CHANGES DUE TO JETTIES AT TILLAMOOK BAY, OREGON

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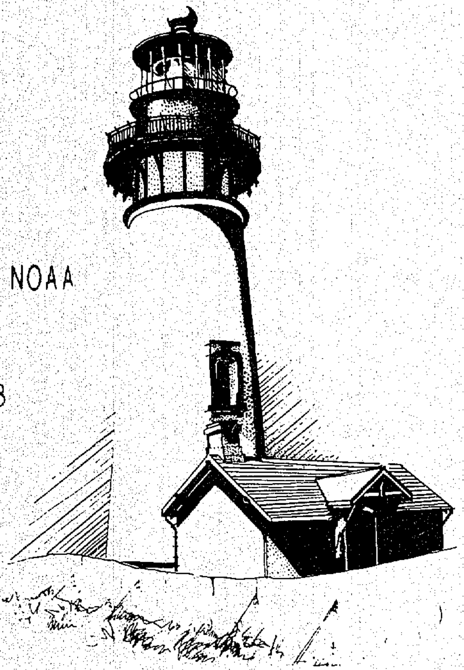

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CHAPTER 104

CHANGES DUE TO JETTIES AT TILLAMOOK BAY, OREGON

Paul D. Komar[1] and Thomas A. Terich[2]

ABSTRACT

Bayocean Spit, separating Tillamook Bay from the Pacific Ocean on the north Oregon coast, underwent severe erosion following construction of a north jetty at the bay entrance in 1914-17. This erosion ultimately led to the complete breaching of the spit in 1952. Simultaneous to the spit erosion south of the entrance, the shoreline north of the north jetty advanced seaward by some 600 m (2000 ft). This pattern of erosion and deposition following jetty construction has generally been interpreted as the jetty blocking a large north to south net littoral drift in the area, estimated by a previous study at 620,000 m^3/yr (800,000 yd^3/yr). Our reexamination of the shoreline changes and patterns of erosion and deposition following jetty construction disagrees with this interpretation, and instead we conclude that all of the changes resulted from local rearrangements of the beach due to the disrupted equilibrium following jetty construction, but at the same time maintaining an overall condition of zero net littoral drift. This interpretation is supported by other evidence that indicates a near-zero net drift on this portion of the Oregon coast. Thus severe coastal erosion can result from jetty construction even in areas of zero net littoral drift.

A new south jetty has been recently completed (1974). The result has been further realignments of the shoreline with accretion and shoreline advance immediately south of the south jetty. This provides further confirmation that a zero net littoral drift exists in the area.

This study also demonstrates the effects of building only a single jetty rather than a pair of jetties. Following construction of the north jetty, the outer bar or ebb-tide delta at the Tillamook Bay inlet grew appreciably in size. Sand deposited there came from erosion of Bayocean

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Spit further to the south. The shoal growth pushed the main channel at the entrance against the north jetty where it has remained since jetty completion. In the process, the channel became much deeper and narrower than the channel geometry prior to jetty construction.

INTRODUCTION

Bayocean Spit on the northern Oregon coast, about 80 km (50 miles) south of the Columbia River, separates Tillamook Bay from the Pacific Ocean (Figure 1). This spit has had a long history of development and

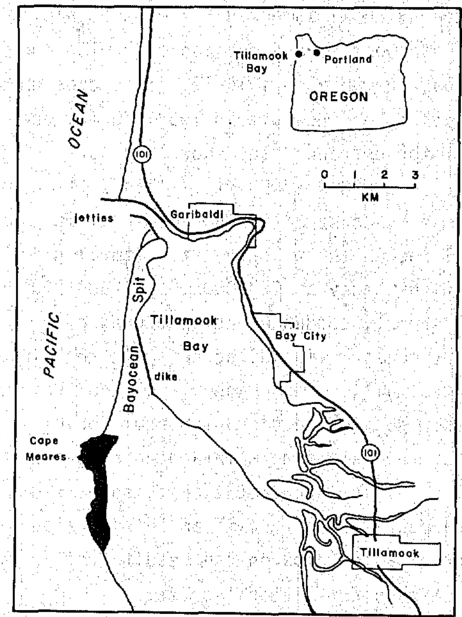

Figure 1: Tillamook Bay and Bayocean Spit.

erosion. The development and ultimate financial failure of Bayocean Park, a resort community built on the spit early in this century, has been discussed by Terich and Komar (1974). The final demise of the community resulted from erosion to the sand spit following construction of a north jetty at the Tillamook Bay entrance in 1914-17. Erosion over some thirty-five years progressively narrowed the spit, and in 1952 it was breached at its narrowest point. This breach has been subsequently repaired by the construction of a dike, and recently a new south jetty has been constructed. The purpose of the present paper is to analyze the shoreline changes that resulted from the jetty construction and led to the erosion of Bayocean Spit. This example of shoreline erosion resulting from jetty construction is unusual in that, as will be shown, this area of the Oregon coast has a zero or near-zero net littoral drift along its beaches. Thus the shoreline changes and erosion are not the more familiar case of jetties blocking a net littoral drift, causing erosion in the downdrift direction. This study also demonstrates the results of constructing only a single jetty under such conditions, rather than a pair of jetties.

LITTORAL DRIFT ON THE OREGON COAST

With the exception of the section of coast near the mouth of the Columbia River, the Oregon coast is a series of long pocket beaches separated by pronounced rocky headlands. All evidence indicates that these areas are experiencing a seasonal reversal in the sand drift along the beaches, but with a zero or near-zero net littoral drift over a several years time span. This is best demonstrated by the effects of jetty construction on patterns of shoreline erosion and accretion. The study of Komar, et al. (1976) investigated these patterns for all jetty systems on the Oregon coast with the exception of the Columbia River jetties. Our study found that following jetty construction, sand would in general accumulate adjacent to the jetties, both to the north and south, filling in the pockets formed between the jetties and the pre-jetty shorelines which curved inward at the entrances. Our study showed that the amount of deposition adjacent to the jetties depended on the sizes of the pockets formed by the jetty construction. Deposition commonly occurred both north and south of the jetty systems, and the relative amounts of shoreline accretion on opposite sides of the jetties could in no way be taken as infering a net littoral drift along the coast. Sand for this shoreline advance next to the jetties came from erosion of the coast at greater distances from the jetties.

The shoreline alterations following jetty construction continued until the shoreline became essentially straight and parallel to the prevailing wave crests, at which point zero net sand transport was again achieved and a new equilibrium reached. As will be shown in this paper, this pattern of deposition adjacent to the jetties and erosion at greater distances along the coast also explains the shoreline alterations at the Tillamook Bay entrance that led to the destruction of Bayocean Spit. The pattern of changes there, however, was complicated by the fact that only a north jetty was constructed initially, not a pair of jetties.

Deposition around jetties therefore indicates that, except near the Columbia River, the Oregon coast beaches have, as close as we can determine, a long term zero net littoral drift. This is also supported by observations that there is a seasonal reversal in the general transport directions due to the patterns of storm systems. During the summer months waves prevail from the northwest, causing a southerly sand transport along Oregon beaches. During the winter months the transport is to the north due to waves arriving mainly from the southwest. The wave data is inadequate, however, to actually carry out any calculations of littoral drift rates in an attempt to demonstrate a zero net drift.

Similar to the jetties, the rocky headlands show no indications of blockage of a net littoral drift, there being no accumulations of beach sand either to the north or south sides. What little study that has been done of heavy minerals in the beach sands also indicates that there is no bypassing of littoral sands around these headlands, which is reasonable considering their sizes and that they extend to considerable water depths. It is because of these barriers that the Oregon beaches can be described as pocket beaches of varying size. The only net littoral drift required within a pocket beach is the small amount necessary to redistribute the beach sand away from its sources to the complete stretch of beach. Previous studies (for example, Komar and Rea, 1976) have shown that sea cliff erosion is the primary source of beach sands in most areas, the river sands being trapped within the estuaries. Therefore even a net drift required for sand redistribution within the Oregon pocket beaches will be very small.

Because there is essentially a zero net drift of littoral sands on the Oregon coast beaches, the erosion of Bayocean Spit following jetty construction clearly is not another example such as the Santa Barbara, California, breakwater, or the Port of Madras, India, where the coastal erosion resulted from blockage of a large net littoral drift by jetty construction.

SHORELINE CHANGES FOLLOWING CONSTRUCTION OF A NORTH JETTY

The principal sources of information on the shoreline changes utilized in this study are: (1) surveys undertaken by the Corps of Engineers, Portland District, before and after jetty construction; (2) aerial photographs from a variety of sources; (3) field studies of old shorelines and other features that are still visible; and (4) the writers' surveys in the case of the more recent construction of the south jetty at Tillamook Bay. In addition to the shoreline changes, once erosion became appreciable on Bayocean Spit, the Corps of Engineers, Portland Dsitrict, monitored the rates of retreat of the dune bluffs and coastal property on the spit; this data has also been utilized. Since most of the shoreline changes and spit erosion occurred more than twenty-five years ago, we have had to rely primarily on historic data rather than on our own measurements. There is of course a certain amount of uncertainty in doing this.

A north jetty at the entrance to Tillamook Bay was begun in 1914 and completed in 1917. For economic reasons, an accompanying south jetty was not constructed at that time. The most apparent immediate response to the north jetty construction was a shoreline advance to the north of the jetty, documented in Figure 2. The buildout of the shoreline there nearly kept pace with the jetty extension. As in the cases of jetty construction elsewhere on the Oregon coast, and already discussed in this paper, this deposition adjacent to the north jetty occurred primarily so that the pocket formed between the jetty and the pre-jetty shoreline, which curved inward toward the bay entrance, would be filled. The shoreline built outward only until it became parallel to the prevailing wave crests, at which point long term changes ceased. The overall position of the shoreline has changed very little in the

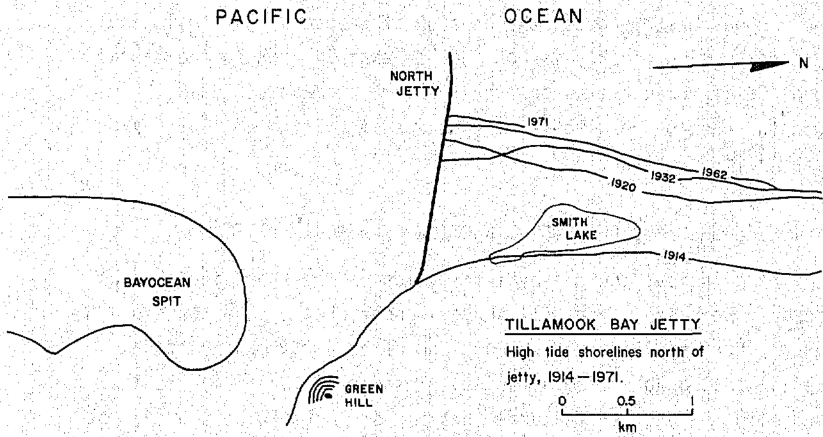

Figure 2: The shoreline advance north of the north jetty at the Tillamook Bay entrance after its completion in 1917. The 1914 shoreline gives a typical pre-jetty location.

past forty-some years, the only alterations being due to partial jetty degradation and reconstruction in the 1930's.

The sand accumulation north of the north jetty amounted to some 6,000,000 m^3 (8×10^6 yd^3). The second most apparent effect of the north jetty construction was the resulting erosion of Bayocean Spit to the immediate south. Based on this pattern of deposition to the north and erosion to the south, previous studies generally concluded that there must be an appreciable southerly net littoral drift. Based on accumulation rates north of the north jetty, this littoral drift was estimated at 600,000 m^3/yr (800,000 yd^3/yr) by the Corps of Engineers (1970), but placed at a lower estimate of 140,000 m^3/yr (180,000 yd^3/yr) by O'Brien (1930). We have already summarized the evidence that argues against such a net littoral drift on the Oregon coast. In the case of the Bayocean Spit and Tillamook Bay area, the pronounced headland Cape Meares exists to the immediate south (Figure 1). If such a large net drift did exist, this cape should also block the transport causing a buildout of the beach there to the north; there is no noticeable buildout, the beach in fact being principally gravel and cobbles, not sand as on the beach to the north fronting the spit, and the cliffs near Cape Meares are undergoing extensive erosion. As already indicated, the deposition north of the north jetty following its construction can be better interpreted as changes resulting from local rearrangements of the beach due to the disrupted equilibrium caused by the jetty's presence but at the same time maintaining an overall condition of zero net drift.

It is difficult to determine when noticeable dune and property erosion began on the spit itself following construction of the north jetty in 1914-17. O'Brien (1930) indicated that there was considerable erosion at that time just to the north of Cape Meares (Figure 1), off the spit itself. He also mentioned, however, that the spit itself had suffered little change, "although the channel has moved northward against the jetty, probably due to the decreased sand pressure from the north." This channel migration following jetty construction and the growth of the shoal outside the bay entrance will be documented later. The sand deposition at the bay entrance came from erosion of the beach along the length of Bayocean Spit. From O'Brien's comment it would appear that there may have been some beach erosion at that time but the erosion had not yet reached the dunes nor threatened any property in Bayocean Park.

O'Brien (1930) also mentioned that the north jetty had weathered down appreciably. For this reason, the north jetty was reconstructed and lengthened in 1932-33. After this reconstruction erosion on the spit became very apparent. Even while reconstruction was in progress erosion began to undermine the sidewalk fronting the natatorium of Bayocean Park, built close to the beach, and by 1936 the structure's roof had collapsed (Figure 3). Erosion of the spit was progressive, although some winters were more severe than others and caused rapid dune and property retreat. For example, during January 1939 a storm broke a small gap along the narrow southern end of the spit, washing sand and gravel into the bay. The natatorium was finally completely destroyed by this storm (Figure 3). Maximum recession of the top of the dune bluff was 7.5 m (25 ft) with an average recession of 2 m (7 ft). In addition to the loss of the natatorium, four houses were undermined and lost, nine were immediately threatened,

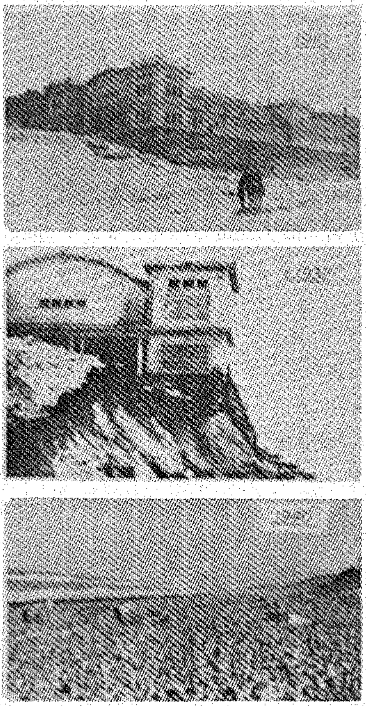

Figure 3: Progressive erosion of the natatorium on Bayocean Spit.

and six had to be moved back for safety.

Washovers of the spit occurred during subsequent winter storms until on 13 November 1952 storm waves together with high tides entirely breached the spit's narrowest southern section, initially removing a 1200 m (4000 ft) long segment of spit. This breach progressively widened, becoming nearly a mile wide at high tide. The breach developed into the natural opening for the bay, the northern entrance with the jetty beginning to shoal and close (Figure 4; 1955 survey). Waves rolled through the breach producing swells within the bay, causing some erosion to farmlands on the bay's edge. For this reason it was decided to close the breach, so in 1956 work was begun on a rubblemound dike, set back within the bay. The construction of this dike and the difficulties in closure are discussed by Brown, et al. (1958). It was anticipated that the

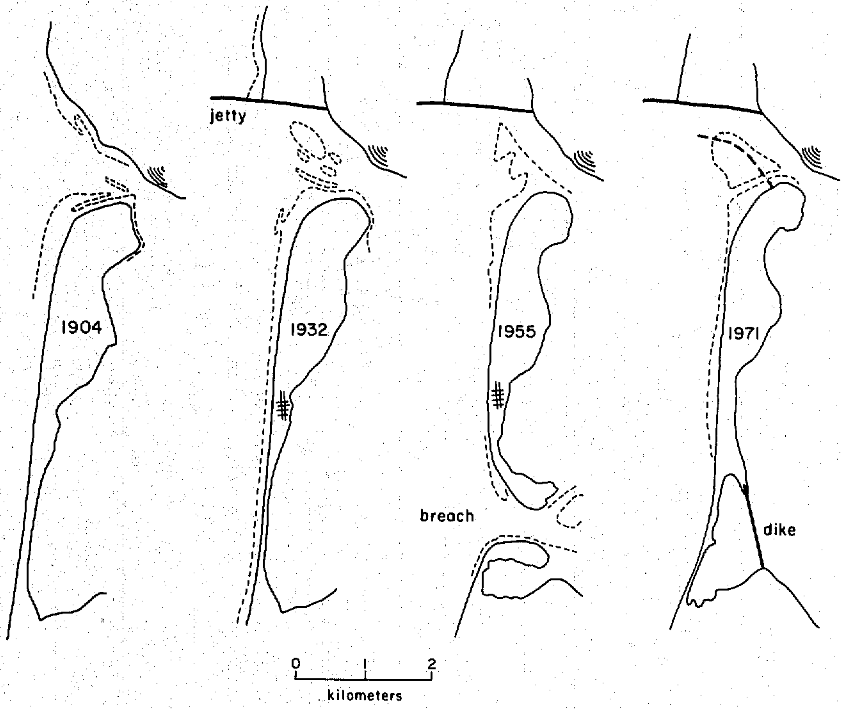

Figure 4: Progressive erosion to Bayocean Spit leading to its breaching in 1952, necessitating the placement of a dike closing the breach.

pocket in the shoreline seaward of the dike would fill and re-establish a sand beach fronting the dike, which it did as can be seen in the 1971 survey of Figure 4.

SHOAL DEVELOPMENT AND CHANNEL CHANGES AT THE BAY ENTRANCE

Although erosion occurred along most of the length of Bayocean Spit following construction of the north jetty, there was some deposition to the immediate south of the jetty (as well as to the north, as already seen). This deposition to the jetty's south at the bay entrance was in the form of a substantial growth to the outer bar or ebb-tide delta. As will be discussed later, it is estimated that some 3.3×10^6 m^3 (4.3×10^6 yd^3) of sand was added to this shoal following jetty construction.

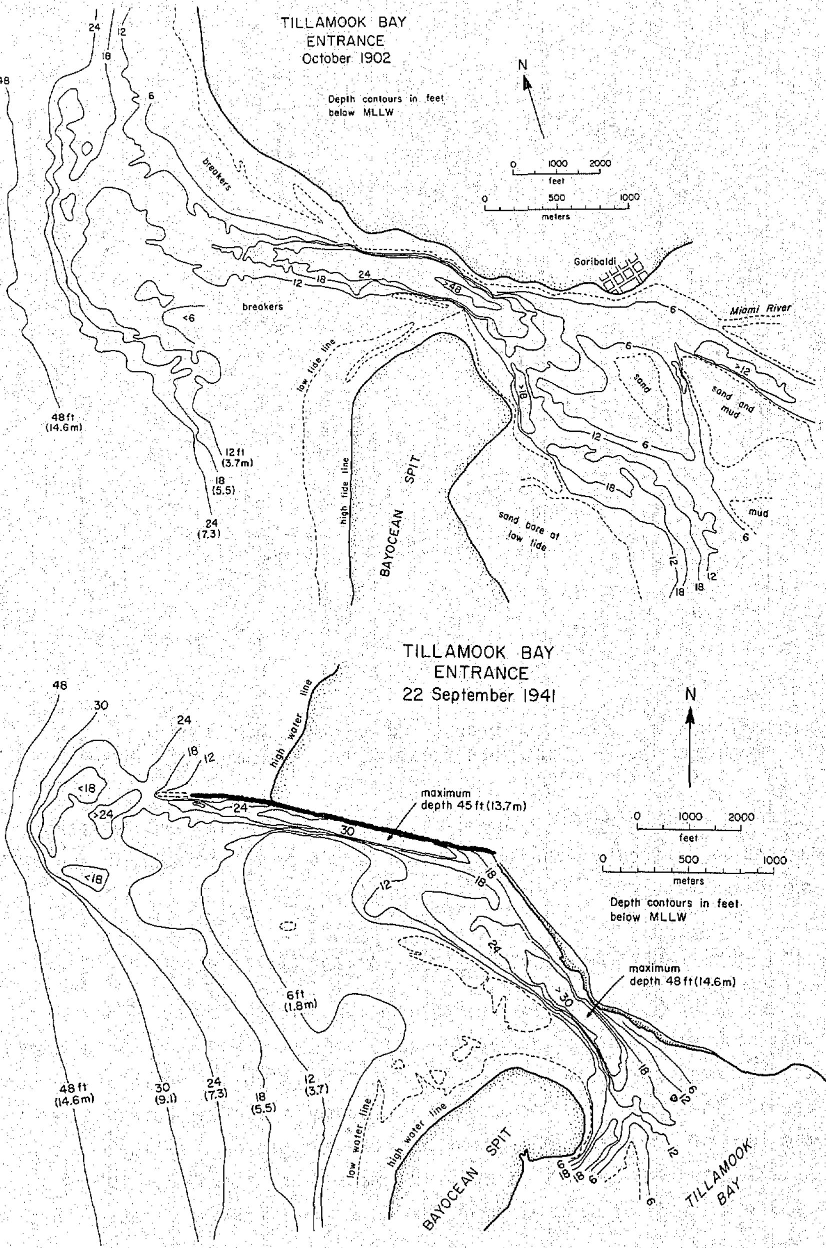

Figure 5: Tillamook Bay entrance before (upper) and after (lower) north jetty construction in 1914-17.

The changes in the shoal and bay entrance are illustrated by Figure 5, the upper survey showing the entrance prior to jetty construction and the lower being typical of the entrance after construction. It is seen that there was an increase in the overall size of the outer bar shoal and a reduction in water depths. Under moderate to high wave conditions, this shoal became entirely covered by breaking waves and surf, making it a hazard to boats using the entrance.

Figure 5 also shows that the channel leading from the bay entrance was pushed northward against the jetty by the growth of the shoal. The channels at the entrances to the Umpqua and Coquille Rivers on the Oregon coast similarly migrated until they became adjacent to the single jetties that were initially built there (Komar, et al., 1976; Kieslich and Mason, 1976). Such a response to a single jetty rather than a pair of jetties has also been shown to occur on other coasts (Kieslich and Mason, 1976).

In addition to the growth of the outer bar and migration of the main channel following construction of the north jetty at Tillamook Bay, there were changes in the geometry of the channel outside the entrance. This is shown in Figure 6 which compares channel cross-sections before (June 1914) and after (June 1920) jetty construction. It is seen that after jetty development the channel became much deeper and narrower than existed prior to construction. These changes are presumably the response of the channel to the pressure from the south by the shoal growth. However changed in depths and widths, the channels before and after jetty construction did not differ significantly in cross-sectional areas. In addition, the changes in geometry did not extend inward along the channel into the entrance itself. Figure 7 shows a number of channel cross-sections immediately north of the spit at the entrance's narrowest point, some before and some after jetty completion. There are no noticeable effects there due to the addition of the north jetty. Despite the changes in channel geometry just outside the entrance and the growth of the shoal, the entrance itself remained relatively unchanged and bore the same relationship to the tidal prism within the bay according to O'Brien's (1931, 1939) relationship.

Although this study undertook no field investigations of the currents and waves in the area of the entrance, the changes in the channel position and geometry, and the growth of the outer bar shoal can be

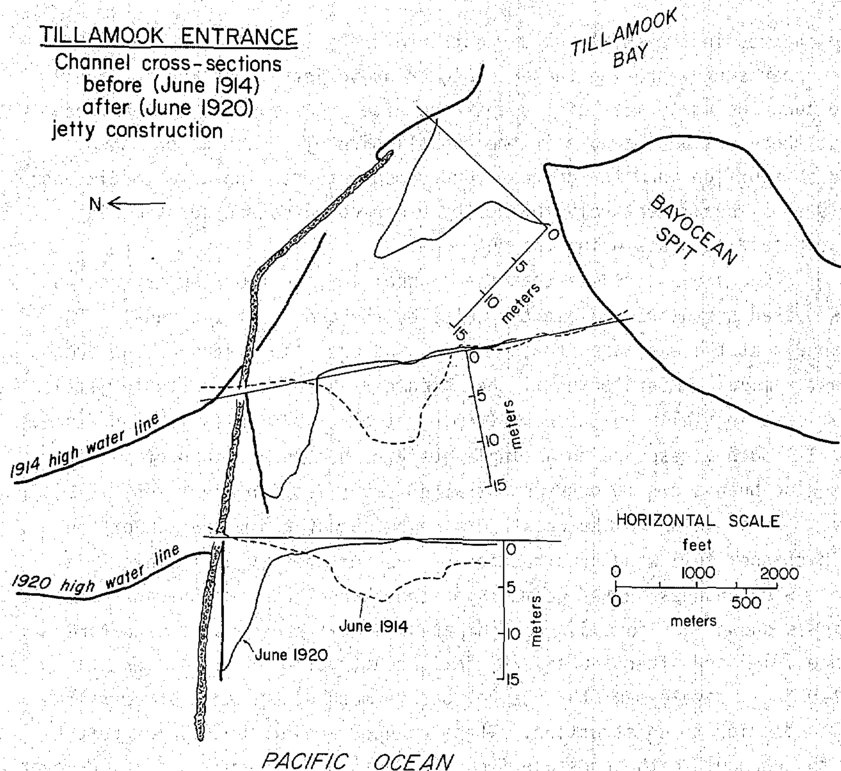

Figure 6: Deepening and narrowing of the channel following construction of a north jetty.

understood in terms of the findings of previous studies of inlets. Processes in the vicinity of inlets are complex in that they are the combined results of tidal-currents, wave action, and possible effects of salinity and thermal stratification resulting in a net inward flow at the bottom of the channel. The main ebb flow currents generally act to carry sand from the bay and nearshore areas to the offshore where it is deposited in the form of a delta, sometimes called the "ebb-tide delta." If located on a coast with a zero net littoral drift, this delta would be symmetrical and arcuate in shape. The existence of a net littoral drift would produce an asymmetry. Although the main ebb flow is directed offshore, currents move inward toward the entrance in the nearshore, from both sides of the inlet. Two eddies or gyres may develop on flanks of the main ebb channel emanating from the inlet; one gyre would be a clockwise flow, the other

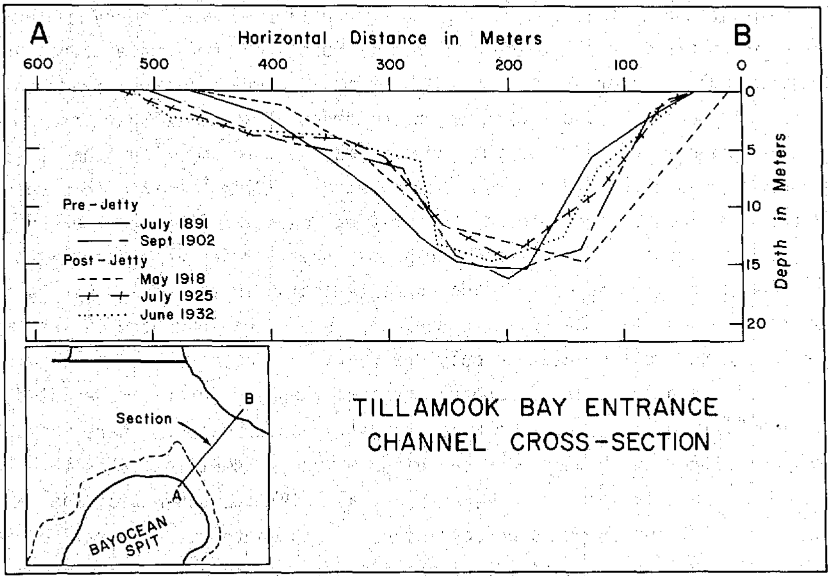

Figure 7: Cross-sections of the Tillamook Bay entrance before and after construction of the north jetty.

counter-clockwise, but both would produce currents directed toward the inlet on their shoreward sides. Lynch-Blosse and Kumar (1976) subscribe to such gyres being important at inlets, and discuss modifications where longshore currents are superimposed due to a general oblique wave approach to the coast. Dean and Walton (1975) point out that the ebb current can be viewed as a jet directed seaward, the high velocities in the central current of the jet transferring momentum outward and entraining adjacent waters, giving rise to the gyres described above. As a result, during ebb flow from the inlet there will be inward moving currents close to the shore, transporting sand toward the inlet and aiding the development of the flanking outer bars or shoals. During tidal flood flows the water converges toward the inlet from all sides, especially in flood channels to the flank of the deeper ebb channel. Thus the flood currents also aid in the development of flanking shoals.

Wave action generally acts to counter growth to the outer bar of the inlet. It does this by transporting sand back onshore to the beaches.

For this reason, on coasts of high wave conditions (like Oregon) the outer bars of inlets tend to be smaller than on coasts of small waves (Dean and Walton, 1975; Walton and Adams, this volume). However, wave refraction over the shoal can also aid in the development of the outer bar, and some studies have suggested that this process may be more important than the current gyres already discussed (Hayes, et al., 1971; Hubbard, this volume). Refraction of the waves around the outer bar causes a longshore current directed toward the inlet from both sides, thus working in concert with any ebb-tide gyres and flood-tide currents acting in the area. With an overall oblique wave approach to the inlet area, the longshore current may be inward toward the inlet on only the updrift side.

As seen in Figure 5 (upper), typical flanking outer bars existed at the Tillamook Bay entrance prior to jetty construction. There was a seaward offset of the northern shoreline which is sometimes taken to indicate a net littoral drift (Hayes, et al., 1971; Lynch-Blosse and Kumar, 1976), but there is no consistency as to whether the shoreline offset is updrift or downdrift of the inlet. The presence of an offset at the Tillamook Bay inlet in an area of zero net littoral drift casts doubts on offset direction as an indicator of net drift direction and on the theories of origin of the offset which rely on the presence of a net littoral drift.

The construction of the single north jetty at the Tillamook Bay inlet provided additional protection from the wave activity. This protection would allow for further growth of the south flanking shoal, the north flanking shoal becoming covered by the shoreline advance to the north of the north jetty. The growth of the south flanking shoal was presumably due to the continuation of an eddy gyre in this region during ebb tide, and perhaps due to wave refraction effects, both described above, but with a decrease in the wave activity that had acted to reduce the size of the shoal. This is partly verified by model studies conducted at the Waterways Experiment Station on the Masonboro Inlet, North Carolina, and reported in Dean and Walton (1975, page 137). Like the Tillamook Bay entrance, the Masonboro Inlet has only a single jetty. The model studies indicated that shoal growth resulted from (a) the jetty's sheltering of the shoal area, thereby creating a sand trap, and (b) a large eddy or gyre carrying sand toward the inlet on both ebb and flood currents.

It is seen that all factors affected by the installation of a north jetty at Tillamook Bay would act to increase the growth of the south flanking shoal. The shoal growth pushed the channel northward against the jetty, and the pressure from the developing shoal also presumably accounts for the narrowing and deepening of the channel.

INTERPRETATION OF SHORELINE CHANGES AND THE BUDGET OF SEDIMENTS

As already indicated, a closer inspection of the changes following construction of the north jetty does not agree with the interpretation of a large net littoral drift identified by earlier studies (Corps of Engineers, 1970). The overall pattern of erosion and deposition is illustrated schematically in Figure 8, and it is seen that the pattern is symmetrical north and south of the jetty, complicated by the fact that only a single jetty was installed. Although erosion occurred along most

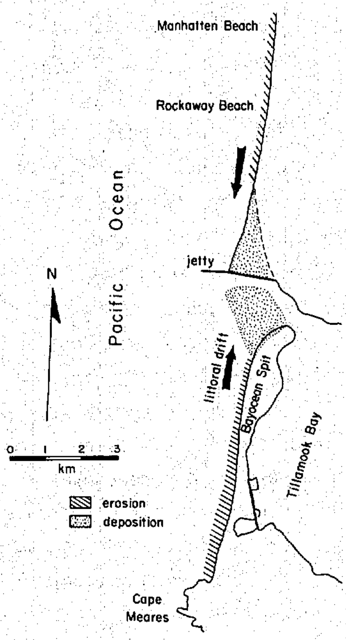

Figure 8: Patterns of erosion and deposition following construction of a north jetty but prior to the south jetty development.

of the length of Bayocean Spit, there was a net deposition just to the south of the jetty in the form of growth to the flanking outer bar. Following jetty construction, sand moved northward from most of the length of the spit and accumulated in this shoal growth. As will be shown shortly, the loss of sand from the spit erosion can be approximately balanced by the amount of sand deposited on the shoal plus that carried into the bay during the 1952-56 breach.

To the north of the jetty sand accumulated and the shoreline advanced (Figure 2). Deposition there probably derived its sand from beach erosion further to the north, symmetrical with the northward movement of sand on the spit to the inlet. This overall pattern of deposition adjacent to jetties and erosion at greater distances was shown to occur at other Oregon coast jetty systems (Komar, et al., 1976), and was reviewed earlier in this paper. Erosion to Bayocean Spit was much greater than erosion to the north of the jetty at Manhatten Beach and Rockaway Beach (Figure 8) because of the longer stretch of beach that exists to the north. Only a small amount of sand had to be eroded per unit length of shoreline to supply sand to the accretion area immediately north of the jetty. In contrast, Bayocean Spit is only a small segment between the jetty and Cape Meares on the south (Figure 8) so that a larger amount of sand had to be supplied by each unit length of spit shoreline erosion to support the shoal growth next to the inlet.

We have attempted to put sediment volumes on the patterns of erosion and deposition illustrated in Figure 8 by the development of a budget of sediments. This budget is for changes following the completion of the north jetty in 1917 but before the construction of the south jetty in 1969. Our estimates are given in Figure 9. Deposition to the north of the jetty amounted to some 6×10^6 m^3, which agrees with previous estimates of the fill (Corps of Engineers, 1970). As already indicated, this sand deposition came from beach erosion further to the north; that erosion value is given in Figure 9 in parentheses because we have no actual measure of the erosion other than the supposition that it will balance the deposition north of the jetty. Of course any transfers of sand around the jetty during or after construction would alter this exact balance; unfortunately we have no way to evaluate such a

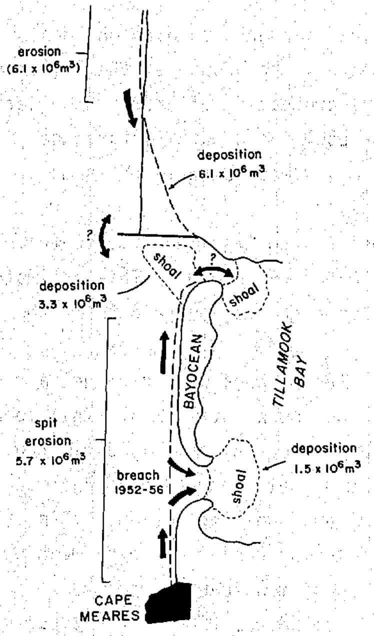

Figure 9: Budget of sediments for areas of erosion and deposition following construction of the north jetty at Tillamook Bay.

transfer around the north jetty, but believe it to be small, especially in comparison with the volume of sand deposited to the north of the jetty. This belief is in part supported by the continued existence of a shoreline offset north and south of the jetties, even after construction of a south jetty. This suggests that the jetties are an effective barrier to longshore movements of sand on the beaches; otherwise sand would presumably transfer from the north to the south beach until they have equal offshore extents.

We estimate that the flanking outer shoal to the south of the jetty increased in volume by 3.3×10^6 m^3 following jetty construction. This estimate is based on comparisons of bathymetric surveys such as those of Figure 5, before and after jetty completion. Our estimate shows reasonable agreement with the results of Walton and Adams (this volume). They place the total volume of the outer bar of Tillamook Bay at 15×10^6 m^3, so the measured growth volume is small in comparison. Of special interest is that Walton and Adams show that outer bars on coasts with small wave energy are some 23% larger than bars on coasts with large wave energies. If we reason that the growth of the Tillamook inlet outer bar is due to the additional protection offered by the jetty from wave attack, and employ their 23% resulting growth factor, one obtains a volume increase of 3.5×10^6 m^3, almost exactly the same as our measured increase (3.3×10^6 m^3).

Erosion of Bayocean Spit and the area to its immediate south up to Cape Meares amounted to some 5.7×10^6 m^3 (Figure 9). This estimate is based on measured beach and dune bluff retreats and heights of the dune bluffs and sea cliffs.

The other large transfer of sand in the area was into the bay when the spit breached in 1952 and remained open until 1956. This volume of deposition and loss from the seaward side of the spit is estimated at 1.5×10^6 m^3, and is based on the volume of spit removed by the breaching process (which gives a minimum transfer) and shoaling values within that portion of the bay. This estimated volume is considered to be much poorer than our estimates of spit erosion or deposition near the jetty.

There is also the possibility of some deposition on the inner shoal (flood-tide delta), within the bay at the jettied entrance. The surveys of the entrance area, before and after jetty construction, suggest that deposition within the bay in this area was small, but we could not make satisfactory measurements from the available data.

Altogether there is a reasonable accounting for the transfer of sand from erosion areas to deposition areas in the region of Bayocean Spit and Tillamook Bay following construction of the north jetty. The shoal growth and sand entering the bay through the breach together account for 4.8×10^6 m^3 of deposition. This is close to the 5.7×10^6 m^3 of estimated erosion from the spit. Considering the inaccuracies of these estimates, the results demonstrate that the patterns of erosion and deposition can be accounted for by local rearrangements of nearshore sands following construction of the north jetty, without blockage of an appreciable net littoral drift by the jetty.

CONSTRUCTION OF THE SOUTH JETTY

The hazardous channel conditions which developed due to the growth of the outer bar following construction of the north jetty prompted renewed considerations for construction of a south jetty. Construction of a south jetty was begun in April 1969 and completed in 1974 with a total length of 2000 m (6,500 ft).

Even as the south jetty was being constructed, sand accumulated between it and the curved pre-jetty shoreline, causing a shoreline advance to the south. This accumulation continued until the shoreline became straight and parallel to the prevailing wave crests, the same as described earlier for other jetty systems on the Oregon coast as well as for the earlier construction of the north jetty. This provides further proof for a zero or near-zero net littoral drift in the area.

SUMMARY OF CONCLUSIONS

(1) With the exception of the section of coast near the Columbia River, the Oregon coast is a series of pocket beaches separated by pronounced rocky headlands. There is a zero or near-zero net littoral drift within these pockets. Shoreline changes due to jetty construction are therefore not due to blockage of a net drift.

(2) Following completion of a single north jetty in 1917 at the Tillamook Bay entrance, the shoreline built outward to the immediate north. This accretion occurred to fill the embayment created between the jetty and the pre-jetty shoreline which curved inward toward the bay entrance. Deposition continued until the shoreline became straight and parallel to the prevailing wave crests, at which time a new equilibrium was achieved with a zero net littoral drift.

(3) Bayocean Spit to the south of the Tillamook Bay entrance suffered severe erosion following construction of the north jetty, culminating in its breaching in 1952. Initially, sand eroded from the spit moved northward and was deposited at the entrance in the form of growth to the outer bar (ebb-tide delta). Later when the spit breached, considerable quantities of littoral sediments were also carried into the bay.

(4) Growth of the outer inlet bar or shoal following construction

of a north jetty can be understood in terms of wave and current processes acting at inlets. The single jetty offered increased protection from the waves and perhaps augmented flanking currents flowing inward toward the inlet.

(5) Considerable coastal erosion can result from jetty construction even in coastal areas that are not experiencing a sizeable net littoral drift; blockage of a net drift by jetty construction is not a necessary prerequisite for erosion.

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