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Sediment Distribution Patterns Offshore of a Renourished Beach: Atlantic Beach and Fort Macon, North Carolina

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ABSTRACT

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Contour plots of sediment characteristics have been used to help delineate the regional distribution of native, renourishment, and relict sediments off a renourished beach on the central North Carolina coast. Shell color, shell polish, and sediment size (sorting) were found to be especially useful indicators of dispersal patterns of renourishment sands, which were characterized by a high percentage of fine-grained sediment and a high percentage of dull, pockmarked shell that was gray-to-black in color. Distribution patterns show that longshore transport of renourishment sediment has been minor and little sand from a recent renourishment project was supplied to the adjacent native beaches. However, possible cross-shore transport was identified in storm layers (shell hash) in offshore sediment cores, and additional evidence was provided by the rippled scour depressions noted in a recent side-scan sonar survey.

ADDITIONAL INDEX WORDS: *Morehead City Harbor Project, Bogue Banks, shell staining, beach renourishment.*

INTRODUCTION

Eastern Bogue Banks along the central North Carolina coast is periodically renourished with backbarrier sediments that are derived from maintenance dredging of the Morehead City Harbor (Figure 1). Although this reach of Bogue Banks has been renourished for the past several decades, the two most recent disposal (renourishment) projects, completed in 1986 and 1994, are the largest to date. According to records from the U.S. Army Corps of Engineers (SHUFORD, 1996) 3.0×10^6 m^3 of sediment were pumped onto the beach in 1986 and an additional 3.6×10^6 m^3 in 1994 (Figure 2). The combined cost for the two projects was approximately $9 million, and was completely federally funded (VALVERDE and PILKEY, 1996).

Because beach renourishment has been and continues to be used extensively for beach stabilization and maintenance, and in many cases is the only option available, securing funds is often a pressing issue. In addition, pre- and post-monitoring studies are increasingly needed since little is known about the post-depositional transport and fate of renourishment sediments. A better understanding will help in evaluating the relative success of current projects, and will be especially useful in designing and estimating longevity of future projects.

The overall objectives of this investigation were to assess the utility of rapid, economical, and simple sedimentological methods to track dispersal of renourishment sediments, and to use these methods to help improve the understanding of post beach-renourishment processes on Bogue Banks. Three questions were addressed during the investigation: 1) How are the renourishment sediments distinct from the native sands? 2) Are these distinctions identifiable in the offshore sediments? And, 3) What processes can be inferred from the sediment distribution patterns?

Sediment characteristics have been used previously to distinguish renourishment sediments from native sands, particularly through examination of quartz staining (PABICH, 1995) and fluorescent tracers (FOSTER *et al.,* 1996). However, we are aware of only one geographic area, off Wrightsville Beach, NC, where previous investigations closely resembled our studies. Nearly 20 years ago, PEARSON and RIGGS (1981) identified an anomalous region of homogeneous sediments off Wrightsville Beach (80 km SW of Bogue Banks) that was described as having a high degree of uniformity in sediment size, color, and shell staining. Sediments that are highly homogeneous are unusual in Onslow Bay, and the sediments were thus attributed to a renourishment project on Wrightsville Beach. THIELER *et al.* (1994) concentrated on the shell constituent of these sediments and found that the shell hash associated with the renourishment sediment could be traced from the beach to the inner shelf.

Studies on both Atlantic Beach and Wrightsville Beach are complicated by the presence of relict lagoonal sediments on the shelf. At Wrightsville Beach, the shoreface has exposed rock outcrops which may have contributed significantly to the

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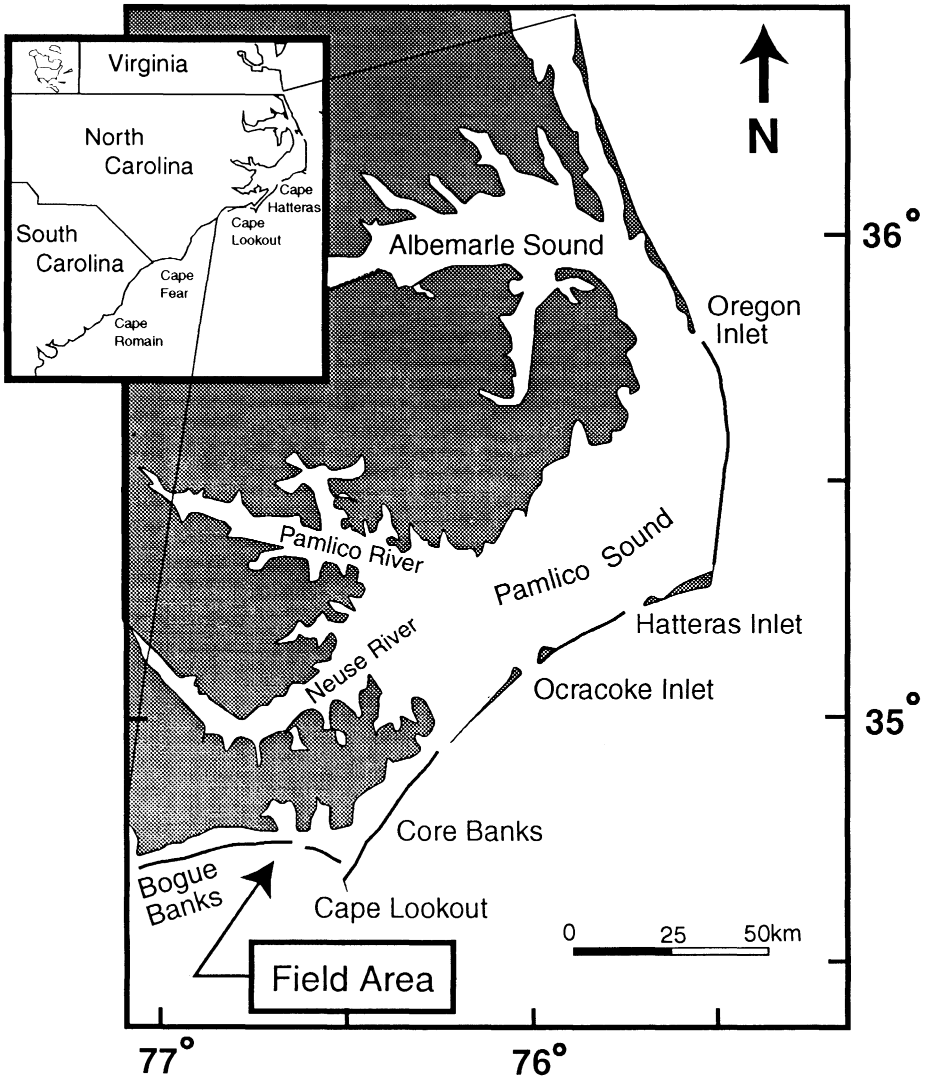

Figure 1. Location map showing the field area.

coarse sediments. Bogue Banks, however, has the advantage of being an historically regressive island with a prograding and inlet-modified stratigraphy (STEELE, 1980) that does not favor outcrop exposure. Further, HINE and SNYDER (1985), who conducted a shallow seismic survey offshore of Bogue Banks, found that the inner shelf was dominated by channel and fill sequences that were covered by a thin layer of modern shoreface sediments to a water depth of about 12 meters.

METHODS

Thirty-six grab samples of the upper 2 cm of sediment were collected off eastern Bogue Banks during each of two sampling periods, fall 1996 and spring 1997 (Figure 3). Sample locations were chosen using a grid and positions were determined using GPS and Loran C. In addition, 21 surface samples were collected on the subaerial beach from locations chosen to best represent the two different sediment types: native and renourishment. The beach samples provided a baseline for use in determining distinguishing characteristics of offshore sediments.

Six push cores, 10 cm in diameter, were collected from the offshore region (Figure 3). Five of the six cores were along a transect parallel to shore at an intermediate depth of approximately 10 meters. The cores were pushed into the sediment to the maximum depth possible, about 60 cm. Core locations were also determined using GPS.

In the laboratory, bulk samples were split to obtain a representative sample of about 50 g. The samples were treated with a 10% Calgon bath for several hours to disperse the sediments. The mud (fine) fractions (>4 phi or <0.063 mm) were separated from the sand and gravel fractions by standard wet sieving techniques (FOLK, 1980), and the percentages of fines were determined using standard pipette analysis on the muds (LEWIS and MCCORD, 1994). Size data were

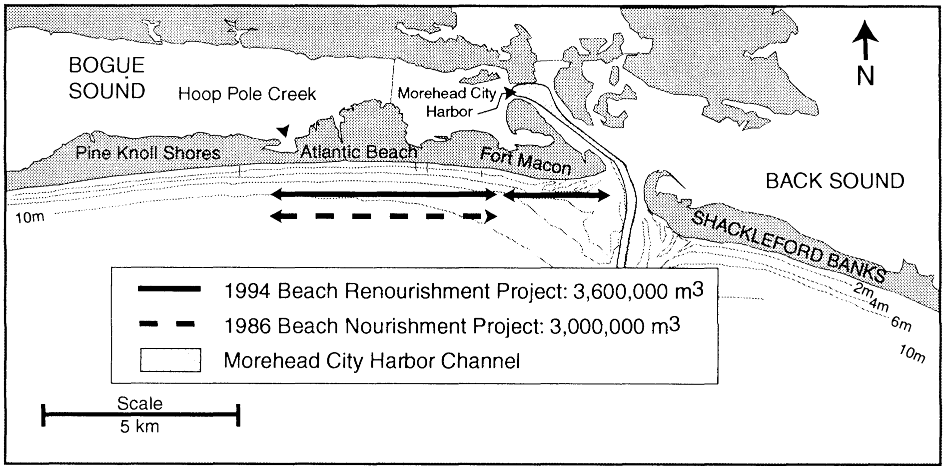

Figure 2. Placement of the sediment on eastern Bogue Banks during the 1986 and 1994 Morehead City Harbor projects. Technically these were disposal as opposed to renourishment projects.

then obtained by dry sieving the samples at 0.5 phi size intervals. Statistical analyses of the grain sizes (mean, standard deviation, skewness, and kurtosis) were calculated using the Method of Moments described by HOEL (1954).

Shell color and polish analysis were performed on the 1.0 phi (0.5 mm) to −2.0 phi (4.0 mm) range of the shell fraction. Point counting with a binocular microscope was done on 100 shell fragments in each sample, and shells were categorized according to color (orange, white, and gray-black) and polish (original/polished and dull/pock-marked). This method was modified from a technique described by POWELL and DAVIES (1989) that used taphonomic descriptions as indicators of relative age.

In order for shell color to be useful it is necessary that the colors are stable when the shells are introduced from one environment to another. A simple experiment was conducted to test the retention of shell color under several environmental conditions. Results from the experiment indicated that none of the shell fragments changed color enough over a one-year period to alter the original color category: orange, white, or black (see REED, 1997 for details).

The push cores were split lengthwise, photographs and x-ray radiographs were taken, and sedimentological descriptions were made. Further details of these methods are given in REED (1997).

RESULTS

Results from the analysis of sediment size, shell color, and shell polish of the subaerial beach samples are plotted in Figure 4 (A–C). The results indicate that sands from native beaches can be discriminated from sediments on the renourished beaches on the basis of sorting, but not by mean sediment size. In most cases, native sands were better sorted.

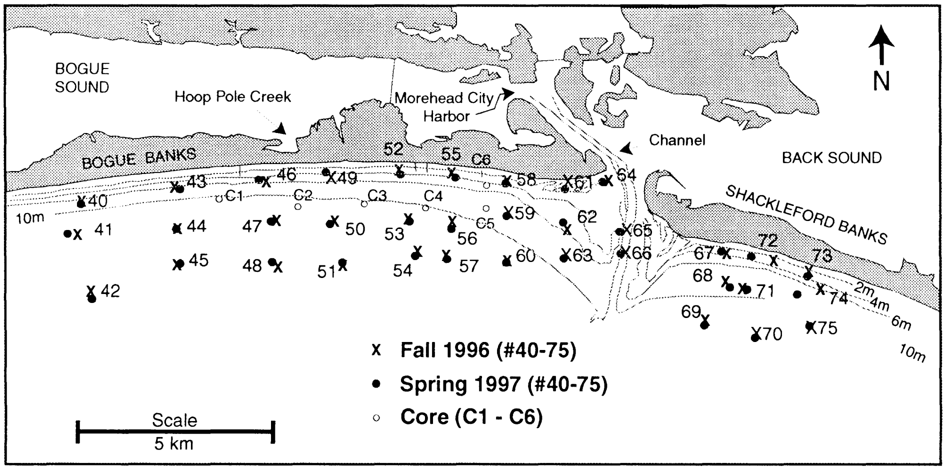

Figure 3. Sample and core map of locations from the 1996 and 1997 data sets.

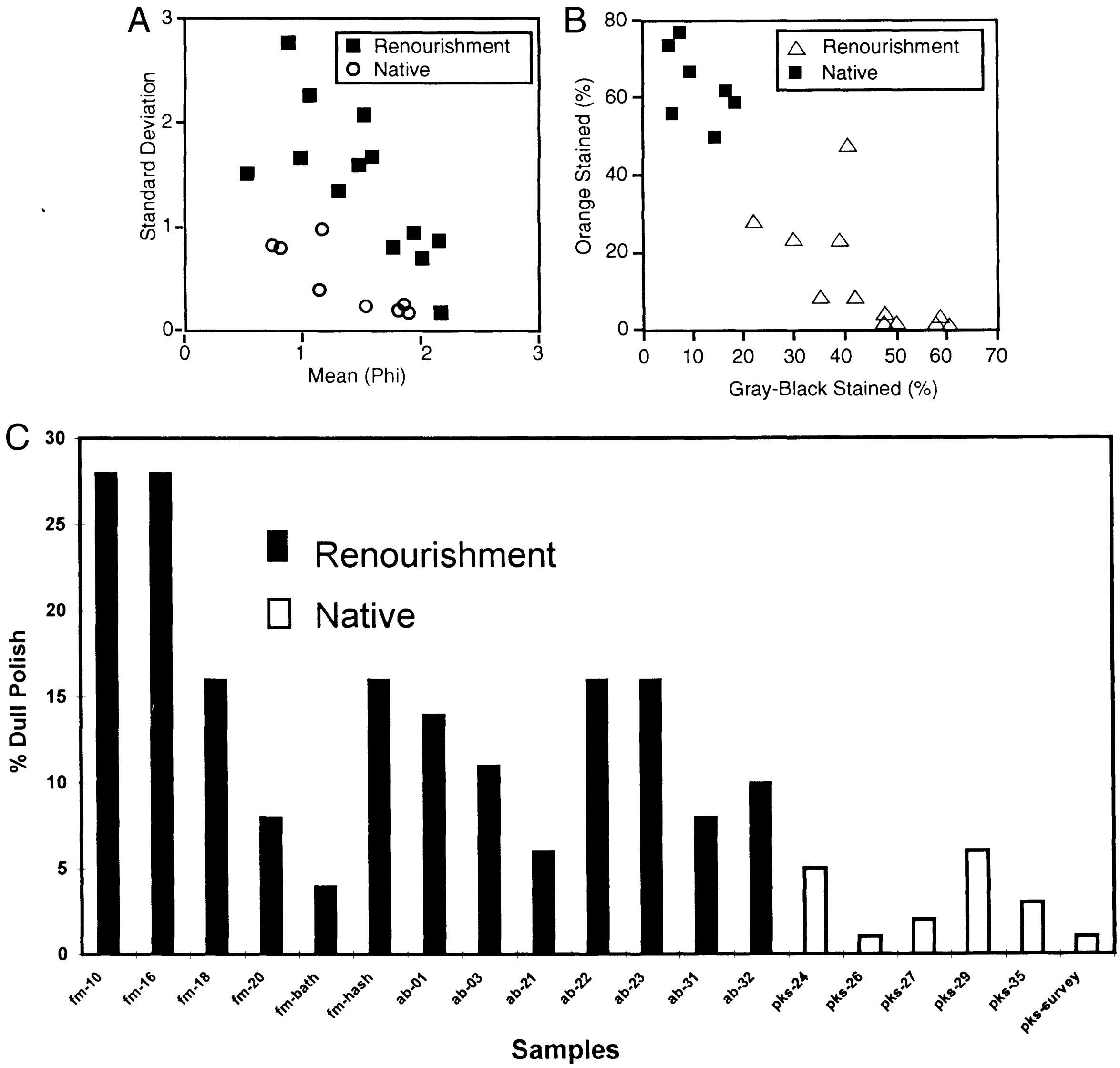

Figure 4. Results of surface sediment analysis for (A) sediment mean vs standard deviation, (B) percent of orange vs gray-black stained shell fragments, and (C) percentage of dull, pock-marked shell fragments.

Analysis of shell color and polish indicate that the sands from the native beaches had significantly more polished and orange-stained shell fragments than the renourished beaches.

Results of offshore samples from the 1997 data are plotted as contour maps (Figure 5A–D) and used for discussion purposes in this paper. However, results from the 1996 samples were very similar to the 1997 results, as illustrated by a series of comparative plots of the two sample sets (Figure 6A–D). For complete tabulated results refer to REED (1997).

Textural results indicate that sediments close to shore in the study area, and offshore of Shackleford Banks and Pine Knoll Shores, had consistently lower standard deviations than the region offshore of the renourished beaches out to a depth of about 10 m (Figure 5A,B). The percentage of fine sediments (>4 phi) varied significantly from negligible to almost 40%, but the general pattern indicated a higher percentage of fines offshore with localized areas of very high concentrations: off Hoop Pole Creek, the western tip of Shackleford Banks, and at a 13 meter depth at the western limit of the study area.

Shell polish was contoured as a percentage of dull/pock-marked shell fragments. Lowest percentages of dull shells were from the inlet region and off the native beaches (Figure 5C). Sediments off Atlantic Beach and Fort Macon State Park had a higher percentage of dull shell fragments than sediments off the adjacent native beaches, although the samples collected farthest offshore, at a depth of about 15 m, tended to have the highest percentage of dull shells.

Shell color was contoured as a ratio of orange stained to gray-black stained shell fragments. A ratio greater than 1.0

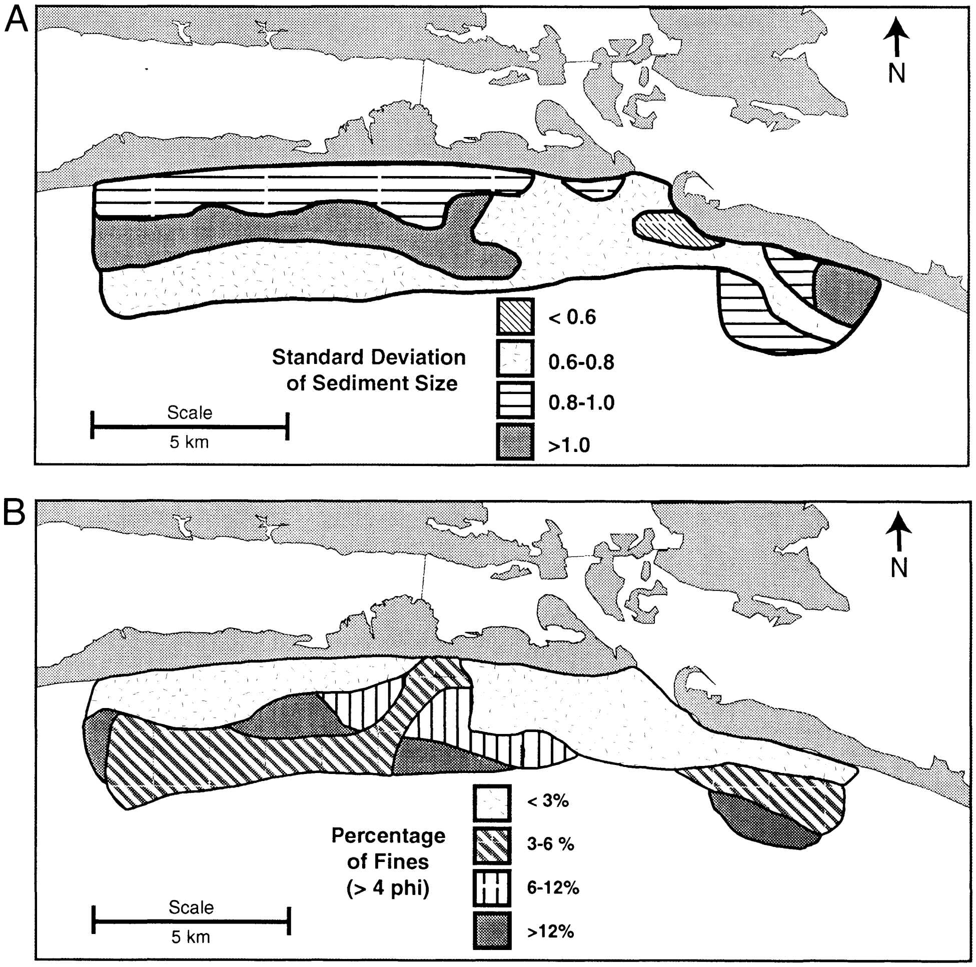

Figure 5. Contour maps showing results of offshore sediment analysis for (A) standard deviation, (B) percentage of fine (<0.63 mm) sediment, (C) percentage of dull shells, and (D) shell color ratio (percentage orange/gray-black stained shells).

represented a highly orange-stained sample and a ratio of less than 0.1 represented a highly gray-black stained sample. The contour map (Figure 5D) shows significant spatial variation in color. Regions close to shore along the native beaches, and in the vicinity of the inlet, had the highest color ratios, whereas the nearshore region along Atlantic Beach and Fort Macon State Park had anomalously low ratios.

The 6 push cores provided insight into the three-dimensional distribution of the shoreface sands. The top 2 cm of each core were subsampled and analyzed in a similar manner to the 1996 and 1997 surface samples. Three general sediment types in the cores were identified from lithologic descriptions, photographs, and x-ray radiographs: (1) fine sand, often finely bedded, light gray with gray shell fragments, (2) very coarse shell-hash layer composed of gray and some orange-stained shell fragments, and (3) muddy, dark gray-black sand without bedding, and containing mostly gray shell fragments. Erosional contacts were identified between the shell hash layers and the underlying muddy sediment.

DISCUSSION

Identifying the source, or depositional environment, of coastal sediments in North Carolina using mineralogy is difficult. Whereas quartz and carbonate are too abundant to be useful, phosphorite is a very minor constituent (see LUTERNAUER and PILKEY, 1967) and shows no detectable variation in abundance between the native and renourished sands. Heavy minerals were not a significant constituent of the sand-sized portion of the samples and generally reflected the amount of fine-grained material in a sample. Sediment size and shell characteristics were found to be the most informative and reliable indicators for purposes of this investigation.

Implications of Grain Size

Previous descriptions of depositional environments in the study area (HERON *et al.*, 1985) suggest that distinguishing renourishment from native sand requires simply distinguishing backbarrier from shoreface and beach sands. Sediment

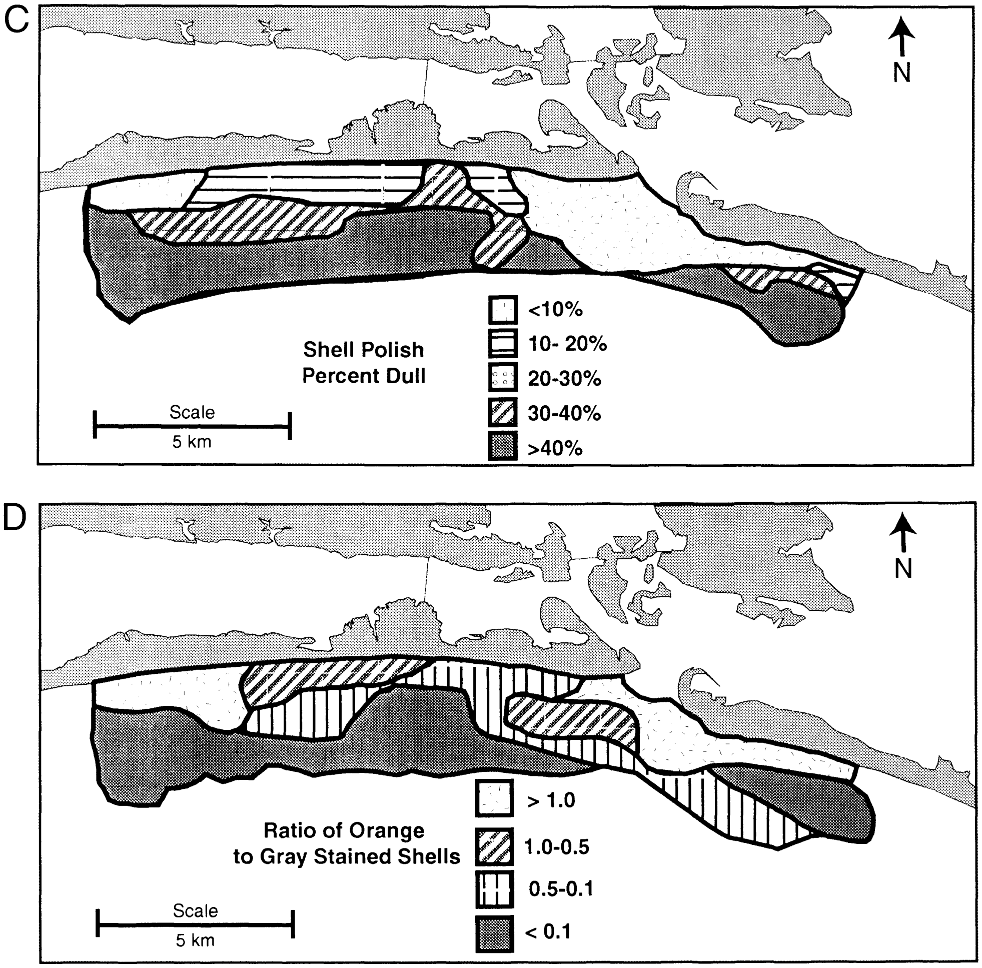

Figure 5. *Continued.*

analyses revealed that mean grain sizes of the native and renourishment sands (Figure 4A) were in fact similar but that the standard deviations of renourishment sediments were significantly higher due to their large amount of mud and shell. Analyses undertaken by the USACE (1993) to determine sediment size differences between the native sands and the borrow (renourishment) material, revealed standard deviations similar to those reported here. HALL (1995) also evaluated the dredged borrow sands with respect to their suitability as renourishment fill on the oceanfront beaches and reported that the renourishment sands were more poorly sorted than the native sands and shell content was significantly greater in the renourishment sands.

Although the goal in most beach renourishment projects is to find borrow sands that are compatible (similar mean grain size) with native sands, opportunistic use of available borrow material may not allow this goal to be achieved. Further, a single mean grain size will not accurately reflect the size distribution of a large quantity of sediment, especially poorly-sorted sediment. Thus, standard deviation, in association with mean grain size, is obviously a better measure for characterizing sediments than mean sediment size alone, and the high mud content that led to poor sorting values provided a good tracer.

Shell Color and Depositional Environment

Shells are good environmental indicators because they can readily acquire diagnostic characteristics from their original environment of deposition that they do not later lose. For example, shells from reducing environments, such as back-barrier lagoons, attain a gray-black stain (DOYLE, 1967, and PILKEY *et al.,* 1969). Doyle examined the accumulation of gray-black stain on several species of shells by subjecting them to sulfate-reducing conditions in the lab, and by burying them in a backbarrier mud. He determined that the stain is composed of a combination of micro-crystalline pyrite, iron monosulfide, humic acid, and organic material.

In oxidizing environments, such as subaerial beaches, the shells are stained-orange from iron-oxides. We were unable to find literature that specifically discussed iron-oxide staining, although a general reference to orange stained shells in

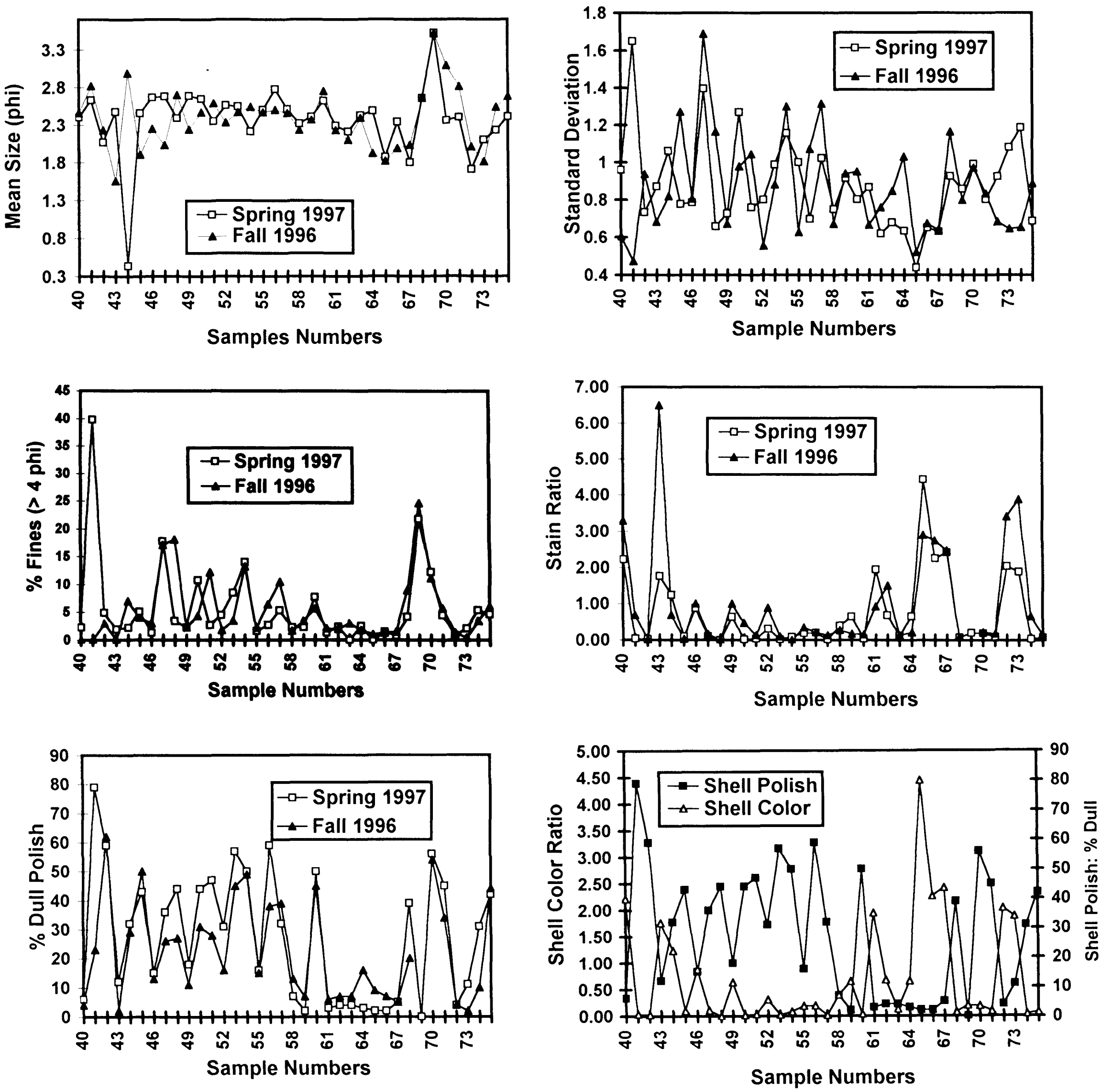

Figure 6. Comparison of 1996 and 1997 samples for (A) top left, mean sediment size (phi) (B) top right, standard deviation of sediment size, (C) middle left, percentage of fines, (D) middle right, shell-stain ratio (orange/gray-black stained shells), (E) bottom left, percentage of dull shell fragments, and (F) bottom right, comparison of shell color and polish for the 1997 sample set.

BRAUER (1974) attributes the staining to iron in fresh water. Regardless of exact origin of the stain, orange-stained shells were well-documented in the native sands of the study area and provide a useful indicator.

White shell fragments were poor environmental indicators because the color was not environment specific; it may have been a result of sun bleaching, age, or simply because the shells were unstained. Also, white shells were found on both renourished and native beaches in significant, but varying quantities.

The usefulness of shell staining was shown by results that indicate a clear relationship exists between shell color (orange or gray-black) and sample location. Sands from the native beaches contained 50–80% orange-stained shell fragments, whereas samples from the renourished beaches contained 0–50% orange-stained shell fragments.

Shell Polish and Relative Age

Stratigraphy and geologic history of the field area provide the key to understanding how shell polish can.be used as a sediment source indicator. Sediments used in the renourishment projects were dredged from a depth of 14 meters (47 ft) below mean low water. Sediments at this depth should stratigraphically correlate with the cores collected by STEELE (1980) on Bogue Banks and SUSMAN (1975) on Shackleford Banks, although detailed stratigraphic work has not verified this assumption. Assuming that the stratigraphy correlates, the sediments in the renourishment project were probably at least 14,000 years old.

Experiments by POWELL and DAVIES (1989) demonstrated a strong relationship between shell texture and age; they concluded that an older shell is duller than a younger shell. Although absolute age relationships are not possible using their method, shells can be grouped into relative age categories. In another study, SWIFT *et al.* (1971) identified relict shelf sands on the basis of shell fragments, and described them as being solution—pitted, abraded, and corroded. They also discussed textural parameters that can be used to identify dual origin of a single sample. The dual origin indicator is particularly applicable to our work considering the dual age of the sediments: the relatively young native sands and the old renourishment sands. From the shell analysis we determined that the renourishment sediments had a significantly higher percentage of dull shells than the native sands (Figure 4C).

Categorization of the Offshore Samples

Sediment samples collected from the subaerial beach were easily categorized as native or renourishment sands by the above sedimentological characteristics. Categorizing the offshore samples into only one of the three possible sediment types was more difficult because the samples may have been a combination of several sediment types: native, renourishment, and/or shelf sands. While one may argue that relict backbarrier sediments cropping out on the beach or shoreface can explain the sediment types observed offshore, the regressive stratigraphy of both Bogue and Shackleford Banks suggest that this is unlikely. The cores collected by STEELE (1980) on Bogue Banks and SUSMAN (1975) on Shackleford Banks reveal that there is only one small region where relict backbarrier sediment could be cropping out near the surface; the other cores indicated that the backbarrier sediments were located in the stratigraphic record at a depth of at least 10 meters below mean water level.

In order to categorize samples into types, it was necessary to assign values to each characteristic. With regard to shell polish, samples with less than 10% dull shells were classified as native sands, 10–30% as renourishment sands, and >30% as relict shelf sediments. With regard to shell color, samples with a color ratio greater than 1.0 were classified as native, between 0.1 and 1.0 as renourishment, and below 0.1 as relict shelf material. Renourishment sands, unlike shelf sands, contain a small, but measurable amount of orange-stained shells not found in the shelf sediments.

When color and polish are used together, a remarkably clear definition of renourishment sand can be established because of the strong negative correlation between orange-stained shell fragments and dull shell fragments. A nonparametric correlation was calculated using Spearman's rank correlation coefficient. The analysis resulted in a Spearman's coefficient of −0.77, which indicates that sediments with well polished shells are usually orange stained, and dull shells are usually gray-black stained. A graphical representation of the correlation is provided in Figure 6E.

Possible sources of fine sediment (<0.063 mm) in the nearshore include outflow from backbarrier environments through Beaufort Inlet, shoreward transport of relict lagoonal sediments from the outer shelf, and renourishment sediments. Fine sediments from the outer shelf are probably not transported from this deeper, lower-energy bottom environment to a higher-energy environment in shallow water, and we believe it unlikely that nearshore fines originated from the outer shelf. Discriminating between fines from the renourishment project and from the outflow of Beaufort Inlet is difficult, although a large plume of fine sediments was observed during the beach pumpout process. In 1986 the water turbidity in the vicinity of the pumpout was up to 250 Nephelometric Turbidity Units (NTU), which greatly exceeded the background levels and levels required to meet the state water quality standard of 25 NTU (USACE, 1993). Measurements for the 1994 pumpout were not available, although similar conditions would be expected since sediments in the 1986 and 1994 projects both originated from the inner harbor. Thus, one can argue that the renourishment of Atlantic Beach/Fort Macon is a likely source for the fines found in the shoreface of Bogue Banks.

Figure 7 shows an interpretation of the distribution of the three sediment types (native, renourishment, and shelf) using a combination of their sedimentological characteristics. Dispersal of fair-weather sediment (Figure 7A) was interpreted from the sediment distribution during the relatively calm 1997 sampling period. According to the interpretation, renourishment sediments were not significantly transported in either the east or west longshore directions; they appear to have remained within a swath directly offshore of the renourished beach. Thus, the renourishment on Atlantic Beach and Fort Macon State Park did not appear to have significantly served as a source of material to the adjacent Pine Knoll Shores region.

Figure 7B is an interpretation of the sediment distribution during storm conditions. The interpretation is based on push cores and the 1996 sediment samples that were collected shortly after two hurricanes, Bertha and Fran, impacted the area. It is important to note that the renourishment sediments were identified out to the mid-depth locations near the Hoop Pole Creek region, which was the site of an inlet in the late 1800's. Cores collected in this region had distinct shell-hash layers that cut into older, relict sediments. The layers of shell hash are indicative of storm-induced transport, and the color and polish of the shells indicate that they were probably transported offshore from the renourished beach, rather than towards shore from the shelf or from in-place exhumation. Surface sample #44, collected off Pine Knoll Shores in 1997, was also composed of a shell-hash material, but contained more orange-stained shells (ratio = 1.24) and was interpreted to have been transported from the native beach. In BATTEN'S (1962 and 1959) maps, regions of shell hash (greater than 40% carbonate) were identified east of the Hoop Pole Creek region, but these shelly regions were not found in the 1996 or 1997 sample sets.

The thicknesses of the renourishment material in the cores were determined from sharp erosional contacts between renourishment sands and underlying relict sands using a combination of lithologic and x-ray radiograph data. It appears that the renourishment sediments were thickest near Fort

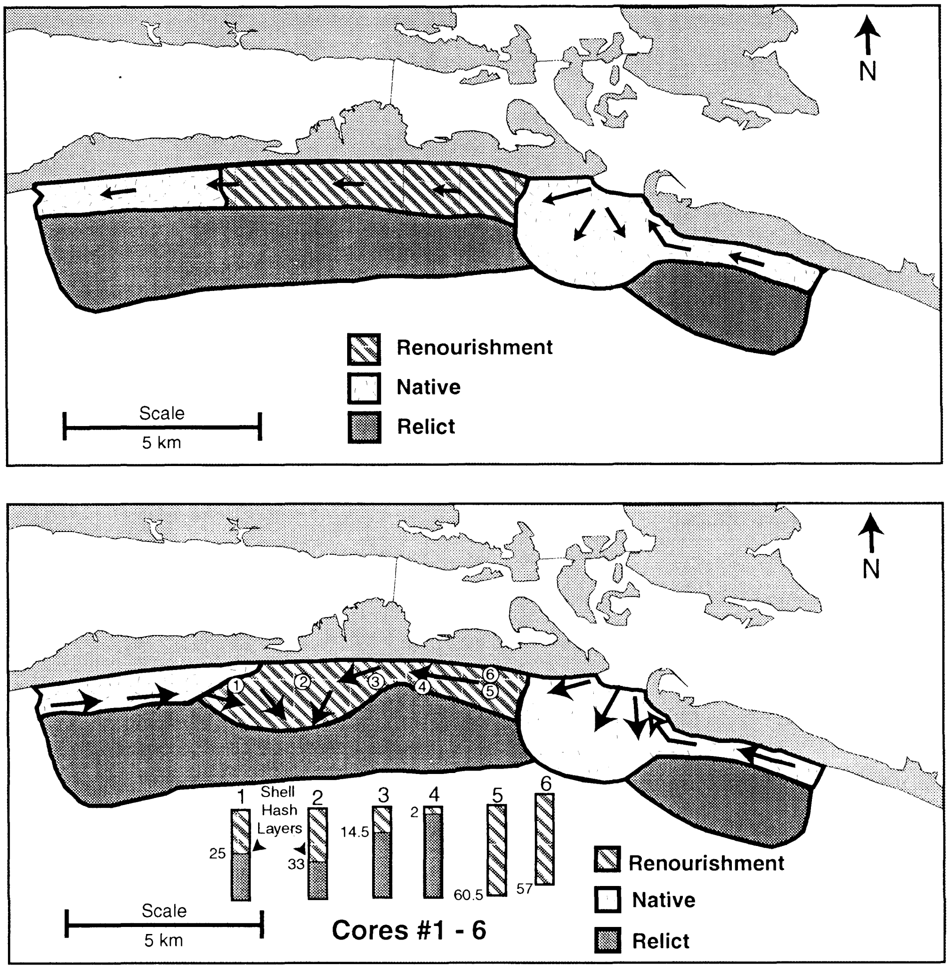

Figure 7. Interpretive maps of sediment types and dispersal directions for (A) top, fair weather conditions, and (B) bottom, storm conditions. Schematic core descriptions show thickness (cm) of the renourishment sediments in the cores.

Macon State Park, and very thin between Fort Macon and Atlantic Beach. None of the cores on the eastern portion of the study area (Cores 3–6) contained shell-hash layers.

Implications of storm layers can be best interpreted in light of a side-scan sonar survey (Figure 8) conducted and made available by THIELER (per com. 1997). The side-scan sonar survey shows areas of fine sand (dark) and coarse, highly reflective sand and gravels (light). Most of the highly reflective sands and gravels were localized in elongate, shore-perpendicular features. Small-scale bedforms (1-m wave length) with their axes parallel to shore were present within the elongate regions. These composite features are interpreted to be rippled scour depressions (RSD).

Although their origin is not well known, CACCHIONE *et al.* (1984) and THIELER *et al.* (1995) found evidence of rapid, storm induced cross-shore transport in association with RSD features. CACCHIONE *et al.* (1984) reviewed characteristics of rippled scour depressions and proposed that the mechanism for their formation was storm-induced downwellings that create bottom currents in the offshore direction. In their study on the inner shelf of California, the highly reflective coarse swaths (RSD) were found to be composed of well-sorted, coarse-grained, shelly sediments, and the low reflective dark areas were composed of fine sediments that contained substantially less shell debris (CACCHIONE *et al.*, 1984). The shell hash layers in Cores 1 and 2, and surface sample #44 from the 1997 sample set, were similar to the highly reflective sediment description above, and we speculate could have been formed under similar conditions.

CACCHIONE *et al.* (1984) proposed that the shell hash associated with RSD are sediments left behind after bottom currents winnow away the finer sands. However, we believe from our investigation that the shell material may have actually been transported offshore from the beach. The color and polish of the shells in the shell-hash layers (as discussed above), along with the erosional contacts found at the base of the shell layers in the cores, provide evidence that contradicts the winnowing hypothesis, and indicates possible storm-induced scour and subsequent deposition.

Results of a related beach profiling study (ROESSLER, 1997)

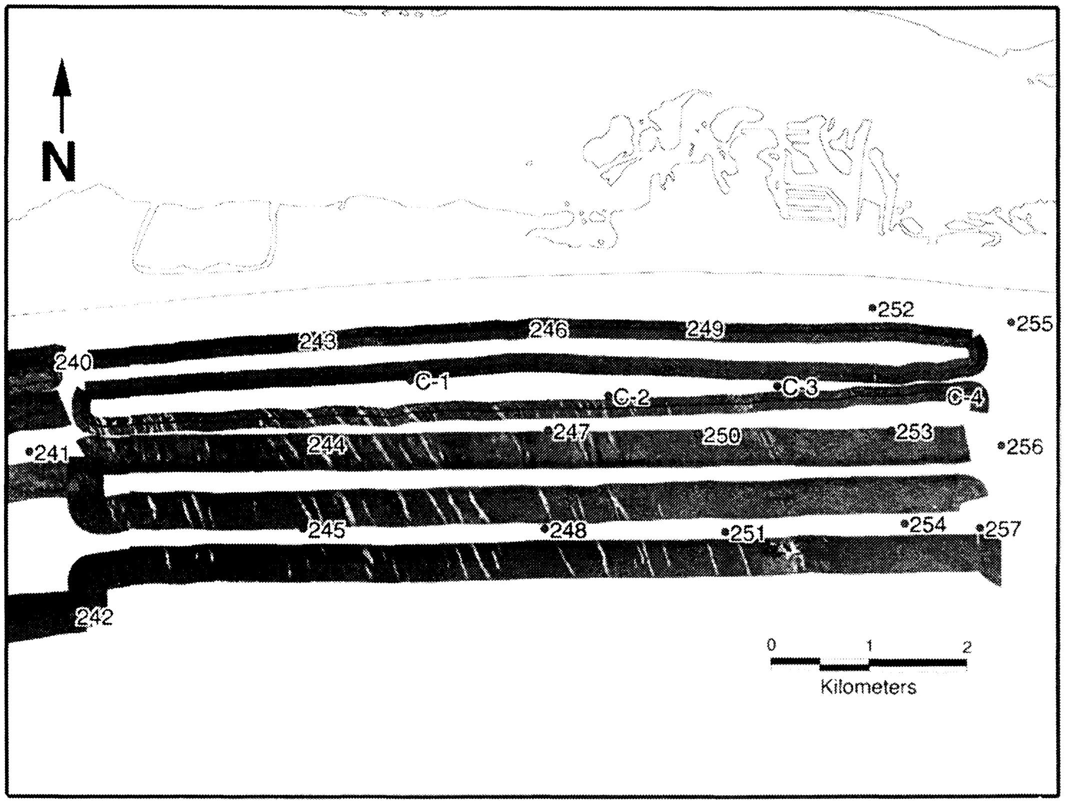

Figure 8. Side-scan sonar survey mosaic from Thieler (per com., 1997). Light areas represent highly reflective, coarse sediments and dark areas represent low reflective, fine sediments. The shore-normal swaths of light colored, highly reflective material are interpreted to be rippled scour depression features.

indicate that there were sites of active erosion on the beaches shoreward of the storm layers (shell hash) identified in sample #44 and in Cores 1 and 2 in the Hoop Pole Creek region. Evidence of RSD were also found offshore of these erosional hotspots. Geologic framework may play an important role in these coastal processes (RIGGS *et al.,* 1996), including the location of RSD features (CACCHIONE *et al.,* 1984). The importance of RSD features, in relation to beach renourishment, lies in the evidence they provide for offshore sediment transport. Offshore transport may provide a possible sink/loss of sediments from the renourished beaches, as well as the apparent lack of renourishment sediments downdrift of their location of introduction.

CONCLUSIONS

This study shows that rapid, inexpensive, and relatively simple methods can be used to determine the distribution of renourishment sediments offshore, and thus can provide insight into the fate of the these sediments. Specifically, we have found that shell color, shell polish, and sediment size are especially useful indicators. Abundant, well-polished, orange-stained shell fragments are characteristic of native beach sands whereas sediments with mostly dull, gray-to-black stained shells are characteristic of renourishment sediments.

1) Shell color, which is directly attributable to iron staining, separates native shell that has been exposed on the subaerial beach from renourishment shell that has been dredged from reducing environments.
2) Shell polish (surface texture) can also be used as a proxy for relative age and exposure history. Whereas renourished beach sands had significantly more dull shells than native sands, the dullest shells were identified in samples collected farthest offshore, which were interpreted to be relict shelf sediments.
3) Grain size characteristics were useful because native sands had lower standard deviations in sediment size than renourishment sediments. High standard deviations in renourishment sediments are attributed to the large amount of mud and the high shell content.
4) Contour plots of sediment characteristics indicate that most of the renourishment sediments tend to remain within the inner shelf environment. Longshore dispersal of renourishment sands was found to be insignificant, but shell hash layers noted in cores and rippled scour depressions noted in side-scan sonar imagery (THIELER, 1997), suggest widespread cross-shore transport.

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