NEARSHORE BAR MORPHOLOGY WITH RELATIONSHIP TO SHORELINE CHANGE ON A RENOURISHED BEACH: HARRISON COUNTY, MS

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Abstract: A long-term pattern of erosion, especially in specific areas – 'hot spots' – along the wholly renourished beach in Harrison County, Mississippi, prompts the need to periodically renourish the entire beach. A dominant characteristic of mainland beaches in Mississippi is their broad, flat, nearshore platforms, which are typified by well developed bar morphologies. Nearshore bar morphology in Mississippi Sound has been broadly studied in the past, but it has not been compared to shoreline change patterns. This study focuses on the relationship between shoreline change and nearshore bar morphology.

Nearshore bar morphology in Harrison County has been categorized from aerial photographs from the 1970's to the middle 1990's. Bar types range from simple shore-parallel bars to multiple bar interfaces. Bar morphology categories and change through time were classified along the shoreline at 50 m intervals; shoreline change was classified in 20 m intervals.

Combined results suggest that highly eroding areas are associated with a dominance of multiple sets of transverse bars indicative of a bimodal longshore sediment transport regime. Areas that show little shoreline change and/or accretion tend to have multiple sets of shore-parallel bars. The overall bar morphology patterns in Harrison County have remained nearly constant in the past twenty years, even with a renourishment taking place. This suggests that bar patterns are an inherent indicator of the dominant physical conditions and a powerful tool in understanding the sediment transport regime at specific locations, e.g. 'hot spots', along the shoreline.

INTRODUCTION

The mainland shoreline in Harrison County, MS consists largely of a man-made beach, which at one point was the longest in the United States (Otvos, 1985). Through time and multiple renourishments, discrete areas have experienced anomalously high erosion rates that ultimately determine the lifespan of the previous renourishment. These 'hot spots' along with the varying patterns of shoreline retreat and advance have been mapped (Schmid, 2002). In some cases patterns of shoreline change can be correlated to variables such as shoreline orientation and man-made structures; however, in other areas the anomalies in shoreline change appear unrelated.

The dominance of a large, flat, nearshore platform and a general seaward-directed loss of sediment from the beach highlights the need to understand the processes taking place beyond the swash zone. Of the sediment lost from the backshore or 'beach', 2/3 is deposited on the nearshore platform and the other 1/3 is lost largely onshore as 'wind loss' (Schmid, 2002). Well-developed and expansive bars that occupy much of the 500 m wide platform highlight the role of the nearshore platform in sediment transport. Not only do they attenuate incoming wave energy (Otvos, 1999), but

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have a high level of control on the transport of sediment across the nearshore platform (Shand and Bailey, 1999).

Conceptual models of bar morphology have expanded from traditional single bar models (Komar, 1976) based on two dimensions, distance offshore and elevation, to models using longshore position as a third dimension (Short, 1979). The more complex 3D models have typically relied upon aerial photography as the basis for measurement (Shand and Bailey, 1999; Shand et al., 1999) since profiles, even closely spaced ones, have limited resolution, either temporally or spatially, in the longshore dimension. Given that the cost of repeated aerial photography is prohibitive, low sampling rates are typical. The present research project is subject to the same limitations. Despite the inherent problems with data collection, several sites were densely sampled and a general trend of cyclic offshore migration was identified (Birkemeir, 1984; Ruessink and Kroon, 1994; Shand and Bailey, 1999; Shand et al., 1999; Wijnberg, 1995) and described as net offshore bar migration (NOM).

Of particular interest to this work is the three-stage model developed to understand the process of bar evolution. In the 'Dutch' model (Shand and Bailey, 1999), bar generation occurs near the shoreline, followed by bar maturity and migration in the middle nearshore and lastly bar dissipation on the outer nearshore. The present study site has a potentially extensive low tide terrace on which bar formation is typically associated (Lipmann et al., 1993). Bar generation in the Dutch model is normally associated with storm conditions and high longshore currents (Shand and Bailey, 1999). The second stage in the Dutch model, maturation and migration, is highly dependent on the nearshore slope, wave conditions, and antecedent morphology. Several parameters, namely lifespan of a bar and return interval, are used to describe the process (Shand et al., 1999). Bar lifespan in Mississippi appears to be substantial (Oivanki, 1997). The last stage of bar dissipation occurs after the bar has progressed across the middle nearshore and reaches the outer portion. Dissipation does not necessarily mean the sediment (like the bedform) is moved offshore; in many instances destruction of the bedform is accompanied by shoreward transport of sediment (Larsen and Kraus, 1992; Wijnberg, 1995).

A study of all locations with bars in Mississippi Sound was carried out in the 1970's by Nummedal et al. (1980). They used aerial photographs and overflights of the area to group the types of bars into four separate categories. The patterns themselves appeared to be time-invariant except during storms. The bar description protocol that they developed has been largely used in this report. While this study went far to describe the overall bar patterns in Mississippi Sound, resolution of the bar distribution is too low for site-specific work in Harrison County.

STUDY SITE

At 27 miles long, the Harrison County Beach system is one of the longest renourished beaches in the United States and at the time of the initial project one of the longest in the world. The beach has been renourished three times (1972, 1988, and 2000) since its initial creation in the 1950's. It remains backed by a seawall that was constructed in the 1920's. Like many renourished beaches, constant maintenance is performed to preserve a consistent beach slope. The present study area consists of the western half of the 27-mile beach (Figure 1).

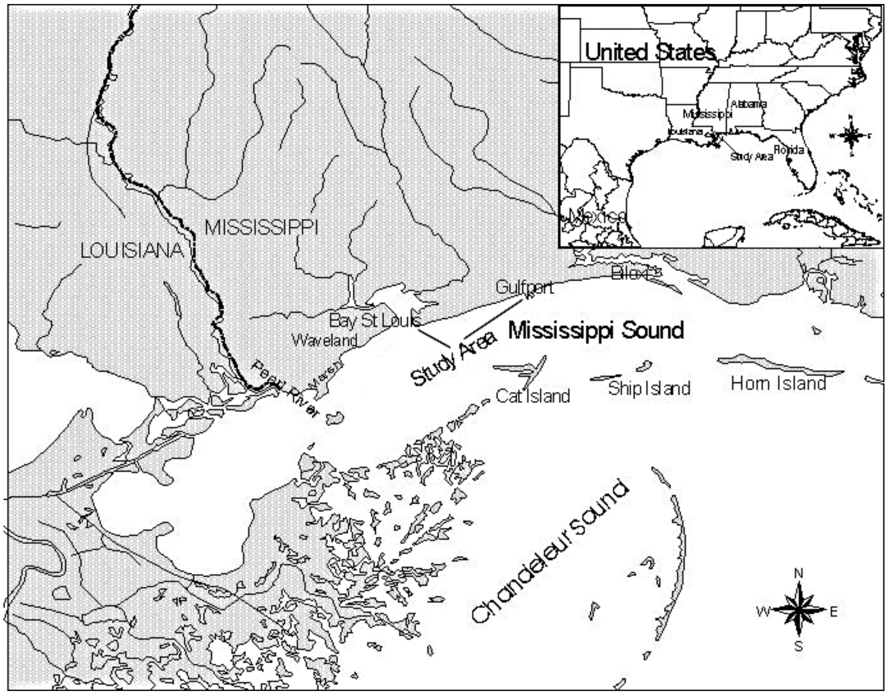

Figure 1. Study area location.

The study area is located on the Mississippi Sound, which is a microtidal, shallow, water body protected from the Gulf of Mexico by a string of barrier islands (Figure 1). Depths in the sound average 3 m (Higgins and Eleuterius, 1978), except in dredged channels, and wave conditions are typified by heights less than 1.5 m and periods that seldom reach more than 3.5 seconds (Moody and Schmid, 2003). The prevailing wind direction is from the south to southeast and creates a westerly-directed longshore current. The strongest winds are associated with tropical storms that cross near the area about three times per decade and from winter cold fronts (Lana, 1998).

The nearshore platform seaward of the beach is wide and shallow, with widths greater than 300 m and depths that seldom reach 1.5 m (Figure 2). At the seaward edge of the platform there is a distinctive drop off and a switch from sand to mud sediment. Sediments making up the nearshore platform are slightly muddy sands with mean sediment sizes of 0.15 mm (Schmid, 2001). The nearshore platform sediments are typically more than 3 m thick, and rest on an underlying sandy Pleistocene unit. A small or subtle low tide step is evident in most profiles of the area; the step height is approximately 0.3 m and occurs about 50 m seaward of the shoreface (Figure 2). The nearshore platform can and commonly does contain more than 10 individual bars, especially in areas dominated by shore-parallel bars.

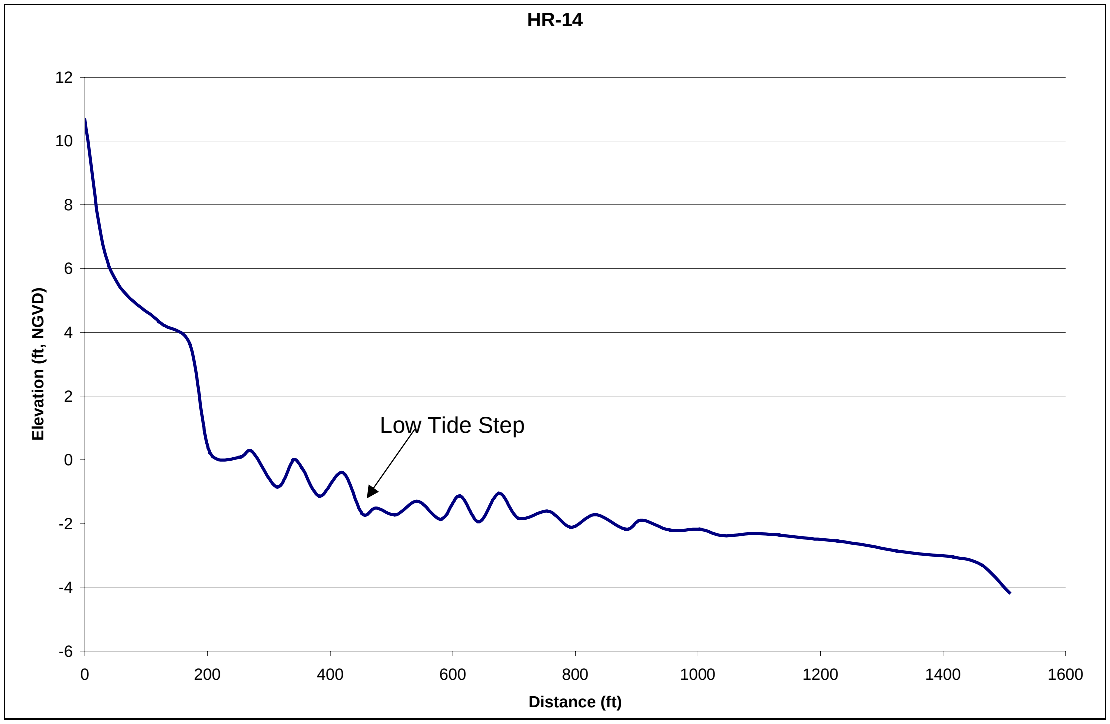

Figure 2. Beach profile from the Harrison County shoreline.

METHODS

Several methods were used to analyze the bar/nearshore character. Profiles have been taken annually to biannually using a total station since 1992 on 16 transects across the 27-mile shoreline to document the changes taking place on the nearshore (i.e. volume change) and the general character of the bars (Figure 2). This wide spacing, however, does not allow for analysis of the 3D character of the bars.

To document the 3D bar character on the nearshore platform, aerial photographs of the site during the fall and winter months from 1977, 1991, and 1997 were used. The 1997 set of color IR aerial ortho rectified photographs were downloaded from the Mississippi Automated Resource Information System (MARIS). The 1977 black and white and 1991 color IR photos were scanned at 200 dpi and then rectified in ArcMap.

Bar patterns from the three sets of photos were characterized using a modified version of Nummedal et al.'s (1980) initial study. Dominant and modifying bar types were noted in each of the 50 m segments. The combination of the two bar types were then categorized into a single bar pattern. To maintain consistency using a somewhat subjective variable (bar type), the classifications were error checked three times. The site exhibited six different bar morphology patterns along with a small percent of shoreline that could not be classified and, thus, labeled 'weak'.

Shoreline change has been measured along the Harrison County shoreline since 1993 using differentially corrected global positioning system (GPS) surveys of the high water line. The high water line was chosen as the most easily reproducible geomorphic feature. The technique provides relative accuracies on the microtidal Mississippi mainland beaches of two to five meters (Hutchins and Oivanki, 1994). To achieve the longest period of comparison without the influence of a renourishment (the most recent taking place in 2000-2001), the summer 1993 and summer 2000 GPS shorelines were used in the analysis. The shorelines were divided into 20 m segments for comparison of offset distances.

Shoreline change was computed using distances between segments, either as erosion or accretion, such that the length of the shoreline within each change level was computed. Based on previous work on the entire Harrison County shoreline (Schmid, 2002), shoreline change rates of 1 to 2 m/yr are considered significant and 2 to 4 m/yr are considered highly significant or 'hot spots'. Once change distances were computed the shoreline segments contained data on shoreline change rate (m/yr), shoreline orientation, and bar morphology (1977, 1991, and 1997) for each segment. Analysis of spatial correlation between bar morphology and shoreline change was performed using ArcMap.

BAR MORPHOLOGY

As mentioned previously, six different bar morphologies were established to describe the bar patterns exhibited along the study area. From simplest to most complex (Figures 3A to 3F) they are Multiple Longshore (ML), Single Transverse (ST), Transverse Multiple Longshore (TML) type 1 and type 2, Interference Transverse (IT), and Multiple Interference Transverse (MIT). The ML (Figure 3A) and ST (Figure 3B) bar patterns can be viewed as the base patterns that in various combinations form the more complex varieties. The difference between the two TML types is the relative degree of the influence between the transverse (ST) and longshore (ML) components (Figures 3C and 3D). The TML bar type, including both type 1 and 2, is the most prevalent at about 50% of the shoreline; the next most prevelent is the IT type at 20% of the shoreline. The least prevalent are the ST and ML types, which indicates that multiple or superimposed bar morphologies dominate the study area.

Table 1. Bar population

	Population	
Bar Type	N	%
TML	184	48%
MIT	65	17%
IT	78	20%
ST	15	4%
ML	21	5%
WEAK	21	5%
Total	384	100%

Figure 3A. Multiple Longshore (ML)

Figure 3B. Single Transverse (ST)

Figure 3C. Transverse Multiple Longshore (TML) Type 1

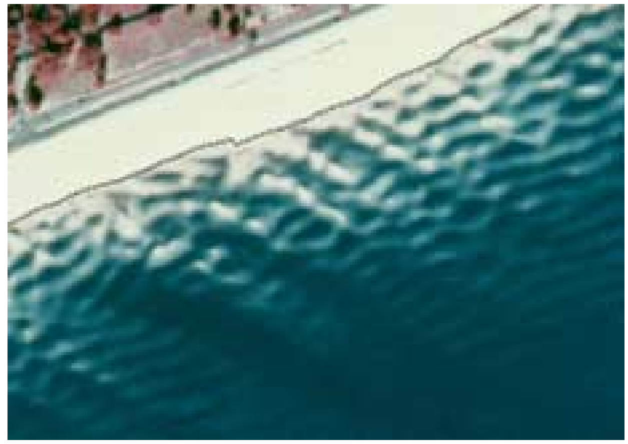

Figure 3D. Transverse Multiple Longshore (TML) Type 2

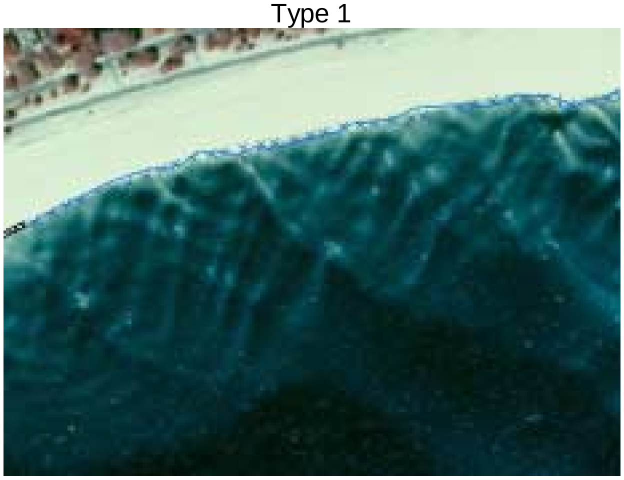

Figure 3E. Interference Transverse (IT)

Figure 3F. Multiple Interference Transverse (MIT)

Change Between Years

Using the established bar pattern identification scheme the entire shoreline was classified for each time period (Figure 4). For each 50 m segment a dominant and modifier pattern was established, with the combination of the two determining the final bar pattern (Figures 3A to 3F). The dominant category is an indication of ML and ST bar patterns, and in which direction the ST bars trended (longshore direction). Based only on the dominant category, about 75% of the bar patterns remained the same from 1991 to 1997 (Table 2). More impressive is that despite a renourishment (1988) the value is nearly the same for the 1977 to 1991 period. Overall, during the 20 year period, about 60% of the shoreline showed the same dominant bar type in each time slice.

Table 2. Dominant bar change through time slices

	1991-1997		1977-1991		1977-1997	
Change	N	%	N	%	N	%
Same	290	76%	259	67%	221	58%
Different	94	24%	125	33%	163	42%


Figure 4. Example of bar patterns and classification in 1997 on a section of shoreline at the study site.

The final bar patterns, a combination of dominant and modifier, changed slightly more than just the dominant patterns during the 20-year period (Table 3). In this case, about 40% of the shoreline had the same exact bar pattern for the three time slices. The TML bar pattern made up the bulk of this group, such that of the 1997 distribution over 50% of the TML shoreline had remained constant for the twenty-year period. At the other end of the spectrum, no portion of the 1997 shoreline with the ST bar type has remained the same for the period.

Table 3. Bar change through time

Change	1977-1997	1997	%Same
Same	147		38%
Different	237		62%
TML	100	184	54%
MIT	24	65	37%
IT	14	78	18%
ST	0	15	0%
ML	7	21	33%
WEAK	2	21	10%

SHORELINE CHANGE

Shoreline change at the study site from 1993 to 2000 can be represented graphically as a cumulative frequency polygon (Figure 5) where shoreline change (-m) is measured on the x-axis and percent of shoreline on the y-axis. This graph shows that 70% of the shoreline is eroding. From the total shoreline, the portion above 85% (about one standard deviation) or more than about 10 m of erosion, which corresponds to 1.5 m/year, is considered moderate erosion for this report. Similarly, the portion above 95% (about two standard deviations) is considered high erosion or 'Hot Spots' and corresponds to 2.5 m/yr. Accretion is considered significant at one standard deviation (about 10 m) or 1.5 m/yr.

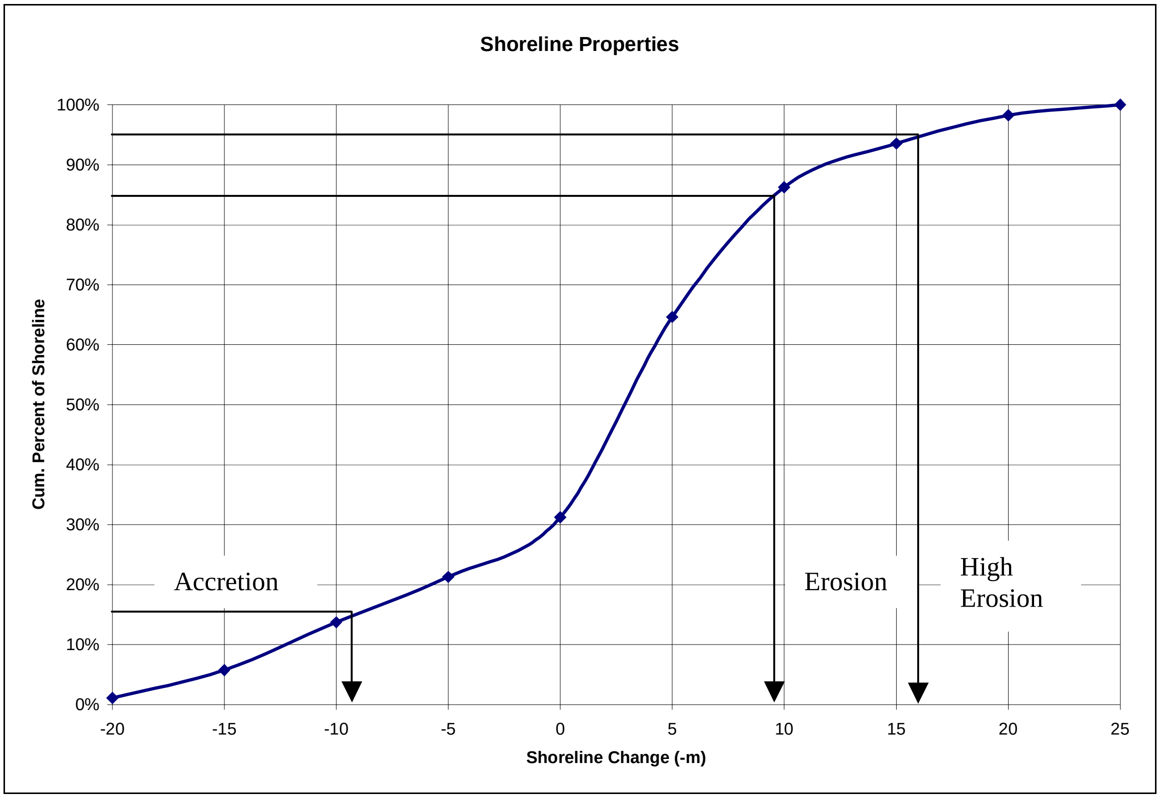

Figure 5. Cumulative graph of shoreline change at the study site.

BAR TYPES AND SHORELINE CHANGE

To highlight the correlation between shoreline change and bar morphology a selection of the total bar population was chosen based on the areas of shoreline defined as high erosion, erosion, and accretion (Figure 5). Each subset represents a sample of the overall bar population that can be compared to each other and to the overall population. Only the 1997 bar types have been used for this analysis (Table 4).

Table 4. Bar statistics for selected change levels and the overall population

	Population	Accretion		Erosion		High Erosion	
Bar Type	%	N	%	N	%	N	%
TML	48%	17	47%	44	60%	4	20%
MIT	17%	3	8%	7	10%	0	0%
IT	20%	2	6%	10	14%	15	75%
ST	4%	0	0%	7	10%	0	0%
ML	5%	7	19%	1	1%	0	0%
WEAK	5%	7	19%	4	5%	1	5%

Table 4 suggests that there are three indicator bar types: TML, IT, and ML. In the accretion and moderate erosion categories, the dominant TML bar type is consistent with the overall population average; for the high erosion category, it is well below the population average. This may indicate that the TML bar pattern is associated with more moderate shoreline change conditions, which are slightly erosional (50% level = 3 m of erosion; Figure 5). The IT bar pattern is strongly associated with high erosion; the ML bar pattern is somewhat favorable to accretion and all but absent in erosional segments. One other notable bar type is the weak category, which is more abundant in the accretion subset.

To test the suggestion that the three indicator bar types are related to shoreline change, the shoreline character adjacent to each of the bar types was compared. In this analysis, the 1993 and 2000 shoreline segments occurring adjacent to the three indicator bar types were selected and compared. The results have been superimposed on the character of the entire shoreline (overall population) to highlight the differences and similarities (Figure 6). It is clear from the graph that the ML bar type is associated with shorelines that are dominated by accretion, whereas shorelines associated with IT bars have a higher level of shoreline retreat, especially high retreat. Shorelines associated with the TML bar type are very nearly the same as the overall shoreline population.

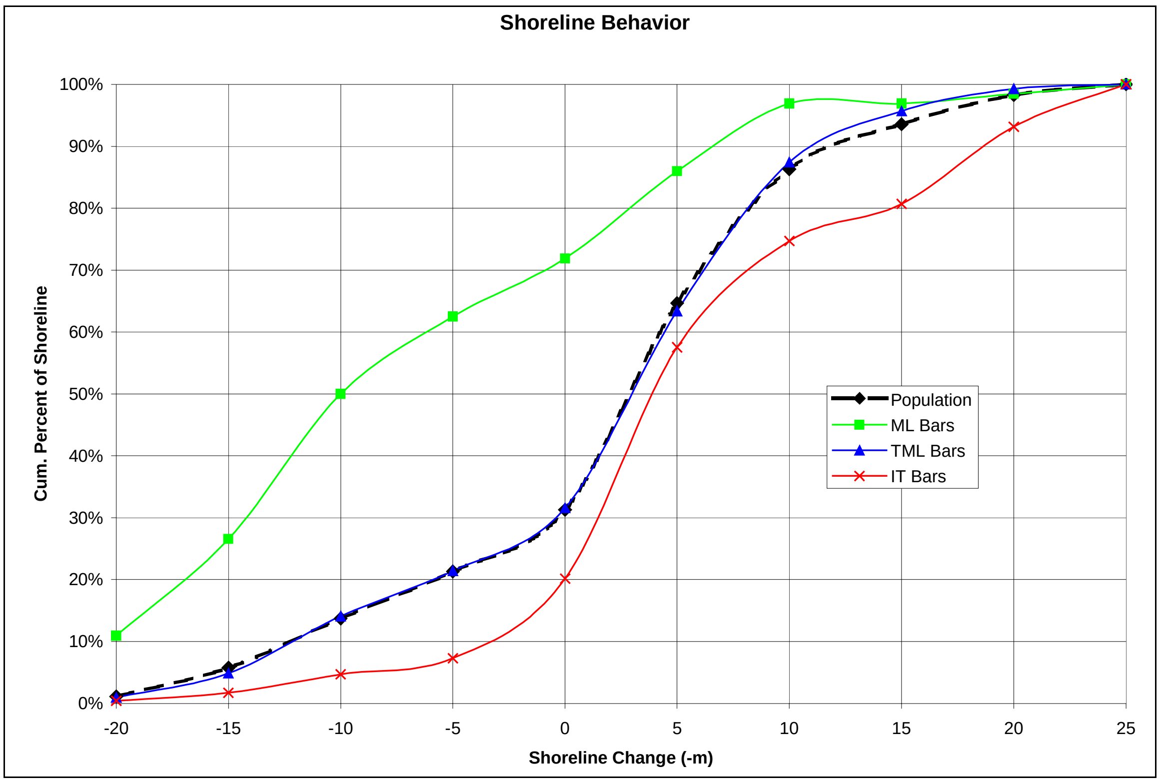

Figure 6. Character of the three bar type shorelines.

DISCUSSION

Bar patterns effect on mid to long-term shoreline change has been recognized in past works (Schwab et al., 2000). For the Mississippi Gulf Coast, this is an especially powerful tool, since the area is dominated by stable nearshore bars that are easily photographed from the air. If the processes for distinguishing bars and, thus, shoreline condition (i.e. erosion-prone, or erosion-resistant) can be photographed it would allow for much quicker determinations on the effects of human modifications or shoreline structures. The results indicate that this is possible.

The Dutch model of bar formation suggests that bar formation occurs on the low tide step and that following bar formation the bars maintain themselves across the nearshore platform (Shand and Bailey, 1999). Oblique bars, which dominate the study area (Figure 4), may be the result of either oblique formation in the very nearshore (Wijnberg, 1995) or as a result of the landward portion lagging behind the seaward portion under the influence of longshore currents (Shand and Bailey, 1999), essentially signifying a variation in longshore current strength between the nearshore platform and low tide step. In either case the oblique bars suggest a higher longshore influence in their formation. Inversely, the opposite may be true of parallel bars (ML) at the study site.

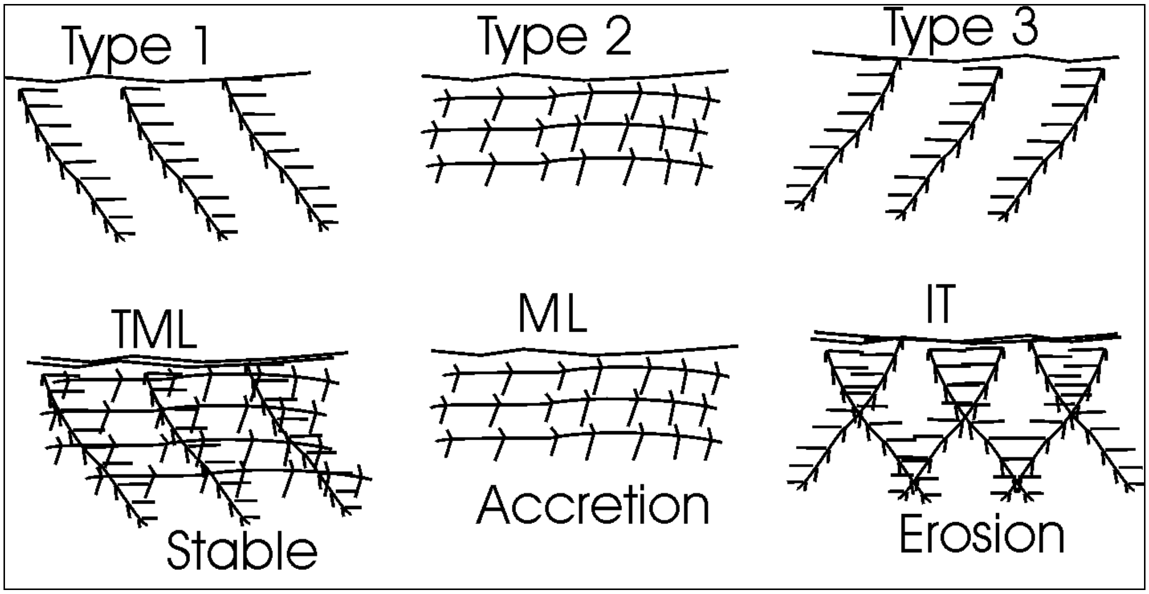

Figure 7. Combinations of bar types for the three indicator bar patterns.

The three indicator bars (ML, IT, and TML) at the study site are composites of the two end types (Figures 3A and 3B) and in which angle the ST bars trend (Type 1 vs. Type 3 in Figure 7). Based on the combination of bar types and the formation mechanisms, the longshore vs. on or offshore (cross-shore) character of the bars appears to be the most likely indicator of shoreline change. Portions of the shoreline with a balance between cross-shore and longshore bar types (TML – the most common) exhibit an 'average' change, which nearly coincides with the net shoreline behavior. This pattern is the one used in the earlier study (Nummedal et al., 1980) to describe the bar patterns at this site. The most highly accreting portions of the shoreline are associated mainly with cross-shore transport (Type 2), which suggests a net onshore transport in areas with ML bars present. Portions of the shoreline with the IT bar pattern may be dominated by opposing longshore transport characteristics, such that average yearly variations in the wind-driven longshore component or man-made structures do not favor cross-shore transport.

These initial results suggest that a definitive set of nearshore processes is responsible for shoreline change behavior at the study site. Future work on specific combinations of bar types (Figure 7), i.e. dominant type vs. modifier type, may increase the resolution of the data and more accurately portray a specific shoreline behavior (change/year). Shoreline orientation and distances from man-made structures, obvious omissions from the present work, may also be added to the list of variables. In so doing, a functional model of the wholly renourished Harrison County shoreline is a reality that may aid in reducing or preventing the future creation of 'hot spots' and more costly renourishment projects.

CONCLUSIONS

Based on the data gathered and analyzed, the following conclusions can be drawn:

1. Nearshore bars along the Harrison County renourished beach have largely maintained their dominant bar pattern through 20 years and one renourishment.
2. Separate bar patterns are associated with different shoreline evolution. ML bar patterns are associated with accretion and IT bar patterns are associated with erosion.
3. The relative degree of cross-shore and a longshore sediment transport is largely responsible for the formation of accretional and 'hot spot' areas.
4. Future work on the specific combinations of bar end-types along with other physical variables will likely lead to a better understanding of the shoreline change process on one of the longest renourished beaches in the United States.

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KEYWORDS

Mississippi Sound, Harrison County, Mississippi, Nearshore Bars, Shoreline Change, Bar Morphology, Aerial Photographs, Sediment Transport