

H.L. HUNLEY

SITE ASSESSMENT



**NATIONAL PARK SERVICE
NAVAL HISTORICAL CENTER
S.C. INSTITUTE OF ARCHAEOLOGY AND ANTHROPOLOGY**

H.L. HUNLEY

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L. E. M

EXECUTIVE SUMMARY

In April 1996, the National Park Service (NPS) was tasked with conducting an assessment survey of a vessel purported to be the Confederate submarine *U.L. Hunley* located in outer Charleston Harbor. The NPS Submerged Cultural Resources Unit (SCRU), in cooperation with the South Carolina Institute of Archaeology and Anthropology (SCIAA) and the US Naval Historical Center (NHC) entered into joint field operations in May and part of June 1996.

The objectives as stated in the NPS generated research design were to determine:

1. If the cultural remains at coordinates identified by the National Underwater and Marine Agency (NUMA) were *Hunley*.

2. If the remains were substantially intact and could be safely raised for conservation and display.

Fieldwork conducted by the joint federal and state underwater archeology team determined the vessel was indeed *Hunley*, that it was substantially intact and that raising was a feasible and, in fact, recommended alternative for preservation.

This report discusses the survey operations conducted over the area using nondestructive remote sensing instrumentation, excavation procedures, analyses of cultural materials recovered or observed in situ and the associated contextual environment. It also presents the rationale for recommended site-treatment options.

CHAPTER 1

Introduction

Daniel J. Lenihan

This document is the final product of an interagency research program that involved cooperation of several state and federal agencies and members of the private sector. Primary project objectives were to confirm the identity, location and condition of archeological remains presumed to be those of the Civil War submarine *H.L. Hunley* in the outer harbor of Charleston, South Carolina.

Hunley was a prototype vessel that conducted the first successful attack on an enemy ship from under water. It has become an icon in American military history. The story began with its secretive construction and infamous trial runs, which resulted in more cumulative loss of life to its crew than occurred during battle. Then, a spectacular success in sinking USS *Housatonic*, followed by its mysterious disappearance after the attack, ensured its place in Civil War folklore as well as history. Various attempts at locating the craft make for an intriguing epilogue to the vessel's active history.

Hunley is a prized relic of a Confederate heritage still cherished by many in the South, but a source of some discomfort to other Americans. Clearly, there were issues in this project beyond routine archeological site documentation. As in the case of other sites investigated by the National Park Service (NPS), including USS *Arizona* and USS *Utah*, *Hunley* touches a chord in people that makes "public archeology" public in the truest sense.

Despite its historic and symbolic importance to many people, work conducted during this project on the vessel assumed to be *Hunley* was fairly straightforward and scientific in nature. The NPS, although engaged in managing several Civil War sites, served, in this particular case, only as a provider of technical services in the field of underwater archeology. A discussion of the discovery, issue of title and ultimate disposition of the site are presented in the administrative history section (Chapter 2) of this report authored by archeologists from the Naval Historical Center (NHC) and the

South Carolina Institute of Archaeology and Anthropology (SCIAA).

The remains that are the subject of this project were initially discovered in the outer harbor of Charleston, South Carolina, in 1995 by a group of divers affiliated with the National Underwater and Marine Agency (NUMA) working in association with SCIAA (Hall and Wilbanks 1995). NUMA is a private-sector organization financially supported in large part and directed by novelist Clive Cussler. After a series of developments described in Chapter 2, the NPS's Submerged Cultural Resources Unit (SCRU) was asked to take the lead in conducting a site assessment. The unit had worked on many US Navy related projects including Pearl Harbor, Bikini Atoll and the Aleutian Islands and at the specific request of the NHIC on CSS *Alabama* in France and the US brig *Somers* in Mexico.

In April 1996, NPS Director Roger Kennedy directed SCRUC to work on *Hunley* in response to a request from Dr. William Dudley, Director, Naval Historical Center. Because field operations were intended for May, a month away, unit archeologists immediately prepared a research design and established a working protocol with archeologists from SCIAA and NHIC. The project research design is presented in Chapter 3.

The design was closely followed except for necessary adjustments to accommodate logistic delays and field exigencies, primarily weather related. We began with a remote-sensing survey of the study area. For archeological purposes, USS *Housatonic* and reported *Hunley* remains were treated as separate components of one site. We used all forms of noninvasive technology at our disposal before disturbing the area with excavation. This included a range of instruments such as magnetometer, depth sounder and various sonar devices, all positioned through Differential-corrected

Global Positioning System (DGPS). A full discussion of the instrument package can be found in Chapter 6 along with the remote sensing results.

In brief, the target remains and those of *Housatonic* appear dramatically represented in the magnetometer record with only one other significant anomaly recorded in the area. The object causing this magnetic anomaly was not visible above the bottom sediment to side scan sonar. Because it would have required excavation to evaluate this anomaly, no attempts were made to determine its nature. Other instruments indicated a relatively uniform, undisturbed bottom with little vertical relief in the study area. A general discussion of the site's environmental context is in Chapter 5.

Intrusive field operations (digging and coring) are discussed in Chapter 7, including excavation strategy, documentation techniques and backfilling procedures. A detailed description of *H.L. Hunley*'s remains as they appeared during archeological documentation is presented in Chapter 8.

Chapter 9 consists of analyses of specific aspects of the site, including a discussion of site formation processes, particularly burial sequence, sediment deposition and potential periods of re-exposure to open sea water. Various natural indicators of post-depositional dynamics such as coral growth and encrustation by various marine organisms are addressed. Other problem domains included in this chapter are questions of hull integrity and weight, critical factors for any potential excavation, recovery and conservation operations.

Chapter 10 is a formal presentation of conclusions and recommendations for long-term treatment of the site, including principal issues to be addressed in a complete recovery of the hull and all associated remains.

The assessment proved conclusively that the NUMA team did indeed find and identify *H.L. Hunley*. There was no indication that

the sediments immediately over the submarine had been disturbed in the last century other than the limited tests around the forward hatch conducted by NUMA. Several features of *Hunley* differed from historical documents, but

that only underscores the complementary nature of history and archeology. The written and material records combined tell a story more fascinating and accurate than could ever be achieved by either discipline working alone.

CHAPTER 2

Administrative History

Robert S. Neyland and Christopher F. Amer

INTRODUCTION

This chapter documents administration of the Confederate submarine *H.L. Hunley* and the negotiation of an agreement between the Department of the Navy and the State of South Carolina providing for its protection and preservation. *Hunley* was discovered and its management negotiated during a time when the political climate in Washington was anti-federal government. Congress was on a mission of deregulation, downsizing or liquidating entire government agencies, and Congress and the president deadlocked over 1996 appropriations resulting in government shutdowns.

Not surprisingly, *Hunley's* discovery raised the issue of states' rights over historic properties important to their heritage versus federal sovereignty over United States-owned shipwrecks within or adjacent to state waters. Issues surrounding management of *Hunley* also reveal the problems faced by both state and federal agencies responsible for providing

protection and management for underwater sites and the need for shipwreck investigators to balance exploration and research with site protection and preservation.

It is important to observe that there were some predictable reactions resulting from *Hunley's* discovery and, therefore, some of the problematic issues that developed could have been resolved between agencies through early coordination and development of an administrative strategy for managing the shipwreck. Given the lack of a formal agreement between the State of South Carolina and the Department of the Navy (Navy) or the General Services Administration (GSA) concerning exploration and administration of the submarine, it was inevitable that *Hunley* would become a controversial and highly politicized shipwreck. Some of *Hunley's* predecessors, whose discoveries and proposed recoveries have resulted in similar controversy, include the shipwrecks *Alabama*, *Somers*, *Tecumseh*, *Hamilton* and *Scourge*.

Despite problems occurring during 1995 and 1996, the major players were able to overcome their differences. Concerns for the submarine's safety and how to best manage it led to exceptional responses, resulting in state and federal cooperation in the management of *Hunley*. Over the course of negotiations concerning *Hunley*, the site became one of the most protected shipwrecks in the United States.

EARLY INVOLVEMENT

The Naval Historical Center's (NHC) involvement with *Hunley* started well before its discovery. Mark Newell of the South Carolina Institute of Archaeology and Anthropology (SCIAA) had initially communicated the SCIAA/National Underwater and Marine Agency (NUMA) survey proposal prepared by SCIAA and NUMA to the NIIC in 1994. Mr. Newell requested a review of the survey proposal and Navy authorization to survey for and ground truth potential anomalies (Newell 1994). This survey proposal recognized that if found, *Hunley* was property of the United States government under GSA jurisdiction, and that in the event of its discovery, it was likely that responsibility for management would be transferred to the United States Navy. This proposal recommended creation of a *Hunley* Task Force that would, "advise the US Navy via the NIIC and anticipated that the US Navy would assume the role of lead agency in further work on the site."

In the NIIC's review of the survey proposal, they recommended that, if *Hunley* were located, the location be kept confidential to prevent looting and to provide time for federal and state authorities to plan for protection and preservation (Dudley 1994). The NHC recognized that lines of communication and cooperation would have to be established between various federal and state agencies, and coordination of preservation and protection plans would take some time to organize. During

this time, the wreck could be vulnerable to those simply curious about the submarine or who might have designs on recovery of artifacts or even establishing an admiralty salvage claim over the wreck in federal court.

DISCOVERY

The NIIC's first notification of the discovery came with a telephone call from Mark Newell informing them that Clive Cussler's survey team reported they had located the wreck. This was later confirmed by a call from Wes Hall of Clive Cussler's team. The NHC's staff became increasingly concerned upon hearing reports of the discovery released in the national press.

NIIC staff notified GSA's Federal Preservation Officer (FPO) and the Property Management Division. It was not at all certain which division of GSA should, or would, take responsibility. Even though the logical authority would be the FPO, administration of *Hunley* in fact stayed within the Property Management Division.

It became apparent that any site verification could not be immediately conducted without giving away location of the site to the news media or other interested parties. A predictable reaction was the involvement of State of South Carolina elected officials, who understandably had a keen interest in *Hunley* and its role in South Carolina history. They reacted very quickly, perhaps as a response to the evolving controversies in the media, but also possibly due to the association of many with the Sons of Confederate Veterans (SCV) camps in South Carolina and Georgia that had supported surveys to locate *Hunley*. Senator Glenn F. McConnell, a prominent SCV member, was appointed chairman of the South Carolina *Hunley* Commission (the commission). Within only ten days of *Hunley's* discovery, on May 17, 1995, Senators McConnell, Passailaigue, Rose and Giese introduced into the state

legislature a South Carolina Concurrent Resolution (S. 844) that memorialized (petitioned) the United States Congress to direct the General Services Administration to transfer ownership of the remains of the attack submarine and to create a nine-member commission consisting of three members from the House of Representatives, three from the Senate and three appointed by the governor. The South Carolina *Hunley* Commission would become the ultimate legal authority representing the state's interest in *Hunley*, assuming authority over the South Carolina Office of the State Archeologist and the State Historic Preservation Officer (SHPO) (Cook 1995).

An immediate and direct benefit of this intense political interest was the Coast Guard's creation of a Regulated Navigation Area (RNA) of approximately one square mile over the *Hunley* site. This RNA went into effect on August 1, 1995, and was initially to stay in effect for only 90 days. The security zone prohibited diving, dredging, anchoring and salvaging in the RNA with a \$25,000 fine plus forfeiture of any vessel caught violating the RNA.

The RNA was extended indefinitely at the request of the Navy, and the NHC became the primary Coast Guard contact for violations. Additional protection was implemented by the Navy through installation of a twenty-four-hour-per-day remote camera monitoring system. Images from the camera are transmitted to the dispatch office at Naval Weapons Station Charleston where security personnel monitor the site and the Coast Guard is summoned in the event of an unauthorized presence or activity in the RNA.

The South Carolina legislature also acted promptly to strengthen South Carolina's laws by amending the 1976 Code of Laws with this addition:

Section 54-7-815. Notwithstanding any other provision of law, no person may excavate or salvage any sunken

warship submerged in the waters of the Atlantic ocean within three miles of the South Carolina coast where there are, or it is believed that there are, human remains without the approval of the State Budget and Control Board. A person violating this section is guilty of a felony and, upon conviction, must be fined in the discretion of the court or sentenced to a term of imprisonment not to exceed five years, or both.

Although the NHC debated whether or not to become involved, they began to receive calls and letters requesting that they take action to protect the submarine and oversee its management. Apparently the public expected NIIC to take the lead to represent the federal government's interest in *Hunley*. With introduction of bills in the United States Congress to transfer title to the State of South Carolina, the Navy and other federal agencies became concerned about *Hunley*'s fate and the precedent that would be established for other naval wrecks. Both the NHC staff and others viewed federal preservation laws as the best legal and regulatory protection for *Hunley*. The many failed attempts to raise naval shipwrecks and the resulting disasters, such as occurred with the wreck of Civil War-era USS *Cairo* (Bearss 1980; McGrath 1981), also influenced NHC's decision to become involved.

The GSA's staff, certain that *Hunley* was federal property under their jurisdiction, wanted to transfer *Hunley* to another federal agency; however, they considered that since it was an historic artifact of national significance they should first offer it to the Smithsonian Institution (Johnson 1995). The Secretary of the Smithsonian deferred management to the Navy, but did express his interest in the possibility of exhibiting "this icon at the Smithsonian on behalf of the American people" (Heyman 1995).

GSA then offered the submarine to the NHC on July 13, 1995. The transfer was only in fact a transfer of responsibility for management because GSA attorneys determined they could not legally transfer full accountability without violating the National Historic Preservation Act of 1966 (NHPA) (Beres 1995).

Predictably, this offer to the Smithsonian alarmed South Carolina politicians who were determined to bring *Hunley* home to Charleston to which its history was closely tied and who also surmised that *Hunley*'s historical interpretation could end up in controversy like the World War II aircraft *Enola Gay*. While federal agencies were indecisive about who would handle the submarine, the State of South Carolina moved toward legislation to transfer *Hunley* directly to the state.

On July 27, 1995, the United States House of Representatives Subcommittee on Fisheries, Wildlife and Oceans held a hearing on the bill (H.R. 1741) introduced by Representative Mark Sanford of South Carolina to transfer title to *Hunley* to the State of South Carolina and establish a federal oversight committee to advise on preservation issues. Also on the same day, the CSS *Hunley* Conveyance Act of 1995 (S. 1084) was introduced into the Senate by Senators Thurmond and Hollings, which provided:

a. Conveyance Required — The president shall direct the appropriate federal official to convey to the State of South Carolina, without consideration, all right, title, and interest of the United States in and to the CSS *Hunley*, a sunken Confederate submarine located in a harbor in close proximity to Charleston, South Carolina.

b. Terms and Conditions — The official under subsection (a) may require such terms and conditions in connection with the conveyance under

that subsection as the official considers to be necessary to ensure the proper preservation of the CSS *Hunley* (United States Government Printing Office 1995).

South Carolina was not the only state with an interest in *Hunley*. The citizens and elected officials of Alabama also expressed interest, which led to the inclusion of a statement in the House of Representatives' Department of Defense Appropriations Bill, 1996, directing the Secretary of the Navy to give "special consideration . . . to historical factors such as the place of construction of the vessel, state of the vessel's home port, and home state of the majority of the crew" when determining a display location for *Hunley*. Alabama's interest would eventually wane, although they continued to support federal management. In the House Committee hearing on H.R. 1741, Alabama Representative Sonny Calahan stated that Congress should not interfere with federal agencies nor make an exception to the federal preservation laws to transfer title to South Carolina in the case of *Hunley*, and that if special legislation is initiated "Alabama will compete for *Hunley* on a level playing field." The Honorable Richard Shelby of Alabama also requested recognition of Alabama's and the city of Mobile's interest in being considered as a location to exhibit *Hunley* (Shelby 1995).

The Clinton Administration would eventually oppose the Senate bill on the basis that it did not adequately ensure preservation of the wreck of *Hunley*:

The Administration opposes Senate passage of S. 1084, because the bill fails to provide adequate safeguards to guarantee the CSS *Hunley*'s long-term protection and preservation.

The *Hunley* is a wreck of national significance, and its long-term

protection and preservation will require substantial financial and material resources. In the past, non-federal efforts to recover and exhibit Civil War wrecks have failed, in part, because of the absence of such resources. The Federal Government can best provide the necessary resources, protection and oversight.

Federal control of the wreck, however, does not preclude the State of South Carolina from conducting archeological activities at the site. Federal law allows the State, under permit issued by the Federal Government, to study, recover and exhibit locally the wreck. Work on the CSS *Alabama* is an excellent example of national oversight of an important archeological project performed, under federal permit, by a local nonprofit organization [Department of Navy 1996].

The Department of Defense would also eventually oppose S. 1084, however, well after an agreement between the Navy and the South Carolina *Hunley* Commission was reached (Miller 1996).

On August 22, 1995, the NHC initiated a meeting of the Federal Oversight Committee for *Hunley*. Agencies represented at this meeting were the Advisory Council on Historic Preservation, GSA, the National Park Service (NPS), National Oceanic and Atmospheric Administration (NOAA), Smithsonian Institution, Department of Justice (DOJ) and the Navy. The consensus of this meeting of federal agencies was encouragement for the NIIC to uphold federal title and apply federal preservation laws to the submarine. The Advisory Council on Historic Preservation offered to draft a programmatic agreement implementing the NHPA. The NHC and the other federal agencies envisioned the resolution

to disputes regarding *Hunley* in a programmatic agreement between the Advisory Council, South Carolina SHPO and NHC, possibly with groups such as the commission participating as concurring parties, if they chose.

It was not until October 1995, that Clive Cussler transferred *Hunley's* coordinates to the NHC. Until this time, neither a federal nor state agency had the coordinates, which was probably best for *Hunley*, considering the intense public and political interest. Other groups and agencies had attempted to gain access to the coordinates including the *Hunley* Commission and the US Army Corps of Engineers/Charleston District. In addition, the NHC received a request under the Freedom of Information Act (FOIA) from the General E. Porter Alexander Camp #158 of the SCV for all materials generated by the NHC concerning *H.L. Hunley* or addressed to or containing the names of several listed specific individuals and organizations (Highsmith 1995). Fortunately, the NIIC had prepared for such a request.

Prior to these requests, the NHC, pursuant to Section 304 (a) of the NHPA, had requested and received authorization from the Keeper of the National Register to restrict sensitive information, including specific location of the wreck's cargo that could encourage looting, existence of armaments and knowledge of grave sites. Access to this information would be evaluated on a case by case basis, dependent upon other agencies' needs to evaluate their actions under Section 106 or legitimate requests for access for the purpose of scholarly research, which assures protection of restricted data (Dudley 1995; Schull 1995). Restriction of sensitive information is also permitted under Section 9(a) of the Archeological Resources Protection Act of 1979 (ARPA). In addition, this restrictive information policy was implemented in a Naval Historical Center Instruction.

Therefore, under the NHPA, ARPA and the NIIC's policy, the coordinates were exempted

from the FOIA and other requests. The commission was also faced with finding the appropriate legal and administrative protection for the coordinates when these were transferred from the NHC to the commission (Cook 1995). This was accomplished by entering *Hunley's* coordinates, as well as all information regarding the site, into the South Carolina State Site Files. The *Hunley* site was given the State Site File number 38CH1651. Under Section 54-7-820 (A) of the South Carolina Underwater Antiquities Act of 1991, records pertaining to the state's submerged archeological sites, including coordinates, "are not considered public record for purposes of the Freedom of Information Act" (S.C.C.L. Article 7, Chapter 54, Sections 610-850, 1976).

NEGOTIATIONS

On October 24, 1995, the *Hunley* Commission requested a meeting with NHC staff in Washington. The NHC assumed this would be an informal meeting at the Naval Historical Center. As the date approached, however, it was found that instead the meeting was scheduled to be held in the Senate wing of the Capitol building with Senators Thurmond, Hollings and other members of the South Carolina delegation present. NHC meeting directly with members of Congress without prior knowledge and approval of the head of Navy Command and the Department of the Navy's Office of Congressional Affairs was strictly against Navy protocol and regulations. Very quickly the Navy's senior civilian lawyer, Steven S. Honigman, general counsel, was appointed as the Navy's chief spokesperson for this meeting.

It was clear that this meeting could set the stage for federal and state cooperation. The

Navy's goals in attending the meeting were to hear the South Carolina delegation's concerns, avoid discord and deal with the issues at a working level. The commission shared similar hopes of resolving any conflicts and moving negotiations with the Navy forward in order to preserve *Hunley*. As stated by Senator McConnell, "It is our hope to reach some common areas of understanding and to be able to work together as a team and avoid any adversarial relationship regarding the *Hunley*" (McConnell 1995). At the meeting, the commission and the Navy found they shared similar goals of protecting and preserving *Hunley*, although they were concerned about different aspects of *Hunley's* management. While the Navy saw selection of appropriate plans for excavation, recovery, conservation and existence of adequate funding as their principal concerns, the commission focused on interment of the crew's remains and final exhibit and interpretation of the submarine's history. The commission suggested sharing title; however, the Navy suggested temporarily putting the title issue aside. The Navy also supported locating *Hunley* in the Charleston area.

Meeting participants agreed the Navy would manage the scientific and archeological aspects of site survey, recovery and conservation of the submarine, and the State of South Carolina would oversee interpretation and exhibition of the submarine and have the right to inter the crew's remains as the commission deems appropriate. The commission would submit their interment plan to the Navy for review and comment. In turn, the Navy would submit an agreement outlining the state and federal partnership to the commission. In addition, the Navy would request site coordinates from Clive Cussler and eventually share these with the commission. Dissension remained over ownership and title.

DISSENSION

Despite the best intentions, relations between the commission and Navy deteriorated over the title issue, release of coordinates, comments on the commission's reburial plan and the proposed site assessment. Another problem was that direct communication between the NHC and the South Carolina agencies (Hunley Commission, SCIAA and SHPO) was restricted as a result of actions on the part of both the Navy and the commission.

A letter dated October 31, 1995, from John Hazzard, Hunley Commission Attorney, addressed to Senator Strom Thurmond's office asserted that the Department of the Navy had attempted "to circumvent the Hunley Commission in its effort to gain control of the *H.L. Hunley*." Presented as evidence were drafts of a memorandum of agreement and programmatic agreements sent to the South Carolina SHPO and letters to SCIAA. This resulted in explicit instructions from Navy counsel that all communications were to be routed through the Navy's Office of General Counsel.

The commission instructed the South Carolina SHPO and SCIAA not to discuss matters of *Hunley* – specifically any agreements – with the Navy. At this stage, only the lawyers were allowed to talk directly. An unfamiliarity with the NHPA and its implementing regulations on the part of officials both in the Navy and South Carolina in part contributed to misunderstandings and difficulties in negotiating an agreement.

The draft programmatic agreement, which had initially been drafted by the Advisory Council and that the NHC had formerly submitted to the South Carolina SHPO, was sent directly to the commission for review. This document contained provisions for perpetual display of *Hunley* in a facility located in South Carolina, recognition that title to *Hunley*

remains with the United States, precise coordinates would be provided to the commission under appropriate guarantees of confidentiality, and establishment of a process for resolving disputes between the Navy and the commission.

The commission rejected the agreement stating that it treated them as an interested party not a partner, it asked them to recognize federal ownership, gave the Navy final decision-making powers and they had yet to hear about review or approval of their interment plan and plans for a *Hunley* site assessment (*The Post & Courier* 1995). Also, the coordinates, which had yet to be shared with them, had become a matter of trust. In addition, Senator McConnell protested that not being able to talk directly with the NHC staff "treats [the] Commission as litigants, which makes cooperation difficult." Negotiations were hampered further when the commission passed a resolution prohibiting them from entering into any discussions whereby South Carolina relinquished their claim to title. The Navy also expressed difficulty in communicating and receiving direct responses to the Navy's proposed agreement. It was obvious that if the differences were not resolved soon, the negotiations would disintegrate into a long and expensive legal battle that would not benefit the State, the Navy or *Hunley*.

Deterioration of talks was also beginning to jeopardize legislation in Congress that was important to the Navy, which was likely to be held up by the South Carolina delegation. To help diffuse the situation, the Navy appointed William Cassidy, Deputy Assistant Secretary for Conversion and Development as the new point of contact with the commission. Mr. Cassidy, who had been involved with the Base Realignment and Closure (BRAC) of the Charleston Navy Yard, allowed the NHC to talk directly with the commission and SCIAA, particularly on technical matters.

As a direct response to congressional pressure, Navy attorneys began examining whether they could transfer site coordinates and *Hunley's* management directly to the commission by placing the conditions of the agreement into a letter format that would be more acceptable. However, Sections 106 and 110 (l) of the NHPA require that historic properties be taken into account during a federal undertaking and prohibits delegation of federal oversight. Both the NHC and the Advisory Council called attention to the Navy's responsibilities under the NHPA and that the council and the Navy had been developing a programmatic agreement, pursuant to NHPA regulations, since August 1995.

RESOLUTION

In the end, it was the site assessment that would allow the programmatic agreement to go forward, for it was this that fostered a spirit of trust and cooperation between the two parties. As early as November 1, 1995, the commission had expressed interest in a joint state/federal site assessment, in order to evaluate proposals for how *Hunley* will be managed in the recovery phase and to answer questions about the current status of the site.

A joint expedition was agreed upon, and the coordinates were shared with the commission on January 31, 1996. In a February 20 letter to Senator Glenn McConnell, Dr. William Dudley, of the NHC, outlined survey goals and parameters and recommended a partnership between the NPS's Submerged Cultural Resources Unit (SCRU), the Underwater Archaeology Division of SCIAA and the Underwater Archaeology Branch of the NHC. This course was also recommended to the Assistant Secretary of the Navy and Deputy Assistant Secretary of the Navy on the basis of potential threats to the submarine from theft and vandalism and the extremely political and

publicly sensitive situation (Dudley 1996b; 1996c).

PROGRAMMATIC AGREEMENT

After numerous revisions and months of negotiation, the programmatic agreement between the *Hunley* Commission, South Carolina SHPO, the Advisory Council, GSA and the Navy went into effect on August 6, 1996. This agreement provided a means for the Navy to fulfill its Section 106 requirements under the NHPA. It settled the issues of ownership and siting: the "United States of America shall retain title to the *Hunley*, and the State of South Carolina shall have custody of the *Hunley* in perpetuity." Site protection is addressed through the continuation of the present security measures, and site protection and stabilization is the primary objective until acceptable plans and funding are in place for archeological investigation and recovery.

A *Hunley* Oversight Committee (same as the Federal Oversight Committee) will provide guidance by reviewing and commenting upon proposals for archeological investigations. In addition, organizations at the national, state and local levels that have an interest in the archeological investigations of *Hunley* will also be provided a review and comment period. The Navy will provide an opportunity for individuals and organizations to submit proposals for the archeological investigation of *Hunley* by due process notification in the Federal Register. Proposals submitted to the Navy must be comprehensive, include a financial plan and comply with the federal standards for archaeology.

A Memorandum of Understanding between the Navy and the repository for the collection must also be executed. The commission will recommend a location for stabilization, conservation, curation and exhibition of *Hunley*, after consultation with the Navy, the Advisory

Council and South Carolina SHPO. The Navy will determine whether the proposed facility meets the standards for long-term curatorial services. Once selected and approved, the curation facility will be loaned *Hunley* in perpetuity, provided they abide by the terms of the curation agreement.

The state will receive all financial benefits and revenues generated by *Hunley*'s exhibition. This agreement does not obligate the Navy to commit funds to *Hunley*'s management except those for administrative duties under the agreement. This agreement may be amended or terminated, except for those sections that determine title and custody and location for curation and display.

FUTURE

The future for *H.L. Hunley* is promising, with creation of the partnership between the State of South Carolina and the Department of the Navy, and development of the programmatic agreement that clearly outlines administrative procedures and responsibilities. Also favoring the submarine's protection and preservation is the intense interest and commitment of the State of South Carolina's elected officials, including both those in the state legislature and the United States Congress. Creation of the *Hunley* Commission has provided leadership at the highest level. This leadership will be essential in locating and securing financial resources and technical expertise necessary for *Hunley* to be raised and conserved. Many questions remain concerning feasibility of an archeological investigation, recovery, conservation and an eventual exhibit. The programmatic agreement between state and

federal agencies, however, insures that any plans will be properly reviewed and hasty actions that might jeopardize the submarine will be avoided.

SUMMARY

The discovery of *Hunley* was fraught with controversy and a potentially costly and time-consuming legal battle over ownership was narrowly avoided. Similar controversies and disputes over ownership have arisen with other naval shipwrecks. Issues of federal ownership, management, and administration that arose with the discovery of *Hunley* emphasize the importance of early coordination between state and federal agencies.

Once elected representatives become involved there can be intense pressure put on state and federal agencies. As in the case of *Hunley*, their involvement can directly benefit the resource if they are provided with accurate information about site management and protection. When there is an attempt to circumvent established laws, however, there is potential for chaos, with potentially dire consequences for the archeological resource. In the end, the NHPA protected *Hunley* and, politics aside, the system worked to forge a state and federal alliance.

The case of *Hunley* also provides a valuable lesson for archeologists. It is easy to become overwhelmed by the rapid progression of events surrounding the discovery of a significant shipwreck. Prior to searching for such shipwrecks, it is important to consider their administration and that the protection of information such as location is ethically responsible and justifiable under the law.

CHAPTER 3

Research Design

Daniel J. Lenihan and Larry E. Murphy

RESEARCH OBJECTIVES

1) Confirm identity of the reported vessel remains located at coordinates provided by the Naval Historical Center (NHC) as that of *H.L. Hunley*; 2) Document the site to the extent conditions permit; and 3) Evaluate feasibility of excavation and removal of the vessel remains. It should be noted that normal behavioral problem domains will, in this case, be secondary to the prime objective of identity confirmation and evaluation of recovery feasibility. The main exception will be investigation of site formation processes – efforts will be made to isolate cultural dynamics from the natural processes that have resulted in the site being at its present location and state of preservation.

This design is purposely ambitious and is presented here largely as it was developed prior to the 1996 field project, which is why it appears in the future tense. It presents an ideal strategy that assumed instrumentation and personnel would be made available, and there would be

no major delays in logistics or weather. The initial proposed operational period was reduced by a week due to logistic problems and funding delays. The principal investigators and field director determined which priorities identified in this design would be kept, and which sacrificed, to meet core mission objectives identified by the NHC and the *Hunley* Commission (the commission).

RESEARCH METHODOLOGY

NONINVASIVE STAGE

Investigators will examine the site with an array of remote sensing instruments to determine the nature and distribution of cultural remains and to define the geological matrix of the site. They will gather other environmental information appropriate to understanding engineering constraints on recovery of vessel remains.

Instrument Coverage

Investigators will define a block that incorporates suspected *Hunley* remains and residues of USS *Housatonic* and subject the area to high resolution magnetometer coverage. This is to be conducted on ten-meter transect sample interval with appropriate tie lines. In association with magnetics, acquire bathymetry and RoxAnn bottom classification data (e.g., sand type, rock, grass) in a format appropriate for Geographical Information System (GIS) display.

A predisturbance survey will be conducted including intrasite sub-bottom profiler with Edge Tech X-STAR chirp profiler mounted on a sled and pushed by divers. [Note: Diving conditions did not allow use of the sled; intrasite sub-bottom profiling was accomplished by towing the instrument on five-meter transects over the site.] The objective is to profile the hull and strata, including possible surface scour and evidence of buried wreck-contemporary scour. There may be shell layers that diminish profiler resolution. The study area will be surveyed by depth sounder and side-scan sonar to locate surface features in the immediate area and to ascertain if the sediment covering the site is anomalous to the general area, which will be an important factor for reburial and site monitoring. Areas surrounding hull will be systematically examined with metal detectors and a hand-held cesium magnetometer supplied by Geometrics, Inc. through the Institute of Nautical Archaeology, Texas A&M University. Anomalous areas will be flagged and hand-fanned or probed, and any material located will be recorded in situ and mapped.

Conventional boat towed instrument passes of the sub-bottom profiler will be made to determine sediment matrix of cultural materials in the general area of the excavation. This will be important for the eventual recovery phase.

The instrumentation and post-processing of these data to be provided by source other than the Submerged Cultural Resources Unit (SCRU); however, SCRUI will provide positioning and will be responsible for integrating information derived from this source into the final report.

All instrument coverage to be positioned with differential GPS (DGPS) provided by SCRUI.

General Sediment Transport Data

Sediment transport processes will be examined for determination of present and future stability and to provide background for determination of best short-term stabilization procedure for site after excavation.

Coring

Short, hand-driven cores will be used near the site and at sufficient distance to determine ambient conditions and sediment composition. If possible, longer cores may be taken and analyzed for aiding sub-bottom profile data interpretation. Sub-bottom profile data interpretation should provide a reliable stratigraphic profile of the immediate area and delineate any wreck-generated features such as scour areas that would inform on site formation and burial history.

Core analysis should include stratigraphic profile and constituent analysis. If University of South Carolina support is available, radiometric analysis (^{210}Pb and ^{136}Ce) should be done. This analysis will provide an accurate indication of sediment disturbance depth for at least the last 50–100 years. Core analysis is necessary to produce information on burial history, corrosion history and for recommendations as to the best method for ensuring in situ stabilization.

Oceanographic Data

Wave height and periodicity averages and peaks need to be determined. Prevailing currents and turbulent water motion as a result of natural factors and boat traffic need to be characterized. This information should be available and not have to be generated as part of this project. If available, data will be included in the final report.

OVERBURDEN REMOVAL, DOCUMENTATION STAGE AND REBURIAL

Removal

Sand and silt overburden is to be removed from site using water induction dredges. All dredges will be handled or controlled by an in-water archaeologist who will be responsible for recording the nature of sediments they are passing through, ensuring that they are not artifact bearing or cultural strata or that the site is being unacceptably impacted in the sediment removal process. Purpose of removal is to expose enough of the site to confirm its identity and permit in situ mapping and documentation. Spoil will be deposited around the hull for reburial. Dredge exhaust will be placed so as to minimize loss of sedimentary fines so they can be used for reburial.

Because hull remains reported by the National Underwater and Marine Agency (NUMA) discovery team are full of sand, extreme care must be taken to not undercut portions of the site in a manner that would allow internal weight of the sand to place enough stress on the hull to cause deformation or collapse. Although it is expected that there will be some adverse impact on the site from any invasive process, the intent of operations in this

design will be to minimize such effects and to conduct minimal impact documentation. If at any point the process is deemed to be too destructive to the resource, the co-principal investigators (Co-PIs) or field director (FD) will have the authority and responsibility to halt the operations.

During excavation, hull encrustation will be closely monitored for:

- a. any breaches in hull;
- b. color changes that may indicate various levels of corrosion and would isolate corrosion sample areas;
- c. evidence of buckling or distortion – intact encrustation indicates the area is stable and features are probably wreck related;
- d. cracks in encrustation, plates or seams, especially ones that appear recent or occurring as a result of excavation, especially if fine black or rusty sediment is present or small gas bubbles are released, which indicate integrity of encrustation has been breached — if cracks or bubbles appear, excavation will cease and the Co-PIs or FD should be notified immediately;
- e. any unusual or fragile features.

Excavation extent will be determined by conditions on site by the Co-PIs and FD. If the hull appears to have sufficient integrity, the upper surface will be completely uncovered. The bow and stern will be excavated for examination and documentation. [Note: A field decision by the Co-PIs and FD reversed this. The rudder, propeller shroud and screw were left undisturbed, and the bow was excavated only enough to examine for presence of the torpedo spar or fittings. Investigators were concerned that they inadvertently harm these delicate areas given the very low visibility diving conditions.] It may be inadvisable to completely excavate the lower hull because it may shift unevenly and cause damage. Some examination of the hull is necessary to assess

integrity and active corrosion level. Appropriate procedure will be determined through on-site analysis.

Post dive observations will be recorded by each archeologist immediately after each excavation dive and added daily to the daily site log. Any accessible interior areas will be sampled at least for dissolved oxygen and pH. If possible, interstitial water will be collected from interior sediments for laboratory analysis.

Documentation

A series of documentation techniques will be employed on the site after it is fully uncovered or in stages depending on field judgments regarding site fragility. Photo and video imaging will be part of the tool kits employed although it is recognized that low visibility conditions will compromise results using these techniques.

Conventional Mapping

Underwater archeological mapping specialists will be made available by SCRUI to draw in detail portions of the site exposed through excavation.

Standard Photo Documentation

SCRUI staff photographer will use a series of film and lighting formats to photograph remains when exposed. [Note: Still photography was also accomplished by South Carolina Institute of Archaeology and Anthropology (SCIAA) staff and a volunteer toward the end of the project as water conditions cleared.]

Convergent Photogrammetry

To be done using film captured from video or digital camera system, depending on conditions and logistic constraints. [Note:

Diving conditions did not allow use of this technique.]

Reburial

Sedimentologists will be consulted to determine the best procedure, whether to use spoil removed during excavation (diminished sediment fines may alter resuspension characteristics), excavate new material from around wreck or introduce ideal exotic sediment. Determination of appropriate procedure will be from a combination of consultation with sedimentologists, remote sensing data and on-site observations. Post-burial analysis will be by high-resolution depth sounder survey to ensure area is not anomalous. If possible, area will be resurveyed one week after reburial to verify stability.

Corrosion/Engineering Studies

a. Visual inspection on site by a Navy salvage officer and/or, if possible, a corrosion engineer. Observations of general state of encrustation with anomalous areas such as cracks, thin areas, escaping gas and discoloration must be noted. During excavation, hull will periodically be examined for cracks and escaping gas that represents disruption of encrustation that may indicate hull distortion resulting from sediment removal.

b. Electrochemical status of hull is to be determined by bathyconrometer measurements of specific sites. These sites will require drilling through encrustation or removal of small area, about 2 inches square, to obtain a reading. Each reading is taken for more than a minute to obtain a stable result. The pH data should be taken concurrently. High pH indicates faster corrosion activity. Both measurements should be taken periodically at different depths as the drill penetrates the encrustation. Depth of encrustation to solid metal should be recorded.

Collection of these data provide a baseline against which future measurements can determine if corrosion is increasing. [Note: Use of a pneumatic drill proved ineffective against the tough encrusting layer; therefore, these measurements were not taken.]

An ultrasonic thickness gauge will be used at the same location to record hull plate thickness. Ideally, this will be coordinated with in-water positioning, video and computer recording of visual and sensor data. A corrosion engineer is necessary to interpret data and characterize corrosion status, current corrosion rate and to assess potential for interrupting natural encrustation process in anticipation of vessel recovery. For example, installation of sacrificial anodes has been demonstrated to stop active corrosion and initiate the conservation process in situ prior to recovery.

c. Ambient Environmental Measurements — Basic seawater and sediment data including temperature, dissolved oxygen, salinity and pH is necessary. Measurements should be made close to the hull and at a distance for comparison.

d. Biological Activity — Note presence of burrowing fauna in seabed and encrustation. Determine species of colonizing communities and evidence of past activities on all surfaces. Microbes are indicated as contributors to corrosion processes (at least one source states 60% of corrosion in anaerobic conditions can be attributed to sulphate-reducing bacteria). Some samples of encrustation will be collected for microbial examination, particularly in buried areas.

e. Metallurgical Status — Cast iron corrosion causes substitution of graphite for iron in surface layers. Corrosion engineers will be consulted for techniques for measuring depth of hull corrosion as represented by depth of graphitization. Knowledge of current hull strength is necessary for planning appropriate recovery strategy. Detailed modeling of corrosion rate of *Hunley*'s hull may create an

effective dating method for iron objects located in Charleston Harbor and surrounding areas with similar environmental variables. Cast iron and wrought iron corrosion processes are somewhat different. Both cast and wrought iron were used in construction of *Hunley*, and these areas should be examined independently. It is possible that the cast iron of the hatches may be in less stable condition.

f. Determination of Burial History — Questions such as "Has the site been buried continuously since its initial stabilization?" and "What is the nature of the surrounding sediments?" will be addressed because they affect the nature of recommendations for post-assessment site stabilization. For example, after excavation and hull documentation, what will be the best backfill procedure to insure protection and restabilization? Would it be better to backfill with removed sediments, which may lack fines; remove surficial sediment from around area to recover; or to import exotic sediment or sandbags? Answering other questions like "Has the hull been subject to periodic exposure and reburial events as a result of natural processes?" may provide insight into hull stability and strength. An indication of exposure and reburial sequences may be presence of black bands within the encrustation whereas uniform white encrustation indicates constant burial. Comparisons of *Hunley* hull top, sides and bottom will be conducted if it is possible to do so without causing damage or negative site impact.

Report

Generation of the final written report will be SCRUI's responsibility, which will involve integration of all information generated from the survey and include contributions from all appropriate investigators. It should be noted that much of the processed data will be best displayed and understood in electronic formats. Such information will accompany the written

report in tape, CD-ROM or other appropriate media. The final report will be completed and forwarded to the Navy for transmittal to the commission.

There will, however, be a number of stages of preliminary reporting in which most of the survey results will be released as soon as they can be made available in draft form. Some of this will occur before the team leaves Charleston. This includes draft images, preliminary evaluation of the site by project personnel, select raw video footage and other items that should allow the Navy and the commission to proceed with their planning and execution of the next phase of the *Hunley* Project.

Project Responsibility and Accountability

1. Overall authorization of project and decision on ultimate disposition of *Hunley* remains: Dr. William Dudley, US Navy and Senator McConnell, *Hunley* Commission.

2. Umbrella archeological responsibility for

all phases of *Hunley* program from compliance and mandate issues through eventual recovery and display: Dr. Robert Neyland, Naval Historical Center and Christopher Amer, South Carolina Institute of Archaeology and Anthropology.

3. Co-principal investigators for the present assessment phase of the project: Daniel J. Lenihan, Program Manager of the National Park Service's Submerged Cultural Resources Unit and Christopher Amer, Deputy State Archaeologist for Underwater, South Carolina Institute of Archaeology and Anthropology.

4. Field Director: Larry E. Murphy, on-site responsibility for all fieldwork.

5. Dive Safety and Accident Management: The National Park Service will maintain control of dive site for safety and accident management purposes and will develop appropriate system for transfer of accident victims to Coast Guard or other evacuation principals and establish protocol with South Carolina personnel to ensure maximum safety and efficiency at the dive site.

CHAPTER 4

Historical Context

Richard Wills

The submarine emerged as one of the world's premier military combat and deterrence weapons in the last century. However, it wasn't until the end of the nineteenth century that the US Navy began to recognize the submersible vessel's potential as a weapon and provided it a significant operational role. A series of decisive events in which American technological and tactical experimentation figured prominently made this development possible. Americans first used a submersible vessel in combat against an enemy warship (David Bushnell's *Turtle*); they developed the first practical navigable submersible vessel (Robert Fulton's *Nautilus*); and they were the first to destroy an enemy naval vessel in combat with a submersible (James McClintock's *H.L. Hunley*).

At the outset of the Civil War, the US Navy and the Southern Confederacy embarked on parallel paths of torpedo craft development that, while differing in the manner of execution, essentially comprised an early arms race to produce a successful offensive submersible

weapon. While vessels like *Pioneer*, *American Diver*, *H.L. Hunley* and others were being built by enterprising individuals within the Southern Confederacy, similar efforts were being undertaken within the Union in the form of Brutus de Villeroi's *Alligator*, and Scovel S. Meriam and Oliver Halstead's *Intelligent Whale*. One of the original missions outlined for *Alligator* was to face the ironclad CSS *Virginia* at Hampton Roads, and if not for logistical problems, the history of this engagement may have been quite different. But while the Union efforts were not as successful as those of the Confederates, they did capture an equal degree of official naval interest in terms of funding, research and development. This is evident in the construction record and in the extent to which Union and foreign agents went to gather intelligence on the Confederate efforts. By the turn of the century, submersibles finally received recognition as a viable (though often misunderstood) component of naval warfare. The American Civil War submersible record on both sides inspired the next generation of

American submarine visionaries, particularly John Phillip Holland and Simon Lake, and set the stage for the future emergence of an American naval-industrial complex capable of designing and delivering operational submarines to the US Navy.

PRELUDE: ANTEBELLUM AMERICAN SUBMERSIBLE VESSEL DEVELOPMENT

The concept of a vessel capable of submerged navigation was not a new idea in America when the Civil War began. Americans had previously attempted to use submersible vessels to help fulfill military aims with varying degrees of unsuccessful performance in both the War for Independence (Abbot 1966; Morgan 1972:1499–1511; Roland 1978:62–88) and the War of 1812 (Field 1908:73–76; DeKay 1990:131; Dudley 1992:211–212). Robert Fulton's *Nautilus* successfully demonstrated that a stable platform capable of sustained underwater navigation could be constructed and employed to meet military objectives (Parsons 1922; Hutcheon 1981).

However, before deployment of a manned submersible vessel in combat could reach its potential, three parallel technical refinements needed to reach maturity: the platform, the weapon employed by the platform and the tactical system of weapon delivery. The definition of the submersible's role relative to the larger military and naval strategy remained largely unchanged. Submersibles were generally considered compatible with riverine and coastal defense and against enemy blockading naval vessels, as had been the objective of such vessels in both the War for Independence and the War of 1812.

Between 1814 and 1861, the American shoemaker Lodner Phillips (Field 1908:80–82; Gruse Harris 1982), the French engineer Brutus de Villeroi (Luraghi 1996:251), and others worked to improve upon Fulton's

fundamentally sound design. During this period, advances had been made in air supply storage and replenishment, ballast configuration and regulation, configuration of movable surfaces for steering and depth control, and instrumentation for navigation and depth control. Perhaps the greatest problem remaining was to devise a self-powered propulsion system capable of operation while running submerged. Bushnell had designed into his vessel the new innovation of hand powered "oar[s] . . . based upon the principle of the screw" (Morgan 1972:1503), which appears to have been the earliest use of screw propulsion in watercraft (Abbot 1966:44). Propulsion systems superior to hand power were sought, and although several dual propulsion systems were proposed, including Fulton's auxiliary sail concept and Alstitt's electromagnetic drive unit, hand power remained the primary propulsion for American vessels built before and during the Civil War.

During this time, work also progressed on weapons systems. Far-reaching advancements on developing galvanically controlled underwater explosive weapons were made by Samuel Colt in the 1840s, building upon the work of Bushnell, Fulton, Elijah Mix, Moses Shaw, Robert Hare and their European contemporaries. In particular, Colt refined contact detonators, remote electrical fire control systems and multicell voltage storage batteries (Lundeberg 1974).

In terms of explosive weapon tactical delivery, three general methods were recognized: use of a time-delay explosive charge (basically a limpet mine) carried on the outside of the boat and manually attached to the hull of the enemy vessel, such as employed by Bushnell's *Turtle*; towing of a contact torpedo in the wake of the torpedo craft in which the idea was to detonate the charge by diving beneath the target in such a way that the charge would collide with the target; and the bow-mounted spar torpedo concept originated by Fulton. McClintock's series of boats would

utilize all three methods at various stages of their progression.

CIRCUMSTANCES THAT PRODUCED *H.L. HUNLEY* AND ITS PREDECESSORS

The American Civil War was the first major armed conflict to reap the benefits of the industrial revolution. It saw the practical utilization of screw-propelled warships powered by steam, ironclad warships, torpedo craft, underwater and subterranean mines, rifled ordnance, troop movement by rail lines, telegraphic lines of communication, and even reconnaissance aviation. Some historians have succinctly described the Civil War as "the only occasion in the course of history when at the beginning of a conflict between two nations facing the ocean, one of the two had incontestable and total dominion over the waters" (Luraghi 1996:61). Confederate States Secretary of the Navy Stephen Mallory, confronted by an overwhelming enemy naval presence, countered with a fourfold strategy based upon "technical surprise" that utilized armored vessels, rifled naval guns, steam-driven commerce destroyers, and submarine torpedoes, or what today are called mines (Luraghi 1996:68). Development of specialized vessels to act as offensive torpedo delivery platforms can be categorized as a variation upon employment of submarine torpedoes. Three general classes of such craft emerged, comprised of traditional surface craft, steam-powered semi-submersible boats (or "David boats"), and hand-powered boats capable of complete submergence such as *H.L. Hunley*.

Submersible development on both sides began as early as 1861. But whereas the US Navy's submersible efforts were laboriously slow and generally less successful than those of their Southern counterparts, within the Confederate States there quickly emerged a somewhat more widespread, independent

interest in submersible construction that localized in a number of coastal and riverine cities. Part of the reason for the rapid Confederate submersible progression was that while Union development was burdened with conventional bureaucratic processes of Navy contracting and evaluation, Confederate efforts were able to benefit from a quick application of private initiative, which was in turn met with swift support from a government unburdened with the traditional bureaucracy of the type existing in the North.

Private Confederate initiatives were spurred by motives of nationalism and profit. A fading but still-remembered tradition of government sanctioned privateering was revitalized through the issuance of letters of marque by the Confederate government. This approach was reinforced by Southern corporations such as John Fraser & Company who placed individual and blanket bounties on the US Navy blockading squadron warships that were gradually gaining an ever-tightening stranglehold on Confederate maritime commerce. One of the approximately 50 Confederate privateers ultimately authorized was James McClintock and Baxter Watson's New Orleans-built *Pioneer*, which comprised an experimental prototype for *H.L. Hunley*. *Pioneer* had the distinction of being the only submersible provided with a Letter of Marque and Reprisal by the Confederate States of America. Some of the Southern efforts soon found cooperative partners in the Confederate military. At least four Confederate boats, *American Diver*, *Hunley*, *St. Patrick* and the unnamed vessel constructed at the Tredegar Iron Works, were either built at government facilities or with the direct assistance of military personnel. However, this cooperation may have later caused unforeseen ramifications for the initial sponsors when some, like McClintock's *Hunley* and John P. Halligan's *St. Patrick*, were subsequently seized by the military.

It is important to view the work of the New Orleans coalition that built *H.L. Hunley* within the larger context of such projects undertaken within the Southern Confederacy. Based upon our present understanding of historical records, Confederate submersible construction efforts were centered in four areas: at the Tredegar Iron Works in Richmond, Virginia (Kane 1954:73–74; Perry 1965:92–93; Coski 1996:116–121; Luraghi 1996:252), at the Leeds Foundry in New Orleans, Louisiana (Robinson 1928:166–167); at the Park & Lyons Machine Shops in Mobile, Alabama (Perry 1965:96; Ragan 1995); and at the Confederate naval facilities at Selma, Alabama (Schell 1992:178–181). The most successful would ultimately prove to be Watson and McClintock in New Orleans backed by their core of financial supporters. Upon the fall of New Orleans and loss of their first boat, some members of this group relocated to where they built and lost a second boat. Ultimately, this group would gain a tactical success off Charleston at the expense of loss of their third boat and some of at least three crews.

MCCLINTOCK, WATSON, THEIR COALITION OF SUPPORTERS AND THEIR BOATS

The core of the submersible boat building program that ultimately produced *Pioneer*, *American Diver* and *H.L. Hunley* was formed by a group of New Orleans machinists and businessmen probably motivated by both nationalism and the possibility of collecting prize money for the destruction of enemy war vessels. The initial New Orleans group consisted of machinists (or “practical engineers”) Baxter Watson and James McClintock; lawyer and Deputy Collector of Customs Horace L. Hunley; customs house employee John K. Scott; Hunley’s brother-in-law Robert Ruffin Barrow; and prominent lawyer Henry J. Leovy. These six men were

the driving force behind *Pioneer*’s construction over the winter of 1861–1862 at the Leeds Foundry, near the Government Yard at New Basin. While the composition of this group would evolve somewhat over the next several years, it would be McClintock and (until his death) Hunley who would remain at its core.

THE FIRST ATTEMPT: *PIONEER*

The effort to construct *Pioneer* was possibly alluded to as early as August 17, 1861, in the *New Orleans Daily Delta* (Kloeppel 1987:6). In February 1862, their submersible was floated at the Government Yard at New Basin, taken up the New Canal, and reportedly underwent trials in Lake Pontchartrain. According to a postwar letter written by McClintock to fellow Confederate underwater warfare specialist Matthew Fontaine Maury, during this shakedown, the boat sank a schooner and two target barges by means of a towed torpedo (Perry 1965:95; Kloeppel 1987:6–9). On March 29, application was made by John K. Scott for a Letter of Marque and Reprisal as a privateer, which was issued to *Pioneer* by Hunley’s supervisor, Collector F. H. Hatch on March 31 under the authorization of U.S. Secretary of State Judah P. Benjamin (a New Orleans lawyer and acquaintance of Leovy’s). The Letter of Marque records the vessel’s name as *Pioneer*, and the vessel type as a “submarine propeller” armed with a “magazine of powder.” The number of crew required is listed as three, with John K. Scott as vessel commander. *Pioneer* measured 34 feet in overall length, 4 feet in beam, drew 4 feet of water and weighed 4 tons. It was painted black and had “round conical ends.” To obtain the Letter of Marque a surety of \$5,000.00 was posted by Hunley and Leovy (USGPO, Official Records 1894).

Pioneer never saw action, for less than a month later New Orleans fell to the combined US forces under Captain (Flag Officer) David G. Farragut and General Benjamin F. Butler, as

part of the strategy to take the Mississippi River Valley from Head of the Passes to Cairo and divide the Confederacy in half. Most likely sometime between April 24–28, 1862, with Farragut and Butler at the door, possibly while the levee front and shipyards were ablaze in the destruction of any goods of material value to the enemy, members of the group either scuttled or hid *Pioneer* near the New Canal. At least three of the group, McClintock, Watson and Hunley, fled to Mobile, Alabama, with the intention of building an improved vessel there incorporating lessons learned from *Pioneer*.

During the subsequent Union occupation of New Orleans, *Pioneer* was discovered, and a study of its construction was made by US Navy Lieutenants Alfred Colin and George W. Baird, engineers aboard USS *Pensacola*. Colin and Baird forwarded their study to the fleet engineer (Baird 1902:845–846). In 1868, *Pioneer* was sold for scrap at a public auction held before the New Orleans Customs House (*New Orleans Picayune*, February 15, 1868, morning and afternoon editions). There has been a great deal of speculation regarding this vessel's dimensions and configuration, as well as whether or not a submersible presently located at the Louisiana State Museum may in fact be remains of *Pioneer* (Robinson 1928; Arthur 1947; Wills 1994; Luraghi 1996). Surviving records of Colin and Baird's documentation have recently been brought to light by researcher Mark Ragan (US Navy Records, Correspondence of Officers below the Rank of Commander, National Archives). Documentation uncovered by Ragan conclusively reveals that the surviving vessel is not *Pioneer*, lending further potential credence to a theory recently proposed by researcher F. C. Furman who suggests the Louisiana State Museum vessel may in fact be the submersible constructed at the Tredegar Iron Works (*Harpers Illustrated Weekly*, November 2, 1861; Kloppel 1987:17; Coski 1996:292 ff).

THE SECOND ATTEMPT: *AMERICAN DIVER*

Upon arriving in Mobile, McClintock, Watson and Hunley were joined in their efforts by engineers Thomas Park and Thomas Lyons of the Park & Lyons machine shops, who provided their facilities for fabricating a new boat. This second boat's construction was funded entirely by Hunley. The group also now began to receive support from the military in the form of engineer William Alexander, an Army lieutenant temporarily detached from the Twenty-first Alabama Volunteer Regiment and duty detailed at Park & Lyons. Upon completion, their vessel (named *American Diver* according to a Confederate deserter) probably measured 40 feet in length, 3½ feet in beam, and 4 feet in depth, according to what are strongly suspected to be plans of it recently uncovered through the Public Records Office (PRO) in London (PRO Admiralty File 1/6236).

McClintock later wrote that the original intention was to build a boat capable of mechanical self-propulsion, stating:

To obtain room for the machinery and persons, she was built 36 feet long, 3 feet wide, and 4 feet high, 12 feet at each end was built tapering or modeled to make her easy to pass through the water. There was much time and money lost in efforts to build an electromagnetic engine for propelling the boat. . . . I afterwards fitted cranks to turn the propeller by hand, working four men at a time, but the air being so closed, and the work so hard, that we were unable to get a speed sufficient to make the boat of service against vessels, blockading the port [Matthew Fontaine Maury Papers, Library of Congress 1968; Ragan 1995:22, 24].

The obscured origin of their electromagnetic engine has been the subject of much conjecture. Records indicate that during the boat's construction, Admiral Franklin Buchanan informed Secretary of the Navy Stephen Mallory that "within the last week or ten days we succeeded in getting a man from New Orleans who was to have made the 'magnetic engine' by which it was to have been propelled" (Kloppel 1987:24). This "man from New Orleans" may have been the "Trenchman" referred to in other correspondence, and may have in fact been the mysterious figure named Alstitt (Schell 1992:168-171). At this same time in Mobile in 1863, Alstitt's electric-powered vessel, sometimes referred to as the *American Ram*, was also purportedly under construction. A somewhat fanciful sketch of this boat appeared in *Harper's Illustrated Weekly* of June 10, 1864. Sources regarding this vessel are extremely sketchy, and it seems likely that they are actually referring to the *American Diver*, perhaps confusing Alstitt's proposed designs and propulsion experiments with his probable work with the McClintock group at Park & Lyons (Schell 1992:169-171). Unfortunately, when it became apparent that the electromagnetic engine was incapable of providing the necessary power required, it was removed and a small, custom-built steam plant was installed in its place. However, that also was unusable and removed (Ragan 1995:22).

The PRO (N.D.) plans include what appears to represent some sort of self-propelling motor and also contains pig-iron ballast, but may actually be stacked electrical storage batteries in closed compartments fore and aft in the vessel. The PRO drawings bear a close resemblance to the vessel represented in a postwar drawing by Baird made in the presence of, and based upon information provided by, McClintock. Baird, apparently assuming that McClintock only built one boat in Mobile, subsequently identified the boat in this drawing as "the vessel that destroyed the USS

Housatonic" (Baird 1902:846). Because of this, it has been commonly assumed that he was attempting to represent *Hunley*, when in fact he may have actually been sketching *American Diver*. In a response to Baird's article written shortly after it appeared, Alexander raised an objection to this identification, noting of the questioned drawing that "after the capture of New Orleans McClintock went to Mobile and built the submarine in Plate I. I don't know where McClintock is living, but hope he will assist in correcting this error" (Ragan 1995:25). Unfortunately, McClintock was never able to correct the record; he was killed in Boston Harbor in 1879 in an accidental explosion while demonstrating some of his underwater contact mine designs for the government (Ragan 1995:164). But while McClintock did not survive long enough to answer Alexander's request, the PRO drawings seem to confirm the accuracy of his memory regarding the design of his second boat in the form of his letter to Maury and his description as relayed to Baird.

American Diver was floated in Mobile Bay in February 1863. It was towed off Fort Morgan with the intention of manning it there and attacking the Union fleet, but as the weather grew worse and the sea became rough, the boat became difficult to manage, filled with water and sank. No lives were lost in this mishap, but the Confederate submariners had been deprived of another vessel in which they had invested much effort, time and funds.

THE THIRD ATTEMPT: *ILL. HUNLEY*

McClintock and Hunley's group would not be discouraged. Financially strapped, they sold shares in the third venture to the Singer Submarine Corps, composed of engineers E. C. Singer, R. W. Dunn, Gus Whitney and J. D. Breaman. Hunley held one-third of the shares, Singer one-third, with the last third split among the others (Ragan 1995:26). During the boat's construction, Lieutenant Alexander was joined

by another Army assignee to this detail, Lieutenant George Dixon, also of the 21st Alabama. Dixon and Alexander were veterans of Shiloh, and Dixon is known to have sustained a serious leg wound there (Ragan 1995:28). Deciding against constructing another submarine on a plate by plate basis, the engineers obtained a long, cylindrical steam boiler that they lengthened, deepened and fitted out to accommodate a crew of nine. Some sources describe the boiler used as being from a steamship, others say it was from a railroad engine. The boat was launched in July 1863 at the Theater Street dock (Figure 4.1). Before Hunley's asphyxiation and the subsequent naming of the vessel for him, this vessel was sometimes referred to as "the fish boat" and "the porpoise." Trials produced pleasing results. Admiral Franklin Buchanan noted that the boat was capable of making four knots (Ragan 1995:30). Years after the war, Alexander

described the construction of the vessel as follows (Figure 4.2):

We decided to build another boat, and for this purpose took a cylinder boiler which we had on hand, 48 inches in diameter and 25 feet long (all dimensions are from memory). We cut this boiler in two, longitudinally, and inserted two 12-inch boiler-iron strips in her sides, lengthened her by one tapering course fore and aft, to which were attached bow and stern castings, making the boat about 30 feet long, 4 feet wide and 5 feet deep. A longitudinal strip 12 inches wide was riveted the full length of the top. At each end a bulkhead was riveted across to form water-ballast tanks (unfortunately these were left open on top); they were used in raising and sinking the boat. In

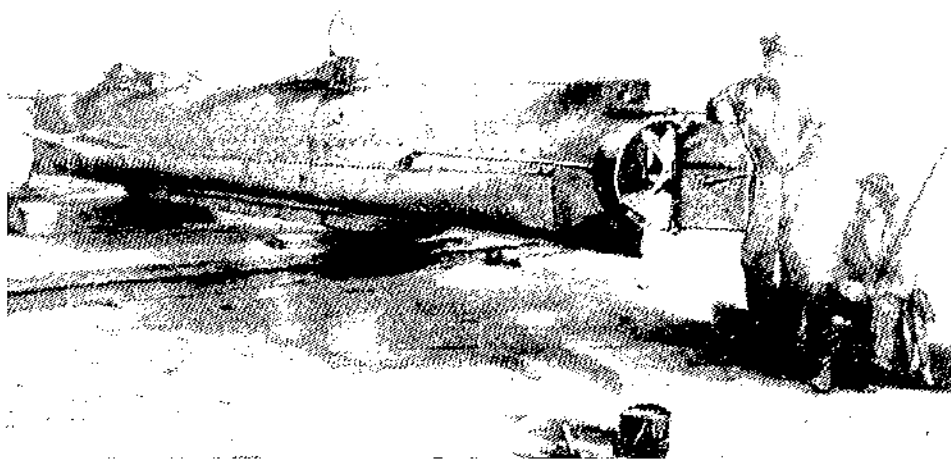


Figure 4.1. Conrad Wise Chapman's contemporary painting of the submarine *H.L. Hunley* (from *Charleston's Maritime Heritage, 1670-1865*, P. C. Coker III, 1987, pg. 267).

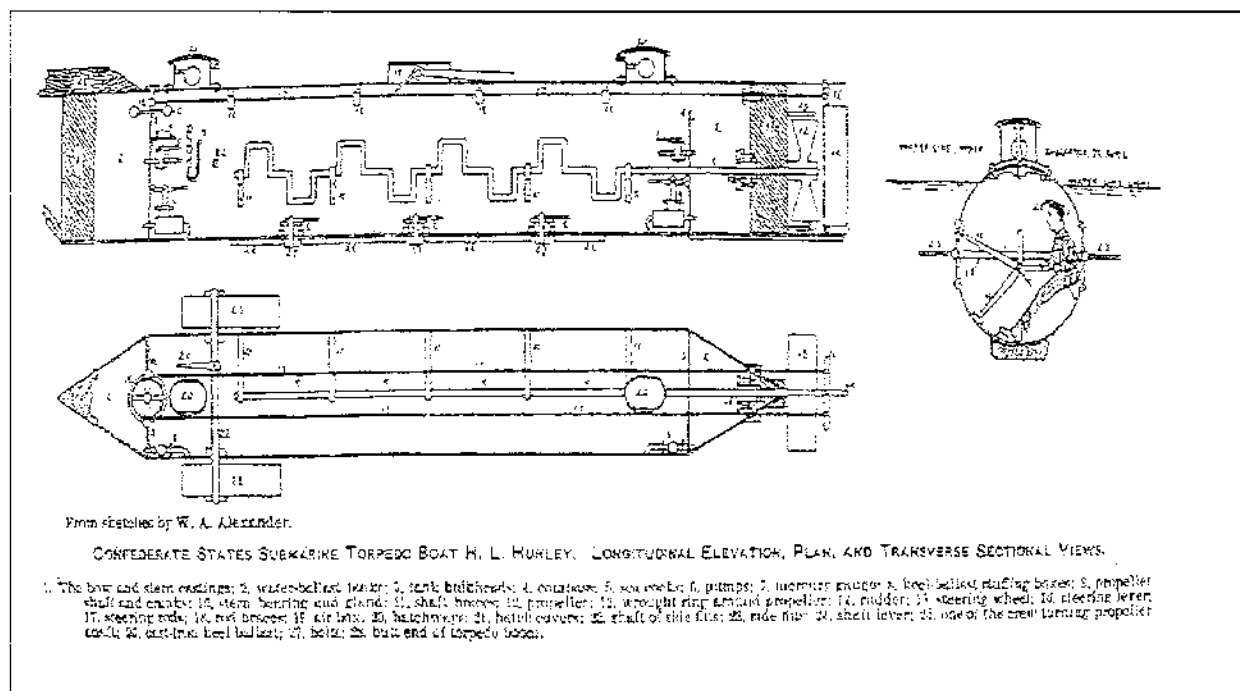


Figure 4.2. William Alexander's drawing of *H. L. Hunley* (from Alexander 1902).

addition to these water tanks, the boat was ballasted by flat castings made to fit the outside bottom of the shell and fastened thereto by "Tee" headed bolts passing through stuffing boxes inside the boat, the inside of the bolt squared to fit a wrench, that the bolts might be turned and the ballast dropped, should the necessity arise.

In connection with each of the water tanks, there was a sea-cock open to the sea to supply the tank for sinking; also a force pump to eject water from the tanks into the sea for raising the boat to the surface. There was also a bilge connection to the pump. A mercury gauge, open to the sea, was attached to the shell near the forward tank, to indicate the depth of the boat below the surface. A one-and-a-quarter-inch shaft passed through stuffing boxes on each side of the boat, just forward of the end of the propeller shaft. On each side of this shaft, outside of the boat, castings, or lateral fins, 5 feet long and 8 inches wide, were secured. This shaft was operated by a lever amidships, and by raising or lowering the needs of these fins, operated as the fins of a fish, changing the depth of the boat below the surface at will, without disturbing the water level in the ballast tanks.

The rudder was operated by a wheel, and levers connected to rods passing through stuffing-boxes in the stern castings, and operated by the captain or pilot forward. An adjusted compass was placed in front of the forward tank. The boat was operated by manual power, with an ordinary propeller. On the propelling shaft there were formed eight cranks at different angles; the shaft was supported by brackets on the starboard side, the

men sitting on the port side turning the cranks. The propeller shaft and cranks took up so much room that it was very difficult to pass fore and aft, and when the men were in their places this was next to impossible. In operation, one-half the crew had to pass through the fore hatch; the other through the after hatchway. The propeller revolved in a wrought iron ring or band, to guard against a line being thrown in to foul it. There were two hatchways — one fore and one aft — 16 inches by 12, with a combing 8 inches high. These hatches had hinged covers with rubber gasket, and were bolted from the inside. In the sides and ends of these combings glasses were inserted to sight from. There was an opening made in the top of the boat for an air box, a casting with a close top 12 by 18 by 4 inches, made to carry a hollow shaft. This shaft passed through stuffing boxes. On each end was an elbow with a 4 foot length of one 1-2 inch pipe, and keyed to the hollow shaft; on the inside was a lever with a stop-cock to admit air.

The torpedo was a copper cylinder holding a charge of ninety pounds of explosive, with percussion and friction primer mechanism, set off by flaring triggers. It was originally intended to float the torpedo on the surface of the water, the boat to dive under the vessel to be attacked, towing the torpedo with a line 200 feet long after her; one of the triggers to touch the vessel and explode the torpedo, and in the experiments made in the smooth water of Mobile River on some old flatboats these plans operated successfully, but in rough water the torpedo was continually coming too near the wrong boat. We then rigged a yellow pine boom, 22 feet

long and tapering; this was attached to the bow, banded and guyed in each side. A socket on the torpedo secured it to the boom [Alexander 1902].

In a letter to the British Navy in Halifax, Nova Scotia, dated 1872, James McClintock describes the boat as having “an Elliptical Shape, with modeled ends. And looked similar to Surf, or Whale Boats, placed one on top of the other. She was Built of Iron 5/8 inch thick, 40 feet long top and bottom, 42 inches wide in the middle, & 48 inches high, fitted with Cranks Geared to her Propellor, and turned by 8 persons inside her” (Public Records Office, ADM 1/6236).

The boat was to be shipped by flatcar to Charleston, South Carolina, for anti blockade duty under the command of General P. G. T. Beauregard. Whereas Mobile’s defenses were well fortified, Charleston was suffering under a much more serious siege. Charleston’s coastal waters may also have presented a more desirable operating environment, especially in terms of greater depth. Furthermore, Charleston’s General Beauregard looked favorably upon unconventional weapons, while Mobile’s General Dabney H. Maury and Admiral Franklin Buchanan were not so open-minded. Finally, the move was undoubtedly encouraged by the bounties being placed upon naval vessels of the South Atlantic Blockading Squadron. The submersible was shipped to Charleston in August 1863.

In a letter “inflicted” upon his fiancé, Lt. George Gift CSN of CSS *Gaines* described how he had “been employed during the past day or two in hoisting out of the water and sending away toward Charleston a very curious machine for destroying vessels,” which he describes:

In the first place imagine a high pressure steam boiler, not quite round, say 4 feet in diameter in one way and 3½ feet the other — draw each end of the boiler

down to a sharp wedge shaped point. The 4 feet is the depth of the hold and the 3½ feet the breadth of beam. On the bottom of the boat is riveted an iron keel weighing 4,000 lbs which throws the center of gravity on one side and makes her swim steadily that side down. On top and opposite the keel is placed two man hole plates or hatches with heavy glass tops. These plates are water tight when covered over. They are just large enough for a man to go in and out. At one end is fitted a very neat little propeller 3½ feet in diameter worked by men sitting in the boat and turning the shaft by hand cranks being fitted on it for that purpose. She also has a rudder and steering apparatus.

Embarked and under ordinary circumstances with men ballast, etc., she floats about half way out of the water & resembles a whale. But when it is necessary to go under the water there are apartments into which the water is allowed to flow, which causes the boat to sink to any required depth, the same being accurately indicated by a column of mercury. Air is supplied by means of pipes that turn up until they get below a depth of 10 feet, when they must depend upon the supply carried down which is sufficient for 3 hours! During which time she could have been propelled 15 miles! Behind the boat at a distance of 100 to 150 feet is towed a plank and under that plank is attached a torpedo with say 100 lb of powder. The steersman has a string by which he can explode the torpedo by giving it a jerk. I saw them explode a vessel as an experiment. They approached within about fifty yards of her keeping the man holes just above water. At that distance, she the submarine sank down and in a

few minutes made her appearance on the other side of the vessel. He pulled the string and smashed her side to atoms. . . [Turner 1995:5-8].

Hunley's dimensions vary somewhat depending on which account is consulted. When put into a table form (Table 4.1) alongside dimensions recorded for the other boats and compared to reliable documented

measurements, these dimensions can be evaluated for their relative accuracy. McClintock emerges as being consistently near the mark in his recollections, if not slightly conservative. Gift is not far off either, while Alexander (who in all fairness cautioned forty years after the fact that "all dimensions are from memory") is somewhat further off the mark. Interestingly, if the PRO drawings are to be believed, they suggest a much closer

Table 4.1. A table comparing the dimensions of the three McClintock-built Confederate submersible craft, using historical and archeological sources.

Vessel	Length	Beam	Depth
<i>Pioneer</i>	"34 feet" (Scott/ <i>USGPO</i>)	"4 feet" (Scott/ <i>USGPO</i>)	"4 feet" (Scott/ <i>USGPO</i>)
	"35 feet" (USN drawing)	"4 ft diameter" (USN drawing)	"4 ft diameter" (USN drawing)
	"30 feet" (McClintock)	"4 feet" (McClintock)	
	"30 feet" (Baird)		
<i>American Diver</i>	"40 feet" (PRO)	"42 inches" (PRO)	"48 inches" (PRO)
	"36 feet" (McClintock)	"3 feet" (McClintock)	"4 feet" (McClintock)
	"about 25 feet" (Alexander)	"[about] 5 feet" (Alexander)	"[about] 6 feet" (Alexander)
<i>H.L. Hunley</i>	39 feet 5 inches (1996 survey)	3 feet 10 inches (1996 survey)	4 feet 3 inches (1996 survey, approximate)
	"40 feet" (McClintock)	"3½ feet" (McClintock)	"4 feet" (McClintock)
		"3½ feet...breadth of the beam" (Gift)	"4 feet...depth of hold" (Gift)
	"about 30 feet" (Alexander)	"[about] 4 feet" (Alexander)	"[about] 5 feet" (Alexander)

relationship in design between McClintock's second and third boats than has previously been suspected.

Following its arrival in South Carolina, the third McClintock designed boat experienced operational difficulties, twice being accidentally lost in Charleston Harbor with fatalities, and twice being salvaged. The first incident killed five members of the Navy crew of nine; most were volunteers from CSS *Chicora* and CSS *Palmetto State*. Following this first accident, the military sent a request to Mobile asking for people more familiar with the boat to come to Charleston and take over the vessel's operation upon its recovery. Horace Hunley, Thomas Park's son (also named Thomas but often misidentified as his father), and approximately six or so other volunteers, probably mechanics from the Park & Lyons shop, answered the call and spent some time putting the boat through "diving and raising" tests. When it finally appeared to observers that all the vessel required was experienced hands, the boat suffered another terrible disaster. While running submerged, Hunley, acting as vessel commander, made a simple error in regulating the water contained within the forward ballast tank, and the boat buried its bow in the harbor mud, stuck fast, and partially flooded, killing the entire crew of eight (which in addition to Hunley, young Park, and the Mobile mechanics, also included Sprague, the team's explosives expert). Dixon and Alexander traveled to Charleston, and upon salvage of the boat, saw their fellow submariners buried in Charleston's Magnolia Cemetery. Surviving members of the group memorialized Hunley's efforts by naming the boat after him.

Saddened but undaunted, Dixon and Alexander enlisted another volunteer crew, and the group moved their operations to Battery Marshall, on Sullivan's Island, where between November 1863 and February 1864, they frequently fought foul weather to cast off on night cruises off Charleston. On February 5,

fate touched Alexander in the form of orders received to report to another project, and he left. On the evening of February 17, 1864, approximately two and a half miles off Charleston Bar, with Dixon at the helm, *Hunley* observed and made for the screw sloop-of-war USS *Housatonic*, which lay at anchor on blockade duty. *Housatonic's* lookout spotted *Hunley* and voiced a warning, but the ship's attempt to get underway was not timely enough to prevent contact, and *Hunley* rammed the blockading vessel on the starboard stern quarter just abaft the mizzenmast, attached its mine, and remotely activated it with a great explosion that sank *Housatonic* in three minutes (Figures 4.3, 4.4 and 4.5).

But a final toll was exacted in exchange for this success. *Hunley* and its crew never returned to Sullivan's Island, even though prearranged lamp signals were believed to have been received from Dixon's crew and interpreted as a request for a light to guide them safely back into port (USGPO, Official Records 1894) (Figures 4.6 and 4.7). Several theories have been put forward regarding how and where the boat was lost. Alexander for a long time believed that *Hunley* had been caught in or beneath *Housatonic* as the Navy warship rapidly sank (Alexander 1902), this belief being based partially upon incorrect observations of government divers. But upon hearing from authoritative Navy sources these observations were not authentic, he still believed the wreck must have nevertheless come to rest not far away, having rapidly settled five feet into the seabed-like *Housatonic*. Alexander noted that an agreement existed between the crew members that if the boat should for any reason be unable to surface, "the sea cocks were to be opened and the boat flooded" in order to prevent the suffering of slow asphyxiation known to have been experienced by *Hunley's* previous crew (Alexander 1902). Another theory is that swift seas prevented the tired crew from successfully regaining port and caused their

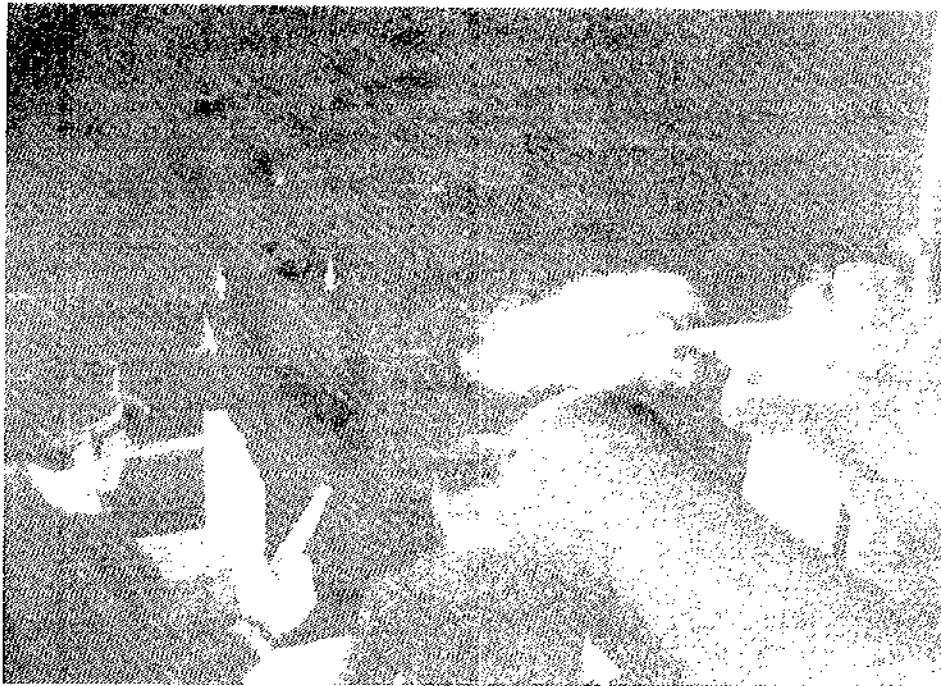


Figure 4.3. Artist's perspective of *Hunley* approaching *Housatonic* during attack. Computer graphic by Dan Dowdey, South Carolina State Museum.

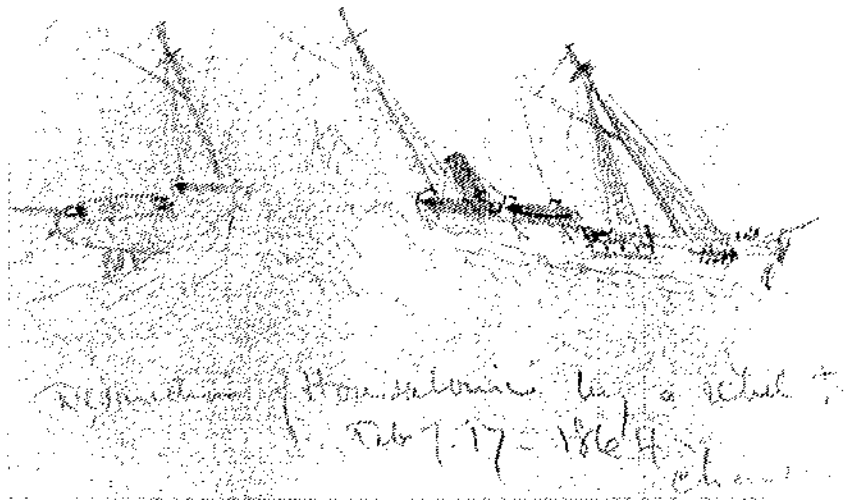


Figure 4.4. Historic drawing of USS *Housatonic* being sunk by *I.L. Hunley*. Courtesy of the US Library of Congress.

delicately balanced boat to founder. McClintock refused to believe that the boat sank during the engagement, but rather was lost in a storm a few hours after the attack. It has also been conjectured that the boat succumbed to structural damage sustained as a result of the

contact, explosion or *Housatonic*'s defending gunfire. It may be likely that the cause of loss was attributable to a combination of these factors.

In retrospect, the Confederate submersible operations, and specifically the successful

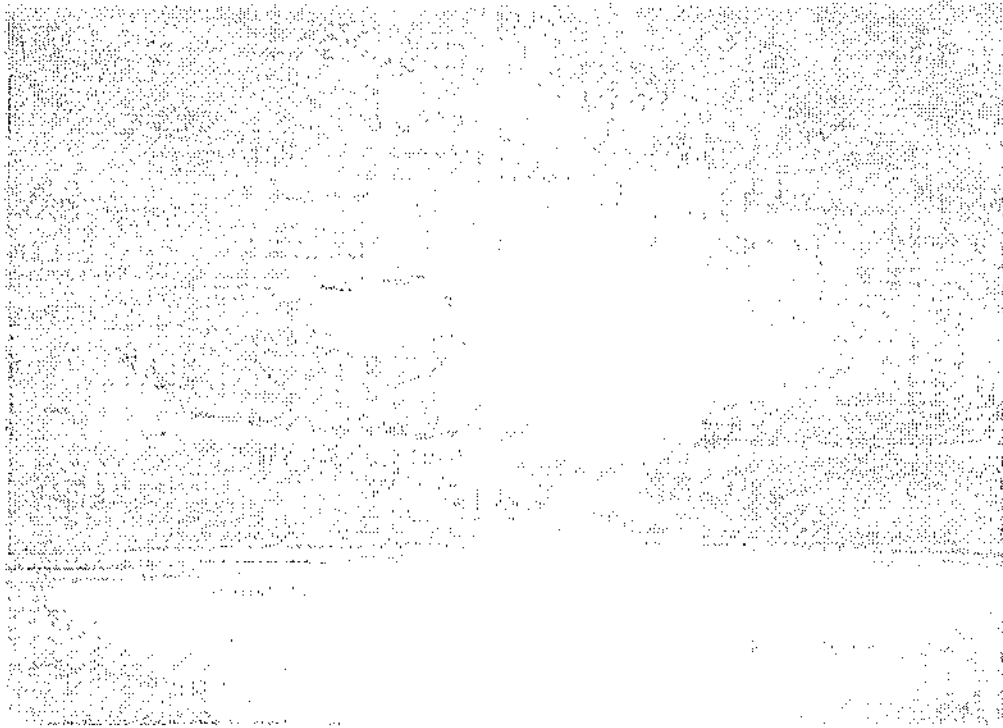


Figure 4.5. Artist's perspective of *Hunley* sinking *Housatonic*. Computer graphic by Dan Dowdey, South Carolina State Museum.

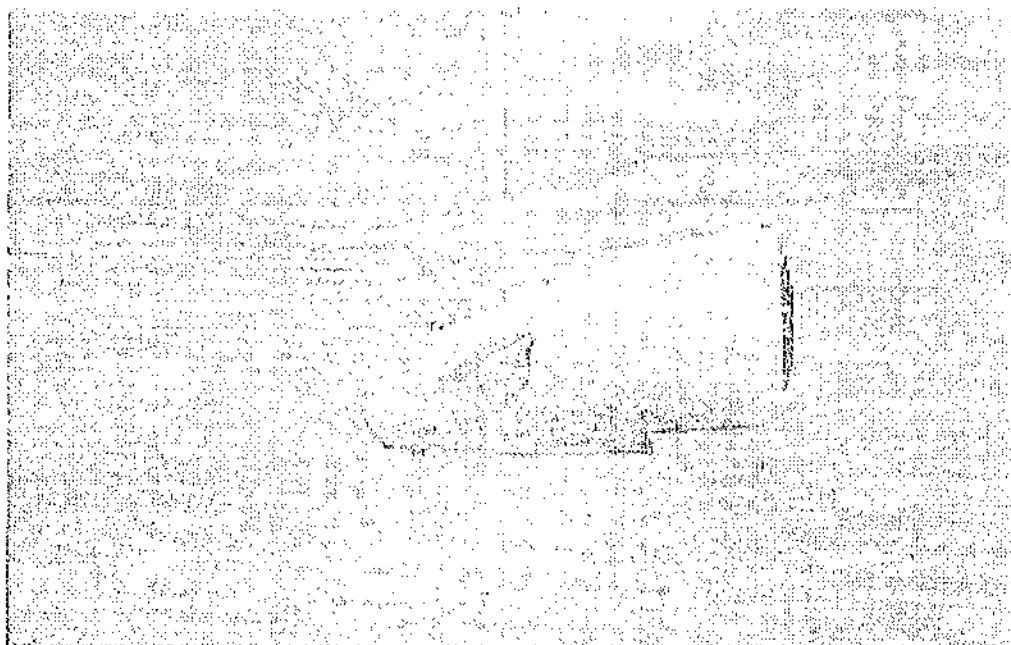


Figure 4.6. Artist's perspective of *Hunley* moving away from *Housatonic* after the attack. Computer graphic by Dan Dowdey, South Carolina State Museum.

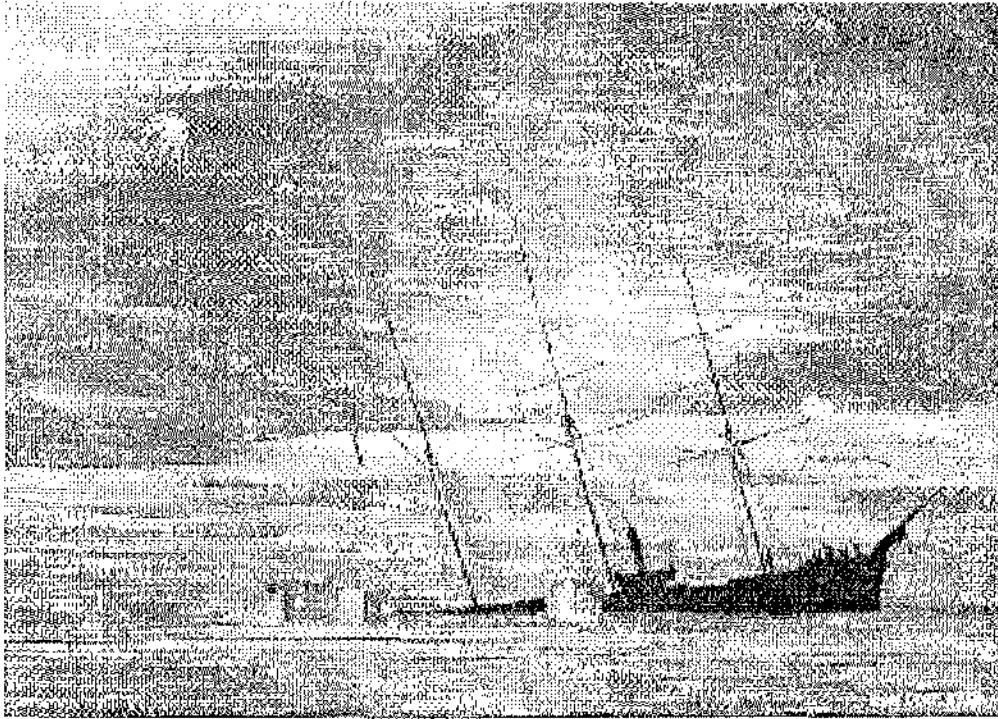


Figure 4.7. Artist's perspective of *Hunley* escaping with *Housatonic* sinking in the background. Computer graphic by Dan Dowdey, South Carolina State Museum.

engagement of *Hunley* with *Housatonic*, had several immediate effects on US Navy operations. They acted as a psychological warfare tool, causing fear among the squadrons, particularly within the South Atlantic Blockading Squadron following *Hunley*'s action. They caused expensive and logistically intensive modifications to Union blockading strategies through causing heightened security in the vessels on station, requiring them to be ready to get underway at all times, and forcing

them to be redeployed further offshore at night. Finally they may have provided the impetus for accelerated Union attempts to gather information and conduct research to develop a similar weapon. But while such attempts were underway as early as 1861, it was *H.L. Hunley*'s attack on *Housatonic* that defined to the US Navy the danger of the submersible torpedo craft in Southern waters, and to the world the military potential of the submersible vessel.

CHAPTER 5

Environmental Context

Scott Harris and Adriane Askins

The *H.L. Hunley* site is located on the inner continental shelf along the eastern Charleston Harbor Estuary periphery in the central South Carolina coastal zone. The modern estuarine, maritime, and nearshore shelf environments have formed over the last 10,000 years as sea-level rise flooded stream valleys and upland areas and forced landward barrier island system migration. Since *Hunley*'s loss, jetties have been installed to redirect the main harbor shipping channel, approximately 45 tropical storms and hurricanes have potentially affected the site, an earthquake measuring 7.9 on the Richter scale razed many sections of Charleston, and sea level has risen approximately 30 centimeters. The most recent and devastating hurricane to pass over the site was hurricane Hugo in September 1989, six years before site discovery.

A general environmental discussion is presented here to serve as a framework for interpreting the specific *Hunley* site conditions encountered. In archeology, site formation processes are critical in explaining the way a

site appears today and understanding the natural and cultural processes responsible for site preservation and artifact distribution. Site formation processes are important to the *Hunley* assessment, and they comprise an important set of research domains in the research design (Chapter 3).

COASTAL GEOLOGY

South Carolina, smallest of the southeastern states, has an area of 80,500 square kilometers (31,113 square miles) and is located between 83°30' and 78°30' west longitude and 35°15' and 32°00' north latitude (Figure 5.1). South Carolina's physical geography comprises three primary physiographic provinces, Blue Ridge, Piedmont and Coastal Plain, ranging from rolling hills and moderately high mountains in the west to mean sea level in the coastal low country and Grand Strand areas (Kovacik and Windberry 1987:13). The coastal zone is of general primary interest for establishing *H.L. Hunley*'s environmental context, and the

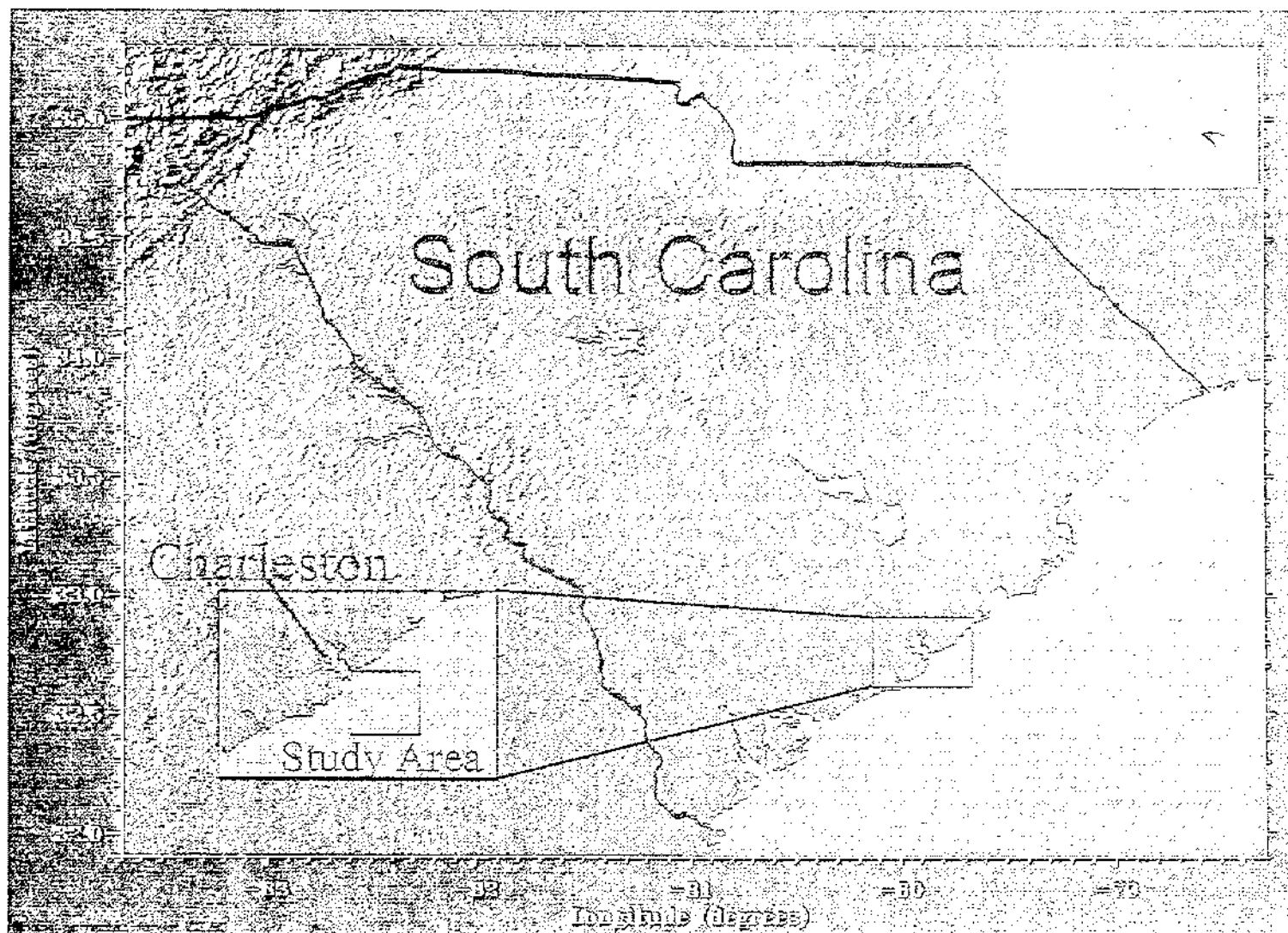


Figure 5.1. Map of South Carolina showing study area.

Charleston Harbor area of particular importance.

The South Carolina coastal zone overlies sedimentary deposits ranging in age from Early Cenozoic to Recent (Shattuck 1906; Cooke 1936; Zeigler 1959; Colquhoun 1965, 1974; McCartan et al. 1984; Gohn 1983; Colquhoun et al. 1991; Weems and Lemon 1993). Basement rocks and Mesozoic basins beneath the coastal plain may be found at sea level along the fall zone, approximately 1,150 meters below sea level near Charleston (Gohn 1983), and approximately 10–15 kilometers deep beneath the Blake Plateau 240 kilometers (150 miles) offshore (Klitgord et al. 1983). This section of the Georgia Bight has formed through four primary geologic phases: (1) initial continental rifting, formation of the proto-Atlantic, and deltaic and basin sedimentation in the Mesozoic; (2) large-scale deep water deposition, high sea levels, and Gulf Stream erosion during the early Tertiary; (3) shallow-water shelf deposition and broad sea-level changes in the late Tertiary; and (4) formation of the lower coastal plain through major barrier island environment transgressions and regressions throughout the Quaternary. The last three phases, approximately 50 million years, have induced a noticeable impact upon the region's current coastal system and continental shelf configuration.

Geologic studies offshore Charleston, South Carolina, have focused on deep structures and regional stratigraphy (e.g., Hersey et al. 1959; Dillon and Klitgord 1978; Boylan et al. 1982; Poag 1984), bottom configuration (Sexton and Colquhoun 1987), bottom sediment type and composition (Stone and Siegel 1969; Field and Pilkey 1969; Sexton and Colquhoun 1987; Gayes and Ealy 1995; Gayes et al. 1998) and influence of physical processes (Field and Duane 1976; Swift 1980; Atkinson et al. 1983; Schwing et al. 1983; Fitzgerald 1984; Swift and Thorne 1991). Studies concentrating on factors influencing regional barrier island

geomorphology and stratigraphy have been made by Miles O. Hayes' group at the University of South Carolina in Columbia (see summary by Hayes 1994). Onshore geologic studies have focused primarily on the Quaternary stratigraphy (Cooke 1936; Colquhoun 1965, 1969; Colquhoun et al. 1991; Krantz et al. 1996; Harris et al. 1997), Tertiary stratigraphy (Ward and Blackwelder 1980; Weems and Lemon 1993), the 1866 Charleston earthquake (Gohn et al. 1983), and phosphate sources (Holmes 1849).

Poag (1984) indicates a general thickening of Neogene sediments away from the North Carolina Platform into the Georgia embayment. Colquhoun (1995) summarizes the Cenozoic evolution of the southeastern Atlantic Coastal Plain as cyclic patterns of sediment deposition from the late Eocene to Oligocene. Overall, Tertiary deposits consist of tabular to lenticular formations with varied lithologies and depositional environments. These older deposits are distinguished from the overlying Quaternary units by their paleontologic, mineralogic, textural, and "...well compacted to partially lithified..." character (Weems and Lemon 1993: Sheet 1). The Ashley Formation, Chandler Bridge Formation, Edisto Formation, Marks Head Formation, and Goose Creek Limestone all subcrop or crop out at the surface near the study area. Some Tertiary units crop out directly offshore South Carolina's coast, creating local hard bottoms (Poag 1984; Harris et al. 1997). Others are emergent, cropping out just at mean water beneath overlying Quaternary deposits (Force 1978a, 1978b; Weems and Lemon 1993). Fluvial incision, shoreface ravinement, inlet incision, and Gulf Stream erosion have modified the top of the Tertiary strata and are responsible for the present topography (Belknap and Kraft 1981, 1985; Popenoe 1986; Tye and Moslow 1994).

Six factors influence the geomorphology, sedimentation, stratigraphy, petrology and geometry of Cenozoic sedimentary units and

diversity of surficial Quaternary coastal deposits: (1) trailing edge continent with gentle downwarping; (2) siliciclastic deposition from Appalachians and Piedmont; (3) humid temperate to subtropical climate; (4) mesotidal mixed-energy coast; (5) dominant southwest longshore transport and (6) submergent sea levels from Cretaceous to Late Eocene/Early Paleocene and mild emergence during the Neogene (Colquhoun 1995).

A complex series of cyclic highstand sequences and incised paleovalleys characterize Pleistocene deposits beneath the South Carolina coastal plain and continental shelf (Colquhoun 1965, 1969; Colquhoun et al. 1991). Multiple sea-level transgressions and regressions throughout the Quaternary have resulted in removal, reworking, and incision of the Tertiary and Pleistocene strata. The uppermost Tertiary strata has locally variable relief, ranging from less than one meter to more than 30 meters (Colquhoun 1969; McCartan et al. 1984; Weems and Lemon 1993). Generally, these paleotopographic low areas have been backfilled with Quaternary fluvial, paludal, paralic, and shallow neretic lithofacies (Colquhoun 1965, 1969; McCartan et al. 1984; Weems and Lemon 1993). The transgressive Quaternary units associated with barrier island migration are thin (McCartan et al. 1984; Weems and Lemon 1993), commonly discontinuous, and generally decrease in age seaward. The stacked, *en echelon* nature of coastal-Quaternary units results from truncation through ravinement or channel migration during sea level rise across the emergent Coastal Plain (Belknap and Kraft 1981; Field and Trincardi 1991; Tye and Moslow 1994). These units' relative depositional history may be inferred from cross-cutting relationships, either geomorphically or through seismic interpretations (Idris 1983; Riggs and Belknap 1988; Toscano and York 1992; Krantz et al. 1994; Harris et al. 1994).

Early Coastal Plain geomorphic studies indicated that many sea level highstands were represented on the coast (Shattuck 1901, 1906; Cooke 1936). The first comprehensive South Carolina Coastal Plain study based on topographic correlation argued for existence of seven individual Pleistocene coastal sequences (Cooke 1930, 1936). Alternatively, some researchers observed six emergent Pleistocene units (Colquhoun and Johnson 1967), but validity of their methods and interpretations have been questioned (Flint 1940, 1971). Other researchers (Cooke 1936; Colquhoun 1965; Flint 1971; McCartan et al. 1984; Colquhoun et al. 1991) have used, directly or indirectly, geomorphic criteria to identify stratigraphic contacts and unit boundaries. The common attributes between each of these models are that there have been multiple major changes in relative sea level in the mid-Atlantic, lithologies are heterogeneous and complexly distributed, these emergent systems have distinct geomorphic expressions, and the sediments span multiple depositional age ranges.

BARRIER ISLANDS

South Carolina's modern coastal morphology is transitional between North Carolina's long, thin barrier islands punctuated by few tidal inlets and Georgia's shorter, truncated barrier islands separated by numerous large tidal inlets. Wind-generated waves and currents create North Carolina's thinner barrier islands, while tidal currents have greater influence on Georgia's inlet-dominated coastal morphology. Central South Carolina's barrier islands lie centrally between these two extremes within the mixed energy, tide- and wave-dominated Georgia Bight, thus maintaining a dominant "drumstick" morphology (Hayes 1994) and sedimentary architecture (Tye and Moslow 1992). Tidal energy increases and wave energy decreases towards the south

(Brown 1977:251; Hayes 1994). The barrier islands' low relief affords little resistance to storm and wind activity, and they tend to erode at an extremely rapid rate.

Recent shoreline changes have been documented from the 1850s to 1983 for South Carolina (Anders 1990), and indicate great shoreline change rate variability depending on proximity to inlets (higher variability) or central island segments (more stability, less variability). Large changes from the mid-1800s to early 1900s occur close to inlets, similar to those observed in main tidal channel shifts identified north of Charleston Harbor in Price Inlet (Fitzgerald 1984). Erosion rates of up to 50 feet-per-year have been documented at Morris Island, south of Charleston Harbor's entrance (Hayes et al. 1984:13).

SEDIMENTS

The central and southern barrier island zones are presently receiving very little sand from fluvial sources (Brown 1977:262). Offshore, in 8-10-meter water depths, waves, currents, and bioerosion rework older Tertiary and Pleistocene deposits and provide coastal system sediment, often as phosphate and shell. The low wave-energy and constant reworking has produced fine sediments, averaging 0.143 millimeters (Brown 1977:262). Side-scan sonar mosaics ground truthed using bottom grabs indicate three dominant sediment types offshore Charleston Harbor: coarse shell hash, fine to very fine sand, and rock outcrop. Bottom grabs indicate some areas contain variable amounts of muddy sands and muds, likely sourced from within the harbor system or through reworking of older deposits (Coastal Carolina University and Minerals Management Service, INTERMAR database 1998).

CLIMATE

South Carolina's climate is classified as humid subtropical, with abundant precipitation distributed inland, which averages between 118 centimeters/year (Kovacik and Windberry 1987:31) and 125 centimeters/year (Davis and Van Dolah 1992). Average temperature for the coastal region is 18.7° C, ranging from 10.0° C in December to 27.2° C in July, generally not exceeding 38° C or -6.5° C (Davis and Van Dolah 1992).

STORMS

Since 1871, approximately 45 tropical storms and hurricanes have affected the South Carolina coast (Department of the Army 1990). The most recent, hurricane Hugo, made landfall just north of Charleston Harbor on September 22, 1989. Estimated storm position during landfall placed the eye directly over the *Hunley* site with a storm surge of approximately 4 meters (Brennan 1991). Wind gusts of approximately 61 meters/second (137 mph) were accompanied by up to 6 meter storm surge 20 kilometers north of the Charleston area (Brennan 1991). Sand and dense debris moved offshore during hurricane Hugo into water depths less than 7 meters (Gayes 1991).

WIND

There are no predominant wind direction approaches, but seasonal trends are apparent along the coast. South and southwest winds prevail during the spring and summer, and northerly winds are most common during fall and winter. National Oceanic and Atmospheric Administration (NOAA) weather station data have been collected approximately 3 kilometers

south of Charleston Harbor on Folly Island and approximately 80 kilometers ESE of the harbor from a fixed buoy. The on-land station recorded an annual average wind speed of 4.4 meters/second (8.6 knots) for the period May 1984 to December 1993, with a minimum average in December of 3.9 meters/second (7.7 knots) and a maximum average of 4.8 meters/second (9.3 knots) in June (NOAA 1998). Offshore buoy data (buoy #41004, 38-meter water depth) recorded an annual average of 6.4 meters/second (12.5 knots) for the period of June 1978 to December 1993, with a maximum average of 7.8 meters/second (15.2 knots) in December and a minimum average of 5.1 meters/second (9.9 knots) in August (NOAA 1998). Wave energy flux values follow the same seasonal trends as the winds (Brown 1977:250).

WAVES

"The most dominant natural force affecting erosional-depositional trends along the coastal zone," wind-produced waves are directly proportional to wind duration and fetch (Hayes et al. 1984:3). Wave energy can be either erosional or depositional. Typically, in calm weather beaches accrete through shoreward transport of offshore sediments; during high wave periods such as storms and hurricanes, beaches erode. Wave data have been collected from offshore buoy #41004 (NOAA 1998) and as a part of a recent United States Geological Survey (USGS) funded South Carolina Coastal Erosion Project (MacMahan 1997). The buoy data recorded an average annual significant wave height of 1.3 meters from May 1980 to December 1993 and an average annual average wave period of 5.0 seconds with an average maximum of 5.5 seconds in February and an average minimum of 4.6 in January. MacMahan (1997) found a 54+/-11% reduction from deep water wave heights (buoy data) to the inner shelf areas. These 3 meter and 10 meter wave gauges recorded mean summertime

wave heights of 0.46+/-0.17 meter with a period of 8.3+/-1.5 seconds. During typical wave climates (mean wave height), it is expected that the critical sediment depth movement will be between 10 and 15 meters water depth in this region.

TIDES

The spring tidal range is approximately 1.7 meters, with a maximum extreme range of approximately 2.4 meters (NOAA 1993). With this tidal range and the wave regime, this segment of South Carolina coast falls within the mixed energy morphodynamic range (Hayes 1994), leading to a typical "drumstick" barrier island geomorphology. With lower tidal ranges, waves dominate and the shore responds more to longshore transport and coastal smoothing; with higher tidal ranges and lower wave energy, the coastal energy is focused perpendicularly shoreward, leading to larger, more stable inlet positions through time (Hayes 1979).

CURRENTS

Tidal and longshore currents are the most important currents affecting South Carolina shorelines. Produced by waves hitting the coast at an oblique angle, longshore currents run parallel to the shoreline and vary in velocity and direction relative to wave angle and energy. In combination with wave action, longshore currents can move large amounts of sand parallel to the coast. These currents generally move sediments southward through both sediment and bed load transport. Tidal currents also move sediments, but generally not in concert with longshore currents. Deposition caused by ebb-tidal currents can move sediments to the mouths of inlets or contribute material to longshore transport. When storms pile up water against the coast, these above-normal high tides can produce strong currents

and offshore flows at harbor entrances, inlets, lagoons, bays and along the coast (Hayes et al. 1984:5).

BENTHIC COMMUNITIES

Penaeid shrimp (*Penaeus setiferus*, *P. aztecus* and *P. duorarum*) and crab species are abundant in the Charleston Harbor estuary and are sought commercially. The most prolific species are white shrimp, brown shrimp and blue crabs (*Callinectes sapidus*). Shrimpers can snag objects above the bottom and affect these features. There are also intertidal oyster beds of *Crassostrea virginica* and large subtidal beds of *Mercenaria mercenaria* hard clams. Numerous finfish species are supported by the estuary waters as well. Included in this group are spot (*Leiostomus xanthurus*), croaker (*Micropogonias undulatus*), spotted sea trout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellatus*), southern flounder (*Paralichthys lethostigma*), summer flounder (*P. dentatus*), white perch (*Morone americana*), and catfish (*Ictalurus catus*, *I. furcatus*, and *I. punctatus*) (Van Dolah and Davis 1989:46–48).

HUMAN IMPACT

Natural forces were not alone in fashioning the area; humans have been altering South Carolina's landscape for at least 12,000 years. The state's first inhabitants, coastal Indians who constructed villages on the mainland and sea islands, exploited the natural vegetation, fish and game. Kiawahs, Edistos, Stonos and Wandos are groups who occupied the area. While their environmental impact was minimal in comparison to modern populations, these coastal Indians did alter the landscape. Their hunting practice of burning areas to drive game into the open created large grassy savannahs fringed by coastal forests, while their shellfish harvesting left large coastal shell midden deposits. European colonists arriving in 1670

immediately began modifying the area, filling in Charleston peninsula creeks and marshes to increase local land area. Over the next two hundred years, the area's economic mainstays, cattle ranching, indigo and rice cultivation, and phosphate mining, contributed to increasing landscape alteration (Goodwin 1989:8).

Success of these industries was undoubtedly due to development of superior shipping facilities at the Port of Charleston. Charleston Harbor ship-berths were located only six to seven miles from the ocean, allowing for a much faster turn-around time and out-competing neighboring ports (Goodwin 1989:9). The port still has one of the fastest turn-around-times for cargo vessels in America today.

Charleston Harbor channel dredging began in 1854, but the first massive sediment removal did not take place until 1874. The City of Charleston moved approximately 76,000 cubic meters of sand from the main channel and bar, which quickly reformed. The Army Corps of Engineers constructed stone jetties in 1896 to "concentrate water discharge from the harbor to maintain scouring action," however, neither the jetties nor sand removal worked sufficiently to guarantee passage of merchant vessels of continually increasing draft. Maintenance dredging was eventually instituted. From 1928 to 1944, 230,000 cubic meters of material per year were dredged from the shipping channels (Goodwin 1989:9).

In 1942, the Santee River diversion into the Cooper River through Lake Moultrie increased its original drainage area from 1,865 square kilometers to 39,865 square kilometers and its flow from 6 cubic meters/second to more than 425 cubic meters/second. Harbor navigation channels were deepened at the same time to between 9 meters and 10.6 meters below mean low water. These two estuary system modifications caused the turbidity maximum zone to migrate into the main harbor, causing a twenty-fold increase in maintenance dredging. In 1966, the Army Corps of Engineers began

rediverting 80 percent of the flow to Lake Moultrie, which was returned to the Santee River. This rediversion was completed in 1985 with construction of the canal connecting Lake Moultrie to the Santee River (Goodwin 1989:9).

The diversion and rediversion of the Santee River caused several physical changes in Charleston Harbor. The initial diversion and its subsequent discharge increase caused a decrease in mean surface salinity and shifted the estuarine zone seaward (Kjerfve 1989:16). Gravitational circulation became the dominant type of residual circulation, and the salinity/

density structure of the estuary changed from a vertically well-mixed matrix to one partially mixed. Since the rediversion completion in 1985, there has again been a salinity level change. No longer dependant on variable discharge rates because discharge is kept at a nearly constant rate, salinity variations are instead affected by spring-neap tidal cycles, tidal phases and far-field meteorological events (Kjerfve 1989:17). The estuary waters tend to remain stratified, although spring tides cause them to become vertically well-mixed.

CHAPTER 6

Predisturbance Remote Sensing Survey

Larry E. Murphy, Matthew A. Russell, Timothy G. Smith and Steven M. Shope

SURVEY OBJECTIVES

Before beginning test excavations to expose *Hunley's* remains for documentation and evaluation, a predisturbance remote sensing survey was conducted over an area that included both the remains of the reported *H.L. Hunley* and those recorded as *USS Housatonic*. For purposes of this study, both *Hunley* and *Housatonic* sites were considered as multiple components of a single site representing *Hunley's* attack on *Housatonic* and the loss of both vessels. Systematic hydrographic remote sensing produced a rapid, three-dimensional reconnaissance that provided a synoptic overview of known and potential cultural remains and relationships within the study area prior to sediment disturbance. Predisturbance surveys are becoming common practice in underwater archeology, and they are part of a minimum-impact approach (Russell and Murphy 1997).

The high-resolution intrasite survey located additional cultural material, characterized the

environmental context and located site-related features above and below the sediments useful for planning the test excavation and aiding site interpretation. Developing a remote sensing-derived site perspective prior to beginning test excavation was important for planning to ensure related features near the principal components were identified and investigated and stratigraphic sequence and scour-related features were identified. Location of outlying ferrous masses possibly associated with the principal target site, or perhaps related to the *Hunley-Housatonic* engagement, was also an objective.

Remote sensing instrumentation included: magnetometer (locates ferrous cultural material possibly representing archeological sites by detecting local variations in the earth's magnetic field); survey depth sounder (determines water depth); sub-bottom profiler (records geological stratigraphy below the seabed); RoxAnn bottom classification device (characterizes surficial seabed sediments); and side scan sonar (generates a topographic

rendition of the seabed and cultural materials on and above it). Utilization of these sensors concurrently provides a cost effective solution to independent natural and cultural resource hydrographic surveys as required by the *Hunley* evaluation research design (Chapter 3). Instrumentation was provided by the National Park Service's (NPS) Submerged Cultural Resources Unit (SCRU) and by manufacturers through cooperative agreements.

SURVEY DESIGN AND RATIONALE

The *Hunley* survey was designed to produce a comprehensive data set that would be immediately accessible for planning and to aid interpretation during the planned test excavation. The survey design was based upon wide-area archeological survey methodology developed by SCRU during the NPS System-wide Archaeological Inventory Program survey of Dry Tortugas National Park beginning in 1993 (Murphy 1997c; Murphy and Smith 1995; Shope et al. 1995).

Data collection, post plotting, analysis and presentation were designed to be utilized in a Geographic Information System (GIS) database to facilitate their use during the *Hunley* project and later incorporation into permanent South Carolina and federal archives. This approach results in an electronic product that can incorporate available digital data, such as aerial imagery and digitized historical maps, so they can be combined with project-specific results and be analytically manipulated to examine relationships that would otherwise be extremely difficult to observe. The project GIS data set was generated to provide a standardized, permanent, cumulative, computer-accessible product for multiple applications of project researchers, managers, and those involved in planning and conducting future site operations.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

GIS is the use of multiple, spatially referenced databases to produce maps that graphically depict user generated combinations of variables presented as themes, layers or coverages. Spatially referenced data are basic to archeological inquiry, but it has only been in the last few years that technological advances in computer software and hardware have overcome difficulties in collecting, collating, storing, editing, querying, depicting and manipulating the large amount of data generated by marine remote sensing survey. *Hunley* project survey results were formulated to be incorporated into a GIS operation in the field to expedite analysis and be easily transferrable to state and federal managers.

GIS provides a methodology to compare variables among many sets of spatial data, such as artifact categories, remote sensing results and natural environmental characterizations, to examine distribution and change over space, and, if sufficient data are available, over time. Rapid manipulation of scale and variables can allow pattern recognition that may not be apparent at other levels. Examination of combined variables is instant because results are presented graphically, greatly simplifying analysis by precluding the necessity of generating mathematical and statistical models to characterize patterned relationships. Current computer and software speed allow rapid manipulation of multiple variable combinations, which allows generation of associations and relationships that might otherwise be unanticipated. Hypotheses can be quickly generated and tested through seamless graphical display. Data manipulation can easily be done by researchers or managers with basic GIS software familiarity, which does not require sophisticated mathematical ability.

GIS data sets can be presented as tabular database files or themes that can be generated, analyzed, scaled, combined, superimposed and displayed through direct user access in unlimited variations. Data themes are presentations of nonspatial data referenced to a common location expressed as geographic coordinates. One way of looking at themes is to consider them x-y horizontal locations that share a category of variable z values, which represent discrete, quantifiable attributes. Analytical techniques include statistical and spatial analysis, measurement and comparisons that can be used to create additional themes reflecting analytical results useful for additional hypothesis testing.

GIS can be contrasted with computer-assisted design (CAD) systems that are generally limited to graphic output such as drawings, pictures and maps and contain no relational database capability nor the ability to generate new data sets based upon analytic functions. CAD systems generally contain no interrogative capability and are unable to manipulate nonspatial database attributes (Murphy 1997a).

Two problems make creating GIS data sets expensive and time consuming: accuracy determination and conversion of various data sets to an appropriate format. Mixing different accuracy levels among data sets degrades overall GIS accuracy and gives a false sense of comparability that can lead to serious analytical problems in data interpretation. Data set conversions must consider fundamental geodetic concepts such as geoid, ellipsoid, datum, coordinate system and projection. Geodesy factors vary over time and space, and each variation is critical to conversion accuracy (Smith 1997). Few archeologists record a chart's datum and projection when generating coordinates. For example, latitude/longitude coordinates in North American Datum 1927 (NAD 27) and those in World Geodetic System 1984 (WGS 84) can vary from tens to hundreds

of meters — confusing these datums introduces serious error. Being given coordinates in NAD 27 and trying to relocate the point with an instrument reading in WGS 84 is an easy and common mistake to make. All data generated during the *Hunley* Project were based on the WGS 84 datum. Other data not collected by SCRUI during the project and not already in WGS 84 datum were converted from their original datum before incorporation into the *Hunley* Survey GIS database.

Although the survey was designed to ultimately produce GIS database products, use of GIS for on-site field manipulation and evaluation of raw field data for immediate reoccupation and ground truthing was critical to the *Hunley* test excavation operations. The survey phase had to provide for immediate and easy utilization of large volumes of field data, develop topographic context of survey blocks and allow investigators to post-process, manipulate, evaluate and assimilate the field data on a daily basis. GIS evaluation was the basis for establishing test excavation sequence and extent.

GIS DATA ARCHIVING

Raw and processed hydrographic survey field data and GIS information archiving is as much a concern as any archeological data archiving, and it must be planned in advance. *Hunley* survey electronic data archiving is in a nonproprietary format, primarily DOS ASCII text, which ensures long-term data accessibility by many scientific disciplines, managers, archeologists and other researchers. All results are stored in latitude/longitude and Universal Transverse Mercator (UTM), WGS 84. SCRUI stores archive data in latitude/longitude coordinates so that the database can be easily converted if future alterations or corrections are made to WGS 84; it is more difficult to convert grid coordinates after a datum revision. Most current computer programs require grid

coordinates, so, themes are also archived in this form. Upon project completion, appropriate state and federal managers will be provided a CD-ROM (some media now have 100-year archival quality) containing all pertinent field data and GIS coverages. This CD-ROM will be directly accessible through ArcView, a readily available GIS program and all other programs that accept ASCII-format databases.

HUNLEY-HOUSATONIC SURVEY BLOCKS AND SAMPLE INTERVALS

Hydrographic survey is conducted in area blocks through which the survey vessel travels along preplotted transects, or lanes, at investigator-defined intervals selected to ensure complete instrumental coverage of the study area. Lane spacing depends upon the survey questions and remote sensing instrument attributes. The *Hunley* survey was conducted with several preplotted blocks to maximize remote sensing coverage and to allow for changes in sea conditions, which can compromise data quality.

Coordinates for both *Hunley* and *Housatonic* remains were provided by the Naval Historical Center. The initial survey block was constructed in an east-west orientation with sides measuring 800 meters by 400 meters positioned to contain coordinates of both sites and associated features (Block CHHR001 — the CHHR is an acronym for Charleston Harbor). Standard SCRUM survey methodology for wide area survey requires 30-meter transects, which have been demonstrated to provide cost-effective magnetic coverage for discovering most submerged colonial-period shipwrecks (Murphy 1984:90–95). In this case, however, precise vessel locations were known; the purpose of magnetometry was to locate smaller, associated features. Ten-meter lane spacing was selected for the sample interval for the intrasite magnetic survey, which should be sufficient to locate small ferrous materials and

environmental features. In addition, a second block would be planned and surveyed with perpendicular lanes over the suspected *Hunley* target to increase survey coverage.

GPS provides a position every second, and all instrument data were collected at less than 2-second intervals and collated with the appropriate DGPS position. At a typical boat speed of 6 knots, a sample is collected about every 4–6 meters along the transect, giving more than 7,000 sample points in this survey block. The depth sounder and RoxAnn were run concurrently with the magnetometer.

Additional blocks (CHHR002–005) were constructed for various purposes. Block CHHR002 was constructed over the *Hunley* site to provide additional magnetic coverage at right angles to Block CHHR001 in order to halve the magnetic survey sample interval in the primary target area. Block CHHR003 was a 50-meter transect block to provide navigation for side-scan-sonar coverage of Block CHHR001. Fifty-meter transects provide 100% overlap for side-scan-sonar coverage. Block CHHR004 was a 100-meter-square block with 5-meter, east-west transects centered on the *Hunley* site to provide high-resolution sub-bottom profiler coverage. Block CHHR005 was the same block as CHHR004, but with north-south 5-meter lanes. Sub-bottom profiler data require a stable platform, so these two blocks were constructed to allow the surveyor to select an orientation that would minimize wave impact to the sub-bottom profiler record. Block CHHR005 was selected and used.

POSITIONING SYSTEM

Archeological hydrographic survey requires real-time positions with very rapid updates (1–2 seconds) for accurate vessel navigation to ensure complete, systematic coverage at the desired sample interval. GIS accuracy requirements are a 2–3-meter circle-of-error or less. Unlike terrestrial archeological survey and

mapping, hydrographic survey usually has no landmarks; simply, on the water, it is very difficult to occupy and then reoccupy the same point and to continually know where you are without real-time positioning.

Accuracy is usually expressed as parts-per-unit (e.g., 1:10,000); plottable accuracy, the accuracy that a point can be plotted, less important now because of GIS digital entry and zoom capability; or circle-of-error, which is an ellipse whose largest radius represents the root-mean-square error of a set of measurements, and whose orientation shows directional uncertainty. This ellipse, centered on the true position, is typically at the 95% statistical confidence level. The least-squares method is becoming standard for positional accuracy description in most applications.

Although several positioning systems are presently available, GPS offers several advantages over most others. GPS has become the state-of-the-art and will likely ultimately replace other systems for survey applications. The US Department of Defense (DOD) developed the GPS system for military purposes. This system uses trilateration of satellite-transmitted signals to determine position. GPS provides one-second updates with global coverage from 24 satellites, meaning four or more space vehicles are continuously in view anywhere on the globe. The satellites produce two signals, known as C/A code and P code frequency, the latter encrypted and available only to military or government users. The GPS is close to an ideal positioning system; it is accurate and continuously available on demand anywhere in the world under any weather conditions.

The GPS and GIS combination has provided a solution for accurate positioning and analysis for archeological purposes, particularly in hydrographic remote sensing. However, some

additions to the basic GPS system are necessary to achieve acceptable accuracy levels. Autonomous civilian GPS receivers produce circles-of-error of about 10–30 meters. Unfortunately, GPS instrumental accuracy is further reduced by “selective availability” (SA), which is intentional, random dithering of the C/A code GPS signals by DOD as a security measure that degrades the signal to a guaranteed accuracy of no more than 100 meters. However, real-time accuracy of 2–3 meters is possible by deploying a base station to compensate for SA through differential GPS (DGPS) correction. Ionospheric variables alter the satellite signal propagation times through the atmosphere and are an additional error source, which are also correctable with a differential base station. The base station, which is set up on a control point whose position is known to a very high accuracy, generates corrections for SA and transmits them via a radio modem datalink to the mobile survey instrument. Broadcast differential corrections are currently available in most coastal areas through US Coast Guard navigational beacons and commercial suppliers, which provide differential corrections at various accuracy levels. For example, the US Coast Guard navigation beacons are guaranteed to a 10-meter circle-of-error, although our tests indicate that accuracy levels are about 5 meters in most areas. SCRUI used its self-contained base station and radio datalink to generate differential corrections because of superior accuracy, which was required for the high-resolution *Hunley* survey.

Geodetic controls of centimeter-level accuracy can be obtained with GPS through static and kinematic survey techniques, which require occupation times as short as two minutes. (The most recent GPS developments include real-time kinematic techniques that provide sub-meter positions.) Geodetic survey

techniques were employed in the *Hunley* project to establish the differential base station position and are briefly discussed below.

SURVEY INSTRUMENTATION

SCRU's GPS-based Archeological Data Acquisition Platform (ADAP) survey system, designed and built by Sandia Research Corporation of Albuquerque, New Mexico, to SCRU specifications, was used during the remote sensing phase of the *Hunley* archeological assessment (Figure 6.1). The ADAP system automates and integrates field data collected with a variety of remote sensing instruments, and it accurately tags each data point with real-time differential GPS position and time references. Data points combining position, instrument reading and time data points were collected every 1½ seconds or less

for the predisturbance survey. Generating survey blocks, navigating the preplotted lanes, and collecting and post-processing data were done with Coastal Oceanographics' Hypack hydrographic survey software. The data were then easily incorporated into a PC-based GIS, in this case, ESRI's ArcView.

POSITIONING

Positioning accuracy was consistently within a 1–2 meter circle-of-error throughout the *Hunley* survey area. A Trimble Navigation, of Sunnyvale, California, Accutime II GPS receiver and radio datalink were used on board the survey boat for positioning survey navigation and data collection.

Differential corrections were provided by a self-contained, shore-based GPS base station, which incorporates a Trimble 4000SE geodetic



Figure 6.1. Archeologist Dave Conlin monitors ADAP instrument consoles on board SCRU survey boat. NPS photo by Tim Smith.

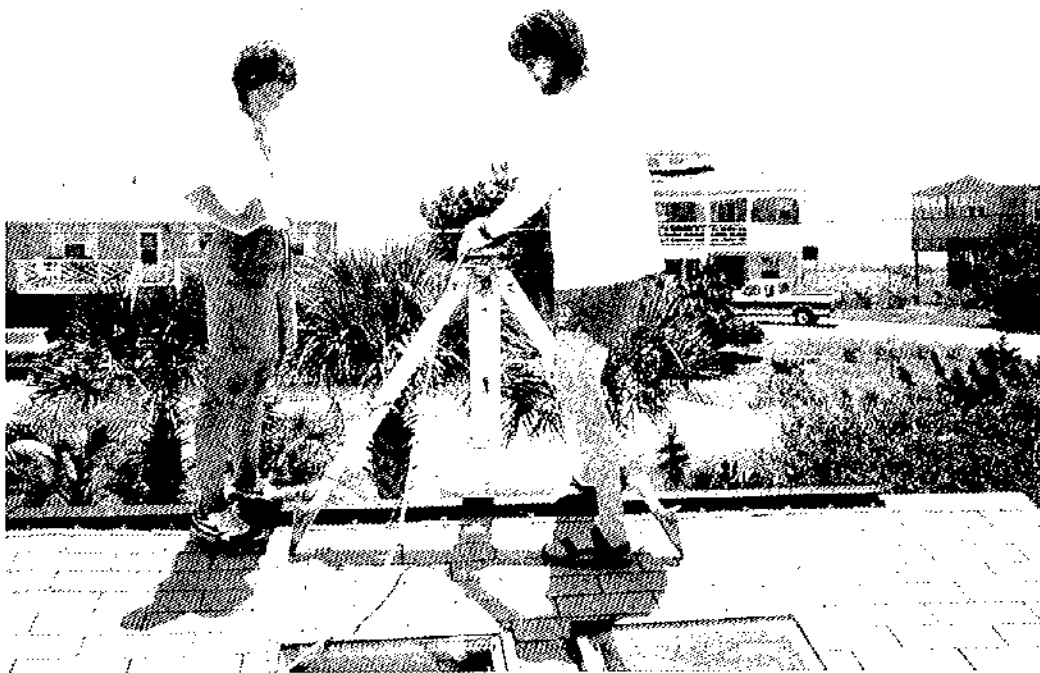


Figure 6.2. Geodesist Tim Smith and a volunteer setting up SCRUI's differential GPS base station in Folly Beach. NPS photo by Dave Conlin.

receiver and VHF radio datalink to generate and transmit a data stream of real-time RTCM-104 differential corrections (Figure 6.2) to the survey vessel. A static geodetic survey, using two Trimble 4000SE receivers, was conducted to establish control coordinates at a point on the roof of the project field headquarters at Folly Beach. The Folly Beach headquarters' roof provided a full, unobstructed view of the survey area. The base station control point was triangulated from two National Geodetic Survey (NGS) control monuments, called #2885 and #2878. Both are second-order horizontal monuments, and #2885 is also a first-order vertical monument.

MAGNETOMETRY

The principal cultural resource detection device used in the *Hunley* survey was a proton precession magnetometer. The magnetometer

has long been a standard archeological survey instrument (Arnold and Weddle 1978; Breiner 1973; Arnold and Clausen 1975; Shope 1997). A Geometrics of Sunnyvale, California, model G-876 proton-precession magnetometer was used during the survey as part of SCRUI's ADAP system (Figure 6.3). The magnetometer detects and quantifies magnetic fields. In hydrographic survey, ferrous or magnetic objects can be located by noting small perturbations or anomalies in the earth's ambient magnetic field. Ferrous objects cause a localized increase or decrease, usually both, in the ambient magnetic field. Objects in this context are typically of cultural origin associated with maritime casualty or depositional sites. The magnetometer output reading is the total magnetic field intensity and independent of sensor coil orientation, consequently, it makes an ideal detection device for submerged cultural resources.



Figure 6.3. SCRU survey equipment on the aft deck of the SCRU survey vessel. Geometrics G-876 magnetometer on left, Marine Sonic Technology side scan sonar on right. Diesel AC generator on left, and a spare under plastic on right. NPS photo by Tim Smith.

Typical proton-precession magnetometer resolution is 1 gamma, and in special cases 0.1 gamma, in the earth's field of approximately 50,000 gammas (nanoteslas). Magnetic readings simply indicate the presence and probable mass of an object. There is no unique relationship between anomaly intensity and isogamma contour configuration and an object; any number of combinations of objects can produce similar anomalies. The only way to determine anomaly sources is by visual investigation (Murphy and Saltus 1990).

The magnetometer is a valuable cultural resource detection instrument, and it is sensitive to many different types of artifacts associated with submerged shipwrecks. Ferrous ship components are prime targets. In a survey mode, shipwrecks are often difficult to detect by visual inspection or sonar-based instruments

because marine life encrustation and sediment coverings can easily obscure a site. The magnetometer sensor is towed behind the survey vessel about 20–40 meters to eliminate influence from the survey vessel's magnetic field.

The G-876 instrument generates a sensor depth and height-over-bottom (sensor altitude) and displays these data during the survey. Sensor height is important for consistent and reproducible magnetic data collection and accurate interpretation.

Another feature of the G-876 important for high-resolution survey such as that required by the *Hunley* survey is that the computer processing instrument package is towed underwater 10 meters ahead of the magnetometer sensor. This instrument, which was designed for deep water survey, produces

a remarkably low noise level because only processed data and power are transmitted over the tow cable. Proton magnetometers of traditional design have the computer on the surface and transmit the raw signal from the sensor to the surface, which creates a much higher noise level because the cable acts like an efficient antenna for extraneous noise-producing electrical energy. Noise is an issue because the gamma reading of a particular ferrous mass, which is proportional to the size of the mass, declines as a cube of the distance between the sensor and the mass. Noise in high-resolution magnetometer survey masks smaller anomalies that might be of archeological interest.

The industry standard (for example, Department of Interior, Minerals Management Service Guidelines for Offshore Lease Block Surveys) specifies a noise level of ± 3 gammas or less. The G-876 typically produces less than 1 gamma of noise, which allows smaller anomalies to be observed. Reliable isogamma contouring for traditional magnetometer data display is rarely done on fewer than 5-gamma contours; the G-876 allows reliable contouring on 2 gammas. The G-876 permits discrimination and recognition of anomalies that are within the noise levels of most other proton magnetometers, consequently very small anomalies may be recognized. Because the *Hunley* survey was attempting to locate undiscovered materials potentially associated with the *Hunley-Housatonic* engagement, discrimination of the smallest possible magnetic anomalies was desirable, and the survey was designed and conducted to maximize low-level magnetic anomaly returns.

SEABED CLASSIFICATION AND BATHYMETRY

The RoxAnn Groundmaster bottom classification device, manufactured by Marine Micro Systems of Aberdeen, Scotland, was used

to characterize surficial sediments in the *Hunley* predisturbance survey area. The RoxAnn device discriminates between seabed material types, such as sand, mud, rock, grass, etc. and outputs the data acquired in a quantitative format ready for computer analysis and incorporation into GIS. This instrument uses the first and second echoes of each single-beam depth sounder transmission and derives two values related to the bottom's hardness and roughness: E1 and E2. Every seabed material has a unique signature that can be represented as a range of hardness and roughness values. These values must be grouped, classified and assigned a color attribute for each data point. Accurate classification requires using type sites that represent categories determined by on-site identification. Details of RoxAnn operation have been reported elsewhere (Murphy et al. 1995).

Bathymetry information was collected using a Furuno Model LS-6000 LCD Video Sounder, which is integrated into the RoxAnn Groundmaster bottom classification device. Sounding area and, consequently, bottom sample area for RoxAnn sea bed classification, is a function of transducer beam width, which is generally a function of frequency. Usually, the higher the frequency, the narrower the beam width. Most depth sounders use a frequency of about 50 kilohertz, which has a beam width of approximately 46° and samples a circular area with a 42-meter diameter in a depth of 50 meters. The Furuno depth sounder uses a 200-kilohertz transducer, which provides a high-resolution sample area and reduces bubble noise. The 200-kilohertz beam-width is about 10° , which provides coverage of about 17 percent of the water depth. The area covered in 50 meters water depth is a circle with a diameter of 9 meters, or an area of 64 square meters. In shallower depths, the sample area is reduced accordingly. The RoxAnn reading is basically an average of the area within the depth sounder transducer sample area.

The Furuno video depth sounder supplies the signal source for RoxAnn. The RoxAnn produces a digital depth from the sounder signal that is collated with position and collected as part of the survey data set at each 1.2–2-second sample interval.

SIDE SCAN SONAR

In addition to the magnetometer, the side scan sonar is the principal remote sensing instrument used in submerged archeological survey. Side scan sonar uses sound waves to image the sea floor and objects laying on it or protruding above it. Normally a towed system, a side scan sonar transmits a microsecond-pulsed, vertically narrow acoustic beam to each side of the tow vessel's path at multiple times per second. The beam propagates through the water and across the sea floor, reflecting incident sound energy back to the sonar sensor. A sonar data processor converts the reflections' intensity and time delays to a visual image for display. The end result is an image of the sea floor of near photographic quality showing areas of dark (strong reflection) and light (areas of lower reflectivity or shadow areas).

For the *Hunley* survey, a Marine Sonic Technology, of Gloucester, Virginia, Sea Scan PC Side Scan Sonar was used. The Sea Scan PC is a digital, high-resolution side scan sonar system that uses a Windows-based personal computer (PC) for all control, display, analysis and storage functions. The reflected signal converted to digital information which is preferred because it allows images to be filtered and enhanced for improved analysis, and it can be processed into mosaics and incorporated into GIS as an image layer, much like aerial photography. The digital format facilitates archival data storage because it is directly transferable to CD-ROM medium.

The Sea Scan PC includes an integrated navigational plotter, using standard DGPS input, that allows all parts of the acoustic image

to be automatically correlated with correct geographic position. During the *Hunley* survey a 600-kilohertz towfish was used for maximum bottom feature resolution. Like the depth sounder, the higher the frequency of the sonar signal, the higher its resolution. This instrument was selected for the *Hunley* survey because prior deployment by SCRU proved it was a robust, easily deployed instrument that produces very high resolution images in a digital format amenable to GIS applications. The Sea Scan meets or exceeds resolution of side scan sonar systems costing many times more than this instrument.

SUB-BOTTOM PROFILER

A sub-bottom profiler uses a low frequency FM pulse to distinguish and image sediment layers beneath the sea floor. Multiple returns measure various layer interfaces, with different densities, to build an overall image of sub-bottom sediment layers. A sub-bottom profiler is typically used in geophysical, engineering and environmental surveys. Although not usually used as a tool of discovery during archeological surveys, sub-bottom profilers can detect man-made objects. More often, however, sub-bottom profilers are used by archeologists to characterize the sediment matrix surrounding a site.

The FM "chirp" sub-bottom profiler is a recent refinement that particularly meets archeological requirements. This instrument was particularly desirable for the *Hunley* survey because the National Underwater and Marine Agency (NUMA) survey team had experienced poor bottom penetration of the hard-packed Charleston Harbor sediments with the more common 3.5-kilohertz sub-bottom profiler (Hall and Wilbanks 1995:7). The chirp system transmits a computer-generated digital wide-band swept FM pulse that allows quantitative evaluation and classification of bottom sediments. The signal, with adjustable pulse

lengths, sweeps over the range between 200 hertz and 30 kilohertz, depending on transducer configuration. The chirp sonar produces essentially noise-free images to a depth of about 100 meters. Chirp's wide bandwidth solves some of the problems inherent in single-frequency sub-bottom profilers. Archeologists are often interested in only the top few meters of bottom sediments, and this is the area that is commonly compromised in single-frequency units. Poor vertical resolution is created by source ringing that creates multiple images at the sediment-water interface and limits vertical resolution of buried facies to between 2 and 3.75 meters for single-frequency devices. The higher resolution chirp instrument was desirable for discriminating stratigraphy and buried features in the *Hunley* survey. An X-STAR full spectrum digital sub-bottom profiler, manufactured by EdgeTech of Milford, Massachusetts, was deployed during the *Hunley* predisturbance survey. The X-STAR transmits an FM pulse that is linearly swept over a full spectrum frequency range, and generates cross-sectional images of the seabed with a resolution of 6 centimeters or better.

HARDWARE

Austin 486DX2/66 PC laptops were used for field data collection and manipulation and a Dell 486DX50 PC workstation for office data manipulation and generation of GIS coverage. An Austin Pentium 120 PC was used for image processing of aerial and satellite data. Trimble Navigation's Accutime II was used for positioning during survey operations; Trimble 4000SE Geodetic receiver for geodetic control work and base station operation; Trimble Pathfinder Basic Plus for diving and site reoccupation operations.

SOFTWARE

SCRU selected several off-the-shelf, PC-based software for cultural resource hydrographic survey operations: AutoCAD by Autodesk (Sausalito, CA); QuickSurf by Schrieber Instruments (Denver, CO.); Erdas Imagine for Windows NT by Erdas (Atlanta, GA); Hypack, hydrographic data collection software by Coastal Oceanographics, Inc. (Durham, CT); and ArcView, a geographical information system by ESRI, Inc. (Redlands, CA). All are PC-based and provided quick and easy access to field data processing and manipulation in a MS-DOS/Windows environment. ArcView provides access to existing data in Arc/Info and AutoCAD formats, two of the most widely utilized GIS and CAD systems. We can supply data in a native format to Arc/Info and other formats, which allows data sharing with many sources.

SURVEY METHODOLOGY

Initial survey preparation took place in SCRUI headquarters, Santa Fe, New Mexico, with assembling background data. Aerial images, current and historical charts and maps were procured and prepared for inclusion into an ArcView GIS database project. Digitized charts of the general survey area were used to create survey blocks and provided a computer screen background to aid survey operations and navigation to and from the site during survey operations. Survey blocks were constructed in desired areas, and computer software was used to generate survey lanes with beginning and ending x-y coordinates at appropriate transect intervals to accommodate the various remote sensing instruments and survey block dimensions. Magnetometer collection lanes

were preplotted at 10-meter intervals, side scan sonar at 50-meter intervals and sub-bottom intrasite lanes at 5-meter intervals. In some cases, multiple blocks were constructed with perpendicular lanes to decrease sample intervals or adjust for variable sea conditions. Hydrographic instruments generally increase in noise output with rough sea conditions, which can sometimes be ameliorated by plotting transects parallel to prevailing waves.

General methodology includes survey with a variable suite of remote sensing instruments with all survey operations DGPS positioned, with corrections provided by the SCRUB base station to maintain a 2-3 meter circle-of-error.

Bathymetry and surficial bottom classification was conducted to characterize the seabed in the general area surrounding the site. These data were collected to determine whether *Hunley* was located in an anomalous area regarding water depth and bottom type. Side scan sonar was used to determine if any material was present above the sea floor before investigations began. Tightly spaced sub-bottom profiler runs over the *Hunley* site could potentially determine hull integrity and locate stratigraphic anomalies representing scour areas and associated features, which would inform excavation planning. Scour area demarcation would influence test excavation procedure; scour areas would have to be carefully excavated because of high potential for presence of battle-associated materials. Analysis of sub-bottom profiler data collected at a wider transect spacing could provide a general sediment matrix characterization over the entire survey block.

High-resolution magnetic survey and in-water survey with hand-held magnetometer and metal detectors were directed toward locating ferrous material possibly related to the *Hunley-Housatonic* engagement or post depositional displacement.

Survey data were post processed and immediately incorporated into a PC-based GIS project that contained all related data. This

cumulative data set was used to plan the test excavation phase and should provide a baseline for future site examination. For instance, if another magnetometer survey is completed over the site should *Hunley* be recovered, those data can be included as another layer in the GIS database for comparability to the predisturbance survey.

SURVEY OPERATIONS

Constant DGPS positioning was employed in all survey operations with an overall accuracy of a 2-meter circle-of-error throughout the survey area. Preplotted survey lanes were followed using navigation information provided by the DGPS and displayed in Hypack. A computer monitor mounted near the helm provided the boat pilot with current position as well as navigation information such as cross-track error, speed, course, distance to end-of-line and bearing to end-of-line (Figure 6.4). In addition to tabular information, a graphical display showed real-time boat position and movement and survey lanes superimposed over a geo-referenced, digitized chart of the area.

Data were stored to the hard drive of an onboard computer as soon as collected. Data collection was continuous; no buoys were used to mark anomalies. Data were backed-up nightly via modem to a computer at the SCRUB office in Santa Fe and processed in the field.

MAGNETOMETRY, BATHYMETRY AND SEABED CLASSIFICATION

Survey operations began on May 2, 1996. The SCRUB survey vessel, equipped with the ADAP system including magnetometer, depth sounder, and RoxAnn bottom classification device, moved offshore to the survey area and began collecting data (Figure 6.5). The survey block (CHIR001) contained forty 800-meter-long lanes 10 meters apart, oriented east-west (Figure 6.6). The survey block was created so

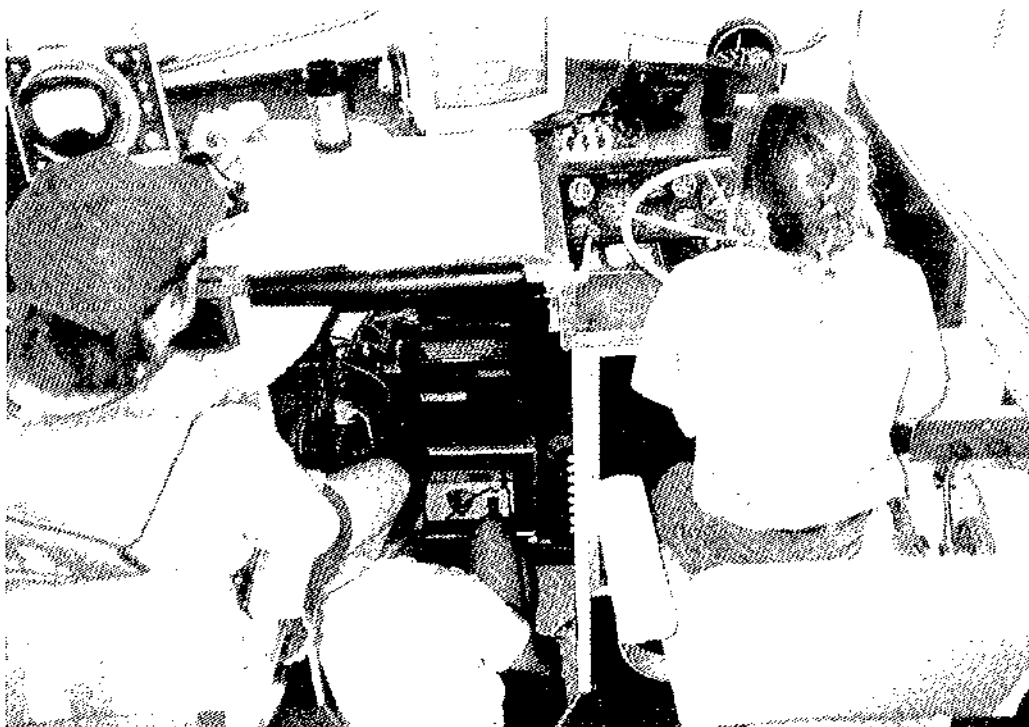


Figure 6.4. Operations aboard SCRU survey boat. Archeologist Matt Russell, left, Captain Diane Richardson, right, Archeologist Dave Conlin, below. NPS photo by Tim Smith.

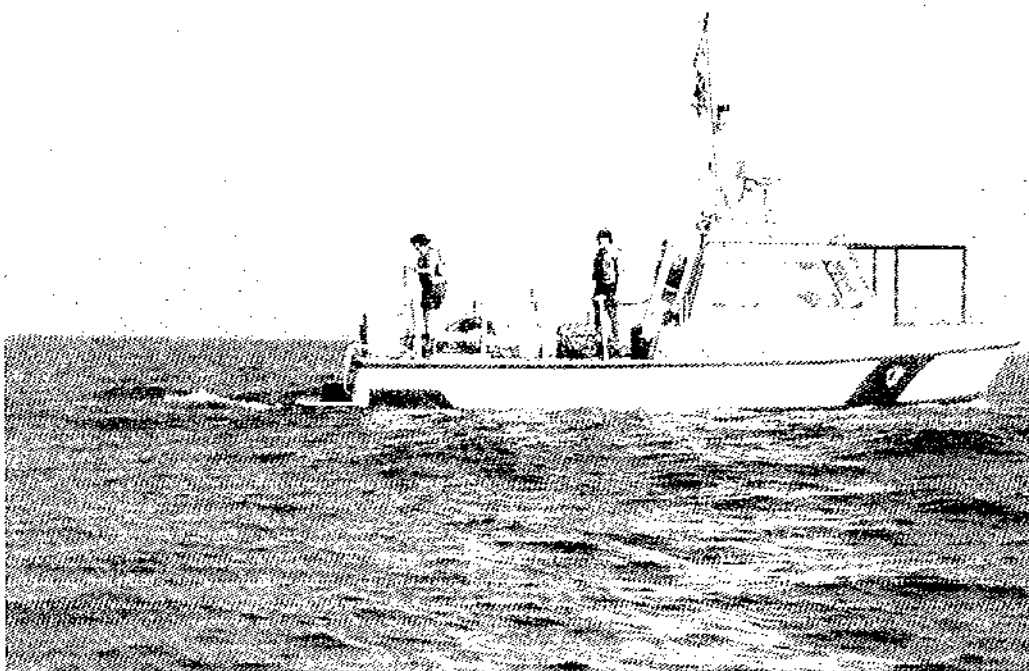


Figure 6.5. SCRU survey boat during *Hunley* Survey. NPS photo by Dave Conlin.

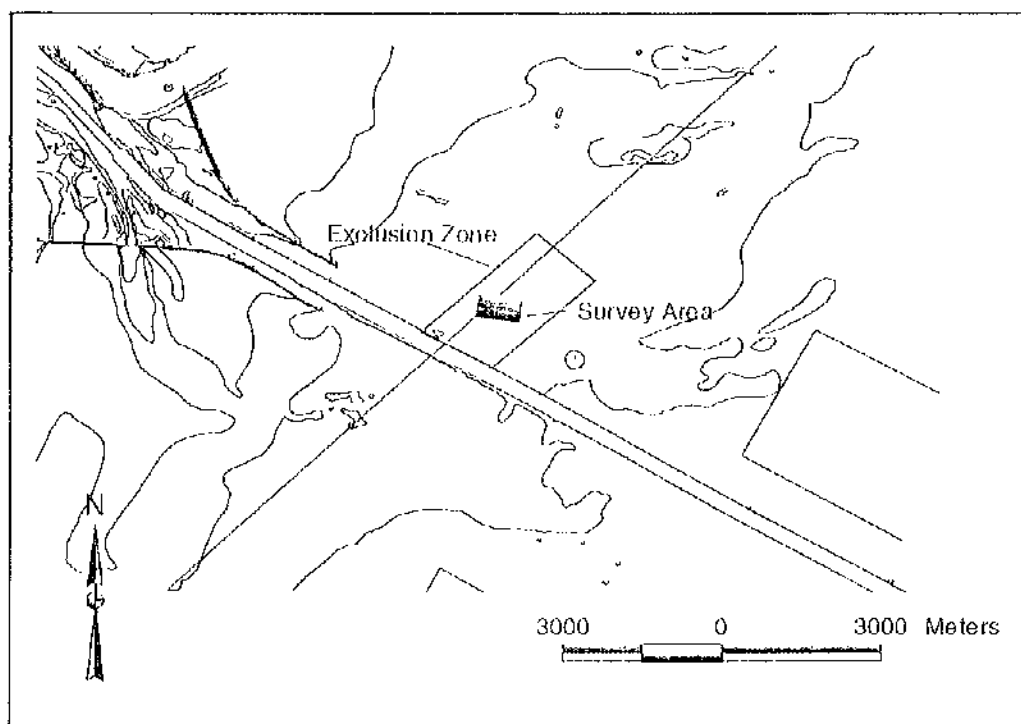


Figure 6.6. The *H.L. Hunley* predisturbance survey area.

that the central lane, lane 20, bisected the two sets of coordinates provided for *Hunley* and *Housatonic*.

The magnetometer was towed at a constant height of 5.0 to 5.5 meters over the bottom. This was facilitated by the nearly constant depth throughout the survey area. Large anomalies were observed near the reported positions of *Hunley* and *Housatonic*, as well as a number of smaller anomalies throughout the block. All 40 lanes were completed. In addition to CHHR001, a second block, CHHR002, was constructed containing seven 10-meter lanes, oriented north-south centered directly over the *Hunley* site coordinates. This block, also completed May 2, was surveyed to provide additional data points that effectively reduced the sample interval in the primary target area (Figure 6.7). On the evening of May 2, the data were processed and contour maps of the magnetic data, bathymetry, and coverage maps of the RoxAnn data generated.

SIDE SCAN SONAR SURVEY

A corporate-partnership with Marine Sonic Technology of Gloucester, Virginia, allowed use of a side scan sonar and operator for predisturbance imaging of the project area. On May 4, 1996, Marty and Pete Wilcox of Marine Sonic Technology installed their instruments on the SCRUI survey vessel, which then moved offshore to the primary *Hunley* target area and tested the instrument. A buoy was dropped on the site coordinates to indicate the site so the instrument operator could pay particular attention in the immediate site area, and the boat pilot could use it as a guide to make some initial passes over the site. Although the buoy line, weight, and PVC pipe placed earlier in the week by Ralph Wilbanks of NUMA to locate the site were clearly visible on the side scan image (sonograph), nothing else was observed, which indicated no part of the submarine was visible before excavation.

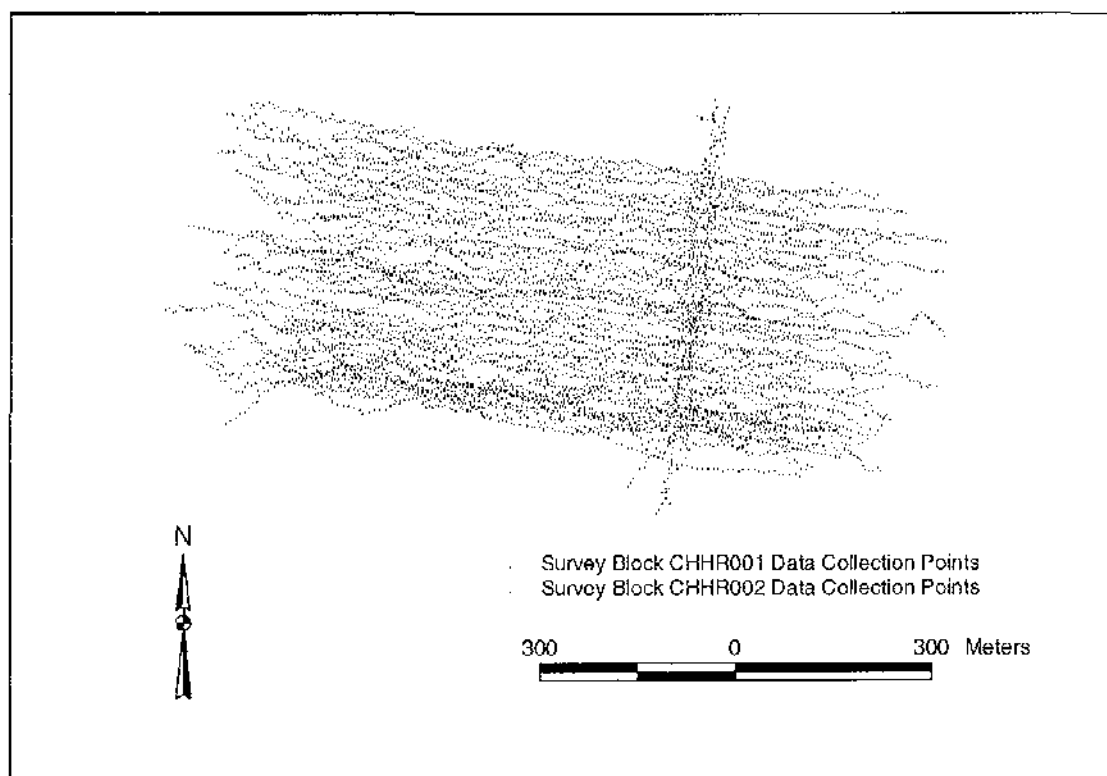


Figure 6.7. Data sample points collected during the *H.L. Hunley* predisturbance magnetometer survey.

Next, the survey block designated CHHR003, which contained fourteen 50-meter lanes oriented north-south over the area of CHHR001 was completed, which gave complete coverage of the original survey area. In general, the sea floor of the survey area appeared virtually featureless except for some possible material above the bottom in the vicinity of the *Housatonic* site.

SUB-BOTTOM PROFILER SURVEY

Another corporate-partnership, this with EdgeTech of Milford, Massachusetts, provided use of a digital sub-bottom profiler and operator Darren Moss to characterize the sediment matrix of the survey area. Two 100-meter-square

survey blocks were constructed over the *Hunley* coordinates with 5-meter lane spacing, CHHR004 oriented east-west, and CHHR005 oriented north-south. On May 5, we deployed the instrument over the *Hunley* site and selected CHHR005 to survey because of prevailing wave conditions. On one pass, a hard return from the sub-bottom profiler indicated that we had passed directly over the hull, but it is not clear at what angle.

After completion of the high-resolution intrasite survey Block CHHR005, we ran CHHR003, the 50-meter side-scan sonar block with the sub-bottom profiler to develop a general characterization of the sub-surface sediment interfaces in the survey area.

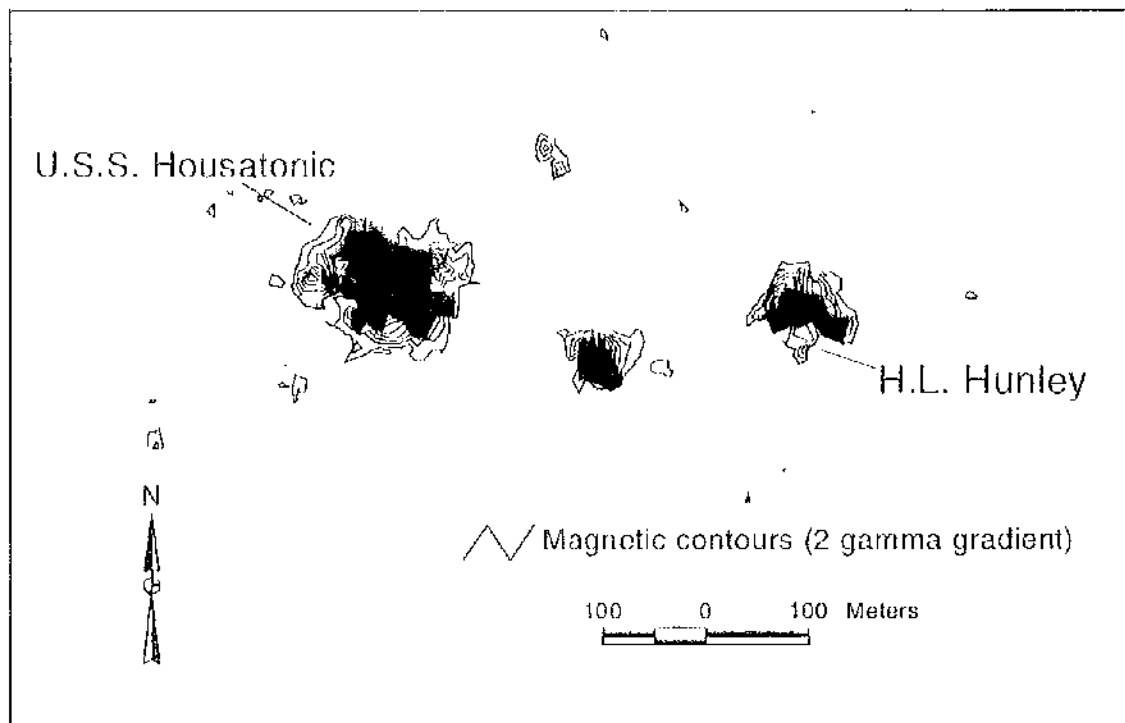


Figure 6.8. Two gamma magnetometer contours, with anomalies representing USS *Housatonic*, *H.L. Hunley* and several unidentified anomalies.

ANALYSIS AND RESULTS

MAGNETOMETRY

The magnetometer data were contoured on 2-gamma interval isogammas using the gradient method. This method, developed by the authors, allows correction for diurnal changes and facilitates incorporation of magnetic data into GIS. Magnetometer survey results indicate three main concentrations of ferrous material within the survey area, and several smaller (less than 10 gamma) anomalies (Figure 6.8). One of the main anomalies is identified as *Hunley*, a second as the *Housatonic* wreck scatter, while the third ferrous concentration, located between the other two, remains unidentified, as do the smaller anomalies.

BATHYMETRY

Bathymetric data indicates a relatively uniform bottom depth throughout the survey area. Depth ranges from 7 meters to 8 meters (Figure 6.9). There are no anomalous seabed features associated with either component.

SEABED CLASSIFICATION

RoxAnn Surficial Seabed Sediment Classification indicates a relatively uniform bottom type of sand/mud throughout the survey area (Figure 6.10). Surficial sediment training sites to coordinate data with specific bottom type was not conducted. RoxAnn data indicates high uniformity in the study area with no anomalous sediment concentrations in proximity to either site component.

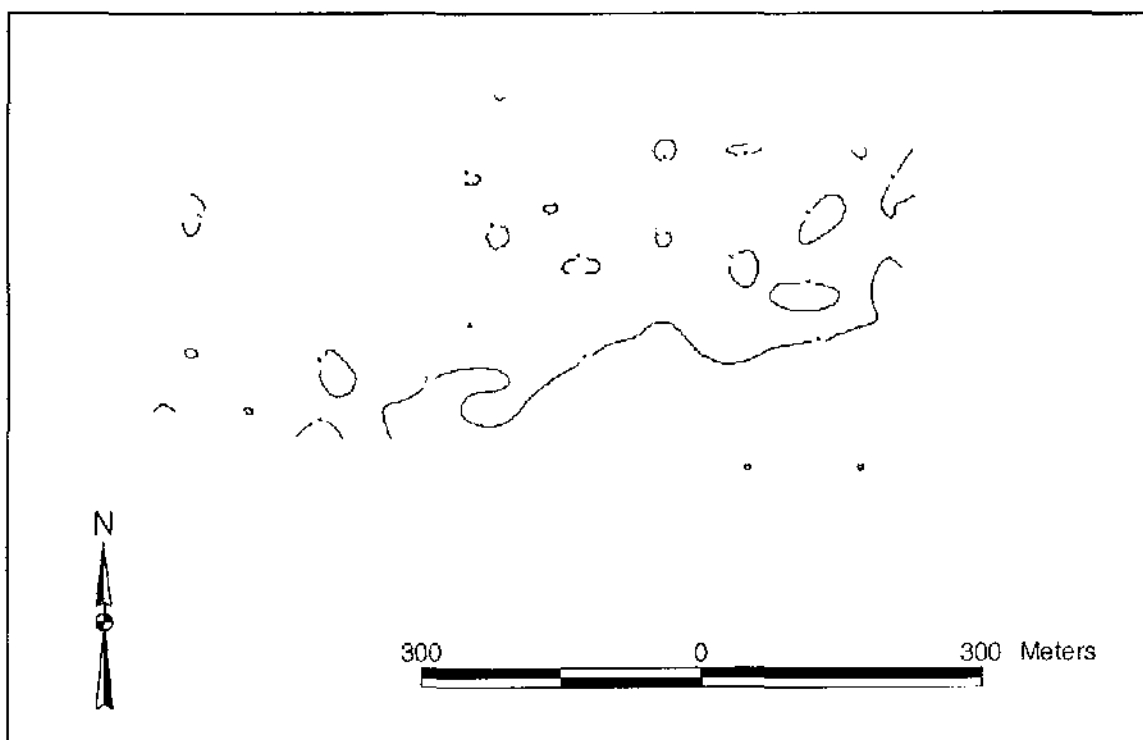


Figure 6.9. One meter bathymetric contours, showing a depth range between 7 and 8 meters throughout the survey area.

SIDE SCAN SONAR

Side scan sonar indicates that no part of *Hunley* was visible above the sea floor before excavation began. Complete side-scan coverage of the survey block did, however, indicate that small portions of the presumed *Housatonic* scatter may be exposed. Side scan sonar data will be provided to the appropriate managers on a CD-ROM.

SUB-BOTTOM PROFILER

Data from the sub-bottom profiler was inconclusive. Observation of data returns during survey operations indicated one possible hard-return that may have been *Hunley*'s hull. Complete analysis of the sub-bottom profiler data, including development of comprehensive

sub-bottom characterization of the entire survey area, was to be supplied by the manufacturer.

CONCLUSIONS

The predisturbance remote sensing survey of the *Hunley-Housatonic* site revealed important information about the study area's cultural and natural environment. Magnetometry indicates, with the exception of several discrete anomalies, a magnetically quiet area. The most intriguing anomaly is the large mass between the larger magnetic anomalies identified as USS *Housatonic* and *U.S.S. Hunley*. Before or during recovery operations, should they be undertaken, this anomaly and the 6-gamma dipolar (contains both positive and negative magnetic readings relative to the ambient field) anomaly north of it should be

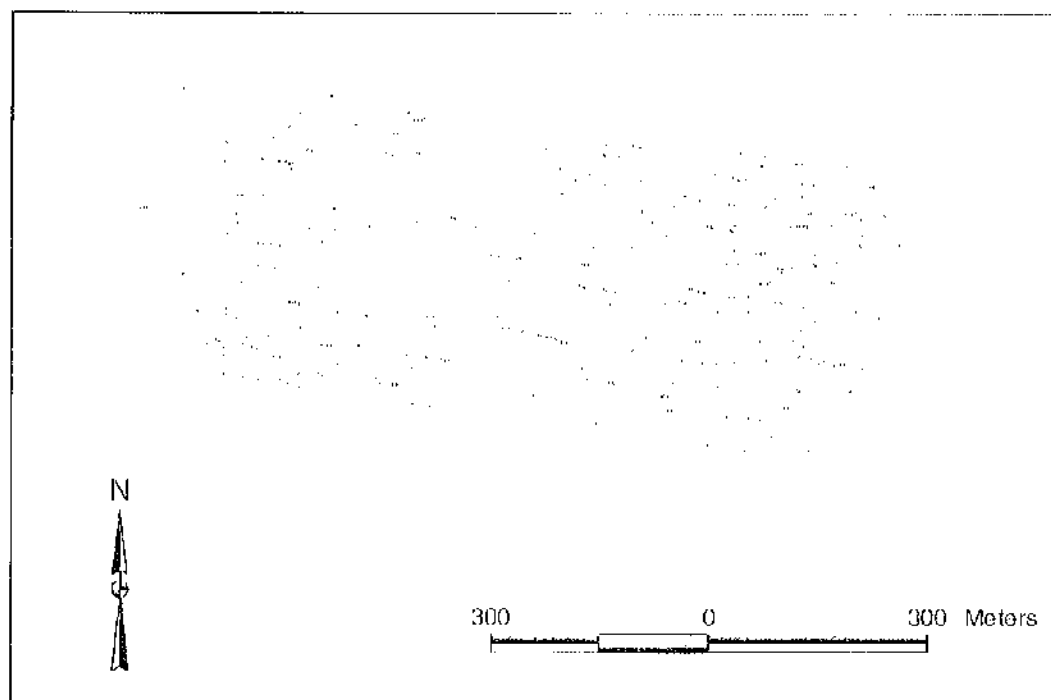


Figure 6.10. Raw RoxAnn data showing different bottom types. These data reflect surficial sediment homogeneity.

ground truthed. Bathymetric, bottom classification, and side-scan sonar data indicate the *Hunley-Housatonic* site is in a relatively flat, homogenous, and featureless benthic region. No mounding was observed over *Hunley*'s remains; it lay completely buried under a featureless, flat bottom.

Upon completion of this report, a CD-ROM will be provided to the Naval Historical Center and the South Carolina Institute of Anthropology and Archaeology with complete raw and processed survey data, as well as the complete *Hunley* Assessment GIS project.

CHAPTER 7

Field Operations

Matthew A. Russell and Larry E. Murphy

At the predisturbance remote sensing survey's conclusion, the *H.L. Hunley* assessment project shifted into an intensive diving and archeological documentation operation. Prior diving on site had been preparatory to the assessment's documentation phase. The first dives were made in an attempt to install large screw-type sediment anchors to moor the principal dive vessel, South Carolina Department of Natural Resources research vessel R/V *Anita*, a 52-foot long stern trawler, over the site. Sediment anchors would have eliminated the possibility of dragging a vessel mooring anchor through the *Hunley* site. After installing the first sediment anchor, this plan was abandoned because of the time and difficulty of jetting the anchors into the bottom. Instead, we established a three-point anchor moor each day with cables long enough to minimize any anchor dragging threat. Initial and periodic visual checks of the mooring anchors by divers further reduced any dragging threat by ensuring anchors were well set throughout the daily activities. In retrospect,

sediment anchors would have reduced vessel mooring flexibility necessary because of the variable and often adverse offshore conditions encountered during the diving investigation.

Ralph Wilbanks, leader of the National Underwater and Marine Agency (NUMA) team that discovered the site in 1995, made the first dive on site for the 1996 assessment project. The National Park Service's Submerged Cultural Resources Unit (NPS-SCRU) requested that Wilbanks and his team relocate the site and place a PVC pipe near their test excavation to precisely locate the target he and his team had investigated and reported to the Naval Historical Center (NHC). Wilbanks requested and received clearance from the NHC for a single site visit, and placed this orientation pipe as requested before the start of the current assessment project's in-water operations. Wilbanks' pipe was used as a subsurface location device, and it was observed on side scan sonar. This procedure eliminated any possibility of target confusion should the project's results have been negative.

Several dives took place on May 3–5. The first dives were made on Global Positioning System (GPS) coordinates selected from the SCRUI magnetometer data collected May 2 using the accumulating *Hunley* Project Geographic Information System (GIS) database. These coordinates were about 42 meters from the coordinates provided by the NUMA team. On May 5, the anniversary of NUMA's original discovery, Wilbanks met with project leaders to discuss project operations and determine the cause of the variance between coordinates. The variance resulted from a shift of coordinates between geodetic datums. NUMA, following US Army Corps of Engineers practice, had used South Carolina State Plane coordinates for their survey, which are in North American Datum 1927. SCRUI uses World Geodetic System 1984 (WGS 84) coordinates, generally standard for most GPS applications. NUMA's coordinates were converted to WGS 84 and found to be congruent with SCRUI coordinates obtained from GIS

analysis of the recently collected predisturbance survey data. Although extremely adverse diving conditions on the first day caused the divers to miss the PVC pipe, the coordinates selected from the survey were ultimately found to be approximately one meter from Wilbanks' pipe. May 7 was a down-day due to weather, though two aborted dives were attempted on site.

GENERAL DIVING OPERATIONS

Diving operations started on May 8 and continued through completion of site backfilling on June 4 (Figure 7.1). Several days during this time were down-days due to weather, including May 11–15 and May 28. A total of 19 days were spent in dive operations including excavation, documentation and backfilling the site. In all, 302 dives totaling 225.16 hours were made during the 1996 assessment project. The project dive summary is reproduced as Appendix A.

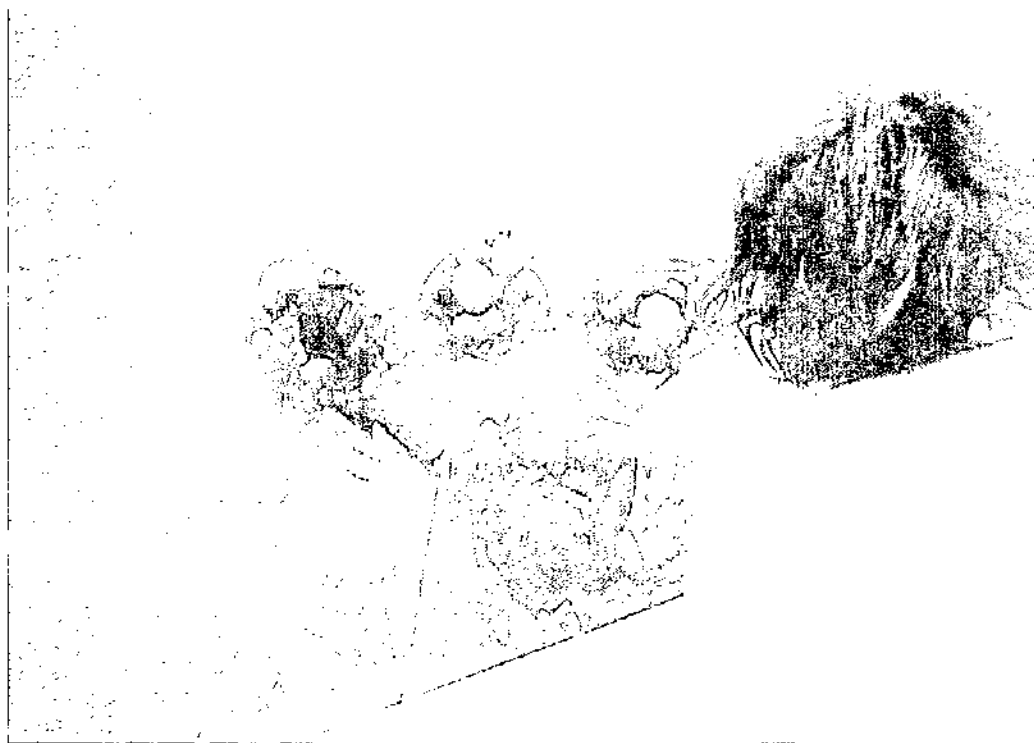


Figure 7.1. Divers preparing for work on site. NPS photo by John Brooks.

The first task was to use water dredges to establish contact with the target. The objective was to first expose what had been previously uncovered during NUMA's 1995 test excavation. The next step would be to systematically excavate along the hull to expose sufficient remains to meet project objectives confirming the remains as *H.L. Hunley* and evaluating its current status. A yellow, 1/4-inch polypropylene line was established down the site's centerline to provide orientation during diving operations. Before placing this orientation line, a series of metal detector and hand-held cesium magnetometer surveys established the hull ends. The line was secured between two PVC pipes driven into the seabed a meter beyond any indication of buried metal.

After the initial site location was established, SCRUI's DGPS equipment was used each day to reoccupy the site. A dive team was dispatched in South Carolina Institute of Archaeology and Anthropology's (SCIAA's) 25-foot dive boat, *C-Hawk*, to relocate the site and prepare the site for the day's work before arrival of R/V *Anita*, which served as the primary dive vessel. The daily procedure was for divers aboard *C-Hawk* to proceed to the site coordinates using DGPS and drop two buoys with padded weights on the site location. Padded weights were used to prevent damage to the iron hull after it was exposed. Two divers then made a circle search until the yellow polypropylene orientation line, which stretched from *Hunley*'s bow to stern along the centerline, was located. The two buoys were then moved to each end of the orientation line. These two buoys served as a guide for aligning *Anita*'s stern directly over the site's center. A downline from *Anita*'s stern using a 30-pound mud anchor was rigged at one end of the site. A second line was rigged on the surface from the downline to the dive ladder on *Anita*'s port side to allow divers to pull themselves against the current to the ladder. This procedure minimized potential

for site intrusion and discovery by potential vandals because no buoys were left on site.

Each day *Anita* was secured over the site in a three-point moor. *Anita*'s bow line was set with an approximate 10:1 scope when the stern was positioned over the site. After setting the bow anchor, and with the stern over the site, two stern anchors were taken out in a small inflatable boat and dropped in the proper locations for safe mooring. Divers were periodically dispatched down each mooring line to verify the anchors were secure. The anchors were situated to minimize potential site damage from an anchor dragging into the study area. At the end of each diving day, the stern anchor lines were buoyed and released to be retrieved by *Anita* after recovering its bow moor.

Daily excavation operations utilized water dredges mounted in *C-Hawk*, which was rafted along side or secured astern of *Anita*. A 6-inch and two 4-inch dredges were used. All excavation was conducted by SCRUI, SCIAA, or NIIC archeologists. To the extent allowed by limited visibility, sediment was examined while being hand-fanned into the dredge. Each diver was debriefed immediately upon exiting the water to provide a cumulative record of site observations and excavation progress. A chalkboard was used aboard *Anita* to track the excavation and for diver briefings before and after each dive (Figure 7.2). Archeologists were instructed to continually monitor the exposed hull for any signs of impact resulting from sediment removal, in particular buckling, encrustation cracking, bubbles emanating from the encrustation, or presence of loose or detached hull material. No impact attributable to site testing was observed during the project.

In general, diving conditions on the *Hunley* site were adverse and difficult. Visibility normally ranged from 0 to 1–2 feet, which made excavating slow and often frustrating. Strong tidal currents also made diving difficult, except during brief windows of slack tide. Once



Figure 7.2. Larry Murphy briefs divers before entering the water. Clockwise from right: Jim Spirek, Dave Conlin, Matt Russell, Joe Beatty, Rich Wills and Bob Neyland. NPS photo by John Brooks.

excavation had proceeded below the seabed, however, divers were shielded to some degree from the currents ripping overhead. In addition to near-zero visibility and strong currents, divers also had to contend with a thick slurry of stinging jellyfish that were continually on site. Most divers wore ice-diving masks, which reduced exposed skin on the face to only the diver's lips. Even so, from time to time jellyfish tentacles would wrap around a diver's regulator and severely sting their lips.

Once the hull was exposed, archeological documentation began. Site documentation consisted of direct measurements, video and photography. Video and photography were difficult because of extremely low visibility. Occasionally, on an incoming tide, a brief clear-water window occurred. In these cases, normal field operations were immediately interrupted to conduct video and photography. In addition, 1200-watt HMI underwater movie lights were

used to enhance video recording. A total of 133 minutes of underwater video was recorded during the project.

Hull mapping, using direct measurements, followed standard archeological procedures. A drawing was completed during field operations to be used as the basis for positioning field corrosion measurements (Figure 7.3). Plan, elevation and profile drawings of exposed portions of *Hunley* were completed in the field.

To aid recording, a device was designed and built from PVC pipe to obtain detailed hull profile measurements. A right angle was constructed that allowed accurately positioned hull perpendiculars to be measured along the hull side. The device was affixed to a small line tightly strung between the snorkel box and aft hatch along the hull centerline. The profile was taken just forward of the aft hatch from the centerline to the keel (see Figure 8.2).

EXCAVATION STRATEGY

The principal excavation objectives were to: 1) verify the reported site as *H.L. Hunley*; 2) determine the site's present condition; 3) evaluate the present vessel state for potential recovery. Site verification was based on congruence of principal features encountered of historical descriptions. Definitive verification depended upon location of particular features unique to *H.L. Hunley*, which included: forward hatch, aft hatch, snorkel box, dive plane, cutwater, screw, rudder features, keel ballast and bow spar or fittings. Verification would be established if five or more of the attributes were located.

General strategy was to uncover NUMA's original area of investigation first to gain experience with excavation in the site's particular sediments and conditions and to refine

excavation methodology before removing previously undisturbed sediments. Investigators wanted to ensure that maximum information would be recovered. After opening the first excavation unit in the forward-hatch and snorkel-box area, a second excavation unit would be opened toward the vessel's stern to locate the aft hatch. The two excavation units would work towards each other and join in the middle.

To locate the first two excavation units, the vessel extremities were established with systematic metal detector examination, and the location for the initial excavation units moved 2–3 meters in from each end of the hull, as indicated by metal detector contact. The excavation concentrated on the center hull area and avoided the stern and bow areas. The stern area was believed to be fragile because of a small piece of graphitized iron located in the



Figure 7.3. From left to right: Chris Amer, Rich Wills, Larry Murphy and Lynn Harris use *Hunley* field drawing to discuss hull corrosion measurements. NPS photo by John Brooks.

aft excavation unit, possibly indicating poor preservation of smaller ferrous stern features. Because of potential damage to the complex rudder, propeller shroud and screw features in the low visibility conditions, the stern area was not excavated. Reduced visibility would not permit adequate control for excavation of fragmented metal structures. Project leaders decided that the potentially fragile stern area should only be excavated once: when the vessel is ultimately recovered, if that decision is made. The after end of the submarine was left undisturbed until the end of the project. At that time, a narrow trench along the top hull centerline was carefully excavated to the aft-most point of the hull to establish accurate overall hull length, not counting screw and shroud. Areas beyond and below that point, however, were not disturbed for fear of losing fragile material. For the same reason, the bow and its potentially fragile spar attachments were avoided until the end of the project. Then, as in the stern, the centerline was carefully excavated forward to finish overall length measurements and determine if any portions of the spar or spar attachments remained on the hull top. The decision to excavate the bow was made after extensive metal detector survey established there was no detectable metal forward of the hull.

EXCAVATION AND DOCUMENTATION

Before beginning excavation, three hand-driven cores were recovered just beyond the site perimeter for predisturbance analysis by a sedimentologist. These cores were used to determine the nature of sediments surrounding the site and their stability. In addition, they were used to help establish a burial sequence and depositional history for *Hunter*.

Dredges were deployed from the SCIAA vessel *C-Hawk*. This vessel was typically rafted alongside *Anita* when conditions allowed.

When waves were too large for safe rafting, *C-Hawk* was attached by a bow line to *Anita's* stern. Using the smaller vessel for an equipment platform worked well. In addition to removing the pump engines from the diving deck, the *C-Hawk* had a much lower freeboard than *Anita*, which minimized pump head lift for maximum dredge efficiency.

Before deploying the dredges, metal detectors and a hand-held cesium magnetometer (provided by Geometries, Inc. of Sunnyvale, California, and Institute of Nautical Archaeology, College Station, Texas) were used to establish site limits and orientation. PVC stakes were set at either end of the site, at least 1 meter beyond the last metal detector contact. A yellow polypropylene line was set between the two stakes, denoting the centerline of the site, as indicated by extensive metal detecting. This line was not a mapping baseline; it was used solely as a diver orientation line. In addition, several stakes were set to either side of the centerline denoting the edge of the metal detector contacts and served as orientation points in case a diver became separated from the site. This systematic metal detecting revealed an object slightly more than 40 feet long, with tapering ends, oriented along 297°-117° magnetic axis.

The first excavation unit was opened in the same location as the 1995 NUMA test excavation near the forward hatch and snorkel box. The forward hatch was the first feature revealed, which was located more than 0.5 meter below the sea bed. The second excavation unit was opened near the stern, approximately 2 meters forward of the aft-most point on the hull (not including rudder, propeller shroud and screw). By the end of diving on May 10, the forward hatch, snorkel box, cutwater and dive plane had been exposed, but the stern excavation unit had not yet revealed the aft hatch. Therefore, identification of the object as *HLL Hunter* could not be verified. Because of

inclement weather from May 11–15, diving operations did not resume until May 16.

Excavation continued on May 16 and 17, the forward excavation unit moving aft, and the aft excavation being pushed forward. Finally, on the last dive of May 17, the aft hatch was discovered in the aft excavation unit. Discovery of the aft hatch finally and unquestionably identified the site as the Confederate submarine *H.L. Hunley*.

Dredging continued May 18–20. On these days, the two excavation units were gradually joined and expanded forward and aft to the full extent of the main excavation, from just forward of the cutwater forward of the forward hatch to more than 2 meters aft of the aft hatch (see Figure 8.3). In addition, just forward of the aft hatch, the excavation was taken down to *Hunley*'s keel ballast, more than 2 meters below the sea bed, so this area could be examined and a hull cross section could be mapped. Preliminary mapping of the submarine's main features began on May 20.

On May 18, an attempt was made to measure hull thickness using three ultrasonic metal thickness measurement devices. These instruments, which are inherently nondestructive, were developed to monitor hull corrosion on modern, steel-hulled vessels. Because the speed of sound is different in wrought iron and cast iron than in steel, iron samples were procured locally for instrument calibration. None of the instruments, including the best, a Cygnus Ultrasound Thickness Gauge, produced reliable readings during approximately 100 attempts in about 20 different hull locations.

The Cygnus gauge, manufactured by Cygnus Instruments, Inc. of Annapolis, Maryland, is a multiple-echo, digital gauge that uses pulsed sound to accurately measure metal thickness underwater. This instrument has produced excellent field results on many commercial applications and accurate metal thicknesses on steel ship's hulls without having

to remove coatings up to 5/16-inch thick. This instrument is usually accurate to .005 inches, +/- .002 inches. The Cygnus gauge also uses a single probe, which is especially effective on curved surfaces, like pipe, and we believed it would be the most effective for *Hunley*. Unfortunately, it was impossible to obtain a steady, unambiguous reading with this instrument, likely due to the hard, resistant corrosion product strongly adhering to *Hunley*'s hull. Apparently, the iron encrustation corrosion product sets up multipaths that negate accurate metal thickness determination with the Cygnus gauge. This instrument and experienced operator, Leonard Whitlock, were supplied by Oceaneering, Inc. of Upper Marlboro, Maryland (Figure 7.4).

After brief dredging to clear the excavation of mud that had accumulated overnight, the majority of May 21 was spent mapping and drawing principal hull features. In addition, Mel Bell and Bob Martore, marine biologists with the South Carolina Department of Natural Resources, made a single dive on *Hunley* at the request of the field director to examine hull encrusting organisms to aid in the determination of the site's burial history.

May 22 and 23 were devoted to corrosion measurements along the hull and collection of various environmental samples. Dan Polly, a corrosion engineer, arrived on site with several instruments, some of his own design, to record *Hunley*'s iron-hull corrosion potential. Water samples adjacent to the hull and midway in the water column were collected and analyzed for salinity and pH.

The remaining days before site backfilling began, May 24–27, were spent completing documentation of the hull and its principal features, including developing a hull profile; and collecting more environmental samples, such as stratigraphic sediment samples using a box core (Figure 7.5), water samples, and coral samples from the hull. In locations where coral or encrustation samples were removed from the



Figure 7.4. Larry Murphy and Leonard Whitlock from Oceaneering, Inc. test the Cygnus Ultrasound Thickness Gauge. NPS photo by John Brooks.

hull, a pH-neutral epoxy was used to patch the hull encrustation, thereby preventing the creation of a local active corrosion cell. This epoxy coating proved particularly effective. The material, Develad 182, produced by Devco Coatings Canada, Dartmouth, Nova Scotia, is a splash-zone barrier coating that is hand applicable underwater. This material is a two-component epoxy polyamide that has excellent cathodic disbondment resistance, and forms an effective corrosion barrier. The material is mixed on the surface and sets up underwater with a pot life of about an hour. This material appeared ideal for this application.

On May 26, a systematic metal detector survey was conducted from *Hunley's* bow to approximately 35 feet beyond. There was no indication of metal material beyond the vessel's bow. The following day, the last before backfilling, a dredge was used to carefully excavate a narrow trench along the hull centerline to the forward- and aft-most points on the hull (not including propeller, shroud, or

rudder) to obtain accurate overall length measurements and determine the presence of the spar or spar attachment fittings.

BACKFILLING

Backfilling began May 29 when exposed hull documentation and sample collection was completed. The initial plan was to place a protective layer of a strong, plastic material called GeoWeb around the hull, and backfill on top of it. This material would serve as an extremely tough, physical barrier to any unauthorized excavation attempt. GeoWeb had been used successfully by SCIAA on sites located in muddy, intertidal zones, but this would be its first use on an underwater site. The material has a honeycomb-like configuration, and was originally 10 inches thick. Project leaders decided this thickness was unwieldy, so it was cut into 3-inch thick segments. A 4-foot wide section was stretched over the hull and pressed into the sediment, but



Figure 7.5. Larry Murphy and Christopher Amer examine one of the box cores used for stratigraphic sediment sampling. NPS photo by Kathleen Middlebrooks.

it was quickly discovered that the material was slightly buoyant. Because the GeoWeb would not stay securely in place and its edges worked up out of the sediment, it was removed as a potential risk. If the material partially worked itself out of the sediment, it could be snagged by shrimping activities or it could increase the risk of unauthorized site discovery.

After removal of the GeoWeb, backfilling began in earnest. A 6-inch and a 4-inch dredge were reversed and sediment surrounding the site was pumped over the hull. Ultimately, backfill dredging proved ineffectual. Because concentration of sediment fines was so high, much of the sediment became suspended and was carried away. Even so, at the end of the first day of backfilling, *Hunley's* hull was covered to approximately hatch level.

Because of several days of bad weather and small craft advisories, *Anita* could not return to the site until June 3. Backfill dredging continued, but it soon became clear another method would have to be devised. The dredging was extremely inefficient, and

excavation of borrow pits surrounding the site could potentially destabilize the whole area. Backfilling was completed on June 4 by placing 56 sand-filled jute bags over the upper hull, hatches and snorkel box. The sandbags were filled with clean mason's sand. Before placing sandbags, several conservators were consulted about potential negative impact from introducing organic jute next to the iron hull. The consensus was there would be no negative impact, increased corrosion or destabilization of hull encrustation (Donny Hamilton, Jon F. Leader, Dan Polly personal communication 1996).

The sand bags were filled on land and transported to the site aboard *Anita*. The bags were dropped close to the site and divers positioned each one atop the hull to bring the sediment level approximately level with the surrounding seabed. Later site visits by South Carolina Department of Natural Resources Divers confirmed the site had stabilized and was indistinguishable from the surrounding seabed.

CHAPTER 8

Site Description

Larry E. Murphy, Matthew A. Russell and Christopher F. Amer

HISTORICAL DESCRIPTIONS

Historical documents describing *H.L. Hunley's* physical appearance are limited to several narratives and a few images, and these can be evaluated in reference to what has been learned about the vessel. Written descriptions include a detailed account by William A. Alexander, one of the submarine's designers and builders; a description by Lt. George Gift of the Confederate States Navy in Mobile; an account by *Hunley* builder James McClintock; and a brief mention by Col. Charles H. Olmstead, who observed the vessel in Charleston. Images include sketches made by Alexander to accompany his written description; a December 1863 sketch and painting made by noted Civil War artist Conrad Wise Chapman; a late nineteenth century sketch made by Simon Lake after a description by Lt. Charles H. Hasker, a survivor of an early *Hunley* sinking; and a possible photo taken December 1863 by Civil War photographer George Cook.

William Alexander, a 21st Alabama Infantry engineer, left a detailed written description and three *Hunley* sketches: deck, plan, and cross-section drawings showing hull and inner mechanical features (see Figure 4.2). Unfortunately, this information was published in the *New Orleans Picayune* June 29, 1902, more than 38 years after the *Hunley's* loss in Charleston Harbor, and it contains some inaccuracies. Although perhaps giving a good vessel control-mechanism description, Alexander's basic hull dimensions are off considerably (Alexander 1902; see Chapter 4 for a complete description). His sketches are also substantially out of proportion and do not portray accurate vessel morphology, which tend to cast suspicions about internal detail accuracy. Along with his written description, however, these sketches provides the only historical clues to *Hunley's* internal works.

Another *Hunley* description was written in Mobile by Lt. George Gift of CSS *Gaines* who helped get the submarine ready for shipping to

Charleston. His description contained in a letter to his fiancé accurately described the vessel's basic dimensions (Turner 1995:5-8; see Chapter 4 for a complete description).

A third description was provided by *Hunley* builder James McClintock, who apparently became disenchanted after the war and considered moving to Great Britain. McClintock, secretly met with the British naval officers in Canada to discuss citizenship and continuing his submarine work for them. He sent a letter to the British officers in 1872 detailing work on *Hunley* and its predecessors, and briefly describing the submarine (Public Records Office, ADM 1/6236; see Chapter 4 for a complete description).

Col. Charles H. Olmstead, who commanded Confederate forces at Charleston's Fort Johnson during the war, provides the fourth *Hunley* description. After observing *Hunley* docked at Fort Johnson, he wrote "[i]t was built of boiler iron, about 30 feet in length, with a breadth of beam of 4 feet by a vertical depth of 6 feet, the figures being approximate only" (Olmstead 1883, in Kloeppel 1987). Like Alexander's, these observations were apparently recorded sometime after the war and, therefore, not entirely reliable.

Probably the most accurate *Hunley* depiction is Conrad Wise Chapman's sketch made while the vessel was dry-docked December 2, 1863, following its second sinking in which namesake Horace L. Hunley lost his life. This sketch was the basis for a later painting, dated December 6, which is the most well-known *Hunley* image (Kloeppel 1987:64) (see Figure 4.1). Chapman was an active Civil War artist who sketched and painted many Charleston war scenes including views of Confederate defenses, ironclads and combat. His *Hunley* views are very detailed, and they provide an accurate general image of the submarine. Chapman's sketch and painting show generally accurate placement of *Hunley*'s main features, including hatches (coming towers), snorkel

box, and dive planes. Although there is no current evidence to judge his depiction of the stern mechanisms and keel ballast, he does accurately depict a fair hull at the bow and stern, unlike Alexander's rather boxy illustration. The only apparent inaccuracies that can be noted, based on archeological observations, are placement of the spar torpedo and the aft cutwater forward of the hatch. It could be, however, that the torpedo delivery system was altered after Chapman's observations.

Another *Hunley* image was produced by Simon Lake, a respected turn-of-the-century submarine expert, and published in *McLures Magazine* January 1899 (Figure 8.1). The sketch was based on his 1898 interview with Charles Hasker, a survivor of *Hunley*'s first Charleston sinking. Lake's sketch is rather crude and contains only two items of particular interest: five deadlights on the upper hull between the hatches (although it does not depict a snorkel box) and the spar torpedo arrangement, which is angled downward to deliver the torpedo well below waterline. This is the only historical source to include deadlights. While this may not be an entirely accurate depiction of the torpedo delivery system, it is the only historical source that shows something other than the bow-mounted, straight torpedo spar. Although spar details still remain speculative, an arrangement that delivered the torpedo charge below the waterline would clearly be more effective than one striking at the waterline mounted upon a straight spar. During its attack on the blockading fleet off Charleston, Commanding General Beauregard ordered *Hunley* not to submerge, making a straight hull mounted torpedo less effective than Lake's arrangement. Furthermore, *Housatonic*'s Assistant Engineer Mayer's testimony suggests the propeller shaft may have been severed in the explosion (Ragan 1995:138). Such an event would be more consistent with an explosion well below the

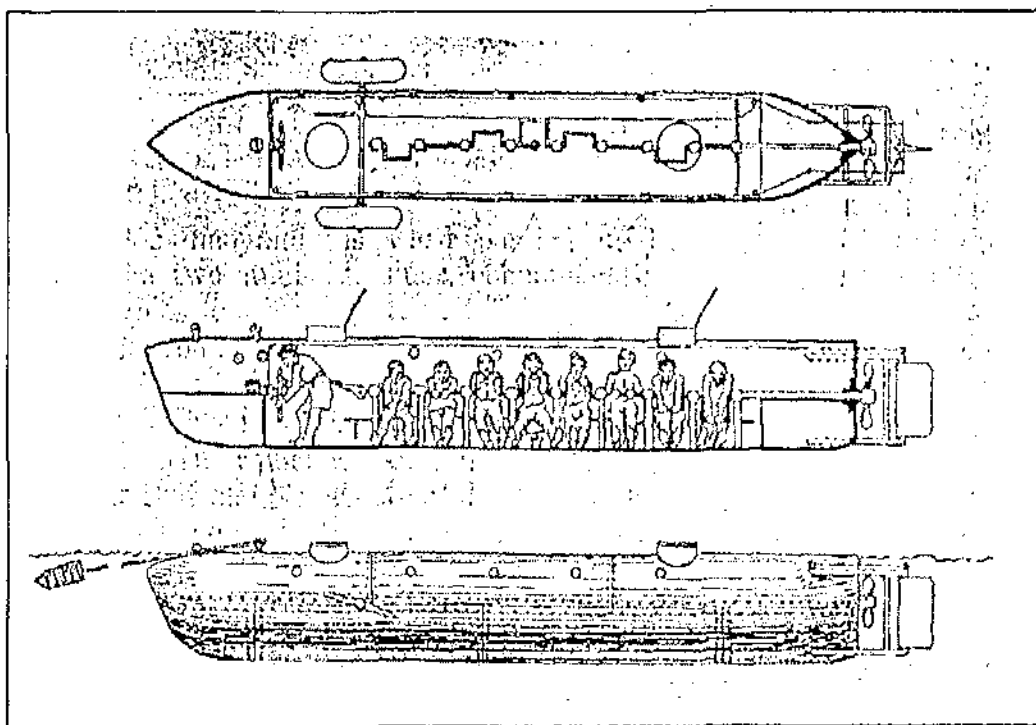


Figure 8.1. Simon Lake's 1899 drawing of *Hunley*. Though inaccurate in many details, it is the only historical depiction that includes deadlights.

waterline than one from an explosion at the waterline where a straight bow-mounted spar would place it.

A final depiction of *Hunley* might be an actual photograph. According to Ragan (1995:127), a black-and-white vessel image is believed to be a George Cook photograph taken in December 1863. Cook's view of *Hunley* is the same as painted by Chapman at the same time. If it is a photograph, it is probably of Chapman's painting rather than the actual submarine. For our purposes, however, which came first and which is based on the other is a moot point. The "Cook photograph" shows nothing different than Chapman's painting.

These few historical documents are the only primary sources located so far describing or depicting *H.L. Hunley*. Chapman's work appears to be the most accurate, but contains a few errors. Although Alexander would seem likely to be the best information source considering his close association with *Hunley*,

the delay between his involvement with the submarine and recording his observations was apparently so great that it led to serious errors and misrepresentations. The same can be said for Lake's sketches, especially since they were done from secondhand information. They include some interesting details, but hold very little weight overall. The information contained in McClintock's and Gift's descriptions, while probably representing the most accurate overall dimensions, provide few additional details as well as several errors.

These few historical descriptions and images served as a basis to develop a set of decisive attributes with which to make the field determination of whether the vessel being investigated was *H.L. Hunley* or not. Excavation planning, documenting and interpreting remains were also based on this historical attribute set. It became clear during the course of this investigation that none of the historical accounts was particularly accurate. It was also

clear that given the paucity of firsthand historical records about *Hunley*, the material record is the best source for accurate vessel information, as it is with most historical shipwrecks.

HULL DESCRIPTION

H.L. Hunley is located in approximately 30 feet of water and buried under about a meter of sediment around four nautical miles offshore Sullivan's Island. The submarine's bow is oriented towards 297° magnetic, pointed nearly directly towards Sullivan's Island. The hull is canted about 45° to starboard. Overall hull length is 39 feet 5 inches, from the tip of the upper bow to the aft-most point on the upper hull, not including propeller, propeller shroud, and rudder assembly, which were not observed (Figures 8.2, 8.3 and 8.4).

Based on profile measurements, the hull is 3 feet 10 inches wide athwartship and 4 feet 3 inches from hull top to the bottom of the keel ballast. The keel ballast is 4¾ inches thick at the edge, but rather than rectangular shaped, it is probably concave on its upper face to fit the hull's bottom radius so it should be somewhat thinner in the middle. The vertical hull dimension is imprecise because the keel-ballast center thickness is unknown.

A very indistinct longitudinal seam from the iron strip inserted during *Hunley*'s construction was observed during the excavation forward of the aft hatch that exposed the keel ballast for measurement. Though described as 12 inches wide by Alexander (1902), this iron strake measures 9 inches wide. Because of marine encrustation, it was only possible to see the top seam in a few locations; the bottom seam was indistinct.

Both bow and stern hull sections have a very fair shape; they narrow almost to a point at either end, but the narrowing is gradual, and the entire hull appears fair. This is only an impression because not enough of *Hunley*'s bow

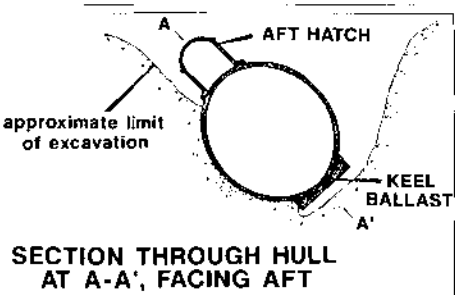
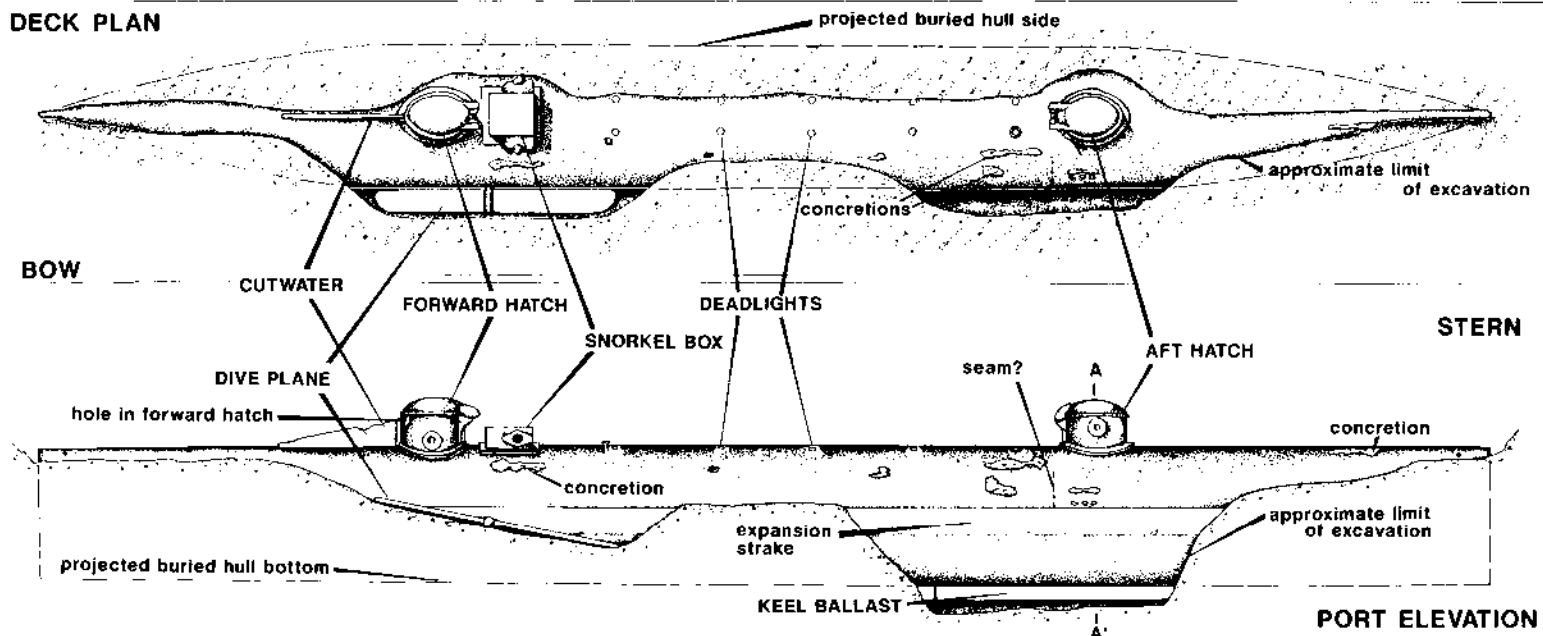
and stern sections were exposed to obtain longitudinal hull lines.

Only one vertical seam was observed on the entire hull. Although others certainly must be present, they are apparently obscured by encrustation and corrosion product. The single vertical seam was slightly forward of the aft hatch, and may be where the first course of plate attached to the original boiler reportedly used in hull construction. If this is the case, then the cast-iron aft hatch is not attached directly to the wrought-iron boiler comprising the central hull.

Hunley's principal features exposed and documented during the excavation include the forward hatch and cutwater, snorkel box, aft hatch, port dive plane, keel ballast and the previously unknown deadlights (Figure 8.2). [Simon Lake's sketch was located after fieldwork ceased.] The propeller, propeller shroud and rudder assembly were left undisturbed and were not observed during this assessment (Figure 8.2 and 8.3).

Hunley has two hatches, or conning towers, located 16 feet 3 inches apart on the hull-top centerline. The hatch covers open towards each other, the forward hatch cover is hinged on its aft end, and the aft cover is hinged on its forward end (Figures 8.2, 8.5–8.8). Each has a double-hinge mechanism (Figure 8.8). Both hatches are oval shaped, 2 feet long at the base, and joined to the hull by a raised flange, and both hatches are 1 foot 2 inches tall on the centerline and 1 foot ¾ inches tall on the outside edges, a function of the hull radius. The hatch covers are 1 foot 11 inches long (2 feet 1 inch including the hinges); they are 1 foot 3 inches wide. Only one viewing port was observed on each hatch coaming, both on the port side (Figure 8.6). Both ports are 5 inches in diameter, including the outer flange. The actual viewing port was mostly filled in by marine encrustation, so a precise measurement was not possible. The forward hatch viewing port is placed slightly lower on the hatch coaming than the one on the aft hatch (Figure 8.2, 8.6 and 8.7). No viewing

DECK PLAN



H.L. HUNLEY

Measured Field Drawing by
Matthew A. Russell and David L. Conlin
Final drawing by Larry V. Nordby
U.S. National Park Service
Submerged Cultural Resources Unit

A COOPERATIVE EFFORT OF:
SOUTH CAROLINA HUNLEY COMMISSION
U.S. NAVAL HISTORICAL CENTER
SOUTH CAROLINA INSTITUTE OF ARCHAEOLOGY AND ANTHROPOLOGY
U.S. NATIONAL PARK SERVICE

FEET
0 5 10

Figure 8.2. H.L. Hunley site map.

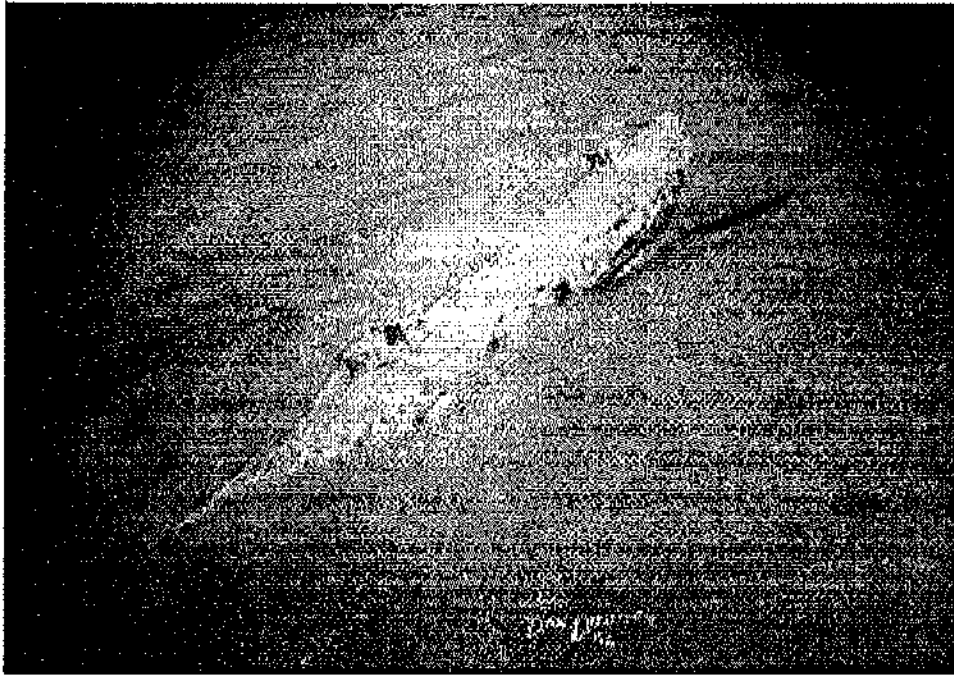


Figure 8.3. Artist's perspective of *Hunley* site at the maximum extent of excavation. Computer graphic by Dan Dowdey, South Carolina State Museum.

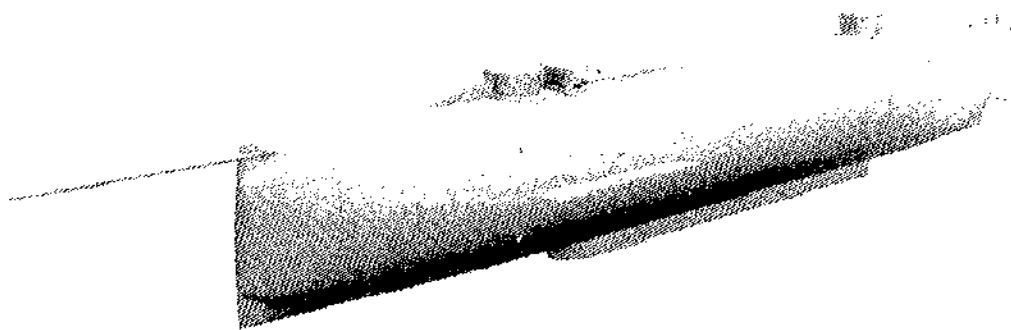


Figure 8.4. Artist's computer reconstruction of *Hunley* based on archeological data. Note: No evidence was detected for the bow torpedo spar depicted. Computer graphic by Dan Dowdey, South Carolina State Museum.

ports were observed on either the forward side of the forward hatch, the aft side of the aft hatch, or the starboard side of either. Because of the hinge assembly, there is no room for a viewing port on either the aft side of the forward hatch or the forward side of the aft hatch. The forward side of the forward hatch coaming, just to port of the cutwater, has a large hole in it, which may be the location of a forward viewing port (Figure 8.7). This is a likely viewport location to allow the pilot to see forward when underway with a secured hatch cover. This area is completely broken out; there were no clear indications here of a viewport flange. This is the only hull damage observed, and it was indeterminate whether this damage occurred during the engagement. The edges are completely encrusted, indicating it is likely contemporaneous with sinking. This hole could have been caused by *Housatonic* small-arms fire, which broke out a forward view port and a section of the solid cast-iron hatch coaming. Future archaeological work may reveal what caused the forward hatch coaming break and revise this speculation.

The snorkel box (or air box), located 4 inches aft of the forward hatch (Figure 8.2 and 8.9), is a rectangular box 1 foot 2 inches wide and 1 foot 3 inches long set on the vessel's top centerline. It is 7¼ inches high at the outboard edges, and 6½ inches high on the centerline, again because of hull curvature. On each outboard side is a diamond-shaped stuffing box and stump of a snorkel (Figure 8.10). Each stuffing box is 11 inches long and 5 inches wide; both snorkel stumps are 3½ inches in diameter.

Forward of the forward hatch is a 3 foot 4-inch-long cutwater (Figure 8.2 and Figure 8.7) that is 8¾ inches high where attached to the forward hatch. Joining it to the forward hatch is a 2¼-inch-diameter rod, which is 7¾ inches tall and sits atop the hatch flange. This cutwater is made from a single iron sheet whose thickness

varies from ½ to 1 inch due to corrosion product. Although Chapman depicts one in his painting, there is no evidence of a cutwater forward of the aft hatch, nor is there a place for one because of the hinge mechanism. It is unlikely the vessel ever had one.

The port dive plane was exposed and documented. It is 6 feet 10 inches long, with a 3-inch-diameter pivot pin in its center connecting it to the hull; an external stuffing box was not visible. The dive plane is 8 inches wide and between 1¼ and 1½ inches thick. Both leading and trailing dive plane edges are rounded. It is tilted upward from horizontal 10°, possibly its final setting by the crew. If so, they were apparently trying to reach or maintain the surface. The starboard dive plane was not exposed.

Depicted only in Lake's 1899 *Hunley* image (Figure 8.1), five pairs of 2-inch diameter deadlights were observed along the hull-top centerline between the snorkel box and the aft hatch (Figure 8.2 and 8.11). Each deadlight is 5 inches off centerline to port or starboard; each pair is 10 inches apart athwartship. The forward-most pair is 2 feet 2½ inches aft the snorkel box, and then each pair is spaced between 2 feet 6 inches and 2 feet 9 inches apart longitudinally sternward along the hull top. Glass is present in all deadlights observed except one, which had marine encrustation filling the opening. In some, the glass was cracked. The aft-most port deadlight appeared to have a ½-inch-wide coaming or collar around it. This was not observed on any other deadlight, but it may be obscured by encrustation on the others.

During documentation, nearly 7 feet of keel ballast were exposed. This solid-iron piece is 4¾ inches thick at the edge, and 1 foot 10 inches wide athwartship. One junction seam near the forward end of the exposed portion was observed, indicating at least two sections of keel ballast are in their original place



Figure 8.5. Aft view of the aft hatch. SCIAA photo by Christopher Amer.

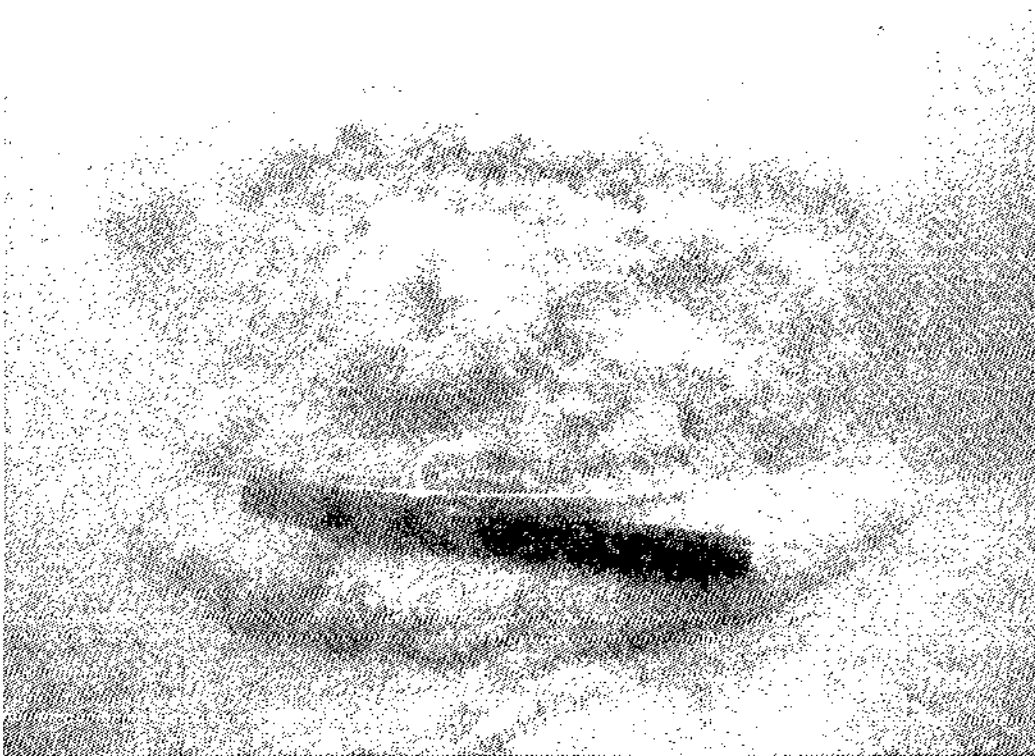


Figure 8.6. Aft hatch, port side showing view port (foot-inch scale stadia). SCIAA photo by Christopher Amer.

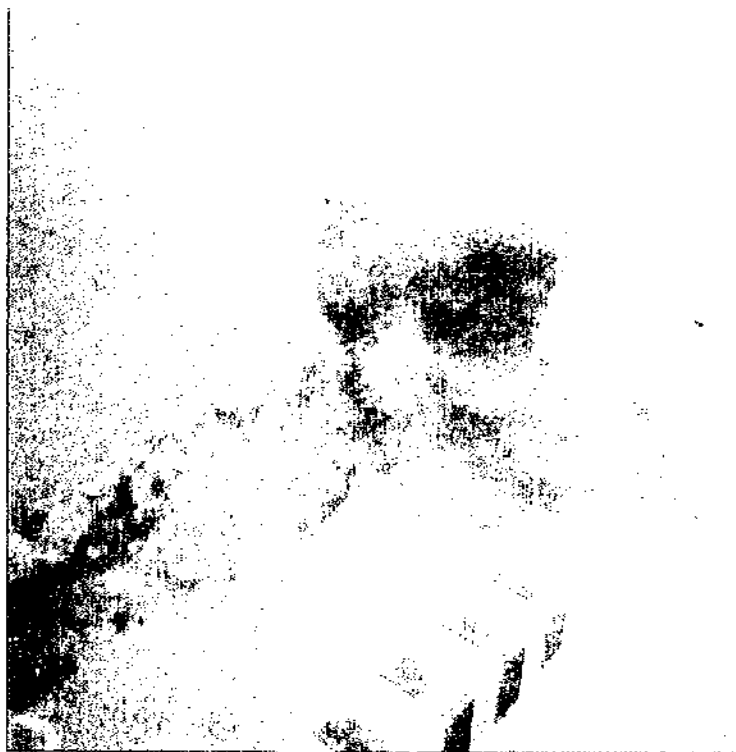


Figure 8.7. Forward hatch from port side looking aft with view port on the right and cutwater running forward on the left (two-inch-square stadia in inches). SCIAA photo by Christopher Amer.



Figure 8.8. Aft hatch cover, top view, right side faces forward (foot-inch-scale stadia). SCIAA photo by Guenter Weber.

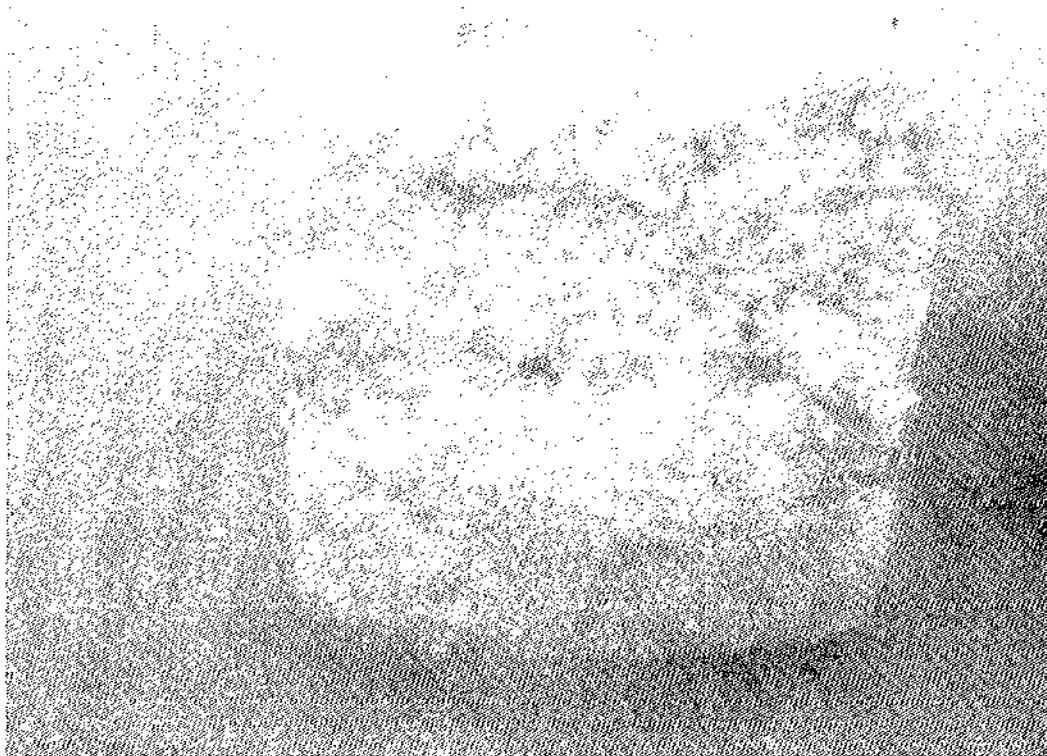


Figure 8.9. Top view of air box, right side faces bow. SCIAA photo by Christopher Amer.

attached to *Hunley* (Figure 8.2). We did not expose the keel ballast's sternward end, so we could not determine how far aft it extends.

A narrow trench was excavated along the vessel's top centerline to its forward-most point. From the cutwater forward, the hull top is smooth, and there is no indication that spar attachment fittings were ever located atop the bow. The iron encrustation, however, is extremely thick, and remnants of such fittings may be obscured.

During the excavation along the hull top to the hull ends, towing or mooring holes were observed on both the bow and stern similar to those depicted in Chapman's painting. These holes pass laterally through the narrow forward and aft hull sections, and appear to pass through solid cast iron. The forward hole is 7 inches aft of the bow and 2 inches below the hull top. The aft hole is 10 inches forward of the stern-edge, and 3 inches below the top. Both holes were blocked with marine encrustation.

For much of the excavation, archaeologists did not dredge further astern than a large concretion attached to the port top hull, just below the centerline and approximately 3 feet from the hull's actual stern edge (Figure 8.2). For much of the project, this concretion was referred to generically as the "rudder actuator," because it is in the approximate location of the point where the port rudder arm leaves the hull as depicted in Alexander's sketch (though not seen in Chapman's sketch or painting). After exposing more of the stern on the last excavation day, it became clear that this feature was just another unidentifiable concretion, of which there are several attached to hull. Although not much beyond the hull's top stern end was exposed, the beginnings of a bulge on the vertical stern edge was noted. To the excavator (Russell), this felt much like the rudder assembly depicted in the Chapman painting, which shows a single rudder-actuator arm protruding aft from a cowl in the stern-

most edge of the hull. Alternatively, however, the bulge may be part of the support for the propeller shroud, and the side rudder-actuator arms (if present) may not have been exposed at all during this test excavation.

At least ten concretions, in a variety of sizes and shapes, were recorded on *Hunley's* hull, all of which are unidentified. These may be original hull features, or merely ferrous objects or fragments that became attached to the hull during the burial process. For instance, a concretion just below the snorkel box may be a snorkel fragment.

During excavation, a very distinct shell layer was observed in the stratigraphy, and several bones and a small piece of wood were recovered from this stratum. One bone was clearly an intrusive marine mammal. Another, with a distinct cut on one end was identified as a portion of bovine sternal cartilage that connects the rib to the sternum likely from a

brisket cut or short plate cut of meat. The cut in the bone was probably made with a saw, rather than a blade. The bone could be from a number of places, possibly one of the blockading vessels or maybe *Housatonic*. It is extremely unlikely, however, that the bone is from *Hunley*. The wood was identified as Douglas fir, and is also intrusive to the site. Two pieces of coal were also recovered during excavation. One was collected from near the shell layer, while the other was actually found under *Hunley's* keel. This indicates the coal is contemporaneous with the sinking, but is obviously not from *Hunley*. Analysis identified it as meta-anthracite, from the northeastern United States. The coal is possibly from *Housatonic*, lost when it sank, or from any of the blockading vessels that dropped coal overboard, possibly during re-coaling. A complete inventory of samples and specimens collected are listed in the Field



Figure 8.10. Air box port side with stuffing box and snorkel stub. Temporary mapping line is visible at air box base (two-inch-square stadia in inches). SCIAA photo by Christopher Amer.

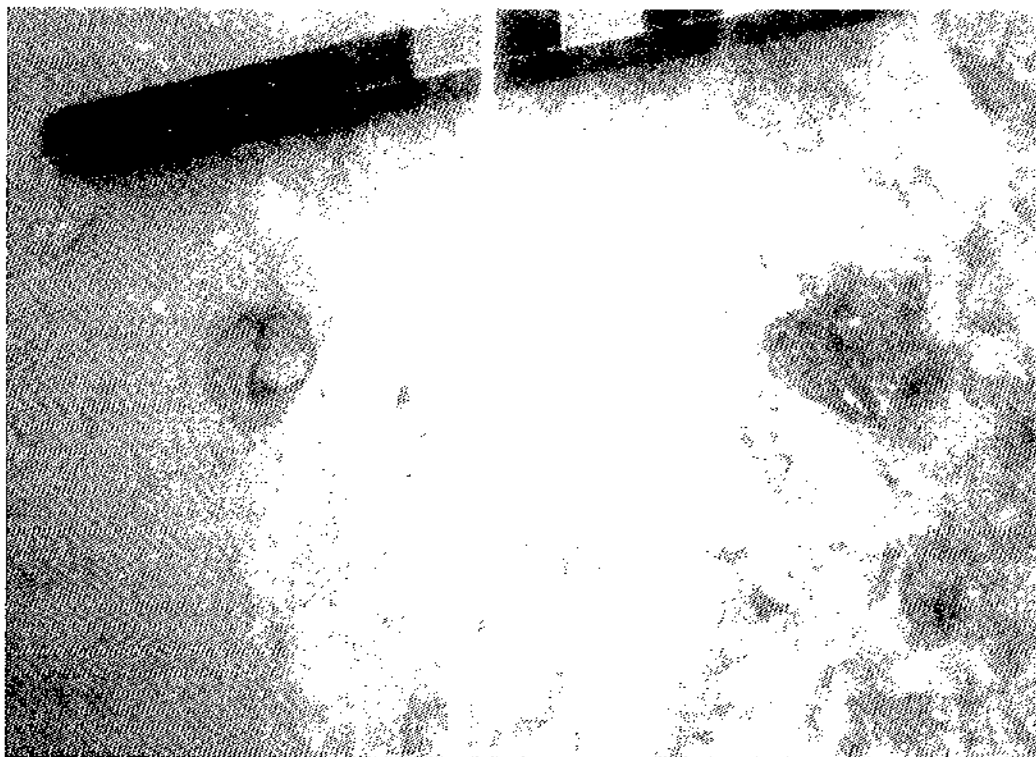


Figure 8.11. Plan view of twin deadlights on either side of vessel centerline. SCIAA photo by Christopher Amer.

Specimen Catalog in Appendix B, and they are discussed further in Chapter 9.

H.L. Hunley's archaeological documentation revealed several discrepancies between historical vessel descriptions and the material record. Some are errors in recollection of people closely associated with *Hunley* writing many years after the fact. Others are because of

erroneous second-hand information. Main vessel attributes described in historical documents, however, were present and aided the site's positive identification as *H.L. Hunley*. After positive identification, the next project objective was an assessment of the submarine's condition. The methodology and results of that assessment are discussed in Chapter 9.

CHAPTER 9

Site Analyses

Larry E. Murphy, Matthew A. Russell and Christopher F. Amer

As stated in Chapter 8, the site examined during this assessment is unquestionably *H.L. Hunley*, sought on two prior occasions by the National Underwater and Marine Agency (NUMA) (Cussler 1981; Browning and West 1984) before they located it May 5, 1995 (Hall and Wilbanks 1995). This chapter presents analytic results, considerations and inferences about *H.L. Hunley* based on archeological evidence and laboratory testing. Several lines of research were conducted to investigate the *Hunley* site. Principal research domains, as specified in the research design (Chapter 3), included site-formation processes, particularly regarding deposition, sediment context and metallurgical attributes relevant to hull corrosion and mechanical strength. After site verification, investigations were directed toward providing information relevant to assessing vessel recovery potential. Various research reports referenced in this chapter are included as appendices.

REMOTE SENSING

Further remote-sensing data analysis has produced some additional information to the general results discussed in Chapter 6. Magnetic and sub-bottom data are addressed to augment the earlier presentation.

MAGNETOMETER

Figure 9.1 depicts *Hunley*'s position relative to the magnetic anomaly recorded during the predisturbance survey. The 20-gamma (nanotesla) contour encompasses a 1,000-square-meter area. The contours presented are absolute gradient contours, produced by subtracting one point from the next and plotting results at the position of the second point, which produces absolute variation from ambient. The configuration is commonly called a multiple-component anomaly consisting of a single 400-gamma positive anomaly and two 200-gamma

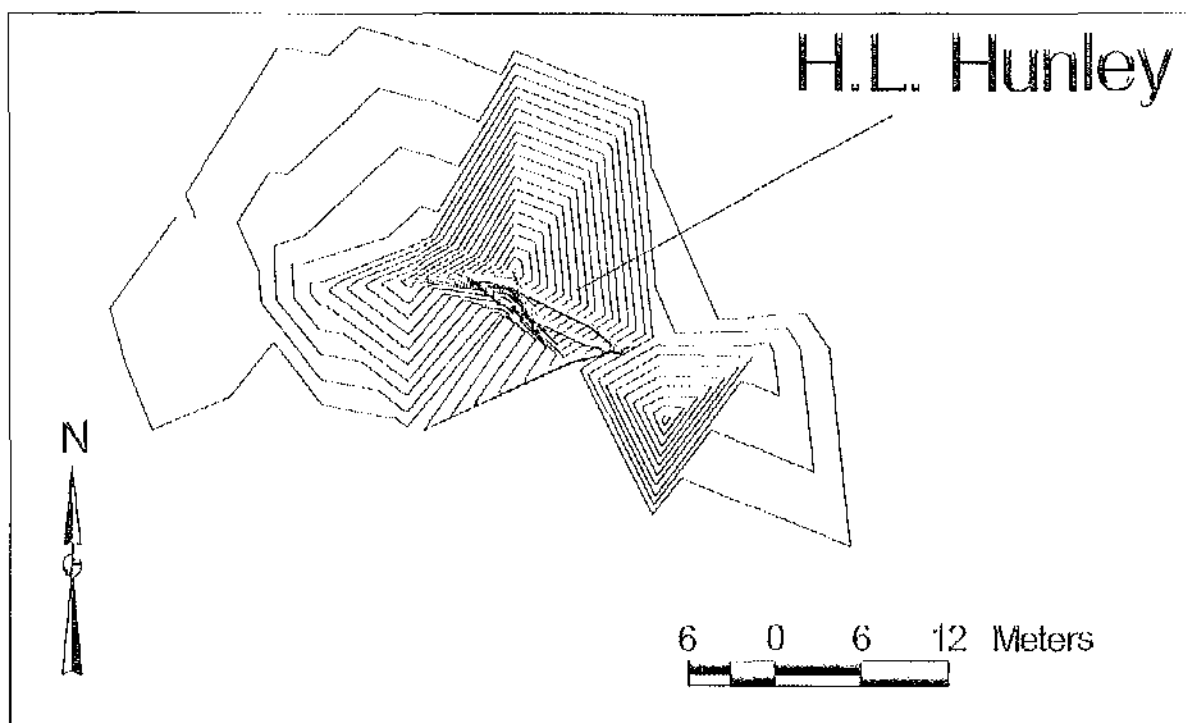


Figure 9.1. 20 gamma magnetic contours over *Hunley* position.

negative anomalies 10–12 meters southeast and southwest of the positive point. *Hunley*, basically a cylinder, would be expected to produce a dipolar (single positive and negative components) magnetic anomaly. The dual negative aspects of the anomaly indicates a possibility there may be additional material southwest of *Hunley*'s bow. The possibility of metallic torpedo spar attached to the lower bow is discussed below.

During the assessment, *Hunley*'s hull top was excavated to ascertain overall hull length, and it was examined for torpedo spar-related features. No features were found. Repeated metal detector surveys and an examination with a hand-held cesium magnetometer gave no indications of additional iron features forward of the bow. The lower bow forward of the dive plane was not excavated. If the hull is recovered, an area forward and southwest of the lower bow for 6 meters away from the hull bottom should be excavated during the recovery to ensure there are no remains of a torpedo spar mounted to or near the hull.

SUB-BOTTOM PROFILER

General Sub-Bottom Record

A sub-bottom profiler record is depicted in Figure 9.2, with a data transect location map in Figure 9.3. These data and interpretation were provided by Scott Harris of the United States Geological Survey (USGS) Coastal and Marine Geology Program.

Sub-bottom profile data were collected April 1995 aboard NOAA research ship *Ferrel* as a part of the USGS South Carolina Coastal Erosion Project. Four prominent geological units are identifiable in the *Hunley-Housatonic* study area: 1) early Tertiary (Eocene) sediments at the base of the profile incised and infilled by; 2) Oligocene Gulf Trough deposits; 3) additional, generally flat-lying, Tertiary deposits (Oligocene to Pliocene), capped by; 4) thin discontinuous incised Quaternary sediments. Because there were no deep cores taken in the area, Holocene and Pleistocene deposits can not be reliably distinguished.

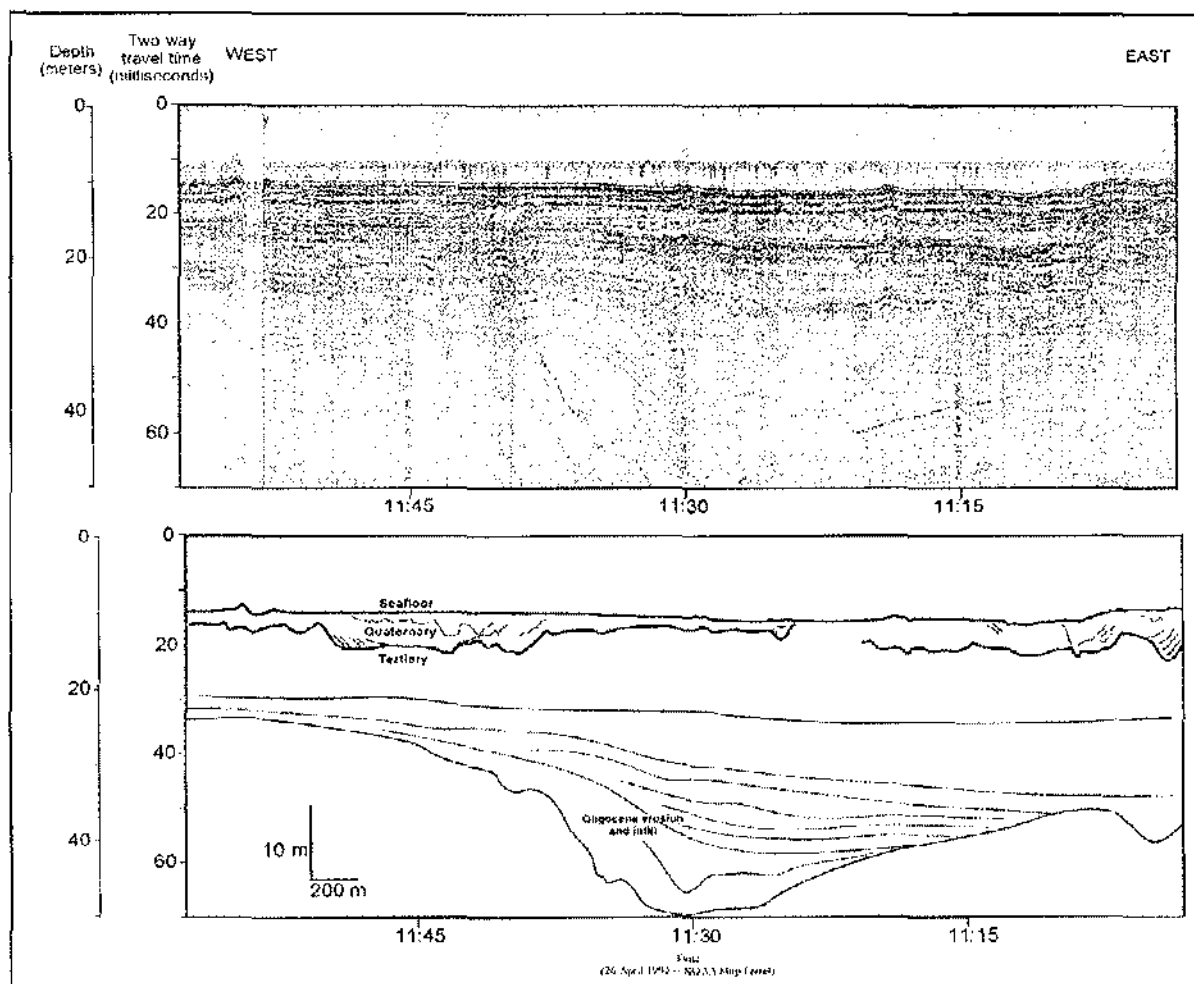


Figure 9.2. Deep penetrating sub-bottom profile of nearby sediments.

However, core data available from north and west of the study area indicate the Quaternary deposits derive from both epochs.

Quaternary deposits along the west side of the profile are correlated to channel materials that backfilled the harbor entrance as it was forced landward during the most recent transgression as sea level rose to its present level. Sea level approached the current level about 6,000 years ago, with fluctuations of about 1-2 meters recorded every 400-500 years (Brooks et al. 1979; Colquhoun and Brooks 1986; Colquhoun et al. 1981). To the east, tidal channel facies backfill Quaternary paleo-incisions, which is typical for former barrier islands resting upon high sections of Tertiary materials along this section of coast.

Specific Sub-Bottom Record

A sub-bottom profiler data screen downloaded from raw data collected on site is shown in Figure 9.4. It is provided by Darren Moss of EdgeTech, Milford, Massachusetts. The first return on the image from the top is the seabed. Although flat, the seabed appears to be hilly, which was caused by variable distances between the sensor and the seabed; it does not represent changes in the seabed itself. The survey vessel was first slowed while going across the site area, which lowered the sensor making the seabed appear to rise. Vessel speed was increased causing the sensor to rise making the seabed appear to deepen. The hard return in the center screen represents returns from

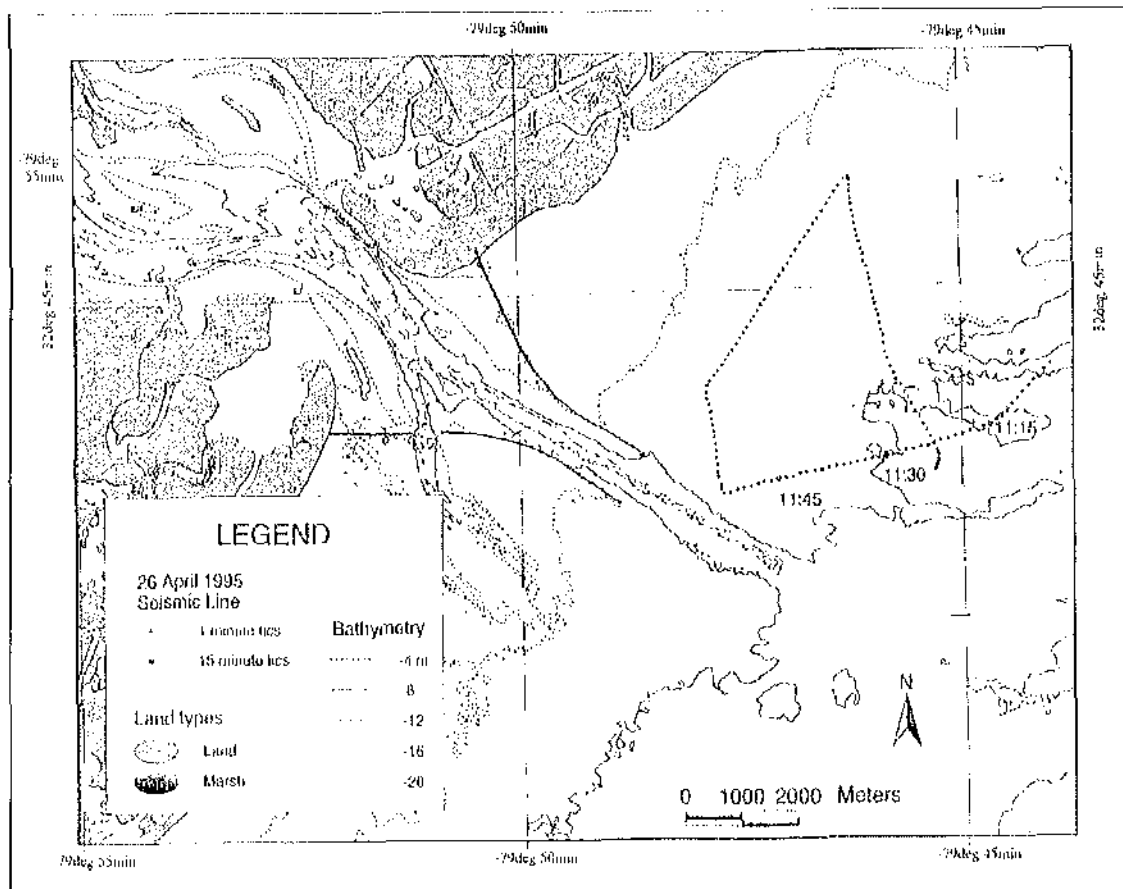


Figure 9.3. Deep penetration sub-bottom transect.

Hunley's hull, whose exact orientation relative to the sensor's path is unknown. This record indicates *Hunley* is buried about 1 meter beneath the seabed, which was verified by the test excavation.

SITE FORMATION PROCESSES

A principal research domain laid out in the research design (see Chapter 3) was investigation of natural site-formation processes. Cultural aspects of the *Hunley-Housatonic* site are concerned with how these ships were lost, and historical accounts are briefly reviewed for what they can illuminate about the archeological material. These wrecks have generated much speculation, which will only be resolved through documentary evidence combined with archeological evidence and inferences based upon both data sets. A

particular question regarding *H.L. Hunley*, as it is with most shipwreck sites, is establishing the burial/reburial sequence, which can be a primary factor in artifact (in this case hull) preservation and establishing archeological associations.

WRECK EVENT

Housatonic Loss

Historical documents suggest *Hunley* approached *Housatonic* from the starboard side near the stern perpendicular to the vessel at a speed of perhaps 3 to 4 knots. The submarine was spotted about 100 yards from the ship and was visible for about two minutes during which *Housatonic*'s engines were started and the anchor slipped. One witness (Fleming) reported spotting the submarine 6-8 feet off the starboard quarter immediately after the

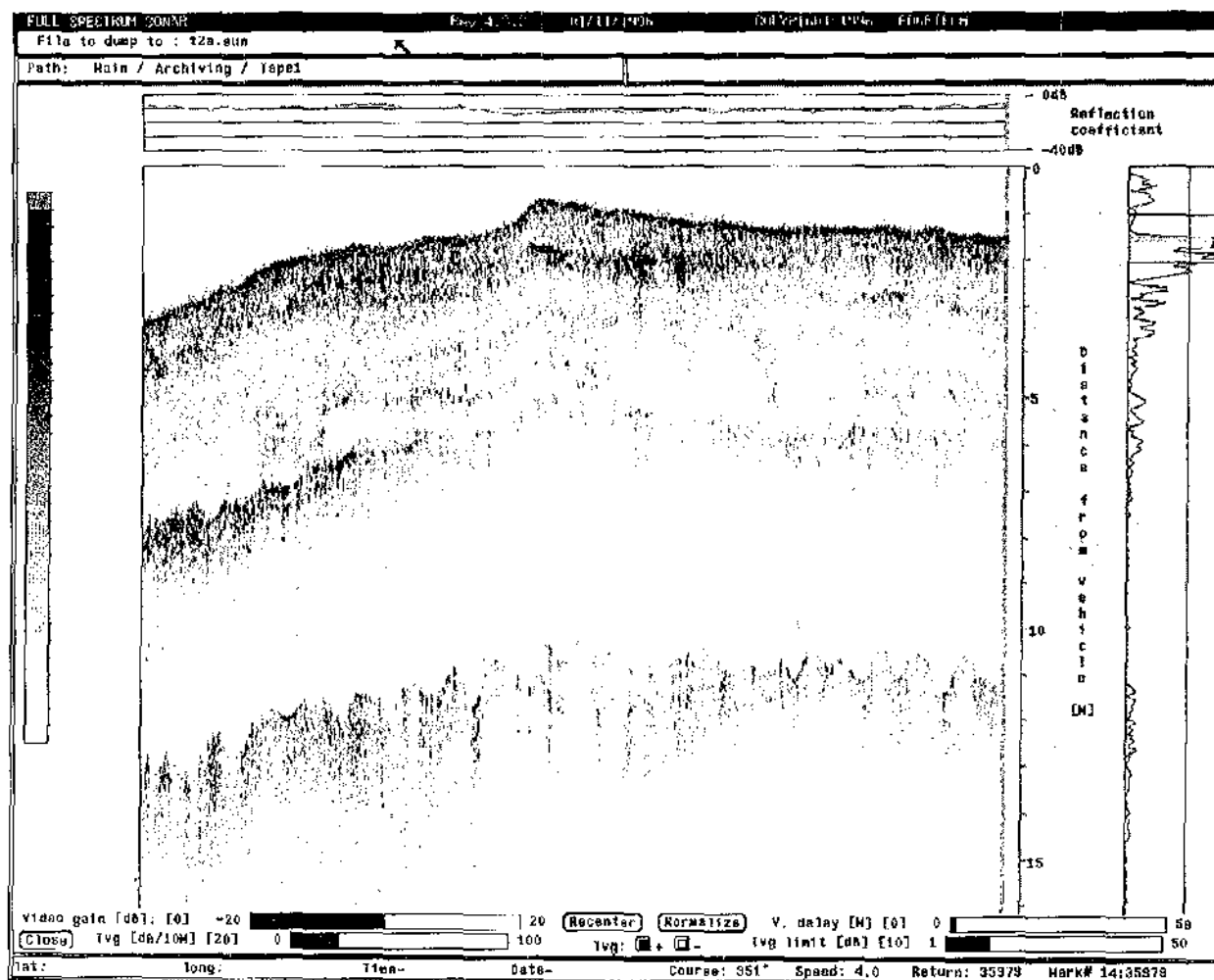


Figure 9.4. Data screen of EdgeTech sub-bottom profiler over *Hunley* site.

explosion, another witness estimated 40–50 feet away (Kloppel 1987:85–87, 94). *Housatonic* listed to port and sank within five minutes with five casualties. There has been no explanation offered to account for the port list from a starboard hull breach.

Historical Blast Description

Eyewitnesses aboard *Housatonic* recorded their observations of the blast set by *Hunley*. Their descriptions support *Hunley*'s torpedo exploding well below the sloop-of-war's waterline after the submarine made contact with the hull and retreated. At least three witnesses agreed during the Naval Court of Inquiry into

Housatonic's loss that the submarine approached at about 3 or 4 knots to within 2 or 3 feet of the hull just forward of the mizzenmast, set its charge, and backed off 40 to 50 feet before exploding the torpedo (Higginson, Crosby and Pickering testimony in Kloppel 1987:86–87). Acting Master John K. Crosby, officer of the deck during the attack, observed: the "explosion started me off my feet, as if the ship had struck hard on the bottom. . . . I saw no column of water thrown up, no smoke and no flame. There was no sharp report, but it sounded like a collision with another vessel" (Kloppel 1987:80). Lack of a water column indicates the charge was placed well below the hull and not on the vertical hull side.

Housatonic Damage Assessment

Captain Joseph F. Green, who examined the wreck on February 20, 1864, three days after the blast, reported the “spar deck 15 feet below the surface of the water. The after part of her spar deck appears to be completely blown off” (Kloeppel 1987:92). A diver investigated the wreck nine months later and observed:

The propeller is in an upright position; the shaft appears to be broken. The rudder post and rudder have been partly blown off; the upper parts of both are in their proper places, while the lower parts have been forced aft [Kloeppel 1987:92].

Hunley Loss

Hunley’s loss has been a mystery, and much of the mystery will remain until completion of detailed laboratory hull examination. One of the most compelling questions requiring direct hull examination is whether the submarine sank as a result of the explosion or some other set of circumstances. It is clear *Hunley* did not sink immediately; historical sources report that blue lights, *Hunley*’s signal to its shore support, were seen by *Housatonic* crew members and those on shore (Kloeppel 1987:94–95).

Either small arms fire or blast damage, or the combination, could have compromised *Hunley*’s hull integrity. If small arms fire penetrated the shell plate, it likely would have been visible on the hull top, the most vulnerable, and the most examined, hull section — none was found. All hull-top deadlights appeared intact, although some glass appears to have cracks, which penetrate its entire thickness. The only hull damage observed was to the forward hatch coaming (conning tower) where we assume a glass viewport similar to the ones on the port side coamings would have been. Wilbanks (personal communication 1996),

among others, has suggested the forward port was damaged by small arms fire during the attack, which fits the material evidence. This port would have been the most likely target — it was the highest object above the water and the most visible, particularly if there was a light aboard the submarine. Apparently it was standard procedure to operate *Hunley* with a candle lit to monitor oxygen level and illuminate the compass, steering wheel and diving lever. Failure to have a candle lit was considered contributory to an earlier *Hunley* crew loss. *Housatonic* crew members reported seeing a light “as if through a deadlight” (Kloeppel 1987:46–47, 72). Blast damage potential is addressed in detail below.

Explosion Analysis

Historical accounts indicate *Hunley* carried a copper torpedo containing 90 pounds of black powder on a bow-mounted 22-foot pine boom. A socket held the torpedo on the boom (Alexander 1902 in Kloeppel 1987:88).

Black powder is classed as a deflagrating or “low” explosive in commercial blasting and as a propellant by the military. Unlike high explosives, black powder does not have true detonating velocity. In confined spaces, black powder has a velocity of 560 to 2,000 feet per second. In comparison, dynamite, a high explosive, has a velocity between 4,000–23,000 feet per second (Blasters’ Handbook 1967:26,77).

World War II prompted extensive underwater explosion analysis. Knowledge and formulas about underwater explosions produced by this analysis are useful to understanding what may have sunk *Hunley*.

For explosions, water is treated as an incompressible medium that spreads an explosive-generated shock wave in all directions, and there is a direct relationship between explosive size and distance and shock-wave intensity. A formula characterizing this

relationship is $P=W^{1/3}/R$, where P is peak pressure in pounds-per-square inch (psi), W is explosive weight relative to TNT in pounds, and R distance in feet from the explosion (Cole 1948:122). To calculate the formula, black powder effectiveness relative to TNT must be established. One relative effectiveness standard relates to breaching charges, and black powder has an effectiveness of .55 of an equivalent amount of TNT for this measure (NOAA 1990:8-32).

Torpedo blast pressures on *Hunley*'s hull can be estimated with this equation. Three distances are particularly relevant: 20 feet represents the spar distance, 50 feet was the distance *Hunley* reportedly retreated prior to the explosion, and 200 feet, the distance *Hunley* was to have towed the torpedo in its original deployment (see Chapter 4). At 20 feet, *Hunley*

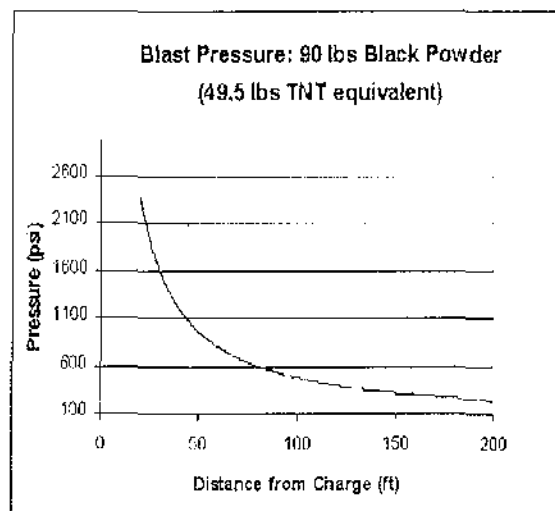


Figure 9.5. Blast pressure.

received a shock wave of 2,383 psi; at 50 feet 953 psi and at 200 feet 238 psi. Figure 9.5 presents blast pressures *Hunley* would have received at various distances.

To put these pressures in perspective, an unprotected person would be injured by a blast pressure wave exceeding 70 psi (NOAA 1990:8-31). It is clear that *Hunley*'s crew survived the blast because they deployed their blue signal lights. The question is, could the

blast have caused hull damage partially responsible for *Hunley*'s loss?

In 1852, a law was passed setting maximum allowable working pressure for any boiler at 110 psi, and each boiler had to be tested yearly at 1½ times its working pressure (Burke 1972:110), which would be 165 psi. Some steamboats operated with higher boiler pressures, for example the USS *Cairo* had five 36-inch by 24-foot-long boilers capable of 140 psi operation (McGrath and Ashley nd:34). Higher pressures, 125-150 psi, were widely employed mid-century (Hunter 1949:131). Consequently, high-pressure boilers capable of operating at 150 psi, would have been expected to withstand pressures equivalent to the 1½-times-working-pressure test or 225 psi. This latter pressure, although illegal but perhaps in common mid-century use, can be considered the upper pressures an intact boiler would be generally capable of routinely withstanding, although their burst pressure would be much greater. Based on blast pressure calculations, *Hunley* would have received pressures in excess of rated test pressures for the boiler composing the central hull portion to at least 200 feet from the torpedo blast.

Hunley's central boiler hull portion was most likely the strongest part of the hull. Plate seams riveted to form the bow and stern tapers and those of the cast-iron bow and stern ends were probably weaker than the boiler, which was made and surely tested as a pressure vessel. Although not conclusive, *Hunley* was likely close enough to the torpedo blast to part some seams, causing a leak that could not be overcome by the pumps. The forward hatch coaming damage may have been the final factor in *Hunley*'s sinking. The question of the blue lights remains. *Hunley*'s crew had to open the hatch to show the blue lights, why would they have rescaled the hatches if the vessel was leaking or damaged in any way?

Escape and evasion of the Union patrol boats by the crew is unlikely, but definitive

evidence is only to be found in the submarine's interior. Potential for preservation of skeletal remains in *Hunley* is high. Skeletal materials, though rare, have been located on shipwrecks in many environments, including warm, shallow seas (Carrell 1997:198-199). For example, human remains were recovered from La Salle's *La Belle*, lost off the Texas coast in 1686 (Arnold 1997:228), from the 1733 Spanish plate fleet vessel *San Jose* lost in the Florida Keys (Peterson 1972), and from thousand-year-old sites in the Mediterranean off the French coast, where bone preservation may have been enhanced by phosphate deposition (Arnoud et al. 1980). There is some evidence that iron contributes to bone preservation. Bones located within the buried Gold Rush storeship *Niantic* in San Francisco were found to be highly mineralized and well preserved, which was attributed to the relatively high iron concentration from nearby ship's fasteners (Smith 1981:184).

This blast analysis has implications pertinent to recovery operations. It may be likely that *Hunley*'s hull seams represent significant lines of weakness because of both blast damage and differential corrosion, which is discussed below. Hull seams were an important aspect of the archeological hull investigation. Only one vertical seam was clearly identified on the hull portion exposed during test excavation; corrosion products obscured all others. Should the hull be recovered, evidence clearly indicates that it must be completely secured prior to any lifting attempts or the hull could be damaged and archeological evidence of *Hunley*'s sinking be lost.

Hull Location and Position

Hunley was located about 1,000 feet east, seaward, of *Housatonic*'s remains. Hull axis was 297° 11', bow to shore similar to the *Housatonic*'s mooring orientation. This

position may represent the final surface orientation. The vessel, filled with water would have been about 11 tons deadweight, represents a substantial object. However, depending on how fast the vessel filled with water, there would have been at least some time partial buoyancy would have allowed current or waves to alter the hull orientation as it sank. Judging from the hull position, the starboard dive plane supported the hull at least as it came to rest. There was no damage observed on the port dive plane; the plane appears to be perpendicular to the hull. This indicates the hull probably settled sufficiently soon after sinking to prevent transverse rocking that could have bent the port dive plane. *Hunley*'s location seaward of *Housatonic* is likely the result of tidal influence during the vessel's sinking.

BURIAL SEQUENCE

Burial sequence data were sought in multiple lines of evidence because it is important to interpreting hull corrosion data relevant to hull strength. Single exposure would indicate *Hunley* shell plate metal might be better preserved beneath the encrustation. Repeated hull exposures could indicate a more advanced state of deterioration, making hull recovery difficult or impractical. Evidence collected pertinent to hull burial sequence includes visual examination of hull encrustation characteristics, historical evidence, modern evidence from examination of comparable structures, biological indicators, sedimentary analysis and sediment-bound radioisotopes measurement.

Historical Evidence

Historical documentation pertinent to establishing a burial sequence begins soon after the *Hunley-Housatonic* engagement. *Housatonic* was investigated in detail in November 1864. In the nine months since

sinking, the vessel hull "settled in the sand about 5 feet." A specific search was conducted for the submarine at that time. Investigators dragged "an area of 500 yards around the wreck, finding nothing of the torpedo boat" (Lieutenant Churchill in *Official Navy Records*, cited in Kloeppel 1987:93). In 1872, the Army Corps of Engineers contracted for work on both wrecks: clearing *Housatonic* wreckage to 20 feet below mean low water and removal of *Hunley*, but "the torpedo boat . . . could not be found." The ship's hull still presented an obstacle, and in 1909 an additional seven feet were removed, which primarily consisted of blasting and removing the ship's boilers (Kloeppel 1987:93). Based on the November 1864 observation, *Housatonic* initially subsided in Outer Charleston Harbor's seabed at a rate of about six inches a month.

Modern Evidence

Artificial Reefs

Subsidence rates for objects in the vicinity of the *Hunley-Housatonic* site have not been scientifically studied. However, there are some pertinent empirical observations from scientists working with analogous steel structures on the seabed in the immediate vicinity. South Carolina Department of Natural Resources (DNR) researchers observed hundreds of artificial reef structures along the South Carolina Coast, and they reported that burial of these artificial reefs, for example, ten-foot long, five-foot diameter steel structures, "is typically gradual with complete burial of objects the size of *Hunley* taking well over 10 years" (Appendix C).

Snag Reports

The hypothesis that *Hunley* rapidly subsided into the seabed after sinking is supported by both historical data and more recent snag

reports. The present study area is in an extremely productive area for shrimp and, consequently, has been intensely fished since at least the 1920s. Had *Hunley* been above the sediments in recent times, at least since intensive shrimping began, it would have likely been repeatedly snagged. Careful visual investigation of upper hull surfaces and hatches revealed no evidence that *Hunley* had ever been snagged. The only hull damage observed was on the forward hatch coaming, which we believe is attributable to events occurring during the *Housatonic* attack. South Carolina DNR, Marine Resources personnel knew of no snags recorded in the immediate *Hunley-Housatonic* site area (Bell, personal communication, 1996; Appendix C). Apparently, there has not been sufficient material above the bottom on *Hunley* or *Housatonic* to snag fishing gear.

Biological Analysis

Biological indicators can be used to establish a burial sequence for objects introduced to the seabed. Well-documented biological pioneering sequences are available for the Charleston Harbor area, and they can be used to inform on *Hunley*'s burial history. Examination of hundreds of steel structures, some within a mile of *Hunley*, monitored by biologists as a normal part of their artificial reef program research evinces a typical pioneering sequence on newly introduced ferrous objects of: barnacles occurring in a matter of months; bryozoans, hydroids and algae next; and hard corals occurring in 3 years.

Project principals requested assistance from South Carolina DNR assistant director John Miglarese for biologists experienced with underwater pioneering organism succession to conduct a biological assessment of *Hunley*'s hull. On May 21, DNR Marine Resource biologists Melvin Bell and Robert Martore, who research artificial reef biology, conducted a survey of the upper hull and hatches being

exposed by excavators. Excavation was halted during their dive to improve visibility, which was variably two feet or less. At that point, the hatches, hull top and port hull-side portions were exposed. There was an area forward of the aft hatch exposed all the way to the keel, which was excavated the day before their examination. The specific hull survey objective was to inventory species for hull burial sequence evidence. We wanted to have this biological survey done early during test excavation to preserve evidence of organisms with fragile

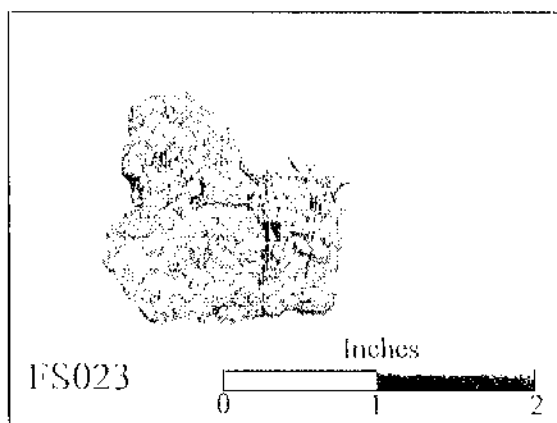


Figure 9.6. Star coral (*Astrangia danae*) removed from *Hunley*'s hull.

holdfasts, which might indicate recent hull exposures.

The biologists examined all exposed hull portions and collected five intact, complete star coral colonies (*Astrangia danae*, Figure 9.6) representative of observed corals. All corals located were on the hull's upper surfaces. Two samples were from each hatch and another from the hull top aft the snorkel box. These slow-growing star corals, the most common in the region, develop in unbranched patches seldom exceeding 5 centimeters in diameter. Laboratory experiments have established a 3–6 polyps-per-year growth rate. Coral colony size indicates continual growth between 5–13 years for four colonies, with one 30-millimeter

x 15-millimeter colony suggesting approximately 10–20 years of uninterrupted growth. Martore and Bell studied these samples to determine whether they were sequential or contemporary. "Based on the discoloration, similarity in size, and degree of wearing of the coral colonies examined, all appeared to be from approximately the same fouling community, suggesting one period of time in which significant bio-fouling took place" (Appendix C).

The biologists observed only one other organism attached to *Hunley*, small (5 centimeters) horse oysters (*Ostrea equestris*), a common subtidal, high-salinity oyster found in local waters individually or in small numbers. They located several specimens, each represented by a single valve; no intact organisms were observed. One representative oyster valve was removed for examination. Measurements indicated these oysters were of a size attainable in 2–3 years' growth, which supports the assertion of a single exposure at the time of *Hunley*'s sinking. Both these coral and oyster species take 2–3 years to establish a viable colony. Consequently, their absence on the lower hull portions suggests the lower hull was buried before these organisms could become established. More detailed laboratory analysis, should the hull be recovered, will augment these field observations.

The biologists' overall conclusion was:

...that after sinking, the *Hunley* subsided into the sandy ocean bottom but remained partially exposed for perhaps 10–15 years during which time a well-developed marine fouling community was established on any exposed surfaces. Eventually the entire vessel was buried and most likely remained so until it was discovered last year. All trace of encrusting organisms, with the exception of the hard parts of the corals and oysters, decomposed

over time (Bell letter to L. Murphy 5/30/1996, Appendix C).

Sediment Analysis

Several sampling methods were employed during *Hunley*'s investigation. Hand cores were taken close to *Hunley*, a gravity box core was attempted, two box cores were collected and bulk samples were recovered by hand from the stratigraphy above the hull. The gravity box core was unsuccessful; the sediments were so hard that the core head and catcher were bent during the sample collection attempt. All other samples were hand collected.

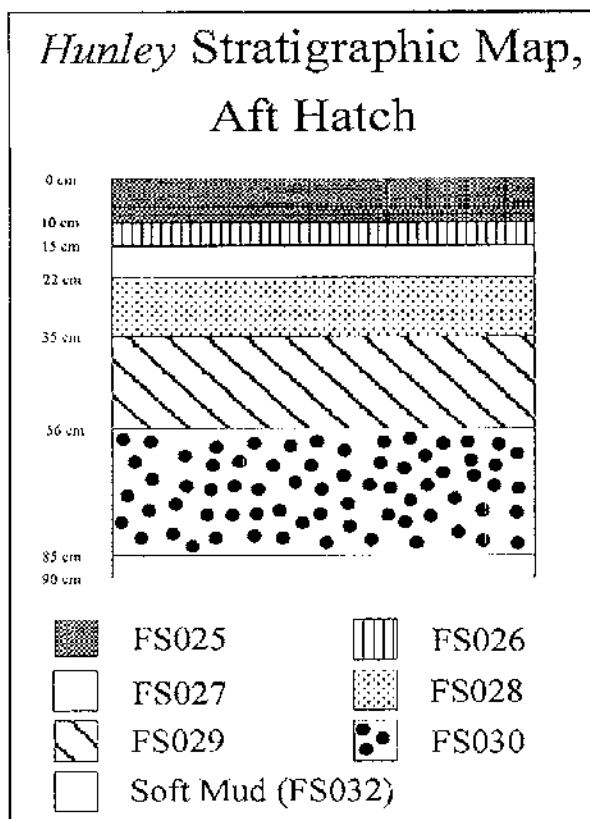


Figure 9.7. Stratigraphic profile.

Stratigraphy

On May 27, Lynn Harris and Larry Murphy mapped a stratigraphic profile (Figure 9.7), and hand collected six bulk-sediment samples,

FS025 030 from distinct strata above the starboard side (north) of the test trench, just aft of the aft hatch. Sample collection methodology involved facing the vertical north wall of the test trench with a sharpened trowel, drawing a stratigraphic map and retrieving a bulk sample by cutting into each stratigraphic layer and placing sediment into a labeled plastic bag that was sealed underwater. Later, each sample was split and repacked, one half to be used for pollen analysis, the other for sedimentological analysis. Offshore stratigraphic analysis has been useful to establishing the date and nature of inundated prehistoric sites and shipwreck depositions in high-energy environments, for example off the Florida coast (Murphy 1990). Stratigraphic analysis has been common in shipwreck investigation for decades (for example: Gifford 1982; McKee 1973; Muckelroy 1978:163-165,175-182). In addition to the bulk samples, a hand-deployed box core was constructed on site and used to collect a large sample of the sediment (FS032) immediately above *Hunley*'s hull for radiometric dating purposes.

Visual examination of the sediment reveals discrete strata, hard and compact, with no indication of storm-lag sequences of a depth sufficient to expose hull portions. Sedimentary analysis was conducted by the University of New Mexico Department of Earth and Planetary Sciences. Sediments encasing the hull are predominately sand, with variable concentrations of fines in the strata (Appendix D). Remarkably, the strata above *Hunley* and below the mobile marine sands were sufficiently compacted to allow vertical walls to be maintained. During stratigraphic mapping, the strata immediately above *Hunley* were faced with a trowel for mapping and sampling. Discrete strata and maintenance of vertical walls indicates these sediments have not been recently homogenized by storm activity and have remained in place for a time sufficient to allow initial lithification.

Sediment Dating

One analytic procedure important to assessing *Hunley* was dating sediments above the hull. If the sediments were of recent origin, it indicates the hull could have been subjected to episodic exposures to oxygenated water, which would increase corrosion rates. Procedures for dating sediments to determine accumulation rates has been often used in marine geology, but it has only recently been applied to archaeological problems.

The core sampling design was to collect two cores close to the *Hunley* site prior to any disturbance. On May 5, Jim Spirek and Peter Hitchcock collected two hand-driven stainless steel, plastic-lined cores (FS001, Core A and FS002, Core B). The procedure was to set a buoy on the site coordinates and collect these two cores approximately 10 meters away to ensure the hull was not encountered. The core represented an off-site sample of the surficial sediments. An additional hand collected core, called a box core (FS032, Core I), was collected containing sediments directly above and in contact with *Hunley*'s keel, representing sediments below 90 centimeters (Figure 9.7).

Radiometric dating for these cores was conducted by measuring the amount of the radioisotope ^{210}Pb (Lead 210) present. This procedure was developed in the 1960s as a means to establish a sediment chronology. In most environments, the maximum dating range for the procedure is 100–150 years. The radioisotope ^{210}Pb is a member of the $^{238}\text{Uranium}$ decay series derived from $^{222}\text{Radon}$, which has a half-life of 3.8 days and decays in the atmosphere. ^{210}Pb , with a half-life of 22.26 years, is supplied to bottom sediments primarily by stream runoff, where it is rapidly transported to bottom sediments and remains chemically immobile (Martin and Rice 1981:1–3). These characteristics provide a dating method that “has become the most important geochronometer for sedimentary geologist/geochemists working

with samples deposited in the last 100 years” (Cutshall et al. 1983:309). This seemed an ideal tool for assessing *Hunley* burial sequence.

Radiometric analysis of the three cores was done by Willard S. Moore, Department of Geological Sciences, University of South Carolina. All three cores were transported to his laboratory for analysis, and his report is included as Appendix E. Moore found the ^{210}Pb content of cores A and B (FS001 and FS002) did not diminish with depth, which indicates coarse well-mixed upper surficial sediments, which would be expected with upper marine sediments. These cores were separated into fine and coarse grains. Fine grains, or muds, contained most of the excess ^{210}Pb activity in Core A (FS001), consequently it was used for comparison. Core I (FS032), which was hand collected directly above *Hunley*'s hull, had depleted levels of ^{210}Pb when compared to the fines of Core A, and like the others, these levels did not diminish with depth. The top 3 centimeters of the fines of Core A were used as a baseline for calculating how long Core I had been out of contact with surficial sediments. Had the sediments at the depth of Core I been equivalent to the upper level of Cores A and B, it would indicate recent sediment mixing through some sort of mechanical process, such as wave activity or bioturbation. If the ^{210}Pb content was less, it would provide an indication of the last time these sediments were replenished with the radioisotope from surface sediments. Core I's ^{210}Pb content indicated it had not been disturbed for about 100 years. Moore summarized his findings: “I conclude that the average age of 100 years for material in Core I [FS032] is probably correct within a 20-year uncertainty.”

The radiometric dating results are consistent with the biological investigation conclusions. Implications of this radiometric sediment dating are important to consider when evaluating results of the in situ hull corrosion measurements. *Hunley* is likely in a better state

of preservation than it would have been had it been subjected to frequent exposures to moving oxygenated water, which typically increases the corrosion process. Instead of assuming the highest rate of deterioration of sound metal in the shell plate, there is sufficient data to assume a rate lower in the expected range of corrosion rates for wrought iron.

Palynological Analysis

Typically, palynological analysis for archeology is conducted for purposes of environmental reconstruction to develop a context for interpreting cultural materials. Underwater, pollen density information can aid assessment of depositional energy levels. Pollen deposited in high-energy aquatic environments rarely survives (Pearson et al. 1986:285–289). In *Hunley*'s case, pollen samples were collected primarily for chronometric purposes. Preliminary results of the biological investigation were supplied to the palynologists so that the hypothesis of rapid, single event burial of *Hunley* could be tested. Specifically, in addition to normal pollen analysis procedures, palynologists were asked to search for any historical markers, such as exotics or native species with established introduction or elimination dates. The assumption was that presence or absence of historical marker pollen in a particular stratigraphic layer could potentially provide a time marker for stratum deposition or disturbance. For example, presence of *Casuarina* (Australian pine), a twentieth-century exotic in the southeast, indicates a stratum is of recent origin, after 1900. Palynologists examining *Hunley* samples were requested to search for any historical pollen markers indigenous to South Carolina. One such potential marker for the study area is American chestnut (*Castanea dentate*), which was all but wiped out by the chestnut blight in 1904. This pollen would indicate sediments

deposited prior to 1900. However, further research concluded American chestnut historical range was limited to western South Carolina, no closer than 100 miles from shore, which eliminates this species as a historical marker. Chestnut pollen would not likely be present even in pre-1900 sediments on the *Hunley-Housatonic* site (Appendix F).

Paleo Research Laboratories of Denver, Colorado, analyzed the six stratigraphic samples collected from the excavation, and their report is included as Appendix F. Palynologists removed pollen from the bulk field samples through chemical extraction and flotation. Light microscopy studies revealed preservation was "excellent to fair." A 201-grain sample was used for each pollen count.

Analytical results included noting general similarity of the six samples, with a predominance of tree pollen. Arboreal types, which are mostly wind blown, are expected to be dominant in any site the distance *Hunley* is offshore. Pine (*Pinus*) was most numerous, followed by oak (*Quercus*) and grasses. There were no pollen types uniquely identifiable that could be used as a historical marker or introduced exotic. The pollen column alone was found to be consistent with sediment deposition at any time between 1863 and present. The researchers' conclusions were: "There is nothing in the pollen record that makes it inconsistent with the current belief that the *Hunley* was buried within 20–25 years of 1863" (Appendix F).

Summary

All evidence consistently indicates a probable burial sequence initiated by an exposure for an undetermined period, estimated at 20–25+ years, while the hull settled in the scabed sediments because of current scouring and wave action. Lower hull parts appear to have subsided within 3 years. No evidence for episodic exposures was found.

ARTIFACTS

There were few artifacts found during the *Hunley* test excavation, and there is no indication that these artifacts are directly related to *Hunley*, but they could be related to the *Hunley-Housatonic* site. Certainly associated in terms of proximity, none can be attributed to a particular source. These materials, while not from *Hunley*, could be from several origins, including *Housatonic*, any of the many blockade and other vessels anchoring in this area over time, vessels passing through the main Charleston Harbor ship channel close to the site, or even from onshore sources transported by storm waves as observed during hurricane Hugo, which deposited shore-related debris offshore in similar depths as the study area (see Chapter 5). The one argument that can be made for closer association is that all artifacts were found near *Hunley*'s hull bottom, perhaps a result of contemporary deposition in a port-side scour pit.

WOOD

A single piece of wood (FS004) was discovered close to *Hunley*'s port side dive plane by Robert Neyland during the test excavations. There were no straight surfaces or tool marks, and the sample appeared sediment abraded. Species identification, conducted by Paleo Research Labs of Denver, Colorado, with microscopic analysis of charred, tangential sections, which showed spiral or helical thickenings, indicated the wood was Douglas Fir (*Pseudotsuga menziesii*) (Appendix F). Douglas fir is native to the western United States ranging from Canada to Mexico. These trees do not grow on the east coast, consequently, this wood did not come from a local tree, but most likely arrived as a commercial product. Douglas-fir wood, sometimes called Oregon pine, is commercially important, widely used for ship hulls, masts and spars (Desmond

1919:16). The wood is also widely used for general construction, railroad ties, containers, boxes and pallets (Panshin and de Zeeuw 1980:465, cited in Appendix F). Like the other artifacts, though not directly associated with *Hunley*, it could be related to the *Hunley-Housatonic* site, or to any of the vessels passing or anchoring in the vicinity. Its location at the port dive-plane level, may indicate the wood was contemporaneous with *Hunley*, perhaps deposited in a scour pit formed during hull subsidence.

BONE

A single bone (FS007), Figure 9.8, was recovered May 23 during the test excavation by Dave Conlin from directly below *Hunley*'s aft hatch at the keel level. The bone was submitted to paleontologist Greg McDonald who reported the bone, most likely cow (*Bos*

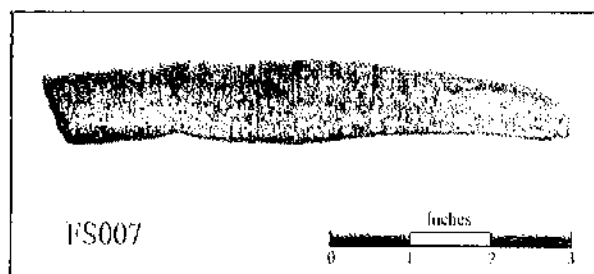


Figure 9.8. Bone (*Bos* sp.) from *Hunley* keel area.

sp.), to be a portion of sternal cartilage that connects ribs, probably from vicinity of ribs 6 to 9, to the sternum (Appendix G). The well-preserved specimen was somewhat ossified, denoting an older individual. Most original sternal cartilage was present, and it appeared to have been severed close to the ribs and sternum attachments. Microscopic investigation of the parallel cut surfaces showed them to be very smooth, indicating a saw rather than a blade cut. No other butchery marks, secondary scraping or cutting, gnaw marks or sedimentary abrasion were observed.

This cartilage represents a butchered meat portion from either a brisket or short-plate cut, most likely cut with a fine-toothed bone saw, which leaves a virtually smooth surface (Lyman 1977:67). Saws dominate in nineteenth century or later butchering practices. While not a single saw mark was found on eighteenth-century bones, the nineteenth-century bones were almost exclusively sawn at Fort Stanwix National Monument (Hanson and Hsu 1975:165). Similar observations occur on other nineteenth-century sites, for example the Hoff store site from Gold Rush San Francisco (Hattori and Kosta 1990:85). However, there is saw mark evidence, although rare, from seventeenth- and eighteenth-century sites (Landon 1996:64).

The beef bone located on the *Hunley-Housatonic* site probably represents fresh produce, rather than ship stores. Salt pork, a basic ships' stores, was much more abundant than packed beef, which apparently did not taste as good nor keep as well as pork (Hattori and Kosta 1990:87; Huelsbeck 1991:63). Congruent with period butchery practices, this bone represents a consumer-sized portion, with usable meat of 4 to 5 pounds, rather than a commercial butchery unit. In terms of status desirability, this cut is socioeconomically low-ranking, just above feet, head and shanks, or about 7 on a scale of 1 to 10, with 1 being the most desirable (Lyman 1979:543; Huelsbeck 1991:67,70), or 4 on a scale of 1-5 (Rothschild and Balkwill 1993:83). If from a vessel, it was probably not officers' fare. This bone could have originated from any vessel utilizing the anchorage or nearby sea lanes, or it could be shore-based storm deposit.

COAL

Two small coal pieces (FS006 and FS024) were recovered from near the keel forward of the aft hatch by Dave Conlin on May 23 and 25. The two coal samples were analyzed by

Curt White and Gino Irdi, physical scientists with the US Department of Energy Federal Energy Technology Center in Morgantown, West Virginia; their report is included as Appendix H.

The coal was subjected to standard petrographic techniques including polishing and microscopic analysis. Both coal samples contained distinct vitrinite, inertinite and clay mineral bands along bedding planes containing little graphite. Vitrinite reflectance of FS006 (larger) was extremely high, 9.20% mean maximum in oil; the second, FS024, was 4.90%. The higher value places that coal in the meta-anthracite category; the second within the upper anthracite range. White and Irdi noted that "New England is the only place in the United States where meta-anthracite could have been mined during the Civil War. No Confederate states' coal is in the anthracite or meta-anthracite rank."

Anthracite coal burns cleaner and more efficiently than the bituminous variety common in the South, but it is more difficult to ignite and keep burning. Although its existence was known in North America as early as 1768 (Greeley 1974:475) and mined as early as 1806, it was not used as a fuel until a grate invented in 1814 allowed continuous burning. Philadelphia produced most anthracite coal in the mid-nineteenth century, with more than a million tons being shipped by 1850 (Bauer 1988:120).

It is tempting to speculate that the coal is from *Housatonic*, and it could be. This vessel carried 220-235 tons of coal (Canney 1990:95). In November 1864, nine months after it sank, *Housatonic* was reported to still have coal heaped in the lower deck (Kloppel 1987:93). However, other sources must be considered. While anthracite coal was not mined in the South, it was available and highly prized for use in blockade runners because it produces little smoke when burned making these clandestine vessels more difficult to see. Many blockade-runner voyages began in Bermuda

where anthracite coal was loaded (Scharf 1887:466). The *Hunley-Housatonic* site area just off the main Charleston Harbor ship channel was heavily used over a long time period by passing and anchoring vessels and, like the bone and wood specimens, the coal could have come from many sources, or even washed from shore.

HULL ANALYSIS

Given the paucity of first-hand historical records about *Hunley*, the material record is the best source for accurate vessel information, as it is with most historical shipwrecks. Clearly, information contained in the archeological record will include much more than technical details about *Hunley*'s construction and appearance. The submarine's remains may hold clues to the events following *Housatonic*'s loss February 17, 1864, and answer such basic questions as: What caused *Hunley* to sink? Was *Housatonic*'s last-minute defense at all effective? What actions did *Hunley*'s crew take to prevent their demise? What items did the submarine's crew bring on the attack voyage? The vessel's remains may also inform on broader anthropological and historical questions (for example, see Gould 1983), such as the nature of Southern industrial capability, extent of its innovation response to Northern industrial superiority, and the nature of risk acceptance in blockading situations; and issues such as adaptive reuse, heroism and perhaps desperation. Clearly, *H.L. Hunley* as an archeological site holds much more potential than augmentation and revision of a scant historical record.

HULL FEATURES

Hull Construction

One detail important for both corrosion studies and determining lift information was

shell-plate thicknesses. *Hunley*'s central hull portion was reportedly constructed from a wrought-iron boiler to which was added additional plates and cast-iron features. There is only one allusion to shell plate thickness recorded historically, McClintock's statement that 5/8-inch thick plates were used in *Hunley*'s construction, which may be referring to both the central boiler portion and the stern and bow ends (Public Records Office, ADM 1/6236). Alexander states the hull was composed of cast ends affixed to a boiler, which may have been, as noted in Chapter 4 above, either a steamboat or a railroad boiler. It was most likely a steamboat boiler, which was probably more available in the port city of Mobile.

During the period of *Hunley*'s construction, western river steamboats from 250 to 350 tons in size carried two to four boilers typically ranging in size between 36 and 42-inches in diameter. To make them much less than 36 inches made them difficult to clean, while over 42 inches sacrificed strength to size. Boiler lengths generally ranged between 24-30 feet long (Hunter 1949:156-157).

As discussed in Chapter 7, several acoustic methods were attempted to nondestructively ascertain a hull-plate thickness. Locally obtained samples of wrought and cast iron were used to establish speed-of-sound parameters for these metals. Normally, acoustic thickness gauges are set for sound speed in steel, but the instruments tried on *Hunley* could be adjusted for the constituent metal being tested to produce more accurate results than could be obtained from extrapolation from steel. During the project, three different acoustic instruments were tried to detect the thickness of solid shell-plate metal. The best instrument, a Cygnus Ultrasound Thickness Gauge developed to penetrate hull fouling on modern vessels, was unable to produce a reliable shell-plate thickness reading during approximately 100 attempts along the hull. Consequently, the only

way to obtain an accurate shell-plate thickness requires physical hull penetration, which was not done during the project.

The central hull was closely examined during the excavation, corrosion studies and hull-thickness testing for features that might indicate the original boiler source. The hull was also examined for areas of weakness related to original construction details or later revisions such as vertical and horizontal seams, man holes, inspection ports, fittings or support bracket locations, etc. Examination of the boiler plates could reveal the manufacturer, if the boiler were of recent manufacture -- an 1852 federal law regulating boiler construction and inspection required boiler plates to be stamped with the manufacturer's name (Burke 1972:110). If the plate manufacturer could be identified, then the company's capabilities could be researched to aid deduction of hull-plate thickness. Another field approach attempted was to utilize historically documented rivet patterns and seam construction details in comparative analysis with *Hunley's* features. An estimate of boiler thickness might have been generated by using contemporary boiler design formulas that specify rivet patterns and pitch (distance apart) for specific plate thicknesses, seam design and overlap (International Correspondence Schools 1921a:34). The approach was to determine *Hunley's* rivet patterns and seam construction, and then use the design formulas to solve for thickness. Unfortunately, encrustation and corrosion product obliterated all hull rivet evidence, allowing recognition of only a single transverse (vertical) seam in the central hull portion (see Figure 8.2). No additional features of the original boiler form like hand holes, manholes, bracket supports, steam fittings, repairs or revisions were observed.

The two hatches, or conning towers in current submarine nomenclature, contained viewports only on the port side, which was unexpected from historical documentation.

This may have been strategic; the starboard would present no hull penetrations vulnerable to small arms fire.

Several hull deadlights appeared to be cracked. Implications are that either these were cracked by the torpedo blast during the attack, or they cracked post-depositionally, which means the hull may have distorted since it was sunk.

Keel

Keel ballast observations bring into question historical information depicting the keel constructed in three detachable sections (for example, as depicted in Alexander's plans, Figure 4.2). The stern keel-section we located, even the incomplete length exposed during the test excavation, appears too massive to be held onto the hull bottom by a single bolt, as depicted by Alexander. Cast-iron keel-ballast volume calculation based on measurements (discussed below) indicate the ballast should weigh 8,200 pounds or 4 tons, or about twice the estimate provided by Lt. George Gift who saw *Hunley* being shipped to Charleston (Turner 1995:5-8). Assuming three keel sections, each would weigh more than 2,700 pounds or 1 1/3 tons, an improbable load to, according to Alexander, be held by a single bolt and turned with a wrench. Investigators of *Hunley's* second crew loss, which included H.L. Hunley, in the Cooper River, noted the crew had apparently attempted to drop the keel ballast, but they "did not turn the keys quite far enough" (Alexander 1902 quoted in Kloeppel 1987:44 and Perry 1965:101).

However, if a keel section were held by two (or more) bolts, then there would be a problem of jamming one bolt when releasing the other(s) to jettison the ballast. Mechanical levering of a long keel section with multiple bolts would probably make dropping the keel impossible unless carefully coordinated, which would be quite difficult in emergency situations; i.e., if

only the forward bolt were released, leverage on the aft bolt might make it impossible to turn it to drop the keel. Another piece in the puzzle is Chapman's December 1863 painting, which shows multiple (at least six) keel-ballast segments. Future work on the *Hunley* site will likely reveal details of the keel ballast attachment system, which may incorporate a more sophisticated release mechanism, if they had a means to reliably drop it at all. In three sinkings, the keel ballast was not successfully released.

Another issue not discussed in the historical record, is whether *Hunley* could float upright on the surface without the keel ballast attached. Speculatively, if the crew dropped the ballast, would the vessel come to the surface, then invert because of hatch and snorkel box weight atop the hull? If the entire keel were dropped, the hull's metacenter would be raised and could cause the hull to roll, much like battleship and cruiser turret weight inverts the hull upon sinking in intermediate water depth, as observed on *Monitor* sunk off Cape Hatteras (Broadwater 1997) or *Nagato* and *Arkansas* sunk at Bikini Atoll (Delgado et al. 1991). Another example is the German battleship *Bismarck*, located in deep water without its gravity turrets, which apparently inverted, dropped its turrets and righted before settling on the seabed in 4,600 meters water depth (Ballard 1990). If *Hunley*'s hull would remain upright without the keel, it is evidence that precise hull buoyancy characteristic calculation must have been made by *Hunley*'s builders, and, even if empirically determined, indicates an unexpectedly high level of sophisticated engineering in its design and construction.

Torpedo Delivery System

There has been much speculation about *Hunley*'s torpedo delivery system, including an Internet discussion group. Alexander records the spar as being 22 feet long and the torpedo a

copper vessel containing 90 pounds of explosive with percussion and friction primer (see Chapter 4, Alexander 1902). If a trip line were deployed, it could have been fired as the submarine backed off a safe distance. There is no mention of any device that would allow affixing the torpedo to the wooden hull and backing off to explode the charge, although one must have been present. One possible alternative would have been to drop a weight to secure a positively buoyant torpedo beneath the hull, much like contemporary mines, and back off before firing with a trip lanyard. A reel, likely a lanyard reel for firing a charge regardless of its deployment, can be seen forward of the forward hatch on Chapman's painting, Figure 4.1.

Considering historically recorded attack details, it seems that a bottom-mounted spar, or one angled downward, is much more likely than the straight, bow-mounted spar depicted in the several contemporary images and models. Certainly the Confederates realized from practical experience that the most effective torpedo placement would be below a ship's waterline. At the time of *Hunley*'s attack, Confederates had experience with spar torpedoes, including the near sinking of *New Ironsides* by *David* the year before *Hunley*'s attack. Although *New Ironsides* was damaged, it did not sink, most likely because the torpedo explosion was not far enough below the waterline (Hunter 1987:142). General Beauregard, commander of Charleston Confederate forces, had ordered *Hunley* not to submerge. Undoubtedly, its crew knew about the unsuccessful *David* attack and rigged the torpedo so it was deployed below the ship's waterline for maximum effect.

Rigging a torpedo spar presented a rather complex engineering problem. The torpedo must have been retrievable from the forward deck. In Alexander's procedural account for the six months training period prior to *Hunley*'s attack, they "shipped" the torpedo on *Hunley*

before leaving and unshipped it upon return (Kloeppel 1987:52). The spar would have had to handle the more than 100-pound combined weight of the torpedo and charge out of the water, although it could have easily been made neutrally buoyant when submerged. If there was a point of some kind to embed in a ship's hull, the torpedo housing would have had to withstand the inertial impact of a ten-ton object going several knots when *Hunley* secured the torpedo to hull timbers. The torpedo spar would also have to be rigged to endure the same impact. The torpedo socket that must have articulated with the spar had to allow a positive release and be angled so as to contact the hull perpendicularly. In addition, because *Hunley*'s attack was to the stern, the spar must have been low, perhaps with double angles to allow the point to reach the keel in the compound curves of the stern, implying that the torpedo depth might have been adjustable because *Hunley* clearly sought targets of opportunity. Ship lines of *Housatonic*, whose draft was 16.7 feet, show the stern fairing to extend well forward of the mizzen mast (Canney 1990:95). Chapman's painting (see Figure 4.1) contains two features, perhaps spar related, on the bow. There is a spar on the hull top and a downward angled second spar apparently affixed to *Hunley*'s lower bow.

The brief archeological examination of *Hunley*'s forward hull top during the excavation revealed no features that could have been attributed to attachments for torpedo-spar rigging. In all likelihood, the attachments would have been on the lower bow, and consequently, future excavation of *Hunley*'s bow must be conducted very carefully. There may be related features to the southwest of the bow as suggested by the magnetic contours, discussed above. Torpedo spar details should become clear with full bow excavation and laboratory analysis.

HULL WEIGHT

H.L. Hunley's hull weight, displacement or deadweight, is not historically recorded. This is, however, critical information for planning purposes should the decision be made to recover the vessel. The following conjectural analysis and the methodology used to develop an estimated hull weight, based upon archeological documentation, is presented as a starting point for considering hull recovery methodology.

Shell-plate thickness, a basic hull dimension necessary for calculating hull weight, was not documented during the test excavation because acoustic testing was unsuccessful, and it could not be derived nondestructively. In absence of archeological information, we must rely upon historical documents, and some speculation. Unfortunately, available documents, like many regarding *Hunley*, are not altogether clear, but two shell-plate thicknesses bracket the range of possibilities: 1/4-inch and 5/8-inch plate, although the latter has been argued excessive considering contemporary boiler-plate thicknesses and cold-rolling technologies. The boiler was variously reported as from a steamship or locomotive (see Chapter 4).

James McClintock, one of *Hunley*'s builders, in post-war correspondence notes that 1/4-inch-thick boiler plate was used for his "first boat" (Kloeppel 1987:1). In all likelihood, McClintock is referring to *Pioneer* in this correspondence. The vessel displayed at Louisiana State Museum, once thought to be *Pioneer*, is constructed of 1/4-inch-thick iron plate (Rich Wills, personal communication 1996), which indicates McClintock found 1/4-inch plate acceptable for submarine construction.

In McClintock's 1872 letter to British Admiralty officers in Halifax written while discussing defection (see Chapter 4), he

describes *Hunley*'s hull as being 5/8 inches thick (Public Records Office, ADM 1/6236). Historical *Hunley* descriptions indicate it was built of a center portion employing a wrought-iron boiler with added wrought iron sheets at both ends, and cast-iron features, including both bow and stern segments and hatches. Iron boiler plates used for constructing *Hunley*'s center, boiler-portion of the hull must have certainly been cold-rolled as were the added bow and stern sheets that faired the hull. Given contemporary technology, 5/8-inch-thick plate would have been much more difficult to cold roll than 1/4-inch-thick plate (Henry Winters, personal communication 1996). While true that 1/4-inch plate would be easier to produce, making it likely more available, the South certainly had rolling mills capable of producing either thickness. At the Civil War's outset, the Confederacy had at least one mill (Tredgar Iron Works of Richmond, Virginia) capable of rolling 2-inch plate and at least two more were built during the war. Although limited in comparison with northern capabilities, the South had at least 82 rolling mills, 11 of which were fairly large (Still 1969:10, 25, 34).

Desmond (1919:213) published a useful set of weights for a square-foot of "hard-rolled" cast- and wrought-iron plate thicknesses: 1/4-inch-thick cast plate weighs 9.386 pounds and wrought 10.07 pounds; 5/8-inch-thick cast plate weighs 23.466 pounds and wrought 25.176 pounds. While acknowledging it is reasonable to believe *Hunley*'s hull is 1/4-inch thick, the following hull-weight calculations were made assuming 5/8-inch thick wrought-iron plate to ensure conservative error for any future hull-lift and support calculations. For calculations concerning the cast-iron keel ballast, weight of a 1-inch-thick cast-iron plate, 37.545 pounds (from Desmond), was multiplied by 12 to produce a weight of 450.5 pounds per cubic foot for cast iron. Originally, calculations were done as if the hull were constructed of a single rectangular piece of iron plate 12.56 feet by 40

feet (502.4 square feet), obtained from unrolling a 4 foot diameter cylinder. An additional amount (originally estimated to be 20 per cent) was added to the hull shell-plate area to account for hatches, cutwater, snorkel box, rivets, seam overlap, propeller shaft and shroud, bulkheads, internal support and mechanisms. A refined calculation by naval architect Henry Winters using computer-generated hull lines based on archeological evidence, less hatches and other mechanisms, produced an area of 428.4 square feet to which he added weight to account for additional features listed above, bringing the estimated total *Hunley* hull area to 603 square feet. A square-foot of 5/8-inch wrought-iron plate weighs 25.176 pounds. The estimated hull weight including additional features is 15,181.13 pounds, or 7.59 tons. Hull displacement is generally given in long tons, which are 2,240 pounds, which give a total of 6.77 long tons.

Hunley's cast-iron keel ballast measures 1.83 feet by 0.4 feet, and for purposes of this hull-weight calculation, its length was estimated at 25 feet, based on length of the hull's central cylindrical portion. For this hull-weight calculation, the ballast was assumed to be rectangular in cross section, although indications (Alexander 1902 and on-site observations) are that it was cast to fit the hull radius contour. Estimated ballast volume is 18.3 cubic feet, giving a weight of 8,244 pounds or 4.12 tons (3.68 long tons).

Total *Hunley* hull weight is estimated to be, assuming 5/8-inch-thick hull plate, 11.71 tons or 10.45 long tons. However, additional factors must be considered for arriving at an estimated lift weight for planning purposes.

Archeological investigations indicate the hull is likely filled with sediment. The only hull breach allowing an interior hull view was on the forward hatch coaming (see Figure 8.7). Sand appeared to completely fill the interior at least to this level, which is clearly above the hull top. There could, of course be voids created

by interior bulkheads, but for these calculations, the assumption is that the hull is sediment filled. This sediment would have to be included in any lift calculations for recovery purposes. The internal hull volume was calculated as a 4 foot diameter, 40-foot-long cylinder minus 20 per cent for tapered ends, which gives an estimated volume of 402 cubic feet. Wet sand weighs about 80 pounds per cubic foot, which gives an estimated interior sediment weight of 32,160 pounds or 16.08 tons (14.35 long tons). Note: this estimate does not take into account the sediments encasing the propeller, shroud and rudder, which should be lifted intact with the hull to be excavated under laboratory conditions (see Chapter 10).

Hunley's minimum weight, assuming 5/8-inch-thick iron shell plating and not considering stern-feature sediments, is approximately 27.79 tons (24.8 long tons). In addition to hull and internal sediment weight, encrustation weight must be considered. Encrustation weight can be considerable; 2,544 kilograms (5,596 pounds) of encrustation were removed from SS *Xantho's* engine during laboratory conservation (McCarthy 1996:322). Because solid metallic hull weight, which has been reduced through corrosion during the encrustation process, must be estimated, and the encrustation thickness, which adds weight through sediment incorporation, is unknown, an additional 20 percent is added to the metal hull weight calculation. Consequently, minimum *Hunley* weight for lift calculations should be: 14 tons for hull and encrustation plus 16 tons for sediment or 30 tons (26.7 long tons). This weight combined with an allowance for stern sediments should be considered the minimum weight for planning purposes.

The following data provide some information for speculating about actual hull weight and giving a check on the assumptions made in the course of these deliberations. For the following calculations, it is assumed that internal hull volume and displacement are the

same. Hull-line calculations give a hull volume of 402 cubic feet, with another 18.3 cubic feet for ballast. An additional 5 cubic feet displacement allows for the hatches and air box giving an estimated 425 cubic feet displacement for *Hunley's* hull. Thirty-five cubic feet of sea water are equivalent to a long ton (Desmond 1919:28). Consequently, hull displacement is estimated to be 12.14 long tons, which gives 1.7 tons positive buoyancy based on the 10.45 long-ton deadweight estimate discussed above. Considering an additional 1,000 pounds for crew would make the hull 1.25 tons positively buoyant, which would require admitting about 43.75 cubic feet of water to attain neutral buoyancy.

As a test to ascertain how these assumptions affect 1/4 to 5/8-inch plate thickness parameters, similar calculations were done assuming 1/4-inch-thick shell plate. If the hull weight is calculated on 1/4-inch-thick plate, the total hull weight is 6.83 long tons, which means the hull would have had 5.31 long tons of positive buoyancy requiring water occupying 185 cubic feet, or nearly half the available internal space, to bring the vessel to neutral buoyancy. Quarter-inch-thick plate for *Hunley's* construction appears much too light, and these estimates seem to support a thicker hull construction; the implications of which are also important to hull strength and corrosion estimates. Consequently, 5/8-inch-thick hull plate appears to be supported in these conjectural calculations. In all probability, *Hunley's* hull is constructed of various shell-plate thicknesses, a mix of cast-iron features and wrought-iron plates, the largest and most common may be 5/8 inch thick.

CORROSION STUDIES

Credible archeological inference must account for factors that alter archeological materials after they are deposited. Examining the genesis of the archeological record and controlling for post-depositional variability has

been a concern for archeological interpretation for nearly two decades. Schiffer (1987:7,11), one of the primary theorists dealing with archeological record variability, recognized two kinds of formation processes affecting the archeological record: cultural, where the transformational agent is human activity; and natural, wherein the transformational agent is the natural environment apart from human impact. Muckelroy (1978:160-175) conducted the first systematic study of site formation processes on shipwrecks when he examined the environmental contexts of 20 wrecks in Great Britain and developed a categorization of shipwreck transformational processes, which he termed extracting filters and scrambling devices. On underwater sites, corrosion is a major transformational process that variably alters site preservation and appearance of materials; iron is especially susceptible. Corrosion can completely remove all but the faintest traces of some iron artifacts on relatively recent wrecks, and preserve others of great antiquity, such as the 2,200-year-old Kyrenia wreck that contained sufficient metallic iron to produce readings on metal detectors and magnetometers (Green et al. 1967).

Corrosion studies are not new to archeological evaluations of submerged metal-hulled vessels. Corrosion studies were conducted on the USS *Tecumseh* as early as 1969, when researchers noted heavier corrosion of rivets relative to wrought iron plates (Baker et al. 1969). In situ studies have been conducted on USS *Arizona* (Lenihan 1989) and USS *Monitor* (Arnold et al. 1991) in the United States; and on SS *Xantho* and *Sirius* in Australia (McCarthy 1996). The problem in the case of *Hunley* is to determine the state of preservation, and by implication, strength of the metal comprising the hull so that a recommendation for future action regarding its preservation can be made. This section presents the rationale, methodology and results of the *Hunley* in situ corrosion study.

Water and Sediment Analysis

Environmental characterization is an important first step for corrosion studies. Several water samples were collected on the *Hunley* site for analysis. On May 23, Carl Naylor used 60 centimeter syringes to collect FS008 from close to the aft hatch and FS009 from mid-water above the site. Additional samples, not attributed sample numbers, were analyzed on site with a refractometer which gave a salinity reading of 33 parts-per-thousand (ppt) for both samples. Readings for on site measurement of pH was 7.5 and dissolved oxygen 1.9 at the hull. FS008 and FS009 were analyzed by John Jones of the South Carolina Department of Natural Resources Laboratory. FS008 read 33 ppt salinity, hydrogen sulphide (H_2S) of 0.12 milligrams/l and ammonia 0.2 milligrams/l. FS009, the mid-water sample, was 33 ppt salinity, H_2S 0.0 milligram/l and ammonia 0.0 milligram/l. Jones stated these readings are typical for the area.

On May 27, Lynn Harris and Larry Murphy hand collected six bulk-sediment samples, FS025-030 from distinct strata above the starboard side (north) of the test trench, just aft of the aft hatch as described above (see Figure 9.7). Sedimentary analysis of these samples, conducted by the University of New Mexico Department of Earth and Planetary Sciences, are presented in Appendix D. Unfortunately, no on-site pH measurements could be taken because there was no submersible meter available. Sediment pH measurements of bulk samples are presented in stratigraphic sequence in Table 9.1.

Iron Corrosion in Sea Water

Iron corrosion, fundamentally an electrochemical process, is a remarkably complex phenomenon that is greatly accelerated in sea water. Estimates of iron corrosion rates in sea water are 10 times faster than in air

Table 9.1. Stratigraphic pH of strata above *Hunley* hull.

SAMPLE	pH	AVERAGE
FS0 25A	7.55	7.54
B	7.53	
FS0 26A	7.76	7.72
B	7.67	
FS0 27A	7.77	7.76
B	7.76	
FS0 28A	7.27	7.29
B	7.31	
FS029A	7.59	7.62
B	7.66	
FS0 30A	7.54	7.53
B	7.53	

(Hamilton 1976:8). Iron corrosion in sea water is typically described in terms of galvanic cells, wherein metals, or areas of the same object, with a negative potential relative to hydrogen, and metals or areas more positive than hydrogen with a positive electrode potential, create an electrochemical cell. When two metals, or areas of the same metallic object, form an electrochemical cell, current is produced and the positive electrode, or anode, erodes, and the more negative electrode, the cathode, is protected. This cell produces a voltage, called corrosion potential, which indicates the corrosion rate. The *Hunley* in water measurements were conducted to measure this voltage as an indicator of which areas were

actively corroding, their location and rate. Factors, such as exposure to flowing, oxygenated water, salinity and temperature affect corrosion rates, generally increasing in a direct relationship.

Both wrought and cast iron are typically found in sea water encrusted with a layer of hard concretion or encrustation, which was the case with *Hunley*. This concretion can be much harder than the partially corroded iron beneath. During laboratory conservation, this iron concretion is removed, and the supporting iron is treated so as to stop further corrosion from taking place. North (1976), who has investigated concretion formation on shipwreck iron, provides a brief description of the process. When an iron object is introduced to most marine environments, coralline algae, siliceous diatoms, foraminifer and bivalve molluscs colonize it and lay down a layer of calcium carbonate. This process continues layer by layer, but corrosion can take place beneath the concretion. Concretion may slow corrosion rates, but clearly does not stop them, particularly in anaerobic conditions where microbes may speed corrosion (MacLeod 1989, 1990; Rodgers 1989).

Hunley In Situ Corrosion Studies

Description and Rationale

From initial project planning, we believed on site corrosion engineer participation to be critical to the *Hunley* assessment to determine its present state and level of active corrosion for planning future site management, whether the option to recover or preserve in situ is chosen. Special funding for this aspect of the site assessment was granted by the Naval Historical Center and the South Carolina *Hunley* Commission.

Project principals generated a series of questions and data sets to be addressed during on site corrosion studies in order to determine appropriate methodology:

- 1) State of present hull corrosion levels and whether it is stable or not. Data should contribute to the question of how much hull metal remains, its corrosion rate and projected deterioration rate.
- 2) Thickness of solid metal, important to inform on advisability of recovery and determination of best method. Structural integrity cannot be assessed visually, some instrumental measurements are necessary. One particular area of concern is the upper surface, which may have been subjected to exposure/burial events and may be less anodic than the buried portions.
- 3) Loci of active corrosion cells on accessible areas of hull. Active corrosion cell location and intensity coupled with hull thickness data should indicate structurally weak hull areas. We should be able to reliably "map" active corrosion of the hull, which will be important to planning recovery.
- 4) Determination of relative potential between different components, such as whether rivets are anodic to shell plates. Structural strength is dependent upon integrity of rivets. Electrical potential data can determine whether rivets are corroding or plate is corroding; i.e., if rivets are cathodic, they may still be sound and be contributing to hull strength and integrity.
- 5) These data should be sufficient to suggest a cathodic protection plan designed to minimize further corrosion

and begin in situ conservation, which may significantly reduce required conservation laboratory time. In situ conservation could significantly reduce conservation costs, should the hull be recovered. Australian investigations report notable consolidation of metal surfaces beneath encrustation in experiments with in situ conservation through cathodic protection.

A specialist was sought with experience directly relevant to minimum-impact in situ measurements of historical vessels. Dan Polly, a consulting corrosion engineer was located and retained for *Hunley* hull analysis. Polly had developed instrumentation capable of measuring corrosion rates remotely without having to remove encrustation.

Objective

The primary objective was to evaluate *Hunley* hull corrosion to determine nature and extent of present active corrosion through in situ measurements of electropotential (E_p), current flux and gradient, pH, sound metal thickness and other variables of accessible shell plates and external hull features. We also wanted to examine galvanic interaction and electrical continuity between components such as hull plates, plates and rivets and between plates and cast features like the hatch coamings. Lack of electrical continuity implies a breach in hull integrity.

Instrumentation

Direct measurement instruments and remote-sensing instruments were deployed. Direct measurement instruments such as bathykorrometers and most sonic thickness gauges require direct contact with hull metal and do not operate reliably through encrustation. Remote sensing instruments are a new

innovation in corrosion measurement technology and require no impact to encrustation.

Polly provided patented instruments of his own design. One, called a RISC wand, was developed to measure the surface current generated by corrosion potentials of iron reinforcing rods encased in concrete and was adapted to underwater use on this project. The surface probe is a computer-connected, remote sensing device that can detect whether active corrosion is present without removing encrustation. This device could determine whether features such as rivets are anodic to hull plates, as well as presence of macro-corrosion cells. The second instrument was developed to detect low level electrical current in seawater. This instrument measures current flux, intensity and direction of corrosion-generated (electrochemical) current. It detects corrosion on a larger scale than the other, such as between shell plates and between wrought and cast iron. This instrument is also connected to a surface computer. Together, the two instruments provide data on surface current flux, sea water voltage gradients, surface potentials and polarization behavior. A discussion of each measurement follows.

Surface current flux - Instrumentation measures magnitude and polarity of electrochemical current flow associated with corrosion activity. Activity is measured directly at the surface without any electrical connection. The system indicates level of activity at the sensor location, and whether activity is anodic or cathodic. With a sufficient number of readings, a current flux contour map of the structure can be obtained, which images the surface to the resolution of the mapping grid spacing.

Sea Water Current Flux /Voltage Gradient - Instrumentation displays real-time measurements of magnitude and three-dimensional vector orientation of current flux in water. High sensitivity ($\mu\text{A}/\text{cm}^3$) and

resolution (cm) allows 4-dimensional plots of current flow magnitude and direction for the survey region.

Potential - Measurements provide an indirect indication of relative anodic and cathodic areas. Dependent on good electrical connection to measurement location. Readings are a broad (not localized) measure of surface potential compared to a reference electrode.

Potentiostatic - Instrumentation measures polarization behavior and the degree of electrical continuity between structure components. Dependent on good electrical contact with components. Method can establish the possibility of galvanic effects and cathodic protection criteria.

Methodology

Measurements requiring direct metal contact were canceled because hull encrustation could not be penetrated with an air drill and masonry bit. Consequently, encrustation thickness was not measured. However, one piece of encrustation (FS010) was removed for analysis from 1 foot forward of the forward port corner of the snorkel box and 1 foot down the hull. This sample was removed with a great deal of effort with a hammer and chisel, and it appeared to represent a cross section above the parent material. Encrustation location was sealed with DevClad 182, a pH-neutral epoxy designed to prevent creation of a local active corrosion cell (see Chapter 7).

Field measurements were conducted May 22 and 23, 1996. A field drawing of the exposed hull was provided to the surface data recorders to plot measurement locations received via diver communications. Measurements were taken by hand-holding the RISC wand sensor approximately 1 1/2 inches above the hull with cable connection oriented perpendicular to hull and pointed to the starboard side. The diver reported location of beginning, direction and ending of each transect and noted major features

such as large hull encrustations. Sensor distance off hull was maintained by the diver holding sensor in his right hand and allowing sensor to sit on inside of ring finger as sensor was moved along hull. Diver attempted to maintain constant speed along each transect, however, speed necessarily varied somewhat. PVC pipes were placed at and 7 feet forward of the aft hatch to aid in positioning sample collection points along the hull. These PVC pipes were plotted on the site field map, and the diver reported each time one was encountered, which assisted surface recorders in accurate positioning sample readings.

In addition to the RISC wand device, point measurements were also taken along the hull. For these measurements the diver carried a 1-foot long section of PVC pipe to position each reading. The instrument sensor base is approximately 4 inches in diameter. So, assuming the sensor detects at the sensor mid point, and the diver placed the 1-foot guide against the edge of the sensor, then sample points were 1 foot 4 inches apart along the hull. The diver reported each point reading, which

was confirmed from the surface when the reading was acquired.

In Situ and Laboratory Corrosion Study Results

Complete results of in situ corrosion measurements and laboratory analysis were provided by Polly (Appendix I), and the following discussion is from that report.

Encrustation Analysis

The encrustation sample (FS010) was analyzed with both a light optical microscope (LOM) and a scanning electron micrograph (SEM). The sample was also subjected to disperse X-ray spectroscopy with an electron micro-probe. Assuming the fragment represents a complete cross section, it supports a low corrosion rate. Metal loss calculations were made on a density comparison between the encrustation and wrought iron, which reflects 0.56 millimeter metal loss "indicating relatively dense corrosion products with approximately 5

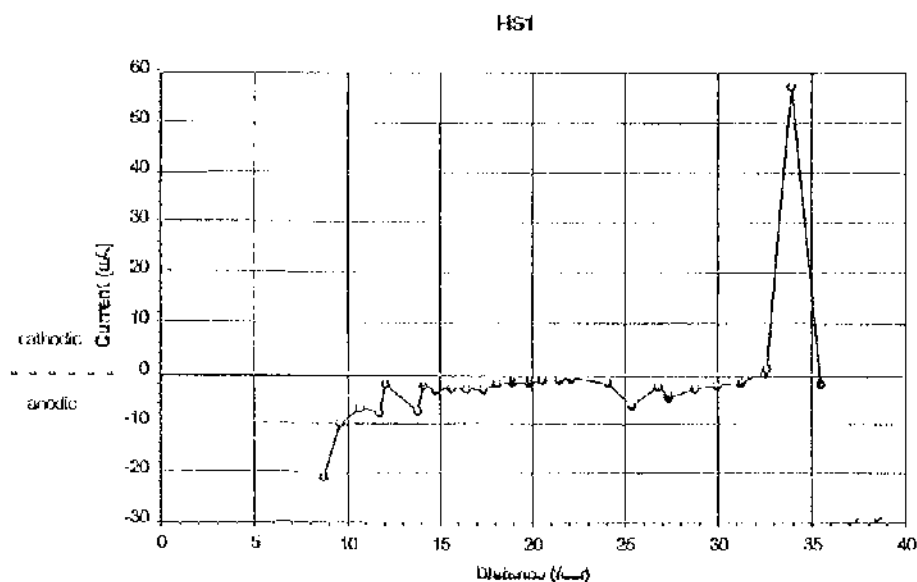


Figure 9.9. Surface current flux for transect HS1.

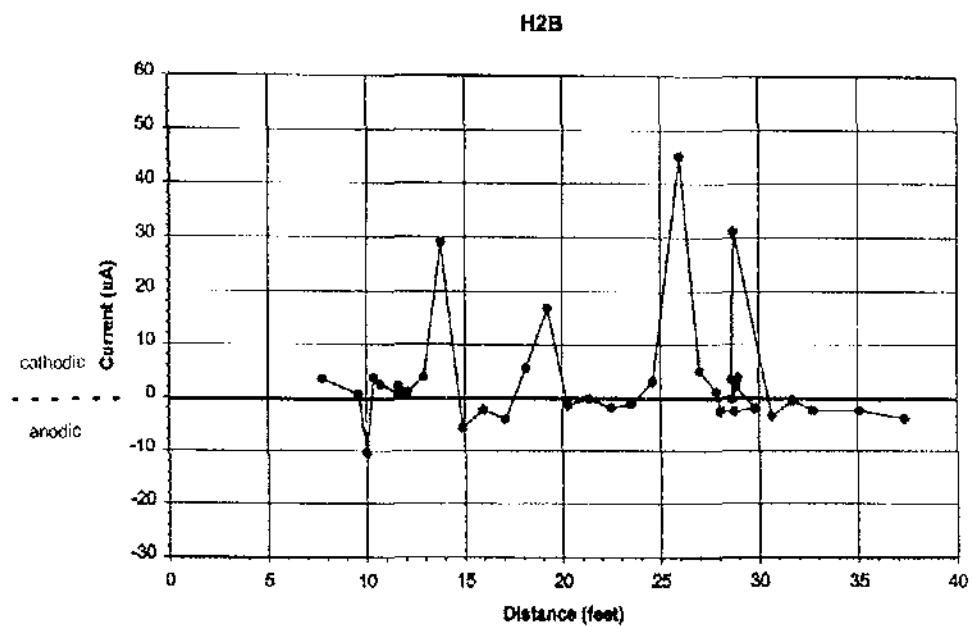


Figure 9.10. Surface current flux for transect H2B.

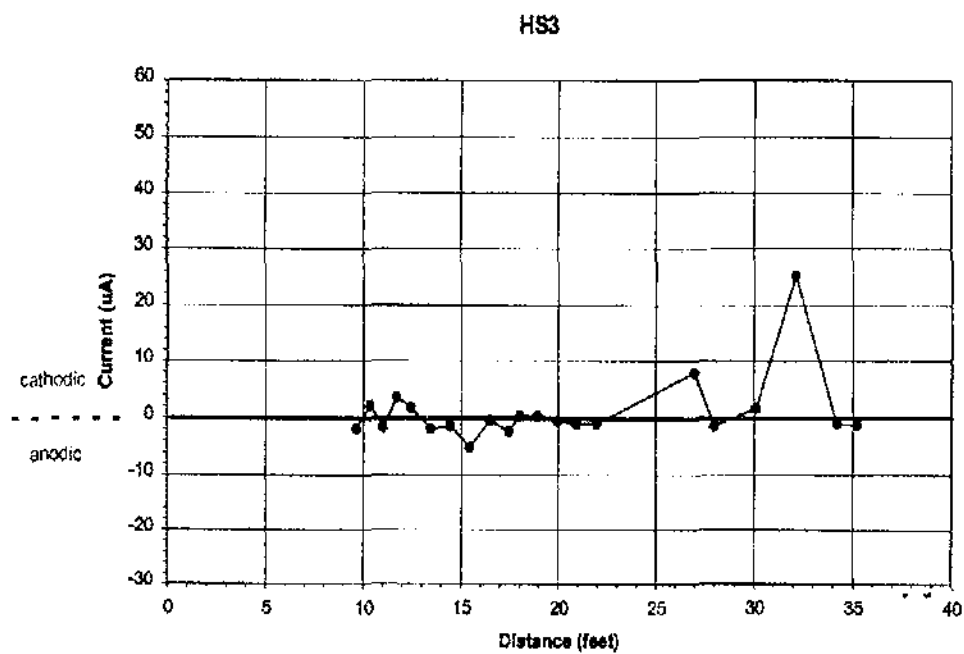


Figure 9.11. Surface current flux for transect HS3.

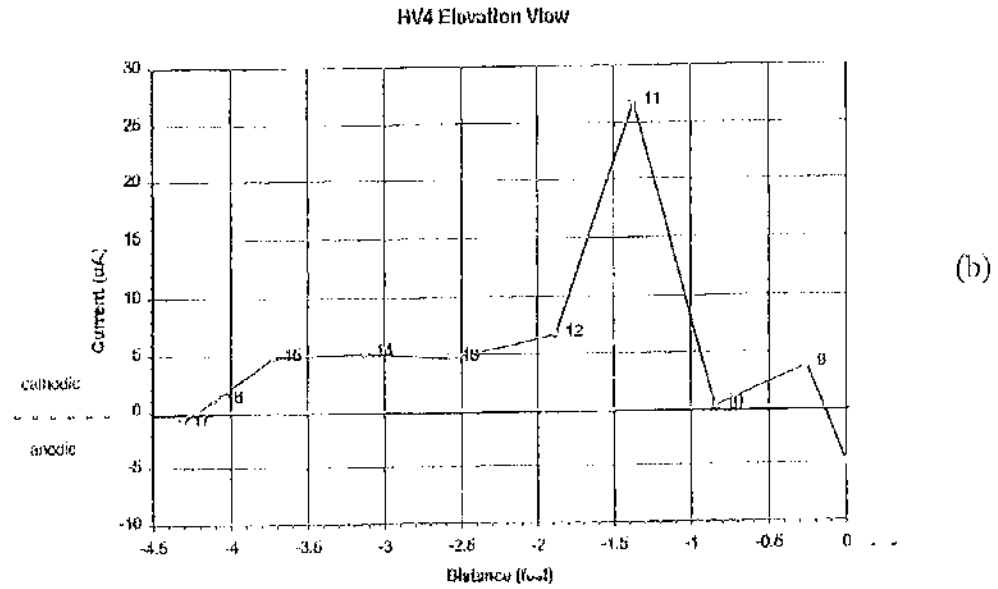
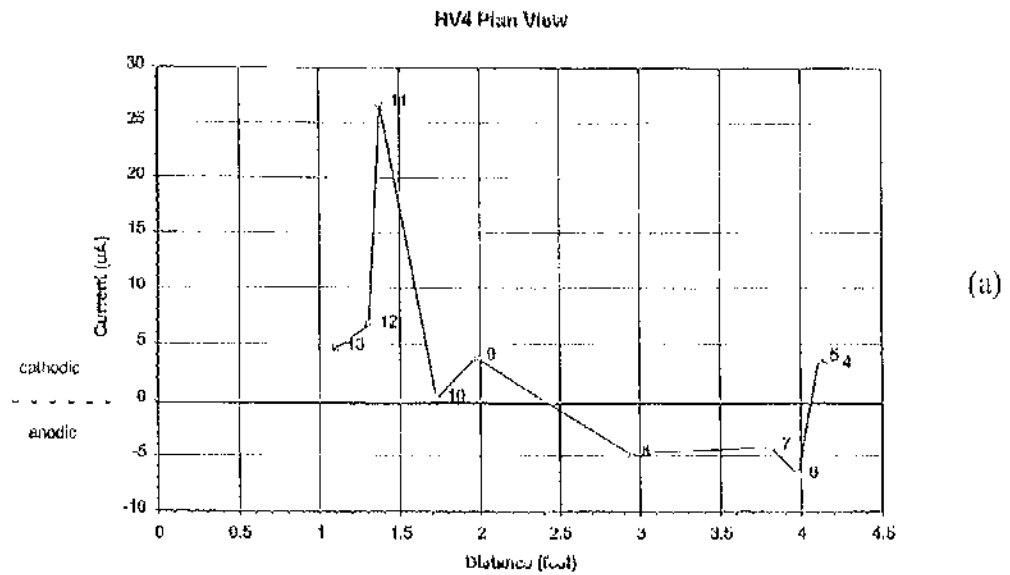


Figure 9.12. Plan (a) and elevation (b) surface current flux for transect HV4.

to 1 product to metal loss ratio.” Physical investigation of the hull supports the corrosion product as a tough, strongly attached layer resistant to mechanical impact and abrasion.

Electrochemical Measurements Reported by Polly

Surface Current Flux - Several transects, with periodic recordings of surface current flux, were made along the hull.

The transect designated H1S is a longitudinal transect proceeding from stern to bow, along the shell plate above the stern concretion, on the starboard side following the edge of the excavation at the excavation/hull interface. Most points are along the centerline of the hull top. Readings are plotted in Figure 9.9.

The transect designated H2B is a longitudinal transect from bow to stern on the port side of the centerline. Readings are plotted in Figure 9.10.

The transect designated H3S is a longitudinal transect from stern to bow. Readings are plotted in Figure 9.11.

The transect designated HV4 is directly aft of the aft hatch, from 18 inches below the aft hatch on the starboard side, up and over the hull top and down along the port side of the hull to the keel. Readings are plotted in Figure 9.12 for plan and elevation views.

Sea Water Current Flux and Voltage Gradients - A number of transects were made along the hull with the sensor positioned approximately 1 1/2 inches above the surface. Subsequent to the dive, sensor malfunction was observed. At what point in the dive this occurred is unknown, making all data suspect.

Potential - Potential readings were taken concurrently with the surface flux transect designated HV4. Connection to the hull was made by attachment, at a hole in the forward hatch, of an epoxy coated C-clamp with a pointed screw. All reading were -0.62 volts

relative to an Ag/AgCl/sea water reference electrode. The constant potential indicates there was inadequate electrical connection through the clamp, or isolation of the attachment point from other areas of the hull. [However, see MacLeod comments below.]

Polarization Behavior - Time constraints did not allow diver connections and equipment configuration required for these tests.

Analysis

Dr. Ian MacLeod, Department of Materials Conservation, Western Australian Maritime Museum, Fremantle, who has pioneered in situ corrosion measurements and conservation procedures on historical vessels, reviewed Polly's report and commented to the authors by email, and his comments are presented here (all figures refer to Appendix I):

From the current measurements it is clear that there is a significant difference in the corrosion environment of the submarine on the port compared with the starboard side. In figure 3 all but a few measurements on the starboard side are anodic to those from the port side which is consistent with there being a general difference in the rate of corrosion from one side of the vessel to the other. This would indicate that the starboard side is receiving a greater net corrosive flux from the dissolved oxygen in the sea water than is the port side where most of the readings are cathodic. The high cathodic current peak at about 35 feet from the bow indicates that there is a sudden shift in the micro environment of the iron and so this is consistent with a possible electrical discontinuity at this point. There may well be a break in the metal near this point of measurement. This localized cathodic point is also seen in

figure 5 which is a measure of the corrosion current as a function of distance from the bow.

Although the data points on the scale plan are reproduced in a very small font, it is clear that in the transect of the aft hatch there is a change in going across the site and downwards to the keel of a difference in corrosion environment. Not surprisingly for such a complex structure which is half buried in the sediments, there is a vast difference in the access of dissolved oxygen to the corroding interfaces and so there is a difference in the local areas from being dominated by the cathodic reduction of dissolved oxygen and the anodic oxidation of the hull.

In his discussion on the one E_{corr} measurement which was performed he stated that the instrument was not working properly because the voltage was -0.380 vs NHE (Normal Hydrogen Electrode, assuming that the sea water silver chloride reference had a calibrated value of +0.240 volts). Now since the concretion was largely composed of magnetite, Fe_3O_4 , it is clear that the iron has been corroding largely in an anaerobic environment and so the equilibrium pH for hydrogen evolution at that voltage is 6.4, which is spot on for a standard low corrosion rate low oxygen micro environment. The fact that the voltage was the same may well simply be a reflection that all the measured points were in the same micro environment.. I have found that even across an iron clipper hull vessel such as the *City of Launceston* (1860) the E_{corr} values may vary by as little as 20 mV

up and down the 50 meters of the site, for points at roughly the same water profile and impact.

In the analysis of the concretion I was not surprised to find there was no evidence of slag inclusions in the concretion as they are not mobilized in the corrosion process but normally remain close to the surface from which they came. Although the slag inclusions tend to help ensure uniform corrosion of wrought iron in the air, in the marine environment the wrought iron is very prone to zonal corrosion and corrosion along the lines of the working of the metal prior to it being placed on the seabed. Ulrich and Evans in the 1950s showed that in the heat of the fusion of the iron during hot forging, it is the copper and nickel oxide impurities which are reduced very rapidly in the increased heat to the metallic state. The necessary heat comes from the compression of the gases during the forging processes. It is these "noble" metals which act as local cells for the facile reduction of dissolved oxygen and so you end up with the zonal corrosion of wrought iron which makes it look like it is aged wood that has been degraded in the desert.

The observation that the corrosion rate appeared to be higher near the areas which had recently been excavated is not surprising as I have readily observed significant elevations of corrosion rate by a factor of about four to six times in the first few hours after accidental removal of the protective concretion layer around wrought and cast iron objects in a marine environment.

. . . The good points to note are that from the lack of any major sudden changes in the corrosion currents as you moved from bow to stern, there does not appear to be any discontinuity which tends to indicate that the submarine is essentially functioning as one electrical entity and so is largely intact. If it were not, the data would be all over the place. There may be a problem area down near the stern, as mentioned above.

In the absence of other data I can only imagine (I have no date for the vessel becoming a wreck) that the vessel lies in about 15–25 meters of water and it has been corroding since about 1865 or thereabouts. This means it has had about 130 years of decay at a rate of about 0.03 millimeter/year which means 3.9 mm loss of metal

SUMMARY AND CONCLUSIONS

Separate lines of evidence indicate *H.L. Hunley* was buried soon after loss, most likely within 25 years. Sedimentary evidence, biological evidence and ^{210}Pb sediment dating indicate the vessel has not been periodically exposed to sea water through episodic burial and reburial events. Exposure to sea water typically increases, and sometimes doubles, corrosion rates. Because *Hunley* appears to have been buried since initial deposition, it can be assumed to be stronger than it would have been if exposed, which indicates vessel recovery is more feasible than it would be otherwise. A lower level of predicted metal loss is acceptable for hull strength evaluation.

Close examination of the entire exposed hull shows the hull is encrusted with a very tough, strongly adhering layer resistant to mechanical impact and abrasion. This layer may

significantly reduce hull corrosion rates. Corrosion is taking place differentially throughout the exposed hull, which is an indication that sound metal is present to some degree. This verifies subjective observations of the investigators that no areas appeared weak, and no obvious areas of differential erosion, thin areas or penetrations in the shell plates were present. Overall, the hull and hatches appear solid, relatively sound and strong, the only damage being the hole in the forward portion of the forward hatch. At this level of investigation, based on hull observations, the hull appears likely able to withstand recovery and conservation. Because corrosion continues, *Hunley* will inevitably become so fragile to obviate recovery plans. Recovery is the desired alternative to long-term preservation in place.

For recovery planning purposes, the hull weight and interior sediments should be calculated on 5/8-inch thick shell plate, which is minimally 30 tons, with additional weight calculated for sediments encasing the propeller, shroud, rudder and other stern features. For engineering strength calculations, 1/4-inch plate (63 millimeter) should be assumed, which corrosion has reduced an estimated minimum of 3.9 millimeter. Shoring and support considerations should be developed to accommodate unexamined hull portions that may be very thin or even breached. The hull must be supported so as not to distort during the recovery and transport process.

Work in Australia (MacLeod 1989,1992; McCarthy 1988;1996) has convincingly demonstrated the desirability of beginning in situ conservation through placement of sacrificial anodes on large submerged iron objects. Should the decisions be made not to recover *Hunley*, or the recovery be delayed, consideration should be given to placing sacrificial anodes on the hull to arrest further corrosion and begin the conservation process.

CHAPTER 10

Conclusions and Recommendations

Larry E. Murphy, Daniel J. Lenihan and Christopher F. Amer

CONCLUSIONS

The site found May 1995, by National Underwater and Marine Agency (NUMA) personnel Ralph Wilbanks, Wes Hall and Harry Pecorelli and reported to the Naval Historical Center is *H.L. Hunley*. All data available to project personnel including scientific measurements, observations and tests so far unequivocally support this date as the initial twentieth century site discovery.

The test excavation revealed *H.L. Hunley* was encased in stable sediments and undergoing active corrosion, which suggests sound metal exists in the hull. Hull thickness could not be determined nondestructively during the project.

All indications are that *H.L. Hunley* is currently at a high level of integrity and preservation, and it retains sufficient hull strength to allow serious consideration of recovery if appropriate controls and care are exercised in all future activities that involve direct site impact.

RECOMMENDATIONS

1. We recommend that the vessel we have concluded is *H.L. Hunley* should be removed from its present resting place in outer Charleston Harbor and transported to a more controlled environment for further study and conservation treatment. Preservation in place is a preferred alternative to excavation in many circumstances. This option often includes the use of sacrificial anodes for in situ cathodic protection of large iron objects. However, project investigators have concluded that *H.L. Hunley* is under potential threat in its current location from unauthorized salvage, and it would serve the long-term interests of historic preservation to undertake archeologically controlled recovery operations.

2. Should complete hull recovery be undertaken, funding for full conservation should be in hand, and endowed funds should be available to support curation funding in perpetuity before initiation of recovery. Other

historic ship recoveries have suffered severely for lack of sufficient curation funds, even when sufficient conservation funds were available to care for the vessel upon initial recovery.

3. A complete recovery plan that includes hull retrieval, immediate post-recovery stabilization and conservation should be developed. Development and implementation of the research design should involve appropriate professionals in the fields of underwater archeology, marine salvage, mechanical engineering, ocean engineering, conservation and museum exhibits. Principal recovery concerns are archeological excavation of bow and stern extremities, internal sediment and complete hull support in situ and during removal and transport to the conservation facility. Stern features are likely extremely fragile. The procedure of choice would be to recover sediments encasing the stern features intact for excavation under controlled laboratory conditions. The hull seems full of sediment, which increases hull dead weight. Because of the archeological sensitivity of hull contents, internal hull sediments must be excavated under laboratory conditions. Proper preparations must be made to accommodate potential human remains. A specific protocol for handling, analysis, treatment and possible military reburial, should be in place before interior hull excavation.

4. A series of general request for proposals (RFPs) should be developed that outline the parameters for: 1) general on-site archeology, recovery, transport of the vessel remains to shore facilities and post-recovery archeology, 2) the laboratory excavation and conservation of the hull and associated sediments and contents, and 3) curation and exhibition of the remains. These RFPs would present the project objectives, major contract requirements, schedules, personnel requirement criteria, contractor qualifications and general provisions to be considered by potential contractors. RFPs should be published in the Federal Register to

ensure access by potential contractors. The RFPs should be administered through the Naval Historical Center and the South Carolina *Hunley* Commission.

5. Ideally, the hull should be recovered intact and immediately moved to a dedicated conservation facility. Transport of *Hunley* should be a safe, seamless and rapid conveyance from the seabed to a proper wet containment shore facility where it can be immediately stabilized, scientifically investigated and conserved so as to ultimately be available for public exhibition. The tasks of archeological investigation, sediment containment, lift, transfer from the seabed to the transport vessel, transport to shore and from transport vessel to shore facility should all be specifically addressed in detail in any proposal.

Intact recovery can be accomplished in several ways. A preferred method would be to encase the hull and surrounding sediments in a tube, or clamshell lift device designed to completely support and stabilize the entire hull length and stern features along with their surrounding sediments. Any device would have to support the hull during transport to shore and during the laboratory excavation phase. The hull would have to be opened for internal excavation, and the hull would have to be completely supported at least until the laboratory excavation phase was completed and the hull transported to a conservation tank. Hull corrosion rates must be continuously monitored from initial disturbance. Temporary electrochemical procedures, such as placement of sacrificial anodes or impressed current, will have to be done to stabilize the hull corrosion rate should exposure to a highly oxygenated environment rapidly increase corrosion. These procedures may have to be conducted during the excavation phase, and several contingency plans should be in place and tested in the event that primary stabilization procedures fail.

6. A complete conservation plan and facility must be in place before recovery. The

conservation plan must include a detailed plan for accessing and excavating hull sediments. A less desirable alternative would be to move the hull to a controlled area to begin in-water conservation before removal to a laboratory facility. Because iron typically corrodes at an accelerated rate when removed from low-oxygen sediments, preventive conservation methods, such as cathodic protection through placement of sacrificial anodes, should begin immediately. In addition, if this alternative is chosen, three factors must be considered: storm protection, security and potential effects conservation procedures might have on archeological materials contained in internal sediments.

7. Should *Hunley* be recovered, the immediate area of the site should be systematically surveyed and excavated to locate any associated material culture remains. The area between *Hunley* and *Housatonic* should also be systematically surveyed and any magnetic anomalies tested. Particular consideration should be given to the anomaly located between the two vessels during the predisturbance survey. Though not critical to *Hunley*'s recovery, it would be desirable to archeologically investigate the *Housatonic* site. This step will provide the archeological context for *Hunley* and augment with material evidence what little is documented regarding the *Hunley-Housatonic* engagement.

REFERENCES

- Abbot, H. L.**
 1966 *The Beginning of Modern Submarine Warfare under Captain Lieutenant David Bushnell*. Archon Books, Hamden.
- Alexander, W. A.**
 1902 The True Stories of the Confederate Submarine Boats. *New Orleans Picayune*, July 29.
 1903 Transcript of a talk given to the Iberville Historical Society, Mobile, Alabama, December 15. On file, Eustace Williams Collection, Emory University Library.
- Amer, Christopher F.**
 1996a *H.L. Hunley* Assessment Expedition Fieldwork Completed. *Legacy* 1(1):1, 14-15.
 1996b *H.L. Hunley* Archaeology Management Plan. South Carolina Institute of Archaeology and Anthropology's *Hunley* Project Working Group, South Carolina Institute of Archaeology and Anthropology. <http://www.cla.sc.edu/sciaa/hunley4.html>
 1997 *H.L. Hunley*. In *Encyclopaedia of Underwater and Maritime Archaeology*, edited by James P. Delgado, pp. 193-194. British Museum Press, London.
- Anders, Fred J.**
 1990 Shoreline Movement: Report 2—Tybee Island, Georgia, to Cape Fear, North Carolina, 1851-1983. *Coastal Engineering Research Center Technical Report* 83(1):152. National Ocean Service Distribution Branch (N/CG33), Riverdale, Maryland.
- Arnaud, G., S. Arnaud, A. A. Bonucci and G. Graziani**
 1980 On the Problem of the Preservation of Human Bone in Sea Water. *International Journal of Nautical Archaeology* 9(1):53-65.
- Arnold, J. B., III**
 1997 *La Belle*. In *Encyclopaedia of Underwater and Maritime Archaeology*, edited by James P. Delgado, pp. 228. British Museum Press, London.
- Arnold, J. B., III and R. Weddle**
 1978 *The Nautical Archeology of Padre Island: The Spanish Shipwrecks of 1554*. Academic Press, New York.
- Arnold, J. B., III and C. J. Clausen**
 1975 A Magnetometer Survey with Electronic Positioning Control and Calculator Plotting System. *International Journal of Nautical Archaeology* 3:353-366.
- Arnold, J. B., III, G. M. Fleshman, D. B. Hill, C. E. Peterson, W. K. Stewart, S. R. Gregg, G. P. Watts, Jr. and C. Weldon**
 1991 *The 1987 Expedition to the Monitor National Marine Sanctuary: Data Analysis and Final Report*. Sanctuaries and Reserves Division, NOAA, Washington, D.C.

Arthur S. C.

- 1947 *Pioneer: The First Submarine Boat Now on Exhibition in Jackson Square, New Orleans. Alabama Historical Quarterly* 9 (Fall):405-410.

Atkinson, L. P., T. N. Lee, J. O. Blanton and W. S. Chandler

- 1983 Climatology of the Southeastern United States Continental Shelf Waters. *Journal of Geophysical Research* 88:4705-4718.

Baker, H. R., R. N. Bolster, P. B. Leach and C. R. Singleterry

- 1969 *Examination of the Corrosion and Salt Contamination of Structural Metal from the USS Tecumseh*. Naval Research Laboratory, Chemical Division, Washington, D.C.

Ballard, R. D.

- 1990 *The Discovery of the Bismarck*. New York.

Baird, G. W.

- 1902 Submarine Torpedo Boats. *Journal of the American Society of Naval Engineers* 14(2):845-855.

Baner, K. J.

- 1988 *A Maritime History of the United States: The Role of America's Seas and Waterways*. University of South Carolina Press, Columbia.

Bearss, E. C.

- 1980 *Hardluck Ironclad: The Sinking and Salvage of the "Cairo."* Louisiana State University Press, Baton Rouge.

Belknap, D. F. and J. C. Kraft

- 1981 Preservation Potential of Transgressive Coastal Lithosomes on the US Atlantic Shelf. *Marine Geology* 42:429-442.

- 1985 Influence of Antecedent Geology on Stratigraphic Preservation Potential and Evolution of Delaware's Barrier System. *Marine Geology* 63:235-262.

Beres, A. W.

- 1995 Letter and Transfer Order Excess Personal Property from Assistant Commissioner Office of Transportation and Property Management, General Services Administration to Dr. William S. Dudley, Acting Director of Naval History. Letter dated July 13. On file, Naval Historical Center, Washington, D.C.

Blasters' Handbook

- 1967 *Blasters' Handbook: A Manual for Describing Explosives and Practical Methods of Use*. E. I. DuPont de Nemours, Wilmington.

Breiner, S.

- 1973 *Applications Manual for Portable Magnetometers*. EGG Geometrics, Sunnyvale.

Brennan, J. W.

- 1991 Meteorological Summary of Hurricane Hugo. *Journal of Coastal Research Special Issue*(8):1-12.

Broadwater, J.D.

- 1997 USS *Monitor*. In *Encyclopaedia of Underwater and Maritime Archaeology*, edited by James P. Delgado, pp. 281–282. British Museum Press, London.

Brooks, M. J., D. J. Colquhoun, R. R. Pardi, W. Newman and W. H. Abbot

- 1979 Preliminary Archeological and Geological Evidence for Holocene Sea Level Fluctuations in the Lower Cooper River Valley, S. C. *The Florida Anthropologist* 32:85–103.

Brown, P. J.

- 1977 Variations in South Carolina Coastal Morphology. *Southeastern Geology* 18:249–264.

Browning, B. and W. West

- 1984 The Search for the *Hunley*: 1981 Survey. In *Underwater Archaeology: The Proceedings of the 13th Conference on Underwater Archaeology*, edited by Donald H. Keith, pp. 111–112. Fathom Eight, San Marino.

Burke, J. G.

- 1972 Bursting Boilers and the Federal Power. In *Technology and Culture: An Anthology*, edited by Melvin Kranzberg and William H. Davenport, pp. 93–118. Schocken Books, New York.

Canney, D. L.

- 1990 *The Old Steam Navy: Volume One: Frigates, Sloops and Gunboats, 1815–1885*. Naval Institute Press, Annapolis.

Carrell, T. L.

- 1997 Human Remains. In *Encyclopaedia of Underwater and Maritime Archaeology*, edited by James P. Delgado, pp. 198–199. British Museum Press, London.

Cole, R. H.

- 1948 *Underwater Explosions*. Reprinted by Dover Publications, New York (1965).

Colquhoun, D. J.

- 1965 Terrace Sediment Complexes in Central South Carolina. *Atlantic Coastal Plain Geological Association Field Conference Guidebook*, p.62. Columbia, South Carolina.

- 1969 Geomorphology of the Lower Coastal Plain of South Carolina. Division of Geology, South Carolina State Development Board MS-15(36).

- 1974 Cyclic Surficial Stratigraphic Units of the Middle and Lower Coastal Plains of Central South Carolina. In *Post-Miocene Stratigraphy Central and Southern Atlantic Coastal Plain*, edited by R. Q. Oaks, Jr. and Jules Du Bar, pp. 179–190.

- 1995 A Review of Cenozoic Evolution of the Southeastern United States Atlantic Coast North of the Georgia Trough. *Quaternary International* 26: 35–41.

Colquhoun, D. J. and M. J. Brooks

- 1986 New Evidence from the Southeastern US for Eustatic Components in the Late Holocene Sea Levels. *Geoarchaeology* 1(3):275–291.

- Colquhoun, D. J., M. J. Brooks, J. Michie, W. B. Abbott, F. W. Stapor, W. Newman and R. Pardi**
1981 Location of Archaeological Sites with Respect to Sea Level in the Southeastern United States. *Stria* 14:145-150.
- Colquhoun, D. J. and H.S. Johnson**
1967 Tertiary Sea-level Fluctuation in South Carolina. *Paleogeography, Paleoclimatology, and Paleoecology* 15:105-126.
- Colquhoun, D. J. and G. H. Johnson, P. C. Peebles, P. F. Huddleston and T. Scott**
1991 Quaternary Geology of the Atlantic Coastal Plain. In *The Geology of North America*. Vol. K-2, edited by R. B. Morrison, pp. 629-650. Geological Society of America, Boulder.
- Cook, R. D.**
1995 Letter from Assistant Deputy Attorney General of South Carolina to the Honorable Glenn F. McConnell, Chairman, *Hunley* Commission. Letter dated November 15. On file, Naval Historical Center, Washington, D.C.
- Cooke, C. W.**
1930 Correlation of Coastal Terraces. *Journal of Geology* 38:577-589.
1936 Geology of the Coastal Plain of South Carolina. *U.S. Geological Survey Bulletin* No. 867, p. 196.
- Cornelius, G.**
1996 Surfacing *Hunley*. *Naval Institute Proceedings*. August:61-66.
- Coski, J. M.**
1996 *Capital Navy: The Men, Ships, and Operations of the James River Squadron*. Savas Woodbury, Campbell.
- Cussler, C.**
1981 Project *Hunley*. In *Underwater Archaeology: The Challenge Before Us. The Proceedings of the Twelfth Conference on Underwater Archaeology*, edited by Gordon P. Watts, pp. 27-32. Fathom Eight, San Marino.
- Cutshall, N.H., I. L. Larsen and C.R. Olsen**
1983 Direct Analysis of ^{210}Pb Sediment Samples: Self-Absorption Corrections. *Nuclear Instruments and Methods* 206:309-312.
- Davis, K. B. and R. F. Van Dolah**
1992 Characterization of the Physical, Chemical, and Biological Conditions and Trends in Charleston Harbor Estuary: 1970-1985. *South Carolina Sea Grant Consortium* 1:123.
- De Kay, James T.**
1990 *The Battle of Stonington: Torpedoes, Submarines, and Rockets in the War of 1812*. Naval Institute Press, Annapolis.
- Delgado, J. P., D. J. Lenihan and L. E. Murphy**
1991 *The Archeology of the Atomic Bomb: A Submerged Cultural Resource Assessment of the Sunken Fleet of Operation Crossroads at Bikini and Kwajalein Atoll Lagoons*. Southwest Cultural Resources Center Professional Papers No. 23. National Park Service, Santa Fe.

Department of the Army

- 1990 Myrtle Beach and Vicinity, South Carolina. Communication from the Assistant Secretary of the Army, October 10. 101st Congress, 2^d Session, *House Document*, pp. 101–248, 383. Washington, D.C.

Department of the Navy

- 1996 Facsimile document dated February 21. On file, Naval Historical Center, Washington, D.C.

Desmond, C.

- 1984 *Wooden Ship-Building*. Vestal Press, [1919] Vestal.

Dillon, W. P. and K. Klitgord

- 1978 Development of the United States Continental Margin from Cape Fear to Cape Canaveral. *Geological Society of America Abstracts with Programs* 10:167.

Dudley, W. S.

- 1992 *The Naval War of 1812: A Documentary History*, Vol.II, edited by William S. Dudley. Naval Historical Center, Washington D.C.

- 1994 Letter from Senior Historian, Naval Historical Center, to Mark Newell, Underwater Archaeology Division, the South Carolina Institute of Archaeology and Anthropology. Letter Ser HN/00281 dated June 2. On file, Naval Historical Center, Washington, D.C.

- 1995 Letter from Acting Director of Naval History to Carol Schull, Keeper of the National Register. Letter Ser HN/00332 dated August 25. On file, Naval Historical Center, Washington, D.C.

- 1996a Letter from Director of Naval History to the Honorable Glenn F. McConnell, Chairman, South Carolina *Hunley* Commission. Letter dated February 20. On file, Naval Historical Center, Washington, D.C.

- 1996b Memorandum from Director Naval History for Assistant Secretary of the Navy (I&E) Memorandum dated March 21. On file, Naval Historical Center, Washington, D.C.

- 1996c Memorandum from Director of Naval History for Commander NAVFAC (Office of Installations and Environment). Memorandum dated April 3. On file, Naval Historical Center, Washington, D.C.

Field, C.

- 1908 *The Story of the Submarine from the Earliest Ages to the Present Day*. Sampson Low, Marston, London.

Field, M. E. and D. B. Duane

- 1976 Post-Pleistocene History of the United States Inner Continental Shelf: Significance to the Origin of Barrier Islands. *Geological Society of America Bulletin* 87:691–702.

Field, M. E. and O. H. Pilkey

- 1969 Feldspar in Atlantic Continental Margin Sands off the Southeastern United States. *Geological Society of America Bulletin* 80:2097–2102.

Field, M. E. and F. Trincardi

- 1991 Regressive Coastal Deposits on Quaternary Continental Shelves: Preservation and Legacy. *SEPM Special Publication* No. 46, pp. 107–122.

- Fitzgerlad, D. M.**
 1984 Interactions Between the Ebb-tidal Delta and Landward Shoreline: Price Inlet, South Carolina. *Journal of Sedimentary Petrology* 54:1303–1318.
- Flint, R.F.**
 1940 Pleistocene Features of the Atlantic Coastal Plain. *American Journal of Science* 238(11):757–787.
- 1971 *Glacial and Quaternary Geology*. John Wiley, New York.
- Force, Lucy M.**
 1978a Geological Studies of Overburden Map, Charleston, South Carolina: Area elevation contours on the top of the Cooper River Formation. *USGS Miscellaneous Field Studies Map MF-1021-A* (1:250,000).
- 1978b Thickness of Overburden Map, Charleston, South Carolina. *USGS Miscellaneous Field Studies Map MF-1021-B* (1:250,000).
- Gayes, P.T. and P. Donovan-Ealy**
 1995 *Assessment of Beach Renourishment Resources Offshore Folly Beach, South Carolina: Final Report*. Center for Marine and Wetland Studies, Coastal Carolina University, Conway, South Carolina.
- Gayes, P. T., P. Donovan-Ealy, M. S. Harris and W. Baldwin**
 1998 *Final Report: Assessment of Beach Renourishment Resources on the Inner Shelf off Folly Beach and Adjacent Island, South Carolina*. Submitted to Minerals Management Service, Herndon, Virginia. Copies available from South Carolina Task Force on Offshore Resources, Coastal Carolina University, Conway, South Carolina.
- Gifford, J. A.**
 1982 Geology and Sedimentology. In *Yassi Ada, Volume I: A Seventh-Century Byzantine Shipwreck*, by G. F. Bass, and F. H. van Doorninck, Jr., pp. 6–7. Texas A&M University, College Station.
- Gohn, G., B. B. Houser and R. R. Schneider**
 1983 Geology of the Lower Mesozoic Sedimentary Rocks in Clubhouse Crossroads Test Hole #3, near Charleston, South Carolina. In *Studies Related to the Charleston, South Carolina, Earthquake of 1886: Tectonics and Seismicity*, edited by Gregory S. Gohn, pp. D1–D17. US Geological Survey Professional Papers 1313.
- Goodwin, M. H.**
 1989 Historic, Geographic, and Socio-Economic Setting. *NOAA Estuary-of-the-Month Seminar on Charleston Harbor: Issues, Resources, Status, and Management Seminar Series No. 16:7–12*. Washington, D.C.
- Gould, R. A.**
 1983 The Archaeology of War: Wrecks of the Spanish Armada of 1588 and the Battle of Britain. In *Shipwreck Anthropology*, edited by Richard A. Gould, pp. 105–142. University of New Mexico Press, Albuquerque.
- Greeley, H.**
 1974 *The Great Industries of the United States*. Volume I. Garland, New York.

Gruse Harris, P. A.

- 1982 *Great Lakes' First Submarine: L. D. Phillips' Fool Killer*. Michigan City Historical Society, Michigan City.

Hall, W. and R. Wilbanks

- 1995 *Search for the Confederate Submarine H.L. Hunley Off Charleston Harbor, South Carolina. Final Report*. Report prepared for and project funded by: Clive Cussler, National Underwater and Marine Agency.

Ham, C. A.

- 1995 Letter from Chief, Regulatory Branch, United States Department of the Army, Charleston District, Corps of Engineers to Ms. Donna Gamble, Property Management, General Services Administration. Letter dated August 3. On file, Naval Historical Center, Washington, D.C.

Hamilton, D. L.

- 1976 *Conservation of Metal Objects from Underwater Sites: A Study in Methods*. Texas Antiquities Committee, Austin.

Hanson, L. and D. P. Hsu

- 1975 *Casemates and Cannonballs: Archeological Investigations at Fort Stanwix National Monument*. National Park Service, Washington, D.C.

Harper's Illustrated Weekly

- 1861 A Rebel Infernal Machine. November 2, 701; June 10, 1864.

Harris, M. S., P. T. Gayes, J. L. Kindinger, J. G. Flocks, M. P. Katuna, J. F. Wehmiller and D. E. Krantz

- 1997 Short- and Long-term Geomorphic Evolution of the Central South

Carolina Coastal Zone: Coastal Response to a Complex Geologic Framework. Fall meeting of the American Geophysical Union, *EOS Transactions* 78(46):F334.

Hattori, E. M. and J. I. Kosta

- 1990 Packed Pork and Other Foodstuffs from the California Gold Rush. In *The Hoff Store Site and Gold Rush Merchandise From San Francisco, California*, edited by Allen G. Pastron and Eugene M. Hattori, pp. 82-93. Special Publication Series, Number 7. Society for Historical Archaeology, Pleasant Hill.

Hayes, M. O.

- 1979 Barrier Island Morphology as a Function of Tidal and Wave Regime. In *Barrier Islands*, edited by Maurice Schwartz, pp. 1-27. Academic Press, New York.
- 1994 Georgia Bight. In *Geology of the Holocene Barrier Island System*, edited by R. A. Davis, Jr., pp. 233-304. Springer-Verlag, Berlin.

Hayes, M. O., T. F. Moslow and D. K. Hubbard

- 1984 *Beach Erosion in South Carolina*. US Department of Commerce, Washington, D.C.

Hersey, J. B., E. T. Bunce, R. F. Wyrick and F. T. Dietz

- 1959 Geophysical Investigation of the Continental Margin between Cape Henry, Virginia and Jacksonville, Florida. *Bulletin of the Geological Society of America* 70:437-466.

Heyman, I. M.

- 1995 Letter from the Secretary of the

- Smithsonian Institution to the Honorable Roger W. Johnson, Administrator, General Services Administration. Letter dated July 11. On file, Naval Historical Center, Washington, D.C.
- Highsmith, W.**
1995 Letter from Commander, Brigadier General E. Porter Alexander Camp #158, Sons of Confederate Veterans to Dr. William S. Dudley, Senior Historian. Letter dated September 23. On file, Naval Historical Center, Washington, D.C.
- Holmes, F. S.**
1849 Notes on the Geology of Charleston, South Carolina. *American Journal of Science* 7:187-201.
- Huelsbeck, D. R.**
1991 Faunal Remains and Consumer Behavior: What is Being Measured? *Historical Archaeology* 25(3):62-76.
- Hunter, A. F.**
1987 *A Year on a Monitor and the Destruction of Fort Sumter*. University of South Carolina Press, Columbia.
- Hunter, L. C.**
1969 *Steamboats on the Western Rivers*.
[1949] Octagon Books, New York.
- Hutcheon, W. S., Jr.**
1981 *Robert Fulton, Pioneer of Undersea Warfare*. Naval Institute Press, Annapolis.
- Idris, F. M.**
1983 *Cenozoic Seismic Stratigraphy and Structure of the South Carolina Lower Coastal Plain and Continental Shelf*. Unpublished Ph.D. dissertation, Department of Geology, University of South Carolina, Columbia.
- International Correspondence Schools**
1921 *Steam-Boiler Design*. International Textbook, Scranton.
- Johnson, R. W.**
1995 Letter from the Administrator of the General Services Administration to the Honorable I. Michael Heyman, Secretary of the Smithsonian Institution. Letter dated June 15. On file, Naval Historical Center, Washington, D.C.
- Kane, H. T.**
1954 *Spies for the Blue and Gray*. Doubleday, Garden City.
- Green, J. N., E. T. Hall and M. L. Katzev**
1967 Survey of a Greek Shipwreck Off Kyrenia, Cyprus. *Archaeometry* 10:47-56.
- Kjerfve, B.**
1989 Physical Processes in Charleston Harbor. *NOAA Estuary-of-the-Month Seminar on Charleston Harbor: Issues, Resources, Status, and Management Seminar Series No. 16:13-24*. Washington, D.C.
- Klitgord, K. D., W. P. Dillon and P. Popenoe**
1983 Mesozoic Tectonics of the Southeastern United States Coastal Plain and Continental Margin. In *Studies Related to the Charleston, South Carolina, Earthquake of 1886: Tectonics and Seismicity*, edited by Gregory S. Gohn, pp. P1-P15. US Geological Survey Professional Papers 1313.

- Kloeppel, J.**
1987 *Danger Beneath the Waves: A History of the Confederate Submarine H.L. Hunley*. Sandlapper, Orangeburg.
- Kovacik, C. F. and J. J. Windberry**
1987 *South Carolina: A Geography*. Westview Press, Boulder.
- Krantz, D., J. F. Wehmiller and M. S. Harris**
1994 Late Quaternary Shorelines on the Lower Coastal Plain of South Carolina. *SECOR: Programs with Abstracts 1*.
- Krantz, D., M. S. Harris and J. F. Wehmiller**
1996 Preservation of Middle and Late Quaternary Sea-level Highstands Events, Lower Coastal Plain of South Carolina. In *Geologic Society of America, Southeastern Section, 45th Annual Meeting, Abstract with Programs* 28(2):19.
- Landon, D. B.**
1996 Feeding Colonial Boston: A Zooarchaeological Study. *Historical Archaeology* 30(1).
- Lenihan, D. J. (editor)**
1989 *Submerged Cultural Resources Study: USS Arizona Memorial and Pearl Harbor National Historic Landmark*. Southwest Cultural Resources Center Professional Papers No. 23. National Park Service, Santa Fe.
- 1996 Surprises Uncovered in *Hunley* Probe. *Naval Institute Proceedings* August:64-65.
- 1997 Time Capsules: Objects in History. *American History* 32(3):74.
- Lenihan, D. J., L. E. Murphy and C. F. Amer**
1997 The Confederate Submarine *H.L. Hunley*: The 1996 Archaeological Assessment. Paper Presented to Society of Historical Archaeology Conference on Historical and Underwater Archaeology, Corpus Christi.
- Lundeberg, P. K.**
1974 *Samuel Colt's Submarine Battery: The Secret and the Enigma*. Smithsonian Studies in History and Technology, Number 29. Smithsonian Institution Press, Washington D.C.
- Luraghi, R.**
1996 *A History of the Confederate States Navy*. Naval Institute Press, Annapolis.
- Lyman, R. L.**
1977 Analysis of Historic Faunal Remains. *Historical Archaeology* 11:67-73.
- 1979 Available Meat From Faunal Remains: A Consideration of Techniques. *American Antiquity* 44(3):536-546.
- MacLeod, I. D.**
1989 The Electrochemistry and Conservation of Iron in Seawater. *Chemistry in Australia* 14:227-229.
- 1992 Conservation Management of Iron Steamships - the S.S. *Xantho* (1872). *Multi-Disciplinary Engineering*

- Transactions*, G. F. No. 1:45-51. Paper presented at the Fifth National Conference on Engineering Heritage 1990.
- MacMahan, J.**
1997 Comparative Wave Characteristics on Two Beaches in South Carolina. Fall meeting of the American Geophysical Union, *EOS Transactions* 78(46): F333.
- Martin, A. E. and C. A. Rice**
1981 *Sampling and Analyzing Sediment Cores for ²¹⁰Pb Chronology*. Open File Report 81-983. US Department of the Interior, Geological Survey, Washington, D.C.
- Matthew Fontaine Maury Papers**
ca. 1968 Undated letter from James McClintock to Matthew F. Maury. Matthew Maury Papers, Manuscript Division, Library of Congress, Volume 46, items 9087-9094.
- McCartan, L., R. E. Weems and E. M. Lemon, Jr.**
1979 The Wando Formation (Upper Pleistocene) in the Charleston, South Carolina, Area. *Changes in Stratigraphic Nomenclature by the U.S. Geological Survey: Geological Survey Bulletin 1502-A*: A110-A116.
- McCarthy, M.**
1988 SS *Xantho*: the Pre-disturbance, Assessment, Excavation, and Management of an Iron Steam Shipwreck off the Coast of Western Australia. *International Journal of Nautical Archaeology* 17(4):339-347.
- 1996 SS *Xantho*: Towards a New Perspective. An Integrated Approach to the Maritime Archaeology and Conservation of an Iron Steamship Wreck. Unpublished dissertation, James Cook University, North Queensland.
- McConnell, G. F., Senator**
1995 Letter from Chairman, South Carolina Hunley Commission to William S. Dudley, Director of Naval History. Letter dated October 18. On file, Naval Historical Center, Washington, D.C.
- McGrath, H. T., Jr.**
1981 The Eventual Preservation and Stabilization of the USS *Cairo*. *International Journal of Nautical Archaeology* 10(2):79-94.
- McGrath, T. and D. Ashley**
ca. 1981 *Historic Structure Report: USS Cairo, Vicksburg Military Park, Vicksburg, Mississippi*. National Park Service, Denver Service Center, Denver.
- McKee, A.**
1973 *King Henry VIII's Mary Rose*. Souvenir Press, London.
- Miller, J. A.**
1996 Letter from the General Counsel of the Department of Defense to the Honorable Strom Thurmond, Chairman, Committee on Armed Services. Letter dated September 16. On file, Naval Historical Center, Washington, D.C.
- Morgan, W. J. (editor)**
1972 *Naval Documents of the American Revolution*, Vol. 6. Department of the

Navy, Naval History Division,
Washington, D.C.

Muckelroy, K.

- 1978 *Maritime Archaeology*. Cambridge University Press, Cambridge.

Murphy, Larry E.

- 1984 Phase I Remote Sensing Survey. In *A Shipwreck Survey of Portions of Point Reyes National Seashore and Point Reyes-Farallon Islands National Marine Sanctuary. Phase I Reconnaissance Survey*, edited by Larry Murphy. Southwest Cultural Resources Center Professional Paper Number 1, pp. 85–140. National Park Service, Santa Fe.

- 1990 *8S117: Natural Site Formation Processes of a Multiple-Component Underwater Site in Florida*. Southwest Cultural Resources Center Professional Papers No. 39. National Park Service, Santa Fe.

- 1997a Geographical Information System (GIS). In *Encyclopaedia of Underwater and Maritime Archaeology*, edited by James P. Delgado, pp. 166–168. British Museum Press, London.

- 1997b Remote Sensing. In *Encyclopaedia of Underwater and Maritime Archaeology*, edited by James P. Delgado, pp. 340–344. British Museum Press, London.

- 1997c Shipwrecks, Satellites, and Computers: An Underwater Inventory of Our National Parks. *Common Ground* 1(3/4):47–51.

Murphy, L. E. and T. G. Smith

- 1995 Submerged in the Past: Mapping the Beguiling Waters of Florida's Biscayne and Dry Tortugas National Parks. *GeoInfo Systems* 5(10):26–33.

- 1997 Global Positioning System (GPS). In *Encyclopaedia of Underwater and Maritime Archaeology*, edited by James P. Delgado, pp. 171–172. British Museum Press, London.

Murphy, L., T. Leary and A. Williamson

- 1995 Standardizing Seabed Classification Techniques. *Sea Technology* 36(7):15–19.

Murphy, L. E. and A. R. Saltus

- 1990 Consideration of Remote Sensing Limitations to Submerged Historical Site Survey. In *Underwater Archaeology Proceedings from the SHA Conference*, edited by Toni L. Carrell, pp. 93–95. Society for Historical Archaeology.

National Oceanic and Atmospheric Administration (NOAA)

- 1990 *NOAA Diving Manual: Diving for Science and Technology*. National Oceanic and Atmospheric Administration, Washington, D.C.

- 1993 Stono and North Adust Rivers, Chart 11522. 15th Edition, April 1993. *National Oceanic and Atmospheric Administration, National Ocean Service, Coast and Geodetic Survey*. (1:40,000).

- 1998 *National Data Buoy Center (NWS/NOAA) Data Archives*. Online.

- Stennis Space Center. Available:
//scaboard.ndbc.noaa.gov/index.html.
February 1998.
- New Orleans Daily Delta**
1861 August 17.
- New Orleans Picayune**
1868 February 15. Morning and afternoon
editions; June 2.
- Newell, M.**
1994 Letter with Attachment, *Preliminary
Proposal for Comment: Identification
of Magnetic Anomalies in Charleston
Harbor off Sullivan's Island, S.C.*, to
Recipients: Invitation to comment.
Letter dated June 26. On file, Naval
Historical Center, Washington, D.C.
- North, N. A.**
1976 Formation of Coral Concretions on
Marine Iron. *International Journal of
Nautical Archaeology* 5(3):253-258.
- Panshin, A.J. and C. de Zeeuw**
1980 *Textbook of Wood Technology*.
McGraw-Hill, New York.
- Parsons, W. B.**
1922 *Robert Fulton and the Submarine*.
Columbia University Press, New
York.
- Pearson, C. E., D.B. Kelly, R.A. Weinstein
and S. M. Gagliano**
1986 *Archaeological Investigations on the
Outer Continental Shelf: A Study
Within the Sabine River Valley,
Offshore Louisiana and Texas*.
Coastal Environments, Baton Rouge.
- Perry, M. F.**
1965 *Infernal Machines: The Story of
Confederate Submarine and Mine
Warfare*. Louisiana State University
Press, Baton Rouge.
- Peterson, M. L.**
1972 Traders and Privateers Across the
Atlantic: 1492-1733. In *A History of
Seafaring Based on Underwater
Archaeology*, edited by George F.
Bass, pp. 253-280. Thames &
Hudson, London.
- Poag, C. W.**
1984 Neogene Stratigraphy of the
Submerged U.S. Atlantic Margin. In
*P a l a e o g e o g r a p h y ,
Palaeoclimatology, Palaeoecology*
47:103-127.
- Post & Courier**
1995 December 15: Editorial, A22.
Charleston, South Carolina.
- Popenoe, P.**
1986 Paleo-oceanography and
Paleogeography of the Miocene of the
Southeastern United States. In *World
Phosphate Deposits: Neogene
Phosphorites of the Southeastern
United States*, edited by W. C. Burnett
and S. R. Riggs, pp. 352-380.
Cambridge University Press,
Cambridge.
- Public Records Office**
Admiralty Office Series 1/6236.
London.
- Ragan, M.**
1995 *Submarines, Sacrifice, & Success in
the Civil War*. Narwhal Press,
Charleston.
- Riggs, S. and D. Bellknap**
1988 Upper Cenozoic Processes and
Environments of Continental Margin

- Sedimentation: Eastern United States. In *The Geology of North America*, edited by Sheridan, R. E. and J. A. Grows, pp. 131-175. Geological Society of America, Boulder.
- Robinson, W. M., Jr.**
1928 *The Confederate Privateers*. Yale University Press, New Haven.
- Rogers, B. A.**
1989 The Case for Biologically Induced Corrosion at the Yorktown Shipwreck Archaeological Site. *International Journal of Underwater Archaeology* 18(4):335-340.
- Roland, A.**
1978 *Underwater Warfare in the Age of Sail*. Indiana University Press, Bloomington.
- Rothschild, N. A. and D. Balkwill**
1993 The Meaning of Change in Urban Faunal Deposits. *Historical Archaeology* 27(2):71-89.
- Russell, M. A. and L. E. Murphy**
1997 Minimum Impact Archeology. In *Encyclopaedia of Underwater and Maritime Archaeology*, edited by James P. Delgado, pp. 278-279. British Museum Press, London.
- Scharf, J. T.**
1977 *History of the Confederate States Navy from Its Organization to the Surrender of Its Last Vessel*. Fairfax Press.
[1887]
- Schell, S. H.**
1992 Submarine Weapons Tested at Mobile During the Civil War. *The Alabama Review* 54(7):163-183.
- Schiffer, M. B.**
1987 *Formation Processes of the Archaeological Record*. Academic Press, New York.
- Schull, C. D.**
1995 Letter from the Keeper of the National Register of Historic Places to William S. Dudley, Acting Director of Naval History Letter H32(413) dated September 28. On file, Naval Historical Center, Washington, D.C.
- Schwing, F. B., B. Kjerfve and J. E. Sneed**
1983 Nearshore Coastal-currents on the South Carolina Continental Shelf. *Journal of Geophysical Research* 88(C8):4719-4729.
- Sexton, W. J. and D. J. Colquhoun**
1987 Morphology, Surface Sediment Character, and Shallow Stratigraphy of the Submerged Santee Delta Inner Continental Shelf, Southeastern United States. *Geological Society of American Abstracts with Programs* 19(1-6):128-129.
- Shattuck, G. B.**
1901 The Pleistocene Problem of the North Atlantic Coastal Plain. *American Geologist* 28: 87-107.
1906 The Pliocene and Pleistocene Deposits of Maryland. *Maryland Geological Survey*, 21-137.
- Shelby, R.**
1995 Letter from Senator from Alabama to William S. Dudley, Acting Director of Naval History. Letter dated July 19. On file, Naval Historical Center, Washington, D.C.

- Shope, S. M.**
1997 Magnetometer. In *Encyclopaedia of Underwater and Maritime Archaeology*, edited by James P. Delgado, pp. 253-254. British Museum Press, London.
- Shope, S. M., L. E. Murphy and T. G. Smith**
1995 Found at Sea; Charting Florida's Sunken Treasures. *GPS World* 6(5):22-34.
- Smith, M. H.**
1981 *An Interpretive Study of the Collection Recovered From the Storeship Niantic*. National Trust for Historic Preservation and the National Maritime Museum Association, Washington D.C.
- Smith, T. G.**
1997 Geodesy. In *Encyclopaedia of Underwater and Maritime Archaeology*, edited by James P. Delgado, p. 166. British Museum Press, London.
- Still, W. N., Jr.**
1987 *Confederate Shipbuilding*. University of South Carolina Press, Columbia.
[1969]
- Stone, L. C., Jr. and F. R. Siegel**
1969 Distribution and Provenance of Minerals from Continental shelf sediments off the South Carolina coast. *Journal of Sedimentary Petrology* 39(1):276-296.
- Swift, D. J. P.**
1980 Shoreline Periodicities and Linear Offshore Shoals: A Discussion. *Journal of Geology* 88:365-369.
- Swift, D. J. P. and J. A. Thorne**
1991 Sedimentation on Continental Margins: A General Model for Shelf Sedimentation. *Special Publications of the International Association of Sedimentologists* 14:3-31.
- Toscano, M. and L. L. York**
1992 Quaternary Stratigraphy and Sea-Level History of the U.S. Middle Atlantic Coastal Plain. *Quaternary Science Reviews* 11:301-328.
- Turner, M.**
1995 The Hunley: A Very Curious Machine. *The Confederate Naval Historical Society Newsletter* 16 (July):5-8.
- Tye, R. S. and T. F. Moslow**
1993 Tidal Inlet Reservoirs: Insights from modern examples. In *Marine Clastic Reservoirs: Examples and Analogues*, edited by E. G. Rhodes, pp. 77-79. Springer-Verlag, New York.
- US Coast Guard**
1995 Order CGD-07-95-054, RIN 2115-AF84, establishing Regulated Navigation Area. Instruction signed on August 11 by R. T. Rufe, Jr., Rear Admiral, US Coast Guard, Commander, Seventh Coast Guard District. On file, Naval Historical Center, Washington, D.C.
- US Department of the Navy**
1901 Office of Naval War Records. *Official Records of the Union and Confederate Navies in the War of the Rebellion*. US Government Printing Office, Washington, D.C.

US Government Printing Office

1894 *Official Records of the Union and Confederate Navies in the War of the Rebellion*. Series I, 30 vols. US Government Printing Office, Washington, D.C.

1995 *Department of Defense Appropriations Bill, 1996: Report of the Committee on Appropriations, July 27*. Report 104-208. US Government Printing Office, Washington, D.C.

US Navy Records

Correspondence from Officers Below the Rank of Commander. National Archives, Washington, D.C.

Van Dolah, Robert F. and Kevin B. Davis

1989 Living Resources of Charleston Harbor. *NOAA Estuary-of-the-Month Seminar on Charleston Harbor: Issues, Resources, Status, and Management Seminar Series* No. 16:26-36. Washington, D.C.

Ward, W. T.

1985 Correlation of East Australian Pleistocene Shorelines with Deep-Sea Core Stages: A Basis for Coastal

Chronology. *Geological Society of America Bulletin* 96:1156-1166.

Ward, L. W. and B. W. Blackwelder

1980 Stratigraphic Revision of Upper Miocene and Lower Pliocene Beds of the Chesapeake Group, Middle Atlantic Coastal Plain. *U.S. Geological Survey Bulletin Professional Paper* 1482:D1-D61.

Weems, R. E. and E. J. Lemon

1993 *Geology of the Cainhoy, Charleston, Fort Moultrie, and North Charleston Quadrangles, Charleston and Berkeley Counties, South Carolina*. USGS Miscellaneous Investigation Series, Map No. I1935, scale (1:24,000), 2 sheets.

Wills, R.

1994 The Confederate Privateer *Pioneer* and the Development of Confederate Submersible Watercraft. *The Institute of Nautical Archaeology Quarterly* 21(1-2):12-19.

Zeigler, J. M.

1959 Origin of the Sea Islands of the Southeastern United States. *Geographical Review* 49(2):222-237.

APPENDIX A

Dive Log Summary

DIVE LOG SUMMARY

<u>DATE</u>	<u>TOTAL DIVES</u>	<u>TOTAL MINUTES</u>
May 3, 1996	4	72
May 4, 1996	4	54
May 5, 1996	2	32
May 7, 1996	2	44
May 8, 1996	19	784
May 9, 1996	10	260
May 10, 1996	16	644
May 11, 1996	2	100
May 16, 1996	24	971
May 17, 1996	17	645
May 18, 1996	18	749
May 19, 1996	17	756
May 20, 1996	18	739
May 21, 1996	16	728
May 22, 1996	13	672
May 23, 1996	13	406
May 24, 1996	12	686
May 25, 1996	13	742
May 26, 1996	19	1,115
May 27, 1996	16	939

<u>DATE</u>	<u>TOTAL DIVES</u>	<u>TOTAL MINUTES</u>
May 29, 1996	29	1,488
June 3, 1996	9	432
June 4, 1996	9	452
TOTALS	302	13,510 (225.16 hours)

APPENDIX B

***Hunley* Field Specimen Log**

HUNLEY FIELD SPECIMEN LOG

<u>FS#</u>	<u>Date</u>	<u>Description</u>	<u>Reason Taken</u>	<u>Disposition</u>
001	5/4/96	Sediment Core	Geological analysis	Permanent transfer, Willard Moore, USC
002	5/4/96	Sediment Core	Geological analysis	Permanent transfer, Willard Moore, USC
003	5/22/96	Sediment	Geological analysis	In storage, SCRUI, Santa Fe
004	5/22/96	Wood	Species ID	Permanent transfer, Paleo Research
005	Void	Void	Void	Void
006	5/23/96	Coal	Source analysis	Permanent transfer, Curt White, DOE
007	5/23/96	Bone	Species ID	Temporary transfer, Greg McDonald, NPS
008	5/23/96	Seawater	Chemical analysis	Permanent transfer, Bob Bandollah, SCDNR
009	5/23/96	Seawater	Chemical analysis	Permanent transfer, Bob Bandollah, SCDNR
010	5/23/96	Encrustation	Corrosion study	A - permanent transfer Jon Leader, SCIAA; B - permanent transfer, Dan Polly, USN
011	5/24/96	Encrustation	Conservation	Permanent transfer SCIAA, Columbia
012	5/24/96	Coral	Isotopic analysis	In storage, SCRUI, Santa Fe
013	5/24/96	Coral	Isotopic analysis	In storage, SCRUI, Santa Fe
014	5/24/96	Dive marker	Museum display	Permanent transfer, SCIAA, Columbia

<u>FS#</u>	<u>Date</u>	<u>Description</u>	<u>Reason Taken</u>	<u>Disposition</u>
015	5/25/96	Sediment	Geological analysis	In storage, SCRUI, Santa Fe
016	5/25/96	Sediment	Geological analysis	In storage, SCRUI, Santa Fe
017	5/25/96	Sediment	Geological analysis	In storage, SCRUI, Santa Fe
018	5/25/96	Sediment	Geological analysis	In storage, SCRUI, Santa Fe
019	5/25/96	Sediment	Geological analysis	In storage, SCRUI, Santa Fe
020	5/25/96	Coral	Isotopic analysis	In storage, SCRUI, Santa Fe
021	5/25/96	Coral	Isotopic analysis	Permanent transfer, Willard Moore, USC
022	5/25/96	Coral	Isotopic analysis	In storage, SCRUI, Santa Fe
023	5/25/96	Coral	Isotopic analysis	Permanent transfer, Willard Moore, USC
024	5/25/96	Coal	Source analysis	Permanent transfer, Curt White, DOE
025	5/27/96	Sediment	Geological and pollen analysis	A - permanent transfer, John Husler, UNM; B - permanent transfer, Paleo Research
026	5/27/96	Sediment	Geological and pollen analysis	A - permanent transfer, John Husler UNM B - permanent transfer, Paleo Research
027	5/27/96	Sediment	Geological and pollen analysis	A - permanent transfer, John Husler, UNM B - permanent transfer, Paleo Research

<u>FS#</u>	<u>Date</u>	<u>Description</u>	<u>Reason Taken</u>	<u>Disposition</u>
028	5/27/96	Sediment	Geological and pollen analysis	A - permanent transfer, John Husler UNM B - permanent transfer, Paleo Research
029	5/27/96	Sediment	Geological and pollen analysis	A - permanent transfer, John Husler UNM B - permanent transfer, Paleo Research
030	5/27/96	Sediment	Geological and pollen analysis	A - permanent transfer, John Husler UNM B - permanent transfer, Paleo Research
031	5/27/96	Encrustation	Conservation	SCIAA, Columbia
032	9/27/96	Sediment	Dating	Permanent transfer, Willard Moore, USC

APPENDIX C

Letter from Melvin Bell and Report by Robert M. Martore and Melvin Bell

South Carolina Department of
Natural Resources



James A. Timmerman, Jr., Ph.D.

Director

Paul A. Sandifer, Ph.D.

Deputy Director for

Marine Resources

May 30, 1996

Mr. Larry B. Murphy
Deputy Chief, Submerged Cultural Resources Unit
National Park Service
P.O. Box 728
Santa Fe, New Mexico 87504

Dear Larry:

Enclosed is a brief report summarizing findings from the exploratory dive Bob Martore and I made on the ILL. Hunley on the 21st of May.

Based on our limited examination of the Hunley, with certainty that at some point in time since it's sinking at least the upper portions of the vessel were exposed above the sand for a period of at least 10 to 15 years. This conclusion is based primarily on the presence of well developed colonies of Star Coral (*Astrangia danae*) found on both hatches and the upper surface of the hull itself. Further detailed analysis of the specimens taken could perhaps provide additional information if desired.

As I mentioned to you earlier, we do have a permitted artificial reef located within a mile of the Hunley site. The reef is partially composed of a large number of solid ten foot long, five foot diameter steel structures which have been in the water for several years. During past monitoring dives on this reef we have been typically interested in the finfish populations associated with these structures, but during future dives I would be more than happy to collect additional data concerning burial and bio-fouling if that would be of some use to you. The burial rate and encrustation by marine organisms associated with these structures may not be much different from that experienced on the Hunley after sinking 132 years ago.

Our overall conclusion is that after sinking, the Hunley subsided into the sandy ocean bottom but remained partially exposed for perhaps 10 to 15 years during which time a well developed marine fouling community was established on any exposed surfaces. Eventually the entire vessel was buried and most-likely remained so until it was discovered last year. All trace

of encrusting organisms, with the exception of the hard parts of the corals and oysters, decomposed over time.

The relative consistency in overall appearance of the coral specimens found from different parts of the vessel as well as a lack of evidence of any recent fouling would indicate one period of exposure in the distant past rather than multiple periods more recently. Additional support for the conclusion that the Hunley has remained buried since at least the mid-1900's is found in the fact that its present location has been an extremely productive area fished by local shrimp fishermen for many years. It is almost certain that if the vessel were exposed to any degree it would have become a well-known obstruction ("hang") and known to the entire shrimping fleet.

If you have any questions regarding our observations or would like to discuss any points further please feel free to give me a call any time.

Sincerely,

A handwritten signature in black ink, appearing to read 'Mel', with a stylized flourish at the end.

Melvin Bell
Manager,
Artificial Reef Program

cc: J. Miglarese
D. Cupka
D. Whitak
R. Martore

Initial findings of a biological survey of the
Confederate submarine H.L. HUNLEY

Robert M. Martore and Melvin Bell
South Carolina Department of Natural Resources

On May 21, 1996, a single dive was made to the wreck of the HUNLEY. During the dive visibility was extremely limited, 0-2 feet, and current was slight. Only limited portions of the hull of the vessel were accessible for examination. Although the entire top of the submarine was exposed, only about 10-12 inches of the sides were accessible for viewing.

During the dive, five colonies of hard coral were extracted. All were taken from the top surface of the exposed vessel and each colony appeared to be intact and complete. Two samples were taken from each hatch and one directly from the hull aft of the snorkel stuffing box. All five were identified as the Star Coral, *Astrangia danae*.

Astrangia is not a true reef coral but is the most common stony coral in this area. It is a small, slow growing coral whose colonies develop in unbranched patches seldom exceeding 5 cm (2 in.) in diameter. Growth rates in laboratory experiments have been reported as 3-6 polyps per year. Measurements taken on each colony are as follows:

<u>Sample #</u>	<u>Diameter</u> <u>(mm)</u>	<u>Height</u> <u>(mm)</u>	<u># Polyps</u>	<u>Approx.</u> <u>Age</u>
1	30	15	60	10-20 yrs
2	22	17	34	6-11 yrs
3	23	20	40	7-13 yrs
4	24	21	40	7-13 yrs
5	26	15	30	5-10 yrs

Based on the discoloration, similarity in size, and degree of wearing of the coral colonies examined, all appeared to be from approximately the same fouling community, suggesting one period of time in which significant bio-fouling took place. Based on the number of polyps found on each colony and the average reported growth rate, we estimate that at least the upper surface of the vessel was unburied and exposed to seawater for a minimum of ten years and probably longer. It should also be noted that in addition to the length of time needed for coral colonies to grow to this size, additional time may have elapsed due to the natural order of succession on newly submerged structures.

We have repeatedly observed the same general order of succession on a variety of structures sunk as artificial reef habitat. Barnacles are usually the first colonizers of newly submerged objects, covering the structure within a matter of months. Encrusting organisms such as bryozoans, hydroids, certain algae and sponges occur next. Hard corals such as *Astrangia* and *Oculina*

are generally last to colonize an object, often taking 3-4 years to establish a viable colony. We have seldom observed coral colonics on an object before a submergence time of 3 years.

The only other organism found attached to the HUNLEY was the horse oyster, *Ostrea equestris*. This is a common subtidal, high salinity oyster, small in size (5 cm), usually found in small numbers as opposed to the Eastern oyster (*Crassostrea virginica*) which can form large oyster reefs. Although several of these were observed, only one was removed. All observations of this species were of a single valve only attached to the hull of the vessel. There were no complete specimens. We believe that the sizes of the specimens observed (<5 cm) could have been achieved in 2-3 years time. Therefore, it appears that the coral species collected would be a better indicator of the length of time the vessel was exposed. The presence of these oysters does, however, support the notion that at least a portion of the vessel remained unburied for a significant period of time.

In conclusion, based on the number of coral colonics observed and the sizes of these colonies, it is our estimate that the upper portion of the submarine HUNLEY remained unburied for a period of at least 10-15 years. From our examination of hundreds of artificial reef structures along the SC coast, burial of such material is typically gradual with complete burial of objects the size of the HUNLEY taking well over ten years. It is likely that the top surface only remained unburied for this length of time. The vessel probably underwent gradual burial during this period, but an examination of the entire hull would be necessary to confirm this. The corals examined on this dive appear to be old (due to dark discoloration) and all approximately the same age, suggesting one period of time of exposure, probably immediately after initial sinking, prior to final burial.

APPENDIX D

Sedimentary Analysis

Sample	EM Wt.	EM + Sample	Total Sample Wt.	Dish & Clay Wt.	Clay Dish Wt.	Clay Wt.	Sample Beaker	Sand Wt.	Dispersant Wt.	% Sand	Summary % Sol	Summary % Clay
FS0 25 A	81.87	103.4	21.53	27,279.5	27,079	0.2005	96.8800	15.01	0.1399	69.72	16.77	13.51
B	81.36	101.69	20.33	30,079.4	29,892.5	0.1869	96.7200	15.06	0.1399	75.55	13.35	11.10
FS0 26 A	91.83	114.84	23.01	29,290.6	29,130.7	0.1599	112.09	20.26	0.1399	88.03	17.8	4.17
B	82.04	103.59	21.55	30,000.7	29,836.3	0.1644	100.64	18.60	0.1399	86.31	8.23	5.46
FS0 27 A	73.05	95.47	22.42	29,179.5	29,034.5	0.1450	94.65	21.60	0.1399	96.77	2.13	1.10
B	70.24	92.07	21.85	28,958.6	28,813.8	0.1448	91.36	21.14	0.1399	96.75	2.17	1.08
FS0 28 A	92.54	114.49	21.95	30,342.5	30,103	0.2395	104.06	11.52	0.1399	52.48	25.74	21.78
B	97.5	118.55	21.05	28,822.3	28,579.6	0.2427	106.84	9.34	0.1399	44.37	32.19	23.44
FS0 29 A	99.83	120.54	21.51	28,066.4	27,913.2	0.1532	117.09	18.06	0.1399	83.96	13.07	2.97
B	95.1	115.92	20.82	27,246.9	27,098.3	0.1486	112.59	17.49	0.1399	84.01	13.99	2.01
FS0 30 A	94.79	115.73	20.94	31,533.5	31,342.6	0.1909	111.03	16.24	0.1399	77.55	10.75	11.69
B	97.91	118.07	20.16	29,878.3	29,703.1	0.1752	113.7	15.79	0.1399	78.32	13.27	8.40
BLANK A				30,694	30,553.4	0.1426						
BLANK B				28,034.1	27,891.2	0.1329						
BLANK C				30,890.2	30,745.8	0.1444						
AVERAGE		0.139967										

SAMPLE	BEAKER WEIGHT	DRIED WEIGHT	TOTAL WEIGHT
FS0 25	392.7	666.6	273.9
FS0 26	232.3	454.1	221.8
FS0 27	231.4	851.7	620.8
FS0 28	303.1	514.8	211.7
FS0 29	390.8	648.2	257.4
FS0 30	394.0	757.0	363.0

*all weights are in grams

SAMPLE	TOTAL WEIGHT	>1.00 mm	>0.710 mm	>0.5 mm	>0.355 mm	>0.25 mm	>0.18 mm	>0.125 mm	>0.088 mm	<0.088 mm
FS0 25	40.96	19.62	1.81	1.67	1.62	2.52	3.85	7.26	1.64	0.95
FS0 26	40.49	16.45	1.42	1.36	1.36	2.77	5.16	9.27	1.77	0.85
FS0 27	41.27	4.47	0.62	0.67	0.84	2.17	9.39	18.16	3.56	1.05
FS0 28	40.76	26.25	1.46	1.44	1.24	1.4	1.82	5	1.14	1.19
FS0 29	41.34	14.21	0.75	0.72	0.83	2.84	8.46	9.88	1.89	1.58
FS0 30	40.08	13.4	1.65	1.61	1.62	5.12	8.07	6.35	1.26	0.67

APPENDIX E

Report from Willard S. Moore

Age Determination of Sediment at the Hunley Site Using ^{210}Pb

Willard S. Moore
Department of Geological Sciences
University of South Carolina
Columbia, SC 29208

Introduction

The determination of accumulation rates in recent marine sediments is a fundamental problem in marine geology. In each environment the method used must be tailored to the factors known to influence particle deposition and movement. When using radionuclides, such factors as sediment mixing and dilution by coarse grained material must be considered.

Profiles of ^{210}Pb (half life = 22.3 yr) with depth in sediments have been used to estimate sedimentation rates in a variety of environments. In an ideal system the activity (A) of a radionuclide will decay with time (t) at a constant rate governed by the decay constant (λ) of the radionuclide. Equation 1 expresses this relationship.

$$\frac{dA}{dt} = -\lambda A \quad (1)$$

The rate of sediment accumulation (S) may be expressed as the change of depth (z) of a sediment particle with time. S has units of cm/yr.

$$S = \frac{dz}{dt}, \quad \text{therefore} \quad dt = \frac{dz}{S} \quad \text{and} \quad S \frac{dA}{dz} + \lambda A = 0.$$

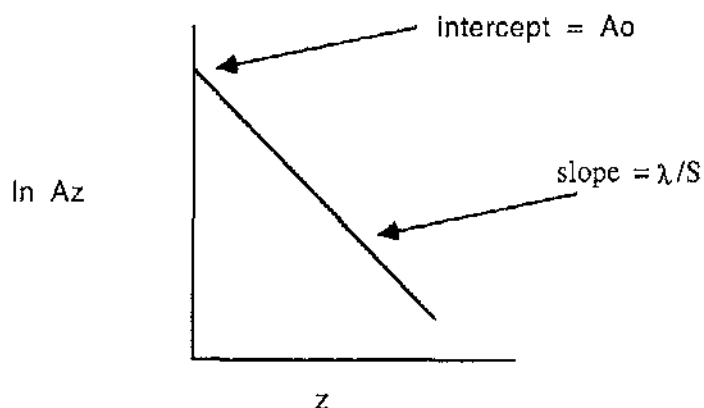
If S is constant and the initial activity of the radionuclide on the sediment is constant, we can solve this differential equation.

$$A_z = A_0 e^{-\left[\frac{\lambda}{S} z\right]} \quad \text{where}$$

A_0 is the initial activity (2)

A_z is the activity at depth $= z$

Converting to natural logs we have $\ln A_z = \ln A_0 - z \frac{\lambda}{S}$. This is the equation of a straight line on a $\ln$ – linear plot.



For ^{210}Pb in nearshore sediments, we must also consider the activity locked inside minerals that does not change with time as it is constantly produced from ^{226}Ra decay. We corrected for this supported activity by subtracting the ^{226}Ra activity of the sediment from the total ^{210}Pb to yield excess ^{210}Pb .

The following assumptions must be made when using the excess ^{210}Pb method:

- (1) The initial ^{210}Pb activity (A_0) is constant.
- (2) S is constant.
- (3) There is no sediment mixing.
- (4) There is no migration of ^{210}Pb within the sediments.
- (5) Production of ^{210}Pb in the sediment is entirely due to ^{226}Ra decay.

Several factors cause nearshore sediments to have excess ^{210}Pb . Decay of ^{222}Rn to ^{210}Pb in the atmosphere and subsequent fallout provides the primary source of excess ^{210}Pb . River-borne particles enter the coastal zone with ^{210}Pb activities slightly above equilibrium with respect to ^{226}Ra , and the desorption of ^{226}Ra as these particles mix with salt water causes the excess of ^{210}Pb activity to increase further. Offshore waters may

deposit additional ^{210}Pb . Decay of ^{222}Rn and its short-lived daughters in the water column is a minor source of excess ^{210}Pb to the nearshore.

The removal of ^{210}Pb onto particles is largely a function of size and organic carbon content. Fine, C-rich particles are the best scavengers; sand is a poor scavenger.

Methods

In May 1996 sediment cores were recovered from near the Hunley site. Two cores (A & B) were collected by divers who drove a stainless steel core barrel with plastic liner into the surface sandy deposit adjacent to the Hunley site. Another core (I) was obtained

from a mud deposit above the Hunley that underlay the sand layer. This core was retrieved after the surface sand layer had been removed.

Cores A and B were cut into 3 cm segments, packed into plastic petri dishes, weighed, sealed with electrical tape and measured for radionuclides on a planer germanium gamma ray spectrometer. After the counting period, the self absorption factor for ^{210}Pb was determined by placing a uraninite sample on top of the sample dish. Core I was sectioned at 1 cm intervals and treated in a similar manner.

The gamma spectra were analyzed using the program HYPERMET and the peaks were quantified using factors obtained by counting NIST standards in the same geometry. Excess ^{210}Pb was obtained by subtracting the ^{226}Ra activity from the total ^{210}Pb activity corrected for self absorption.

After the samples from core A were counted, the sediment was dispersed in water and poured into a 1 cm diameter plastic tube and allowed to settle. The sand settled rapidly and produced a layer at the bottom of the tube. After all of the sediment had settled, the bottom of the tube was frozen and the sand layer was separated from the remaining sediment. These fine (mud) and coarse (sand) fractions were recounted in the germanium detector to determine the fraction of the excess ^{210}Pb activity contained in fine grained sediment.

Based on counting statistics and the reproducibility of measuring standards and duplicate samples, the overall uncertainty for an individual measurement is about 5%. However, the error on the excess ^{210}Pb activity may be considerably larger. This is because each of the individual errors must be propagated when the ^{226}Ra activity is subtracted from the total ^{210}Pb activity. For example if the total ^{210}Pb activity is 4.00 ± 0.20 and the ^{226}Ra is 3.00 ± 0.15 , the excess ^{210}Pb activity will be 1.00 ± 0.25 . As the excess ^{210}Pb activity decreases, the error increases substantially.

Results and Discussion

The results are given in Table 1. Most of the samples contained a slight excess ^{210}Pb activity; but, the activity did not diminish with depth as predicted by equation 2. Therefore, these data cannot be used to determine sedimentation rates. Sediment mixing and dilution with coarse grained material probably causes the non ideal behavior.

The reason for separating the material in core A into fine and coarse fractions was to use the activity in the top of core A to estimate the initial activity of ^{210}Pb in the fine grained mud from this site. This should provide a baseline activity of initial excess ^{210}Pb

in the material comprising core I. A comparison of excess ^{210}Pb activity in the mud and sand fractions of core A reveals that almost all of the activity is in the mud.

A comparison of the excess ^{210}Pb activities in the fine grained material from core A with activities in core I reveals that the mud deposit overlying the Hunley (core I) is considerably depleted in excess ^{210}Pb with respect to fine grained surficial material (mud fraction of core A). If we assume that the initial activity of excess ^{210}Pb is given by the

activity in the fine grained material in the top 3 cm of core A, we can calculate how long the material in core I has been out of contact with the surface. In this case the age (t) is given by

$$t = \frac{\ln \frac{A}{A_0}}{\lambda}$$

(3)

Taking the initial excess Pb activity to be 12.8 dpm/gm, the ages of the fine grained material in core A range from 9 to 44 years with little trend with depth. For core I, ages range from 80-124 years with no trend with depth. The range of ages may reflect differences in initial excess ^{210}Pb activity or may be due to the considerable error associated with the measurement of these low excess ^{210}Pb activities. I conclude that the average age of 100 years for material in core I is probably correct within a 20 year uncertainty.

Site	Depth	Ra-226	exPb-210	exPb-210	Age
	(cm)	dpm/gm	dpm/gm	error	(yr)
A total	0 to 3	3.51	6.25	0.52	
	3 to 6	5.57	1.17	0.44	
	6 to 9	3.37	0.96	0.27	
	9 to 12	2.65	0.87	0.22	
	18 to 20	6.25	1.25	0.49	
	12 to 15				
	15 to 18				
B total	0 to 3	3.45	0.25	0.25	
	3 to 6	3.87	0.13	0.28	
	9 to 12	4.07	-0.17	0.28	
	12 to 15	3.39	0.19	0.25	
	15 to 19	2.73	0.54	0.21	
A mud	0 to 3	3.50	12.82	0.83	0
	3 to 6	6.39	7.40	0.76	-18
	6 to 9	7.18	5.62	0.73	-26
	9 to 12	9.32	9.67	1.06	9
	12 to 15	6.00	7.26	0.73	-18
	15 to 18	4.31	6.40	0.58	-22
	18 to 20	4.58	3.28	0.46	-44
A sand	0 to 3	5.88	0.54	0.44	
	3 to 6	5.97	-0.15	0.42	
	6 to 9	3.69	0.18	0.27	
	9 to 12	2.84	0.69	0.23	
	12 to 15	2.71	0.22	0.20	
	15 to 18	3.90	-0.07	0.27	
	18 to 20	6.89	-0.84	0.46	
I	0 to 1	4.22	0.27	0.31	-124
	1 to 2	2.80	0.74	0.23	92
	2 to 3	2.78	0.77	0.23	-90
	3 to 4	3.33	0.92	0.27	-85
	4 to 5	3.04	0.45	0.23	-108
	10 to 11	2.68	0.75	0.22	-91
	20 to 21	2.70	1.05	0.23	-80
	30 to 31	2.37	0.48	0.18	-106
	45 to 47	2.14	0.39	0.17	-112
				I mean	-99

APPENDIX F

Pollen Analysis of Sediments and Identification of Wood Associated with *H.L. Hunley*

POLLEN ANALYSIS OF SEDIMENTS AND IDENTIFICATION OF WOOD ASSOCIATED
WITH THE *H. L. HUNLEY*, SOUTH CAROLINA

By

Thomas E. Moutoux
Kathryn Puseman
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Paleo Research Laboratories
Denver, Colorado

Paleo Research Labs Technical Report 96-58

Prepared For

Submerged Cultural Resources Unit
National Park Service
Santa Fe, New Mexico

September 1996

INTRODUCTION

The *H. L. Hunley* was a Confederate submarine that sank in February 1863 just outside Charleston Harbor, South Carolina. Six pollen samples were collected from a sediment column approximately 85 centimeters deep that had accumulated atop the *H. L. Hunley* after its demise in 1863. Analysis of these six samples should assist in identifying the nature of the sediments, particularly with respect to timing of sedimentation. In addition to the six pollen samples, a single piece of wood recovered from near the *Hunley* in a probable scour hole was submitted for identification.

METHODS

Pollen

A chemical extraction technique based on flotation is the standard preparation technique used in this laboratory for the removal of the pollen from the large volume of sand, silt, and clay with which they are mixed. This particular process was developed for extraction of pollen from soils where preservation has been less than ideal and pollen density is low.

Hydrochloric acid (10%) was used to remove calcium carbonates present in the soil, after which the samples were screened through 150 micron mesh. The samples were rinsed until neutral by adding water, letting the samples stand for 2 hours, then pouring off the supernatant. A small quantity of sodium hexametaphosphate was added to each sample once it reached neutrality, then the beaker was again filled with water and allowed to stand for 2 hours. The samples were again rinsed until neutral, filling the beakers only with water. This step was added to remove clay prior to heavy liquid separation. At this time the samples are dried then pulverized. Zinc bromide (density 2.1) was used for the flotation process. The samples were mixed with zinc bromide and centrifuged at 1500 rpm for 10 minutes to separate organic from inorganic remains. The supernatant containing pollen and organic remains is decanted and diluted. Zinc bromide is again added to the inorganic fraction to repeat the separation process. After rinsing the pollen-rich organic fraction obtained by this separation, all samples received a short (20 minute) treatment in hot hydrofluoric acid to remove any remaining inorganic particles. The samples were then acetoluted for 3 minutes to remove any extraneous organic matter.

A light microscope was used to count the pollen to a total of 201 pollen grains at a magnification of 400–600x. Pollen preservation in these samples varied from excellent to fair. Comparative reference material collected at the Intermountain Herbarium at Utah State University and the University of Colorado Herbarium was used to identify the pollen to the family, genus, and species level, where possible.

Pollen aggregates were recorded during identification of the pollen. Aggregates are clumps of a single type of pollen, and may be interpreted to represent pollen dispersal over short distances, or the introduction of portions of the plant represented into an archaeological setting. Aggregates were included in the pollen counts as single grains, as is customary. The presence of aggregates is noted by an "A" next to the pollen frequency on the pollen diagram. Indeterminate pollen includes

pollen grains that are folded, mutilated, and otherwise distorted beyond recognition. These grains are included in the total pollen count, as they are part of the pollen record.

Wood

A 5 x 30 mm piece of wood was removed from single large sample that was submitted. This smaller piece of wood was dried, then charred. The charred piece of wood was broken to expose fresh cross and tangential sections and examined under a binocular microscope at magnifications up to 80x. The sample was identified using manuals (Core et al. 1976; Paishin and Zeeuw 1980), and by comparison with modern references.

DISCUSSION

The Confederate submarine, *H. L. Hunley*, sank in 1863 approximately 6 miles outside Charleston Harbor, South Carolina. Corals growing on the hull of the submerged submarine suggest that this entirely iron vessel was exposed on the ocean floor for approximately 20–25 years before being completely covered by sediment (Larry Murphy and Dave Conlin, personal communication, September 16, 1996). Rapid burial of the *Hunley* is possible considering the combined processes of ocean current scour, displacement of the ocean floor sediments under the weight of the iron vessel, and the simple accumulation of sediment from the overlying water column. Local lore has it that the *Hunley* was located during the 1970s and was totally exposed. No evidence supporting this account was found in the 1995 field season.

Sediment recovered for the pollen column was located above the aft hatch area of the starboard side of the *Hunley*. The sediment column in this area was approximately 85 cm thick and consisted of several distinct layers of sand and mud. Pollen column sample 030 was collected at a depth of 80–85 cm and represents the layer of sediment directly overlying the surface of the submarine. Samples 029 through 025 were recovered from layers within the sediment column at depths ranging from 0 to 60 cm (Table 1). The pollen spectra from these six samples were very similar to one another. Pinus pollen dominated the record, followed by a moderate quantity of Quercus pollen (Figure 1, Table 2). Betula, Cupressaceae, and Poaceae pollen generally occurred in moderately small quantities, and small amounts of Alnus, Carya, Liquidambar, Low-spine Asteraceae, Chenopods, and Cyperaceae pollen generally occurred in all six samples. Pollen types that were noted in three or more of the samples include small quantities of Fraxinus, Ostrya/Carpinus, Ulmus, High-spine Asteraceae, Ilex, Vitis, indeterminate, and unidentified pollen. Pollen types noted in less than half of the samples include small quantities of Acer, Corylus, Juglans, Platanus, Salix, Apiaceae, Ceanothus, Celtis, Liliaceae, Rosaceae (scabrate), Toxicodendron, and Typha angustifolia-type. Non-pollen forms identified include dinoflagellates, foraminifera, and monolete and trilete spores.

No pollen types uniquely representative of introduced species or historic marker species, such as Castanea, were identified in any of the six samples. Castanea dentata (American chestnut) was systematically all but wiped out subsequent to the introduction of chestnut blight in 1904. If American chestnut grew near the coast of South Carolina before the turn of the century, Castanea pollen should be represented in pollen samples at the *Hunley* site that represent sediments pre-dating the early 1900s. However, the current range of American chestnut includes only the western half of the

state of South Carolina, approximately 100 miles from the coast. Since this range is similar to the range reported for chestnut blight and, therefore, the historic distribution of chestnut, *Castanea* pollen would not be expected to be recovered from sediments associated with the *Hunley*, even in samples pre-dating the turn of the century. In the absence of an expected historic marker, this pollen column is consistent with current belief that the *Hunley* was buried a mere 20-25 years after its demise. However, the pollen column alone also is consistent with deposition of sediments at any time between 1863 when the *Hunley* sank and present.

The pollen record is composed primarily of pollen representing trees. Tree pollen is released at least 20 feet in the air, giving it a significant advantage over pollen representing herbaceous plants that is released near ground level when traveling on the wind. The pollen of introduced plant species, even ones as prevalent as kudzu, would not be expected in any appreciable quantity at the *Hunley* site. This is due, in large part, to the fact that the introduced plant forms in the south are insect-pollinated herbaceous plants that do not produce large quantities of pollen. Also, this pollen is not readily transported by the wind. Since wind transport of pollen is likely a major contributing factor to the pollen deposition at the *Hunley* site, it is unlikely that pollen from introduced plants would be represented in sediments six miles from shore. Even pollen transported by river currents is likely to be primarily tree pollen.

A single piece of wood was recovered from outside the hull of the *Hunley* in an area that may have been a scour hole. This wood was identified as *Pseudotsuga menziesii* (Table 3, Figure 2), representing use of Douglas-fir wood. Douglas-fir wood can be positively identified by the presence of spiral or helical thickenings in the tangential view. Douglas-fir is considered the most important timber tree in western North America, with a range extending from Canada to Mexico. Trees from coastal areas in southern British Columbia and western Washington/Oregon are most abundant and attain their largest size. Only the Sequoias of California are larger. Wood from Douglas-fir trees in the coastal regions is finer-grained, more uniformly textured, and lighter in color than wood from trees in mountain and intermountain areas. Douglas-fir trees in mountainous areas are smaller, and the wood is softer and redder in color (Johnson 1973:83; Record 1934:144). Red wood has wider rings, and is stronger and more refractory under tools. Douglas-fir is sometimes sold as "red fir." Douglas-fir is used for general construction; planing-mill products (sash, doors, flooring, and general millwork); railroad cars; boxes, crates, and pallets; containers for corrosive chemicals; silos and tanks; ship and boat building; insulating and other types of fiberboard; particle and hardboard; poles, piling, mine timbers, and railroad ties (Panshin and Zeeuw 1980:465).

SUMMARY AND CONCLUSIONS

The pollen column samples produced a very homogeneous signal dominated by arboreal pollen types. A signal such as this is expected at a site so far off-shore due to the effects of wind transport on the pollen assemblage and the greater abundance of pollen produced by arboreal species. The absence of *Castanea* (chestnut) in the eastern half of the state of South Carolina eliminates this pollen type as a potential historic marker. No other historic marker pollen type is expected from this area. The pollen from introduced herbaceous plants is not expected from the *Hunley* site due, in large part, to the distance off the coastline. There is nothing in the pollen record that makes it inconsistent with the current belief that the *Hunley* was buried within 20-25 years of 1863.

TABLE I
PROVENIENCE DATA FOR SAMPLES FROM THE *ILL HUNLEY*

Sample No.	Depth (cm)	Provenience/Description	Analysis	Pollen counted
025	0-10	Grab sample from aft hatch area on the starboard side.	Pollen	201
026	10-15	Grab sample from aft hatch area on the starboard side.	Pollen	201
027	15-22	Grab sample from aft hatch area on the starboard side.	Pollen	201
028	22-35	Grab sample from aft hatch area on the starboard side.	Pollen	201
029	50-60	Grab sample from aft hatch area on the starboard side.	Pollen	201
030	80-85	Grab sample from aft hatch area on the starboard side, directly overlying the surface of the submarine.	Pollen	201
004		Wood from probable scow hole outside the hull.	Wood ID	ID

A piece of Douglas-fir wood was discovered near the hull of the *Hunley*. Because Douglas-fir is found only in the western United States, this wood was not obtained from a local tree. The wood sample represents use of Douglas-fir as commercial timber.

TABLE 2
POLLEN TYPES OBSERVED IN SAMPLES FROM THE *H.L. HUNLEY*

Scientific Name	Common Name
ARBOREAL POLLEN:	
<u>Acer</u>	Maple
<u>Alnus</u>	Alder
<u>Betula</u>	Birch
<u>Carya</u>	Hickory, Pecan
<u>Corylus</u>	Hazelnut
<u>Cupressaceae</u>	Cypress family
<u>Fraxinus</u>	Ash
<u>Juglans</u>	Walnut
<u>Liquidambar</u>	Sweet gum
<u>Ostrya/Carpinus</u>	Hophornbeam/Hornbeam
<u>Pinus</u>	Pine
<u>Platanus</u>	Sycamore
<u>Quercus</u>	Oak
<u>Salix</u>	Willow
<u>Ulmus</u>	Elm
NON ARBOREAL POLLEN:	
<u>Apiaceae</u>	Parsley/carrot family
<u>Asteraceae</u>	Sunflower family
Low-spine	Includes ragweed, cocklebur, etc.
High-spine	Includes aster, rabbitbrush, snakeweed, sunflower, etc.
<u>Ceanothus</u>	Buckbrush
<u>Celtis</u>	Hackberry
<u>Chenopium</u>	Pigweed (amaranth) and the goosefoot family
<u>Cyperaceae</u>	Sedge family
<u>Ilex</u>	Holly
<u>Liliaceae</u>	Lily family

Scientific Name	Common Name
NON-ARBOREAL POLLEN (continued):	
Poaceae	Grass family
Rosaceae	Rose family
<u>Toxicodendron</u>	Poison-ivy
<u>Typha angustifolia</u>	Cattail
<u>Vitis</u>	Grape
SPORES:	
Monolete	
Trilete	

TABLE 3
WOOD FROM THE H.L. HUNLEY

Sample No.	Description	Identification	
		Scientific Name	Common Name
004	Wood from probable scour hole near the hull.	<u>Pseudotsuga menziesii</u>	Douglas fir

REFERENCES CITED

Core, H. A., W. A. Cote, and A. C. Day

1976 Wood Structure and Identification. Syracuse University Press, Syracuse, New York.

Johnson, Hugh

1973 The International Book of Trees. Simon and Schuster, Inc., New York.

Panshin, A. J. and Carl de Zeeuw

1980 Textbook of Wood Technology. McGraw-Hill Book Co., New York.

Record, Samuel J.

1934 Identification of the Timbers of Temperate North America. John Wiley and Sons,

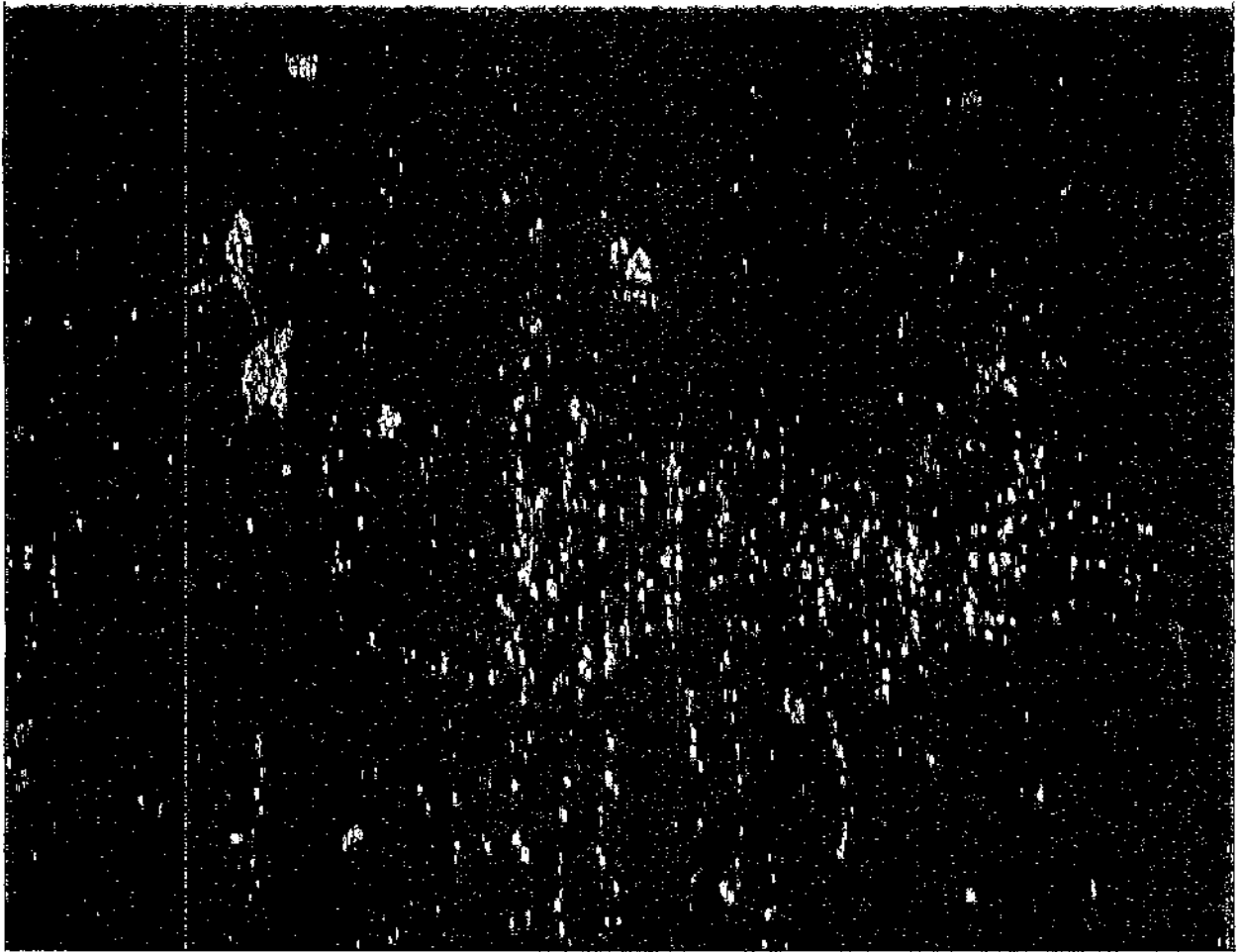


Figure 2. Pseudotsuga mensiesii wood from near the hull of the *H.L. Hunley*, 60x.

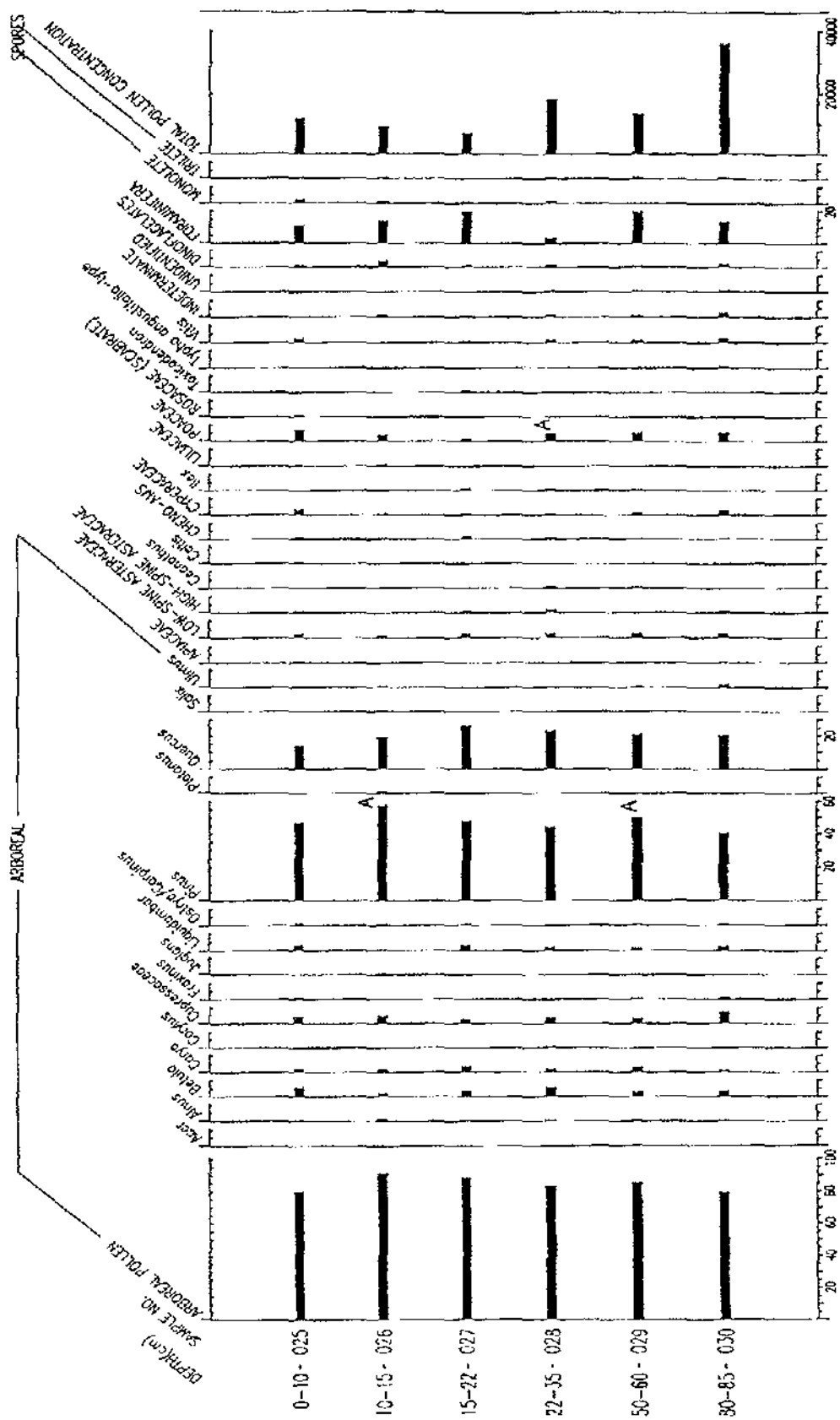


FIGURE 1. POLLEN COLUMN DIAGRAM FOR THE H.L. HUNLEY.

APPENDIX G

Letter from Paleontologist Greg McDonald



United States Department of the Interior

NATIONAL PARK SERVICE

Hagerman Fossil Beds National Monument

221 North State Street

P.O. Box 570

Hagerman, Idaho 83332-0570

IN REPLY REFER TO:

October 10, 1996

Dave Conlin
Submerged Cultural Resources Unit
National Park Service
Southwest Region
P.O. Box 728
Santa Fe, New Mexico 87504-0728

Dear Dave,

Finally! A little breathing time to get caught up on obligations such as the "rib". You'll notice that I've put rib in quotes since upon closer examination it is not really a rib but a portion of sternal cartilage that connects the rib to the sternum. The specimen is somewhat ossified suggesting an older individual but because of the porous nature of the cartilage and the lack of any solid material no real cut marks are visible. Most of the original sternal cartilage is present and it seems to have been cut very close to its attachment to the sternum and the rib. The two cuts are roughly parallel and if I had to venture an observation would probably guess cut with a saw rather than hacked with a blade since the actual surface of the bone is rather smooth, even when viewed under magnification. Given the size of the specimen I think cow is a good guess. While I had access to cow ribs for comparison, the specimen did not have the sternal cartilage so actual placement in the animal is not possible although I would say it represents the sternal cartilage somewhere in the neighborhood of ribs 6 to 9. I've enclosed copies of some illustrations with the cartilage highlighted to show how this fits into the overall animal.

I've also enclosed a couple of illustrations of cuts of meat. Given the probably position in the rib cage this would be part of a brisket cut or possibly the short plate. As you will note from the enclosed illustration from "Animal Bone Archaeology" page 14, both of these are cheap cuts of meat in the late 19th century.

If you would like me to pursue this further I can retain the specimen until I can make a trip to the Idaho Museum of Natural History. They will have a cow skeleton which may retain the sternal cartilage and would permit me to be more specific as to which rib this cartilage attached. If you feel that what I have done is sufficient for your purposes, let me know and I will return the specimen.

Again, my apologies for the overly long time it took to get this small amount of information back to you.

Sincerely

Greg McDonald
Paleontologist

APPENDIX H

Letter from Curt N. White and Gino Irdi



**U. S. Department of Energy
Federal Energy Technology Center**

3610 Collins Ferry Road
P.O. Box 888
Morgantown, WV 26507-0888

526 Cochran Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940



May 8, 1997

Mr. Matt Russell
Archeologist
Submerged Cultural Resources Unit
National Park Service
Southwest Region
P. O. Box 728
Santa Fe, New Mexico 87504-0728

Dear Mr. Russell,

We have examined the coal from the *C.C.S. Hunley* that you sent using standard petrographic techniques. Two small ($\approx$ 1 inch diameter) chunks were taken from the first larger piece of the *Hunley* sample and one small chunk was taken from the second sample. The chunks were polished along the coals' bedding plane so that the various lenses of macerals and minerals could be observed.

The examination showed that both coal samples were of extremely high rank and that there were distinct bands of vitrinite, inertinite, and clay minerals along the bedding planes. The vitrinite reflectance of the first coal was an extremely high 9.20 % mean max in oil. The second coal gave a vitrinite reflectance of 4.90 % mean max in oil. The first value would place the coal in the meta-anthracite rank, while the second value is in the upper range of anthracite. There were only a few areas of graphite in the samples; but this may be due to the fact that we only examined a small amount of the original coals.

The question of the coals' source can not be answered with absolute certainty, but some educated "guesses" can be made. Since we know that the *Hunley* was human-powered, it most likely did not carry any coal with it. The *Housatonic* (the Union ship that was sunk by the *Hunley*) was a privateer that was named for the Housatonic area in New England, and probably carried coal for

REPLY TO: Pittsburgh Office

Voice (412)892-5808

FAX (412)892-4152

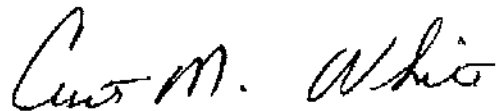
curl.white@fetc.doe.gov

<http://www.fetc.doe.gov>

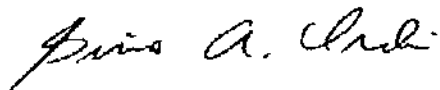
heating and/or power purposes. The New England area is the only place in the United States where meta-anthracite could have been mined during the Civil War. No Confederate states' coal is in the anthracite or meta-anthracite rank. Therefore, the anthracite and meta-anthracite coals that were recovered in the proximity of the Hunley probably came from the *Housatonic's* coal storage bunkers.

Thank you for sending us this sample. We enjoyed working on it and hope that the above information is useful to you. If you have any questions concerning this, please call us. When you recover any additional coal samples from this or other wrecks, we would be pleased to work on them.

Sincerely,

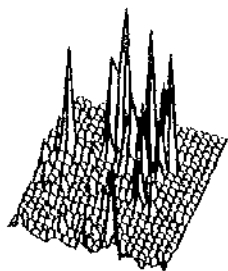
A handwritten signature in cursive script that reads "Curt M. White".

Dr. Curt N. White, Physical Scientist
Mr. Gino Irdi., Physical Scientist

A handwritten signature in cursive script that reads "Gino A. Irdi".

APPENDIX I

Corrosion Characterization of Confederate Submarine *H.L. Hunley*



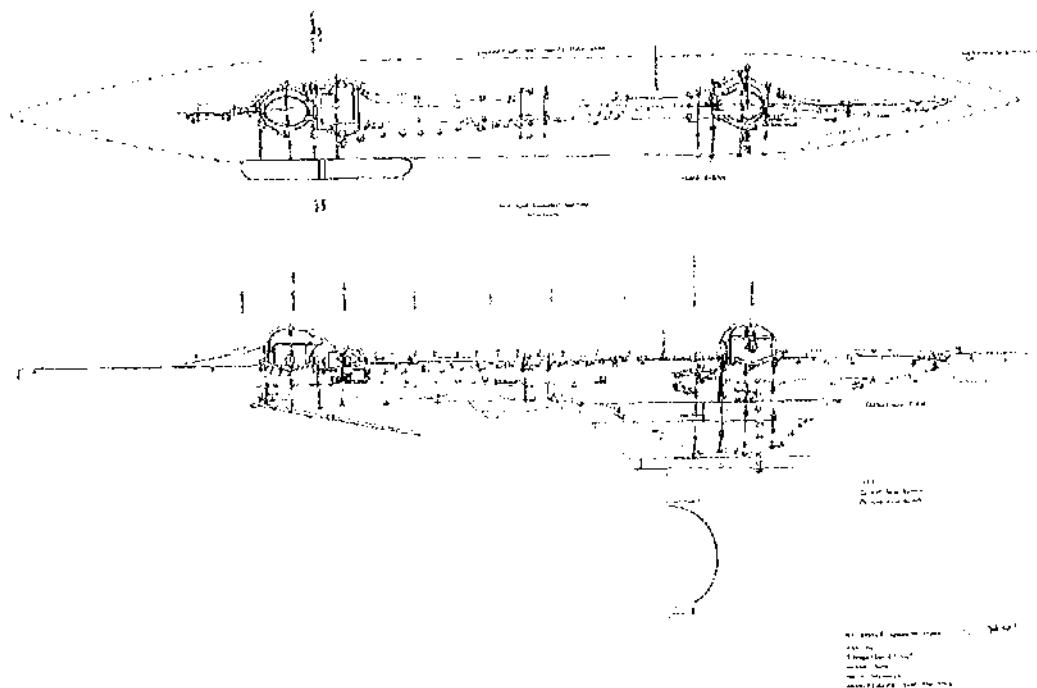
D. R. Polly
(805) 984-6183

2971 Loeward Way
Oxnard, CA 93035

Site Specific Report

SSR-0002-DRP

CORROSION CHARACTERIZATION OF THE CONFEDERATE SUBMARINE *HL HUNLEY*



February 1997

Distribution authorized to U.S. Government agencies; February 1997.
Other requests for this document shall be referred to National Park Service.

Corrosion Characterization of Confederate Submarine H L Hunley

I. Background

The National Park Service, requested participation of corrosion consultants in the archeological investigation of the Confederate submarine HL Hunley. Justifications, directed at the U. S. Naval Historical Center and the South Carolina Hunley commission, were for two on site participants, one with direct experience assessing historic hulls, and another with proprietary instrumentation for detection and quantification of corrosion activity. The services of the corrosion engineer with historic hull experience could not be secured. However, time was contributed toward physical measurements of corrosion characteristics through the use of non-intrusive sensors.



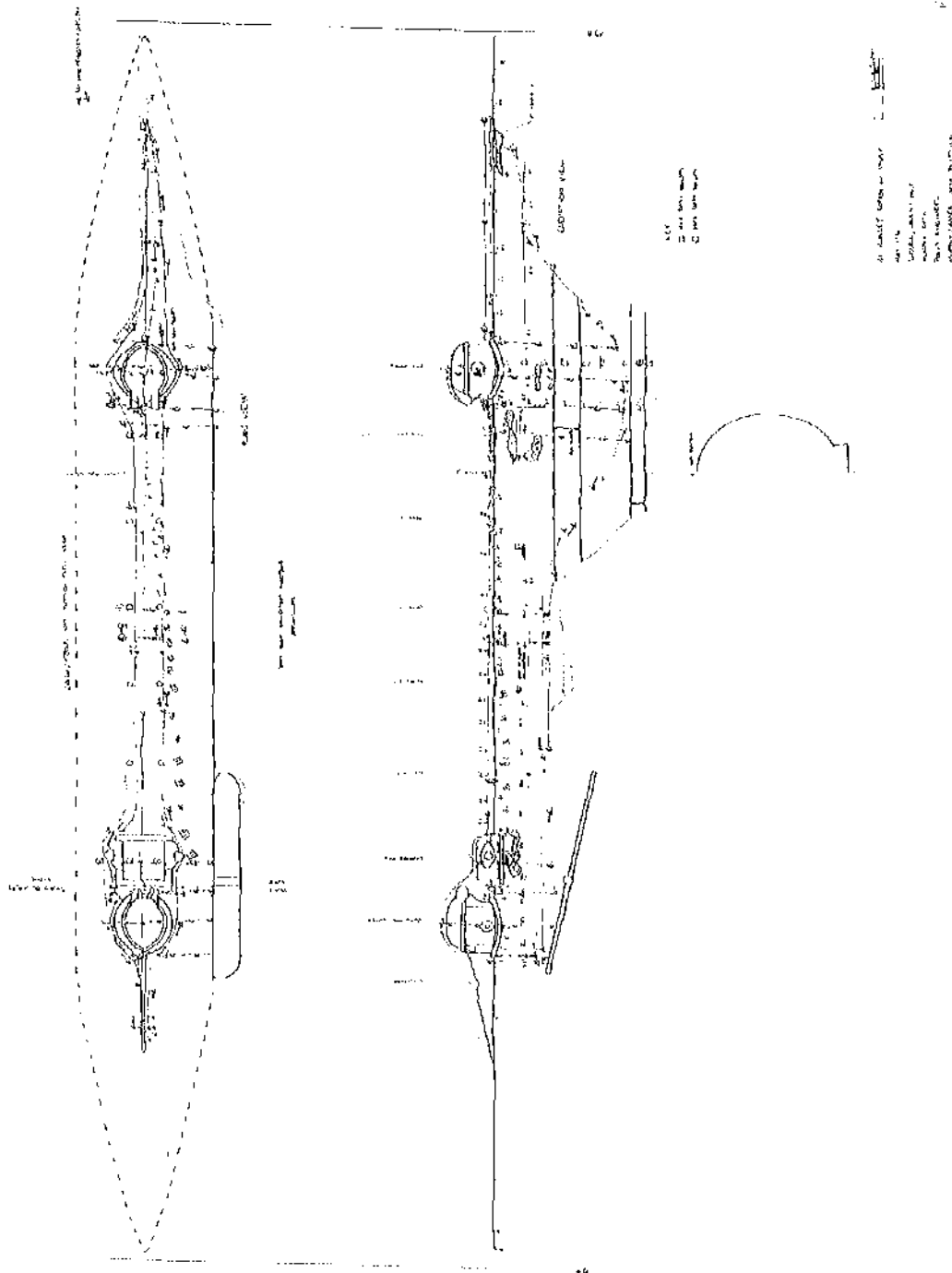
Figure 1. LOM macrograph of encrustation cross section.

The intent was to use in situ measurements of electrochemical activity to determine the nature of general and localized corrosion.

An encrustation fragment (Figure 1) recovered from the site was also examined.

II. Instrumentation

Instrumentation, with modifications for this specific investigation, was taken on site for investigation of surface current flux, sea water voltage gradients, surface potentials, and polarization behavior.



Surface current flux instrumentation measures the magnitude and polarity of electrochemical current flow associated with corrosion activity. Activity is measured directly at the surface without any electrical connection. The system indicates the level of activity at the sensor location, and whether the activity is anodic or cathodic. With a sufficient number of readings a current flux contour map of the structure can be obtained which images the surface to the resolution of the mapping grid spacing.

Sea water current flux / voltage gradient instrumentation displays real time measurements of magnitude and 3-dimensional vector orientation of current flux in water. High sensitivity ($\mu\text{A}/\text{cm}^3$) and resolution (cm) allows 4-dimensional plots of current flow magnitude and direction for the survey region.

Potential measurements provide an indirect indication of relative anodic and cathodic areas. Dependent on good electrical connection to measurement location. Readings are a broad (not localized) measure of surface potential compared to a reference electrode.

Potentiostatic instrumentation measures polarization behavior and the degree of electrical continuity between structure components. Dependent on good electrical contact with components. Method can establish the possibility of galvanic effects and cathodic protection criteria.

III. Measurements and Examination

Surface current flux. Several transects, with periodic recordings of surface current flux, were made along the hull. Figure 2. shows the location of these transects as series of colored dots on plan and elevation views of the submarine.

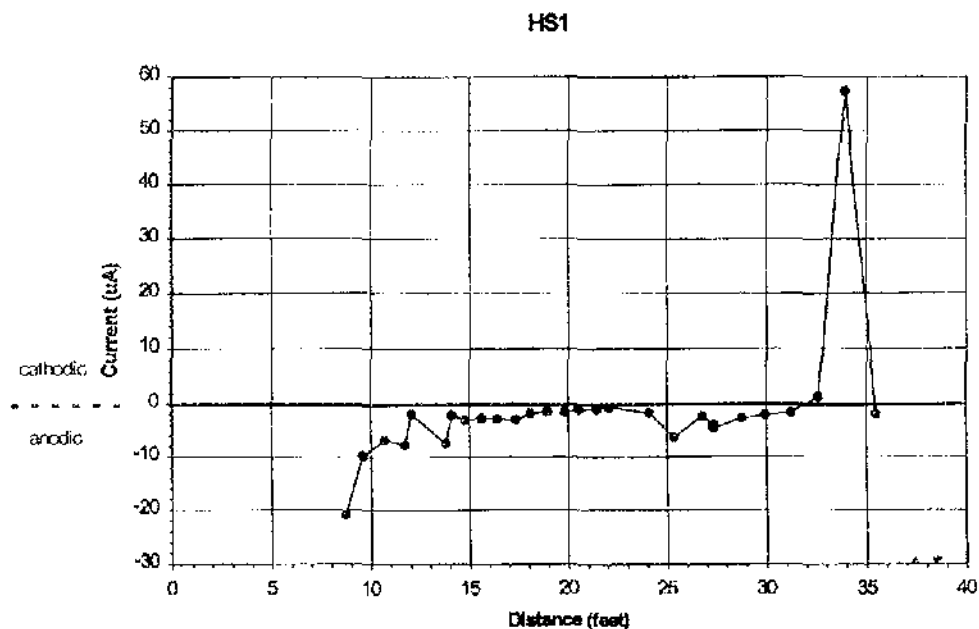


Figure 3. Surface current flux for transect HS1.

Transect designated H1S, shown as red dots, is a longitudinal transect proceeding from stern to bow, along shell plate above stern concretion, starboard side following the edge of the excavation at the excavation/hull interface. Most points are along the centerline of the hull top. Readings are plotted in Figure 3 with respect to longitudinal zero indicated in Figure 2.

Transect designated H2B, shown as green dots, is a longitudinal transect from bow to stern on the port side of centerline. Readings are plotted in Figure 4 with respect to longitudinal zero indicated in Figure 2.

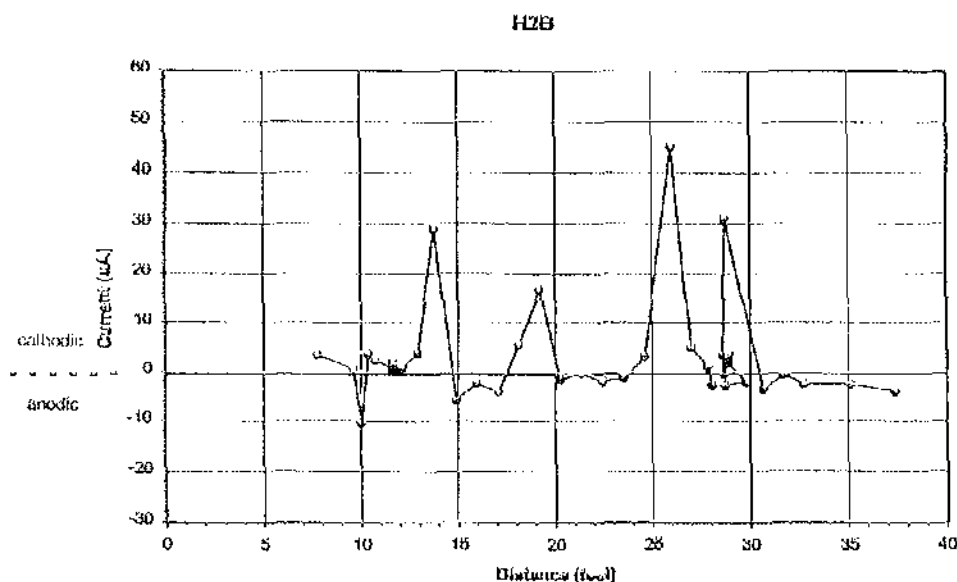


Figure 4. Surface current flux for transect H2B.

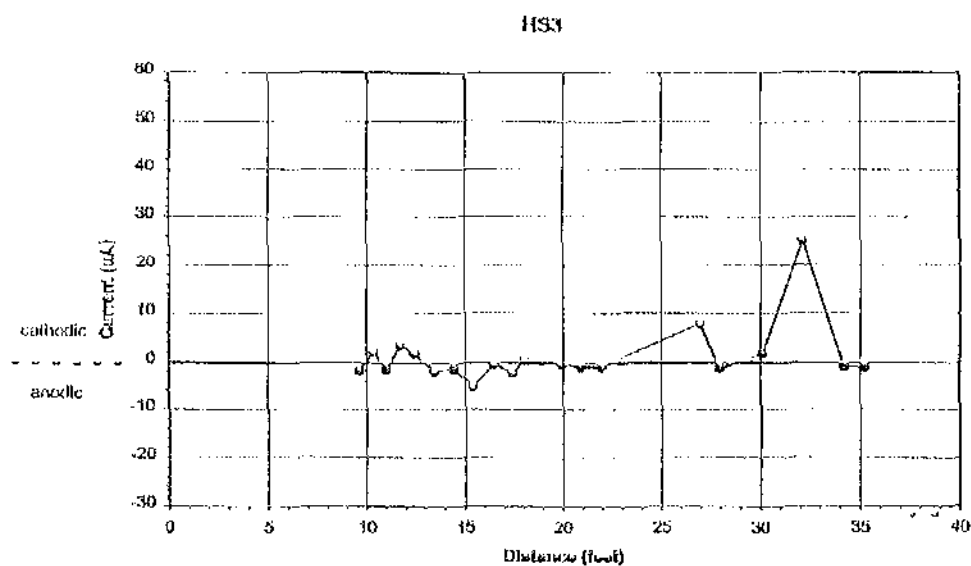


Figure 5. Surface current flux for transect H2S.

Transect designated II3S, shown as blue dots, is a longitudinal transect from stern to bow. Readings are plotted in Figure 5 with respect to longitudinal zero indicated in Figure 2.

Transect designated HV4, shown in yellow dots, is directly aft of the aft hatch, from 18 inches below the aft hatch on the starboard side, up and over the hull top and down along the port side of the hull to the keel. Readings are plotted in Figure 6 for plan and elevation views with respect to zeros indicated in Figure 7.

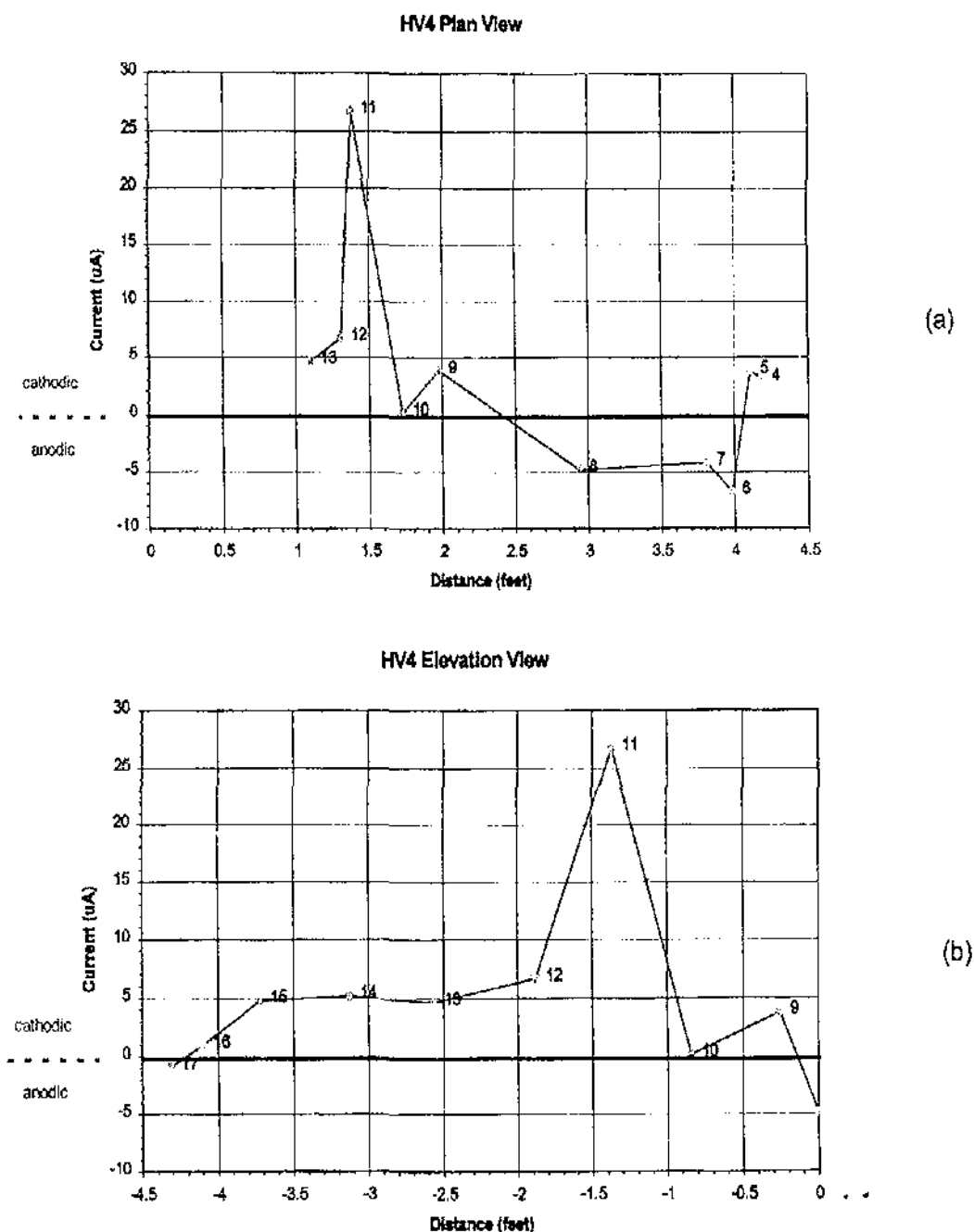
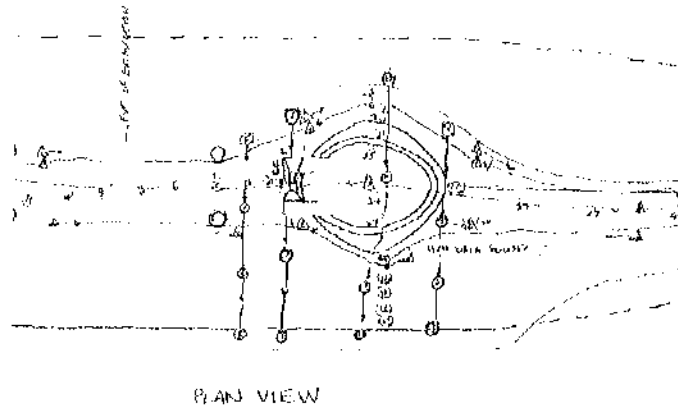
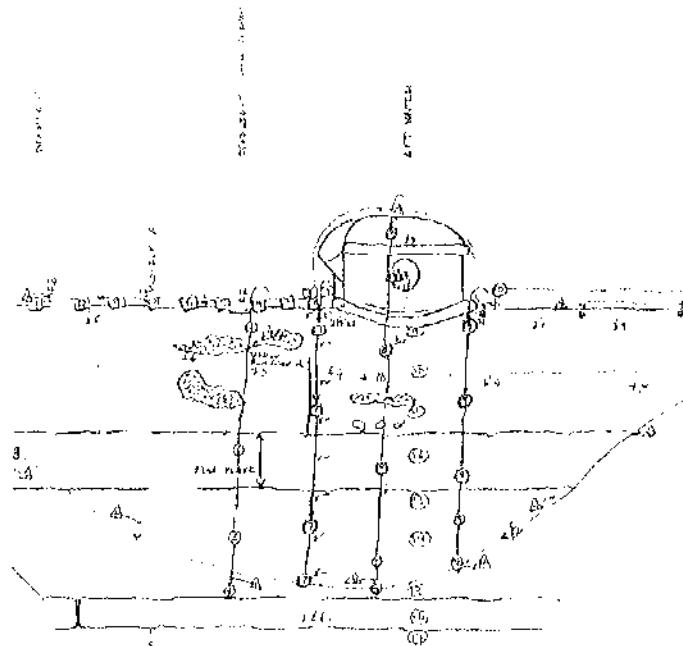


Figure 6. Plan (a) and elevation (b) surface current flux for transect HV4.



PLAN VIEW



SECTIONAL VIEW

Sea water current flux and voltage gradients. A number of transects were made along the hull with the sensor positioned approximately 1 1/2 inches above the surface. Subsequent to the dive, sensor malfunction was observed. At what point in the dive this occurred is unknown, making all data suspect.

Potential. Potential readings were taken concurrently with the surface flux transect designated HV4. Connection to the hull was made by attachment, at a hole in the forward hatch, of an epoxy coated C-clamp with a pointed screw. All reading were -.62 volts relative to a Ag/AgCl/ sea water reference electrode. The constant potential indicates there was inadequate electrical connection through the clamp, or isolation of the attachment point from other areas of the hull.

Polarization behavior. Time constraints did not allow diver connections and equipment configuration required for these tests.

Encrustation fragment. The fragment was removed from a location 1 foot forward and 1 foot down from the forward port corner of the snorkel box. Reportedly, it is comprised of an encrustation layer removed fully to sound metal. Figure 1 is a light optical macrograph (LOM) of a fresh cross sectional surface made by breaking the fragment. Figure 8 is a scanning electron micrograph (SEM) of the same surface.

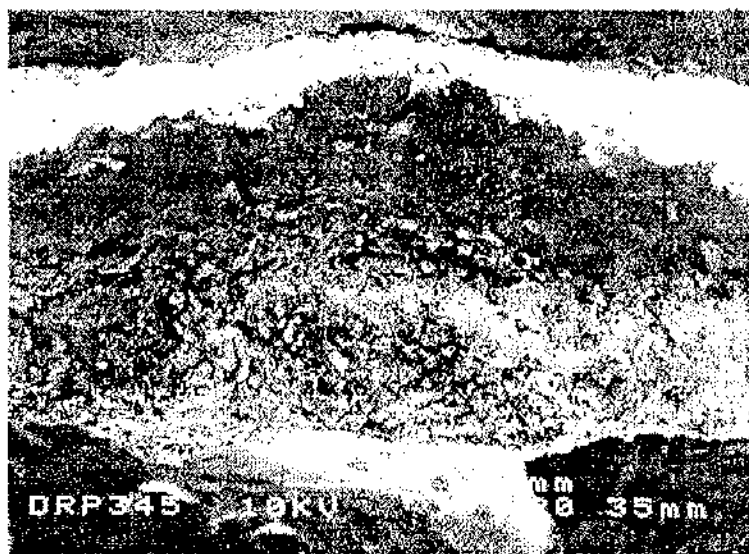
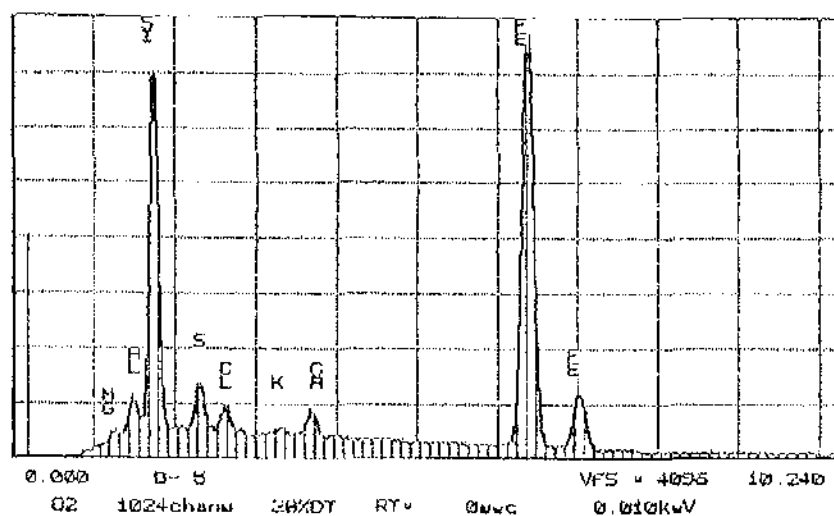
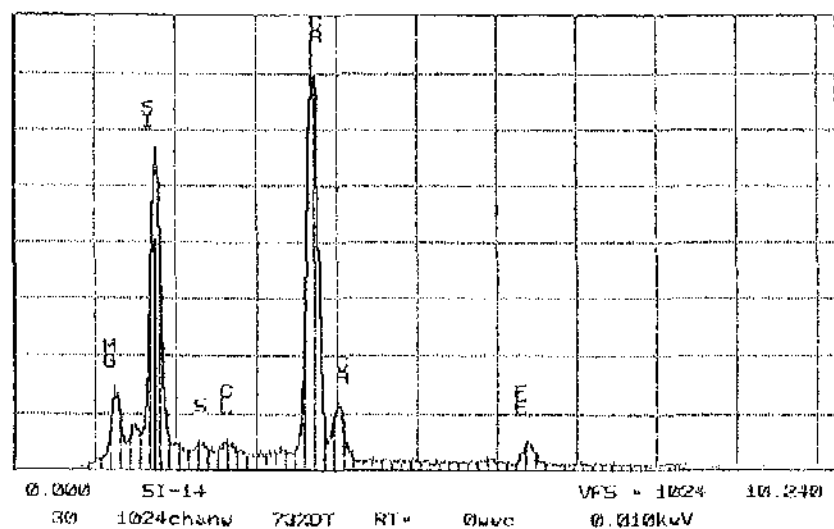


Figure 8. SEM Micrograph of encrustation cross section.

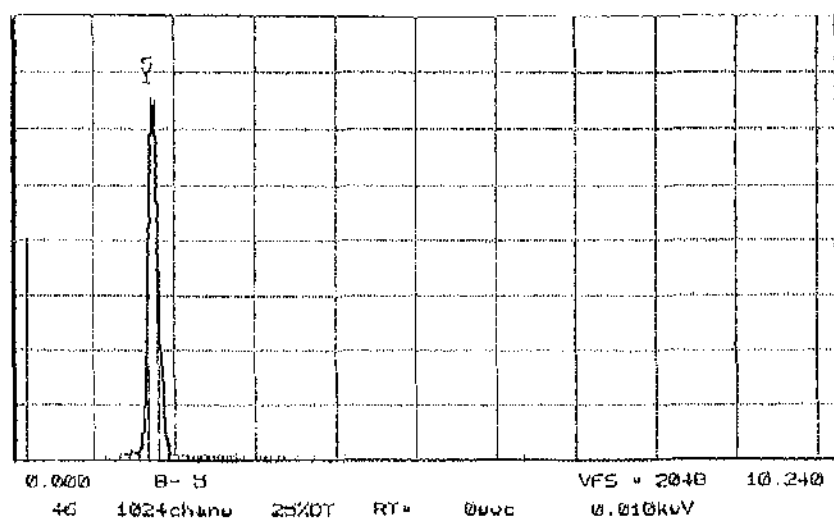
In this secondary electron image, charging of the white (LOM) calcareous layer at the upper surface is shown as a light region approximately 0.5 mm thick. While biological growth was evident on other fragments, this layer could not be tied specifically to biological origins. Elemental analysis of the surface by energy disperse X- ray spectroscopy is presented in Figure 9b.



(a)

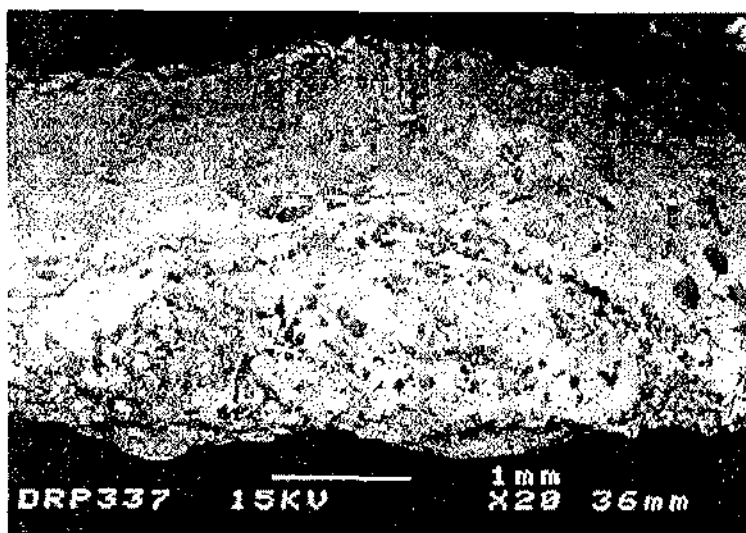


(b)

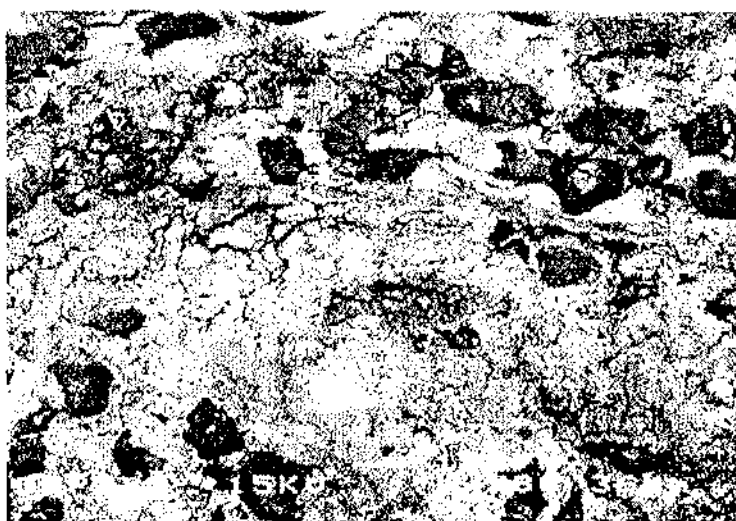


(c)

Figure 9. Electron microprobe X-ray spectrum for (a) bulk, (b) upper surface, and (c) embedded particles.



(a)



(b)



(c)

Figure 10. BSE electron micrographs at (a) 20x, (b) 80x, and (c) 200x.

The remainder of the fragment matrix is black (LOM) Fe_3O_4 . Throughout the cross section there are angular particles of embedded silica (Figure 9c) sediment. In the backscattered electron images of Figure 10 these particles appear darker than the matrix. The particles are approximately 100 μm in size. No slag fibers, which typically would have a nominal diameter of 10 μm , were found. At its maximum, the matrix is approximately 2.8 mm thick.

The bottom surface is reddish (LOM) Fe_2O_3 , no doubt having converted subsequent to removal from the site.

III. Discussion

Speculation on the results of long term immersion is best left to historical experts. However some generalization can be made. As discussed below, the corrosion rate of steel immersed in sea water is dependent on numerous factors, including galvanic coupling, fouling, pH, pollution, water velocity, and scouring. All factors which have no doubt changed significantly at this site over the years. Therefore, the corrosion rate could vary greatly from nominal rates for steel immersion in sea water. The commonly accepted rate of 5 mils per year for initial exposure, decreases significantly with time. One investigation of long term exposure showed losses of approximately 2 mils per year averaged over the first 20 years, with 1 mil per year loss thereafter. These rates imply there would be a loss of approximately 150 mils (3.8 mm). This loss, for general corrosion of steel, is higher than what would be expected for comparable exposure of wrought iron.

Wrought iron inherently has a higher corrosion resistance than steel. This is due to iron silicate fibers, formed by the slag inclusions incorporated by the hand-puddling process employed in the late 1700's and the 1800's. After the sponge-like mass from the refining operation was "rolled" and "piled" into the desired shape, there could be as many as 250,000 or more siliceous slag fibers per in² of cross section. Considered impurities in earlier times, the slag fibers serve as mechanical barriers to pit penetration, forcing more uniform progression of corrosion. Characteristically, corrosion products are dense and adherent. Studies of old wrought irons has shown large variations in chemical composition, but records indicate that these variations had little effect on corrosion resistance.

Electrochemical measurements. Detection and quantification of electrochemical processes is key to understanding present corrosion behavior. The HL Hunley is susceptible not only to corrosion of a general nature, but localized attack. Differential aeration cells are possible from variations in oxygen content due to sediment cover, biological growth, water flow, and encrustation, in general. Galvanic cells can occur with electrical continuity between components such as the shell plates, rivets, keel, screw, dive plane, and the snorkel box.

Insufficient measurements were made for construction of activity contour maps showing individual component behavior. Encrustation obscured features such as rivets. Therefore, no correlation's between certain features and individual measurements could be made. However, some generalization are possible.

- At the locations of measurement where readings were anodic, activity was low. The highest anodic current flux was found at the excavation/hull interface on the starboard side of the bow (Figure 3).
- Cathodic current flux readings are much higher, on average, than anodic readings. This is somewhat unusual in that low level cathodic activity over large areas normally supports higher level localized anodic activity. Measurements indicate that inaccessible (or unmeasured) surfaces or components are active anodically.
- Figure 6 indicates that the starboard side of the hull at the aft hatch is anodic with respect to the port side.
- Readings presented in Figure 6 indicate the keel is not cathodic with respect to the adjoining shell plate as would be expected.
- High cathodic activity corresponds to areas identified as "concretion" or encrustation.

Readings represent activity at the time of measurement. In the case of the HL Hunley, where some excavation occurred prior to measurement, some disturbances in the previous conditions has no doubt occurred. These disturbances are probably minor though, with respect to the influence of conditions available for promoting localized corrosion.

Encrustation fragment. The encrustation fragment, recovered from the hull, corroborates a low corrosion rate, assuming that the fragment is a complete representation of the full thickness of the rust layer.

Metal loss calculations were made based on the following Fe density comparison between encrustation and wrought iron.

Encrustation

fragment desiccated weight = 1.46476 g

volume: vacuum impregnated weight (deionized water) - immersed weight

= 0.62512 g

density of encrustation = 2.34 g/cm³

Assuming a 90 wt.% Fe₃O₄ (conservative):

1.52 g Fe/cm³ encrustation <-----

At the measured encrustation thickness of 2.8 mm:

0.42 g Fe/cm² encrustation

Wrought iron

For typical hand-puddling $= 7.7 \text{ g/cm}^3$

Assuming a chemical composition typical of more modern wrought iron:

iron silicate: 2.5 wt.% (1.36 to 6.22% historically)

other elements: 0.3 wt.% (as high as 0.73 historically)

7.5 g Fe/cm³ wrought iron $\leftarrow$ -----

Metal loss is then,

$$\frac{(0.42 \text{ g Fe/cm}^3 \text{ encrustation})(1 \text{ cm}^3 \text{ wrought iron}/7.5 \text{ g Fe})}{-0.56 \text{ mm}} \leftarrow$$

indicating relatively dense corrosion products with approximately a 5 to 1 product/ metal loss ratio.

IV. Summary Recommendations

The discussion of corrosion characteristics is based on very limited data. While no hull measurements or calculations for the recovered encrustation fragment indicates large losses, particular attention should be paid to certain areas in preservation or recovery efforts.

The estimate based on general steel corrosion, places cross sectional loss at 7.6 mm for exposure of both sides of plate. This estimate is no doubt conservative, and calculations based on the encrustation fragment place the minimum cross sectional loss at approximately 1 mm. However, the anisotropy of the wrought iron must also be considered. Corrosion of cut ends of wrought iron plate is generally considered to be more severe than corrosion of the rolled surface. Therefore, recommend examination of representative joints of structural significance. Not only are rivets likely to be prone to preferential attack, but also the edges of the plate they connect.

No high anodic cell readings were made which could focus more specific investigation, except for the tendency to higher activity toward the underside. Recommend that the lowest elevation be examined in any further effort at specific determination of remaining cross section.

Cast iron (keel) galvanic effects appear small. However, the relatively high cathodic activity must be supported by anodic surfaces at some location. Dissimilar metal interfaces should be scrutinized.

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and work to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under US Administration.