1881 U.S. Coast and Geodetic Survey coastal chart. The process of ebb-tidal breaching has been responsible for bar formation off northern Atlantic City Beach.

of bar complexes while FitzGerald has documented the landward migration and attachment of these bars to the downdrift inlet shoreline. Oblique aerial photographs (1971) of northern Parramore and Hog Islands illustrate different bar morphologies as they weld to the downdrift inlet shorelines of Wachapreaque and Quinby Inlets, respectively (Fig. 16).

Figure 16. Oblique aerial photographs of a. northern Parramore Island, Virginia and b. northern Hog Island, Virginia (photographs by Sue Halsey).

The East Friesian Islands are a chain of barriers located along the West German North Sea coast (Fig. 17). The pattern of inlet sediment bypassing along these islands has been studied by Nummedal and Penland (1981). Generally, sand is moving in an easterly direction along the coast due to the strong component of easterly wave energy flux. Sand bypassing occurs in the form of migrating swash bars (Nummedal and Penland, 1981). Tracks of bar movement at Norderneyer Seegat over a 31 year period of time are given in Figure 18. The tracks illustrate that bars migrate in a semi-circular pathway along the ebb delta periphery. As they move close to shore they tend to stack, forming large bar complexes which may extend along the beach up to a 1km or more. Photographs of bar complexes migrating toward the updrift barrier shorelines of Langeoog and Spiekeroog are shown in Figure 19.

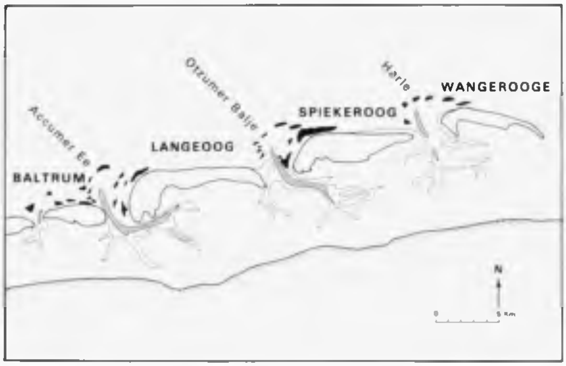


Figure 17. Map of the eastern two thirds of the Friesian Islands, West Germany. Note that the bulbous portion of these barriers coincides with the location where bars are attaching to the beach.

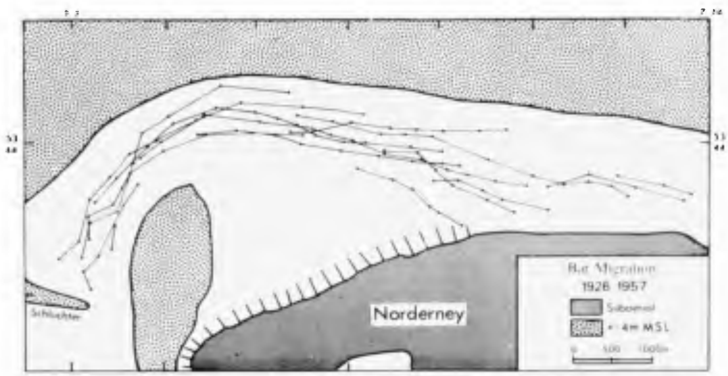


Figure 18. Map showing the pathway of easterly bar migration along the delta periphery. Each segment between adjacent dots indicates the amount of bar movement during a period of one year (from Homeier and Kramer, 1957).

a.

b.

Figure 19. Oblique aerial photographs of a. Langeoog and b. Speikeroog. These bars are over a kilometer in length.

The chain of barriers that fronts the Copper River Delta in the Gulf of Alaska is an unusual type of shoreline morphology to occur along a collision coast. Sediment discharged from the river has undoubtably been responsible for the existence of these islands. As Hayes et al (1976) have described, the barriers of this group have bulbous updrift ends (Fig. 20). They have attributed this barrier morphology to the uplift that occurred to this region in March 1964 and as a result of wave refraction around the ebb-tidal delta which produces a longshore transport reversal along the downdrift inlet shoreline. An oblique aerial of Egg Island, Alaska (Fig. 21) from Hayes et al (1976) reveals that progradation of the updrift end of the barrier may also be a product of the onshore migration of bar complexes.

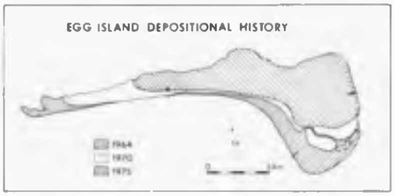


Figure 20. Depositional history of Egg Island, Alaska. The progradation of the eastern end of the island has, in part, resulted from the welding of bar complexes to the beach (from Hayes et al, 1976)

Figure 21. Oblique aerial photograph of Egg Island, Copper River Delta, Alaska. Note the bar (arrow) that is migrating onshore to the downdrift inlet shoreline. (from Hayes et al, 1976)

The Georgia coast fits well into the mixed energy (tide-dominated) coastline classification of Hayes (1979) and Nummedal and Fischer (1978) (Fig. 2). Although it has very similar coastal morphology, including inlet size and barrier island length, compared to that of the East Friesian Island coast, bar complex development does not appear to be an active process at the sounds along this coast. The reason for this is most likely related to the large tidal prisms (10^9-$10^{10}m^3$, Jarrett, 1976) and small wave energies (wave height = 80 cm, Thompson, 1977) of the Georgia coast. The large ebb tidal deltas associated with these sounds extend 6-8km offshore where the depth is 5-6m. The low gradient slope (1:1200) created by the ebb deltas results in a gradual attenuation of the wave energy over the swash platform. Consequently, the formation of swash bars and their subsequent landward migration is not a large scale process on the ebb deltas. Oertel (1977) has shown that most of the transfer of sand from delta to the beach occurs very close to the inlet (200m) and affects a very small section of shoreline compared to the size of the inlet (width 1.5-6km) and the ebb tidal deltas. The presence of large landward migrating bar complexes along the East Friesian Island coast undoubtably is due to much greater wave energy of this shoreline compared to that of the Georgia coast.

LOCATION OF BAR WELDING

In the previous section it was shown that inlet sediment bypassing along mixed energy (tide-dominated) coasts occurs through the attachment of bar complexes to the downdrift inlet shoreline. From the time of bar's formation to the time that they weld to the beach can take anywhere from 3 to 7 years. The position where the bars come onshore has particularly important influence on the erosional-depositional patterns along the barrier island. A case has been made by FitzGerald et al (1982) that the location of bar attachment can significantly influence barrier island morphology. Notice in Figure 17 of the East Friesian Islands and Figure 20 of Egg Island that the bulbous portion of the barrier coincides with the site where bar complexes weld to the beach.

The location where the bar complexes move onshore and the length of barrier island shoreline that will be directly affected by the process is controlled by: 1) inlet size, 2) wave versus tide dominance, and 3) channel orientation (Fig. 22). There exists a fairly good correlation between inlet size and the size of the bar complexes that form on the ebb delta. Generally, larger inlets have larger bar complexes. The size of the bar complexes that are formed during the bypassing process is also strongly influenced by the net long shore sediment transport rate. The greater the rate of sand movement along the coast the greater is the volume of sand that must bypass the inlet. This would suggest that inlets that occur along coasts with high longshore sediment transport rates should have relatively large bar complexes. In support of this contention are the bar complexes that are found along the East Friesian Islands. Here the longshore transport rate is about 270,000m^3/yr and the bar complexes are over a kilometer in length (FitzGerald et al, 1982).

The dominance of wave action versus tidal currents at an inlet has been shown by Bruun and Gerritsen (1959) and Hubbard (1977) to control the manner in which sand bypasses the inlet. At wave dominated inlets sand is continuously transferred around the inlet by wave action on subtidal or intertidal bars (Fig. 22). At tide dominated inlets sand is bypassed in packets in the form of bar complexes welding to the beach.

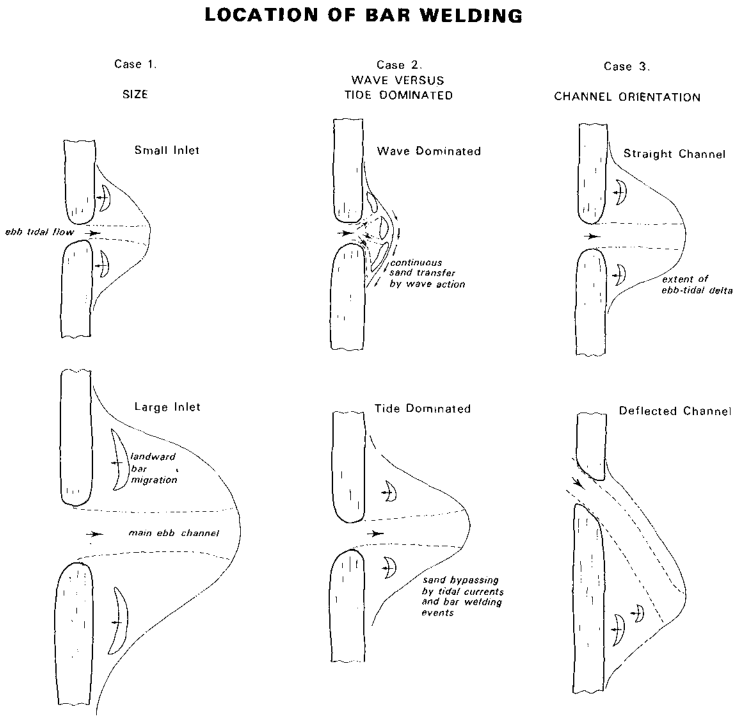


Figure 22. Model of the factors affecting the type of inlet sediment bypassing and where the bar complexes weld to the downdrift shoreline.

The orientation of the main ebb channel controls the distance away from the inlet that bar complexes attach to the shoreline (Fig. 22). If the channel has a straight seaward pathway out of the inlet then the bar complexes will attach to the beach relatively close to the inlet. A deflected channel position, downdrift deflection is most common, will result in bar complexes welding to the beach some distance away from the inlet. The deflected position of the main channel can be caused by preferential addition of sand to one side of the ebb-tidal delta or it may result from backbarrier tidal creeks approaching the inlet mouth at an angle. Prior to being jettied, Murrells Inlet on the South Carolina coast had a deflected main ebb channel due to both of these factors (Fig. 23). Parker River Inlet in Massachusetts (Fig. 10) is another example of an inlet that has a deflected main ebb channel. At this inlet the dominant southerly longshore transport direction combined with northerly approach of the Parker River produce a main ebb channel that hugs the downdrift barrier. Along the downdrift barrier there is a distinct bulge in the shoreline where bar complexes weld to the beach.

Figure 23. Oblique aerial photograph of Murrels Inlet, South Carolina. Inlet sediment bypassing at this inlet occurred through ebb-tidal delta breaching prior to being jettied.

CONCLUSIONS

1. Two mechanisms, referred to as stable inlet processes and ebb-tidal delta breaching, account for most of the sand bypassing that occurs at mixed energy (tide-dominated) tidal inlets. These processes result in the formation of large bar complexes that migrate landward and attach to the beach. This means that along mixed energy (tide-dominated) coasts sand is not continuously transferred past inlets but rather it is added to the downdrift shoreline in discrete packets. This mode of inlet sediment bypassing comprises a separate class in Bruun and Gerritsen's (1959) scheme of sand bypassing with "r" values between their wave-dominate (r>200-300) and tide-dominated (r<20-30) classes.

2. Bar complexes are much larger features than the ridge and runnel systems of a constructional beach. Their morphology is highly variable with widths ranging from 40 to 300m and lengths from 300 to over 1500m. The size of the bar complexes appears to increase with increasing inlet size and volume of sand that is bypassing the inlet. An exception to this trend is the Georgia coast.

3. The location where the bar complexes move onshore and the length of coastline that experiences progradation directly from this bar welding process is dependent on: 1) inlet size, 2) wave versus tide dominance of the inlet and 3) orientation of the main ebb channel. The last factor is controlled by the configuration of the backbarrier tidal channels, dominant longshore sediment transport rate and direction, and bank stability of the main ebb channel.

ACKNOWLEDGEMENTS

The author's understanding of tidal inlet processes has benefitted greatly from discussions with Miles Hayes, Dag Nummedal, Dennis Hubbard and Shea Penland as well as from the pioneering work of Dr. Per Bruun. Drafting in this paper was done by Eliza McClennan, University Cartographer, Boston University Cartographic Services Laboratory. Some of the photographs and diagrams were supplied by Miles Hayes, Dag Nummedal, Sue Halsey and Ken Fink.

REFERENCES

Bruun, P., 1966, Tidal Inlets and Littoral Drift: v. 2, Universitelsforlaget, Oslo, 193 p.

Bruun, P., and Gerritsen, F., 1959, Natural bypassing of sand at coastal inlets: Jour. of the Waterways and Harbors Div., Amer. Assoc. of Civ. Eng., v. 85, p. 75-107.

Davis, R.A., and Fox, W.T.,1972, Coastal processes and nearshore sand bars: Jour. of Sed. Pet., v. 42, p. 401-412.

Davis, R.A., and Fox, W.T., 1980, Interaction between wave and tide generated processes at the mouth of a mesotidal estuary: Matanzas River, Florida: Marine Geol., v. 40. p. 49-68.

FitzGerald, D.M., 1976, Ebb-tidal delta of Price Inlet, South Carolina: geomorphology, physical processes and associated inlet shoreline changes: In: Terrigenous Clastic Depositional Environments (Hayes and Kana, eds.), Tech. Rpt. No II-CRD, Geology Dept., Univ. of South Carolina, Columbia, S.C., p. 158-171.

FitzGerald, 1981, Patterns of shoreline changes along Atlantic City Beach caused by Absecon Inlet processes: Tech. Rpt. No. 6, Coastal Environmental Research Group, Dept. of Geology, Boston University, Boston, MA. 60 p.

FitzGerald, D.M., 1982, Depositional processes along Ocean City Beach, New Jersey: Tech. Rpt. No. 7, Coastal Environmental Research Group, Dept of Geology, Boston University, Boston, MA, 53 p.

FitzGerald, D.M., and Fink, Jr., L.K., 1981, Sedimentation processes along Popham Beach, ME: 1981 SEPM Northeast Fieldtrip Guidebook, ed. by B. Timson (in press), p. 27.

FitzGerald, D.M., and Hayes, M.O., 1980, Tidal inlet effects on Barrier Island management: Proc. Coastal Zone 1980, American Soc. of Civil Engineers, p. 2355-2379.

_____, Hubbard, D.K., and Nummedal, D., 1978, Shoreline changes associated with tidal inlets along the South Carolina coast: Proc. Coastal Zone 1978, American Society of Civil Engineers, p. 1973-1994.

_____., and Levin, D., 1981, Hydraulics, morphology and sediment transport patterns at Pamet River Inlet: Truro, Massachusetts: Northeast Geol., v. 3, p. 216-224.

_____, Nummedal, D., and Kana, T., 1976, Sand circulation patterns at Price Inlet, South Carolina: Amer. Soc. of Civil Eng., Proc. 15th Coastal Eng. Conf., p. 1868-1880.

_____, Penland, S., and Nummedal, 1982, Tidal inlet control of East Friesian Island morphology: International Assoc. of Sedimentologist Conf., Abs. with Prog., Hamilton, Ontario, p. 163.

Halsey, S.D., 1979, Nexus: New model of Barrier Island development: In: Leatherman, S.P., ed., Barrier Islands: From the Gulf of St. Lawrence to the Gulf of Mexico: New York, Academic Press, p. 185-210.

Halsey, S.D., Ashley, G.M., and Farrell, S.C., 1981, Post-beach nourishment sediment dispersal patterns: Northern Long Beach Island, NS: Northeast section of Geol. Soc. of Amer., Abs. with Programs. v. 13, p. 136.

Hayes, M.O., 1979, Barrier island morphology as a function of tidal and wave regime: In Leatherman, S.P., ed., Barrier Islands: From the Gulf of St. Lawrence to the Gulf of Mexico: New York, Academic Press, p. 1-28.

Hayes, M.O., and Boothroyd, J.C., 1969, Storms as modifying agents in the coastal environment, In: Coastal Environments: NE Massachusetts, Hayes, M.O., ed., p. 290-315.

Hayes, M.O., Ruby, C.H., Stephen, M.F., and Wilson, S.J., 1976, Geomorphology of the Southern Coast of Alaska, Amer. Soc. of Civil Eng., Proc. 15th Coastal Eng. Conf., p. 1992-2008.

Hine., A.C., 1975, Bedform distribution and migration patterns on tidal deltas in Chatham Harbor Estuary, Cape Cod, Massachusetts: In Cronin, L.E., e., Estuarine Research: Academic Press, New York, v. 2, p. 235-252.

Homeier, H., and Kramer, J., 1957, Verlagerung der Platen im Riffbogen von Norderney und ihre Anlandung on den Strand, Uber, Forschungstelle Norderney, vol. 8, p. 37-60.

Hubbard, D.K., 1975, Morphology and Hydrodynamics of the Merrimack River Ebb-Tidal Delta, L.E., ed, Proc. 2nd International Estuarine Res. Fed. Conf., Myrtle Beach, SC, p. 253-266.

Hubbard, D.K., Barwis, J.H., and Nummedal, D., 1977, Sediment transport in four South Carolina inlets: Proc. Coastal Sediments 1977, American Society of Civil Engineers, p. 582-601.

Hubbard, D.K., Oertel, C., and Nummedal, D., 1979, Development of tidal inlet sand bodies: Jour. of Sed. Petrol., v. 49, no 4, p. 1073-1092.

Jarrett, J.T., 1976, Tidal prism-inlet area relationships. General Investigations of Tidal Inlets. Rep. no. 3., Coastal Eng. Research Center, Ft. Belvoir, VA, 32 pp.

Luck, C., 1976, Inlet changes of the East Friesian Islands, Amer. Soc., of Civil Eng., Proc. 15th Coastal Eng. Conf., p. 1938-1957.

Magee. A.D., and FitzGerald. D.M., 1980, Investigation of shoaling problems at Westport River Inlet and sedimentation processes at Horseneck and East Horseneck Beaches, Tech. Rpt. No. 3, Coastal Environmental Research Croup, Dept. of Geology, Boston University, Boston, MA. 118 p.

Nummedal, D., and Fischer, I.A., 1978, Process-response models for depositional shorelines: the German and the Georgia Bights. Proc. 16th Coastal Eng. Conf., Amer. Soc. of Civil Eng., p. 1215-1231.

Nummedal, Oertel, G.F., Hubbard, D.K., and Hine A.C., III, 1977, Tidal inlet variability--- Cape Hatteras to Cape Canaveral: Coastal Sediments 1977, American Society of Civil Engineers, p. 543-562.

Nummedal, D., and Penland, S., 1981, Sediment dispersal in Norderney Seegat, West Germany, Proc. of National Meeting on Holocene Marine Sedimentation in the North Sea Basin, International Assoc. of Sedimentologists Spec. Pub. 5, Texel, Netherlands, p. 187-210.

Oertel, C.F., 1972, Sediment transport of estuary entrance shoals and the formation of swash platforms: Jour. of Sed. Petrol., v. 42, p. 857-863.

Oertel, 1975, Ebb tidal deltas of Georgia estuaries: In Cronin, L.E., ed., Estuarine Research: New York, Academic Press, v. II, p. 587.

Oertel, C.F., 1977, Geomorphic cycles in ebb deltas and related patterns of shore erosion and accretion: Jour. of Sed. Petrol., v. 47, No. 3, p. 1121-1131.

Oertel, C.F., and Howard, J.D., 1972, Water Circulation and Sedimentation at Entrances on the Georgia Coast: IN: Swift, D.J.P., Duane, D.B., and Pilkey, D.H., eds, Shelf Sediment Transport: Process and Pattern, p. 411-428.

Rice, T., Niedoroda, A., and Pratt, A., 1976, Coastal processes and geology, Virginia barrier islands: in Virginia Coast Reserve Study: Ecosystem Description, The Nature Conservancy, Arlington, VA, p. 109-382.

Sexton, W.J., and Hayes, M.D., 1982, Natural Bar-Bypassing of sand at a tidal inlet, Amer. Soc. of Civil Eng., Proc. 18th Coastal Eng. Conf. (in press).

Thompson, E.F., 1977, Wave climate at selected locations along U.S. coasts: Washington, D.C., U.S. Army, Coastal Engineering Research Center, Tech. Rpt. No. 77-1, 364 p.