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RECONSTRUCTING SHOAL AND CHANNEL CONFIGURATION IN BEAUFORT INLET: 300 YEARS OF CHANGE AT THE SITE OF *QUEEN ANNE'S REVENGE*

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ABSTRACT

Beaufort Inlet, which has served as a conduit between ocean and sound since at least the early 1600s, is fronted by a large ebb tidal delta that holds the artifacts of *Queen Anne's Revenge*, which ran aground in 1718. Approximately 25 maps and charts, dating to the early 1700s, have been digitized in order to reconstruct the early configuration of the inlet, determine how the inlet has changed over the past three centuries, and answer the question as to why, in such a shallow, heavily-traveled and close-to-shore location, the artifacts remained undiscovered until 1996. Results indicate that the main channel at Beaufort Inlet was oriented to the southwest throughout most of the 1700s and that there was extensive offshore pivotal movement of the channel but little net migration. Depth plots show five episodes of burial at the wreck site with average duration of 45 yr, and nine distinct changes in channel orientation from southeast to nearly due west. Depth and duration of burial were clearly tied to channel location with deepest burial occurring when the inlet channel was oriented to the south. Early bathymetry suggests that the ship ran aground on the terminal lobe of the ebb tidal delta (perhaps intentionally) after safely crossing the 4.5-m-deep outer bar; bathymetric information also suggests that the wreck has been buried for much of its life on the bottom (225 out of the past 282 yr), thereby diminishing the chances for discovery.

INTRODUCTION

Tidal inlets are one of nature's most dynamic coastal features. As conduits between ocean and sound, tidal inlets are shaped by wave-, tide-, and storm-driven currents, and they open and close in accordance with the balance between deposition of sediments and scour by currents. Beaufort Inlet, formerly Old Topsail Inlet, is one of North Carolina's largest and oldest tidal inlets. It is reported to have opened and been navigable prior to 1600 (Fisher, 1962) and now, four centuries later, provides deepwater access to the Port of Morehead City. From an historical perspective, Beaufort Inlet is also one of the state's most interesting inlets because it holds on its ebb shoal the remains of Blackbeard's flagship, the *Queen Anne's Revenge (QAR)*, which ran aground in 1718, yet was not discovered until 1996 (Lusardi, 2000).

Virtually all inlets are fronted by a composite shoal system referred to as the ebb tidal delta (Hayes, 1980; Nummedal and others, 1977). Sands in these shoals modify incoming wave energy and influence adjacent barrier islands (Cleary and Marden, 1999). They are also a significant hazard to navigation. The discovery of the *QAR*, approximately two km offshore and just west of the present navigation channel in Beaufort Inlet, has led to much speculation as well as new collaboration between marine archaeologists and geologists working at the site. The grounding of the *QAR* in approximately 3.7 m of water (established from the draft of the ship) was almost certainly within the shoal complex of the ebb tidal delta, thus leading to

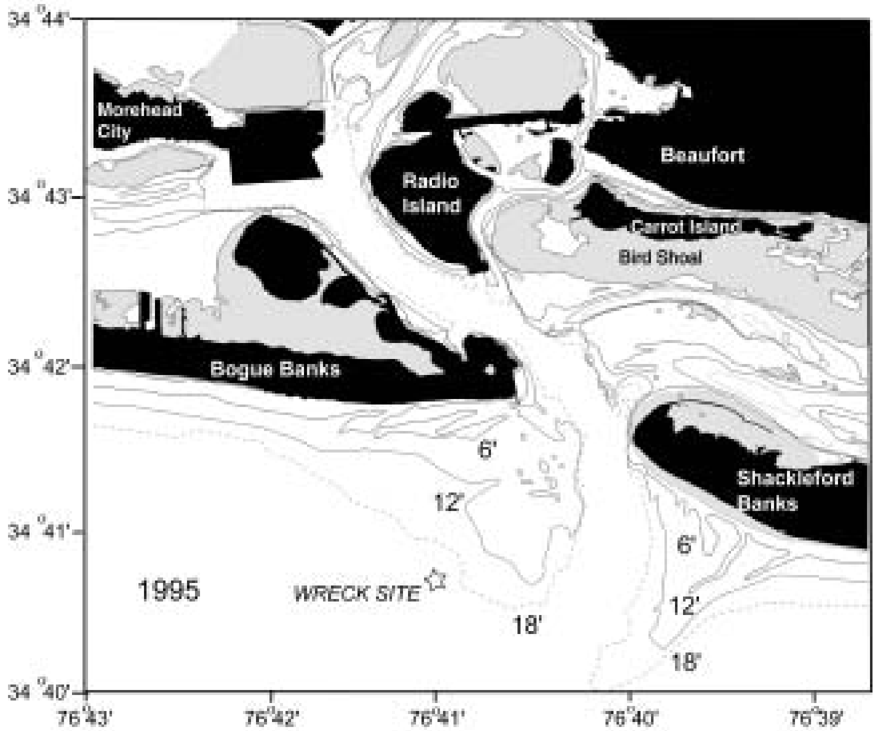

Figure 1. Map showing Beaufort Inlet and location of the *QAR* wreck site. The platform of sand extending seaward of the inlet defines the ebb tidal delta. Swash bars migrate across the tidal delta surface often attaching to the adjacent barrier islands.

many interesting scientific questions. For example, what did Beaufort Inlet look like when the ship ran aground in the early 1700s? How has the inlet changed in the ensuing three centuries? Why wasn't the wreck discovered sooner in this shallow, heavily-traveled, close-to-shore location? And, what role might geology play in helping to find or understand other wrecks?

The purpose of this paper is to reconstruct the early configuration of Beaufort Inlet and to determine the patterns of change that have occurred in the main channel used for navigation and on the shoals of its ebb tidal delta. Using data from historic maps and charts, this paper addresses some aspects of the changes in the configuration, size, orientation, and depth of the channel and shoal system; from this information it has been possible to infer the speed and duration of burial and scour that result from inlet processes operating on decade time scales. The following companion paper addresses more specifically the impact of waves and currents at the wreck site, especially during storms, and provides a conceptual model for scour of the seabed and settling of artifacts. This geological information, in turn, provides important clues on the archaeological history of the *QAR.*

METHODS

Approximately 40 historic maps and charts (mostly copies) were purchased or obtained on loan for this study. Primary sources included the North Carolina Maritime Museum, Ft. Macon State Park, the National Archives and, in the case of more recent maps, those produced by the U.S. Coast and Geodetic Survey and its successor the National Ocean Survey (National Oceanic and Atmospheric Administration). After screening for quality, a subset of 22 maps spanning 265 years was selected for analysis. Our original intent was to find at least one survey very close to or possibly preceding the date of the grounding (1718); however, the earliest available map was that of Edward Moseley in 1733 and the earliest map considered to be of reasonably good quality was the Wimble Chart of 1738. We recognized early on that it would not be possible to use the 1700s maps except for obtaining depths of the inlet channel and orientation of the inlet channel.

Maps selected for analysis were digitized electronically on a Calcomp 9500 digitizing table using Didger software. Digitizing the shoreline and bathymetry over successive surveys allowed for digital transformation and display at any scale, thereby allowing comparisons that give the sequence of change over time. The land-water interface was usually well delineated; however, on some maps, even throughout the 1800s, there was uncertainty in the boundaries of tidal flats and intertidal wetlands. Because our primary interest was in the inlet channel and offshore shoals, this uncertainty was of minor concern. The lack of latitude and longitude, or an accurate distance scale, on maps throughout much of the 1700s presented a more significant problem. Great liberty was evidently taken by mapmakers in areas where survey data were scarce, and the maps of the 1700s were generally disappointing with regard to the information that they provided. The vertical datum also presented a potential source of error since mean sea level, mean low water, and mean lower low water were all used at various times for vertical reference. The gradual rise in sea level (~0.5 m over the past 280 years) was probably accounted for on the maps each time a vertical datum was reestablished, but has nevertheless resulted in an actual increase in water depth at the site. Because of their importance to safe passage through the inlet, we believe that the early marine surveyors would surely map the main navigation channel and surrounding hazards most carefully; we therefore believe that the orientation and depth of the main channel are the most accurate features depicted on these maps. By the early 1800s the reliability of maps had increased significantly, and by the mid-1800s the quality is considered very good to excellent.

RESULTS AND DISCUSSION

History of Inlet Change

Beaufort Inlet is located within the low-energy depositional limb of the Cape Lookout Cuspate Foreland along the central North Carolina coast (Figure 1; also see Steele, 1980 and Moslow and Heron, 1994). Situated between Bogue and Shackleford Banks and opening to the south, the inlet is sheltered from northeast storms, yet periodically experiences significant wave energy from southwest winds and during hurricanes. Previous sampling has shown that the ebb tidal delta is comprised of compact, fine to medium sands that have been derived from the adjacent longshore transport system (Reed and Wells, 2000). Layers of shell hash, which are common throughout at least the upper 1-2 m of sediments, are probably indicative of storm deposits. Waves frequently break on the ebb tidal delta and, during hurricanes, there may be significant residual transport of sediment (McNinch and others, this issue).

Throughout most of the 1700s, the navigation channel opened offshore to either the southwest or west-southwest and made a rather consistent arc back to the north and northwest once inside the barrier islands (Figure 2). The 1738 Wimble chart gives an especially clear indication of alignment for safe passage through the inlet, which required siting on the eastern margin of Bogue Banks and the “white house” in the town of Beaufort (knowledge of the early channel alignment was used to narrow the search for the *QAR*; Masters, 1998). The early maps depict tremendous variation in the length and orientation of Bogue Banks and Shackleford Banks, but it is unlikely that these islands are accurately portrayed (except in the proximity of the inlet) because the maps were made for marine rather than terrestrial purposes. Although the ebb tidal delta was poorly defined in maps of the 1700s, and there were few soundings outside the main navigation channel, most surveys show an intertidal or shallow subtidal shoal extending nearly due west off Shackleford Banks. The consistent channel alignment to the southwest and west-southwest through-

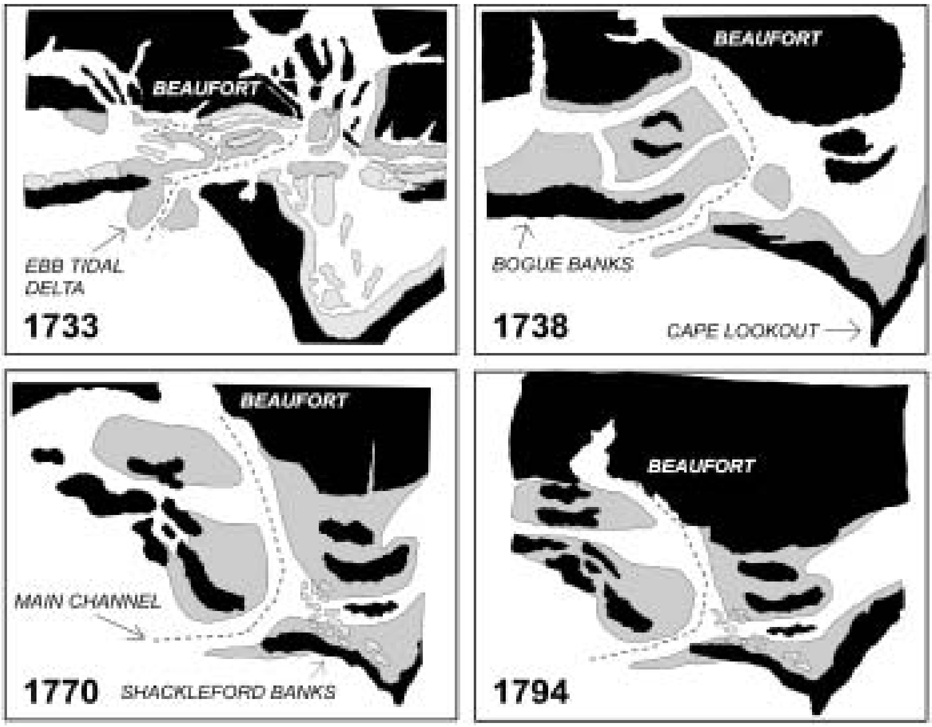

Figure 2. Maps of the 1700s showing the location and orientation of the main navigation channel. These maps have been reproduced, insofar as possible, at the same scale. Lack of latitude/longitude and accurate distance scales suggest substantial errors in many of the early maps; however, we believe that the channel orientations are correct and that channel depths (not shown; see Table 1) were reasonably accurate. The map references/surveyor names are Edward Moseley (1733), Wimble Chart (1738), John Collet (1770), and Holland Chart (1794).

out the 1700s was clearly tied to the persistence of this feature. Water depths within the channel ranged from 3.6 to 12.5 m (taken directly off the charts) but the outer bar, where the distal channel shoals quickly, remained at about 4.5 m (15 ft).

By the early 1800s the map-making process had improved so significantly that details of the ebb tidal delta could be used more effectively in navigation. For example, a chart in 1806 depicted, perhaps for the first time, a more realistic-looking ebb tidal delta, and by the mid-1800s the maps had as much detail as those in the early to mid 1900s (Figure 3). Maps of the 1800s also revealed the strong connection between the inlet and the adjacent barrier islands, which has been well documented in the literature (FitzGerald, 1988). Unlike the 1700s, the navigation channel showed considerable offshore movement throughout the 1800s, undergoing pivotal motion that spanned an arc of at least 90 degrees within the ebb tidal delta. Deflection of the channel typically resulted in erosion of one of the flanking barriers and development of a highly skewed ebb tidal delta orientation (Cleary and Marden, 1999). Despite the pivotal movement, there was little net migration and Beaufort Inlet, in contrast to many of North Carolina's inlets, has occupied a relatively fixed position between Bogue and Shackleford Banks. Several of the surveys were annotated with warnings about the "constant breakers" that occurred along the margins of the channel and on the broad swash bar platform as far as 2 km offshore. Water depths within the channel (taken directly off the charts) ranged throughout the 1800s from 4.5 to 12.5 m and the outer bar continued to maintain a nearly constant depth of

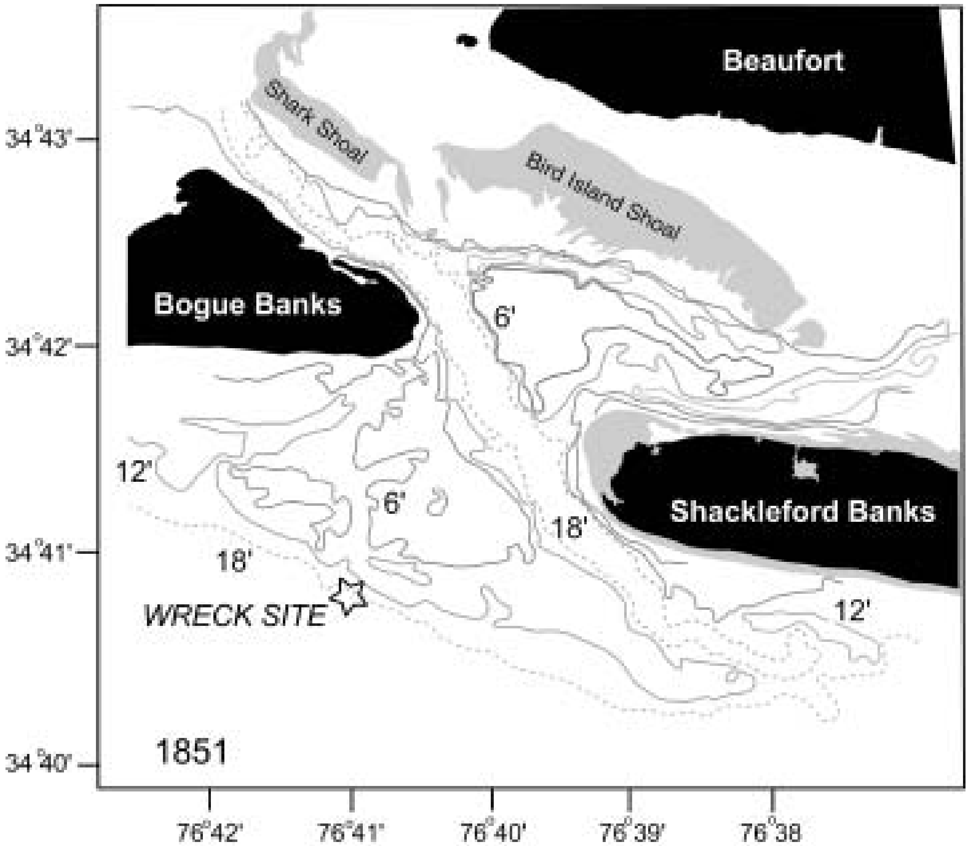

Figure 3. Detailed map of 1851 showing orientation of channel to the southeast, impinging on the western end of Shackleford Banks. The inlet has narrowed considerably since the mid-1800s.

4.5 m (15 ft).

Beaufort Inlet was dredged beginning in 1911 and by 1995 a total of approximately 17 million cubic meters of sand had been permanently removed and placed in an offshore disposal area seaward of the ebb tidal delta (Roessler, 1998). Therefore, throughout most of the 1900s and especially over the past 50 years, natural channel processes were continuously and significantly altered. The channel now maintains a southwest orientation and is dredged to a navigation depth of 14.3 m (USACE, 1994). According to Cleary and Marden (1999), by 1952 dredging in the channel had segmented the ebb tidal delta, reducing bypassing of sand through or around the inlet by natural processes. The effect was rapid elongation of a 1.3-km-long spit on Shackleford Banks that contained an estimated 4.6 million cubic meters of sand. A tendency for slight movement to the west during the mid 1900s led to the construction of a jetty on the eastern margin of Bogue Banks in 1969, immediately halting further movement of the channel.

Figure 4 is a composite map that shows from selected surveys the range of channel orientations and locations over the past three centuries. The channel has swept across the *QAR* site several times over the study period. Although there was a wide range in orientations, there was also a high degree of stability at the inlet throat between Bogue Banks and Shackleford Banks, and the channel has undergone essentially zero net migration. Changes in channel orientation have had little effect on the depths of the outer bar, the distal end of the ebb tidal delta's terminal lobe where the *QAR* ran around. Table 1 shows that, until dredging led to significant

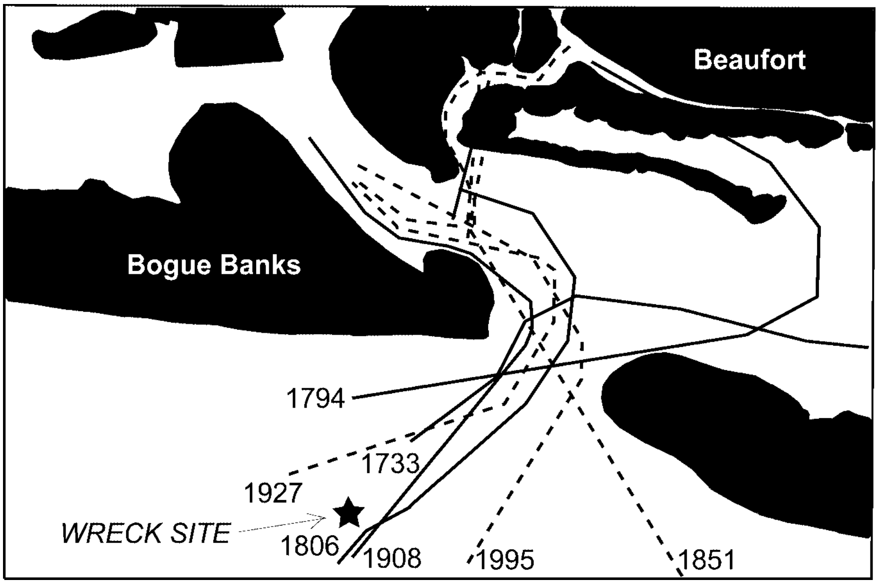

Figure 4. Composite map showing locations of former channels superimposed on modern-day island configuration. Although there has been substantial pivotal change offshore, there has been little net channel migration.

deepening of the channel, the outer bar appears to have been naturally maintained at about 4.6 m (15 ft), a depth that offered little leeway for a ship with a draft of 3.7 m (12 ft).

Table 1. Variations in channel depths of outer bar. Depths reported in the 1962 and 1998 surveys reflect deepening of the navigation channel by dredging. All depths were taken from soundings written directly on the charts; our assumption regarding channel depths on the early charts is that this, most critical information, was accurately determined by lead line soundings. We have no way of assigning error bars to these numbers.

Date	Outer Bar Depths	Map Name/Surveyor	Quality
1733	4.0 m (13 ft)	Edward Moseley	Poor
1770	4.6 m (15 ft)	John Collet	Fair
1794	4.6 m (15 ft)	Holland Chart	Fair
1806	5.5 m (18 ft)	Coles & Price	Good
1830	4.6 m (15 ft)	Blount Map	Very Good
1851	4.6 m (15 ft)	Bache Survey	Very Good
1899	3.0 m (10 ft)	Lucas Chart 561	Very Good
1908	4.6 m (14 ft)	Perry, Jones & Howe	Excellent
1927	4.0 m (13 ft)	USC&GS 420	Excellent
1962	10.7 m (35 ft)	USC&GS 1233	Excellent
1998	14.3 m (47 ft)	NOAA Chart 11545	Excellent

Episodes of Burial

Water depths at the *QAR* site have undergone episodic and significant changes over the past 282 yr. Figure 5 shows that, following the grounding in 1718 when water depth was a maximum of 3.7 m (12 ft), depths (relative to mean low water) have ranged from a minimum of 0.9 m (3 ft) in the mid 1800s to a maximum of 7 m (23 ft) in 2000. Moreover, the variations were tied to five distinct episodes of shoaling that had an average duration of 45 yr. Each episode of shoaling resulted in burial of the artifacts and each was related to changes in channel orientation. For example, the shoalest water depths at the wreck site occurred when the channel was oriented to the south or south-southwest and the greatest water depths occurred when the channel orientation was either southwest or southeast. Since pivotal movement of the channel influences the behavior of swash bars and dictates the location of the levee-like channel margin bars (Cleary, 1996), these changes essentially control the water depths at any given location (e.g. the *QAR* site) on the ebb tidal delta.

It is clear from data in Figure 5 that, despite

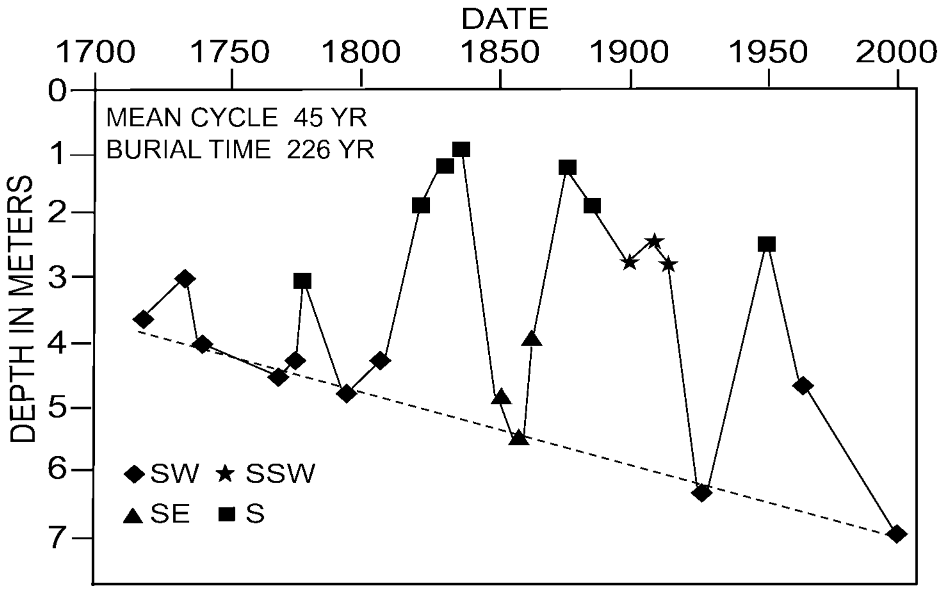

Figure 5. Depth variations at the *QAR* site showing five distinct episodes of artifact burial. Maximum depth of scour has deepened progressively over the past three centuries.

being buried for long periods of time, the artifacts have been settling to greater depths as a result of the progressive increase in bottom depth with each new episode of scour (see McNinch and others, this issue). In other words, the erosion which brings to an end each cycle of burial also leads to a greater substrate depth than before. Thus the artifacts have been settling into or onto deeper and deeper substrates with time. The dashed line shows that the long-term increase in maximum substrate depth has been nearly constant with a rate that, had it occurred gradually, would have averaged 12 cm per decade. Although it is possible that the five episodes of burial (based on 22 maps) are an oversimplification of the actual burial-scour process, e.g. due to storm processes, the observed pattern of inlet change suggests that this is not necessarily the case. For example, as the channel pivoted across the ebb tidal delta between 1800 and 1850, it was changing from a southwest to south to southeast orientation; as the channel pivoted between 1850 and 1900, it was changing back from a southeast to south to south-southwest orientation. In all, there were at least nine distinct changes in channel orientation. Since the artifacts will remain buried until scour creates new water depths that exceed those at the beginning of a burial cycle, it is possible to estimate the total amount of time that the artifacts were buried. If the 5 episodes of burial are a reasonable portrayal of what occurred on the bottom, then the *QAR* has been covered with sand for approximately 226 of the past 282 years, or 80% of its life on the bottom. We recognize, of course, that stabilization of the inlet channel by extensive dredging in the latter 1900s accounts for part of the burial duration.

CONCLUSIONS

The *QAR* ran aground on the terminal lobe of the ebb tidal delta, either deliberately or in trying to cross the outer bar or while navigating the distal end of the southwest-oriented channel. Shallow swash bars and levee-like channel margin bars, which are defining features on ebb tidal deltas, created dangerous shoals that were in many places much shallower than the assumed 3.7 m draft of the vessel. Depth profiles along the channel reveal that the terminal lobe always shoals rapidly towards the outer bar, which apparently has maintained a relatively stable channel depth of 4.5 m over the past several hundred years.

Historic maps show that the main navigation channel at Beaufort Inlet has undergone extensive offshore pivotal movement without net migration of the channel. The channel appears to have changed orientation at least nine times since 1718, affecting change in ebb tidal delta configuration with each orientation change. Changes in channel orientation and in configuration of the ebb tidal delta influence, and are influenced by, the adjacent barrier islands.

Water depths at the *QAR* site have ranged from 0.9 m in the mid 1800s to the present depth of 7 m. There were at least five distinct episodes of burial of the wreck artifacts, averaging 45 yr each. Since the artifacts, once buried, will remain covered by sand until subsequent scour exceeds the previous depth horizon at which burial took place, it is possible to estimate a total period of burial of 226 yr.

It is reasonable to assume that the wreck was not discovered sooner because it has been buried for approximately 80% of the time that it has been on the bottom (due in part to channel stabilization through dredging). Although the channel has pivoted extensively, impacting the water depths at the site, scour from the channel itself has been insignificant in dispersing the artifacts which still remain largely intact. Artifacts have settled from 3.7 m to 7 m as a result of an incremental increase in substrate depth over time; each increase in depth is tied to a burial-scour episode.

Channel modifications which are now having an impact on the ebb tidal delta may also have an impact on the wreck site. Since the position of the navigation is now fixed, burial related to or resulting from channel movement is no longer possible. In fact, loss of sand to dredging and possible flushing of sediment beyond the swash platform may lead to loss of shoulder sand and ebb tidal delta reconfiguration (Cleary and Marden, 1999). Wave refraction modeling indicates that dredging of the channel is forcing the ebb tidal delta farther offshore and that, during the passage of hurricanes, waves can actually break as far offshore as the wreck site (Roessler and Wells, 2000).

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