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Abstract

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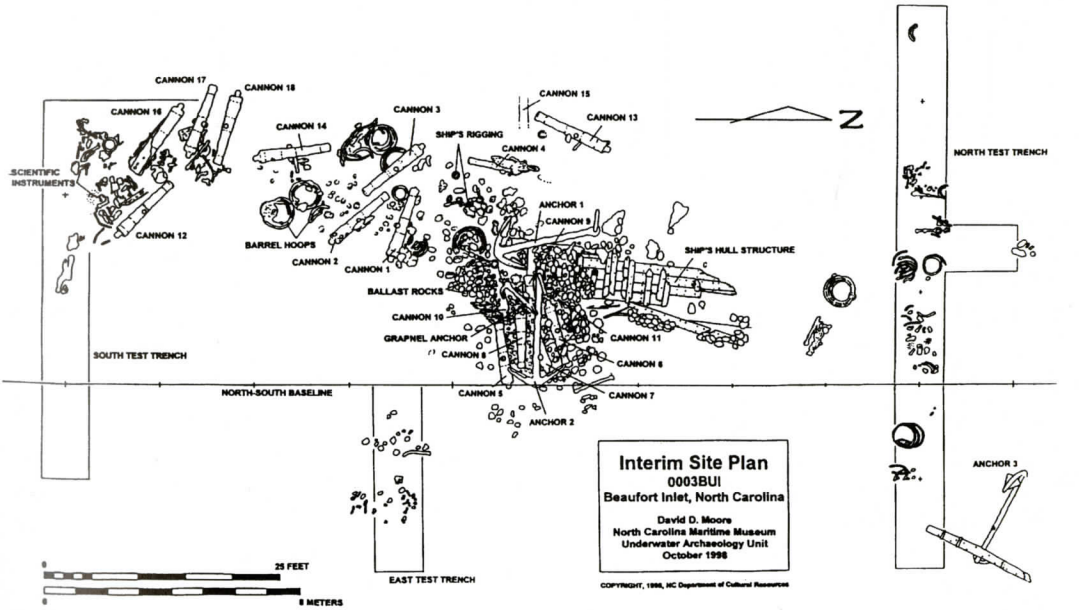
SOUTHEASTERN GEOLOGY

Geoarcheological Investigations at the *Queen Anne's Revenge* Shipwreck Site, Beaufort Inlet, North Carolina



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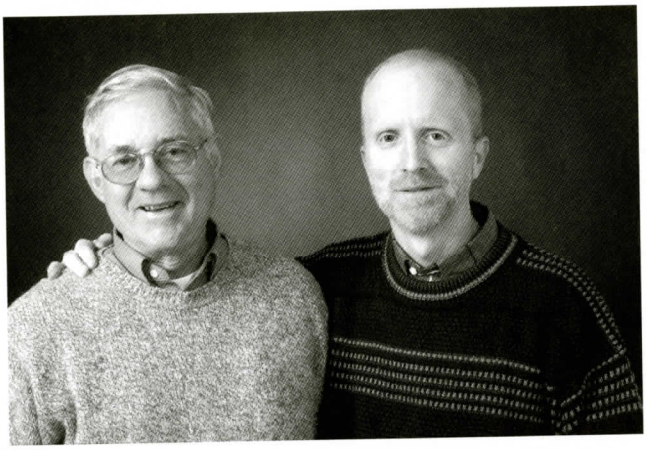

John Callahan was introduced to the geology of the southeast by Dr. Charles Cazeau, at SUNY at Buffalo in 1965, who suggested that he should do his masters' studies at UNC - Chapel Hill. He has been on the faculty of Appalachian State University since 1970, and his work has involved using heavy minerals in exploration geochemistry and environmental geochemistry. He has worked with teachers interested in earth science throughout North Carolina and has completed more than 60 teacher workshops. He was involved with many other geological and educational professionals for at least a ten year period in an effort to have the North Carolina State Dept. of Education accept Earth Science/Environmental Science as the third science required for high school graduation.

John Callahan's involvement with the Blackbeard project began in the summer of 1997 while on a teacher workshop trip to Beaufort's Maritime Museum where ballast stones from shipwreck number 0003BUI (*Queen Anne's Revenge*) were on display with other artifacts. A couple of phone calls enticed colleagues Bill Miller (co-guest editor) and Jim Craig (Virginia Tech) on board, and they've been hooked ever since. Since then he and his colleagues William Miller and James Craig from Virginia Tech have examined many artifacts from this shipwreck.

Bill Miller is an Associate Professor of Environmental Studies at the University of North Carolina at Asheville, where he has taught geology for 11 years. Previously he taught at Ohio Wesleyan University and was a mine geologist at the Austinville zinc-lead mine in southwestern Virginia. His research interests include investigations of metal interactions in sediments, surface and ground water; textural and geochemical studies of ores; regional geological studies (Blue Ridge); and now geoarcheological studies of ballast stones and artifacts from historic shipwrecks. Bill enjoys working with teachers and many colleagues, as well as collaborating with his mentors-turned-collaborators and true friends, Jim Craig and Jack Callahan.

PREFACE

Interest was renewed in the fate of Blackbeard and his ship when Mike Daniel and Phil Masters of Intersal discovered the remains of a shipwreck in Beaufort Inlet, North Carolina. Eventually the wreck was transferred to the Underwater Archaeology Unit of the North Carolina Division of Archives and History, which has led and coordinated efforts to preserve and document the find. Readers of this issue will find details on the history and discovery of the wreck, the physical conditions of the wreck site, description of the artifacts and their corrosion, nature of the encrusting organisms, radiocarbon ages of wooden artifacts and characterization of the ballast stones and their origins. All evidence suggests that the wreck off Beaufort Inlet is indeed that of the *Queen Anne's Revenge*, although no irrefutable evidence of the ship's true identity has been found to date. Research in this truly interdisciplinary effort continues on this wreck and others that are firsts for marine geoarcheology in the southeastern United States.

DEDICATION

This issue is dedicated to Dr. Charles Cazeau (1931 — 1999), who launched many geology students on long and fruitful careers in the southeast and around the world. Chuck was a true gentleman geologist who will long be remembered by anyone he touched by his knowledge and kindness. Chuck leaves behind two wonderful daughters, Sharon and Suzanne, and thousands of devoted former students.

Chuck Cazeau, 1964, Cobalt Series tillite, Kirkland Lake, Ontario, Canada.

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IN SEARCH OF BLACKBEARD: HISTORICAL AND ARCHAEOLOGICAL RESEARCH AT SHIPWRECK SITE 0003BUI

RICHARD W. LAWRENCE

MARK WILDE-RAMSING

Underwater Archaeology Unit
North Carolina Division of Archives and History
Kure Beach, NC 28449

ABSTRACT

In November 1717, English pirates captured the French slave-ship *La Concorde* near the island of Martinque. Led by the notorious Blackbeard, the pirates converted *La Concorde* into their flagship and renamed the vessel *Queen Anne's Revenge*. After spending the winter searching for prizes in the Caribbean, the pirate fleet, consisting of *Queen Anne's Revenge* and three smaller sloops, blockaded the port of Charleston in May 1718. Continuing up the coast, Blackbeard lost his flagship while attempting to enter Beaufort Inlet, North Carolina, and five months later he was killed in a bloody battle at Ocracoke.

Nearly three hundred years later, in November 1996, the private research firm Intersal Inc. discovered a shipwreck in Beaufort Inlet believed to be the remains of *Queen Anne's Revenge*. Since then, this site, designated North Carolina shipwreck 0003BUI, has been the focus of an intense archaeological examination to determine its condition, affiliation, age, and surrounding environment. Over 30 scientists and technicians from 18 universities and research institutions have participated with the North Carolina Underwater Archaeology Unit in conducting research on this intriguing shipwreck. Over the past three years, divers have spent more than a thousand hours on the ocean bottom examining the site armed with a variety of tools and techniques.

One particularly successful geophysical instrument used at the site is the magnetic gradiometer, which provided a means to accurately predict distribution of iron artifacts beneath the seabed prior to excavation. After taking over two thousand readings at the site, researchers identified potential cannon and large metal artifact targets, as well as the overall distribution of cultural materials. Based on this study, archaeologists are now able to project that this shipwreck was a very heavily armed vessel, and carried at least 24 carriage-mounted cannon at the time of sinking. These results, added to those from a battery of other scientific tests conducted at the Beaufort Inlet shipwreck site, provide a compelling body of evidence to support its identification as Blackbeard's *Queen Anne's Revenge*.

HISTORICAL OVERVIEW

The pirate Blackbeard is arguably the most notorious of the sea robbers who plagued shipping lanes off North America and throughout the Caribbean in the early-eighteenth century—an era commonly referred to as the Golden Age of Piracy. Despite his legendary reputation, little is known about the early life of Blackbeard. Even his true name is uncertain, though it is usually given as some variation of Edward Thatch or Teach. He is reported to have served as a privateer during Queen Anne's War (1701 - 1714) and turned to piracy sometime after the war's conclusion. Maritime archaeologist and historian David Moore, spent considerable time tracing the history of Blackbeard. The earliest primary source document that Moore located that mentions the pirate by name dates to the summer of 1717. Other records indicate that by the fall of 1717 Blackbeard was operating off

Delaware and Chesapeake bays in conjunction with two other pirate captains, Benjamin Hornigold and Stede Bonnet. Late in the fall of 1717, the pirates made their way to the eastern Caribbean. It was here, off the island of Martinique, that Blackbeard and his fellow pirates captured the French slaveship *La Concorde*—a vessel he would keep as his flagship and rename *Queen Anne's Revenge* (Moore, 1997).

By examining a variety of primary and secondary French documents, researchers have pieced together a limited history of *La Concorde.* The prominent French merchant, Rene Montaudoin, owned the ship, which operated out of the port of Nantes. French records recount three slave trading expeditions of Montaudoin's *La Concorde*; one in 1713, a second in 1715, and the third and final voyage in 1717. Unfortunately, records have yet to be located that describe how Montaudoin acquired *La Concorde* or the date and place of the ship's construction (Mettas, 1978).

During the eighteenth century, Nantes, located at the mouth of the Loire River, was the center of the French slave trade. For much of that century, the Montaudoin family operated the leading company involved in this nefarious but lucrative trade. Ships would leave Nantes in the spring loaded with trade goods and travel down the west coast of Africa. There, the captain would purchase a cargo of enslaved Africans to be transported to the New World. The transatlantic voyage, known as the Middle Passage, would take up to two months to complete. The Africans were usually sold at the French islands of Guadeloupe, Martinique, or Saint Domingue where they served as laborers in the sugar cane fields. Emptied of their human cargo, ships would take on new freight, usually sugar, and return to France.

The last voyage of *La Concorde* and the ship's subsequent capture by pirates are documented in depositions filed by two of the vessel's officers, Captain Pierre Dosset and Lieutenant Francois Ernaut, when the two finally returned to France. According to Dosset and Ernaut's reports, *La Concorde* left Nantes on March 24, 1717. The 200-ton ship was armed with sixteen cannon and had a crew of seventy-five. On July 8, *La Concorde* arrived at the port of Judas, or Whydah, in present-day Benin. There they took on a cargo of 516 captive Africans. The captain and officers also obtained about twenty pounds of gold dust for their own account. *La Concorde* took nearly eight weeks to cross the Atlantic and the hardships of the notorious Middle Passage took their toll on both the Africans and the French crew. By the time they reached the New World, sixty-one slaves and sixteen crewmen had perished (Dosset, 1718, Ernaut, 1718).

After crossing the Atlantic, and only 100 miles from Martinique, the French ship encountered Blackbeard and his company. According to Lieutenant Ernaut, the pirates were aboard two sloops, one with 120 men and twelve cannon, and the other with thirty men and eight cannon. With the French crew already reduced by sixteen fatalities and another thirty-six seriously ill from scurvy and dysentery, the French were powerless to resist. After the pirates fired two volleys at *La Concorde*, Captain Dosset surrendered the ship (Ernaut, 1718).

The pirates took *La Concorde* to the island of Bequia in the Grenadines where the French crew and the enslaved Africans were put ashore. While the pirates searched *La Concorde*, the French cabin boy, Louis Arot, informed them of the gold dust that was aboard. The pirates searched the French officers and crew and seized the gold. The cabin boy and three of his fellow French crewmen voluntarily joined the pirates, and ten others were taken by force including a pilot, three surgeons, two carpenters, two sailors, and the cook (Ernaut, 1718). Blackbeard and his crew decided to keep *La Concorde* and left the French the smaller of the two pirate sloops. The French gave their new and much smaller vessel the appropriate name *Mauvaise Rencontre* (*Bad Encounter*) and, in two trips, succeeded in transporting the remaining Africans from Bequia to Martinique (Mettas, 1978).

Leaving Bequia in late November, Blackbeard with his new ship, now renamed *Queen Anne's Revenge*, cruised the Caribbean taking prizes and adding to his fleet. According to David Moore's research, from the Grenadines,

Blackbeard sailed north along the Lesser Antilles plundering ships near St. Vincent, St. Lucia, Nevis, and Antigua, and by early December he had arrived off the eastern end of Puerto Rico. From there, a former captive reported that the pirates were headed to Samana Bay in Hispaniola (Dominican Republic). No historical records have been located to chronicle Blackbeard's movements during the first three months of 1718, but by April the pirates were off the Turneffe Islands in the Bay of Honduras. It was there that Blackbeard captured the sloop *Adventure*, forcing the sloop's captain, David Herriot, to join him. Sailing east once again, the pirates passed near the Cayman Islands and captured a Spanish sloop off Cuba that they also added to their flotilla. Turning north, they sailed through the Bahamas and proceeded up the North American coast. In May 1718, the pirates arrived off Charleston, South Carolina, with *Queen Anne's Revenge* and three smaller sloops (Moore, 1997).

In perhaps the most brazen act of his piratical career, Blackbeard blockaded the port of Charleston for nearly a week. The pirates seized several ships attempting to enter or leave the port and detained the crew and passengers of one ship, the *Crowley*, as prisoners. As ransom for the hostages, Blackbeard demanded that the pirates be given a chest of medicine. The medicines eventually delivered, the captives were released, and the pirates continued their journey up the coast (Lee, 1995).

Soon after leaving Charleston, Blackbeard's fleet attempted to enter Old Topsail Inlet in North Carolina, now known as Beaufort Inlet. During that attempt, *Queen Anne's Revenge* and the sloop *Adventure* grounded on the ocean bar and were abandoned. Research by David Moore, and others, has uncovered two eyewitness accounts that shed light on where the two pirate vessels were lost. According to a deposition given by David Herriot, the former captain of *Adventure,* "the said Thatch's ship *Queen Anne's Revenge* run a-ground off of the Bar of Topsail-Inlet." Herriot further states that *Adventure* "run a-ground likewise about Gun-shot from the said Thatch" (Herriot, 1719). Captain Ellis Brand of the HMS *Lyme* provided additional insight as to where the two ships were lost in a letter (12 July, 1718) to the Lords of Admiralty. In that letter Brand stated that: "On the 10th of June or thereabouts a large pyrate Ship of forty Guns with three Sloops in her company came upon the coast of North carolina ware they endeavour'd To goe in to a harbour, call'd Topsail Inlett, the Ship Stuck upon the barr att the entrance of the harbour and is lost; as is one of the sloops" (Moore, 1997).

In his deposition, Herriot claims that Blackbeard intentionally grounded *Queen Anne's Revenge* and *Adventure* in order to break up the company, which by this time had grown to over 300 pirates. Intentional or not, that is what happened as Blackbeard marooned some pirates and left Beaufort with a hand picked crew and most of the valuable plunder (Herriot, 1719).

Blackbeard's piratical career ended six months later at Ocracoke Inlet on the North Carolina coast. There he encountered an armed contingent sent by Virginia Governor Alexander Spotswood and led by Royal Navy Lieutenant Robert Maynard. In a desperate battle aboard Maynard's sloop, Blackbeard and a number of his fellow pirates were killed. Maynard returned to Virginia with the surviving pirates and the grim trophy of Blackbeard's severed head hanging from the sloop's bowsprit (Lee, 1995).

DISCOVERY AND RESEARCH

In 1988, the private research firm Intersal Incorporated received a permit from the North Carolina Underwater Archaeology Unit (UAU) to search for the remains of *Queen Anne's Revenge* and *Adventure* in Beaufort Inlet. Intersal also held a permit to search the same area for the Spanish ship *El Salvador*, which was lost in 1750. For nearly ten years, Intersal conducted intermittent surveys in Beaufort Inlet with little result. Then, in 1996, Intersal hired shipwreck researcher Mike Daniel to direct field operations. Using historical accounts provided by Intersal President Phil Masters, Daniel selected a survey area that he felt encompassed the inlet's early-eighteenth century entrance channel and bar. In November 1996, the Intersal crew locat-

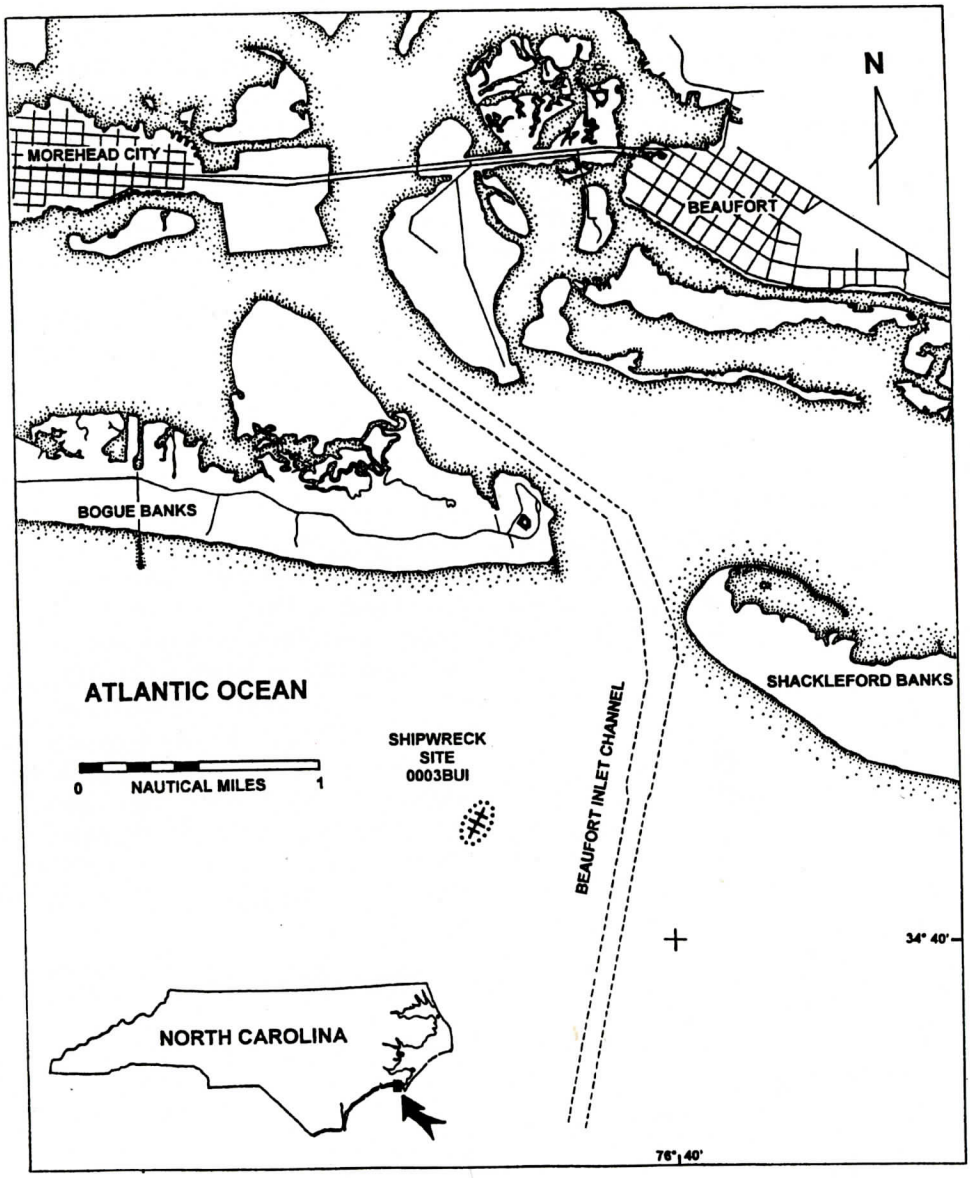

Figure 1. Shipwreck 0003BUI location map.

ed a shipwreck at Beaufort Inlet that they tentatively identified as *Queen Anne's Revenge* (Figure 1). Researchers based that identification on the large number of cannon observed on site and artifacts dating to the early-eighteenth century including a brass blunderbuss barrel and a bronze bell with a date of 1709. The UAU assigned site number 0003BUI to the newly discovered shipwreck.

Since the discovery of site 0003BUI, field studies have included numerous daylong visits to the wreck site and several month-long expeditions, which usually occurred in the fall of each year to take advantage of favorable weather conditions. The primary purpose of those investigations was to collect basic information to prepare a comprehensive site assessment. Underwater archaeologists established a reference

system to map exposed portions of the wreckage, which consisted of a mound of cannons, anchors, and other cultural debris (Figure 2). Using remote sensing surveys and diver searches, researchers also investigated the area surrounding the site to identify associated materials. Finally, exploratory excavations helped define limits of artifact dispersal and provided valuable insight into the shipwreck site's layout. The accompanying papers in this volume attest to the involvement of specialists in the associated fields of geology, biology, and history and reach out geographically throughout North Carolina and beyond its borders. The interpretation of the archaeological findings has been greatly enhanced through interdisciplinary participation.

Initial examination of the shipwreck revealed an exposed mound measuring 25 feet (7.62 meters) by 15 feet (4.57 meters). That mound consisted of eleven cannons, two large anchors, a grappling hook, numerous iron cask hoops, several iron deadeye strops used to secure the ship's rigging, a cluster of cannonballs, and a large number of ballast stones and concretions. Divers located a third anchor 50 feet (15.24 meters) north of the main concentration. The maximum relief above the surrounding seabed is approximately 4 feet (1.22 meters), with most of the exposed remains being less than 2 feet (.61 meters) high.

Intersal conducted a remote sensing magnetometer survey to initially locate *Queen Anne's Revenge*. The magnetometer detects variations, or anomalies, in the earth's magnetic field produced by ferrous objects. Additional surveys conducted in the general vicinity of *Queen Anne's Revenge* located a large anchor south of the main site. The anchor may be associated with the shipwreck since it appears to date from the same time period. Recently, side-scan sonar surveys have been valuable in viewing the surrounding seabed terrain as it relates to the exposed portions of the site.

What has proved even more useful in terms of site interpretation is the use of diver-assisted, magnetometer surveys. This technique provides the means to accurately predict the distribution of buried, iron artifacts prior to excavation. Diver-assisted surveys in which the submersible magnetometer sensor is placed on grid points across the bottom is not new. The first such survey was by archaeologist Jeremy Green during what he referred to as a close-plot magnetometer survey over thirty years ago on the Kyrenia shipwreck in Cyprus (Green, et al, 1967). Green took readings at 2-meter intervals over a 280 square meter area and after contouring the data, was able to predict the presence of buried ferrous materials and/or amphora cargo. During the study, researchers also experimented with the height of the sensor above the bottom in an attempt to determine the mass of the source object.

In 1979, North Carolina geophysicist I. J. Won conducted what he called a precision magnetic survey to evaluate anomaly targets located in Masonboro Inlet near Wilmington, North Carolina. Dr. Won's primary concern was to determine the depths of the causative bodies. To accomplish this, researchers placed the magnetometer sensor on 10-foot (3.05-meters) centers and at varying heights above the bottom. After contouring the data, Won predicted the source object's orientation, length, ferrous mass, and depth, which exceeded 25 feet (7.62 meters) beneath the sand (Won, 1980). A major inlet shift is needed to remove enough sand to ground-truth Won's target; however, the results of his precision survey were promising, as were the close-plot magnetometer surveys conducted by Green and others. After reviewing the environmental characteristics of the *Queen Anne's Revenge* site, as well as other remote sensing instruments currently available, the magnetometer appeared to hold the most promise for effectively investigating its buried remains.

The remote sensing instrument used on this site was a Schonstadt Model GAU-30 Underwater Magnetic Locator. This is called a magnetic gradiometer, since the instrument's sensor is made up of two separate heads and processes data from both to provide a digital readout of the difference between heads. Therefore, much like earlier precision surveys in which the sensor was placed at varying heights, the reading registers only those iron objects that influence one sensor, presumably the lower one, over the

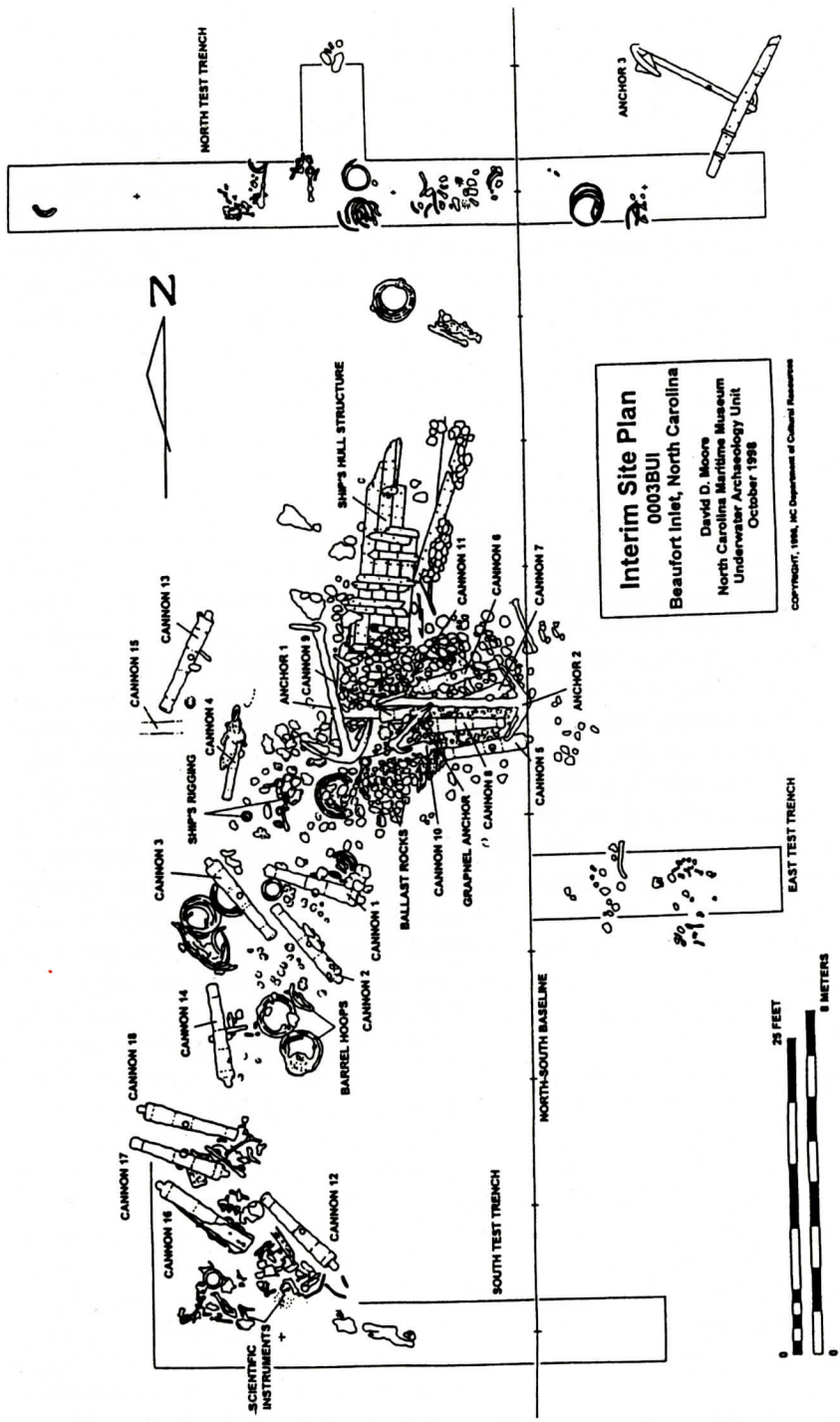

Figure 2. 1998 site plan of shipwreck 0003BUI.

other. Its advantage on the *Queen Anne's Revenge* site, which contains many large objects, such as cannons and anchors, is the fact that magnetic disturbances from the iron mass laying more than a few feet away affect both sensors the same and therefore is negated. This in turn enables researchers to isolate individual objects directly beneath the sensor. A distinct advantage of the gradiometer over total field magnetometers is its ability to mask diver's only a few feet from the sensor, which markedly increases survey coverage in a given amount of time. The instrument is also not affected by diurnal variations making the processing of data considerably easier and providing more accurate results.

During the 1999 field season divers took 2,064 readings at the shipwreck site every 2.5 feet (.762 meters) over an area 90 feet (27.43 meters) X 150 feet (45.72 meters). Divers pushed the sensor sled down a marked transect line, pausing at each location for a reading, which they signaled to the surface using wireless communication gear, and, once given the okay, continued to the next position. The total effort took approximately forty dive hours. At the completion of the survey, readings were entered into a data management spread sheet (Excel) and then fed into the Surfer contouring program. After processing the data, the outcome was a road map to the site's buried remains. Two anomalies suspected to be cannon were further investigated. Excavations confirmed that one was a nine-foot, six-pounder (C20) estimated at 1,700 pounds. On the northern side of the site, an anomaly-producing object was recovered and when cleaned turned out to be two small one-pounder cannon (C19 & 21) lying side by side and weighing a total of 514 pounds. Less intense anomaly targets were also matched with previously recorded iron artifacts, such as barrel hoops, and with iron stakes and mooring screw eyes placed there by archaeologists. As excavations continue and physical evidence is compared to the magnetic gradiometer survey, it is hoped that a correlation will be achieved by linking the smallest of iron artifacts, even magnetite in individual ballast stones, with magnetic signatures.

Limited test excavations have been employed to explore the extent of the shipwreck's artifact distribution, while determining what equipment best suits the site. The site's stratigraphy is relatively shallow. With the exception of the fluke on the highest anchor (A1), the exposed portion of the site rises only 2 feet (.61 meters) above the surrounding bottom. This can be deceptive to the diver because often there is a deeper scour area immediately surrounding the exposed wreckage. Moving out from this area, cultural materials are covered by as much as 4 feet (1.22 meters) of sand overburden. The cultural deposits are intermixed with coarse sand and shell in a layer ranging from 9 inches (.22 meters) to 1.25 inches (.03 meters). The vertical dispersion of artifacts depends to some degree on their relative density and the period during which they were deposited. Lighter materials, especially intrusive modern debris such as plastic drink bottles, are nearer the surface, while the heavier objects associated with the shipwreck, such as lead shot, are found at the lowest level. Underlying the cultural layer is a hard-packed stratum of consolidated sands. Artifacts do not appear to have penetrated this layer. While the disturbance of shipwreck materials from ocean currents is obvious, it also appears that the lower portions of the cultural layer may be less affected, as evidenced by a portion of preserved hull structure and the recovery of two intact glass wine bottles.

Evidence from test excavations provided some clues to the extent of artifact dispersion and its nature. Buried materials observed during exploratory excavations on the north side of the site include iron concretions, such as cask hoops and a large number of unidentified objects, as well as a section of wooden hull. Ballast stones were the most dominant artifact found on the east portion of the site, while to the south archaeologists uncovered a rich collection of small artifacts including numerous lead shot, pewter plates and chargers, intact glass wine bottles, pottery fragments, medical and scientific instruments, and even a few flakes of gold.

General site dimensions encompass an area approximately 150 feet (45.72 meters) by 50 feet (15.24 meters). Numerous features associ-

ated with the *Queen Anne's Revenge* site have been observed and recorded. Twenty-one cannon have been located, the majority of which appear to be 6-pounders. Of the five recovered and cleaned, two are 6-pounders, one a 3-pounder and two are one-pounders. They not only vary in size but in country of origin--two are English, one Swedish and the remaining two are possibly French. Their off-center trunnions indicate a manufacture date in the mid-to late-seventeenth century. At least four of the cannon were loaded at the time of sinking. The Swedish gun, which provides the only manufacture date, 1713, also had a unique load consisting of three large iron rods in addition to a one-pound cannon ball. Loose munitions include various sized round shot, iron bar shot, and lead shot with cloth impressions in the surrounding concretion that may represent bag shot or grapeshot (Lusardi, 2000).

The anchor located on the north end of the site, which measures 13 feet (3.96 meters) in length, has an intact wooden stock and probably represents a bower anchor deployed or dropped from its lashings after the vessel ran aground. The fact that the anchor ring is tucked under the shank and that the anchor lies perpendicular to the orientation of the vessel suggests that it was not set. The two anchors in the center of the site appear to have been stored in the hold of the ship, along with a group of six cannon underneath. Both are approximately the same size as the north anchor. An anchor located 420 feet (128.02 meters) south of the exposed wreckage features a well-preserved wooden stock similar in style to the north anchor. The south anchor is two-thirds the size of the other anchors, and it may represent a kedge anchor set in an attempt to free the vessel from the sandbar since it appears to have been deployed, with its cable ring stretched out and pointing toward the main site.

A section of hull structure approximately 27 feet (8.23 meters) in length and 8 feet (2.44 meters) wide was observed, excavated, recorded, and recovered on the north side of the exposed wreckage. The remains of eleven paired frames, many deteriorated on their upper surfaces, were fastened to a series of extremely well preserved hull planks. Both frames and planks were identified as *Quercus* sp., oak, white-type anatomy (Newsom, 1999). Sacrificial sheathing, mostly sprung or otherwise dislocated from the hull section was also recovered. Botanical analysis of the sheathing revealed it to be Pinus sp., *sylvestris* anatomical group (Newsom, 1999). While the absence of the keel, keelson, or other readily identifiable hull feature precludes positive identification of the original position of this section on the ship, based on surrounding evidence it is likely to be part of the vessel's port side just forward of amidships and below the waterline.

Iron hoops that would fit large wooden casks are abundantly distributed throughout the site. Many appear to be stacked inside one another and may have been collapsed for storage. Archaeologists have located a number of iron rings representing ship's fittings such as chain plates and deadeye strops. The calculated size of the deadeyes that fit within the iron strops varies from 8.5 inches (.21 meters) to 11.5 inches (.29 meters) in diameter and matches the size of deadeyes used on ships of several hundred tons.

The concentrated artifact distribution suggests that the vessel sank and deteriorated during a time when there were no significant storms. The dispersion of cultural materials and the direction of the planks and frames contained in the hull section are oriented on a north-south axis and reflect the vessel orientation. The bow of the shipwreck appears to be at the north end of the site and pointed toward shore, based on the location of the north anchor, which probably represents the ship's bower anchor. The collection of valuable artifacts found in the southern portion of the site likely came from the officer's quarters in the stern. Large ballast stones on the east side and the adjacent grouping of anchors and cannon probably were stored deep inside the vessel's hull. It appears that the ship heeled over on its port side after sinking. That finding is supported by the large number of cannon and elements of ship's rigging found along the site's western margin. As the vessel listed to port, those items at or above deck level would have been tossed and deposited in a westerly direction. As excavations continue, these assump-

tions will be tested and a clearer understanding of the site layout will be achieved.

While the shipwreck located in Beaufort Inlet has not been positively identified by a single conclusive piece of evidence, archaeologists and their colleagues who have extensively studied the shipwreck, are certain that the site represents the remains of Blackbeard's flagship *Queen Anne's Revenge*. Their confidence is based on mounting circumstantial evidence, which strongly suggests that the site is in the historically reported location and represents a vessel of the appropriate size and armament. Furthermore, the artifact assemblage dates the wreck to the proper time period and compares well with that from the *Whydah*, a contemporary pirate vessel lost a year earlier (Hamilton, 1992). Finally, exhaustive historical research has produced no other shipwreck candidates lost in the area that could possibly produce the archaeological record other than the *Queen Anne's Revenge.*

ACKNOWLEDGEMENTS

The authors would like to recognize the staff of the Underwater Archaeology Unit and the North Carolina Maritime Museum for their efforts in all aspects of the *Queen Anne's Revenge* shipwreck project. In addition, the administrators of the Department of Cultural Resources, the Division of Archives and History, and the Office of State Archaeology have provided the project with invaluable support and guidance. Finally, a host of state agencies, universities, colleges, and private companies have generously provided the project with funding, equipment, personnel, expertise, and analytical research. Those groups include the North Carolina Division of Marine Fisheries, the University of North Carolina at Chapel Hill - Institute of Marine Sciences, East Carolina University, the University of North Carolina at Wilmington, Cape Fear Community College, Appalachian State University, the University of North Carolina at Asheville, Virginia Polytechnic Institute, Wake Forest University, the University of North Carolina Center for Public Television, Maritime Research Institute, Intersal Inc., and Surface Interval Diving Company.

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

JOHN T. WELLS

Institute of Marine Sciences
University of North Carolina at Chapel Hill
Morehead City, NC 28557

JESSE E. MCNINCH

Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062

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

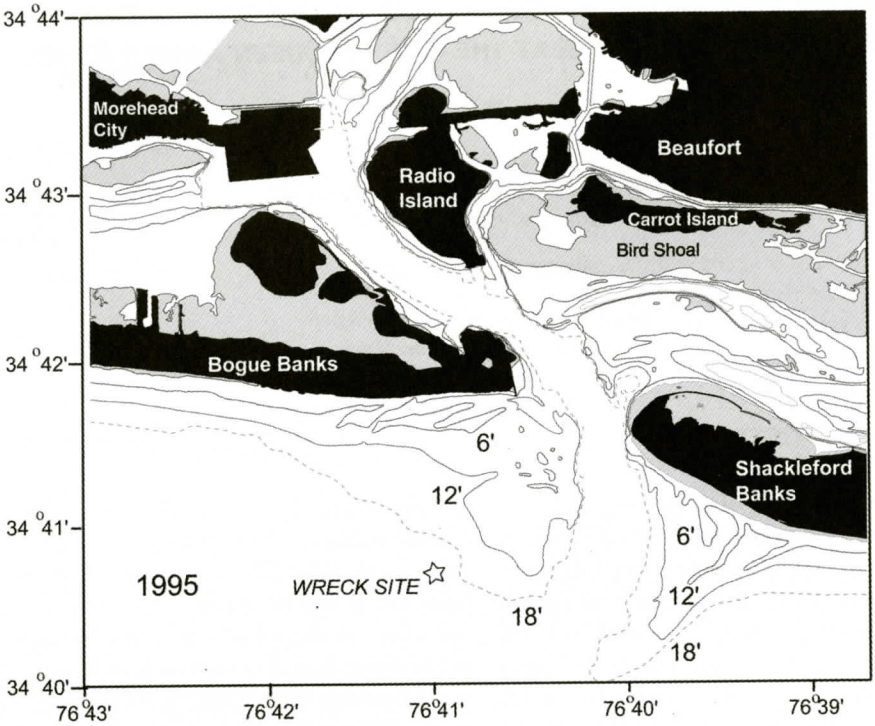

Figure 1. Map showing Beaufort Inlet and location of the *QAR* wreck site. The platform of sand extending seaward of the inlet defines the ebb tidal delta. Swash bars migrate across the tidal delta surface often attaching to the adjacent barrier islands.

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-

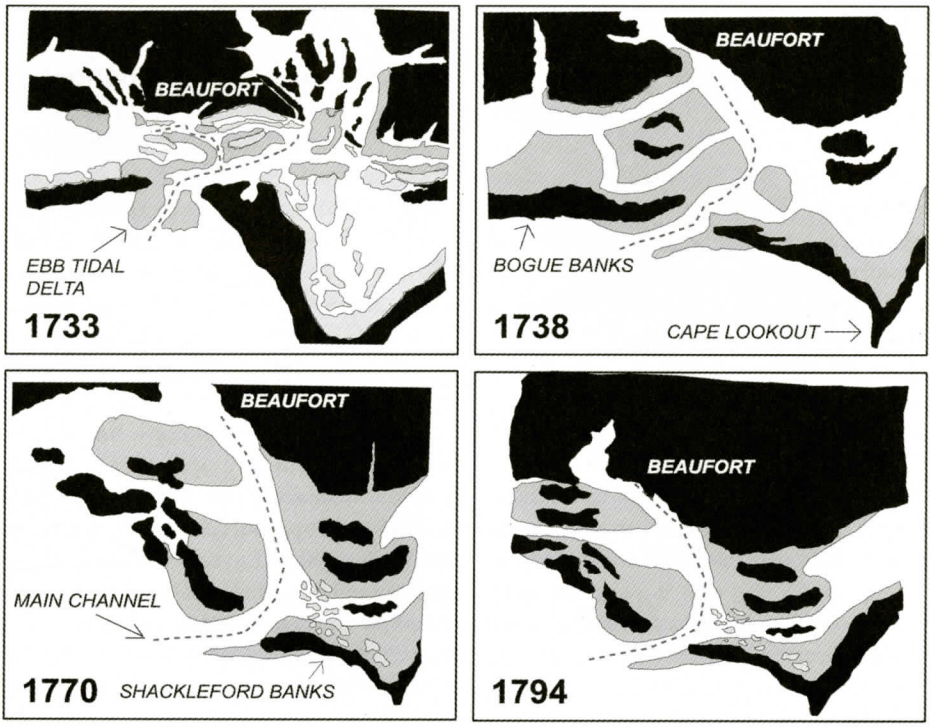

Figure 2. Maps of the 1700s showing the location and orientation of the main navigation channel. These maps have been reproduced, insofar as possible, at the same scale. Lack of latitude/longitude and accurate distance scales suggest substantial errors in many of the early maps; however, we believe that 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

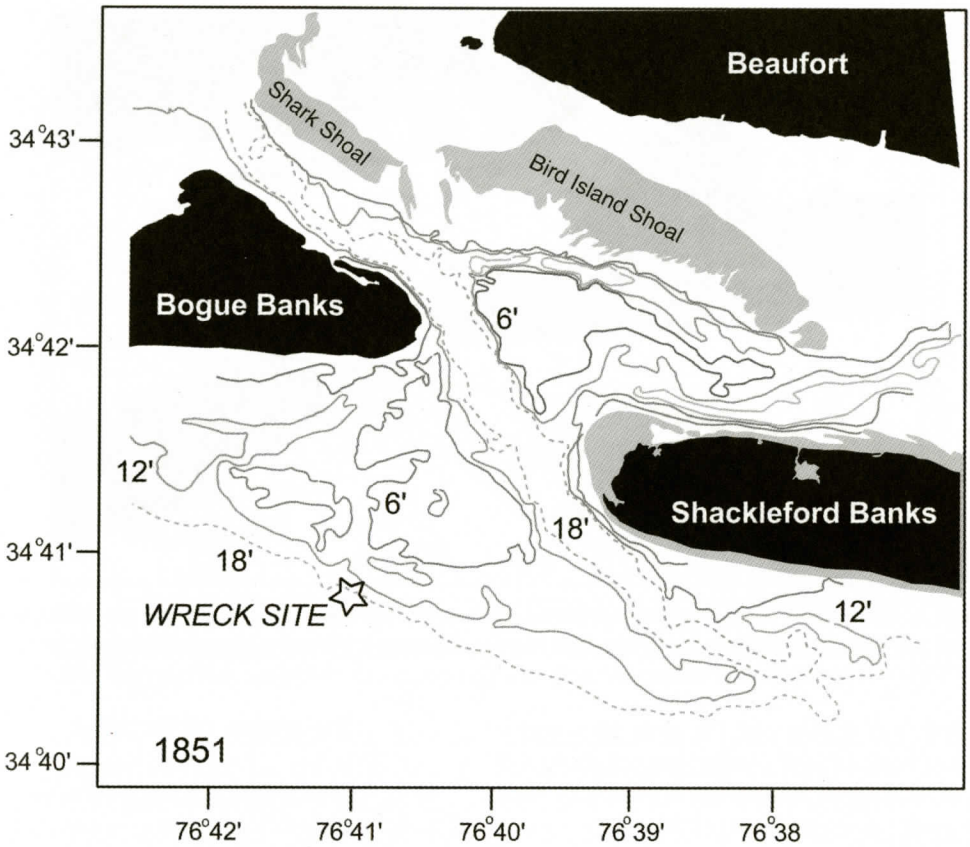

Figure 3. Detailed map of 1851 showing orientation of channel to the southeast, impinging on the western end of Shackleford Banks. The inlet has narrowed considerably since the mid-1800s.

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

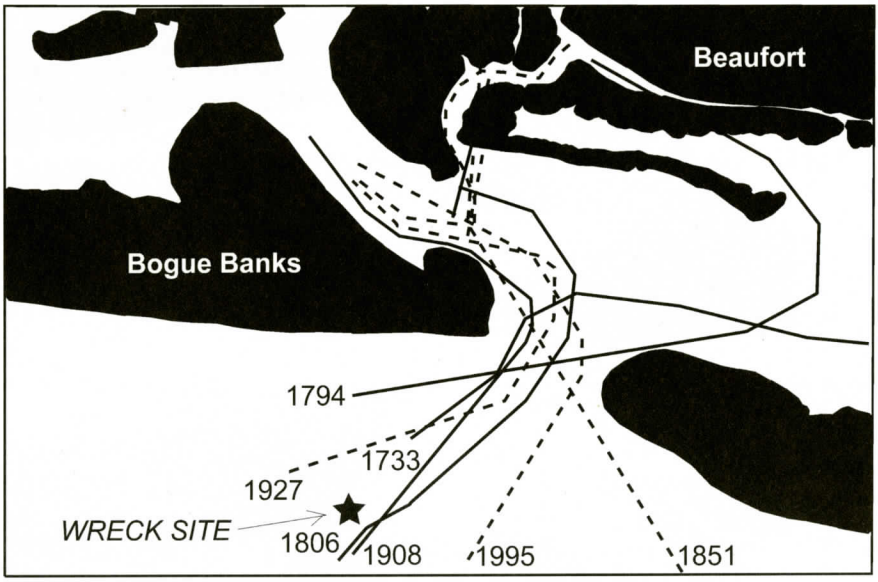

Figure 4. Composite map showing locations of former channels superimposed on modern-day island configuration. Although there has been substantial pivotal change offshore, there has been little net channel migration.

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

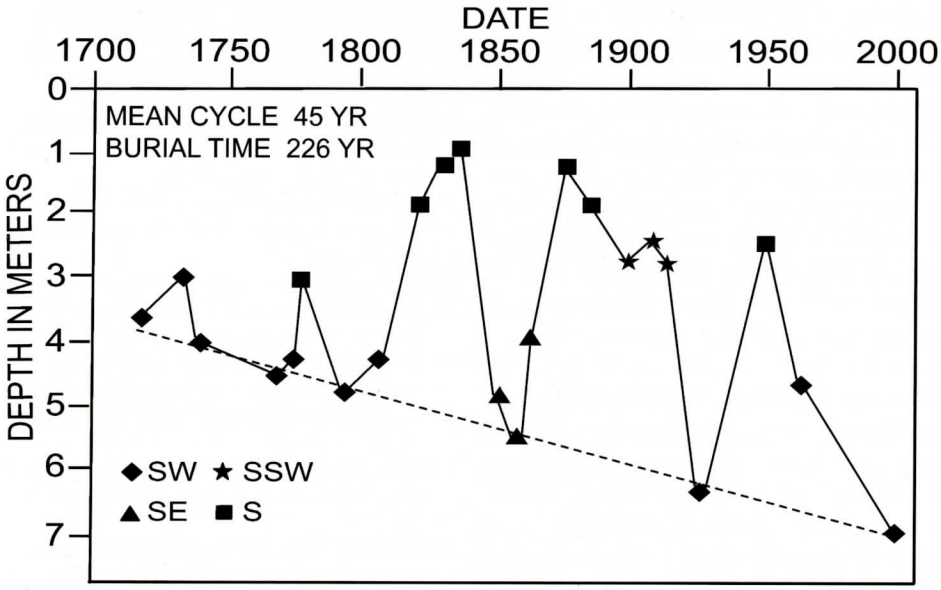

Figure 5. Depth variations at the *QAR* site showing five distinct episodes of artifact burial. Maximum depth of scour has deepened progressively over the past three centuries.

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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THE FATE OF ARTIFACTS IN AN ENERGETIC, SHALLOW-WATER ENVIRONMENT: SCOUR AND BURIAL AT THE WRECK SITE OF *QUEEN ANNE'S REVENGE*

JESSE E. MCNINCH

Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062

JOHN T. WELLS

Institute of Marine Sciences
University of North Carolina-Chapel Hill
Morehead City, NC 28857

THOMAS G. DRAKE

Department of Marine, Earth and Atmospheric Sciences
North Carolina State University
Raleigh, NC 27695

ABSTRACT

The discovery of an early 18th century shipwreck near Beaufort Inlet, NC provides a unique opportunity to examine the long-term effects of scour from storms and inlet migration and to speculate on the fate of the artifacts. The ship, believed to be *Queen Anne's Revenge,* ran aground in waters less than 4 m deep while attempting to navigate Beaufort Inlet and now rests in 7 m of water on the shoals of the ebb tidal delta, exposed to waves and tides and their combined impact on the bottom. In this study, we address process-related questions from near-bottom currents and waves measured over a nearly continuous interval of one year which fortuitously captured the effects of a hurricane. Estimates of sediment transport reveal that sediment was stable under fair-weather and moderate storm conditions but that a significant volume of sediment was mobilized when wave heights exceeded 1.5 m. High-resolution bathymetric surveys reveal a depression on the northwest side of the main rubble mound, suggesting this area is subjected to active scour during severe storm events. Storm-related scour around the rubble mound may be responsible, in part, for the intact settling of the hull and artifacts over the past 300 years. We believe this information may be useful for site management and in establishing a timetable for artifact recovery.

INTRODUCTION

Queen Anne's Revenge (QAR) is the oldest shipwreck discovered in North Carolina and thus provides a rare chance to investigate the long-term fate of artifacts exposed to the harsh conditions of a shallow-ocean setting. Preliminary examination of some of the artifacts such as medical and survey instruments, ship parts and equipment, personal effects, and armament has already given archaeologists insight into 18th century maritime life and spawned additional questions about Blackbeard and his ship (Lusardi, 2000). In this paper, we consider the physical setting and dynamic processes that have influenced this wreck since it reportedly ran aground on a bar at Beaufort Inlet. The location and condition of the wreck in this dynamic and energetic environment present both questions and clues regarding the circumstances surrounding its sinking, the physical processes responsible for its preservation and recent exposure, and the fate of other wrecks in similar

environments.

Beaufort Inlet, a barrier island tidal inlet, has remained open and navigable since at least 1585 (Fisher, 1962). Consistent channel depths of 5 m have availed heavy travel by fishing, commercial, and military fleets since the late 18th century. The inlet is sheltered from east and northeast storm waves by the adjacent barrier islands, Bogue and Shackleford Banks, and by Cape Lookout Shoals (see site location map in companion paper; Wells and McNinch, this issue). The inlet is therefore passable during the strongest storms which generally have winds and seas from the north and northeast (NDBC, 1999). Only hurricanes and severe southwest winds create conditions that are unsafe for navigation through the inlet. Despite the relatively benign nature of Beaufort Inlet, conditions across the shallow portions of the ebb tidal delta (ETD) can be quite treacherous. The channels and bars of the ETD, the fan-shape composite of shoals on the seaward side of Beaufort Inlet, are shaped by a balance between tidal flow through the inlet, wave energy, and sand supplied from the adjacent barrier islands and are thus subject to rapid changes particularly when large waves from the south converge with an ebbing tidal current. Although we are not aware of documentation that describes sea conditions when the *QAR* sank, it seems entirely possible that a change in orientation of the main channel from its previously charted position or a slight navigation error relative to the main channel could bring disaster to a sailing vessel even during fair weather.

The wreck now rests in 7 m of water on the southwestern flank of the ebb tidal delta. Artifacts appear to be scattered over an area of approximately 30 x 50 m and rest near the same depth horizon, although larger pieces are typically more exposed and perched on the seafloor surface. The wreck site includes a large primary mound and several smaller ones. The main rubble mound, measuring roughly 5 x 10 m, contains the lower portion of the hull and a host of artifacts such as cannons, ballast stones, and anchors that have become concreted into one indistinct mass. Smaller mounds encasing cannons, anchors, and smaller artifacts that were likely separated from the vessel at the time of sinking litter the perimeter of the main rubble mound.

Queen Anne's Revenge, formerly the French slave ship *Concorde*, was a three-masted ship of approximately 250-tons (Bond, 2000; Moore, 1997). Keels of early 18th century vessels of this size and design typically extended approximately 3.5 m below the surface of the water (Moore, personal communication). Written documentation by David Harriot, who sailed with Thatch, noted that the *QAR* "ran aground" while attempting to enter Beaufort Inlet (Moore, 1997). This rare glimpse into the events surrounding the sinking highlights a discrepancy between running aground at a depth comparable to the *QAR's* draft and finding the remains of a vessel on a sandy horizon almost twice as deep. The presence of an anchor separated from the main rubble mound, perhaps deployed after grounding in an effort to kedge the vessel from the shoal, suggests the vessel did not drift into deeper waters after the initial grounding. Therefore, from a marine geological perspective, we question whether the eyewitness account of *QAR* running aground can be reconciled with a mechanism that accounts for an additional settling of 3-3.5 m over the past 282 years, assuming sea level rise has been on the order of 0.5 m (Komar, 1998; Emery and Aubrey, 1991).

This paper presents evidence that suggests settling of this magnitude, in fact, can and did occur. Results from current and wave measurements collected near the wreck, analyses of historical charts, and high-resolution bathymetric surveys are examined to address the following four questions: 1) why do all of the artifacts, regardless of size, rest on the same horizon and remain relatively intact after such an extended period of time in this high-energy environment; 2) why, in such a shallow, heavily-traveled and close-to-shore location, was the wreck not discovered until 1996; 3) why have the timbers from the lower portion of the hull only recently become exposed, and is additional exposure likely; and 4) does this wreck and the processes responsible for its exposure and earlier preservation give insight into the fate of other wrecks

in similar settings? A companion paper (Wells and McNinch, this issue) provides the history of change in Beaufort Inlet and gives a broad overview of channel and ETD processes.

METHODS AND RESULTS

High-Resolution Seafloor Mapping

The seafloor immediately surrounding the main rubble mound, an area of approximately 1600 m^2, was mapped with a high-resolution bathymetric and side scan sonar system in October, 1999. The mapping device, a Submetrix interferometric seabed inspection system combined with differential GPS, collected over 128,000 soundings equaling roughly 80 measurements of depth and seafloor backscatter (side scan sonar) per m^2. With horizontal and vertical survey accuracy of 2 m and 15 cm, respectively, the soundings provided resolution of larger features across the rubble mound as well as large nearby bedforms such as sand bars and scour holes.

The top panel in Figure 1 shows the seafloor topography around the rubble mound. Two prominent features are the main rubble mound, which projects 1.5 m above the seafloor, and the large scour hole on the northwest side of the mound. Divers report that the scour hole began to develop during Hurricane Bonnie in August, 1998 and may have progressed during Hurricanes Dennis, Floyd, and Irene in 1999. The scour depression is teardrop-shaped, 20 m long and 10 m wide, and roughly 1 m deeper than the surrounding seabed. The bottom panel in Figure 1 shows the same area as the contour chart in a surface 3-dimensional form. The surface plot visually accentuates the scour hole and mound as well as what appears to be localized scour around the base of the main rubble mound.

Currents, Waves, and Sediment Transport

An electromagnetic current meter with integrated pressure sensor, InterOcean S-4A, was deployed approximately 15 m southwest of the main rubble mound to provide information on waves and currents near the wreck. The S-4A was rigidly mounted to a stand that held the sensors 1 m above the bottom. Measurements of pressure and flow were collected at 2 Hz for 12 minutes every hour. This sampling scheme was continued for 298 days from May 1998 to April 1999.

Measurements of current and pressure collected by the S-4A were analyzed for both wave-driven flows (high-frequency, oscillatory currents) and mean currents driven by tides and wind. In an effort to characterize conditions to which the wreck may be exposed in a given year, five types of commonly-occurring weather events were selected for analysis: a direct impact from a hurricane (Hurricane Bonnie), a marginal impact from a hurricane (Hurricane Georges), an extratropical winter storm (Northeaster), a sustained southwesterly wind, and an extended period of calm winds. A 2-week data record encompassing each of these meteorological events was analyzed. Wave properties (significant height, direction and period, and oscillatory flows) were calculated from a 12-minute data burst every 3 hours. Mean velocities represent an average of each of the 12-minute bursts. An estimate of sediment transport forced by near-bottom currents was calculated using Bailard's (1981) combined mean and oscillatory flow equation:

$$Q_x = K_b\left\{\left\langle\left|\vec{u}\right|^2\tilde{u}\right\rangle + \left\langle\left|\vec{u}\right|^2\bar{u}\right\rangle - \frac{\tan\beta}{\tan\phi}\left\langle\left|\vec{u}\right|^3\right\rangle\right\} + K_s\left\{\left\langle\left|\vec{u}\right|^3\tilde{u}\right\rangle + \left\langle\left|\vec{u}\right|^3\bar{u}\right\rangle - \frac{\varepsilon_s}{W}\tan\beta\left\langle\left|\vec{u}\right|^5\right\rangle\right\} \quad (1)$$

where Q_x is cross-shore sediment transport volume per unit width per unit time (cm^3/cm/s). The total horizontal velocity vector, $\vec{\mu}$, is comprised of orthogonal components μ and v (positive east and north, respectively), and $\bar{\mu}$ and $\tilde{\mu}$ are mean and oscillatory cross-shore currents, respectively. Local bed slope is represented by tan β. Coefficients K_b and K_s are given by:

$$K_b = \frac{\rho_w}{(\rho_s - \rho_w)g} C_f \frac{\varepsilon_b}{\tan\phi} \text{ and } K_s = \frac{\rho_w}{(\rho_s - \rho_w)g} C_f \frac{\varepsilon_s}{W}$$

where W is fall velocity, tan ϕ is friction angle of the grains in the bed, and the so-called effi-

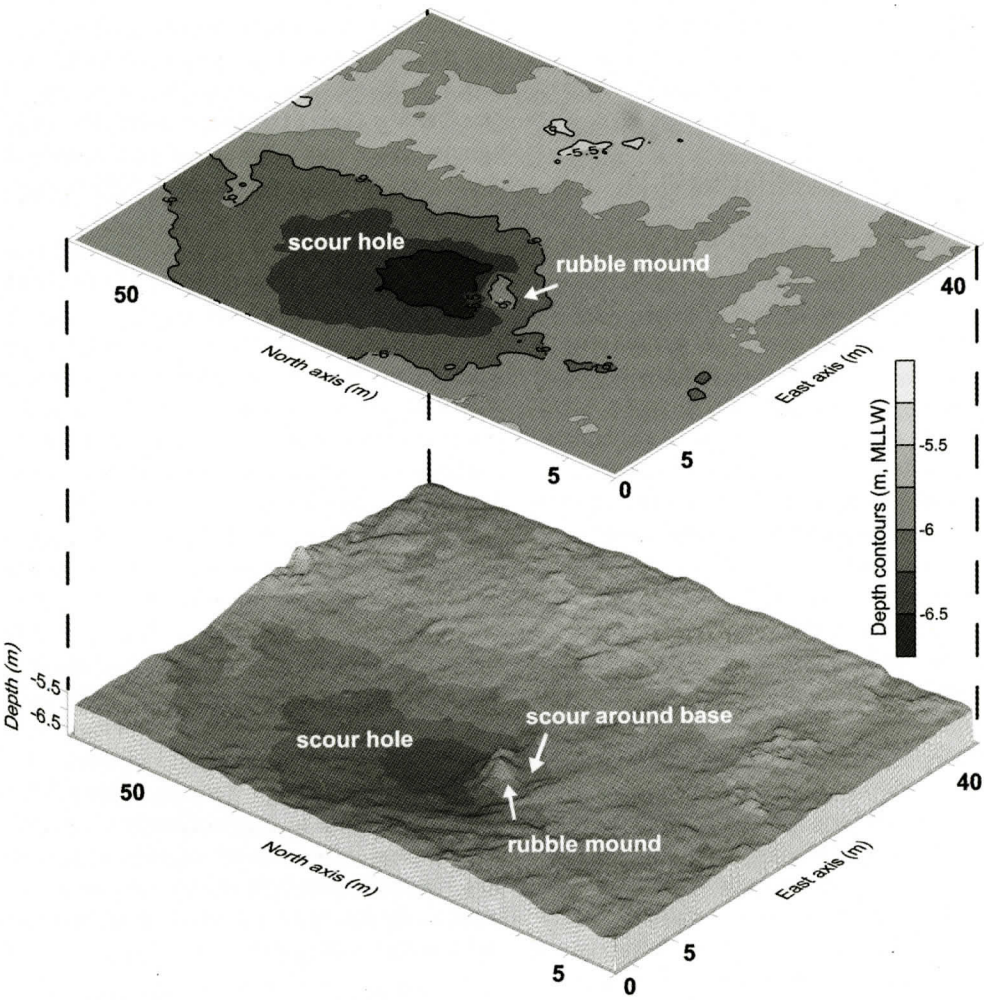

Figure 1: Contour chart of the seafloor surrounding the wreck site (top panel) and a surface plot of the same area (bottom panel) showing scour around the base of the rubble mound and a large scour hole on the northwest side.

ciency factors, ε_b and ε_s, are set to 0.135 and 0.015, respectively, following Gallagher and others (1998). A bed drag coefficient, C_f = 0.003, is used. Although estimated sediment transport for the *QAR* site was not independently verified, justification for use of this model exists through successes of Gallagher and others (1998) and Thornton and others (1996) in predicting the movement of nearshore sand bars.

Current and wave observations during 1998 indicate that near-bottom conditions close to the *QAR* wreck were quiescent with minimal sediment transport under each of the weather events except Hurricane Bonnie. Significant wave heights did not exceed 2 m except during hurricane-related periods, and the direction of wave approach was generally from the south during all observed events. Near-bottom flows during the non-hurricane time periods rarely exceeded critical threshold velocity. Although sediment is mobilized when wave heights approach 1 m, the volume of transport is quite small, less than 0.1 $cm^3/cm/s$ or an order of magnitude less than the flux during Hurricane Bonnie. Sediment is substantially mobilized near the *QAR* wreck only when wave heights exceed 2 m and mean cur-

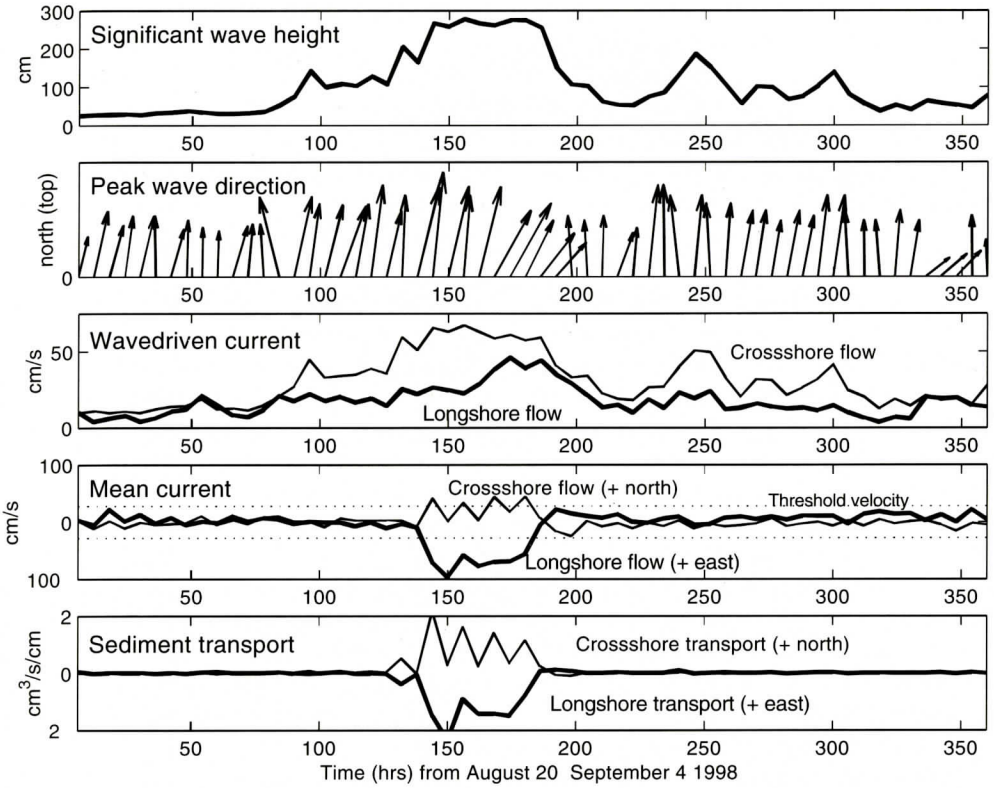

Figure 2: Wave and near-bottom current observations from a two-week period around Hurricane Bonnie. Panels from top to bottom show: significant wave height; direction of wave propagation with north towards the top; wave-related current velocities (standard deviations); tide or wind-driven mean current velocities (12-minute averages); and volume and direction of sediment transport.

rents (probably wind-driven) are very strong.

Critical threshold velocity, or the minimum velocity necessary to suspend and transport sediment, was calculated from the typical sand characteristics found at the wreck site. The characteristic threshold velocity used here is based on quartz sand in seawater at 20× C subject to steady flow (Miller and others, 1977; Sundborg, 1956). Threshold velocity neither incorporates the influence of wave-derived oscillatory flows nor provides an estimate of the volume of sediment transported. Critical threshold velocity is plotted relative to mean velocities simply to demonstrate consistency with the Bailard transport estimates. Times during which the Bailard equation (Equation 1) indicates significant sediment transport should coincide with periods when mean currents exceed critical threshold velocity.

Figure 2 shows wave and current observations and sediment transport estimates from a 2-week period surrounding Hurricane Bonnie. The impact of the hurricane is apparent in the significant wave height (top panel) where heights of almost 3 m were sustained at the site for approximately 2 days (hours 140-190). Wave-driven currents, defined as standard deviations of the 12-minute velocity records, exceeded 1 knot throughout the 2-day period (3rd panel). The direction of mean flow during the storm was towards the northwest and exceeded critical threshold velocity throughout much of the storm (4th panel). Sediment transport estimates (5th panel) are closely aligned with time periods when mean currents exceed critical threshold velocity. Transport estimates indicate

that sediment was being moved towards the northwest, in the same direction as the mean flow, at an average of 1 $cm^3/cm/s$ during the hurricane. Approximately 18 m^3/m of sediment was transported over the 50-hour storm period or, in practical terms, a volume equivalent to 2 dump-truck loads of sand was transported across a 1 m wide patch of seafloor in the immediate vicinity of the wreck.

Sediment transport estimates include the volume of sand entrained in both bedload and suspended load at the point which currents are measured and assume that sediment was suspended prior to arriving at this location. If the volume of sediment transported into a given region equals the volume exiting the region, the fluxes balance and there is no net erosion or deposition in the region. Since currents were measured at only one point in this study and we were limited to one flux estimate, a true difference in sediment transport flux cannot be calculated. We believe, however, that a difference in flux occurred between the immediate area of the wreck and the lee or down-current side of the main rubble mound. The large rubble mound, which acts as an obstruction to near-bottom flow, diminishes the volume of sand delivered to the lee, or northwest side, relative to the surrounding areas. This process, discussed below, could explain the formation of the scour depression in Figure 1.

DISCUSSION

Scour and Settling – An Episodic Process of Protection

Observations of currents and waves, seafloor bathymetry, and analysis of historic charts suggest that the wreck site is periodically exposed to considerable energy. The main inlet channel appears to have migrated across the site numerous times since 1718, and its strong currents have eroded the surrounding seafloor to depths of at least 5-6 m. Since energy at the bottom is depth-dependent, past wave and tidal currents were almost certainly stronger when the depth at the wreck site was shallower. If recent storm-induced currents were sufficient to create the scour hole observed in October, 1999, then scour around the artifacts was probably greater when they rested on a shallower horizon. Thus, there has been more than adequate energy to erode the seabed and account for the settling of the wreck to a deeper horizon than its original grounding depth.

Given that the area around the wreck site has undergone considerable erosion, it seems incongruous that artifacts of different size and mass are all resting on the same horizon after 282 years on the bottom. Remarkably, evidence ranging from the relatively unspoiled condition of the bottom timbers, location of all the artifacts at roughly the same depth horizon, and young encrusting coral (less than 15 years old; N. Lindquist, personal communication) all suggest that a process which preserves the artifacts through burial and maintains an equal rate of settling regardless of size has been operating. Basic principles of seafloor scour, demonstrated from studies of bridge piles, pipelines, and freestanding objects, may explain these observations.

Several hydrodynamic effects are important to scour near an obstruction: 1) horseshoe vortices around the front and sides, 2) spatially accelerated flow that is deflected around the object, and 3) wake vortices in the lee of the object. A horseshoe vortex, resulting from the vertical gradient in stagnation pressure on the upstream side, is initiated as downward flow and is carried around the sides of the object. Horseshoe vortices are considered to be a primary mechanism for sediment scour around piles (Smith, 1999). Accelerated flows around the object and wake vortices that develop on the lee side are important in scour because they result in higher velocities at localized places where eddies impact the seafloor. When flows approach or exceed critical threshold velocity, the size and strength of the vortices and the resulting depth of the scour hole depend on the size of the object. The proportionality of object size and scour depth is important with respect to exposure of artifacts because it implies that, with sufficient flow speed and underlying sandy sediment, the exposed surface area of the artifacts will continue to generate scour until the

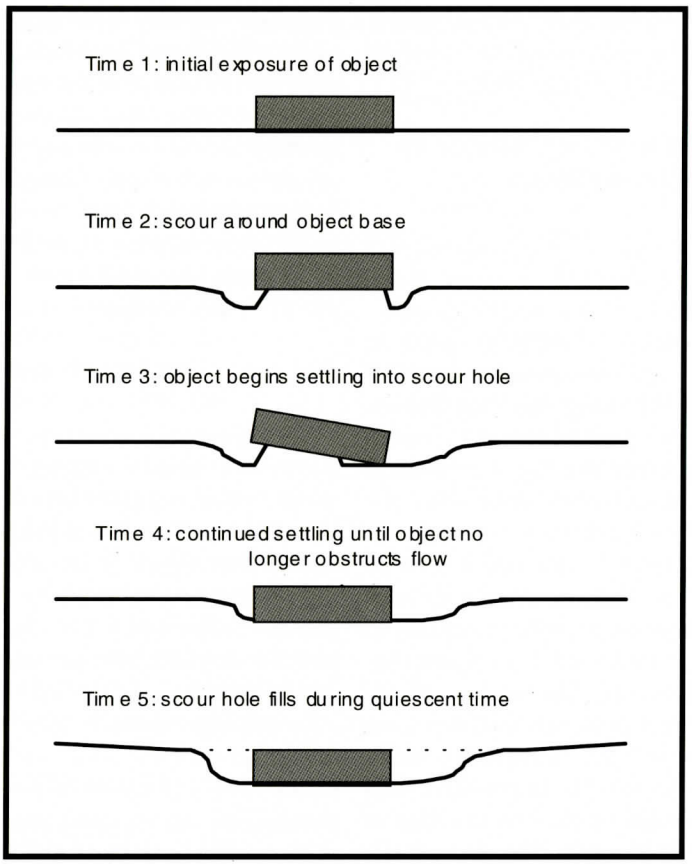

Figure 3: Schematic of scour and settling processes when a free-standing object is placed on an unconsolidated substrate and exposed to flows that are near or above critical threshold velocities (after DeWall, 1983).

object(s) settles into the hole and becomes roughly level with the surrounding seabed. Figure 3 is a schematic drawing of scour and settling around a slab (DeWall, 1983). It shows that scour progresses until the slab eventually settles to a level at which it no longer acts as an obstruction to flow. During quiescent periods, the scour hole will fill with finer-grained sediment that probably settles from the water column.

We believe that a similar sequence of scour and settling occurred episodically at the *QAR* site after the vessel ran aground. The lower hull and intact artifacts probably settled quickly into the sandy shoal after the initial destruction of the masts and superstructure by waves. Strong tidal and wave-driven currents would have created rapid scour and subsequent settling until all of the artifacts that were littered around the hull, and the hull itself, became level with the surrounding shallow seabed. This sequence of scour and settling probably repeated itself whenever strong flows from a storm or from the inlet channel caused erosion of the surrounding bed. Rapid lowering of the seabed would expose the wreck, and the strong flows would initiate new scour. Once the artifacts were exposed, subsequent tidal and wave-driven currents would continue the scour process until the objects settled to a level roughly equal to the new bed depth. The scour holes would then fill with fine-grained sediment and may have been buried further by migrating sand waves, ripples, or swash bars moving across the ebb tidal delta (see Wells and McNinch, this issue). Ultimately, the artifacts would achieve a depth equal to

the maximum level of scour by currents unless the artifacts reach an erosion-resistant substrate and the settling process is interrupted.

Implications to Other Wrecks in Similar Settings

Rapid scour and settling into the seabed may in part explain why the *QAR* remained undiscovered until 1996 in such a shallow, heavily-traveled inlet. Remains of the *QAR* appear to have reached the maximum historical depth for complete settling. Following Hurricane Bonnie, current velocities were not sufficient to continue scouring to an extent that the large artifacts and main rubble mound could settle below the present horizon. The 7-m horizon may thus represent the deepest level to which the natural inlet channel and the average wave and tidal-driven flows have provided sufficient energy to scour completely around the objects and thus allow substantial settling. The result, from the perspective of artifact preservation, is that scour will occur when the site is affected by hurricane-strength processes but that the artifacts will otherwise remain perched on the edge of the storm-initiated scour hole. This may explain why timbers from the lower portion of the hull have only recently become exposed. When the hull rested in shallower waters, scour and complete settling would have occurred much more rapidly such that the wood near the lower portion of the hull would have remained buried and thus preserved after the initial sinking.

Our findings suggest that other vessels which ran aground or sank in shallow, energetic waters may have been preserved just beneath the seabed but eventually could become exposed as they reach a horizon where local currents can no longer effectively complete the scour and burial process. For example, a ship that initially ran aground off a beach in depths of 3-4 m may now be visible on the seafloor surface at depths of 7-10 m. The portion of the hull and artifacts that survived the initial breakup would quickly scour and settle into the sandy substrate of the outer surf zone. Remains of the wreck probably settle to deeper horizons through time after repeated erosion of the seafloor from storms, inlet migration, and long-term increases in depth and position relative to the beach as sea-level continues to rise and most US barrier beaches migrate landward. We believe the lesson for locating and reconstructing the fate of other vessels in shallow-water sandy environments is that the wreck will likely lie on a horizon below its original grounding depth and above the maximum depth of scour dictated by regional wave, tide and wind conditions.

CONCLUSIONS

1. Near-bottom current observations indicate that scour around the *QAR* artifacts is negligible at the present depth horizon except during severe wave and wind conditions created from nearby hurricanes. Diver observations and a high-resolution bathymetric survey indicate that recent hurricanes have formed a large depression on the northwest side of the wreck's rubble mound. Sediment transport calculations show that approximately 90 m^3 of sand was mobilized across a 5 m wide swath near the rubble mound during Hurricane Bonnie. Similar scour depressions and transport volumes could have been created by each of the 50-75 hurricanes that have affected North Carolina over the past three centuries.

2. Basic scour principles suggest that the *QAR* artifacts should settle together such that their tops would share the same depth horizon, and probably remain partially buried except during brief erosive events. We suspect that the wreck remained undiscovered in part because the artifacts quickly scoured and settled into the substrate when the wreck was on a shallower horizon and strong scouring currents occurred more frequently. This rapid scour, settling, and burial mechanism that occurs whenever the surrounding seafloor was eroded by a storm or through inlet migration most likely accounts for the long-term preservation of much of the lower hull.

3. We believe that the *QAR* remains may now have reached a depth at which only the most severe events can mobilize the sediment. The scour and burial process has reached a point where currents are not adequate or of sufficient

duration to either scour the objects to a new depth or bury them deeper. The artifacts are thus left perched on the seabed surface with only the beginning of scour from infrequent storms. With this exposure, damage to the artifacts is now more likely than at any time since the vessel first ran aground. Our findings at the *QAR* site suggest that other vessels sinking in similar high-energy, sandy substrate environments may be preserved and may ultimately become exposed at similar limiting depths.

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RADIOCARBON DATING OF WOOD SAMPLES AND PLUTONIUM SEDIMENT DISTURBANCE STUDIES AT THE *QUEEN ANNE'S REVENGE* WRECK SITE

CHRISTOPHER S. MARTENS

CB-3300, Department of Marine Sciences
University of North Carolina at Chapel Hill
Chapel Hill, NC 27599-3300
Email: cmartens@email.unc.edu

ANN P. MCNICHOL

Department of Geology and Geophysics and National Ocean Sciences AMS Facility
Woods Hole Oceanographic Institution
Woods Hole, MA 02543-1539
Email: amcnichol@whoi.edu.

ABSTRACT

Radiocarbon dating of wooden and other organic artifacts from the putative *Queen Anne's Revenge* (*QAR*) wreck site (North Carolina Shipwreck 0003BUI) yields ages consistent with a ship construction date between 1690 and 1710 AD. Combined dates for twelve documented samples cluster between 1630-1670 AD using conventional radiocarbon ages calibrated by the OxCal program (Bronk, 1995; http://www.rlaha.ox.ac.uk/oxcal). The radiocarbon ages for two different anchor stocks found at the wreck site differ by 120 ± 85 radiocarbon years; however, OxCal calibrations based on changes in the abundance of natural radiocarbon in the atmosphere allow their calendar year ages to overlap in the mid 1600's.

Disturbances of the wreck site since the 1950's including potential exposure or exchange of sediments beneath presently buried hull components and ballast rocks with the surrounding sea floor environment were studied through measurements of bomb plutonium produced during the 1950's through early 1970's by atmospheric nuclear weapons testing. Sediments sampled from underneath the hull and ballast rocks contained from 9% to 41% of the plutonium activity measured in exposed surface sediments surrounding the wreck site. These low activities suggest little disturbance of the remaining intact hull and ballast rocks since the mid-1950's.

INTRODUCTION

A shipwreck (North Carolina Shipwreck 0003BUI) found near Beaufort Inlet, North Carolina, on November 21, 1996, may be the remains of the *Queen Anne's Revenge* (*QAR*), lost in the inlet in 1718 by pirate captain Edward Teach, better known as Blackbeard (Lawrence and Wilde-Ramsing, this issue). The shipwreck is the oldest documented in North Carolina waters, dating to the early 1700's. For convenience, we will refer to the site as the *QAR* wreck site throughout the paper. The primary objective of this paper is to estimate a construction age for the ship using radiocarbon dating of wooden and organic samples from the remaining hull structure and planking. All radiocarbon dates were obtained through a cooperative project with the National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) facility located at the Woods Hole Oceanographic Institution.

In addition, measurements of the plutonium activity in sediments underlying the remaining hull fragments and ballast rocks as compared to that in surrounding exposed seafloor sediments are used to determine whether these artifacts have been disturbed since the mid-1950's. Radioactive isotopes produced artificially during nuclear weapons testing have proven extremely useful for tracing the movements, deposition,

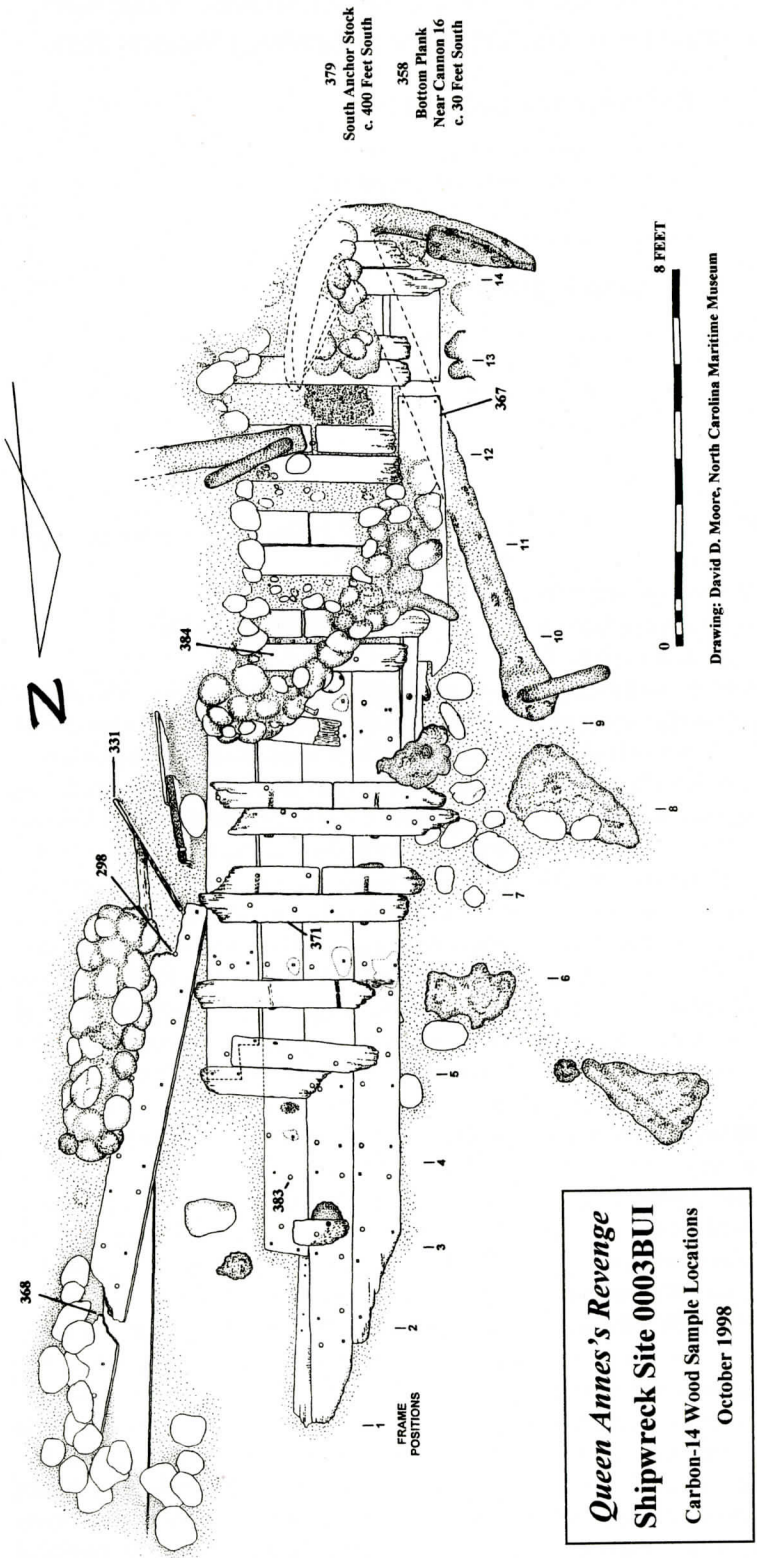


Figure 1. *QAR* shipwreck site map showing remaining port side hull structure and locations of wood samples utilized for radiocarbon analyses. The south anchor (379 stock; 381 puddening) is located 128m SSW of the anchors in the main rubble pile. The north anchor (386 stock) is located 16m NNE of the rubble pile.

Table 1. Summary of Preparation data for *Queen Anne's Revenge* samples. OS is NOSAMS run number, UAU# is the NC Underwater Archeology Unit sample number, Wt is the weight of the sample combusted in mg, Ct is the micromoles of CO_2 generated from the combustion, %OC-Ct is the percentage of C as organic matter by weight, #base is the number of base rinses required to remove all color from the sample, $\delta^{13}C$ is the value measured on the combusted sample, age is the Radiocarbon Age of the sample, fm is the fraction modern of the sample.

OS	UAU#, description	Wt	OC-Ct	%OC	#base	δ13C	age	error	fm	error
19822	331, No. 3 sacrificial plank	3.9	199.5	61.4	6	-25.48	350	60	0.9574	0.0038
19823	367, No. 7 sacrificial plank	4.7	221.0	56.4	6	-26.16	255	60	0.9687	0.0037
19920	368, No. 5 bottom plank	2.4	110.0	55.0	6	-26.95	275	70	0.9663	0.0044
19821	358, No. 1 south plank	3.8	132.4	41.8	6	-26.83	145	60	0.9820	0.0038
19824	371, frame No. 9	3.5	235.3	80.7	6	-26.59	290	60	0.9643	0.0036
19923	384, frame No. 8	1.6	66.4	49.8	6	-26.55	300	60	0.9635	0.0038
19825	298, treenail N90E92	3.5	159.0	54.5	8	-25.77	155	60	0.9809	0.0038
19820	383, treenail No. 5	3.9	168.5	51.8	6	-25.29	245	60	0.9703	0.0038
19922	386, north anchor stock	3.2	135.2	50.7	5	-23.59	210	60	0.9743	0.0037
19826	379, S. anchor stock E. tip	3.4	149.7	52.8	6	-25.50	330	70	0.9597	0.0041
19946	302, hair from lead strip	32.9	66.6	2.4	9	-25.55	385	40	0.9531	0.0040
20199	381, puddening from S. anchor	3.3	129.5	46.9	14	-28.71	60	90	0.9929	0.0057
19921	modern sand fence wood	5.0	200.6	48.1	3	-25.86			1.4196	0.0044

and accumulation rates of sediments, as well as some of the individual materials of which they are comprised. Of particular interest to our studies of the *QAR* wreck site is plutonium, which was first delivered to the environment as a result of atmospheric weapons testing beginning in the mid-1950's. The presence of plutonium activity in sediments under the hull and ballast rocks equaling that of surrounding exposed seafloor sediments would indicate complete sediment mixing and exposure of the artifacts during the past 50 years. A complete lack of weapons-produced plutonium underneath the wreck artifacts would prove that they have lain undisturbed since at least 1955.

SAMPLE COLLECTION AND DESCRIPTION

Radiocarbon Samples

Twelve samples for radiocarbon analysis were selected from documented components of the hull and anchors found at the wreck site and collected during October 1998 (Table 1). All wood samples were sectioned directly from these components using a clean metal saw. The wood samples from the wreck site included two pieces of oak plank, two pieces of sacrificial red pine plank, two pieces of oak frame, two sections of treenails used to join the planking, and single samples from the stocks of the south anchor and north anchor. In addition, a sample of what appeared to be modern wood derived from "sand fencing" used to control beach dune erosion was collected on the sediment surface at the wreck site. Two other non-wood samples were chosen for analysis. These samples consisted of preserved hair from a lead strip and puddening (cloth wrapping around anchor ring used to prevent anchor rope chaffing) scraped from the south anchor ring. Sub-samples were taken from plastic storage bags containing the original material. The *in situ* locations of each sample are illustrated in Figure 1.

Sediment Plutonium Samples

Sediment samples were collected for plutonium analysis at the wreck site on October 13, 1998 using SCUBA. Two coring methods were employed. Sediments under apparently undisturbed ballast rocks were sampled by prying up individual rocks and quickly inserting a 20 cm diameter PVC core pipe with a sharpened edge before disturbed sediment along the walls of the crater created could slump into it. In practice, it proved difficult to obtain sediments without addition of fine-grained sediment from the surrounding sea floor. After sealing the core top

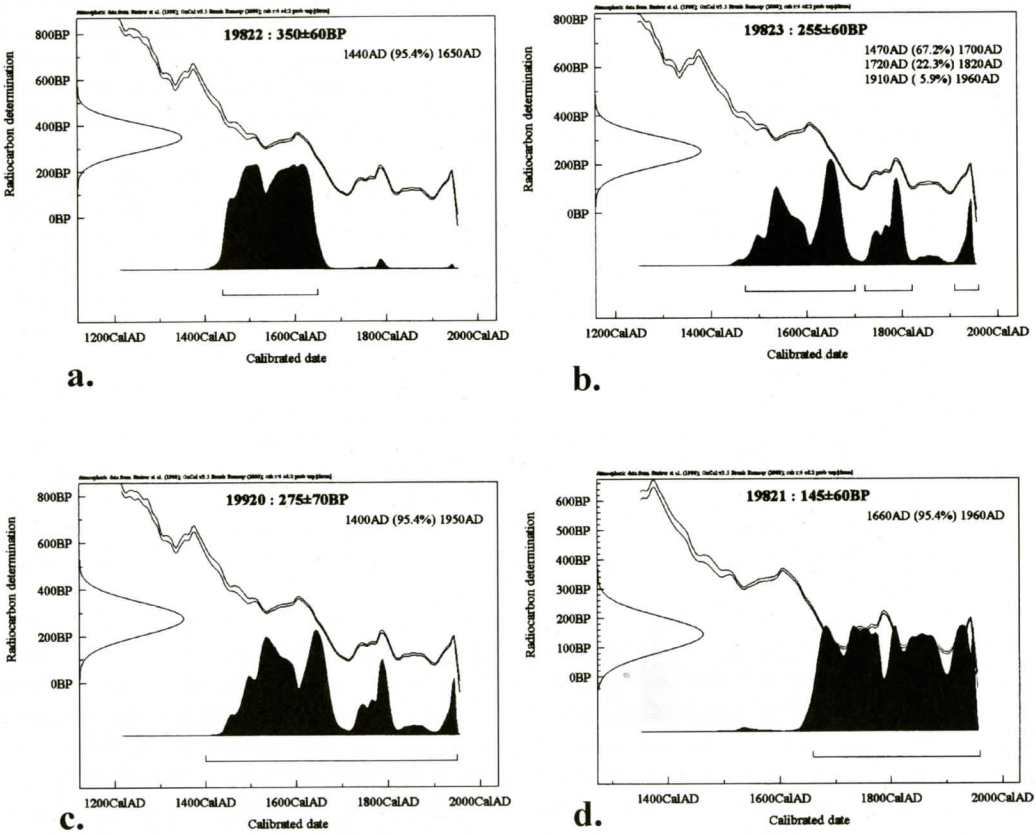


Figure 2. Radiocarbon and calculated calendar age range probability from the plank samples described in Table 1: a) sacrificial pine plank 331, b) sacrificial pine plank 367, c) oak bottom plank 368, d) oak bottom plank 358. In Figures 2-4, the RA, the relevant portion of the calibration curve, and the probability of a sample with the reported RA and error having a particular calendar age range are shown for each sample. The line along the vertical left axis displays the RA and its error. The irregular pair of lines display the relevant portion of the radiocarbon calibration curve. It can be seen that the reported RA will intersect with the calibration curve at many spots thus giving rise to a number of potential calendar age ranges. The black shaded regions show the probability the sample will have a particular calendar age range.

with a fitted plastic top to keep out sediment raised into suspension or filling in from the sides, the core was vigorously rotated and pushed down for up to a minute in order to drive it as far into the sandy sediment as possible. A bottom plate then was fitted under the corer after digging out around it. All three samples reported here were collected near the east test trench whose location is illustrated on the cover of this issue. Sediment samples were collected under the wooden planks of the remaining hull structure between frame samples 383 and 373 (see Figure 1). Sections of 10 cm OD core liner were shoved repeatedly back and forth under the planks by hand in order to obtain sufficient sample size. The liners were sealed at each end with rubber stoppers. No attempt was made to avoid homogenization of the sample inside the liner. Some contamination of these samples with surrounding seafloor material is likely to have occurred as material caved into space created during the initial insertion and repeated back and forth movements of the core liner.

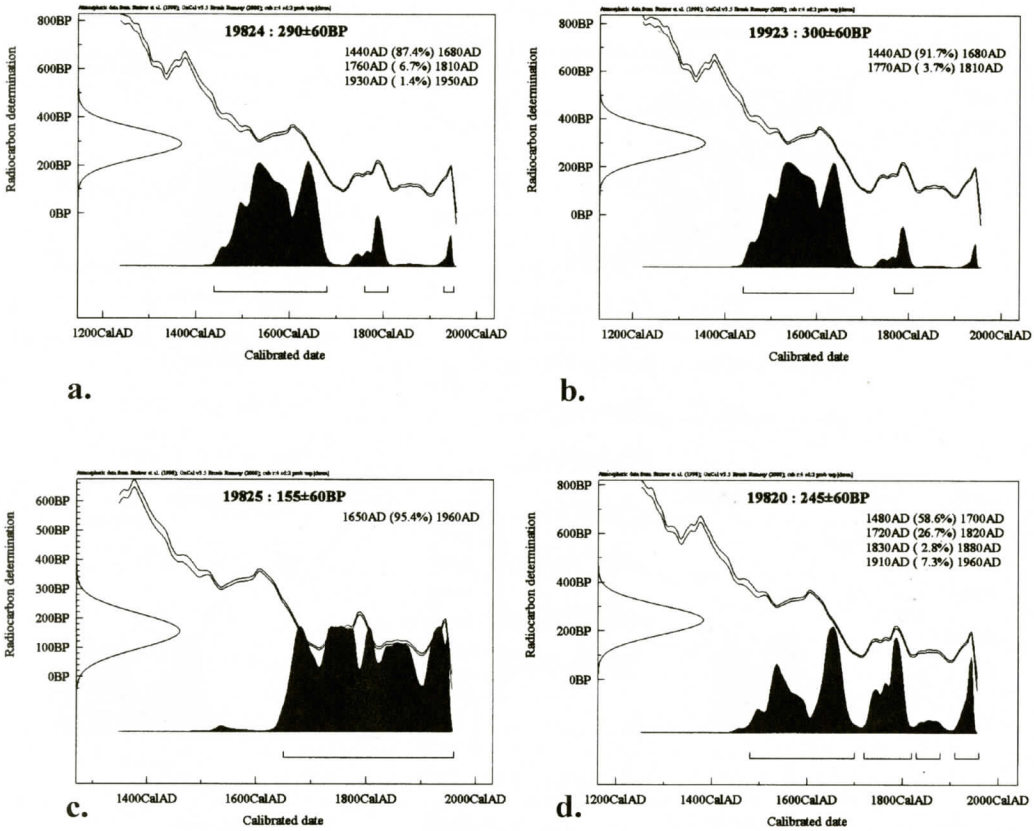


Figure 3. Radiocarbon and calculated calendar age range probabilities from the frame and treenail samples described in Table 1: a) oak frame 371, b) oak frame 384, c) treenail 298, d) treenail 383.

LABORATORY METHODS

Radiocarbon Sample Preparation Procedures at NOSAMS

All of the *QAR* samples (Table 1) underwent normal pre-treatment procedures for the NOSAMS Sample Preparation Laboratory. Samples that arrived as large pieces were divided with a razor blade. The razor blades were washed with Sparkleen detergent, rinsed with distilled water, rinsed with a 10% solution of hydrochloric acid (HCl), then rinsed a final time with organic free distilled water (MilliQ H_2O). When slicing off a piece of wood, we tried to obtain material from the inner, unexposed part of the sample. A number of smaller slices were obtained and processed for each sample.

Each sample was put into a clean, baked-out glass centrifuge tube. Approximately 8-10 ml of organic-free 10% HCl solution (enough to cover the sample) were added to the tube, which was then capped and placed in a 60°C water bath for 3 hours. Next, the acid was decanted from the tube using a baked-out disposable glass pipette, and the sample was rinsed using MilliQ H_2O. After rinsing the sample to neutral pH, the first base rinse was performed. Approximately 20 ml of 2% sodium hydroxide (NaOH) solution was added to the centrifuge tube, which then was capped, and placed in the water bath for one hour. After that time, the color of the solution was observed. If any brown discoloration was seen, the base was decanted and then another 20 ml of "fresh" base was added. The tube was then put into the water bath for another hour. This step was repeated until the solution appeared clear (free of any humic and/or

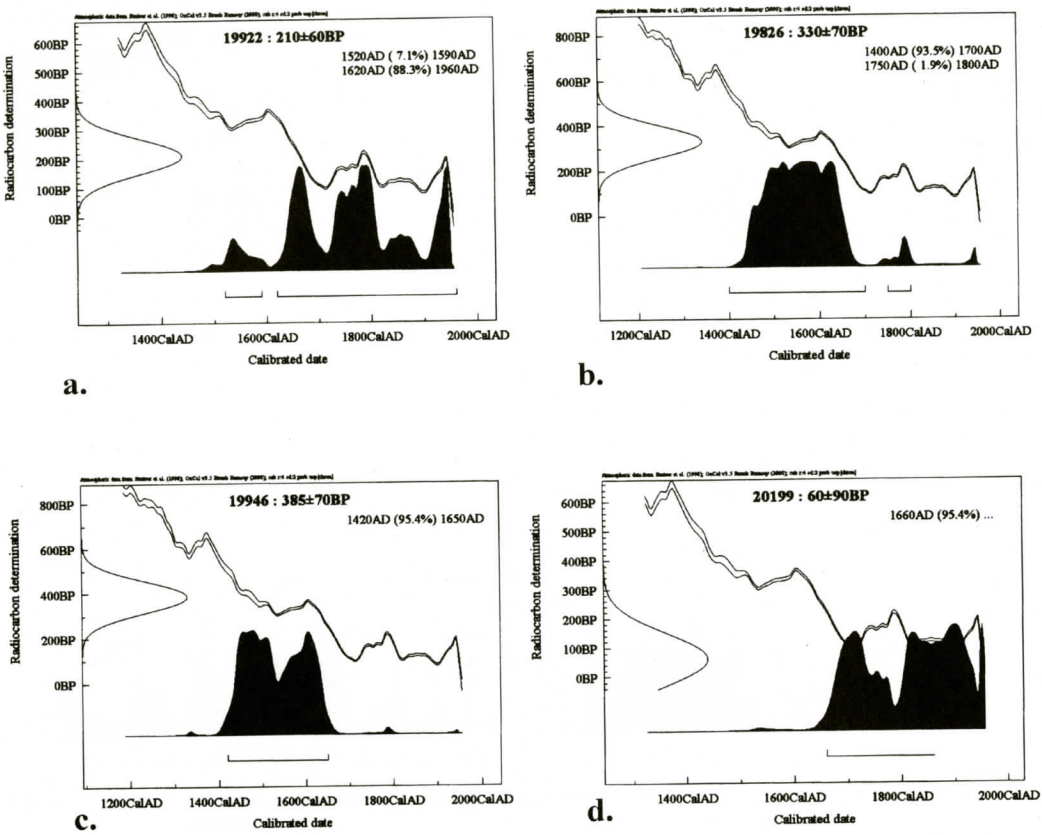


Figure 4. Radiocarbon and calculated calendar age range probabiliies from the remaining *QAR* samples described in Table 1: a) North anchor stock 386, b) south anchor stock 379, c) caulking hair 302, d) puddening from south anchor ring 381.

fulvic substances). Table 1 indicates the number of base steps required for each of these samples.

Once the solution was clear, it was decanted from the centrifuge tube, and the sample was rinsed well using MilliQ H_2O. After rinsing the sample to neutral pH, a final acid step was performed. About 5-10 mL of 10% organic free HCl were added to the tube, which was again capped and placed in the 60°C water bath for one hour.

After the final acid step, the sample was rinsed to neutral and then filtered using a vacuum-pump filtration unit. The sample was dried at 60°C in a glass petri dish. After drying, the sample was placed in a dessicator box until further processing.

All of the samples except OS 19923 were combusted using a closed-tube technique. A portion of the processed sample was transferred to a Vycor tube containing CuO and Ag. The tube was evacuated, flame-sealed and baked in a muffle furnace at 850°C for 5 hours. OS 19923 was combusted with a CN analyzer combustion/CO_2 trapping system. A small amount of sample was weighed into a tin cup, which was subsequently loaded into the sample carousel to await combustion within the CN analyzer. Following combustion, samples were converted to graphite and run on the NOSAMS accelerator using standard techniques (McNichol and others, 1995; Schneider and others, 1994; 1995).

Plutonium Analysis

Methods utilized to analyze the plutonium samples are described in detail by Benninger (1998). Whole wet sediment core samples were

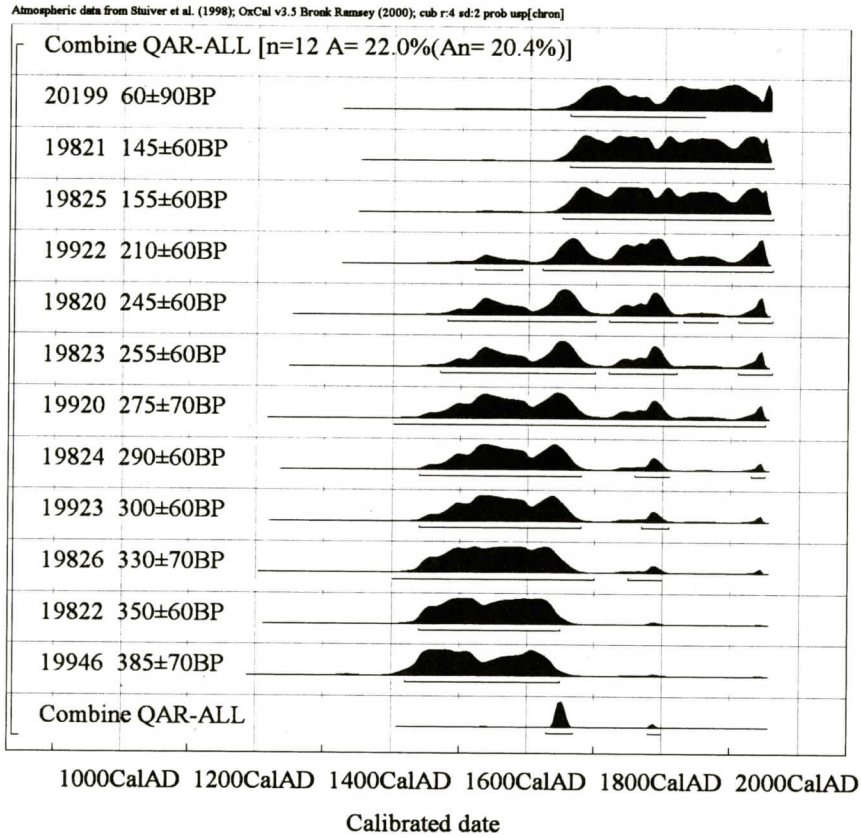


Figure 5. Summary of the calculated calendar age range probabilities for all the *QAR* samples.

oven-dried and extracted for 5-6 hours with hot, ~12M HCl. Following evaporative concentration of the filtrate and addition of ^{242}Pu as a yield tracer, the nuclides were scavenged by precipitating hydroxides and counted using alpha spectrometry.

RESULTS AND DISCUSSION

Radiocarbon Results

In Table 1, we report the radiocarbon concentration as fraction modern and as Radiocarbon Age (discussed below). The errors reported in the table are twice the reported accelerator error. We feel this represents the true sample to date error more accurately. The sand fence sample placed in the *QAR* sample group as a "ringer" gave the expected 1.42 fraction modern (fm) result indicating bomb carbon enrichment and will not be discussed further.

Conversion of Radiocarbon Ages to Calendar Ages

The amount of radiocarbon in a sample does not convert directly to a calendar or chronological age and is reported as a Radiocarbon Age (RA). Radioactive "clocks" will record the correct "time" **if** they all start with the same amount of radioactive material when they are set. The radiocarbon clock is set as living organisms grow and acquire ^{14}C naturally either photosynthetically through the atmosphere or through the carbon they eat. The amount of ^{14}C in the atmosphere has varied significantly over time and therefore requires calibration of the radiocarbon clock. Researchers have calibrated the clock using the radiocarbon stored in tree rings from long-lived, known-age trees (see

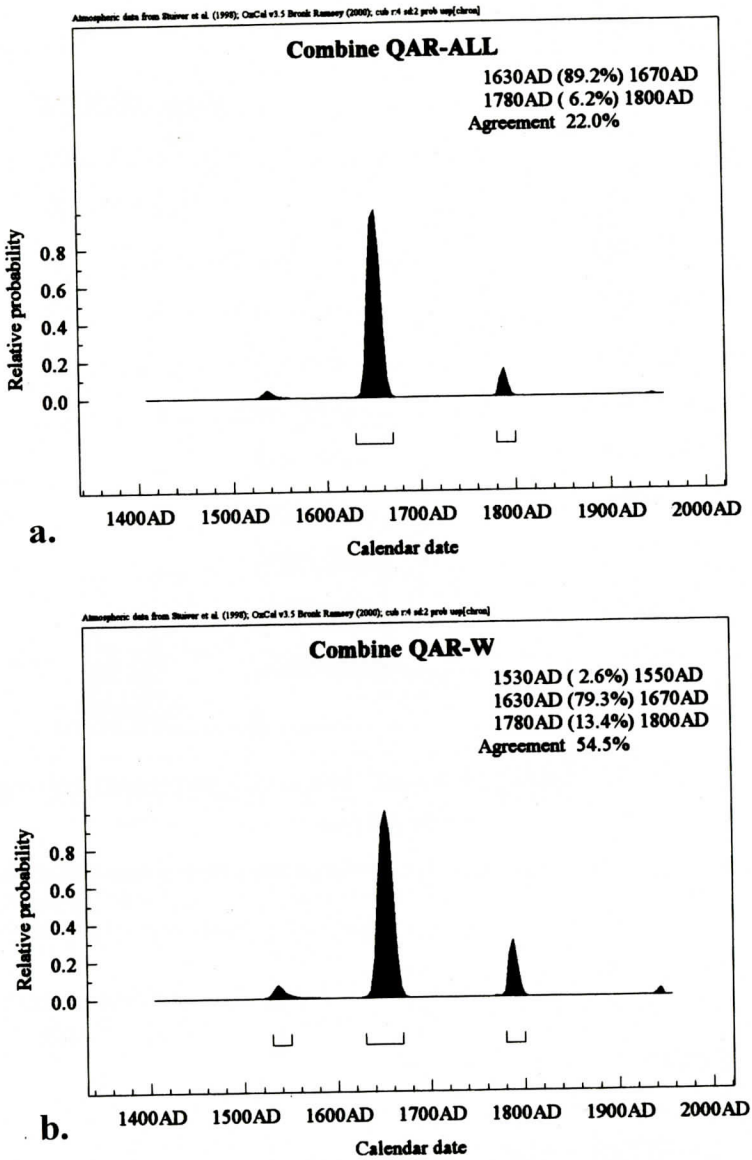
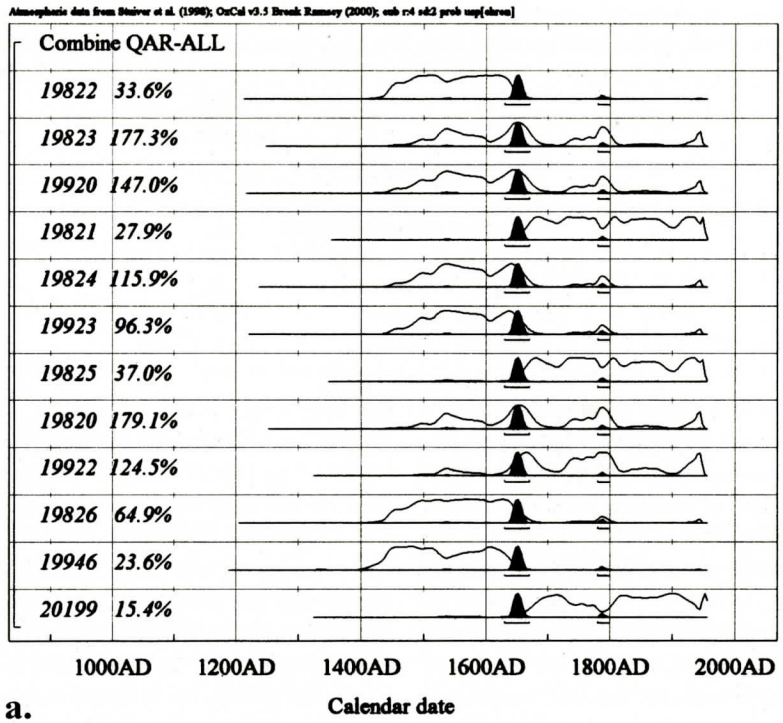


Figure 6. a) The most probable age ranges for the combined *QAR* total sample suite (*QAR*-ALL) shown as the black peaks. b) The most probable age ranges for the eight *QAR* hull wood sample suite (*QAR*-W) are shown as the black peaks. The total sample suite (*QAR*-ALL) and hull wood (*QAR*-W) sample suite and yield 89.2% and 79.3% calculated probabilities, respectively, for the age range 1630 to 1670 AD.

Calibration Issues of the journal Radiocarbon). Unfortunately for this project, the past 350-400 year period is a particularly difficult one for determining calendar ages. So much natural variation has occurred that each RA corresponds to more than one discrete calendar age. For example, we report a RA of 290 ± 60 yr BP for Sample OS 19824 (Table 1, UAU#371, frame No. 9). This age and error were entered into the OxCal calibration program (Bronk, 1995; OxCal web site is http://www.rlaha.ox.ac.uk/oxcal) to calculate the possible calendar ages and the



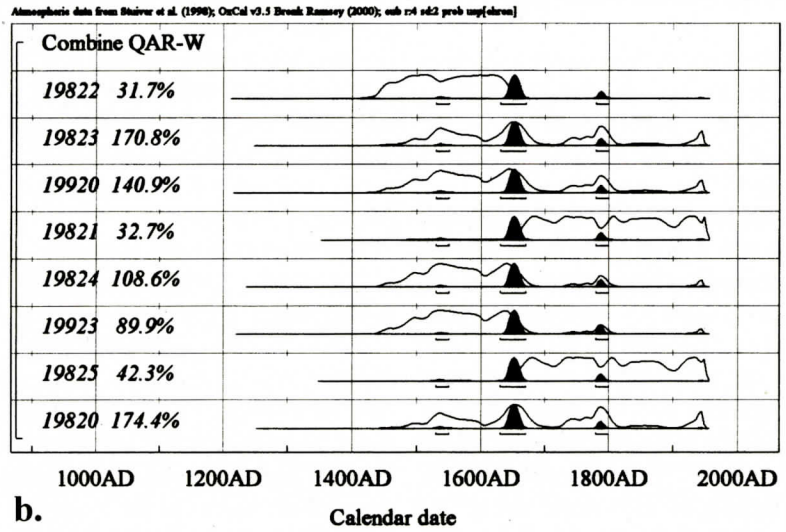


Figure 7. a) The most probable age range for the total *QAR* sample suite (*QAR*-ALL) shown as the black peaks superimposed on the individual sample age probabilities. On the left-hand side of the figure the OS number is shown along with a percentage that is related to how well the individual age agrees with the combined age as described in the OxCal manual (http://www.rlaha.ox.ac.uk/oxcal). The value may rise above 100% and the greatest confidence is found in samples showing an agreement greater than 60%; this is equivalent to a 5% confidence level for a chi squared test. b) the most probable age range for the combined *QAR* plank, frame and treenail samples (*QAR*-W). It is indistinguishable from that of the total combined samples.

Table 2. Summary of plutonium data from the Queen Anne's Revenge wreck site. The raised ballast stones were all along the east transect line. The sediments collected under planking all came from under the remaining hull structure between radiocarbon samples 383 and 371 (Figure 1).

Sample No.	Description	$^{239,240}Pu$ mBq/kg	Error 1 SD
H 376	Sediment under ballast stone	1.61	0.52
H 377	Sediment under ballast stone	3.25	0.69
H 378	Sediment under ballast stone	2.94	0.86
LC 2	Sediment under planking	5.87	1.29
LC 6	Sediment under planking	6.42	0.92
SC 25	Background sediment	15.9	1.6
SC 75	Background sediment	18.3	2.3

probability for each (Figure 3a) using the relevant portion of the calibration curve. The line along the left vertical axis displays the RA and its error. The pair of irregular lines descending across the figure illustrate the relevant portion of the calibration curve. It can be seen that the reported RA will intersect with the calibration curve at many spots thus giving rise to a number of potential calendar ages. The black shaded regions show the probability that the sample will have a particular calendar age range.

Calculated Radiocarbon Ages

Potential calendar year age ranges have been calculated for each of the samples; the results are shown in Figures 2-4. Comparison of the potential calendar age distributions for all 12 samples (Figure 5) indicates an overlap of the probability distributions in the region between 1600 and 1700 AD. The program OxCal allows combination of the probability distributions of a suite of samples to calculate the most probable age calendar age of the suite, assuming all these samples had a similar origin. The combined results for the eight hull wood samples (*QAR*-W: planks, frames and treenails) and the entire twelve samples (*QAR*-ALL) from the *QAR* site are shown in Figures 6a and b respectively. The *QAR*-W suite and *QAR*-ALL suite yield 79.3% and 89.2% calculated probabilities, respectively, for the age range 1630 to 1670 AD (Figure 6). Not surprisingly, other information from the site independently rules out the1780-1800 age range which has a lower probability according to our radiocarbon results (see Wilde-Ramsing and others, this issue). The most probable age distributions for the two different sample suites (*QAR*-W and *QAR*-ALL) are plotted with the data for each individual sample in Figures 7a and b. The suite probable ages are shown as the black peaks superimposed on the individual sample age probabilities. On the left-hand side of the figure the OS number is shown along with a percentage that is related to how well the individual age agrees with the combined age as described in the OxCal manual (http://www.rlaha.ox.ac.uk/oxcal).

The radiocarbon ages (Figure 4a and b) for the two different wooden anchor stocks found at the wreck site differ by 120 ± 85 radiocarbon years (Table 1). However, OxCal calibrations based on changes in the abundance of natural radiocarbon in the atmosphere allow their calendar year ages to overlap in the mid 1600's (Figures 4 through 7).

The combined radiocarbon results are consistent with an age range from1630 to 1670 for the randomly collected samples from planks, frames, treenails and anchor stocks. Tree ring counts (Michael Baillie, personal communication, 20 July, 2000) of several large oak samples from the ship yield a maximum number of growth rings of 62 (plus 1 incomplete). None of the timbers seems to be older than about 70 years at most. Thus, the potential ages of the wood sampled should span a period of approximately 70 years when missing sapwood is included. No younger sapwood was present at the site, suggesting that the wood used to construct the ship should have been growing at least 10 and possibly 20 years later. A correction for this

lack of sapwood suggests that the 1670 age, the younger end of the 1630 to 1670 range, should be extended to approximately 1680 or 1690. In addition, uncertainties in individual sample ages combined with the limited number of randomly selected wood samples analyzed suggest that the overall age range likely covers the early 1700's, at least as recent as 1710.

Plutonium Activities

The plutonium activities measured in all sediment samples are summarized in Table 2. The activity of $^{239,240}Pu$ in two samples from shelf sediments surrounding the wreck site ranged from 15.8 to 18.3 mBq/kg, a range expected for shallow inner shelf sandy environments from previous surveys of North Carolina sediment activity distributions (Benninger, 1998). Plutonium activities in sands cored from underneath three ballast stones ranged from 1.6 to 3.3 mBq/kg. The ballast stones and sediment underlying them should contain zero plutonium activity if they had remained in place since before the mid-1950's. However, the low activities found may be a result of sampling difficulties. During diver removal of each ballast stone, a small amount of sediment from the adjacent seafloor surface cascaded into the newly created crater-shaped cavities. Thus, some contamination of the sediment underlying each stone by plutonium-enriched surrounding sediment would be expected. The low plutonium values found under ballast stones in comparison with those for the surrounding seafloor probably represent a mixture of the two sources. Similarly, plutonium activities in two sediment samples collected under the shipwreck's remaining planking were relatively low, ranging from 5.9 to 6.4 mBq/kg. These activity values probably reflect a mixture of low plutonium material from under the wooden structure mixed with sediment from the surrounding seafloor.

Sediments collected under the remaining hull structure and ballast stones contain plutonium activities ranging from 9% to 41% of that found in exposed surface sediments surrounding the wreck site. The source of at least some of the plutonium under the shipwreck artifacts is exposed surface sediment that was mixed in during sampling. In spite of this contamination problem, the results suggest little disturbance of the remaining intact hull and ballast rocks since the mid-1950's.

CONCLUSIONS

Radiocarbon ages for the randomly collected samples from planks, frames, treenails, anchor stocks and other organic materials found at the putative *QAR* wreck site are consistent with a calendar year age range from1630 to 1670 AD. The combined data yields ages consistent with a ship construction date between 1690 and 1710 AD.

Sediments sampled from underneath the remaining hull structure and ballast rocks of the *QAR* contained from 9 to 41% of the plutonium activity measured in surrounding exposed surface sediments. These results suggest that little disturbance of the remaining intact hull and ballast rocks have occurred since the mid-1950's.

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laboratory of L.K. Benninger at UNC-CH.

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PRELIMINARY STUDIES OF SOME BASE AND PRECIOUS METALS FROM THE *QUEEN ANNE'S REVENGE*

JAMES R. CRAIG

Department of Geological Sciences
Virginia Tech
Blacksburg, VA. 24061-0420

JOHN E. CALLAHAN

Department of Geology,
Appalachian State University
Boone, N.C.28608-2068

J. WILLIAM MILLER

Department of Environmental Studies,
University of North Carolina at Asheville
Asheville, N.C. 28804-8511

WAYNE R. LUSARDI

North Carolina Underwater Archaeology Unit
% Institute of Marine Sciences
3431 Arendell Street, Morehead City, N.C. 28557

ABSTRACT

Metal-bearing artifacts recovered from the wreck site of the *Queen Anne's Revenge* have been subjected to various oxidizing and reducing conditions during the nearly 300 years that they lay on the sea floor. The base metals respond to these conditions by forming corrosion layers of oxides and hydroxides under oxidizing conditions and layers of sulfides under reducing conditions. These phases alter the surfaces of the metals but also then serve as protective layers that preserve the underlying metal from further corrosion or dissolution. The precious metals are represented by numerous small placer gold grains that have been recovered. They contain gold-rich rims that are characteristic of a placer origin, but it is not yet possible to determine the site of original extraction. Preliminary lead isotopic data confirm a European/Mediterranean origin, consistent with the ship having been constructed in France.

INTRODUCTION

Recovery efforts from the first several seasons of work on the *Queen Anne's Revenge* (*QAR*) site, have yielded an array of artifacts, many of which are composed in whole or in part of base and precious metals (Lusardi, 1999). The pieces themselves aid in interpreting the activities on board the ship, help to trace the course of its journey, and may assist in confirming the identity of the ship as the *QAR*. The metals of which many artifacts are composed may offer other useful information including the localities from which metals were initially extracted, the conditions under which the artifacts have lain for nearly 280 years, and some general, but potentially widely applicable, data on the corrosion/ preservation of metal artifacts. Certainly, characterization of corrosion products is an important initial step in planning the procedures to be employed in conservation efforts.

Only a very small proportion of the metal artifacts of the *QAR* have been retrieved, and as many as one million separate items may ultimately be recovered. Samples already available

range over the length and breadth of the wreck site and have been found from the surface of the sediment to depths of approximately five feet in the sediment. They range from iron barrel hoops, anchors, and nails, to brass nautical devices, to lead shot and stripping, to pewter plates and a syringe, to gold grains. Hence, the metal artifacts are probably representative of most of the materials that will ultimately be excavated. Recognizing that this is only a preliminary report, the authors do feel that the observations reported here (and briefly given in some oral presentations, Craig and others 2000) will remain valid and may help in the study and interpretation of artifacts yet to be recovered. Some of the observations made here should be applicable at other sites because the conditions of burial at the *QAR* site are similar to those at many other shipwreck sites.

BASE AND PRECIOUS METALS AT THE *QAR* SITE

The discovery and recovery of metal-bearing artifacts at underwater wreck sites is always fortuitous and always subject to the vagaries of the waters in which they reside. In contrast to some mineralogical and geological studies where one can plan and conduct orderly investigations based on expected directions of water or earth movement, submarine wreck sites are haphazard jumbles of materials whose original spatial arrangements can only be surmised after artifacts have been carefully recorded, recovered, cleaned (sometimes this is not useful from the mineralogist's perspective), studied, and interpreted. The wreck site has been sampled from the outside (top and flanks) inward so that materials are not damaged or allowed to move or corrode unnecessarily. Thus there is always the possibility that deeper parts of the debris mound may contain some specific materials that were held in unique sites on the vessel or contain materials that have been subjected to a different set of preservation conditions than those on the top. At the time of this manuscript preparation, the metal-bearing objects recovered include the following:

Iron- cannon, barrel hoops, nails - range from well preserved to completely converted to hydroxides

Copper — small pieces of sheeting, alloyed in brass, and in some pewter

Zinc — in brass surveying and map reading instruments

Lead — shot of various sizes, sheets to reduce leaks in hull, small tack-like nails,

Tin — pewter plates in a variety of sizes, medical syringe

Mercury — alloyed with gold and silver in ornamental clasps, inside a medical syringe

Gold — small free grains, small ornamental clasps

Silver — alloyed with gold in small ornamental clasp

All of the samples were likely subjected to varying conditions of oxidation and reduction while they lay buried in the sediments near Beaufort Inlet for nearly 280 years. The metals may act as geochemical indicators of the conditions within the sediments by developing different kinds of surficial corrosion minerals. Under oxidizing conditions, copper or lead may form oxides or hydroxides, whereas, under reducing conditions, these metals readily form sulfides. Whether the surfical corrosion phases remain of one type or shift back and forth as the result of changing oxidation - reduction conditions, the corrosion phases generally serve valuably as an "armor" protecting the underlying metal. For example, metallic lead is moderately soluble and would dissolve away if long exposed to fresh or saline waters. However, the surficial coatings of the hydroxycarbonate, hydrocerussite ($Pb_3(CO_3)_2(OH)_2$) that form under oxidizing conditions or the sulfide galena (PbS) that form under reducing conditions, provide protection. The solubility of the corrosion phases are nearly always very low - otherwise they could not form - and therefore they serve as very effective protective capsules. The brief discussions and the illustrations presented below are restricted to the base and precious metals and are intended to give "snapshots" into the natures of the base and precious metal-bearing phases and the types of minerals forming as a result of the corrosion. The discussion attempts to be broad but not detailed nor complete.

BASE METALS

Lead

Lead is widespread at the *QAR* site in the form of lead shot ranging from approximately 2 mm to more than 20 mm in diameter (Figure 1).

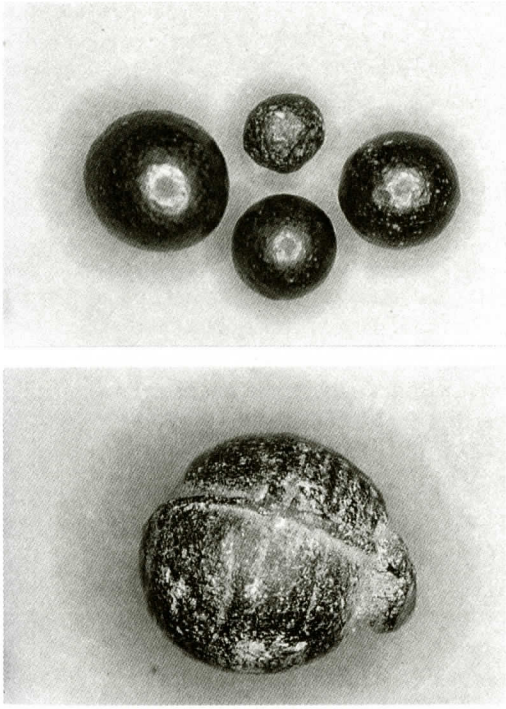

Figure 1. Lead shot recovered from the wreck site of the *QAR*. (a) 2 to 4 mm shot of the type found widely dispersed at the wreck site. (b) An 8 mm lead shot on which is clearly visible the mismatch of a two part mold.

In portions of the *QAR* site, distinct horizons consist almost entirely of scattered lead shot. In some of the buried portions of the site, the lead shot and the interstitial sand are cemented into solid masses (Figure 2). Lead is well known for its ability to persist in marine environments and has a long history of recovery from wrecks more than 2000 years old in many parts of the world. The lead at the *QAR* site reveals two different modes of corrosion. Under oxidizing conditions, the lead rapidly begins to form an oxide and then to form the hydroxycarbonate, hydrocerussite. This phase occurs on the surfaces of many grains as randomly oriented platelets

Figure 2. Cemented mass of lead shot and interstitial sand. This material has been extracted as solid masses which are cemented by a mixture of lead oxides, hydroxides, and sulfide (See also Figure 5).

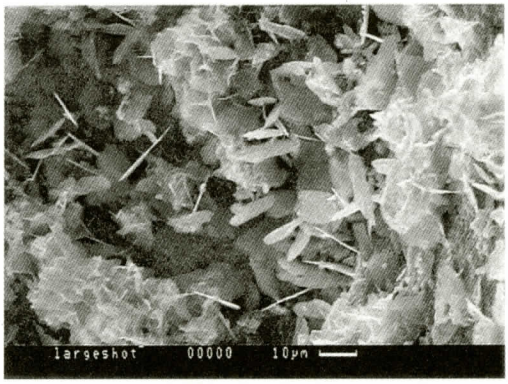

Figure 3. Plate-like crystals of hydrocerussite that have formed by reaction of a grain of lead shot with sea water. Once this surface forms, the underlying lead is protected from further reaction with the sea water.

as shown in Figure 3, but may also occur as beautiful sphere-like masses as shown in Figure 4. Under the reducing conditions preserved at depth in the sediments, the release of sulfur by sulfate reducing bacteria allows for the formation of galena (PbS). The piece of lead shot shown in Figure 5 has thin coatings of lead oxide and hydroxycarbonate overlain by a zone in which the galena resides interstitially among blades of aragonite. All of this was over-grown by thin layers of pyrite (FeS_2) which is also present as small necklace-like beads around many quartz grains. The combination of galena, pyrite, and aragonite needles serve to cement the masses together as is visible in Figure 2.

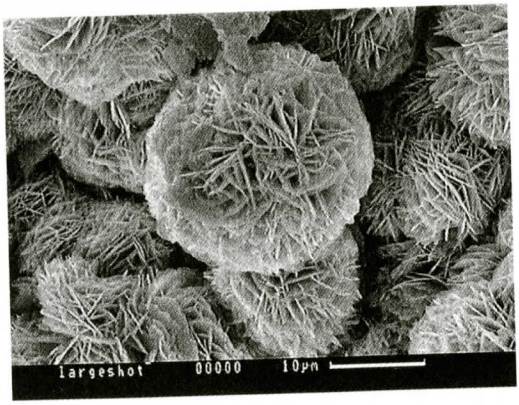

Figure 4. A sphere of hydrocerussite platelets that has formed along a margin where the lead shot molds did not match perfectly (see Figure 1b). The mismatched edges provided protection during recovery and handling of the specimen.

Figure 5. Back scattered scanning electron image of the margin of a lead shot grain from a cemented cluster as shown in Figure 2. There is a narrow zone of lead oxide and hydroxide overlain by a zone with galena interstitial to aragonite needles. This is all overgrown by a layer of pyrite. The various layers and the interlocking texture have cemented the mass together.

There is, of course, also the potential of using the lead isotopic ratios in determining the provenance of the metal. Preliminary data available, courtesy of A.K.Sinha, are consistent with lead sources in Europe and the Mediterranean as would be expected from the *QAR*.

Tin

Tin has found extensive use over the past several thousand years because it resembles silver, has been relatively inexpensive, is easy to work, and is reasonably resistant to corrosion under normal conditions. Pewter is basically a tin-based alloy but may contain varying amounts of a variety of metals. Early pewters commonly contained significant amounts of lead, but this was largely phased out by the late 1600s. The other most common metal in pewter is copper which may range from traces to tens of percents. Pewter artifacts from the *QAR* include several sizes of plates and a medical syringe.

Most of the plates reveal no knife marks and several contain impressions that appear to have been formed by enclosing burlap bags. Accordingly, it is believed that most of these plates were not actually in use but rather were being carried for barter or sale. Some of the plates bear legible hallmarks indicative of manufacture in London near 1700; the provenance of others is unknown. The plates display variable behavior during burial in that some were completely folded over, whereas others apparently broke in a brittle manner instead of bending. The pewter objects are generally only lightly corroded and are readily recognizable when recovered, in contrast to iron objects that are commonly completely encrusted with oxides and carbonates. Preliminary electron microprobe analysis of some small representative fragments of the pewter plates reveal that some plates are nearly pure tin whereas others contain 10 or more percent copper. In these latter samples, the copper is not uniformly dispersed but rather occurs as irregular clots (up to 10s of microns across) within a matrix of tin. We do not yet have sufficient data to be able to correlate the malleability of brittleness of the plates with specific textures, but it is likely that some chemical or textural difference controls the behavior. The tin of the pewter apparently slowly reacts with sea water forming thin black sooty layers of tin oxides, hydroxides, and chlorides commonly referred to as "tin pest" (North and MacLeod, 1987). Preliminary data reveal numerous small scale complexities that will be addressed in a

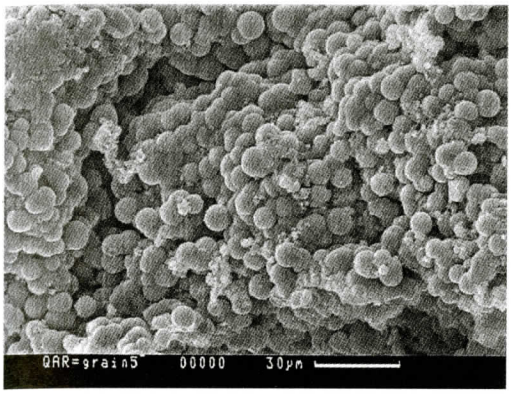

Figure 6. Botryoidal mass of tin sulfide (believed to be herzenbergite, SnS) that formed inside a pewter medical syringe. Sulfur produced by sulfate reducing bacteria reacted with the tin of the pewter in the confines of the syringe to produce a crust of sulfide.

later paper.

The pewter syringe has yielded some interesting tin sulfides (Figure 6) and some mercury (discussed below). The presence of the tin sulfides indicates very reducing conditions, at least in the interior of the syringe. The sulfur is believed to have been generated by sulfate reducing bacteria in the sediment, and the tin presumably came from the interior of the syringe. The small botryoidal tin sulfide masses have not yet been specifically identified but other corroded samples of the pewter have been found to contain small amounts of herzenbergite (SnS); accordingly, we believe that these masses are also herzenbergite.

Mercury

Although no specific mercury compounds have been identified, mercury concentrations of up to 10,000 parts per million were found in the sediment that was extracted from the syringe. The use of mercury compounds to treat a variety of medical conditions in the early 18th Century is well documented. Hence, we believe that the mercury may be a residual material left from medical treatments that were administered with the syringe.

Copper

Most of the copper at the *QAR* site occurs in the form of brass which exhibits the typical development of a greenish patina as expected in the marine environment; this material has not been studied in detail as yet. Some small pieces of copper sheeting of unknown use have been recovered. The copper has been oxidized along the margins and has apparently been corroded to form copper oxide (probably cuprite, Cu_2O).

PRECIOUS METALS

Gold

Gold has been found as free grains in the sediment of the *QAR* site and in one small metal clasp. Approximately 100 loose gold grains (Figure 7a) ranging from less than 1 to 10 mm have been recovered to date at the *QAR* site.

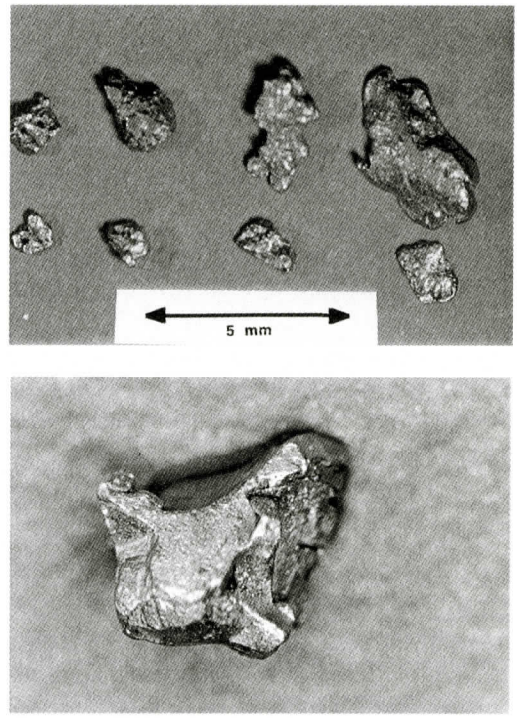

Figure 7.(a) Eight representative placer gold grains recovered from the *QAR* site. (b) A 1 mm grain of gold showing partial development of crystal faces.

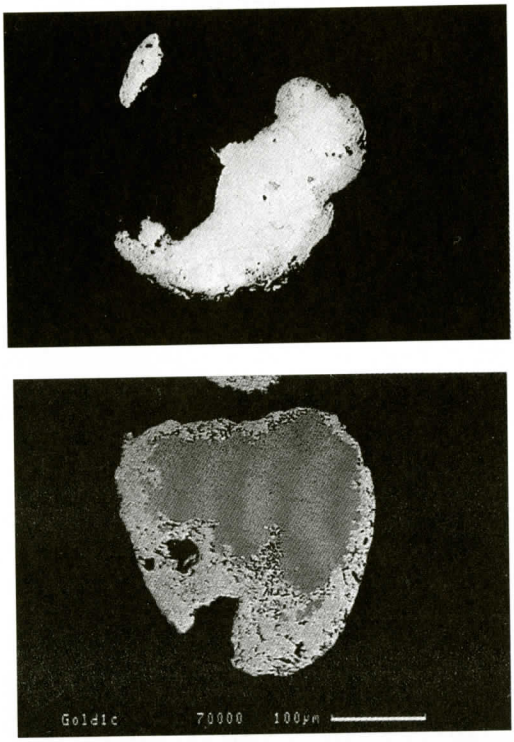

Figure 8.(a) Optical photomicrograph of a grain of placer gold showing the presence of a pure gold rim about a core of gold-silver alloy with approximately 65 percent gold; the grain is approximately 0.3 mm across. (b) Back scattered electron image of a portion of the grain shown in Figure 7a; the gold rich zone is made clear by the higher scattering power of the gold.

Most of these were found associated with lead shot in an exploratory trench that was cut in the northwest part of the site to examine for the presence and nature of artifacts at depth. The discovery was unanticipated and fortuitous, and it is presently impossible to estimate what additional quantity of gold may be scattered about the *QAR* site. Some reports indicated that the *QAR* carried 20 pounds of gold when she went aground, but such a quantity of gold would have been one of the first things rescued from the stricken vessel along with other valuable materials. The origin of the small amounts of gold so far recovered is not known, but the workers on the *QAR* speculate that this may be gold that had been secretly hidden behind beams to prevent theft by the pirates when the ship was commandeered by Blackbeard. The original owners were probably unable to return to recover it and Blackbeard did not know of its existence; subsequently, the gold would have been scattered about the *QAR* site as the ship was broken up by waves and the original container (perhaps a leather pouch) decomposed. Wave and current action would have caused some dispersal, but the high specific gravity of the gold would have resulted in its rapid burial in the sand: there was probably little movement afterward. Lead shot, because of its high specific gravity would have behaved in a similar manner; hence the co-occurrence of the materials.

The gold grains, which are totally free of corrosion or other coatings, are mostly somewhat rounded but one of the grains displays some development of crystal faces (Figure 7b). Several of the grains were mounted in cold-setting epoxy, sectioned, and polished for standard reflected light microscopic and scanning electron microscopic examination. Although some grains are uniform in composition, some of the grains contain a core rich in silver and a surrounding rim of pure gold. This is clearly shown in the optical photomicrograph and the back scattered electron image shown in Figure 8 a and b. These rims are typical of placer gold grains found in many parts of the world but are unknown in gold grains recovered directly from lode sources. Thus, although the mechanism of high-fineness rim development is not entirely clear, the presence of the rims clearly indicates a placer origin gold grains which is entirely consistent with the grain shapes. Figure 9 is an electron microprobe traverse across one of the rimmed gold grains that illustrates the compositional variation and the sharpness of the boundary between the core and the rim of the grain. The compositions of the cores of the gold grains vary from approximately 65 weight percent gold to about 90 percent gold, and the degree of rim development varies from extreme in the sample shown to non-existent in other grains. The core of each grain contains silver alloyed with the gold; this is typical of placer gold throughout the world. Lode gold sites yield grains with rather consistent gold compositions in their cores; the significant variation observed

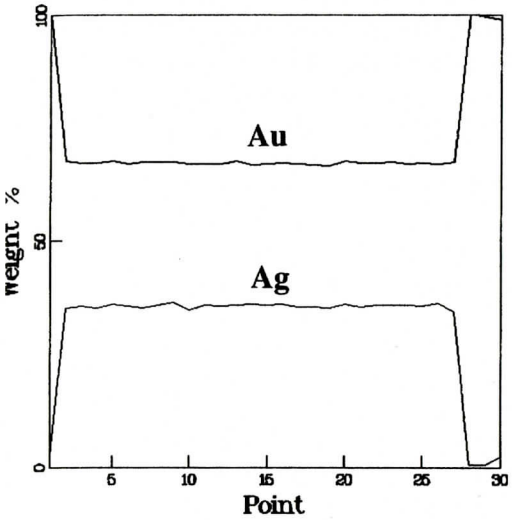

Figure 9. A compositional profile showing the gold (upper curve) and silver (lower curve) contents of a rimmed gold grain. The analytical points, numbered at the bottom, were 2 microns apart and illustrate the sharpness of the boundary between the core and the rim on the grain.

in the *QAR* samples examined, suggests that the gold grains found may have come from multiple sources.

Currently, no feasible way exists to determine the actual sources, but the gold may have been acquired at one or more places along the route. No gold production had been reported in what is now the United States by 1718, but several potential sources were known in Mexico, Central America, South America, and West Africa (Bethell,1984). It is also possible that the gold had been carried from Europe. If the ship traveled from Europe, to Africa, and then to the Americas as believed, there would have been several opportunities for the taking on of gold, the exchange of gold dust, and the mixing of gold from multiple sources. Gold was a medium of exchange, commonly being weighed out, exchanged, and intermixed with gold dust from other sites.

One small (approximately 1 cm across) five lobed ornamental clasp has been recovered; it is composed of gold and silver with some apparent mercury amalgamation on the surface. The function is not known, but it appears to have been sewn to some piece of clothing.

Silver

Silver as a free or refined pure metal has not been observed, but silver constitutes a significant proportion of the placer gold grains and is a constituent of the small gold-silver-mercury clasp noted above.

SUMMARY

Base and precious metals constitute significant portions of the artifacts recovered from the wreck of what is believed to be the *Queen Anne's Revenge*. All of the metals, except for the loose gold grains, reveal varying degrees of corrosion as the result of submersion in sea water and sediment for nearly 300 years. The pewter has withstood the corrosive effects of the sea quite well but is being altered slowly to tin oxides where conditions are oxidizing and to tin sulfides where conditions are reducing. Lead is abundant in the form of shot and has developed surface layers of lead hydroxycarbonate where oxidized and lead sulfide where conditions are reducing. Preliminary lead isotope data suggest a European or Mediterranean site or origin that would be completely consistent with a French origin for the ship. Placer gold grains have survived with no visible corrosion effects but display well developed rim structures.

ACKNOWLEDGEMENTS

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BALLAST STONE STUDIES FROM NORTH CAROLINA SHIPWRECK 0003 BUI, THE *QUEEN ANNE'S REVENGE*: HAND SPECIMEN, X-RAY, PETROGRAPHIC, CHEMICAL, PARAMAGNETIC AND ^{40}K - ^{40}AR AGE RESULTS

JOHN E. CALLAHAN

Geology Department
Appalachian State University
Boone, North Carolina 28608-2067

J. WILLIAM MILLER

Department of Environmental Studies
University of North Carolina at Asheville
Asheville, North Carolina 28804-8511

JAMES R. CRAIG

Department of Geological Sciences
Virginia Tech
Blacksburg, Virginia 24061-0420

ABSTRACT

Ballast stones recovered from a wreck site known as North Carolina site 0003BUI, thought to be the *Queen Anne's Revenge*, have been studied using hand specimen, polished thin section, and powder X-ray diffraction analyses. Whole rock and trace element compositions, as well as magnetic susceptibility signatures were determined for many of the samples. Three samples were age dated by ^{40}K - ^{40}Ar whole rock analyses.

The majority of the 131 (232 kilograms) ballast stones studied, 32 weight percent, are microporphyritic, olivine basalt, of high alumina, subalkaline affinity and metamorphosed to greenschist facies. ^{40}K - ^{40}Ar age dates on two of these samples indicate early (19.6 Ma) and middle Miocene (13.9 Ma) ages. Others are: porphyritic to felsic-intermediate volcanics (21%), one of which yielded a ^{40}K- ^{40}Ar date of Eocene age (47 Ma); volcaniclastics (20%); hornblende gabbro and altered hornblende gabbro (20%). Others include amphibolite (2%), limestone (2%), granitic rocks (1%), and a few samples of sandstone, conglomerate, vein quartz, a flint pebble, and a single sample of an altered pumpellyite-rich basalt.

A Phil Callahan Soil Magnetic Meter was used to group samples according to their magnetic susceptibility, which correlated with general lithology. Some susceptibilities overlapped between lithologies, but gross lithologic groups were discernible when combined with hand specimen identification.

Chemistry and mineralogy of the igneous ballast rocks are indicative of an island arc environment, probably the Caribbean.

INTRODUCTION

This study is being conducted to determine source areas from which the ballast stones in North Carolina shipwreck site 0003BUI originated. If source areas match sites where Blackbeard is known to have visited, this information will provide support to confirm that this wreck is indeed that of the *Queen Anne's Revenge*.

In sailing ships, ballast is used to lower the center of gravity. Ballast often consisted of rounded stones to avoid abrading the hull against which they were placed. Large permanent ballast was often placed in a ship's hull at the time of construction, and would most likely indicate where the ship was built. Temporary ballast was placed as needed in a ship's hull to compensate for loss of cargo and was added or

removed as conditions warranted.

North Carolina shipwreck number 0003BUI was discovered in 1996 in Beaufort Inlet, in six meters of water. The site is approximately one nautical mile south southwest of Beaufort, North Carolina (see Figure 1, Lawrence and Wilde-Ramsing, this issue). This wreck is presumed to be that of Blackbeard's ship, the *Queen Anne's Revenge* sunk off Beaufort, North Carolina in June of 1718.

A total of 131 ballast stones weighing 232 kilograms have been used for this study. The main ballast pile is 7.6 meters by 4.6 meters by 1.2 meters high and contains an estimated 30-38 tons of ballast stones (see Figure 2, Lawrence and Wilde-Ramsing, this issue). The stones were retrieved from several locations by divers from the North Carolina Underwater Archeology Unit during 1997, 1998, and 1999. Samples from different parts of the mound yielded essentially the same lithologies and approximately the same weight percentages of each type. Although the work reported here is based on only a small portion of the ballast stones in the mound, it is believed to be fairly representative, as ballast obtained from separate areas had similar compositions.

PREVIOUS WORK

About a dozen articles on various aspects of ballast stone studies appear in the literature. Borreson (1939), (Lamb and others,1990), was probably the first to attempt to use ballast to identify a shipwreck off of North Carolina. Emery and others (1968) traced upper Cretaceous age flint ballast from locations on the east coast of the United States to the shores of England and France. The most complete study of ballast found to date was by Lamb and others (1990). They examined 1199 ballast stones from the Molasses Reef wreck, located in the Turks and Caicos Islands, British West Indies. Samples consisted mainly of quartzites, high aluminum basalt of Eocene age, most likely from Lisbon, Portugal and alkali, olivine basalt perhaps from one of the islands of the central eastern Atlantic intraplate group, such as Lanzarote in the Canary Islands. Miocene age limestone likely from the east coast of Spain, limestone from near Bristol, England and calc-schist, probably from the Cartagena area of Spain were also identified. Smith and others (1998) examined 46 samples of ballast from the Emanuel Point shipwreck in Pensacola Bay, Florida. The majority of the stones were quartzites (34%), olivine basalts (15%), and mudstones (15%). A specific source area could not be determined for any of the lithologies. Some ballast work has evidently been done on the *Nuestra Senora de Atocha* site from a ballast pile estimated to be 33 meters long,18 meters wide and 1-1/2 meters high, by an unknown author, but nothing has appeared in print to our knowledge. Other articles dealing with shipwreck ballast include those by Olds (1976), Audy and others (1981), Mascle (1981), Gifford (1982) and Redknap (1984).

The authors have previously examined a number of ballast stones provided to them by Joe Kimball of the Caribbean Shipwreck Museum from other wreck sites. Two samples of ballast from the Spanish galleon *El Infante*, sunk in 1733 off of Key Largo, Florida were examined. One was a large welded tuff and the other a small mafic volcanic tuff. A sample of a small flint pebble from the English warship *H. M. S. Fly*, sunk off of John Pennekamp State Park, Florida, was of Cretaceous age, and most likely from the southeastern English Coast or western French coast, based on the fossil assemblages (Frank McKinney, personal communication, 1996).

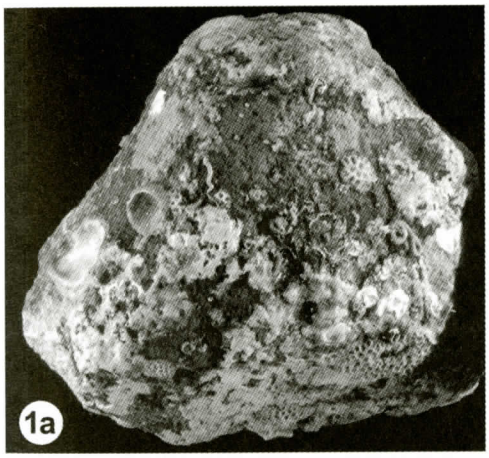
FIELD AND LABORATORY TECHNIQUES

The Underwater Archeology Unit of the North Carolina Department of Cultural Resources provided 131 ballast stones from the wreck site for this study. Samples ranged in size from that of a pea weighing only a few grams to one larger than a basketball weighing more than 27 kilograms. The majority of the samples were rounded to sub-rounded, and had been cleaned of encrusting marine organisms in the early phases of the study. Ballast collected more recently have not had the encrusting organisms removed and have been studied by Hagemar

(this issue).

The stones were weighed, measured and the degree of rounding described. Most of the samples were cut with a diamond saw to expose fresh rock, because encrusting organisms and weathering rinds obscured lithologies (Figure 1a). Polished or standard thin sections, were made from representative samples. Small chips from most larger samples were analyzed by powder X-ray, and major and trace element chemical analyses was completed by a commercial laboratory (ACME Analytical Laboratories of Vancouver, Canada). Mössbauer studies (Miller and others, this issue) were also completed on a number of the samples. Most samples were X-rayed to aid in determining the mineral content. Two samples of basalts with different magnetic susceptibility signatures, and a third sample of a porphyritic intermediate volcanic were submitted to Geochron Laboratories for ^{40}K-^{40}Ar isotope whole rock age date analyses.

A Phil Callahan Soil Meter was used to measure the magnetic susceptibility (μ CGS units) of some ballast rocks to determine if they could be grouped according to lithologies by magnetic susceptibility. Chips from larger ballast stones were ground to minus 40-mesh (0.470 mm), placed in scintillation vials, and the magnetic susceptibility measured.



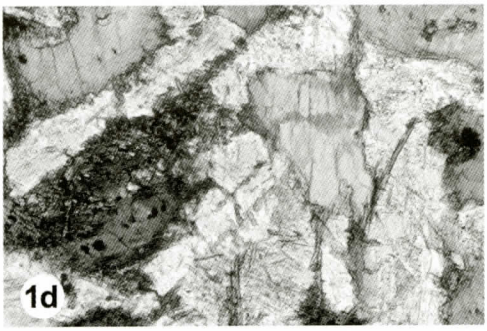


Figure1a. A typical encrusted porphyritic andesite ballast stone. Sample 0003BUI 442 is approximately 21 cm wide and weighs 4,800 grams. 1b. Photomicrograph of microporphyritic basalt 0003BUI 0069 in plain light with augite phenocrysts, plagioclase (anorthite) and magnetite in a fine-grained groundmass. Field of view is 1.2 mm. This sample was age dated at 13.9 +/ - 0.7 Ma. 1c. Photomicrograph of a porphyritic andesite sample number 3BUI0070 in plain light. Hornblende phenocrysts, plagioclase and magnetite are readily visible. Field of view is 1.2 mm. 1d. Photomicrograph of a hornblende/actinolitic gabbro sample number 0003BUI0122 in plain light. Hornblende/actinolite and plagioclase (anorthite) make up the majority of the sample. Field of view is 1.2 mm.

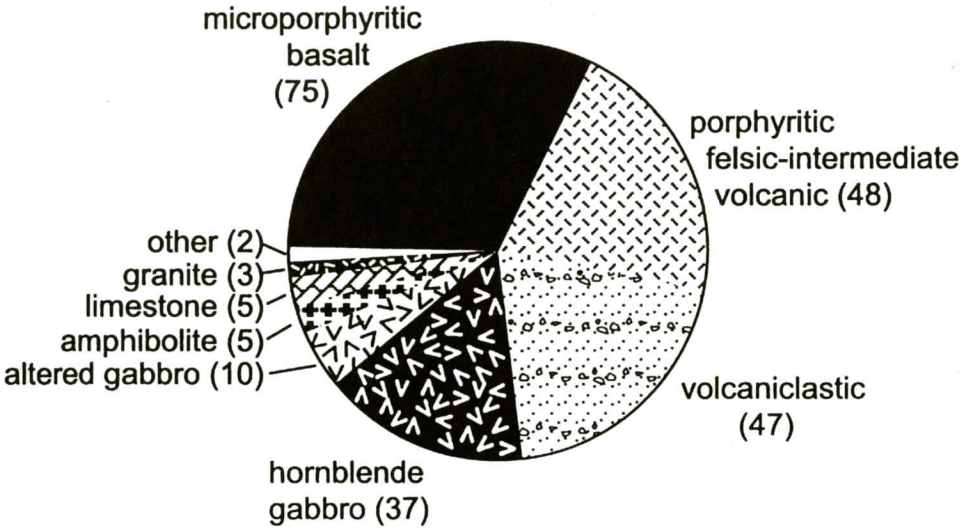


Figure 2. Weight percentages of lithologies in kilograms based on data from 131 ballast stones. Total kilograms for each rock type are listed. "granite" includes all phaneritic, felsic igneous rocks.

RESULTS AND DISCUSSION

Lithologic and Chemical Studies

Hageman's recent marine organism study (this issue), indicated that the ballast did not contain fauna foreign to the wreck site. Based on Hageman's study, the shape and degree of rounding of the ballast determined that most of the samples probably originated in a fluvial environment, and/or pebble beach, or possibly a volcanic mudflow.

The most common rock type is a microporphyritic, olivine basalt, which comprises 30 stones and 32 weight percent of the samples (Figure 2). The basalt consists mainly of plagioclase (anorthite), clinopyroxene (mainly augite), olivine altering in many cases to iddingsite, and trace amounts of magnetite and epidote (Figure 1b). These greenish-black basalts have been altered to greenschist facies. Eleven of these samples analyzed for whole rock and trace elements have an SiO_2 content for basalts close to the basaltic-andesite boundary (Table 1). Many show a strongly trachytic texture, and the larger phenocrysts are clinopyroxene. Alkalies are low averaging 4.02%. Titanium oxide ranges averaged 0.62%, and Sr values as high as 632 ppm, indicate an island arc source. A discrimination plot of alkalies versus SiO_2 of these basalts show they belong to the subalkaline, high aluminum series of basalts (Figure 3). A Pearce and Cann discrimination plot (1973) of Ti versus Zr indicates that these basalts fall into the mixed or low-potassium tholeiite class of basalts (Figure 4). Mg numbers for 11 of these basalts averaging 0.50, indicate a non-primitive magma source. Whole-rock chemistry, as indicated by an (*) in Table 1, and thin section petrography, indicates that these basalts are probably from an arc setting (island arc, tholeiite basalt) subjected to greenschist facies metamorphism.

A sample of an olivine basalt, obtained from the north coast just west of Puerto Plata in the Dominican Republic where Blackbeard was reported to have traveled, does not have a chemical (Table 1) or mineral composition similar to the basalts recovered from the ballast pile. This sample is more typical of an ocean island tholeiite basalt (OIT, Table 1) in composition and therefore does not match the basaltic ballast from the wreck site.

The second most abundant lithology (21%) is the porphyritic felsic-intermediate volcanic. These samples vary in color, but all have a

Table 1. Chemical analyses for 11 microporphyritic basalt ballast stones, and one olivine basalt from the Dominican Republic. Average data from ocean island tholeiites (OIT) and island arc tholeiites IAT) after Wilson,1989. Note: The * indicates the composition of basalt ballast is similar to that of island arc tholeiites.

	11 Basalt Ballast Stones		Dominican Republic Basalt	Averages for OIT Basalts	Averages for IAT Basalts
	Range Weights %	Average Weight %	Weight %	Weight %	Weight %
SiO_2	51.09 - 52.16	51.63	48.38	50.51	51.90*
Al_2O_3	17.48 - 18.07	17.74	14.91	13.45	16.00*
CaO	8.50 - 9.04	8.73	11.11	11.18	11.80
Na_2O	2.82 - 3.18	3.04	2.12	2.28	2.42
K_2O	0.89 - 1.04	1.00	0.29	0.49	0.44
$Na_2O + K_2O$	3.71 - 4.22	4.02	2.41	2.77	2.86
MgO	4.16 - 5.48	4.98	6.48	7.41	6.77
MnO	0.14 - 0.18	0.17	0.20	0.17	0.17
$Ti0_2$	1.02 - 1.18	1.12	2.29	2.63	0.80*
Ti	0.61 - 0.66	0.62	1.23	1.58	0.48*
Sr (ppm)	632 - 684	664			
Mg Number	0.47 - 0.53	0.50	0.48	0.58	0.41

greenish cast due to greenschist facies metamorphism. The more felsic ones are composed essentially of quartz and plagioclase feldspar (albite) with trace amounts of chlorite and epidote. The intermediate volcanics are composed dominantly of plagioclase (sodium-anorthite) and hornblende and/or clinopyroxene and traces of epidote and/or chlorite and opaques (Figure1c).

The third major group of rocks, often difficult to distinguish from the felsic-intermediate volcanics, is volcaniclastic (20%), with most samples composed of quartz and potassium feldspar or plagioclase. One unusually large volcaniclastic stone weighs 27 kilograms and is composed of clinopyroxene (augite) and plagioclase (anorthite).

Hornblende gabbro and altered gabbro consists of plagioclase (anorthite), and hornblende and/or actinolite, and in some instances clinopyroxene with trace amounts of magnetite (Figure 1d). Together, hornblende gabbro and altered gabbro makes up approximately 20 % of the samples. Some of the altered gabbros are difficult to distinguish from amphibolites that make up approximately 2 % of the samples. Samples of hornblende gabbro from streams draining the Rio Bobo complex in the north and eastern coastal portions of the Dominican Republic, where Blackbeard is reported to have traveled, are similar in hand specimen to the hornblende gabbro ballast stones. However, major oxides and trace element compositions of the Rio Bobo gabbro are quite different from the hornblende gabbro and therefore unlikely to be a source of the gabbro ballast. Other lithologies include granitic rocks (Figure 2), various types of limestones, conglomerate, sandstone, one flint pebble, several samples of vein quartz, and an altered pumpelleyite-rich basalt.

Paramagnetic Studies

Microporphyritic basalts are characterized by susceptibility values from 790 to 1475 μ CGS units (Figure 5a) and appear to show at least two different populations of basalt, a low group between 800 μ CGS and 1200 μ CGS and a group with higher values up to almost 1500 μ CGS. Miller and Whatleys' Mössbauer studies (this issue) however suggest a single common origin for the basalt. The variation in susceptibility for the basalt samples is probably indicative of different concentrations of magnetite.

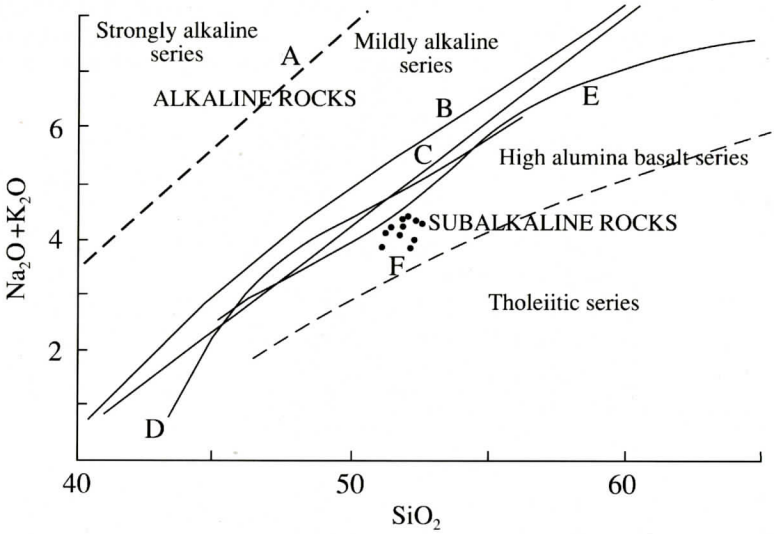


Figure 3. Discrimination plot of alkalies versus SiO_2 (after Schwarzer and Rogers, 1974). These 11 basalts are within the subalkaline, high alumina, series of basalt field.

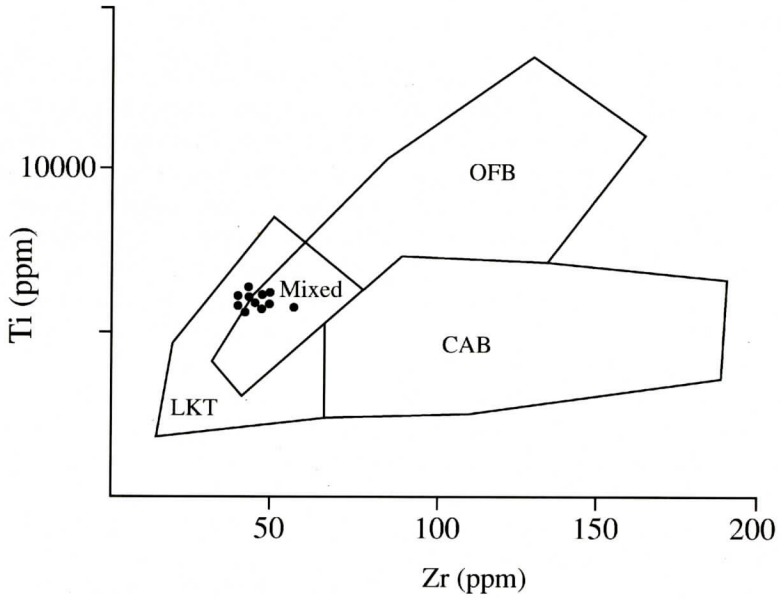


Figure 4. Discrimination plot of Ti versus Zr (after Pearce and Cann, 1973) shows that these 11 basalts belong to the mixed or low-potassium tholeiite basalts.

The majority of the other mafic rocks, gabbros (45-110 μ CGS) and amphibolites (45-170 μ CGS) have values of less than 100 μ CGS (Figure 5b). Felsic-intermediate volcanics /volcaniclastics (30-465 μ CGS) and granitic rocks (55-565 μ CGS) have magnetic susceptibilities of between 30 and 565 μ CGS (Figure 5c), and three samples of magnetite-rich porphyritc (hornblende) andesites with susceptibility greater than 1900 μ CGS (1900-2560) had the highest values obtained.

The magnetic susceptibility with some overlap between rock types is helpful in defining and categorizing specific lithologies of ballast

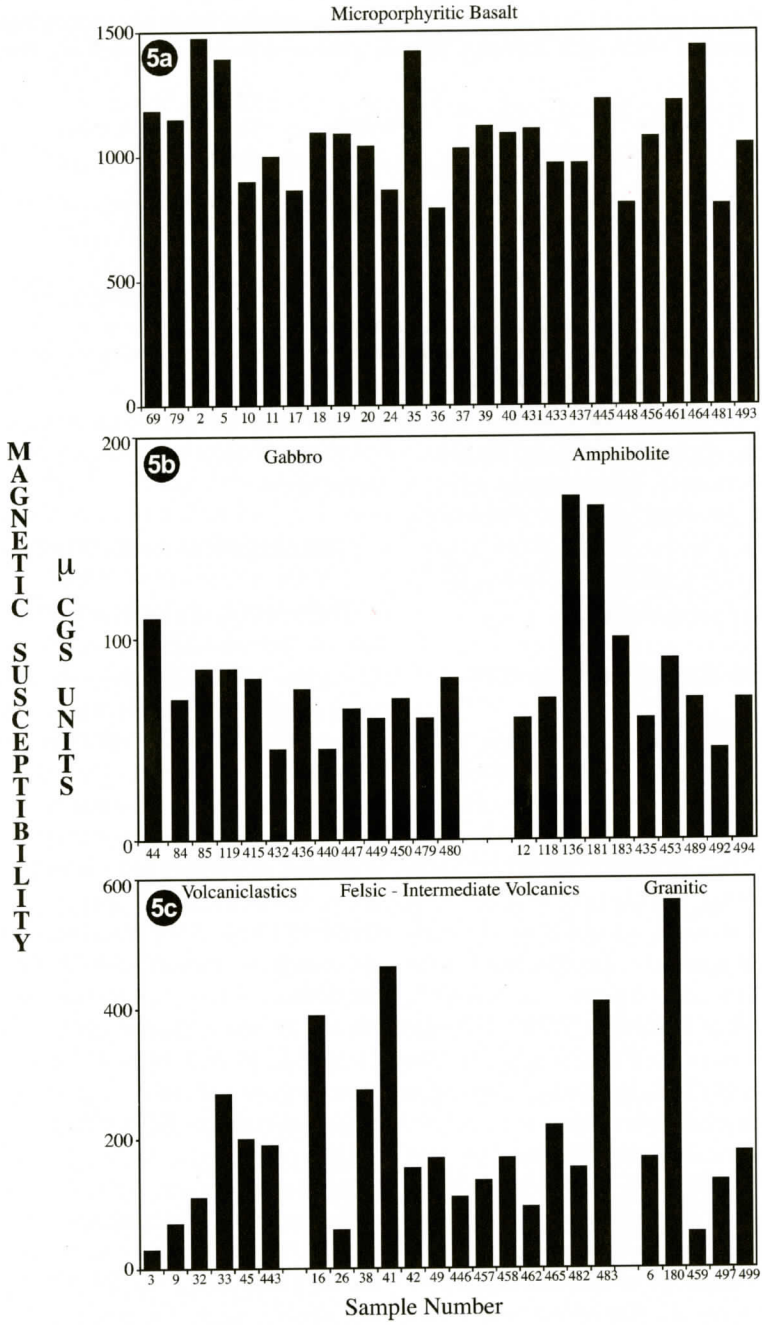


Figure 5. Magnetic susceptibility of ballast lithologies as measured on a Phil Callahan Soil magnetic susceptibility meter: 5a microporphyritic basalt; 5b hornblende gabbro and amphibolite; 5c volcaniclastics, felsic-intermediate volcanics, granitic rocks. Three magnetite-rich andesites plotted off of the graph with values of 1900, 2050 and 2560 μ CGS.

Table 2. ^{40}K - ^{40}Ar whole rock age dates for three ballast samples taken at random from the ballast pile of North Carolina shipwreck 0003BUI. Data is from a commerical laboratory, Geochron Laboratories.

Sample Number	Magnetic Susceptibility μ CGS units	Lithology	^{40}K - ^{40}Ar Age	Epoch
69	1200	microporphyritic basalt	13.9 ± 0.7 Ma	middle Eocene
431	800	microporphyritic basalt	19.6 ± 0.7 Ma	early Miocene
490	2560	Int. porphyritic volcanic	47.0 ± 1.2 Ma	middle Miocene

stones. It can be used to differentiate basalt (high susceptibility) from gabbro and the felsic-intermediate volcanics (low susceptibility). Magnetic susceptibility provides a relatively simple and quick technique of grouping samples without utilizing more time consuming detailed analysis of each sample.

^{40}K - ^{40}Ar Whole Rock Studies

Two subalkaline, olivine-rich, high aluminum basalts and a porphyritic intermediate volcanic were sent to Geochron Laboratories for whole rock potassium-argon age dating. Both basalts (Table 2) are of early to middle Miocene age (13.9, 19.6 Ma), and the intermediate volcanic is of middle-Eocene age (47 Ma). The early Eocene peak at approximately 50 Ma for the porphyritic intermediate volcanic, corresponds closely to a peak of volcanism in the Caribbean related to activity in the Cayman arc. The two basalt age dates at 13 Ma and 19 Ma correspond well to tephra layer distributions in the Caribbean sediments obtained from ODP Leg 165 (Sigurdsson, 2000). Though care was taken to obtain the freshest material possible, these ballast samples likely have been exposed to weathering prior to use as ballast and have also been exposed to seawater for almost 300 years. Both may have affected the potassium and argon values, by increasing potassium and decreasing argon levels (Pearce, 1976), which would have resulted in a younger radiometric age for the samples than reported here. Both the basalts and the intermediate volcanic analyzed show evidence of greenschist facies metamorphism and that also could have affected the ages. These samples may indeed be older than the ages reported, and these ages might actually be minimum ages.

DISCUSSION AND CONCLUSIONS

Ballastology is a relatively new type of scientific study that incorporates techniques from disciplines within the fields of archeology and geology to study ballast stones. In this study of ballast stones from North Carolina shipwreck 0003BUI (the *Queen Anne's Revenge*), hand specimen identification alone could not identify or classify all of the stones into representative groups of lithologies or indicate possible source areas. Hand specimen, petrographic, X-ray diffraction, chemical, paramagnetic studies, and age dating techniques were helpful for grouping the ballast and providing information on possible source areas. Ballast stones are mainly microporphyritic olivine basalt, felsic-intermediate volcanics, volcaniclastics, hornblende and altered gabbro, and amphibolite.

The results indicate that the majority of the stones recovered are likely from an island arc source probably of Caribbean affinity. Samples collected from Jamaica, the Dominican Republic, St. Lucia, and Bequia in the Grenadines are not likely sources for either the gabbro or the basalts. Samples of basalts obtained from these islands have been more olivine-rich, are not altered, and do not match the basalt ballast samples recovered to date. Samples of hornblende gabbro, from streams draining the Rio Bobo complex in the northern and eastern Dominican Republic, appear similar in hand specimen to the hornblende gabbro ballast from the wreck

site, but not chemically similar to the ballast stones recovered to date.

No definitive source(s) for the ballast has (have) been identified in the study, and additional work will be necessary to better understand the distribution of ballast at the wreck site and determine source areas of this ballast.

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BALLAST STONE STUDIES FROM NORTH CAROLINA SHIPWRECK 003BUI, THE *QUEEN ANNE'S REVENGE*: MÖSSBAUER SPECTROSCOPY

J. WILLIAM MILLER

Department of Environmental Studies
University of North Carolina at Asheville
Asheville, North Carolina 28804-8511

KATHERINE M. WHATLEY

Department of Physics
University of North Carolina at Asheville
Asheville, North Carolina 28804-8511

JOHN E. CALLAHAN

Geology Department
Appalachian State University
Boone, North Carolina 28608-2067

JAMES R. CRAIG

Department of Geological Sciences
Virginia Tech
Blacksburg, Virginia 24061-0420

ABSTRACT

Mössbauer spectroscopy is being used to distinguish ballast stones of various rock types found in the reputed wreck of the Queen Anne's Revenge (*QAR*). The ultimate aim is to develop unique signatures of the stones to match with bedrocks of origin.

The most abundant stones are tholeiitic micro-porphyritic basalt, porphyritic felsic-intermediate volcanic rocks, volcaniclastic rocks, and hornblende gabbros. Initial Mössbauer studies have concentrated on the most intense spectral line each for basalts, hornblende gabbros, and porphyritic felsic-intermediate volcanic rocks. Based on quadrupole splitting (Δ) and isomer shift (δ) of samples analyzed, sixteen basalts consistently fell into one group, four hornblende gabbros into two groups, and four porphyritic felsic-intermediate volcanics into two groups. The ranges of the groups fell into two realms. Realm 1, Δ = 2.0-2.4 mm/s and δ = 1.0 to 1.3 mm/s, included all basalts, three porphyritic felsic-intermediate volcanics, two altered hornblende gabbros, plus one quartz diorite. Realm 2, Δ = 2.7-2.8 mm/s and δ = 1.1-1.2 mm/s, included two unaltered hornblende gabbros plus two granites. One volcaniclastic rock was analyzed and was found to be distinctly different with Δ = 1.2 mm/s and δ = 0.4 mm/s.

Although individual differences can be seen among lithologic groups, it is not yet clear whether Mössbauer spectroscopy can be an effective fingerprinting technique for the identification of bedrock sources.

INTRODUCTION

Ballast stones from the reputed wreck of the *Queen Anne's Revenge* (*QAR*) are being characterized with the aim of determining their provenance. A match of the ballast with bedrocks along known routes of Edward Thatch's ("Blackbeard") travels would support other evidence that the wreck in Beaufort Inlet is indeed the *Queen Anne's Revenge*. Ballast stones are being characterized by rock types, whole rock major and minor element compositions, petrographic textures, age dates, and Mössbauer spectroscopy. This paper focuses on the efficacy

of Mössbauer signatures as an identifying technique for the ballast stones.

The total amount of ballast stones at the wreck site is estimated at 40 (metric) tons, based on the size of the ship. Of these, 131 stones of a total 348 kg were recovered from three separate dives on the wreck. Approximately 15,000 stones remain, if the size distribution mimics those already recovered. Although less than one percent of the ballast stones have been studied, they were recovered randomly and are considered to be somewhat representative of the ballast pile.

Mössbauer spectroscopy is a nuclear gamma ray resonance emission and absorption technique that allows characterization of materials by measuring changes in the nuclear energy levels of an atom caused by changes in its chemical environment (Dickson and others, 1986; Cranshaw and others, 1985). Mössbauer spectroscopy must be performed with a particular isotope; for these studies ^{57}Fe was the isotope of interest. In Mössbauer spectroscopy a radioactive source (in this case ^{57}Co) that decays to the isotope of interest is used to send gamma rays through a sample and into a detector. The source is set into motion to Doppler-shift the narrow-energy-width gamma ray to a range of energies. When the energy of the gamma ray matches a transition energy in the sample, the gamma ray is absorbed and then reemitted isotropically. The detector measures reductions in the intensity of radiation coming from the source (absorption peaks). It is possible to obtain multiple absorption peaks from the same sample depending on the chemical environment (crystal structure, lattice and bonding characteristics) of the sample.

The three main parameters obtainable from a Mössbauer spectrum that yield information about the structure of a material are 1) isomer shift (δ), 2) quadrupole splitting (Δ), and 3) magnetic field strength at the nucleus. The isomer shift is a measure of the s-electron density inside the nucleus and is seen in the spectrum as the shift of the centroid of an absorption peak (or group of peaks) away from the energy of the standard transition. Quadrupole splitting is a measure of the interaction between the quadrupole moment of the nucleus and the electric field gradient produced by the orbital electrons and the crystal lattice. This interaction causes a single peak to be split into two peaks of (usually) equal intensity. The size of the splitting is reflected in the distance between the two absorption peaks in the spectrum. The magnetic hyperfine interaction allows measurement of the internal magnetic field strength at the nucleus. In iron, this interaction causes a single peak in the spectrum to split into a group of six peaks whose intensities have a known proportionality relationship to each other. In addition to these three main parameters, the intensity and width of the absorption peaks yield information about the amount of iron at a particular site or in a particular oxidation state. Mössbauer spectroscopy has many uses in the analysis of material and minerals (Stevens and others, 1998a, b). The method has been used successfully in the determination of original firing temperature and provenance in studies of pottery sherds (Cranshaw and others, 1985; Leute, 1987; Whatley and McKenzie, 1994). The authors' experience with Mössbauer studies of clays and provenance led to the current effort using Mössbauer spectroscopy to determine the provenance of rocks in ballast stones from the wreck of the *QAR*.

BASIC ROCK TYPES

The dominant rock types of the stones recovered thus far are microporphyritic basalts, porphyritic felsic-intermediate volcanics, volcaniclastic rocks (mostly plagioclase), and hornblende gabbros. Lesser amounts of stones included altered and sheared hornblende gabbros, granites, limestones, amphibolites, and traces of a few others. So far, our Mössbauer study has concentrated on the basalts and unaltered hornblende gabbros because they are among the most abundant ballast stones and will have consistently strong Mössbauer signatures. The major rock types and their corresponding minerals with significant iron are listed in Table 1.

Table 1. Minerals in major rock types for *QAR* ballast stones.

basalt	hornblende gabbro	porphyritic felsic-intermediate volcanics	volcaniclastic rocks
			quartz
Ca-plagioclase	Ca-plagioclase	Na-plagioclase	Na-plagioclase
augite	(clinopyroxene[1])	clinopyroxene	clinopyroxene
	clinoamphibole[2]	clinoamphibole	
(olivine)			
		chlorite	
(biotite)		(biotite)	(biotite)
(epidote)	(epidote)	(epidote)	
magnetite	(magnetite)		
	(sulfides[3])		

1. augite or pigeonite
2. hornblende or actinolite
3. pyrite, marcasite, or chalcopyrite

minerals in minor amounts (1-10 wt.%) are in parentheses

EXPERIMENTAL

Mössbauer spectra were acquired at room temperature (20° C) from 0.5 g samples of ground (-40 mesh, 0.425 mm) ballast stones using an Elscint model MDF-N-5 Mössbauer spectrometer, a Reuter-Stokes model P3-1605-261 Xe-filled proportional detector, a ^{57}Co/Rh source and an ORTEC/ACE board in a personal computer. Counting times ranged from one to three days, depending on the intensity of the Mössbauer signal. Spectra were fit to sums of Lorentzian peaks with MOS Mössbauer Plot and Fit Program version 960709/A by S. Nagel and A. Khasanov. A total of 30 samples were tested; two spectra (one amphibolite and one volcaniclastic rock) could not be analyzed because they contained an insufficient amount of iron. Spectra for several stones were measured multiple times and fit independently to ensure consistency in the fitting results. All isomer shift data is reported relative to metallic (alpha) iron.

MOSSBAUER SPECTROSCOPIC SIGNATURES

^{57}Fe Mössbauer spectroscopy was used for this study because of the abundance of iron in the dominant rock types. On the basis of iron content alone, it may be difficult to distinguish between porphyritic volcanic rocks and hornblende gabbros but simple to distinguish between basalts and volcaniclastic rocks (Table 2). However, each mineral phase will have a unique Mössbauer signature, depending on the location and bonding characteristics of the iron in the crystal structure.

Table 2. Total iron content of *QAR* ballast stones*

	ave. wt.%	std. dev.
basalt (11)	6.6	0.5
gabbro (7)	4.4	1.3
porph. felsic-intermed. volc. (8)	4.5	1.2
volcaniclastic rocks (3)	2.0	0.3

Number of rocks analyzed in parentheses.

Sixteen of the samples studied were basalts; all were classified as microporphyritic basalts. Spectra for these samples were complex. Each spectrum was fit with three distinct quadrupole splittings and two magnetic sextets (Figure 1). A plot of the quadrupole splitting versus isomer shift for the most intense quadrupole doublet shows the consistency of the data from the microporphyritic basalts (Figure 2a). This doublet is produced by Fe^{2+} of M1 and M2 sites in the augite, and corresponds almost exactly with basaltic rocks from other regions (Table 3).

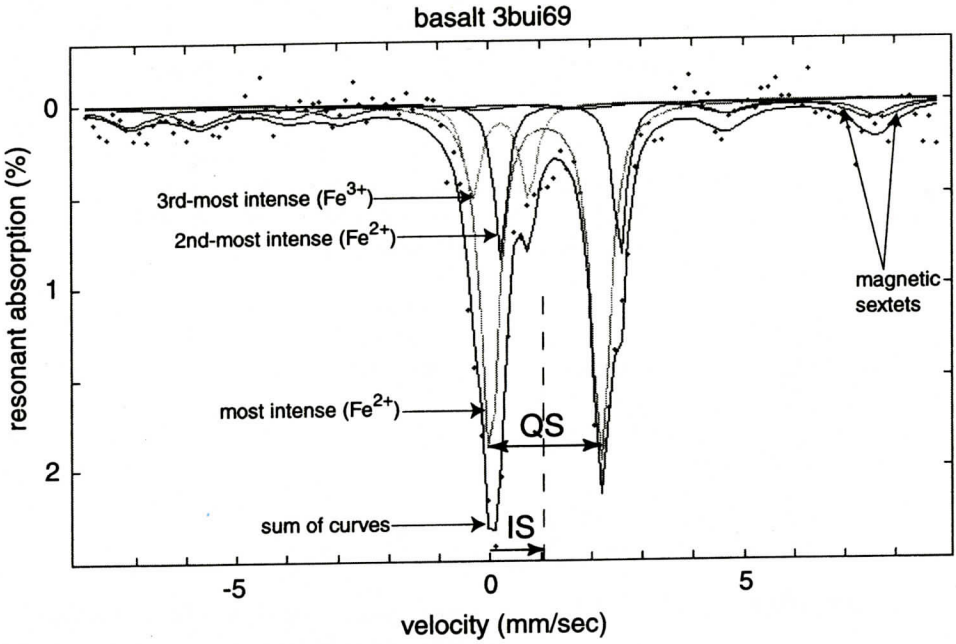

Figure 1. Mössbauer spectrum for sample 3BUI-69, a microporphyritic basalt with isomer shift (IS) = 1.403 mm/s and quadrupole splitting (QS) = 2.352 mm/s.

Four hornblende gabbro samples were analyzed. Two of the samples came from one ballast stone (3BUI-84) of unaltered hornblende gabbro, and two from a second stone (ASU 4-22-44) of altered hornblende gabbro. All samples were fit with three distinct quadrupole splittings. The most intense quadrupole splitting was found to be characteristic of hornblende (Stevens and others, 1998a, p. 308-313). Magnetic subspectra were present in the samples from ASU 4-22-44 but not in 3BUI-84. The presence of the magnetic subspectra in one stone but not the other may indicate that stones of different origin may be distinguished on the basis of the presence or absence of magnetic component, such as magnetite. A plot of the quadrupole splitting versus isomer shift for the most intense quadrupole doublet also allows discrimination of the two gabbro forms (Figure 2b).

Four porphyritic felsic-intermediate volcanic samples were studied. Three were fit with three distinct quadrupole splittings and two magnetic sextets; the fourth was fit with two quadrupole splittings and two magnetic sextets. A plot of the quadrupole splitting versus isomer shift for the most intense quadrupole doublet distinguishes the three samples fit with three splittings and the fourth sample fit with only two (Figure 2c).

The remaining four samples were found to be quartz diorite (one sample), granite (two sam-

Table 3. Comparison of Mössbauer parameters* with other basaltic rocks

Locality	rock type	δ	Δ	reference
Karak, Jordan	basalt	1.13	2.20	(Mahmood and others, 1992)
QAR (ave.)	basalt	1.10	2.20	(this study)
Hawaii	palagonite	1.08	2.04	(Golden and others, 1993)
Bohemo-Silesian volcanic arc (ave.)	melabasanite	1.07	2.15	(Szumanska-Pajchel, 1978)
Mariana Deep	basalt	1.04	2.25	(Minai and others, 1978)
Lower Silesia	basalt	1.04	2.08	(Bakun-Czubarow and others, 1993)

*doublet from clinopyroxene Fe^{2+} M1/M2 site

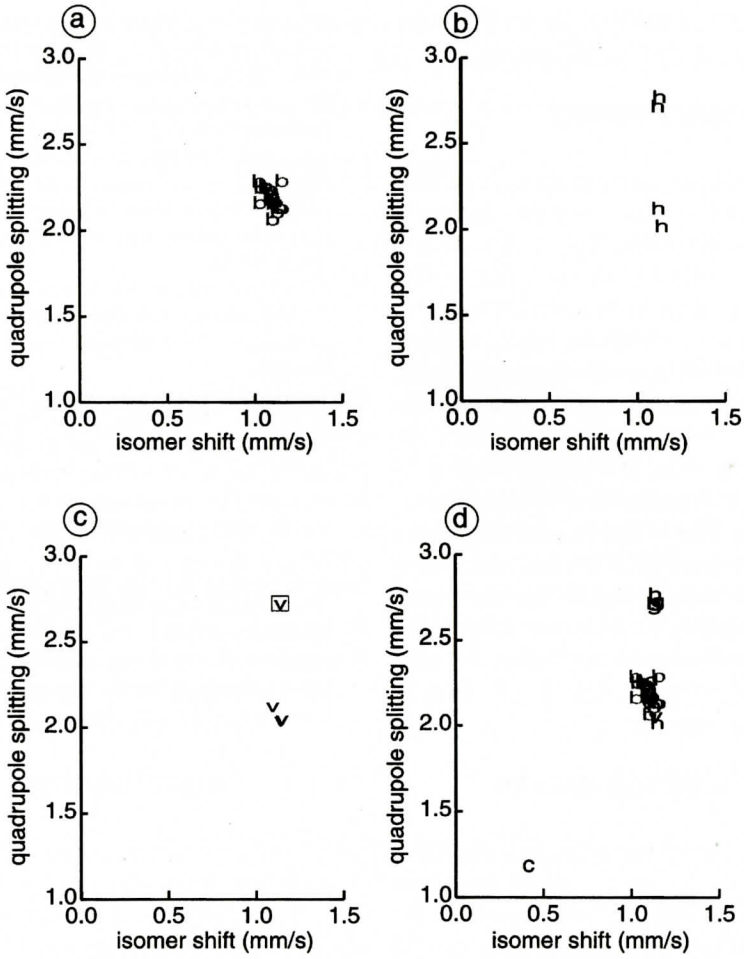

Figure 2. Quadrupole splitting (Δ) versus isomer shift (δ) for the most intense quadrupole doublet for all samples. 2a: 16 microporphyritic basalt samples. 2b: Δ of 2.5-3.0 mm/s were from altered hornblende gabbro 3BUI-84, and Δ of 2.1-2.2 mm/s were from unaltered hornblende gabbro sample ASU 4-22-44. 2c: porphyritic felsic-intermediate volcanics fit with a three quadrupole doublets each; sample with symbol enclosed in a square was fit with only two quadrupole doublets. 2d: all samples studied. Symbols are b=microporphyritic basalt, h=hornblende gabbro, v=porphyritic felsic intermediate volcanics, c=volcaniclastic, d=quartz diorite (one sample near top of basalt cluster), and g=granites (two in cluster of points at ~Δ_1=2.7 mm/s).

ples) and a volcaniclastic (one sample). The quartz and granite Mössbauer data are similar to that measured for basalts. One volcaniclastic rock was analyzed and was found to be distinctly different from the others. Figure 2d shows the quadrupole splitting versus isomer shift for the most intense quadrupole doublet for all samples studied; the volcaniclastic sample data is easily distinguishable.

The Mössbauer spectra for samples of the same rock type were consistent. However, this study was undertaken in part to determine if samples of the same rock type taken from different locations could be distinguished. The strongest spectrum line for the basalts was nearly identical to those of basalts from other localities (Table 3), but provenance studies on rocks will rely on the presence or absence of (probably) small amounts of impurities. The Mössbauer spectra studied are already complex; it

may not be possible to distinguish the Mössbauer signatures of impurities consistently.

CONCLUSIONS

Clearly, Mössbauer data can assist in the precise characterization of rock samples. More data is needed, but this preliminary study indicates that rock types from the *QAR* wreck site considered thus far are discernable with Mössbauer spectroscopy. The combination of conventional geoscience methods and Mössbauer spectroscopy should allow the clear distinction between rock types.

It is unclear whether provenance of the rock samples will be identified by Mössbauer spectroscopy alone due to the complexity of the spectra, similarity of *QAR* basalts with others from different localities, and the probable weak intensity of impurity peaks in the data. Additional studies will be necessary before the utility of Mössbauer signatures in provenance studies becomes apparent.

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ENCRUSTING INVERTEBRATE FAUNAS AND SHIPWRECK HISTORIES: BALLAST STONES FROM NORTH CAROLINA SHIPWRECK 03BUI (*QUEEN ANNE'S REVENGE*)

STEVEN J. HAGEMAN

Department of Geology
Appalachian State University
Boone, NC 28608-2067

ABSTRACT

The nature of marine invertebrate organisms that encrust artifacts from shipwrecks can provide clues to the history of the ship, both prior to and after the wreck event. Ballast stones from the ostensible wreck of Blackbeard's flag ship, *Queen Ann's Revenge*, have a benthic encrusting fauna composed predominantly of forms typical of the wreck site just offshore from Beaufort, NC, with growth histories indicating less than a decade of exposure on the sea floor.

INTRODUCTION

When artifacts from shipwrecks are exposed on the seafloor, they are commonly colonized by marine encrusting invertebrates. Hard, stable objects such as ballast stones and cannons provide attractive substrates for benthic, encrusting invertebrates such as corals, bryozoans, hydroids, worms, and oysters. The purpose of this paper is to determine what the encrusting marine invertebrate fauna reveal about the history of the ballast stones from Shipwreck 03BUI, Beaufort, North Carolina (ostensibly Blackbeard's flagship, the *Queen Anne's Revenge*).

In theory (Figure 1), the nature of encrusting organisms can provide information about the overall history of the ballast stone, such as: (1) where the organisms grew, site of the shipwreck or site of the original collection point of the ballast stones, or combination of both; (2) the environment in which the organisms grew; (3) the length of time that the ballast stone was exposed on the sea floor surface before original collection and after the wreck; and (4) the relative degree of exposure/transport since the most recent growth episode of encrusters. It should be noted, that no single piece of information is precise enough to provide a definitive story alone, but the combined methods outlined herein can provide insights into the history of ballast stones, and inferentially, their parent ship.

Beyond characterizing the history of this wreck's ballast stones, this paper also has the goal of developing methodology for the application of encrusting benthic faunal and floral interpretations for marine archaeological studies in general. Relatively little has been done in this

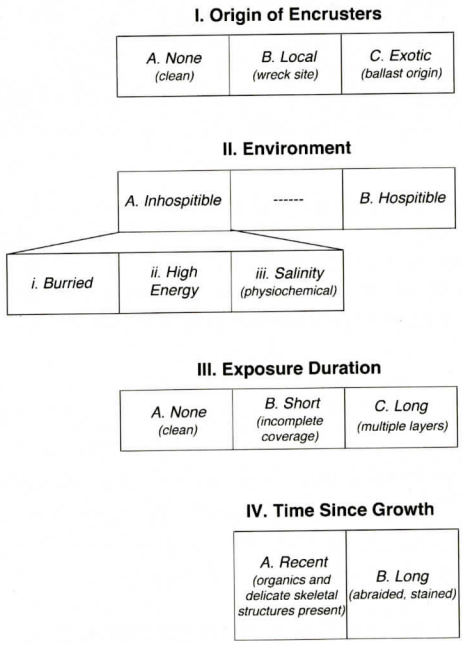

Figure 1. Characteristics of ballast stones and encrusting organisms that can provide information about the overall history of shipwrecks. Stones can be characterized by selecting the most appropriate block from each tier.

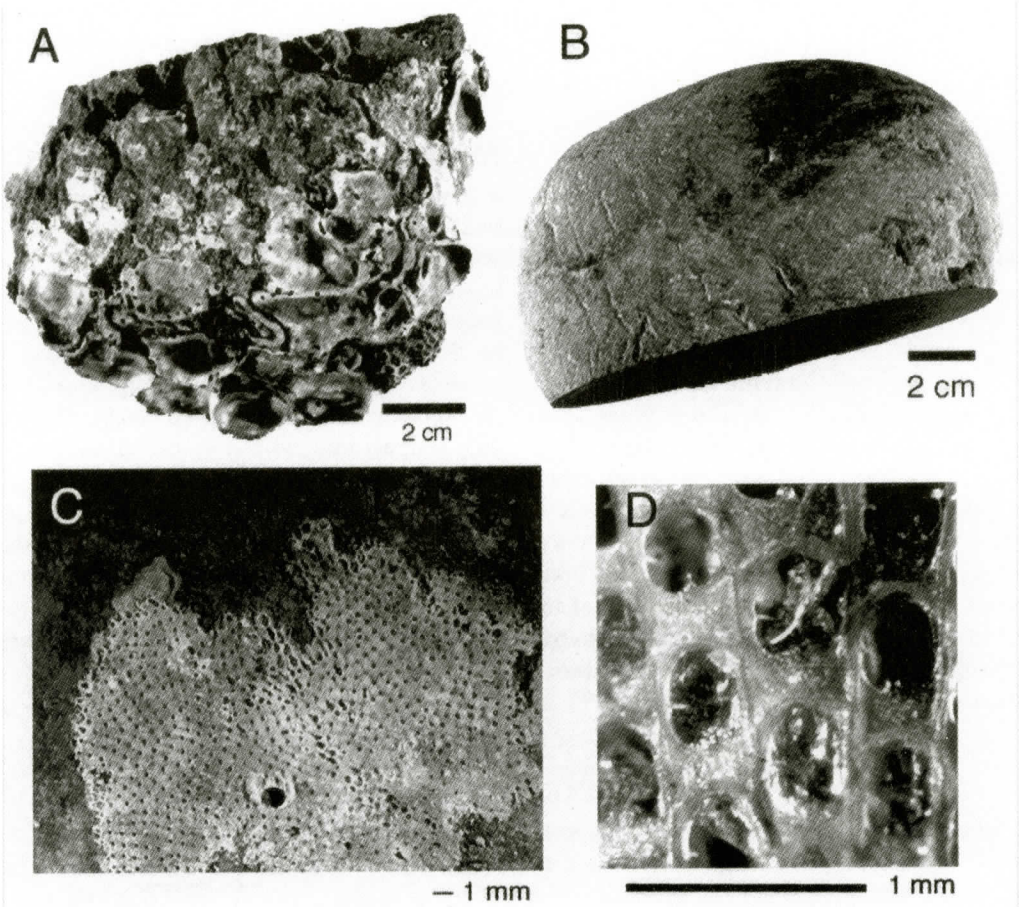

Figure 2. Ballast stones and encrusting bryozoans. (A) ballast stone with rough surface encrusted with oysters (bored by *Cliona*), worm tubes, and bryozoans; (B) ballast stone with no encrusting organisms (naturally clean); (C) *Schizoporella* sp. encrusting bryozoan on ballast stone, small dots are apertures of individual zooids; (D) close up of encrusting bryozoan *Membranipora savartii*, organic cuticle present.

area (e.g., Cuffey and Fonda, 1983; Cuffey, 2000), but these kinds of data have promise in marine archaeological studies of provenance and residency time. The methods applied in this paper are direct and exploratory. Sophisticated analytical approaches could undoubtedly be developed for more refined questions.

MATERIALS AND METHODS

Ballast stones of the shipwreck are characterized in Callahan and Miller (this issue). An estimated 25,000 to 30,000 kg of total ballast is present in the wreck site, of which 232kg (131 individual stones) have been recovered by SCUBA. A map of the wreck site (Wilde-Ramsing and others, this issue), shows that the ballast stones are distributed across the entire area of the wreck.

In this study fifty-five ballast stones, collected during the 1998 dive session, were analyzed (e.g., Figure 2A, 2B). These stones are represented by four primary lithologic types, basalt, gabbro, volcaniclastics and porphyritic volcanics. Including minor lithologic types, a total of ten lithologic varieties are present (Callahan and Miller, this issue). Because the ballast stones were not collected systematically, the

potential exists for a bias in sampling. However, comparison with material collected from the 1997 to 1999 collecting seasons shows that these samples are probably representative.

Why Bryozoans?

Bryozoans are one of the most abundant and by far the most diverse encrusting organisms present on these ballast stones, e.g. see Figure 3. For these reasons and others related to their colonial life mode, this study focused upon bryozoans. Although bryozoan specimens are generally not recognized by the public, the phylum Bryozoa is one of the most common and diverse marine invertebrates. Bryozoans are colonial organisms comprised of asexually produced zooids that have a suspension feeding structure that forms an inverted cone of ciliated tentacles. The bryozoan groups analyzed in this study have calcareous skeletons, with individual boxes or tubes for each feeding structure (Figure 2C and 2D). Living bryozoans have a common tissue covering the surface of the colony (Figure 2D), which rapidly decays after death, revealing the calcareous boxes (Figure 3C). Bryozoan colonies grow by asexual addition of individual boxes. Modular growth allows for realization of surprisingly complex colony forms (Hageman and others, 1998). All bryozoan colonies in this study are, however, encrusting sheets, of one or more layers of zooids cemented directly to ballast stones, or growing on other organisms that are encrusting the stone.

Four Approaches

In this study, four approaches were applied to the question of what encrusting faunas can tell us about the history of ballast stones from a shipwreck. (1) Biogeography: the geographic ranges and environmental limitations were established for all of the bryozoan species present. Thus, it could be determined whether these organisms encrusted the ballast stones in the biogeographic province that includes the wreck site (most likely at the wreck site itself near Beaufort, North Carolina), or in some foreign province, prior to the stones being collected for ballast. (2) Growth rates: although growth rates of most benthic invertebrates are variable and poorly known, estimates of the relative duration (length of time) that ballast stones were exposed on the sea floor can be inferred from growth and development. (3) Taphonomy: taphonomy is the study of the history of a fossil, from the time of the organism's death to when it is collected for study. None of the encrusting invertebrates are fossils (all < 10,000 yrs. old); however, analyzing the preservation of the (sub-?) modern skeletons can provide information about the history of these specific organisms and thus the history of the ballast stones. (4) Surface texture: the surface texture of the ballast stones and associated fauna were evaluated as a clue to determining the original environment from which the stones were collected.

BIOGEOGRAPHY

All fifty-five ballast stones were surveyed in a census of the marine invertebrates present. Individual organisms were identified to species using Maturo (1957), Winston (1982), Gosner (1978), Abbott and Percy (1995) and Truelove (1998). Where species could not be identified with confidence, related individuals were grouped in descriptive categories (e.g., agglutinating worms). Once a list of all encrusting taxa had been developed (Table 1), each species/category was evaluated for its relative importance on each ballast stone and indexed as follows: 0–absent, 1–rare, 2–common, 3–abundant. Note that this index of relative importance is subjective in that values represent relative importance *within* each category. Thus, the total biomass represented by an abundant oyster and an abundant hydroid are not directly comparable.

For each species/category, the indices were summed across all fifty-five ballast stones. For example, the index sum for *Membranipora arborescens* is 63 (Table 1).

Biogeography Results

Table 1 provides the complete data set. Bryozoan species can be ranked according to their

Table 1. Characterization of shipwreck's ballast stones. Relative importance of encrusting organisms on each ballast stones, indexed as follows: 0–absent, 1–rare, 2–common, 3–abundant.

Stone #	Lithology	Mass (g)	Length	Width	Height	Surface texture	Total surface coverage	Astrangia danae star coral	Ostrea equestris oyster	Spirobis borealis worm tube	Hydroides dianthus worm tube	aglutinated worm	Balanus amphirite barnacle	encrusting hydroid	Cliona sp. boring sponge	Membranipora savartii	Membranipora arborecens	Anarthropora sp.	Electra monostachys	unident-abraid	Parasmittina sp. A	Parasmittina? sp. B	Cryptosula sp.	Schizoporella cornuta	Schizoporella sp. A	Schizoporella sp. B	Microporella umbracula
B431	basalt	1451.5	15.5	10.0	7.0	1	40%	1	2	1	1	2	1	3	1	1	2	0	3	0	2	0	0	1	0	0	0
B432	gab-bro	1587.6	16.0	10.5	7.0	1	70%	0	3	0	1	2	0	1	1	0	2	0	3	0	1	0	1	0	2	0	0
B433	basalt	1134.0	17.0	12.5	5.0	1	50%	0	3	1	0	2	1	0	0	0	3	0	2	0	0	0	0	0	3	0	0
B434	gab-bro	907.2	12.0	10.5	4.0	0	<1%	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
B435	gab-bro	575.2	0.1	0.1	0.0	2	15%	0	2	2	2	0	0	0	1	0	0	1	1	0	2	0	0	0	3	0	1
B436	gab-bro	384.5	9.5	7.0	3.5	3	15%	0	2	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	2	0
B437	basalt	1587.5	15.0	13.5	6.0	2	15%	0	2	0	0	0	0	2	0	0	3	0	2	0	0	0	0	0	0	0	0
B438	amphi bolite	485.1	14.0	7.5	4.5	2	20%	0	2	0	0	1	0	0	0	0	2	0	3	0	1	0	0	0	1	0	0
B439	oolitic lime-stone	300.1	10.5	8.0	5.5	2	5%	1	1	0	1	2	1	2	0	0	0	0	3	0	0	2	0	0	0	0	0
B440	gab-bro	350.4	10.0	6.0	4.5	3	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B441	gab-bro	102.4	5.5	5.0	3.5	1	5%	0	2	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
B442	porph. int. vol.	4989.5	20.5	19.0	13.0	1	70%	2	2	3	2	2	0	2	2	0	2	2	0	0	3	0	0	0	0	0	0
B443	volca-niclas-tic*	2494.8	20.5	13.0	9.0	2	80%	1	2	3	1	0	1	2	2	0	4	0	0	0	0	0	0	0	0	0	0
B444	gab-bro	312.4	11.0	6.0	3.5	2	50%	1	2	1	1	1	0	1	1	0	0	3	1	0	1	1	0	0	2	0	0
B445	basalt	4173.0	19.5	12.0	12.0	2	5%	1	1	0	1	0	1	1	0	1	2	0	2	0	1	0	1	2	3	0	0
B446	porph. int. vol.	2948.0	18.0	16.0	8.0	2	70%	1	3	1	2	3	2	3	1	3	1	0	3	0	1	0	0	3	0	0	0
B447	gab-bro	907.0	13.0	8.0	4.5	2	75%	0	3	0	0	2	0	2	1	0	3	1	3	0	0	1	0	3	3	1	0
B448	basalt	2585.0	19.0	13.0	9.0	1	5%	0	1	0	0	0	1	0	0	1	0	0	3	0	0	0	0	0	0	0	0
B449	gab-bro	471.0	9.0	5.5	5.0	1	10%	1	2	0	0	0	0	0	2	0	2	0	0	0	2	0	0	1	0	0	0
B450	gab-bro	299.0	9.5	9.0	3.0	2	70%	0	3	0	2	0	0	1	1	0	3	0	1	0	1	0	0	0	3	0	0
B451	qrtz vein	130.0	6.0	5.0	3.5	3	60%	0	3	0	1	0	0	1	1	3	0	0	2	0	0	0	2	0	1	0	0
B452	qtz. Sand-stone	105.0	6.0	5.5	3.0	2	75%	2	2	0	1	0	0	0	0	2	0	2	1	0	2	0	1	0	0	0	0
B453	amphi bolite	65.0	7.0	3.0	2.5	2	25%	1	1	0	0	0	0	1	0	0	3	0	1	0	1	1	0	0	0	0	0
B455	gab-bro	38.0	5.0	2.5	2.0	3	15%	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
B456	basalt	4082.0	20.0	13.0	12.5	2	20%	1	2	1	1	1	1	1	0	0	3	0	3	0	2	0	0	2	0	0	0
B457	porph. int-volca-nic	3175.0	18.5	14.0	9.0	2	40%	1	1	3	1	0	1	1	1	2	1	2	0	0	2	0	0	0	2	0	0
B458	porph. int-volca-nic	2267.0	18.0	11.5	9.5	1	40%	1	1	2	3	1	1	2	2	3	1	0	0	0	3	0	0	0	2	0	0
B459	gran-ite	331.0	9.0	8.0	4.0	2	70%	1	3	0	2	1	1	0	1	1	0	0	3	0	0	0	0	0	3	0	0
B460	amphi bolite	75.0	5.0	4.5	3.0	3	<< 1%	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
B461	basalt	2495.0	16.0	11.0	10.0	2	30%	3	2	2	2	0	1	1	0	1	1	0	3	0	3	0	0	0	0	0	0

Stone #	Lithology	Mass (g)	Length	Width	Height	Surface texture	Total surface coverage	Astrangia danae star coral	Ostrea equestris oyster	Spirobis borealis worm tube	Hydroides dianthus worm tube	aglutinated worm	Balanus amphirite barnacle	encrusting hydroid	Cliona sp. boring sponge	Membranipora savartii	Membranipora arborecens	Anarthropora sp.	Electra monostachys	unident-abraid	Parasmittina sp. A	Parasmittina? sp. B	Cryptosula sp.	Schizoporella cornuta	Schizoporella sp. A	Schizoporella sp. B	Microporella umbracula
B462	porph. int-volca-nic	2041.0	15.0	11.0	11.0	2	10%	2	2	2	1	0	1	1	1	2	1	0	1	0	3	1	0	0	1	0	0
B463	highly altere d basalt	1588.0	15.0	12.5	8.0	0	80%	1	3	1	2	1	1	2	2	3	3	0	3	0	0	1	1	0	0	0	0
B464	basalt	1360.0	13.0	10.0	7.0	1	20%	1	2	3	1	1	0	3	0	2	3	0	2	0	1	0	0	0	0	0	0
B465	porph. int-vol.	907.0	10.0	7.0	8.0	2	30%	0	1	0	0	1	0	1	0	3	3	0	2	0	0	0	1	0	0	0	0
B477	amphi bolite	53.0	5.5	4.0	2.0	1	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B478	qrtz vein	343.0	9.0	8.0	4.0	1	5%	0	2	1	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
B479	gab-bro	504.0	9.0	7.5	5.0	3	<< 1%	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
B480	gab-bro	583.0	11.0	9.0	6.0	1	15%	0	2	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	0	0	0
B481	basalt	-	14.0	9.0	3.0	1	40%	1	2	3	1	1	1	3	2	0	2	1	0	0	1	1	0	1	2	0	0
B482	porp. Int-vol.	1270.0	13.0	10.5	7.5	1	15%	0	2	0	1	1	0	1	1	0	2	0	3	0	3	0	1	0	3	0	0
B483	porp. Int-vol.	1632.9	16.5	10.0	7.0	2	15%	0	2	0	1	0	1	0	1	0	0	0	3	0	0	0	0	1	3	0	0
B486	amphi bolite	34.0	5.0	2.5	2.0	2	15%	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
B487	gab-bro	79.0	6.0	4.5	2.0	2	10%	0	1	0	1	0	0	0	0	0	2	0	0	0	1	1	0	2	0	0	0
B488	lime-stone	65.0	6.5	4.5	2.0	1	0%	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
B489	amphi bolite	952.5	13.0	8.0	4.5	1	70%	1	3	0	1	0	1	2	0	0	2	0	0	0	0	0	0	2	0	0	0
B490	porp. Int-vol.	1633.0	14.0	10.0	10.5	1	10%	0	2	0	1	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0
B491	gab-bro	507.0	12.0	6.5	7.0	1	<< 1%	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
B492	amphi bolite	1134.0	15.0	7.0	6.0	1	10%	0	2	0	1	0	2	1	0	2	3	0	2	0	0	0	0	0	0	0	0
B493	basalt	2177.0	12.0	10.0	14.0	2	<1%	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0
B494	amphi bolite	113.0	6.5	4.0	2.5	3	<< 1%	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
B495	amphi bolite	190.0	8.0	6.0	3.5	3	<< 1%	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B496	gab-bro	267.0	7.0	7.0	4.5	1	<< 1%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B497	gran-ite	369.0	10.0	7.0	5.0	2	15%	0	2	0	1	0	0	0	1	1	3	0	2	0	3	0	0	2	3	0	1
B498	lithic aren-ite	371.0	12.0	7.5	4.5	2	<<1%	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
B499	gran-ite	382.0	9.0	8.0	3.0	2	<1%	0	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0
						1.7*	25%*	25	87	32	37	27	22	44	31	35	63	12	74	3	40	9	9	20	40	4	2
							mean*	Sum of importance indices																			

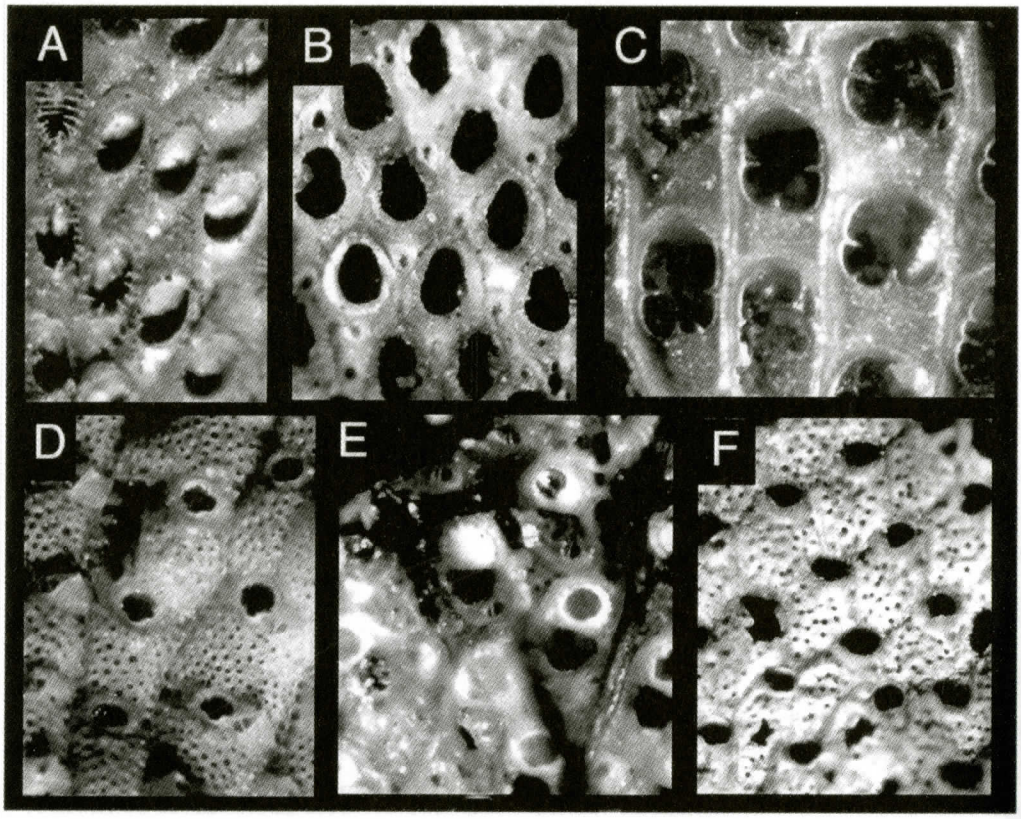

Figure 3. Common bryozoans encrusting on ship's ballast stones; vertical frame 1.25 mm for each, (A) *Electra monostachys*, (B) *Anarthropora* sp., (C) *Membranipora savartii*, (D) *Schizoporella cornuta*, (E) *Schizoporella* sp. B, (F) *Schizoporella* sp. A.

relative importance by summing indices across all fifty-five stones (bottom row of Table 1). *Electra monostachys* and *Membranipora arborescens* are the most common and abundant bryozoans, followed by *Parasmittina* sp. A, *Schizoporella* sp. A, *Membranipora savartii* and *Schizoporella cornuta* (Figure 3).

All of the bryozoan species present are typical for the temperate western Atlantic (Maturo, 1957; and Winston, 1982). Most of these taxa have known geographic ranges from Cape Cod or Cape Hatteras in the north, extending to either Florida or Brazil in the south. None of the taxa present are restricted to the tropics (e.g., Caribbean) or exotic (e.g., eastern Atlantic).

The eight other encrusting benthic invertebrate taxa listed in Table 2 are common in temperate western Atlantic waters and are geographically widespread (Gosner, 1978; Abbott and Morris, 1995). One of the most common encrusters, the star coral *Astrangia danae* is restricted to temperate waters (Table 1).

Results from biogeographical analysis can be summarized as follows: (1) All encrusting fauna are typical of those living in the waters of the wreck site, Beaufort, North Carolina. (2) The absence of encrusters from exotic provinces suggests that the stones were clean (i.e., no encrusting fauna present) at the time they were collected for ballast. (3) Therefore, the entire encrusting, benthic fauna grew on the ballast stones near Beaufort, North Carolina, some time after the ship was wrecked.

RATES OF SKELETAL GROWTH

The amount of time that a given ballast stone has been exposed on the sea floor can be rough-

Table 2. Geographic ranges of the most abundant encrusting organisms on the shipwreck's ballast stones.

Taxa	Common name	Geographic Range	Source
Astrangia danae	star coral	Cape Cod to Florida	Gosner (1978)
Ostreola equestris	crested oyster	Virginia to Brazil	Abbott and Morris (1995)
Spirorbis borealis	worm tube	Arctic to ?	Gosner (1978)
Hydroides dianthus	worm tube	Cape Cod to West Indies	Gosner (1978)
unident.	agglutinated worm	?	-
Balanus amphitrite	barnacle	Cape Cod to Carribean	Gosner (1978)
unident.	encrusting hydroid	?	-
Cliona sp.	boring sponge	Long Island to Gulf of Mexico	Gosner (1978)
Membranipora savartii	-	Beaufort to Brazil	Winston (1982)
Membranipora arborecens	-	Cape Hatteras to Brazil	Winston (1982)
Anarthropora sp.	-	?	-
Electra monostachys	-	Estuaries on Atlantic & Gulf Coasts	Winston (1982)
unident. abraided	-	?	-
Parasmittina sp. A	-	?	-
Parasmittina? sp. B	-	?	-
Cryptosula sp.	-	?	-
Schizoporella cornuta	-	Cape Cod to Caribbean	Winston (1982)
Schizoporella sp. A	-	?	-
Schizoporella sp. B	-	?	-
Microporella umbracula	-	Circumtropical	Winston (1982)

ly estimated based on the amount of skeletal encrustation that has covered its surface. It should be emphasized that absolute rates of growth for most invertebrates are very poorly known and likely to be highly variable (Pätzold and others, 1987; Smith and Nelson, 1994; Bader, 2000). However, in environments dominated by shifting sand such as the wreck site (McNish, this issue), the presence of large, stable, hard objects prove very desirable as substrates for encrusting, benthic organisms. Thus, any large, hard object exposed on the sea floor can be expected to attract colonizers, and be covered by encrusting invertebrates within a few seasons.

In this study, the surface coverage of each ballast stone by encrusters was estimated by the author and independently by J. Deardorff (research assistant) as a percentage of the total area of the ballast stone (± 5%). A third and final assessment was made by author, which incorporated discrepancies between the first two. Results are listed in Table 1. Note that the maximum expected coverage by a stable stone sitting on the substrate (never overturned) is significantly less than 100%, because some area of the stone must be in contact with the substrate.

Cluster Analysis (SYSTAT 5.2, average linkage), which grouped ballast stones based on indexed abundance of benthic encrusting species present (Table 1), did not reveal any substrate preference by encrusters based on the lithology of the stones.

Growth Rates Results

The average coverage of ballast stones by encrusting benthic invertebrates is 25%, and the median coverage is 15% (Table 1). In addition, overgrowth (multiple layers of encrusters growing on top of each other) is not common.

Complete coverage and multiple overgrowth could be expected within the first couple of decades of exposure (Choi, 1984; Baynes and Szmant, 1989; Gherardi and Bosence, 1999). Although extremely slow growth rates can not be discounted in this case, most of the oysters and colonies of bryozoans and corals observed could easily reach the observed size within three to five years. Because no traces of durophagous grazers were observed, growth rates suggest that the ballast stones have experienced

limited exposure on the sea floor.

TAPHONOMY

The preservation condition of the delicate details of bryozoan colonies can tell us something about the history of the ballast stones. If the stones have been sedimentologically reworked the surfaces of colonies will be abraded. Damage to colonies could also be expected if they were present at the time that the stones were transferred onto and off of the ship.

Taphonomy Results

Presence of original organic tissue on many bryozoan specimens (Figure 2D) indicates that the colonies were alive (or *very* recently dead) at the time that archeological divers recovered the stones. In addition, many bryozoans retained delicate skeletal structures such as spines (Figure 3A). These colonies were frequently found growing directly on the ballast stone, (i.e., older abraded colonies were generally not hidden by younger ones). Therefore, stones were clean of encrusting organisms prior to collection as ballast and most growth appears to be very recent and not the result of multiple exposure events.

SURFACE TEXTURE OF BALLAST STONES

Most of the ballast stones (gravel to cobble size) are sub-rounded to very well rounded. However, a broad range of variation is present in the smoothness of the surfaces of these stones, Table 1. Some are highly abraded and nearly smooth (= index of 3; Figure 2B), whereas others still have relatively rough surfaces (= index of 0; Figure 2A). Surface texture index is subjective and is defined for this study. On stones with very smooth surfaces (no surface texture differences at crystal boundaries), it can be presumed than any *original* benthic encrusting fauna would have been completely abraded away prior to original collection as ballast. On stones with rough surfaces (and even locally on most stones that are predominantly smooth), the crevices between irregular crystal boundaries are large enough to protect remnants of pre-existing encrusting fauna.

Surface Texture and Original Encrusters

In the surface sculpture of some irregular stones rare, highly abraded bryozoan fragments are present. These relicts are apparently remains of the geographically wide spread, and environmentally tolerant, bryozoan genus *Electra*. These marginally recognizable fragments are the *only* evidence of precollection encrusting fauna. The stones appear to have been virtually clean of encrusters.

The size and shape of clasts in the available ballast stone population are consistent with a high energy environment such as cobble beach or fluvial (Callahan and Miller, this issue). The clean surfaces of the stones suggest that they did not spend a significant residency in a normal marine setting prior to being incorporated into the beach system. A parsimonious explanation consistent with these observations is that the stones were collected for ballast near to their original source area at the mouth of a river. Although inferential, this would also be consistent with the fresh water needs of the ship's crew at the proposed time of refitting, and the preference of the crew to not handle biologically fouled stones or to have the foulers subsequently decompose in the ship's hold.

SUMMARY

The benthic encrusting marine invertebrate fauna present on the ballast stones from North Carolina shipwreck 03BUI is typical of temperate fauna at the shipwreck site near Beaufort, North Carolina. Had species from a different biogeographic province been present, they would have indicated provenance outside of the region where found now. Growth rates of the encrusting organisms suggest that the stones were exposed on the sea floor for a relatively short time, perhaps 5–10 years. The presence of many living encrusting organisms and overall excellent preservation of delicate features, indi-

cate a single, recent exposure episode.

The pervasive absence of encrusting fauna prior to collection as ballast indicates that stones were collected from a high energy cobble beach or fluvial setting. Presence of highly abraded, *Electra* sp. remnants does demonstrate that a few stones resided in a marine/esturine setting prior to collection by the original ship's crew.

Taken as a whole, the encrusting marine invertebrate fauna thus provides valuable information about ballast stone histories from shipwrecks like this one. The potential exists to refine methodologies and contribute significantly to the interpretation of shipwrecks in future studies.

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