

H. L. Hunley
Recovery Operations



Edited by
Robert S. Neyland and Heather G. Brown

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A Collaborative Project of:
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Satisfactory and important as have been the performances of the navy at this interesting period, they are scarcely more wonderful than the success of our mechanics and artisans in the production of war vessels which has created a new form of naval power.

-- Abraham Lincoln

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List of Abbreviations

| | |
|--------|---|
| ACHP | Advisory Council for Historic Preservation |
| AFM-DC | Assistant Field Manager for Data Collection |
| AFM-L | Assistant Field Manager for Logistics |
| CSN | Confederate States Navy |
| DOD | Department of Defense |
| FEA | finite element analysis |
| FeRB | iron reducing bacteria |
| FOTH | The Friends of the Hunley, Inc. |
| GSA | General Services Administration |
| HAT | Hunley Archaeological Team |
| HOC | Hunley Oversight Committee |
| HRC | Hunley Research Center |
| IAL | International Archaeological Lifts, L.L.C. |
| LIC | level indicating controller |
| MSL | mean sea level |
| NHC | Naval Historical Center (processor organization to NHHHC) |
| NHE | normal hydrogen electrode |
| NHHHC | Naval History and Heritage Command |
| NOAA | National Oceanographic and Atmospheric Administration |
| NPS | National Park Service |
| NUMA | National Underwater Marine Agency |
| OII | Oceaneering International, Inc. |
| ORP | oxygen reduction potential |
| PAL | Public Affairs Liaison |
| RFP | request for proposals |
| RO | reverse osmosis |
| ROM | rough order of magnitude |
| SCDAH | South Carolina Department of Archives and History |
| SCDNR | South Carolina Department of Natural Resources |
| SCHC | South Carolina Hunley Commission |
| SCIAA | South Carolina Institute of Archaeology and Anthropology |
| SRC | Submerged Resources Center (National Park Service) |
| SPAWAR | Space and Naval Warfare Systems Command |
| SRC | Submerged Resources Center |
| UAB | Underwater Archaeology Branch (NHHHC) |
| USCG | United States Coast Guard |
| WLCC | Warren Lasch Conservation Center |

Editor's Note

One of the more mundane challenges in documenting the *Hunley* recovery was reconciling the measurements. The global scientific standard is to use metric, while American engineers still use the U.S. customary units. The original engineering plans used feet and decimal inches, while many of the materials used were sold in fractions of inches. The hull and artifacts were predominately measured in in metric; however, since the submarine itself was built using the American system, occasional references to sizes or weights were recorded in that system.

This has led to some interesting choices in order to make the data accessible to the widest possible audience while maintaining accuracy. As a result, the report lists all measurements in both systems, first in the standard of the original measurement as being the most accurate, followed by the converted value in parentheses. Due to the cumbersome nature of notating feet and inches, however, all such values have been converted to decimal feet. Fractions are used when less than an inch and represent a standard product gauge. Every effort was made to maintain consistency in the units being compared, as represented in the table below.

| U.S. | Metric |
|---------------------------------|---|
| in. – inches | cm – centimeters |
| ft. – feet | m – meters |
| mi. – miles | km – kilometers |
| lb. – pounds | kg – kilograms |
| tn. – U.S. tons | t – metric tons |
| p.s.f. – pounds per square foot | k/m ² – kilograms per square meter |
| p.s.i. – pounds per square inch | bar – bar |

Foreword

In November 1999, I was privileged to be one of the 10 “authorities” gathered together for an international symposium in Charleston that was convened to consider a proposal to recover, conserve, enter, and excavate the famous and newly-found *H. L. Hunley*. Experienced and highly qualified corrosion specialists, expert experienced ship and object conservators, archaeologists, and museologists were there—their brief to present the lessons learned at *CSS Alabama*, *USS Arizona*, *HM Monitor M33*, *USS Monitor*, the British submarine *Resurgam*, *SS Xantho*, and elsewhere. There with my colleague Ian MacLeod, who would present what “we” (a close knit team of Australian and international archaeologists, conservators, volunteers, and technicians) had learned from the in-situ conservation, recovery, deconcretion, dismantling, subsequent conservation, and (at the time) imminent reassembly of *Xantho*’s former Royal Navy horizontal trunk engine, mine was to be an entirely different task.

From the point of our first contact with the *H. L. Hunley* program, Ian and I both knew that the Charleston assembly were acutely aware of the decades of individual, collective, and institutional commitment, of public involvement, enormous sponsorship, and institutional backing that interpretation and exhibition facilities required—at *Xantho* for example, we are now only just completing our work after 30 years.

As a result, I looked elsewhere for something to say and presented the notion that the submarine was a new class of archaeological site, one that remains unlike all other submerged historic vessels, an often still-sealed capsule breached not by the sea and its organisms as is the case at all other boats and ships lying on the world’s seabeds. Even when breached, submarines invariably have sealed compartments, entombing for centuries longer than will any other ship, their contents and in

some cases even their unfortunate crew—theirs is then an unopened tomb. Enter it in full recognition of that fact and know full well that you are establishing a precedent, both archaeological and ethical, and if you proceed, know you are helping pioneer a new avenue of research and inquiry. The world will await your results. This was part of the message provided to those not already well aware of their onerous responsibilities should *H. L. Hunley* be raised.

Finally I expressed a belief, formed from what I had read of the *H. L. Hunley* project and from what I knew of its proponents and of those specialists already involved, that the project would “raise the bar” in maritime archaeology. This was for me a perception clearly reinforced by the presence of those speaking and those gathered to listen.

And so the bar has been raised.

Ample proof of that fact appears in this comprehensive work. It is one that ably brings to the world the complexity of such a multi-faceted project, its own history, including the search and finding, the engineering problems and solutions, the archaeology, conservation, historical research, public access, and future exhibition plans. Clearly evident is the fact that it has all required perseverance, dedication, and exceptional time management from not only the archaeologists, researchers, and conservators, but those who managed the funding and the enormous resources required to complete the project. What editors Robert Neyland and Heather Brown have brought together and presented in what follows is a fitting and lasting tribute to the project’s many and various constituents and, like *H. L. Hunley* itself, it is a monument to its builder and to its three brave crews, young men once lost and now known to all.

— Dr. Michael McCarthy
Western Australia Museum
March 2016

Acknowledgments

A project of the magnitude of the *H. L. Hunley* recovery could not have been conducted without the dedication, generosity, and enthusiasm of many people. These included military and civilians, scientists and engineers, corporations, small business owners, financiers, and politicians. Recovery could not have been accomplished without the strong political support from federal, state, and local governments. The public-private partnership established between the South Carolina Hunley Commission (SCHC), Friends of the Hunley (FOTH), and Naval Historical Center (now Naval History and Heritage Command) made the project a success. Donations of services, manpower, equipment, and funds all contributed to the successful recovery of the Civil War submarine *H. L. Hunley*. A debt of gratitude is owed to everyone who participated in person or in spirit in this effort. A listing of project personnel is provided in Appendix B and the companies who provided essential services in Appendix C.

Major funding for the planning phase, \$200K, as well as \$2 million for the recovery was provided through the Department of Defense (DOD) Legacy Resources Management Program. This federal program was established in 1990 by Congress to assist the DOD and military services in preserving both natural and cultural heritage resources under DOD jurisdiction. The program also funded post-recovery conservation efforts to preserve the historic vessel, totaling \$3 million over five years. The State of South Carolina provided \$1 million to the recovery effort as well as \$2 million for renovation of a former Navy warehouse at the former Charleston Naval Shipyard. Recovery would not have happened without having a dedicated conservation facility ready to receive the submarine. The Charleston Naval Complex Redevelopment Authority generously leased the building for a nominal \$1 a year for eight years and later included a five-year extension of this agreement and the donation of a former base house that was used as temporary housing for students, interns, and visiting scientists to assist with the project, and in the case of the former, to obtain training and professional work experience.

The project could not have happened without the commitment of two key individuals, Warren Lasch, Chairman of the FOTH and the Honorable Glenn McConnell, South Carolina State Senator and Chairman of the SCHC and later Lt. Governor of South Carolina. Both men provided outstanding leadership and organizational skill, as well as committing large segments of their time. Chairman Lasch not only gave freely of his time but also assisted in financing the project through personal donations and a bank loan that ensured project expenses could be covered. Other Hunley Commission members during the time of recovery include Chris Sullivan (Vice-Chair), South Carolina state senators John Courson and Ernie Passailaigue, state representatives Rick Quinn, Harry Hallman Jr., and Chip Limehouse, businessman Randy Burbage, and Rear Admiral William Schachte, USN (Ret).

Dr. William Dudley, director of the Naval Historical Center (1995–2004), assisted with the review of project objectives and methodology, and generously allowed Dr. Robert S. Neyland to go on loan to the State of South Carolina under the Intergovernmental Personnel Act from 1998 to 2004. The Navy also assisted with obtaining project funds through DOD Legacy Resources Management Program, loan of Navy equipment from Naval Sea Systems Command (NAVSEA) Emergency Ship Salvage Material (ESSM), and participation of NHC Underwater Archaeology Branch staff and diving assets. SPAWAR System Center Atlantic, Naval Weapons Station Charleston, and U.S. Coast Guard (USCG) Sector Charleston cooperated to provide site security. U.S. Navy Special Warfare Combatant Craft Special Boat Units 20 and 22 provided additional on-site security.

The National Park Service (NPS) supported the project through the Submerged Resources Center (SRC), which provided on-site personnel, David L. Conlin, Matthew Russell, and Brett Seymour, as well as the expertise of its full staff. SRC Chief Dan Lenihan and Larry Murphy, although not on site, were available throughout the recovery to offer advice and support. NPS Fort Moultrie National Monument provided the

docking facilities for the daily crew transport, a site for a project office trailer, and a location for press conferences. Fort Moultrie also assisted the project through their mission of telling the history of the Fort and *Hunley* during the Civil War. The USCG Charleston District was instrumental to the protection of *Hunley* following its discovery in 1995 until its recovery in 2000. USCG Charleston established a Restricted Navigation Area (RNA) around the site that restricted anchoring, diving, dredging, and salvage. In preparation for recovery, they installed the mooring points for the large support vessel *Marks Tide* and the materials barge involved in the recovery. During the recovery, the USCG provided a security perimeter on site and, during *Hunley's* transport on the day of recovery, assisted with a moving security zone around the vessels transporting the submarine. The United States Army Corps of Engineers (USACE) Savannah District took a variety of core samples for geologic analysis and USACE Charleston District consulted with the recovery team on preparing and submitting the EPA Environmental Assessment and consultation.

Several South Carolina state agencies provided significant project support. The South Carolina Department of Archives and History (SCDAH) oversaw the Section 106 review under the NHPA and the resulting Programmatic Agreement between the federal agencies and South Carolina. It also served as the state partner with Navy in the Intergovernmental Personnel Act (IPA) agreement that permitted Neyland to be temporarily assigned to State of South Carolina. The South Carolina Institute of Archaeology and Anthropology (SCIAA) provided project technical review and other support, including archaeological diving and data collection, and project photo-documentation. South Carolina Department of Natural Resources (SCDNR) coordinated and maintained 24-hour security at the *Hunley* site during the recovery. SCDNR biologists collected and analyzed coral colonies and other macro-faunal samples from the submarine's hull prior to recovery. Throughout the many surveys and projects SCDNR made their vessels available to the project. South Carolina Educational Television (SCETV) carried out complete video documentation of the recovery, aired statewide TV updates, conducted live scientist interviews with schools, and provided video footage to National Geographic and major media networks. Tom Posey, SCETV producer, was with the project throughout the recovery overseeing project video documentation for the State of South Carolina.

National Geographic Society (NGS) filmed, produced and aired the National Geographic Explorer documentary *Raising the Hunley*, as well as producing a magazine article and several internet updates. They also made a cash contribution to the overall project. Producers John B. Bredar and Rakhi Varma were a pleasure to work with throughout the project and

their documentary told the story of *Hunley* to millions of people around the world. NGS, through both the film and magazine divisions, contributed \$200K in funds. Ira Block, an independent photographer and owner of Ira Block Photography working for the magazine *National Geographic*, produced exceptional still photographs of the recovery project. Cramer Gallimore, owner of Cramer Gallimore Photography, donated his time and photographic and pilot expertise to capture the only still aerial photographs of the site on the day of recovery. Mr. Gallimore would continue to donate his time during the excavation as a photographer.

The National Underwater and Marine Agency (NUMA) and founder Clive Cussler assisted in an advisory capacity and contributed to the recovery project in order for Mark Ragan to conduct archival research and create a project archive of historical documents related to *Hunley*, the builders, the crew, and other Civil War submarine attempts. These documents are archived at the Warren Lasch Conservation Center. He also followed this support up with funds that allowed Mr. Ragan to draft a report based on sponsored research on Civil War submarine development and, in particular, the efforts of the Confederate Singer torpedo group. Clive Cussler was on site during the recovery, watching the operation from the same boat used to locate the historic submarine in 1995, and has continued to stay interested in *Hunley* throughout its recovery, excavation, and preservation.

Oceaneering International, Inc. (OII) was the primary source of marine engineering during the planning phase, providing oversight for procurement of recovery-related materials, construction, dive support, and a variety of engineering services. Leonard Whitlock, OII Program Manager, assisted with making the initial connection between FOTH and Oceaneering, and, after leaving Oceaneering, worked directly with the recovery team as an independent contractor, providing invaluable planning and project monitoring assistance. Steve Wright, OII Project Director, worked directly with the archaeologists first in preparing the recovery options study, then the recovery engineering design, and finally overseeing all OII operations during the project. Perry Smith, OII Engineering, worked with archaeologists, architects, and engineers to design both the *Hunley* truss system for the lift and the conservation tank in which *Hunley* would be placed. OII's president, Jack Huff, took direct interest in the recovery operation and visited the project several times.

The initial work platform was the offshore supply boat *Marks Tide*, provided by Tidewater Marine LLC of Amelia, Louisiana. It provided an excellent dive platform, and the company's owners and personnel were very disappointed when they were unable to complete the lift due to conditions outside their control. On relatively short notice, Titan Maritime, LLC, agreed to provide the

heavy-lift crane, barge, and personnel necessary to raise *Hunley* from the bottom of the sea and transport it to the former Charleston Naval Base, using the jack-up barge *Karlissa-B*. Titan Maritime reflagged *Karlissa-B* to the United States in order to conduct the lift of *Hunley*.

The engineering analysis and science was supported by a donation of time and equipment from Dennis Donovan of Coastal Inspection Services, who provided seven days of non-destructive testing research and services at no cost. The equipment for this research was custom built by Krautkramer Branson especially for the ultrasonic testing of *Hunley's* wrought iron hull. Mike Gatto, of NCS Supply Inc., selected the correct foam product manufactured by Froth-Pak to be injected into the recovery sling bags and was on site advising during the bag injection process. Engineer Kenny Johnson, of Soil Consultants Inc., analyzed the geological core samples and advised regarding the type and installation of piles to be used for the truss support. Mr. Johnson and his associates recommended driving piles that would reduce the vibration and potential impact to the submarine. Their concerns led to the selection of suction piles for the project. Rick Fielder, of YSI Inc., with help from local representative Johnston Inc.'s Roger Lymon and Rodney Edward, loaned a multiparameter probe used for taking environmental measurements around the hull under water.

Thompson Pump, Summerville, South Carolina branch, donated the large pumps to operate the OII dredges and provided on-site maintenance and expertise to keep them operational. The *Hunley* dive team was supported by donations from Body Glove International, represented by John Dailey, with wetsuits for the archaeological dive team, and Marketing Solutions's Todd Beckett generously donated the silk screening of project logos for the dive suits. Divers Alert Network donated emergency training material,

an oxygen supply kit, and provided dive insurance for archaeologists. The Wet Shop of North Charleston, South Carolina, owned by Ralph Wilbanks, one of the original discoverers of *Hunley*, discounted dive equipment, air fills, and provided the pool for training purposes.

Finally, this report could not have been written without the help of many people. Perry Smith and Steve Wright of Oceaneering provided the original reports used for drafting the engineering and commercial diving operations sections, along with feedback from Leonard Whitlock. National Park Service archaeologist David Conlin assisted with sections regarding the archaeological operations and his colleague Matthew Russell prepared the initial site plan. The staff and volunteers at the Warren Lasch Conservation Center, including Paul Mardikian, Maria Jacobsen, Michael Scafuri, Benjamin Rennison, Fred Tetor, and Steve Weise, as well as Kellen Correia of the Friends of the *Hunley*, provided essential information on a multitude of events, people, and research regarding *Hunley's* logistics and recovery. Michael Scafuri was the lead archaeologist at Clemson University who assisted with resolving many research questions, patiently checked artifact and submarine measurements, and was always available to provide thoughtful input regarding *Hunley* research. Dr. Stéphanie Cretté and Dr. Néstor González-Pereyra of the Clemson University Restoration Institute graciously allowed access to staff and records. Many others, both in Charleston and Washington, helped with editing or illustrating sections of this report, including James Hunter, Eugene Bialek, Mari Hagemeyer, and Ivor Mollema. Jeffrey Enright and Search, Inc. kindly assisted with several GIS maps.

Many people, agencies, corporations, and not-for-profits supported *Hunley's* recovery. It is possible that some have been overlooked. I extend my apologies in advance for any omissions and oversights.

— Robert S. Neyland
Project Director

1. Introduction

Robert S. Neyland

On 3 May 1995, a team of maritime investigators under the direction of novelist Clive Cussler made a remarkable discovery four nautical miles (7.4 km) off the coast of Charleston, South Carolina: the wreck of the Confederate submarine *H. L. Hunley*, lost without a trace since the night of 17 February 1864, shortly after it exploded a torpedo filled with black powder underneath *USS Housatonic*, sending that ship to the bottom within minutes. This event marked the first time a submarine sank an enemy ship and at once exemplified both the promise and the risks of underwater warfare.

The discovery culminated many years of search by the team, and many others, over 130 years since *Hunley's* loss (Chapter 4). News of the Civil War find was celebrated by many who had long wondered why the small underwater craft never made it home that fateful night, as well as by those who had a keen interest in the maritime history and technological developments of the 19th century. It was also a double-edged sword: by locating the site, opportunities for scholarship and public education were opened up, but so were avenues for illicit looting or well-intentioned but ill-planned recovery attempts that would destroy the site and possibly the boat itself.

With the site located outside of state waters, responsibility for its protection fell to the federal government, eventually resting with the U.S. Navy's Naval Historical Center (now the Naval History and Heritage Command). The obligation to study and preserve this truly unique artifact of American history was clear, but the way forward for such an ambitious project was not as obvious. The recovery of a shipwreck requires a significant investment of time, money, and ingenuity. The logistical difficulties of rigging a multi-ton lift under water while ensuring that delicate, historic material is not damaged or lost is daunting in its own right. However, the long-term conservation work required after recovery is just as vital to the mission of preserving an invaluable piece of history for future generations, and must be fully in place before any attempt is made to raise it. Nevertheless, the threat to the site from

potential looting was deemed significant enough that recovery was seen as the only way to guarantee preservation of the submarine (Chapter 5).

There were several precedents for intact shipwreck recoveries. Almost all were wooden-hulled ships, such as Sweden's 17th century warship *Vasa*, lifted in 1961; the collection of five Viking ships from Skuldelev, near Roskilde, Denmark, recovered in 1962; the 14th century Bremen cog in Bremerhaven, Germany, discovered that same year; and finally, the widely-publicized remains of Henry VIII's flagship *Mary Rose*, recovered off the coast of England in 1982. In addition, the Dutch had recovered a number of late and post-medieval vessels from land sites in the drained polders of the Netherlands. In the United States, the most well-known intact shipwreck recovery projects consisted of the Revolutionary War gunboat *Philadelphia* raised from Lake Champlain, Vermont, in 1935; the Civil War ironclad *USS Cairo* pulled from the Yazoo River, Vicksburg, Mississippi, in 1964; and the remains of French explorer LaSalle's ship *La Belle*, excavated and recovered off the coast of Texas between 1996 and 1997. There were also the lesser known recoveries of the 18th century Brown's Ferry vessel, War of 1812 veteran-ship *USS Ticonderoga*, several Confederate vessels—*CSS Chattahoochee*, *Jackson*, and *Neuse*—as well as the 1846-built topsail schooner *Alvin Clark*. Many of these American examples of recoveries were not successful templates for operations that resulted in preservation and exhibition. Perhaps the closest recovery of a vessel of similar complexity to that of *Hunley* was the recovery of the *Holland 1* submarine that was salvaged in 1982 for the Royal Submarine Museum. At the time of planning for *Hunley's* recovery, *Holland 1* was in the process of being retreated, the corrosive salts removed, and, after more than a decade, properly conserved. Its conservation had been neglected when it was initially recovered and the submarine had suffered irreparable damage to its hull (Barker et al. 1997). Of smaller scale were the recoveries and subsequent conservation difficulties of the steam engines from the shipwrecks *SS Xantho* in

Western Australia and *Columbus* in Maryland. There were, thus, far more grave examples of failures than successes in the spectrum of shipwreck recovery. The extensive damage to the iron structure of *Holland 1* due to poor initial conservation was a particularly important lesson in the face of *Hunley's* own iron structure. Hence, conservation was integral to *Hunley's* recovery planning (Mardikian et al. 2009:82–83). The lack of success stories involving the recovery and conservation of large complex iron objects led to the gathering of world experts in submerged iron and composite artifact conservation in Charleston, South Carolina, in 1999 (Chapter 5). Hence, from the beginning, *Hunley* conservation planning was integral to ensuring the recovery would result in a positive outcome that would raise the bar for shipwreck recoveries. Conservation would ultimately require the establishment of a professional laboratory located in North Charleston to handle a project of *Hunley's* magnitude (Chapter 7).

Previous recovery projects and the conservation symposium provided lessons for how to proceed and how not to. *Hunley* posed a few unusual challenges, however. Factors that need to be considered when deciding how to raise a sunken ship safely include the depth and conditions of the site, the distance from shore, the structural integrity of the vessel, and cost. Certain of the above shipwreck recoveries involved disassembly in situ and recovery of the ships' hull timbers, a feat accomplished more easily with a wooden vessel than an iron one. The disassembled examples lacked superstructure of one or more decks and did not have inaccessible spaces prohibiting access to artifacts and in-situ excavation. This would not have been practical for *Hunley*, which contained a wealth of archaeological data inside that would have been lost if it was disassembled, not to mention the impracticality of the process, which would have required the drastic measures of drilling rivets or the use of cutting torches or metal saws.

La Belle provided an unusual precedent, as it was excavated inside of a cofferdam. The site was at a depth of only 12 ft. (3.66 m) within the relatively protected waters of Matagorda Bay on the Texas coast. The Texas Historical Commission was able to construct a double-walled dam around the site, allowing them to drain all the water out and excavate as if it were a land site. *Hunley*, however, was 4.6 mi. (7.4 km) offshore in the Atlantic Ocean where a cofferdam could fail during a tropical storm or hurricane and would require a long period of costly offshore operations. Fortunately for the *Hunley* project planners, the relatively shallow depth and moderate currents at the site allowed for long dive windows, an invaluable asset when planning a full underwater recovery. The site could also be relatively quickly covered with sandbags should there be an evacuation due to storm or hurricane.

Rigging a sunken ship and raising it as a complete unit had been accomplished successfully with *Philadelphia*, *Mary Rose*, and *Vasa*, but it had also been attempted with disastrous results with USS *Cairo* in 1964. Most of these vessels were raised using slings to support the vessel from underneath. At only 53 ft. (16 m) with a single deck, *Philadelphia* was closest to *Hunley* in size, but it was raised from relatively calm waters and was structurally robust, having been submerged in cold, fresh water. The flexibility of a wooden structure is also more conducive to a sling lift. Even the massive 47.5 m (156 ft.), four-decked *Vasa* was lifted with steel cables slung through a series of six tunnels dredged beneath the hull (Hocker 2011:177).

With such examples, it may have seemed like a straight-forward project to bring *Hunley* up. But the attempt to raise the 175 ft. (53 m) ironclad *Cairo* with cables slung beneath the hull resulted in the vessel being essentially cut apart at the sling points by the overwhelming weight of the vessel once it transitioned from water to air. *Hunley* was a much smaller prospect, but the weight of the iron hull completely filled with wet sediment would considerably exceed its original structural specifications. Also, since the internal structure of *Hunley* was hidden and the strength of the rivets uncertain, an insufficiently supported lift could rupture or, in effect, unzip the hull plates along the lines of rivets. The stiffness and brittleness of the wrought-iron structure also posed risks of cracking even if properly supported. In addition, in order to preserve as much evidence as possible that might help solve the mystery of why *Hunley* sank, it was vital to raise, transport, and excavate the vessel at the same 45° angle at which it was found.

The overall condition and strength of *Hunley's* hull was unknown, although preliminary investigations of the hull (Chapter 4) had revealed only minor damage (Hall 1995; Murphy 1998). The survival of the rivets, which held the wrought-iron plates of the hull, was the greatest worry. Conservation and corrosion experts agreed that the iron of the rivets would be sacrificial to the iron of the hull plating and could have completely corroded away or converted to a mineralized state. To better understand the key factors of hull integrity and rivet strength, additional hull testing and sampling was required before a plan could be finalized (Chapter 8). Ultimately, it was determined that hull thickness and rivet integrity were sufficient to allow a supported lift.

The engineering plan, including piles, truss, and conservation tank, would undergo many modifications from concept to final delivery. The project had to remain relatively flexible, all the while maintaining the guiding goal that it had to be done correctly and shortcuts should not be taken that would jeopardize the submarine or the recovery of archaeological information. While knowledge of past recoveries of historic

wrecks, both successful and unsuccessful, informed the design of the *Hunley* recovery project, collaboration with experienced salvage engineers tempered with preservation principles was maintained throughout and ultimately resulted in a system designed solely to meet the specific needs of *Hunley* (Chapter 9).

The project elevated archaeological and conservation goals over logistical and financial aspects of the undertaking (Chapter 10). While a portion of the submarine had been exposed upon initial excavation, it was not known whether there were any hull breaches resulting in spillage of interior contents, or even if a crewmember had escaped the vessel and perished beside it. Thus the excavation was approached with meticulous care, always with the awareness that something unexpected could be encountered at any point. Artifacts or loose hull components associated with or contemporary with the wreck were to be documented in situ before being recovered, magnetic anomalies adjacent to *Hunley* had to be investigated, the submarine's position in relation to associated loose vessel components and artifacts were to be mapped, in-situ hull drawings drafted, environmental samples collected, and a monitoring system for the hull improvised to ensure there would be no loss of integrity. Sediment samples from around the site would contribute significantly to our knowledge of the conditions in which *Hunley* lay for so long and to the reconstruction of the events of the sinking (Chapters 3 and 13). In order to be assured that all artifacts were recovered from the site, additional work was planned for after the removal of the submarine, when magnetometer readings would not be skewed by the presence of such a large iron mass in the area (Chapter 11).

In keeping with archaeological ethical standards, all data recovered from the original site have been distilled and presented in this volume. All artifacts, both original to the site and intrusive, were collected and documented (Chapter 15). There is an overview of the submarine's components and condition as observed prior to conservation (Chapter 12) and a preliminary analysis of the hull design in comparison to historical accounts and other submersibles from the period (Chapter 14). However, discussion of the interior workings has been left for a future work.

The history of *Hunley* and its recovery has been told in several popular works preceding this report. *Charleston Post and Courier* journalists Brian Hicks and Schuyler Kropf were close to the project throughout and witnessed the lift firsthand. Their account *Raising the Hunley: The Remarkable History and Recovery of the Lost Confederate Submarine*, published in 2002, recounted the history of the submarine, its discovery, and recovery, laying out the principal players and events leading up to the vessel's installation in the Warren Lasch Conservation Center. Their book enlightened the

general public on the historical importance of the wreck and the remarkable efforts, both technical and managerial, involved in recovering it safely.

A good many new primary and secondary sources had been unearthed since *Hunley's* discovery, particularly by Mark Ragan under the auspices of the Friends of the *Hunley*. The documents he brought to light led to a much fuller understanding of the circumstances surrounding the submarine's origins and the development of underwater warfare in general. Many of his initial findings were published in his 1995 work *The Hunley: Submarines, Sacrifice, and Success in the Civil War*. He updated this volume with new finds in 2006, and expanded his scope to cover a broader sphere in *Submarine Warfare in the Civil War* (2002). Tom Chaffin (2008) utilized much of the new historical and archaeological research in *H. L. Hunley: The Secret Hope of the Confederacy*, which focused more intensively on the historical background on the submarine and the forces leading up to its construction and final mission. There were also books on *Hunley* for the young reader with Sally Walker's *Secrets of a Civil War Submarine: Solving the Mysteries of the H. L. Hunley* (2005) and Fran Hawk's *The Story of the H. L. Hunley and Queenie's Coin* (2004). More recently there is Brian Hicks's *Sea of Darkness: Unraveling the Mysteries of H. L. Hunley* (2014) which seeks to cover more of the story of the recovery project and the recent research.

The aforementioned works cover the perceptions of popular writers. A certain amount of myth and historical inaccuracy has crept into the story of *Hunley* with each retelling. Writers of secondary source works frequently jump to conclusions and misinterpret archival sources. This report complements and corrects some of the previous works by restating the historical records as precisely and accurately as possible without making assumptions (Chapter 2). The authors' goal is the documentation of the archaeological and logistical aspects of the recovery based the research of the project's principal investigator and staff archaeologists. This report documents the archaeological findings specific to *Hunley* and provides a detailed example of what goes into responsibly planning and executing a successful shipwreck recovery. Every wreck recovery project has its own unique features that require customized methods and equipment. By providing an in-depth account of *Hunley's* archaeological and logistical complexities, the authors establish a basis for further *Hunley* research as well as an example for future archaeological project planners to consider (Chapters 6 and 7).

The question of *Hunley's* demise is still to be resolved. There is a range of possibilities with some seeming more likely than others (Chapter 16). It can be anticipated that the ongoing research will first eliminate several scenarios and, through this process, eventually lead to the most likely interpretation. There

are many details about the vessel and crew that have been revealed in the years between *Hunley's* recovery and this publication, and it is tempting to try to include them all here. Indeed, the finalization of this volume has been a challenge simply in deciding where to stop. The scope of the entire project, however, is too large for a single volume, and the authors in this work

have struck a balance between providing details from published research along with new data pertinent to the recovery operation, the submarine prior to the excavation of the interior, and surrounding artifacts, while leaving the monumental task of documenting the interior of the craft, analyzing the remains of the crew, and cataloging their personal effects for future work.

2. Historical Background

Shea McLean

Mariners have always marveled at, and often feared, the variety of denizens inhabiting the aquatic world. For centuries, a common fear among sailors was the possibility that they might be suddenly and violently attacked from beneath the waves. Classic works of literature such as Herman Melville's *Moby Dick* or Jules Verne's *20,000 Leagues under the Sea* exemplify this fear. As a result, many nations originally considered the concept of underwater warfare reprehensible. In fact, many years passed and several conflicts were fought before submarines achieved a "respectable" status in naval warfare. Today, submarines are one of the world's most advanced forms of human technology and are widely considered to be the best deterrent to nuclear war. Although submersible vehicles have been built for centuries, one historic event focused world attention on this specialized watercraft and its deadly potential. The sinking of USS *Houatonic* on 17 February 1864 proved that the best-prepared surface ship was completely vulnerable to attack from underwater. Consequently, naval warfare would be changed forever.

Early Submarine Development

As early as 400 B.C., ancient sponge divers operating in the Aegean Sea reportedly used inverted cauldrons to supply air while under water (Pseudo-Aristotle 960b). In 300 B.C., Archimedes described the physical principles needed to achieve submersion from the surface. By the 12th century A.D., apocryphal tales had emerged of Alexander the Great venturing beneath the waves in a crude glass diving bell around 332 B.C. (Gaster 1897). All of the aforementioned reveal the deep infatuation with undersea travel that humans have harbored since ancient times. Interestingly, the impetus for these early submersibles or diving bells was somewhat benign. Ancient "submariners" were generally tasked with the collection of sponges or the salvage of sunken ships. However, being lowered into the sea via a surface tether

(i.e., with a diving bell) and moving freely beneath the surface (via submarine) are two completely different concepts requiring two completely different types of submersible vehicle.

As time progressed, nations expanded their power at sea and developed more effective ways to wage war. Nations with large fleets soon found themselves in a position to affect international trade. Economic warfare was born. One form of maritime economic warfare was the interception and destruction of enemy merchant shipping. However, such an undertaking could prove time consuming and costly on the high seas. A more viable alternative was simply to deny access to the sea by blockading an adversary's ports. Nations that lacked large numbers of warships were often unable to combat the naval blockade of a superior adversary. Smaller nations that lacked the variety and number of resources needed to build and maintain a large naval fleet eventually resorted to more non-traditional methods of defense. One of the most innovative and dangerous forms of asymmetrical naval warfare was the invention of non-tethered submersibles.

Leonardo da Vinci, the renowned scientist, artist, and inventor, conceived one of the earliest designs for a non-tethered submersible. Da Vinci, who claimed to have developed a design for a "diving craft," refused to publish his invention because of "the evil nature of men" that might "practice assassination at the bottom of the sea" (Harris 1997:1). However, da Vinci's prophetic message did not deter others who would design and eventually build working submarines.

In 1578, Englishman William Bourne described a ship that should be able to submerge completely under the water by contracting its size via leather-clad movable joints (Harris 1997:5–6). Subsequent speculation on how to interpret this idea led to various proposals for incorporating internal ballast tanks that allowed a ship to sink through the displacement of air with water. In 1623, Cornelis Drebbel, a Dutch inventor and engineer, constructed the first true diving boat. The vessel was outfitted with oars that protruded through watertight

seals, propelled by twelve oarsmen, and was apparently conned via a magnetic compass (Harris 1997:9). Although Drebbel's ship reportedly could remain underwater for a few hours, it likely only submerged to a shallow depth (Harris 1997:8). The boat was apparently successful and was demonstrated in the Thames River for King James I (Harris 1997:9). An associate of Drebbel, Constantijn Huygens (1631), provided an insight into one of Drebbel's motives for building such a boat.

[I]t is not hard to imagine what would be the usefulness of this bold invention in time of war, if in this manner (a thing which I have repeatedly heard Drebbel assert) enemy ships lying safely at anchor could be secretly attacked and sunk unexpectedly by means of a battering ram. (Harris 1997:11)

After Drebbel's revolutionary demonstration in the Thames, several similar inventions appeared over the next two centuries. In 1652, French inventor De Son designed a 72 ft. (21.95 m) long submarine propelled by a paddle wheel and equipped with rams at both ends (Harris 1997:16). Although his invention was never successfully tested, De Son is noted as the first to develop a submersible for the sole purpose of sinking a surface ship. In the late 17th century, Denis Papin experimented with a one-man diving apparatus that may have been the first to incorporate detachable ballast, an internal barometer (depth gauge), and the use of pumps and valves to regulate water ballast (Harris 1997:17).

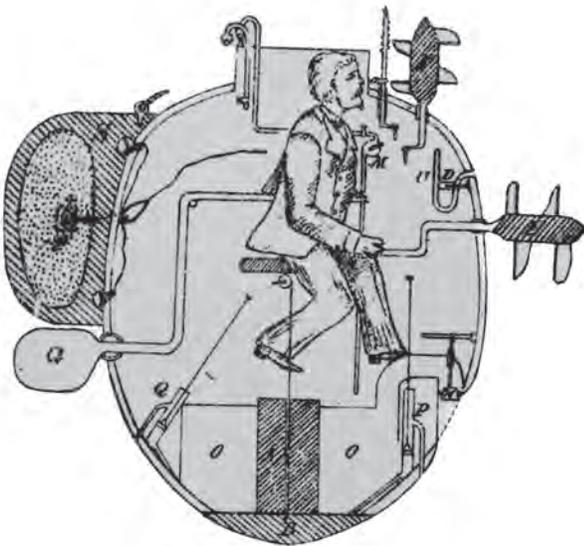


Figure 2.1. This widely published 1875 drawing of Bushnell's *Turtle* by Francis M. Barber is based only on written descriptions of the vessel, and likely contains many inaccuracies, particularly in the propellers, which were likely closer to standard screw propellers.

A diagram of his design was published in the December 1747 issue of the *Gentleman's Magazine and Historical Chronicle* and may have influenced future designers, including David Bushnell (Manstan and Frese 2010:37–38). In 1773, an English wagon maker named J. Day converted a small fishing boat into a crude submarine and reportedly completed a successful dive to 30 ft. (9.14 m) (Fyfe 1907:160). According to one account, on 28 June 1774, Day and his submarine disappeared while attempting to remain submerged for 12 hours at a depth of 100 ft. (30.48 m) (Fyfe 1907:162).

On 6 September 1776, during the American Revolution, David Bushnell's one-man wooden submarine *Turtle* became the first submersible to attack an enemy warship (Figure 2.1). Bushnell's boat incorporated all of the successful innovations created by previous inventors. It had a 200 lb. (90.72 kg) keel weight, which could be dropped 40 to 50 ft. (12.19–15.24 m) below the vessel to provide instant buoyancy, a depth barometer, and pumps to adjust the vessel's water ballast (Bushnell 1799:303–305). Additionally, Bushnell incorporated a means to extend operation while submerged. The vessel was equipped with two air pipes, one for intake and one for exhaust, "so constructed, that they shut themselves whenever the water rose near their tops," that allowed its pilot to replenish the submersible's air supply during operation (Bushnell 1799:304). An oar "formed upon the principle of the screw" propelled the boat, and another at the top of the vessel was used to rise to the surface (Bushnell 1799:305). *Turtle's* weaponry consisted of a wooden keg filled with 150 lb. (68.04 kg) of black powder that was to be fastened to the hull of its intended victim via a small woodscrew and ignited by a mechanical time apparatus set to detonate after the submarine had reached a safe distance from its target (Bushnell 1799:307–308). *Turtle* attempted three attacks on the British fleet in the vicinity of New York City, but failed to sink an enemy ship.

Before his world-renowned invention of the steamboat, Robert Fulton launched a comparatively less famous 21 ft. (6.4 m) hand-cranked, copper-clad submersible in Paris on 24 July 1800 (Parsons 1922:25, 33). The vessel, dubbed *Nautilus*, was fitted with a sail for added power on the surface, distinguishing it as the first vessel to be equipped with two separate methods of propulsion for travel above and below the water (Figure 2.2). Fulton traveled to France in 1797 to aid the French in their attempt to break England's naval blockade during the War of the First Coalition. Fulton attempted to sell his submersible to Napoleon after an impressive demonstration in which a target vessel was sunk in the port of Brest. Fulton spent a considerable amount of time and money perfecting the vessel; however, Napoleon declined Fulton's offer after the French naval hierarchy questioned the morality of using such an ignoble device. Undeterred, Fulton offered his

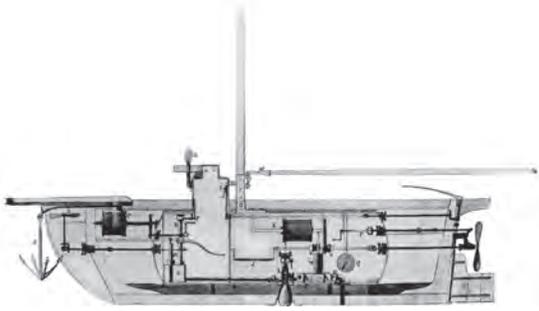


Figure 2.2. Fulton's Nautilus was unique in its design to function as a sailboat on the surface. (NHHC Photo Archives #NH 2057)

invention to Napoleon's archrival, Great Britain. Again, after considerable time and money were committed to the project and its abilities successfully demonstrated, the British Admiralty rejected the vessel. Regardless of its failed salability, *Nautilus* was a masterpiece of design and ingenuity. It was the first vessel to utilize compressed air and the first to actually sink a ship with an explosive device (Parsons 1922:42–43).

Wilhelm Bauer, a pioneering Prussian inventor, spent 25 years developing submarines on behalf of the governments of at least five different nations. He completed his first submersible *Brandtaucher* ("Incendiary Diver") in 1850 to repel a blockading Danish fleet during the first Schleswig War (1848–1851). Seawater leaked into the vessel during a test dive in February 1851, causing it to sink in Kiel Harbor to a depth of 50 ft. (15.24 m). During its unintentional descent, *Brandtaucher's* sliding ballast weight slid too far forward, causing the vessel to plunge nose first into the harbor's muddy bottom (Harris 1997:69). Over seven hours later, Bauer opened the submarine's hatch when air pressure inside the hull, compressed by water leaking into the submarine, equalized with the water pressure outside. He and his crew swam to the surface to find their funeral services already in progress. After failed attempts to sell his invention to Austria and the United States, Bauer sold a prototype to the British Navy at the onset of the Crimean War. However, Bauer was dismissed from British service after producing another, considerably more lackluster prototype. Undaunted, Bauer approached England's wartime nemesis, Russia, and built *Le Diable-Marin* ("The Sea Devil") (Harris 1997:70). The 52 ft. (15.85 m) iron submarine accommodated a crew of 11 and was powered by a treadmill-driven screw propeller. Bauer's newest design was extraordinarily successful. It completed as many as 134 test dives without incident. On the occasion of Czar Alexander II's coronation in 1855, Bauer submerged with 16 observers (including several band members) at Kronstadt Naval Base and played the Russian national anthem while on the bottom. He experimented with various methods

of chemical air purification and underwater communication. Bauer also took photographs through the submersible's view ports; these are probably the first such images taken under water.

Submarines and the American Civil War

With the possible exception of Bauer's contributions, no significant advancements in submarine technology were made between Fulton's experiments in the early part of the 19th century and the American Civil War. However, submarine development assumed new urgency when, on 19 April 1861, Abraham Lincoln announced the blockade of all Southern ports during the first few days of the American Civil War:

I, Abraham Lincoln, President of the United States . . . have further deemed it advisable to set on foot a blockade of the ports within the States aforesaid, [South Carolina, Georgia, Alabama, Florida, Mississippi, Louisiana, and Texas¹] in pursuance of the laws of the United States and of the law of nations in such case provided. For this purpose a competent force will be posted so as to prevent entrance and exit of vessels from the ports aforesaid. If, therefore, with a view to violate such blockade, a vessel shall approach or shall attempt to leave either of the said ports, she will be duly warned by the commander of one of the blockading vessels, who will endorse on her register the fact and date of such warning, and if the same vessel shall again attempt to enter or leave the blockaded port she will be captured, and sent to the nearest convenient port for such proceedings against her and her cargo as prize as may be deemed advisable. And I hereby proclaim and declare that if any person, under the pretended authority of the said states . . . shall molest a vessel of the United States . . . such person will be held amenable to the laws of the United States for the prevention and punishment of piracy. (ORN 1.4:156–157)

By this time, Southerners considered themselves citizens of a new and independent nation and most deemed Lincoln's action an infringement on their

1 The blockade was extended to Virginia and North Carolina on 27 April 1861.

sovereign rights. Early in the war, the Confederate Congress passed a bill authorizing the government to issue letters of marque to individual citizens who wished to act as privateers. Independent commercial entities soon joined in and promised to pay bounties on any blockading ship destroyed by private means. In Charleston, South Carolina, the firm of John Fraser & Co. offered \$100,000 to anyone who could destroy either of the two largest Union navy vessels blockading their harbor, *New Ironsides* or *Wabash*. Additionally, \$50,000 was offered for the destruction of a *Monitor*-type ironclad. The production of an effective military submarine now appeared inevitable because the inventor of such a device stood to gain handsomely if just one blockader could be eliminated. Essentially, a combination of patriotism and profit motive became the incentive for Southern submarine development during the Civil War.

Franklin G. Smith, a chemist, inventor, and patriotic Southerner who may have been acquainted with the earlier exploits of Fulton and Bushnell, advocated the use of submersibles in a 10 June 1861 *Columbia (TN) Herald* article entitled "Submarine Warfare":

Excepting our Privateers, the Confederate States have not a ship at sea. We may safely originate plans for blowing up the vessels employed in blockading our ports, without danger of being 'hoisted by our petard' ...

Throughout our Southern seaports, men of a mechanical turn and of the right spirit must go to work, maturing the best plans for the destruction or the capture of every blockading ship.

All things invite the enterprise. From the Chesapeake to the mouth of the Rio Grande, our coast is better fitted for submarine warfare than any in the world. It has all been most minutely surveyed and mapped. It has almost no tides, it has uniform currents, and a bottom always sandy, seeming to invite adventurous feet to travel over it. It is probable 'submarines' are now traversing these sands, acquiring confidence in their new element and skill in the use of their terrible engines of destruction. ...

But I would have every hostile keel *chased* from our coast by submarine propellers. The locomotive Diving Bell is well known. The new vessel must be cigar shaped for speed—made of plate-iron, joined without external rivet-heads, about 30 feet [9.14 m] long, with a central section of about 4 by 2 feet [1.22 × 0.91 m]—driven by a spiral propeller, a fishtail sculler, or, (far better,) by a steam engine, occupying the

after part of the boat. ... A harpoon point, easily separated from the forward end of the boat after being driven into the enemy's side, (some ten feet [3.05 m] under water,) carries the wire that holds the shell. ... The air-pump, the inhalation tube, the eye glasses, are already used.—The new Aneroid Barometer, made for increased pressure will enable the adventurer easily to decide his exact distance below the surface. ...

I am preparing a detailed Memoir on Submarine Warfare, discussing matters not proper to be spoken of here, illustrated with engravings. Copies of the pamphlet will be sent to the Mayor and municipal authorities of Southern maritime cities. (Smith 1861)

Smith's article was later reprinted in several Southern newspapers throughout the Confederacy including the *Mobile Advertiser and Register* (26 June) and the *Richmond Whig* (2 July). The article apparently sparked the imagination of many people in the South and may have been the impetus for several submarine building programs.

Smith's article apparently caused some alarm in the Northern states. At least two letters were addressed to (United States) Secretary of the Navy Gideon Welles immediately after its publication:

My purpose in addressing you ... on this subject is, that I am induced, by a vague hint in a New Orleans paper, to suspect that they now have in preparation on the Mississippi a plan ... for running into and sinking some of the blockading vessels in the Gulf.

I am of the opinion that it would be worth while to put our naval commanders there on their guard against that particular danger.

—Charles Ellet, Civil Engineer, Georgetown, DC, 21 June 1861 (ORN 1.22:288)

Yesterday morning I met a lady belonging in the New England States, who has been engaged ... in teaching school, a little north of New Orleans. ... She tells me that the rebels in New Orleans are constructing an infernal submarine vessel to destroy the *Brooklyn*, or any vessel blockading the mouth of the Mississippi; from her description, she is to be used as a projectile with a sharp iron or steel pointed prow to perforate the bottom of the vessel and then explode.

—E. P. Dorr, Buffalo, NY, 25 June 1861 (ORN 1.22:288)

In 1878, a diver on the dredge boat *Valentine* discovered a small submersible in Bayou St. John that resembled Dorr's description (Kloeppel 1992:11). Although it is unclear who built the vessel, it was displayed at the Old Confederate Soldiers' Home in New Orleans and for many years was believed to be the earliest predecessor of *H. L. Hunley*. The vessel, which was 20 ft. (6.1 m) in length, 6 ft. (1.83 m) deep, and 3 ft. (0.91 m) wide, was eventually moved to the Louisiana State Museum in New Orleans (Figure 2.3).

On 21 October 1861, Charles P. Leavitt of Company K, 2nd Virginia Regiment, wrote a letter to the Secretary of War of the Confederacy, Judah P. Benjamin, requesting that he be allowed to go to Richmond to draft plans for an invention he called "a submarine gunboat." He described the craft as:

A vessel . . . built of boiler iron of about fifty-tons [45.36 t] burden, made of an oval form with the propeller behind. . . . Placed in the bow is a small mortar containing a self-exploding shell. As it strikes the enemy, the shell explodes, and blows in the ships [sic] side. (Smythe 1907:1)

The 19 year old machinist's letter also detailed the construction and operation of a submersible steam engine, as well as a method for producing breathable oxygen inside a submarine with carbonic acid and

limewater. Leavitt's ideas so impressed the Secretary that he was summoned to Richmond in December 1861. Between August 1861 and May 1862, at least two submersible boats were built at the Tredegar Iron Works in Richmond (Wills 2000:40). Acting Master William G. Cheeney, CSN, supervised the construction of these vessels. Although both vessels were tested successfully, and at least one made an attempted attack on a blockading vessel, neither was able to inflict any damage on the Union fleet. It is unclear whether Leavitt was recalled to Richmond to contribute to Cheeney's work.

As the Union blockade gained momentum during the early months of the war, the U.S. Navy received reports that Confederate forces planned to break the blockade of the James River. The Confederate navy had raised the sunken warship *Merrimac* (scuttled as Federal forces abandoned the Gosport Navy Yard three days after Virginia's secession) and was refitting the vessel with a thick armored casemate. *Merrimac* (renamed CSS *Virginia*) was intended to break the blockade and, perhaps, enter the Potomac River and bombard Washington, DC (Ragan 1999:22). The fact that the Union hurried construction of its own ironclad (USS *Monitor*) to thwart Confederate attempts on Washington is historically well documented. However, it is a little-known fact that the U.S. Navy attempted to build a submarine to achieve the same task. A French submarine builder, Brutus de Villeroi, was contracted to supervise construction of the U.S. Navy's first combat submarine. De



Figure 2.3. An unidentified submarine, once thought to be *Pioneer*, being moved to the Louisiana State Museum in New Orleans. The vessel is sometimes called *Bayou St. John Confederate Submarine* after the location where it was originally discovered. (Detail from NHHHC Photo Archives #NH 42860)

Villeroi began construction of the 46 ft. (14 m) long submersible (christened *Alligator*) at the Philadelphia Navy Yard on 1 November 1861, and launched it in April 1862 at an estimated cost of \$14,000 (Harris 1997:85). Once completed, *Alligator* was deemed too large and slow for operations in the James River. After being refitted with a hand-crank propulsion system and judged ready for service, *Alligator* was lost in a storm off Cape Hatteras on 2 April 1863, while being towed to Port Royal, South Carolina.

There were many other attempts by many groups in many cities (both North and South) to build submersibles for the purpose of tipping the balance of naval power in favor of one side or the other. Unfortunately, much of the documentary evidence that detailed these pioneering efforts has been lost. Confederate records, in particular, suffered. Most of these documents were destroyed in the final chaotic days of the war as Confederate leaders attempted to deny the enemy details of their wartime progress. Many inventors feared they would be tried as pirates after the war if they could be linked to privateering vessels or the production of weapons of questionable morality. What can be deduced from fragmentary archival sources is this: each group that constructed submersibles during the Civil War borrowed from and built upon previous innovations. Bourne's introduction of ballast tanks, Drebbel's experiments in mobility, Bushnell's use of screw propellers, Fulton's use of auxiliary power, Papin's incorporation of detachable ballast, internal barometers, and water ballast pumps, and Bauer's experiments with various methods of chemical air purification were but a few of the seemingly endless progression of innovations that eventually culminated in the creation of the world's first successful military submarine.

Development of *Pioneer*, *Pioneer II*, and *H. L. Hunley*

Like many accounts that outline the development and production of Civil War submarines, the story of *H. L. Hunley* and its two predecessors is riddled with exaggerations and inconsistencies. Even primary archival sources, when compared, often contradict one another. Consequently, the following historical analysis is based on interpretation of the most credible of these conflicting sources. It attempts, as much as possible, to dispel many of the myths associated with the submarines, their crews, and their inventors.

Desperate times breed desperate measures, and desperate measures in turn can transform ordinary individuals into extraordinary historical figures. Such was the case when a group of young engineers, finan-

ciers, and Southern patriots combined their respective energy and expertise to produce the world's first successful combat submarine. Prior to the Civil War, James R. McClintock and Baxter Watson manufactured steam gauges and parts for steam engines at a shop at 31 Front Levee, located on the New Orleans waterfront. The team made its first contribution to the war effort by inventing a cold-press lead bullet mold for the Confederate army in the summer of 1861 (*New Orleans Daily Delta* 1861). McClintock was born in Cincinnati, Ohio, in 1829 and was sometimes referred to as "the youngest steamboat captain on the river." Little is known about Baxter Watson except that he—like McClintock—was an experienced machinist and practical marine engineer. The duo began construction of a two to three man submersible at nearby Leeds Foundry, located at the corner of Fourcher and DeLord Streets in mid-1861 (Kloeppel 1992:6–7, Perry 1993:94).

This creative team was soon joined by a man with three important qualities: wealth, connections, and an unwavering belief in the potential of submarines. Horace Lawson Hunley was born on 9 December 1823 in Sumner County, Tennessee. He and his younger sister Volumnia were the only children of John and Louisa (Lawson) Hunley. John Hunley left his Tennessee home and accompanied Andrew Jackson during the Indian Wars of 1812–1814 and fought at the Battle of New Orleans on 8 January 1815 (Duncan 1965:19). John Hunley's experiences in New Orleans during the war may have prompted him to move his family from Tennessee to the port city. His name first appears in the New Orleans directory in 1830; the listing describes him as "a broker . . . engaged in the buying and selling of cotton" (Duncan 1965:19). After John Hunley's untimely death in 1834, his young widow, Louisa, remarried. Her new husband, James R. Connor, was a cotton broker and plantation owner (Duncan 1965:20). Horace Hunley followed in his father's and stepfather's footsteps and became a wealthy cotton merchant and plantation owner. He was well educated and received a Bachelor of Law degree at the University of Louisiana (now Tulane University) in 1849. He later held the office of New Orleans Deputy Collector of Customs (Duncan 1965:53–54). Hunley, like McClintock and Watson, was quick to contribute to the war effort. He traveled to Cuba in June 1861 to procure foreign arms and munitions for the Confederate military. It is not clear exactly when or how Hunley joined the McClintock-Watson team (Figure 2.4); however, historical sources indicate that he became acquainted with the duo during the construction of *Pioneer* in 1861 and continued to play an active role in the development of Confederate submersibles until his death in October 1863. It appears that Hunley had the political connections and the capital needed to transform McClintock and Watson's engineering vision into reality.

Pioneer

This relatively small, cylindrical vessel (approximately 30 ft. [9.14 m] in length and 10 ft. [3.05 m] in circumference) was constructed of ¼ in. (6.35 mm) iron plate wrapped around iron support frames. The forward and aft sections of the hull were fitted with conical ends, which gave the vessel a crude cigar-shaped appearance. *Pioneer* was propelled by a hand-cranked screw propeller and steered laterally with a rudder; the vertical attitude was controlled with “vanes” mounted to the submarine’s sides. The latter acted in a manner similar to the “pectoral fins of a fish” (Baird 1902:845). The explosive charge, or torpedo, was fitted with percussion fuses and towed behind *Pioneer* on a long tether. When *Pioneer* was completed, John K. Scott was selected as its commander. During trials, Scott found that the submarine responded sluggishly when maneuvered and was difficult to steer when submerged. He also discovered that *Pioneer’s* magnetic compass swung crazily when underwater, making it practically useless (Perry 1993:95). Scott learned that, with some practice, he could surface intermittently and visually reacquire his intended target with some degree of success. Eventually, the new captain felt confident that he and his crew were ready to attempt a simulated attack on a target vessel. In March 1862, *Pioneer* successfully sank a test barge in Lake Pontchartrain.

Before their submarine could officially engage an enemy vessel, the *Pioneer* team required a letter

of marque (privateering commission) from the Confederate government. This would grant legal permission for *Pioneer* to “cruise the high seas, bays, rivers, estuaries, etc., in the name of the Government, and aid said Government by the destruction or capture of any and all vessels opposed to or at war with said Confederate States, and to aid in repelling its enemies” (ORN 2.1:399). On 31 March 1862, the submarine’s crew received its commission. Details derived from the letter of marque and associated Customs House records provide most of the information concerning *Pioneer*, including its dimensions, crew, and the names of its owners/investors. The vessel was officially designated a “submarine propeller” with an overall length of 34 ft. (10.36 m), maximum diameter of 4 ft. (1.22 m) and displacement of 4 tn. (3.63 t). The vessel was conically shaped at both ends and painted black. *Pioneer’s* armament was described as a “magazine of explosive matter” (this presumably was a reference to the submarine’s torpedo).

The letter named Scott as the submarine’s skipper and referred to an additional crew consisting of one or two unnamed individuals. There is some indication that Horace Hunley’s influence may have determined *Pioneer’s* commander: Scott was an employee of the Customs House where Hunley served as Deputy Collector of Customs. The Register of Commissions kept at the Customs House Collector’s Office lists the vessel owners as James R. McClintock, Baxter Watson,

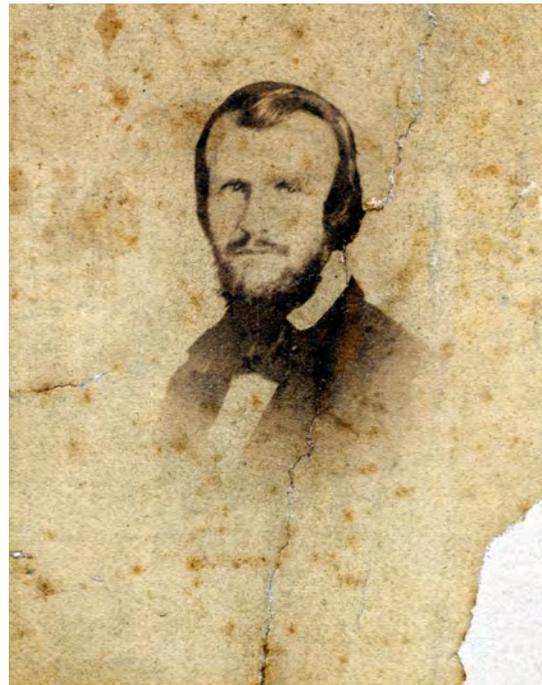


Figure 2.4. Photographs of James R. McClintock (left) and Horace L. Hunley (right). There is no known photograph of Baxter Watson. (Left: NHC Photo Archives #NH 95279; right: Horace Lawson Hunley ca. 1860, Gift of Mrs. Kathleen Grosclose, Courtesy of the Louisiana State Museum)

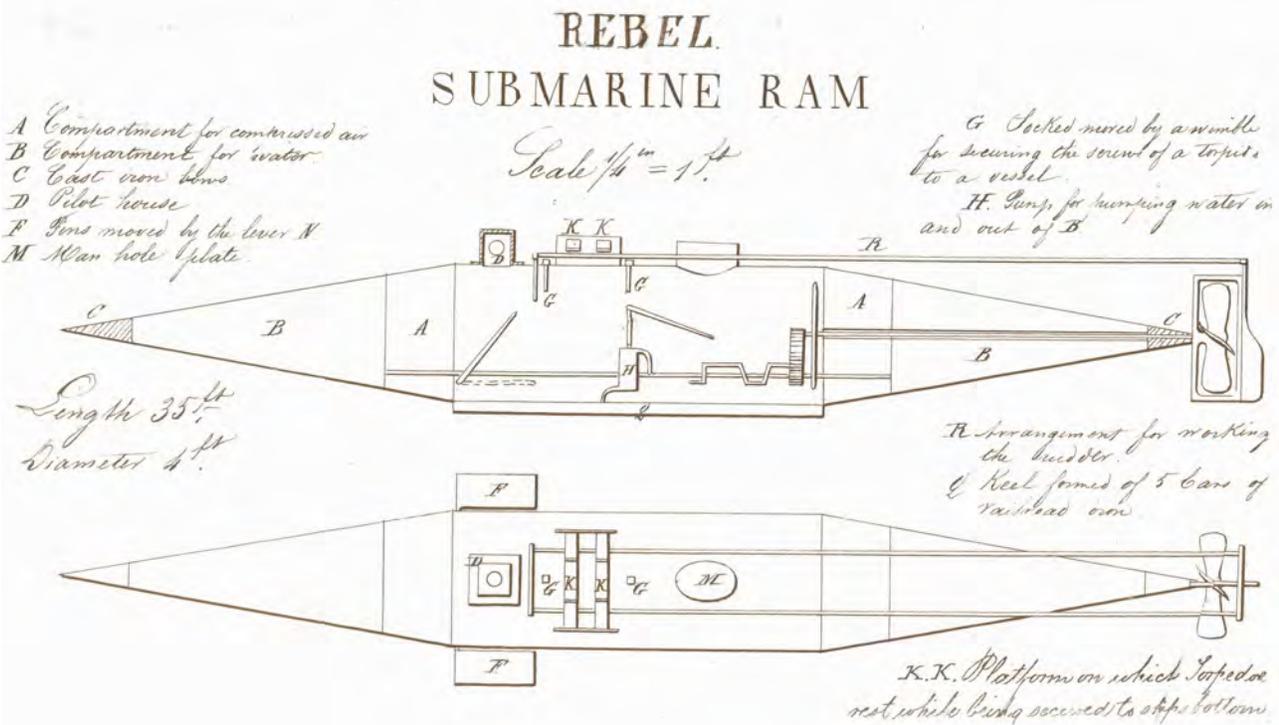


Figure 2.5. Tracing of Pioneer enclosed in William H. Shock's (1864) report to the Assistant Secretary of the Navy, presumably based on the work of Second Assistant Engineer Alfred Colin, showing the boat's main functional features. (Image courtesy of NARA)

and Robert R. Barrow. Barrow was a wealthy patron of the project who also happened to be Horace Hunley's brother-in-law (Duncan 1965:64). Customs House records also indicate that the commission collected a surety bond of \$5,000. The bond lists Hunley and an associate, Henry J. Leovy, as guarantors (ORN 2.1:401). Leovy was a prominent local attorney and, interestingly, editor of the *New Orleans Picayune*, and, as such, may have been familiar with Franklin Smith's article "Submarine Warfare."

Pioneer never had an opportunity to engage an actual enemy ship. On 28 April 1862, less than one month after the submarine's owners received their letter of marque, New Orleans fell to Union land and naval forces. Hunley, McClintock, and their associates were forced to scuttle the submarine and flee the city. During the occupation of New Orleans, *Pioneer* was discovered by Federal troops. A U.S. naval engineer named Alfred Colin and his assistant, G. W. Baird, examined the vessel from late 1863 to early 1864. Baird, who met McClintock after the war, published an article with the following account of the boat:

When a Third assistant on board the *Pensacola* during the Civil War, I had the pleasure of assisting Second Assistant Engineer Alfred Colin in the measurements and drawings of a submarine torpedo boat

[Figure 2.5] which had been fished out of the canal near the "New Basin," between New Orleans and Lake Pontchartrain. Mr. Colin's drawing was sent by the Fleet Engineer (Mr. [William H.] Shock) to the Navy Department.

The boat was built of iron cut from old boilers. . . . She was thirty feet [9.14 m] in length; the middle body was cylindrical, ten feet [3.05 m] long, and the ends were conical. She had a little conning tower with a manhole in the top and small, circular, glass windows in its sides.² She was propelled by a screw, which was operated by one man. . . . Mr. McClintock (whom I met after the Civil War had ended) informed me that he made several descents in his boat, in the lake, and succeeded in destroying a small schooner and several rafts. . . . His boat required but two men to operate it. . . . He frankly stated that the model of the boat was improper, in that the small displacement afforded by the sharp ends was insufficient to keep the boat on even keel if a man moved a few inches forward or aft, and that this was a serious objection. (Baird 1902:845–846)

² This is contradicted by drawings (Figures 2.5 and 2.6), which show a separate hatch and pilot house.

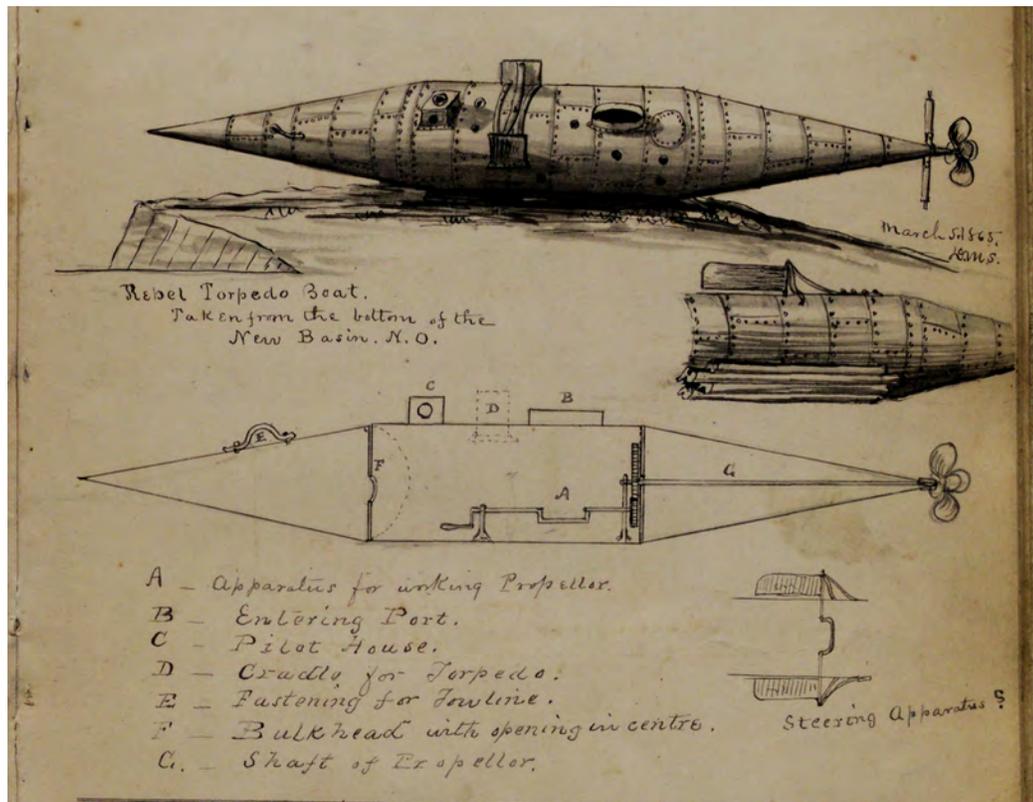


Figure 2.6. A drawing of the exterior of *Pioneer* made by Ensign Stauffer showing the boat's main functional features. (Original artwork by David Stauffer, David M. Stauffer, 1864. Courtesy of The Gilder Lehrman Institute of American History, GLC07713.01, p. 17.)

While long confused with the vessel discovered at Bayou St. John (see Figure 2.3), the sketch provides clear evidence that *Pioneer* was a different boat altogether. Its ultimate fate is unknown. One possible explanation comes from the morning edition of the 15 February 1868 *New Orleans Picayune*. The newspaper posted an auction ad for:

A torpedo boat, which was built in this city or hereabouts during the war, and which is now lying on the banks of the New Canal, near Claiborne Street, is to be sold at public auction to-day, by the United States authorities, at 12 o'clock. . . . The boat in question, which is built of iron and weighs about two tons, was sunk in the Canal about the time of the occupation of the city by the Federal forces, in 1862.

A follow-up in the newspaper's evening edition reports "[t]he torpedo boat, of which we made mention this morning, was sold at public auction, to day, at noon, for forty-three dollars. It cost, originally, twenty-six hundred" (Ragan 1995:21). That the article mentions that the submarine was found "lying on the banks of the New Canal" may hint at its identity. Historically,

the New Canal connected Lake Pontchartrain to New Basin, which was also mentioned by Baird (1902:40) in reference to the boat he documented. An 1865 sketch by David M. Stauffer, then an ensign on USS *Alexandria*, depicts the same boat drawn by Colin and is labeled as coming "from the bottom of the New Basin, N.O." (Figure 2.6). McClintock claimed that the submarine crew practiced operational procedures and conducted simulated attacks in Lake Pontchartrain. The area near Claiborne Street, where the submarine was discovered, is only eight blocks from the New Basin. The New Basin, incidentally, is only eight blocks from where *Pioneer* was built at the Leeds Foundry (located at 923 Tchoupitoulas Street). It is the closest water access to Lake Pontchartrain from the foundry (Figure 2.7).

Pioneer II

After New Orleans fell to Union forces, McClintock and his associates regrouped in Mobile, Alabama. Mobile, like New Orleans, was a major Southern seaport on the Gulf Coast and possessed the resources and manufacturing facilities to produce another submersible. Upon their arrival in Mobile, the group discovered that the city's military commander, Major



Figure 2.7. Map of New Orleans showing discovery locations of (a) the Louisiana State Museum vessel, and (b) *Pioneer*, as well as (c) the Leeds Foundry where *Pioneer* was built. (Annotated detail from Abbot 1863)

General Dabney H. Maury, was a strong proponent of torpedo and submarine warfare. Several Southern cities, including Mobile, New Orleans, Savannah, Richmond, Galveston, and Norfolk, hosted a number of independent groups that were actively developing alternative weaponry. Franklin Smith, author of the 1861 article that endorsed the use of submarines by the Confederacy, had procured a patent and may have been building his own submersible in Mobile in January 1862 (Ragan 1999:42). Maury welcomed McClintock's team and supported its efforts by arranging an introduction between *Pioneer's* owners/inventors and members of the firm Park and Lyons. Thomas W. Park and Thomas B. Lyons, like McClintock and Watson, were machinists and practical engineers. Before the war, both men were engaged in construction and repair of steam engines, and boilers. Park and Lyons were already heavily engaged in the production of artillery, steam engines, and machinery for the Confederate government when McClintock and his associates arrived, but were able to arrange an agreement under which the team's second submarine would be produced (Perry 1993:96). Two young army officers assigned to the machine shop—both of whom were experienced practical engineers and machinists—soon developed a keen interest in the project. These men were Lieutenants William A. Alexander and George E. Dixon.

William Anthony Alexander was born in London on 21 December 1837 to Scottish parents. He immigrated to Mobile at the age of 22 and began business as a practical engineer and consulting machinist. In

May 1861, Alexander enlisted in the Confederate army and served with Ketchum's Battery, Company B, Alabama State Artillery, 21st Alabama Regiment (ADAH, n.d.). He was given command of fortification efforts at Fort Morgan, located on the eastern shore of the entrance to Mobile Bay. He remained at Fort Morgan until reassigned to Park and Lyons.

George E. Dixon's origins are more enigmatic. The details of his early life are unknown and the circumstances surrounding his arrival in Mobile are unclear at best. Dixon was likely born in Kentucky or Ohio, and was licensed as a steamboat second engineer in 1859 at St. Louis, Missouri (*Mobile Daily Item* 1910; BSI 1859:131). By 1861 he had made his way to Mobile, where his name appears in the city directory as "Dickson [sic], Geo, Engineer, steamer *Flirt*" (*Mobile City Directory* 1861:19;

O'Brien, pers. comm.). While in Mobile, he joined the Mobile Greys, an auxiliary police force. Dixon's senior officer in this organization, Major Palmer Pillans, stated in a local newspaper article that the Mobile Greys were established "to aid and strengthen the police force of the city, which, at that time, was totally inadequate to properly police the city" (*Mobile Daily Register* 1895). Apparently, Pillans thought highly of Dixon. The same article reports that "the ladies of Mobile" presented the commanding officer with a "handsome flag" that he gratefully received and later "turned . . . over to young Dixon, whom he had chosen as color bearer." Pillans stated, "Lieutenant Dixon was . . . a splendid specimen of physical manhood, and . . . the Southern people should always revere and hold sacred the memory of this brave man."

At the beginning of the Civil War, the Mobile Greys were absorbed into the 21st Alabama Infantry Regiment. Captain John F. Cothran, Dixon's Commanding Officer in that regiment, described Dixon as "very handsome, fair, nearly six feet tall, and of most attractive presence" (Hartwell 1900). Dixon, like many of his peers, enlisted as a private early in the war. However, he quickly rose through the ranks. By the beginning of 1862 he was appointed sergeant and departed with his unit for Corinth, Mississippi, that spring. It was later reported that:

On the day before . . . the regiment left . . . Sergeant Geo E. Dixon . . . called on some ladies with whom he was familiarly

acquainted to bid them good bye. In the course of the visit some turn of the conversation induced him to take a \$20 gold piece from his pocket, which one of the ladies told him he had better leave with her to remember him by. But he said no; he believed he would keep it; that it might save his life. (*Memphis Daily Appeal* 1862)

George Dixon, gold coin in hand, arrived with his regiment in March 1862, where they were integrated with a 45,000-strong force commanded by General Albert S. Johnston. On 6 April 1862, Johnston's army engaged 47,700 Federal troops under the command of General Ulysses S. Grant at Shiloh, Tennessee. The Confederates were gaining ground by the end of the day, but reinforcements arrived overnight from Major General Don Carlos Buell's Army of the Ohio, and the two-day battle ended with the Union army in possession of the field. Casualties were heavy on both sides. The final tally of dead or missing exceeded 13,000 for Union forces and 10,500 for the Confederates. The 21st Alabama lost six successive color-bearers; approximately 200, or 31%, of the 650-man contingent deployed on the battlefield were either killed or wounded. George Dixon was among the casualties during the first day of the engagement. According to Dixon's Company A commander, Captain James M. Williams, he (Dixon) was "shot in the hip, the ball striking a gold piece ranged upwards and came out of his side; will probably recover if he can be well cared for" (Folmar 1981:53). The event was remarkable enough to have been picked up by the press, reporting that his life was saved by a gold coin.

In the heat of the battle of Shiloh, Dixon felt a severe rap upon the part of his body near the hip where he carried his pocket book, and at the same moment was placed hors du combat by a severe wound. On examination it was found that a Yankee bullet had passed through one side of his pocket book, bending the \$20 gold piece, and glancing, wounded him badly in the hip. Had the bullet not so glanced, it would have killed him. (*Memphis Daily Appeal* 1862)

Dixon was promoted to the rank of Second Lieutenant on 9 May 1862 while convalescing from his wound, and promoted again to First Lieutenant on 30 August 1862. Although the wound Dixon received did not kill him, he reportedly "never recovered, and was sent to Mobile. Although he could not give his bodily powers, nevertheless his mind was still in good condition" (*Mobile Daily Item* 1910). Presumably, Dixon was reassigned to the Park and Lyons machine shop

because of his debilitating condition. It was here that he developed an interest in submarines.

McClintock, Watson, and Hunley (with the aid of Alexander, Dixon, and the Park and Lyons staff) began construction on a second submarine by the summer of 1862. The five-man vessel, launched in late January 1863, is commonly referred to as *Pioneer II*, since no historic reference that directly cites the name of the second submersible is currently known to exist (Ragan 1999:93). In testimony from two Confederate deserters, Belton and Shipp, the name "American Diver" is used to identify the submarine practicing in Charleston, known to be the team's third submarine (ORN 1.15:229, 231; discussed below). Many historians have attributed the name to the second vessel, based on Belton's remark that he "worked near her in the same shop" while in Mobile (ORN 1.15:229). However, no historical evidence has emerged to clarify whether this name was applied to the second or third boat, both of which were built in Mobile. Since the name *American Diver* only appears in the above-mentioned depositions, which are clearly in relation to the Charleston craft, it has not been applied here to the second craft. If Belton was unaware of the loss of the second vessel, however, the name may indeed have been tied to the second craft.

For reasons that remain unclear, Hunley's key financial supporters in New Orleans, Henry Leovy and Robert Barrow, did not provide monetary support to the project while it was based in Mobile. Consequently, Hunley assumed sole responsibility for the cost of the second submarine (Kloeppe 1992:23). According to McClintock (1872), *Pioneer II*, like *Pioneer*, was constructed of $\frac{1}{4}$ in. (6.35 mm) thick rolled boilerplate but was larger, at 36 ft. (10.97 m) in overall length, 4 ft. (1.22 m) high, and 3 ft. (0.91 m) wide. The submarine's ends were reportedly "tapered like a wedge" (McClintock 1872). Alexander recalled that "[t]he cross section was oblong, about 25 feet [7.62 m] long, tapering at each end, 5 feet [1.52 m] wide, and 6 feet [1.83 m] deep" (Alexander 1902b:165). Based on their respective accounts of *Hunley*, it is likely McClintock's figures are more accurate. The stern was fitted with a propeller 30 in. (0.76 m) in diameter that was initially powered by a steam engine. A prototype electromagnetic engine later replaced this propulsion system. The steam engine was a complete failure when the submarine was submerged, and the electromagnetic system proved to be about as reliable as the steam engine. Consequently, it, too, was abandoned. Despite their contradictory statements regarding the vessel's dimensions, both McClintock and Alexander agreed that the experimental electromagnetic engine was useless. After the Civil War, McClintock addressed a letter to the British Admiralty in which he stated that "[t]here was much time and money lost in this endeavor . . . in its place, a hand crank was installed and operated by four men" (McClintock 1872).

A second hatch and coaming was added to facilitate entry and egress of two additional personnel, as well as to provide a means by which the submarine's crew could examine the stern while underway. Like its predecessor, *Pioneer II* was armed with a torpedo that was towed behind the submarine on the water's surface. To engage and sink an enemy vessel, *Pioneer II* would pass beneath its intended victim and drag the torpedo into its hull. Contact with the enemy hull at—or slightly below—the waterline caused the torpedo to detonate. *Pioneer II* maneuvered better than its predecessor but several design flaws and operational problems associated with the latter soon developed. The air within the submarine quickly turned foul (due to constant cranking) and caused the crew to tire easily. In addition, its speed was limited and the helmsman had difficulty conning the vessel when it ran submerged for any length of time. In spite of these problems, *Pioneer II* underwent a quick series of tests and entered into service in February 1863.

Alexander provided one of the few surviving accounts of the loss of *Pioneer II*, stating "It was towed off Fort Morgan, intending to man it there and attack the blockading fleet outside, but the weather was rough and with a heavy sea the boat became unmanageable, and finally sank, but no lives were lost" (Alexander 1902a).

Although Mobile's military commander, Major General Dabney H. Maury, was an enthusiastic proponent of submarine warfare, Mobile's naval commander, Admiral Franklin Buchanan, was not. Buchanan had served in the U.S. Navy before the outbreak of war, but joined the Southern cause in 1861. He commanded the ironclad CSS *Virginia* (*Merrimac*) against the USS *Monitor* at the Battle of Hampton Roads on 8–9 March 1862. Although described as an open-minded man, Buchanan had little faith in the submarine's abilities. He stated his position clearly in a letter to Confederate Secretary of the Navy Stephen R. Mallory:

I have witnessed the operations of the boat in the water when propelled by hand, the steam engine being a failure and had to be removed.

On that occasion its speed was not more than two miles per hour [3.22 kph]. Since then other trials have been made all proving failures. The last trial was about a week since when the Boat was lost off this harbor and was sunk[,] the men came very near being lost. I never entertained but one opinion as to the result of this Boat, that it would prove a failure, and such has been the case. . . .

I considered the whole affair as impracticable from the Commencement. (Buchanan 1863a)

No attempt was ever made to raise the vessel. In fact, Buchanan's letter seems to imply that he was happy to be rid of it. The submarine's inability to achieve sustained speeds greater than two m.p.h. (3.22 kph), coupled with Buchanan's overall lack of confidence in its operational abilities, essentially sealed the submarine's fate. *Pioneer II* was abandoned where it sank.

H. L. Hunley

The loss of *Pioneer II* was a tremendous setback for McClintock, Hunley, and Watson, who now found themselves without work and lacking funds to build another submarine. Hunley, who had bankrolled most of the construction and operational costs for *Pioneer* and completely funded the *Pioneer II* project, could not afford to finance a third submarine on his own. Luckily for Hunley and his associates, a like-minded group of engineers and machinists were also developing "infernal" weapons for the Confederate government in Mobile. The Texas-based group was founded and directed by Edgar C. Singer and was commissioned to strengthen Mobile Bay's defenses. Singer and his compatriots had developed a variety of naval contact mines—or torpedoes—and were in the process of placing the devices in upper and lower bay obstructions when they met McClintock, Hunley, and Watson. Singer and three associates, R. W. Dunn, J. D. Breaman, and B. A. Whitney, together with Hunley, invested the \$15,000 needed to build a new submarine (Hill 1916; Duncan 1965:63–64; ORN 1.26:188). This third and final submarine would be the most practical, innovative, and effective. It would also be the most deadly.

For years, historians have speculated where exactly in Mobile *Pioneer II* and *H. L. Hunley* were designed and assembled. Most archival sources agree that both submarines were manufactured at the Park and Lyons machine shop, located on the corner of Water and State Streets. However, post-war recollections from witnesses suggest that, while major components of both craft were manufactured in the Park and Lyons machine shop, their assembly actually took place in one of the two Seamen's Bethels on Water Street in the 1860s. Bethels were non-denominational churches for seamen established in many American maritime communities in the 19th century. The first bethel in Mobile was located between Theatre and Monroe streets, but was sold to Michael Hines in 1860 after a larger plot was acquired one block over, on the corner of Water and Church streets (O'Brien 2005:37). One witness, Benjamin Cox, claimed that as a child he and his friends used to go to "the old Bethel" on "the west side of Water Street second north of Monroe" to watch "the construction and play about the boat" (O'Brien 2005:33). However, an older, therefore possibly more reliable, witness,



Figure 2.8. The second Seamen's Bethel at its current location on the University of South Alabama campus in Mobile. (Photo by Shea McLean)

Major Pillans, recalled that the new Seamen's Bethel on Church Street was used:

The boat was built in the Seamen's Bethel on Church Street, the floor being taken up for the purpose. When the boat was finished it was found that she was too wide to take through the exit of the Bethel, so that pieces had to be cut out of each of the columns to get her out. (*Mobile Daily Register* 1895)

Pillans's son, Harry, claimed to have accompanied his father in his youth and published a similar article in 1924:

The vessel was built in or at least completed in the old Bethel, on Water Street, behind the old soldiers' home at the corner of Church Street. There shortly before its launching, the writer saw and went over it within and without. (Pillans 1924)

Given the relative youth of Cox when he witnessed the boat and the number of other errors in his account, it is likely Pillans and his son are more reliable sources (O'Brien 2005:37).

After the war ended, the bethel at 75 Church Street remained largely abandoned due to the economic strife that characterized the post-war South. However, religious services eventually resumed in 1879. In 1901, the church's steeple and columns were removed in an attempt at modernizing the building. It was sold in 1923 to The Little Theatre of Mobile, who had been renting it as a performing arts venue the previous two seasons (*Mobile Register* 1923). In the mid-1930s it was then sold to J. W. Hooge, who used the upper floor

for storage and rented out the first floor for meetings (O'Brien 2005:37). It was acquired by the state of Alabama in the 1960s and moved from its original location to avoid demolition (Figure 2.8).

Since both the bethel and the machine shop were located on the same street and separated by only a few blocks, transporting newly-constructed submarine components from one locale to the other would have been a relatively simple matter. Once the various parts were transported to the church, they could have been assembled without attracting too much attention to the project. By contrast, assembling the submarine in a busy machine shop frequented by clientele and the general public would have removed all elements of secrecy from its construction.

Although it is unclear exactly what role Lieutenants Dixon and Alexander played in *Hunley's* construction, Alexander provided a revealing description of the submarine's basic features and method of construction:

We ... took a cylinder boiler which we had on hand, 48 inches [1.22 m] in diameter and 25 feet [7.62 m] long (all dimensions are from memory).³ We cut this boiler in two, longitudinally, and inserted two 12-inch [30.48 cm] 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 [9.14 m] long, 4 feet [1.22 m] wide and 5 feet [1.52 m] deep. A longitudinal strip 12 inches [30.48 cm] wide was riveted the full length on 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 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 end of 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 the 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

³ Many of Alexander's dimensions have proved incorrect upon examination of the recovered vessel; however, his overall description of the components and how they worked is generally reliable. See Chapter 12 for archaeological findings.

tank, to indicate the depth of the boat below the surface. A one and a quarter shaft passed through stuffing boxes on each side of the boat, just forward of the end of the propeller shaft. On each end of this shaft, outside of the boat, castings, or lateral fins, five feet long [1.52 m] and eight inches [20.32 cm] wide, were secured. This shaft was operated by a lever amidships, and by raising or lowering the ends 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 in the ballast tanks.

The rudder was operated by . . . 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 propeller 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. . . . 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 [40.64 × 30.48 cm] with a combing 8 inches high [20.32 cm]. 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 [30.48 × 45.72 × 10.16 cm], made to carry a hollow shaft. This shaft passed through stuffing boxes. On each end was an elbow with a 4-foot [1.22 m] length of 1 ½ inch [3.81 cm] 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 [40.82 kg] 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 [60.96 m] long after her, one of the triggers to touch the vessel and explode the torpedo. (Alexander 1902a)

Alexander's description indicates that the design of the third submarine was based on both successful and unsuccessful attributes of its predecessors. For example, the overall hull form of *Pioneer II* was retained, but its length was extended to accommodate additional crewmen. Because the mechanical engine was discarded from the submarine's design altogether, more crewmen were needed to propel the vessel for extended periods of time and at greater speeds. The "air box" was likely added as a measure to prevent (or at least curb) the amount of foul air created in the hull by the introduction of additional crewmen. It was probably only used while the vessel cruised on the surface.

On 31 July 1863, the team successfully demonstrated the submarine's abilities in the Mobile River. Mobile's naval commander, Franklin Buchanan, was impressed with its performance and expressed his opinion in a letter to Charleston Naval Squadron Commander John R. Tucker:

I yesterday witnessed the destruction of a lighter or coal flat in Mobile River by a torpedo which was placed under it by a sub-marine iron boat, the invention of Messrs Whitney and McClintock; Messrs Watson and Whitney visits [sic] Charleston for the purpose of consulting Genl Beauregard and yourself to ascertain whether you will try it, they will explain all the advantages, and if it can operate in smooth water where the current is not strong as was the case yesterday, I can recommend it to your favorable consideration; it can be propelled about four knots per hour, to judge from the experiment of yesterday. I am fully satisfied it can be used successfully in blowing up one or more of the enemy's Iron Clads in your harbor.

Do me the favor to show this to Genl Beauregard with my regards. (Buchanan 1863b)

Service in Charleston

By mid-1863, the siege of Charleston, South Carolina, by Federal forces had attained a new level of intensity. Charleston was regarded as the "cradle of secession" and its capture was one of the Federal government's highest priorities. Union advances into Hilton Head, Folly Island, and Morris Island threatened the city's southern approaches. Additionally, a long-range cannon nicknamed "Swamp Angel" was used to indiscriminately shell parts of downtown Charleston from a position on Morris Island. For two years, the Union navy had implemented a naval blockade of Charleston Harbor, adding to the misery of the city's inhabitants (Figure

2.9). The increase in Union vessels not only reduced the number of successful blockade-running attempts into and out of the port, but also served as a supply line for the Federal troops advancing toward the city from the south. On 7 August 1863, Charleston's military commander, General Pierre Gustave Toutant Beauregard, telegraphed "Quartermasters and Railroad agents on Lines from Charleston, S.C., to Mobile, Alabama" and ordered them to "[p]lease expedite transportation of Whitney's submarine boat from Mobile here. It is much needed" (ORA 1.28(2):265). Beauregard hoped that *Hunley* could be successfully employed to break the Union blockade of Charleston.

Interestingly, Beauregard refers to the vessel at this point as "Whitney's submarine." This is a curious discrepancy, but understandable, given the following facts: although McClintock usually accompanied *Hunley* to instruct others in its operation, B. A. "Gus" Whitney (a part owner and representative of the Singer Group) was responsible for its transportation to Charleston. Further, he was the individual who managed all financial matters pertaining to the submarine while it remained in South Carolina. There is no historical evidence to indicate that the third submarine was named for Horace Hunley prior to its arrival in Charleston. The submarine is referred to as "the Hunley" for the first time in official Confederate correspondence in a letter from Hunley himself to Beauregard dated 19 September 1863 (discussed below).

Although the vessel is referred to as *Hunley* in several wartime documents after this point, so far no sources calling it by this name have been found that predate Hunley's letter to Beauregard. Based on the testimony of Belton discussed above, the third submersible may have originally been called *American Diver* and was later renamed *H. L. Hunley* after it arrived in Charleston.

The boat was secretly loaded onto two flatbed rail cars within two days of Beauregard's telegram and arrived in Charleston shortly thereafter. Historical sources indicate that Whitney was chosen as the Singer Group's representative and was responsible for collecting any bounties that might result from the destruction of any enemy ships. Shortly after the team's arrival in Charleston, Whitney received the following message from General Beauregard's chief of staff, General Thomas Jordan:

I am authorized to say that John Fraser & Co. will pay over to any parties who shall destroy the U.S. steam iron-clad *Ironsides* the sum of \$100,000, a similar sum for the destruction of the wooden frigate *Wabash*, and the sum of \$50,000 for every monitor sunk.

I have reason to believe that other men of wealth will unite and give with equal munificence toward the same end. (ORA 1.28(2):285)



Figure 2.9. Detail from an 1863 map showing the positions of Charleston's primary defenses as well as the distribution of Union blockading forces. (Detail from Tomlinson 1863)

Horace Hunley, who served as a captain in the Confederate army, was called to duty and spent much of the summer of 1863 performing various governmental tasks in Mississippi and Georgia. Although Hunley could not accompany the submarine and crew to Charleston, he maintained a keen interest in their mission. This is understandable, since he was one-third owner of the vessel and had invested a considerable amount of time, money, and energy in its conception and construction. Hunley wrote a letter on 15 August 1863 from an army camp near Enterprise, Mississippi, and expressed his views to McClintock and crew soon after their arrival in Charleston:

I have been extremely anxious about your experiment at Charleston. It is not at all on the question whether you will succeed in blowing up a vessel of the enemy for I think that more than probable and of itself only a small matter. It is whether your success will be made available in effecting a real solid benefit to the Confederacy and conferring glory on its originators. I am anxious first and above all for a dead silence on our part that the enemy may be lost in uncertainty and mystery which is more dreadful than any understood evil even of the greatest magnitude. Secondly. While in a panic if you succeed the enemy if properly pressed before he can make preparations to resist the consequences of your success might be possibly driven entirely from Morris Island. . . . Therefore as I can not join you I would be glad to have you in a conversation with Genl Beauregard if this reaches you before your experiment to ask him (by way of suggestion) if you should be so fortunate as to succeed, and if that success should create a panic and consequent retreat, if a rapid descent by vessels and men could not drive the enemy from the island . . . and then by at least one spare torpedo, for a second attempt make a heroic attempt to produce this panic. Remind your crew of Manassas & Shiloh and the consequences of faltering in the hour of success and make one grand effort & you may have cause to rejoice as long as you live. . . . Read this to Whitney. (Hunley 1863a; Duncan 1965:65–66)

Archival evidence suggests that Lieutenant Dixon may have accompanied the submarine from Mobile. James M. Williams, a good friend and fellow officer in the 21st Alabama Infantry, added the following statement in a letter to his wife dated 9 August 1863:

I have heard that the Sub-marine is off for Charleston, I suppose that Dixon went with it.— with favorable circumstances it will succeed, and I hope to hear a report of its success before this month is out; still there are so many things which may ruin the enterprise that I am not so sanguine of its triumph as Dixon. (Folmar 1981:118)

If Dixon did accompany the submarine to Charleston, it is likely that he returned to Mobile soon thereafter, as McClintock, Whitney, and Hunley never mention his presence in their correspondence.

The submarine and its crew could not have arrived in Charleston at a more desperate time. Battery Wagner, a Confederate fortification that guarded the entrance to Charleston Harbor, had survived two Union assaults in July but was not anticipated to repulse another attack. On 17 August, only five days after *Hunley's* arrival, Union forces began the first major bombardment of Fort Sumter. Although the fortification withstood the assault, its 5 ft. (1.52 m) thick outer walls were reduced to rubble within seven days (Figure 2.10). To compound Confederate woes, the dreaded Swamp Angel began firing 200 lb. (90.72 kg) shells directly into the heart of Charleston on 22 August. McClintock had relatively little time between the crew's arrival and their first attempted assault to drill them in the waters around Charleston. Nevertheless, he and his crew set out on their first nighttime excursion on 23 August.

The same day, a letter from Brigadier General T. L. Clingman, Commander of Confederate forces on Sullivan's Island, arrived at the office of General Beauregard's Adjutant in Charleston. It stated simply, "[t]he torpedo boat started out at sunset, but returned, as they state, because of an accident. Whitney says that though



Figure 2.10. The interior of Fort Sumter photographed by George S. Cook on 8 September 1863. (Courtesy of Library of Congress, LC-DIG-ppmsca-35434)

McClintock is timid, yet it shall go to-night unless the weather is bad” (ORA 1.28(1):670). General Clingman submitted an even less complimentary dispatch separately: “The torpedo-boat has not gone out. I do not think it will render any service under its present management” (ORA 1.28(1):670). Beaugard quickly lost patience with *Hunley’s* crew and, by 24 August 1863 (less than two weeks after the submarine’s arrival), the boat had been confiscated and placed under military jurisdiction (ORA 1.28(2):376). Following this event, McClintock completely disappears from all official Confederate correspondence. It is unclear whether he and the rest of the crew remained in Charleston or returned to Mobile. Whitney also disappears from official records after this point.

First Sinking

The “fish-boat” (as the submarine was now referred to around Charleston) did not remain idle for long. A crew of volunteers under the command of Naval Lieutenant John A. Payne took possession of the boat after the Confederate military confiscated it. Payne, a native Alabamian and executive officer aboard the ironclad CSS *Chicora*, was given very little time to train the new crew and fully familiarize himself with the submarine’s operation. Nevertheless, Beaugard ordered the boat into active service within a week of its confiscation. Beaugard’s haste would have tragic results. On 29 August 1863, while undergoing final preparations for a mission, the submarine sank in waters immediately adjacent to the southern shore of Charleston Harbor, near Fort Johnson dock. Colonel Charles H. Olmstead, the fort’s commanding officer, submitted a report of the incident to Beaugard’s office the following day:

An unfortunate accident occurred at the wharf yesterday, by which 5 seamen of the *Chicora* were drowned. The submarine torpedo-boat became entangled in some way with ropes, was drawn on its side, filled, and went down. The bodies have not yet been recovered. (ORA 1.28(1):551)

In a post-war publication, Beaugard also described the submarine’s loss:

While tied to the wharf at Fort Johnson, whence it was to start under cover of night to make the attack, a steamer passing [*Etowah*] close by capsized and sunk it. Lieut. Payne, who at the time was standing in one of the man-holes, jumped out into the water, which, rushing into the two openings, drowned two men then within the body of the boat. (Beaugard 1878:153)

A *Charleston Daily Courier* (1863) article published two days after the accident corroborates Olmstead’s letter and reports the loss of five seamen—as opposed to only two casualties reported by Beaugard:

Unfortunate Accident – On Saturday last, while Lieutenants PAYNE and HASKER, of the Confederate Navy, were about experimenting with a boat in this harbor, she parted from her moorings and became suddenly submerged, carrying down with her five seamen, who were drowned. The boat and bodies had not been recovered up to a late hour on Sunday. Four of the men belonged to the gunboat *Chicora*, and were named FRANK DOYLE, JOHN KELLY, MICHAEL CANE and NICHOLAS DAVIS. The fifth man, whose name we did not learn, was attached to the *Palmetto State*.

The fifth crewman, from CSS *Palmetto State*, was Absolum Williams. His name appears in the vessel’s pay receipts ledger with the footnote “Drowned in the submarine battery on 29th August, 1863.” The survivors of the incident included Lt. Payne; William Robinson, an Australian who enlisted in the Confederate navy at New Orleans, and was described as “a giant in size and strength”: Charles Sprague, listed on pay records as a “torpedo boatman” and probably assigned to *Hunley* to maintain and rig the torpedo; and Lieutenant Charles Hasker (Ragan 1995:74–75). Hasker, who joined the submarine’s roster as a last-minute replacement for another crewman, provided a vivid account of the sinking:

‘We were lying astern of the steamer *Etowah*, near Fort Johnson, in Charleston harbor. Lieutenant Payne, who had charge, got fouled in the manhole by the hawser and in trying to clear himself got his foot on the lever which controlled the fins. He had just previously given the order to go ahead. The boat made a dive while the manholes were open and filled rapidly. Payne got out of the forward hole and two others out of the aft hole. Six of us went down with the boat. I had to get over the bar which connected the fins and through the manhole. This I did by forcing myself through the column of water which was rapidly filling the boat. The manhole plate came down on my back; but I worked my way out until my left leg was caught by the plate, pressing the calf of my leg in two. Held in this manner, I was carried to the bottom in forty-two feet of water. When the boat touched bottom, I felt the pressure

relax. Stooping down, I took hold of the manhole plate, drew out my wounded limb, and swam to the surface.' (Fort 1918:459)

When Hasker reached the surface, Daniel M. Lee, a young midshipman, quickly removed his tunic and dove into the water to assist the exhausted survivor. Significantly, Hasker's rescuer was the nephew of General Robert E. Lee, Commander of the Army of Northern Virginia (Metzger, n.d.).

By the beginning of September 1863, the defenders of Charleston were experiencing the full impact of the war. The Swamp Angel was hurling shells into the city on a daily basis; on 6 September beleaguered forces at Battery Wagner abandoned their post and the remainder of Morris Island. Left with little time and no money to build another submarine, the Confederates opted to raise the one now lying at the bottom of Charleston Harbor. The task of recovering the vessel was granted to two civilian salvage divers, Angus Smith and David Broadfoot. Hard-hat diving was still in its infancy during the Civil War and the duo (both of whom were Scottish-born immigrants) held a virtual monopoly on underwater salvage in Charleston Harbor. Prior to the submarine's loss, Smith and Broadfoot had performed various tasks for the Confederate government, including installation of submerged obstructions and placement of underwater contact mines (torpedoes). On 14 September, Smith and Broadfoot raised the submarine, removed the corpses of all five crewmen, and towed the vessel to the Charleston railroad wharf. As soon as it arrived at the wharf, Lieutenant Payne once again assumed command of the submarine. All five men who perished aboard the vessel were buried in a mariner's cemetery on the outskirts of Charleston.

Upon hearing of the disaster that befell the submarine and its crew, Horace Hunley petitioned General Beauregard for command of the vessel:

I am a part owner of the torpedo Boat the *Hunley*. I have been interested in building this description of boat since the beginning of the war, and furnished the means entirely of building the predecessor of this boat which was lost in an attempt to blow up a Federal vessel off fort Morgan Mobile Harbor. I feel therefore a deep interest in its success. I propose if you will place the boat in my hands to furnish a crew (in whole or in part) from Mobile who are well acquainted with its management & make the attempt to destroy a vessel of the enemy as early as practicable. (Hunley 1863b)

Within a week, Lieutenant Payne was relieved of command and operational control of the submarine

was granted to Horace Hunley. William Alexander chronicled the event with the following passage:

General Beauregard then turned the boat over to a volunteer crew from Mobile known as the 'Hunley and Parks [sic] crew.' Captain Hunley and Thos. Parks [sic] (one of the best men), of the firm Parks [sic] & Lyons, in whose shop the boat had been built, were in charge, with Messrs. Brockbank, Patterson, McHugh, Marshall, White, Beard, and another as the crew. . . . Nearly all the men had had some experience in the boat before leaving Mobile, and were well qualified to operate her. (Alexander 1902a)

These may have been the same men who crewed the boat with McClintock before the submarine was seized by the Confederate government in August 1863. Although little is known about this group, some of its members were known to have associated with Thomas Park's partner, Thomas B. Lyons. Lyons was the foreman of Mobile's Washington Fire Company No. 8 between 1860 and 1861. The list of volunteer firemen serving with Lyons during that period includes three of the names in Alexander's list (Taylor 1972: 34–35). Although Alexander does not identify the last member of the crew by name, some evidence suggests that this individual may have been Lieutenant George Dixon. Dixon's service record reveals that he was detached from the 21st Alabama on 1 October 1863. General Beauregard provides additional evidence that Dixon left Mobile for Charleston, stating that "[a]fter the recovery of the sunken boat Mr. Hunley came from Mobile, bringing with him Lieutenant Dixon, of the Alabama volunteers, who had successfully experimented with the boat in the harbor of Mobile, and under him another naval crew volunteered to work it" (Beauregard 1878:153). Based on Beauregard's statement, it appears that George Dixon, rather than Horace Hunley, piloted the submarine during operations in the waters off Charleston.

H. L. Hunley was not the only torpedo boat operating in Charleston Harbor during this period. On 5 October 1863, a steam powered, semi-submersible vessel called CSS *David* attacked the formidable Union warship USS *New Ironsides* (Figure 2.11). The vessel was the invention of Theodore D. Stoney and Dr. St. Julian Ravenel. It was named after the biblical hero David who, though much smaller, confronted and slew his seemingly invincible adversary, the mighty giant Goliath. *David* was cigar-shaped and armed with a retractable, bow-mounted percussion spar torpedo loaded with 65 lb. (29.48 kg) of black powder (Tomb, 1914:168). *David* was rendered temporarily inoperable when the explosion from the torpedo filled the boat with water,

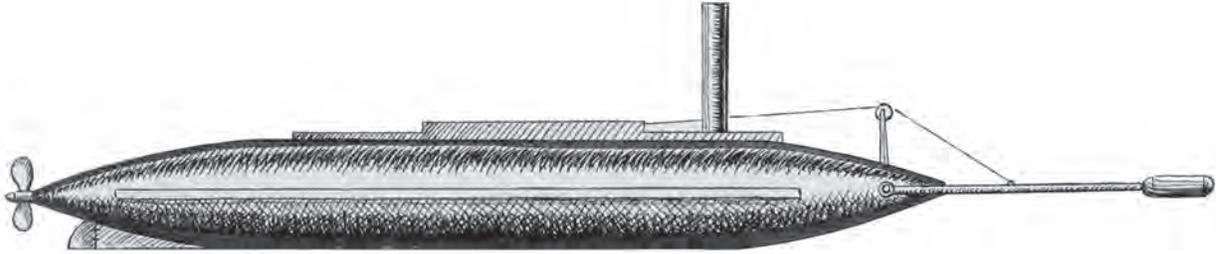


Figure 2.11. A 1960s reconstruction of a Confederate torpedo boat designed like CSS David, with spar torpedo deployed. (NHHC Photo Archives #NH 95242)

extinguished the boiler, and nearly sank the vessel. Consequently, *David's* commander, naval Lieutenant W. T. Glassel, ordered the vessel abandoned. As the stricken craft drifted away from *New Ironsides*, *David's* chief engineer, James Tomb, managed to swim back to his vessel, where he discovered another crewmember (who could not swim) clinging to the hull. Together, both men boarded *David*, relit the boiler, and steered the vessel back to friendly waters. *New Ironsides* was damaged in the attack, and eventually had to be sent to Philadelphia to effect proper repairs. The Union fleet learned a valuable lesson from the ordeal; in the coming weeks, preparations were made throughout the blockading fleet for future submarine encounters.

At the same time, Dixon, Hunley, Park, and the rest of the submarine's crew were busy conducting practice runs with their vessel in Charleston Harbor. It is unclear what reaction, if any, the submarine's crew might have had to news of the *David-New Ironsides* encounter. They may have been heartened by the near success of *David's* attack; alternatively, considerable concern may have existed among the crew in regards to the Federal fleet's heightened state of preparedness.

Second Sinking

On 15 October 1863, the submarine suffered its worst catastrophe up to that point. According to Beauregard (1878:153), while Dixon usually piloted the vessel, "one day when he was absent from the city Mr. Hunley, unfortunately, wishing to handle the boat himself, made the attempt. It was readily submerged, but did not rise again to the surface, and all on board perished from asphyxiation."

Captain Horace Lawson Hunley and a seven-man crew died while performing a routine diving exercise under the Confederate receiving ship CSS *Indian Chief* (then moored at the mouth of the Cooper River). According to the *Journal of Operations* kept at Confederate headquarters in Charleston, the morning of 15 October was rainy and "too hazy to get report of the fleet" (ORN 1.15:692). The submarine departed

the wharf at 9:25 A.M. and submerged at 9:35 A.M. (ORN 1.15:692). Shortly thereafter, observers on a nearby dock noticed a stream of bubbles emanating from the point where the vessel slipped beneath the water. According to eyewitnesses aboard *Indian Chief*, the submarine submerged a short distance from the port side of their vessel, after which "All on board went to the starboard side of the ship to see her rise to the surface after diving under us, but she did not come to the surface. Then all went to the side she went down and saw a great quantity of bubbles rising from the river" (Museum of the Confederacy, n.d.).

Some observers postulated that one of the hatches may not have been properly closed, but did not consider this a serious discrepancy at the time. However, after several hours it became apparent that Hunley and his crew were lost. No immediate attempts at rescue were made due to the depth of water (nearly nine fathoms, or approximately 54 ft. [16.46 m]) in the channel where the submarine sank (ORN 1.15:692). George Dixon was not aboard the submarine that fateful day, but he did reportedly witness the event. James H. Tomb, First Assistant Engineer on CSS *Chicora* and Chief Engineer, and later Commander, aboard CSS *David*, recounted, "Lieutenant Dixon, James A. Eason, and myself stood on the wharf as she passed out and saw her dive, but she did not rise again" (ORN 1.15:335).

The following day, Dixon received orders to return to Mobile. While there, he spent time with his friend William Alexander. When the submarine was transported to Charleston three months before, Alexander remained in Mobile and worked at the Park and Lyons machine shop to develop a breech-loading gun for the Confederate Army. Since McClintock had been dismissed from the project, and Hunley, Park, and most of the Mobile crew were dead, few people remained who were familiar with the vessel's operation.

Following its second fatal accident in as many months, General Beauregard was hesitant to allow the submarine's continued operation. Beauregard (1863) telegraphed Dixon in Mobile on 5 November 1863 and stated the following: "Lieutenant Dixon: I can have

nothing more to do with that submarine boat. It's more dangerous to those who use it than the enemy." Dixon and Alexander were either already en route to Charleston when the telegraph arrived, or elected afterwards to meet Beauregard in person to persuade him to change his mind. Regardless of the situation(s) surrounding their return, both men arrived in Charleston prior to the submarine's recovery and presumably witnessed the opening of its hatches. Although the vessel had been located only three days after it sank, it was not raised until 7 November (Kloeppel 1992:43). After 23 days on the bottom of Charleston Harbor, the sights and smells within the submarine must have been unspeakably grotesque. General Beauregard was present as the hatches were opened, and described what greeted the first men to peer inside: "When the boat was discovered, raised and opened, the spectacle was indescribably ghastly; the unfortunate men were contorted into all kinds of horrible attitudes; some clutching candles, evidently endeavoring to force open the man-holes; others lying in the bottom tightly grappled together, and the blackened faces of all presented the expression of their despair and agony" (Beauregard 1878:153). Alexander's account of the scene is somewhat more restrained but equally affecting:

The boat, when found, was lying on the bottom at an angle of about 35 degrees, the bow deep in the mud. The holding-down bolts of each cover had been removed. When the hatch covers were lifted considerable air and gas escaped. Captain Hunley's body was forward, with his head in the forward hatchway, his right hand on top of his head (he had been trying, it would seem, to raise the hatch cover). In his left hand was a candle that had never been lighted, the sea-cock on the forward end, or Hunley's ballast tank, was wide open, the cock-wrench not on the plug, but lying on the bottom of the boat. Mr. Parks' [sic] body was found with his head in the after hatchway, his right hand above his head. He also had been trying to raise his hatch cover, but the pressure was too great. The seacock to his tank was properly closed, and the tank was nearly empty. The other bodies were floating in the water. Hunley and Parks [sic] were undoubtedly asphyxiated, the others drowned. The bolts that held the iron keel ballast had been partly turned, but not sufficient to release it. (Alexander 1902c:85-6)

Historians have debated the cause of the calamity for years. Rumors spread widely almost immediately

after the incident. A letter from General Henry A. Wise (1863) to his wife stated "a bottle was found tied with a strong cord to her wing which had so wound around & clogged the machine it could'nt work—evidently a secret enemy did it." The most likely culprit, however, is pilot error. In the following passage, Alexander describes the standard operating procedure for diving and surfacing the vessel:

All hands aboard and ready, they would fasten the hatch covers down tight, light a candle, then let the water in from the sea into the ballast tanks until the top of the shell was about three inches under water. This could be seen by the water level showing through the glasses in the hatch combings. The seacocks were then closed and the boat put under way. The captain would then lower the lever and depress the forward end of the fins very slightly, noting on the mercury gauge the depth of the boat beneath the surface; then bring the fins to a level; the boat would remain and travel at that depth. To rise to a higher level in the water he would raise the lever and elevate the forward end of the fins, and the boat would rise to its original position in the water. (Alexander 1902b:167)

Tomb reported simply that "Dixon said that they failed to close the after valve" (ORN 1.15:335). However, Alexander's reconstruction of the chain of events, based on his own experience, the evidence from the submarine, and position of the bodies, suggests the problem was at the bow:

Captain Hunley's practice with the boat had made him quite familiar and expert in handling her, and this familiarity produced at this time forgetfulness. It was found in practice to be easier on the crew to come to the surface by giving the pumps a few strokes and ejecting some of the water ballast, than by the momentum of the boat operating on the elevated fins. At this time the boat was under way, lighted through the dead-lights in the hatchways. He partly turned the fins to go down, but thought, no doubt, that he needed more ballast and opened his sea cock. Immediately the boat was in total darkness. He then undertook to light the candle. While trying to do this the tank quietly flooded, and under great pressure the boat sank very fast and soon overflowed, and the first intimation they would have of anything being wrong was the water rising

fast, but noiselessly, about their feet in the bottom of the boat. They tried to release the iron keel ballast, but did not turn the keys quite far enough, therefore failed. The water soon forced the air to the top of the boat and into the hatchways, where Captains Hunley and Parks were found. Parks had pumped his ballast tank dry, and no doubt Captain Hunley had exhausted himself on his pump, but he had forgotten that he had not closed his sea cock. (Alexander 1902a)

Alexander suggests that Hunley was careless due to over-familiarity with the submarine's operation; however, he was not in Charleston prior to the sinking on 15 October, and General Beauregard asserts that it was Dixon, not Hunley, who piloted the submarine during that time. Therefore, it may have been Hunley's unfamiliarity with the boat that doomed him and his crew.

We may never know how experienced Hunley was with operations, but his mistakes may have been compounded by Park, who, in an attempt to surface and unaware the forward sea cock was open, pumped the rear ballast tank dry. As the stern's buoyancy increased, so too did the attitude at which the submarine descended. The vessel's crew were probably further disoriented when its bow impacted with the riverbed. While the crew struggled to assess the situation, water continued to enter the forward ballast tank and silently spill over the forward bulkhead. Rising water within the hull eventually drowned the crew and forced Hunley and Park into their respective conning towers. Since the water pressure was too great for either man to open his hatch, Hunley and Park appear to have succumbed to asphyxiation within their coamings. Alexander's description of the open forward seacock, the dislodged seacock handle, and the unlit candle provide damning evidence that pilot error contributed to the loss of the submarine.

Hunley and the rest of the second crew were buried with full military honors at Charleston's Magnolia Cemetery on 8 November 1863. The men interred were Horace L. Hunley, Robert Brookbank (according to Alexander, the correct spelling for this individual's last name was "Brockbank"), Joseph Patterson, Thomas W. Park, Charles McHugh, Henry Beard (who has since been identified as Henry Baird), John Marshall, and Charles L. Sprague.

Dixon Takes Charge

Following the funeral, Dixon and Alexander wasted no time refitting the submarine and petitioning Beauregard for a new crew. One of the main changes to the boat as part of the refit was to change the method of deploying the torpedo. The difficulties of the towed

system were attested by Tomb, who was detailed on several occasions to take *Hunley* in tow from *David*:

The last night the 'David' towed him down the harbor his torpedo got foul of us and came near blowing up both boats before we got it clear of the bottom, where it had drifted. I let him go after passing Fort Sumter, and on my making report of this, Flag-Officer Tucker refused to have the 'David' tow him again. (ORN 1.15: 334–5)

Tomb strongly recommended using a spar like *David* and the other torpedo boats being used in Charleston. With this method, the weapon was fixed to a long iron spar at the bow with a single hinged joint so that its position could be adjusted as needed. This allowed for the torpedo to be lowered into the water to a depth calculated to inflict the most damage to an enemy vessel's hull beneath the waterline, while the attacking boat remained at the surface. General Beauregard (1878:174) agreed with this assessment and, mindful of the many men lost already in failed dives, ordered *Hunley* to operate as a semi-submersible with a spar-mounted torpedo.

Finding another group of men willing to risk their lives in such an untried vessel was Dixon's next challenge. According to Alexander, both men:

reported to General Jordan, chief of staff, that the boat was again ready for service, and asked for a crew. After many refusals, and much dissuasion, General Beauregard finally assented to our going aboard the C.S.N. receiving ship *Indian Chief*, then lying in the river, and secure volunteers for a crew, strictly enjoining upon us, however, that a . . . full explanation of the hazardous nature of the service required of them, was to be given to each man. (Alexander 1902a)

Only one piece of wartime correspondence that lists the new recruits by name is known to exist. Captain M. M. Gray, a Confederate army officer "in [c]harge of [t]orpedoes," provides the following roster of names in a letter to Major-General Maury of Mobile dated 29 April 1864: "I am informed that he [Dixon] requested Commodore Tucker to furnish him some men, which he did. Their names are as follows, viz: Arnold Becker, C. Simkins, James A. Wicks, F. Collins, and ——— Ridgeway, all of the Navy, and Corporal C. F. Carlsen, of Captain Wagener's company of artillery" (ORN 1.15:337–8). The recovery of the remains of the crew in 2001 and the ensuing forensic research by Dr. Douglas Owsley and genealogy conducted by Linda Abrams has resulted in a better identification of the crew and

understanding their personal histories than was previously known. We now know the crew (listed in order of their physical position in the submarine) consisted of Lieutenant George E. Dixon, CSN Captain's Cook Arnold Becker, CSN Quartermaster Lumpkin, CSA Corporal J. F. Carlsen, Seaman Frank G. Collins, an unidentified man named Miller, CSN Boatswain James A. Wicks, and CSN Quartermaster Joseph F. Ridgeway (Jacobsen 2004). While research is on-going, an overview of the findings to date provides a fascinating picture of the men who volunteered for such hazardous duty.

First Lieutenant George E. Dixon

While accounts of Dixon's wartime service have been presented above, the research brought new details to light about this charismatic leader. His age based on forensic analysis was 24 to 28 years, with a height of 5 ft. 9 in. (175 cm) (Figure 2.12). General health issues included a deviated nasal septum that would have restricted airflow through the right half of his nasal chamber and teeth with cavities and abscesses. Six of his lower jaw teeth had a total of eight cavities, some of which had been filled, five with gold fillings and one with a silver amalgam; the ones near abscesses had been extracted (Olds 2004). His teeth were also stained from tobacco, but were without the wear marks associated with pipe use, suggesting use of cigars or chewing tobacco. The most dramatic injury was that of the gunshot wound to the upper left thigh, which, while it did not break the bone due to the fortuitous placement of his 20 dollar gold coin, still produced significant soft tissue damage that was manifested in a bone spur as well as tiny metallic particles embedded in the femur (FOTH 2004a:4).

Reports of Dixon's midwestern origins are supported by forensic research, which uses the ratio of carbon isotopes 12 and 13 in tooth enamel to characterize grains ingested during childhood (Olds 2004; Neyland 2009:377). Archival research revealed that in 1860 he was a steamboat engineer on the Mississippi River route between St. Louis and Cincinnati, but the beginning of the Civil War found him in Mobile, Alabama, where he was a member of the Masonic Lodge and the Mobile Grays. His official enlistment in the 21st Alabama infantry began in October, 1861. He rose from private to lieutenant quickly and was educated, as evidenced by the letters he wrote. His personal effects attested to a measure of personal wealth: besides the gold-filled teeth and coin, he carried a gold watch with a Mobile Masonic Lodge fob, a diamond ring, and brooch.



Figure 2.12. Facial reconstruction of Lt. George Dixon. (Photo by Chip Clark, courtesy of FOTH)

However, there is no evidence of land ownership or a bank account that would indicate status and position. Instead his wealth was portable, carried on his person or stored in a trunk with his landlord in Mobile (Willey 1866). That he cared for his men and his mission is evident from his correspondence to his friend Henry Willey of Mobile, in which he describes his men as "a splendid crew of men the best I think I ever seen" (Dixon 1864).

Seaman Arnold Becker

The individual stationed aft of Lt. Dixon was the youngest member of the crew, a European immigrant named Arnold Becker (Figure 2.13). His age was determined by Owsley to be 19 to 22 years and his height was 5 ft. 5 in. (165 cm), which made him the shortest of the crew. Although short of stature, his skeletal remains suggested an occupation requiring strength and hard labor to an extent that his vertebrae had deteriorated at the joint surfaces. It is speculation, but a small medicine bottle located on the bench near his seat might have dispensed pain relief for his back. Becker was not only born in Europe, but was a recent immigrant, as shown by the ratio of carbon 12 and 13 isotopes. He had also suffered childhood illness and/or malnutrition, which was indicated by disruption in the linear tooth growth. Although the specifics of his childhood are unknown, his health and young adult occupation as a seaman suggests a poor or working class upbringing. Tobacco staining on the teeth indicated that, like Dixon, he might have smoked cigars or chewed tobacco, but did not incise his teeth from clenching the stem of a pipe (Olds 2004).

Becker, although a relatively recent arrival, was in the United States when the war began, working on the Mississippi riverboat *Ed Howard* or *Howard*, which was purchased by the Confederate government. Becker enlisted in the Confederate navy in New Orleans on 19 October 1861 and was assigned to his former vessel, since converted to a timberclad and renamed *CSS General Polk* (Raegan Quinn 2006:4). He was presumably on board when it was scuttled and burned in the Yazoo River on 26 June 1862 to prevent capture after the fall of New Orleans to Union forces. Four months later, in October 1862, records show Becker was in Charleston, assigned to the gunboat *CSS Chicora*. There he was promoted to the rank of Captain's Cook and on the ship's pay roster until September 1863 (NARA n.d. a, n.d. b). He was then assigned to *CSS Indian Chief* and was one of four volunteers from that ship recruited by Dixon (ORN 1.15:337).



Figure 2.13. Facial reconstruction of Seaman Arnold Becker. (Photo by Chip Clark, courtesy of FOTH)

Quarter Gunner C. Lumpkin

The third person aft in the submarine is primarily known by the last name of Lumpkin (Figure 2.14). His name was mistakenly identified as Simkins or Simpkins when transcribing original handwritten documents (ORN 1.15:337), but genealogist Linda Abrams was able to determine his correct name was Lumpkin. The CSS *Indian Chief* pay roster from October 1863 clearly lists him as “C. Lumpkins” and a note written by William Alexander (1898) mentions “Lumpkin” as being on the submarine.



Figure 2.14. Facial reconstruction of Quarter Gunner Lumpkin. (Photo by Chip Clark, courtesy of FOTH)

Lumpkin, like Becker, was European born; however, isotope analysis revealed he had been in North America for some time. Owsley interpreted that, of the Europeans on *Hunley*, he had been away the longest. He was also one of the oldest men on board, between 37 and 44 years, but probably in his early forties. He was a relatively large man, standing 5 ft. 10 in. (178 cm). He had had a strenuous life, perhaps as a sailor, and had a series of injuries that resulted in a broken nose, cheek, and foot. The breaks had all healed prior to his service on *Hunley*, but still he suffered from arthritis in his back and might have walked with a slouch. Adding to his health problems were the deeply worn notches in his teeth from pipe use and tobacco staining. His pipe was with him when he died, as was a sewing kit and pocketknife.

The date and location of Lumpkin’s enlistment in the Confederate navy is unknown. He appears in the Charleston Naval Squadron’s regular payroll roster, from which he was stricken on 31 October 1863, coinciding with the time Dixon was assembling his new crew for *Hunley* (NARA, n.d. a, n.d. b). His position as Quarter Gunner indicates that he had experience handling explosives and suggests that he may have been responsible for arming the submarine’s torpedo.

Corporal J. F. Carlsen

The fourth *Hunley* crewman was J. F. Carlsen, another European-born volunteer, possibly from Scandinavia (Figure 2.15). Owsley’s forensic analysis determined he was 20 to 23 years old and 5 ft. 10 in. (178 cm) tall. Abrams’s genealogical research found he had enlisted in Company A, Light Artillery South Carolina Volunteers, which was also called the German Artillery.

Abrams found that, prior to his enlistment, he was helmsman on the privateer *Jefferson Davis* when it sailed from Charleston on 28 June 1861. On its privateering voyage, *Jefferson Davis* captured seven merchant ships and their crews. This success led to complications

that eventually resulted in a trial of mutiny for some of the captured crewmen. Having placed prize crews on all the captured ships, *Jefferson Davis* found its complement much reduced and outnumbered by the merchant crewmen imprisoned onboard, who took advantage of this weakness and attempted to take over the ship. The ensuing fight caused *Jefferson Davis* to wreck off the coast of St. Augustine, Florida, in August 1861. While in Charleston to sign witness statements for the trial in September 1861, Carlsen enlisted in the German Artillery, which was bivouacked nearby (CSN 1861). He was with them at the Battle of Fort Walker in November 1861 and was cited for his bravery (FOTH 2004b:5).

In early 1864, Carlsen volunteered for service on *Hunley* (ORN 1.15:337), as one of two men Dixon reportedly recruited from the German Artillery after William Alexander was ordered back to Mobile (Alexander 1902b:173). The German Artillery muster roll states that Carlsen was “lost in the Submarine Torpedo Boat on the 16th, [17th], of Feb 1864 while in the act of sinking the U.S. Steamer Housatonic” (FOTH 2004b:5).

Seaman Frank Collins

The fifth person stationed aft in *Hunley* was Frank Collins (Figure 2.16). He was the largest crewmember at 6 ft. 1 in. (185 cm) in height, and it is perhaps because of his size and strength that he was positioned to turn the crank in the middle of the submarine. Collins and his brother John were orphaned and raised by their grandparents in Fredericksburg, Virginia. The 1860 census records him as a day laborer. It is possible he had trained as a cobbler, for both his grandfather and uncle were cobblers. This theory is supported by the “tailor notches” caused by holding needles or pins between his front teeth that were identified by Owsley (FOTH 2004b:4).

Collins enlisted in the Confederate States Navy on 25 April 1863 in Richmond, Virginia. His rating as a seaman, rather than landsman, might indicate he had some prior seafaring experience. He served on CSS *Indian Chief* in Charleston, and also disappears from the Charleston Naval Squadron’s regular payroll roster after 31 October 1863, when he became one of four of



Figure 2.15. Facial reconstruction of Cpl. J. F. Carlsen. (Photo by Chip Clark, courtesy of FOTH)



Figure 2.16. Facial reconstruction of Seaman Frank Collins. (Photo by Chip Clark, courtesy of FOTH)

the volunteers chosen by Dixon (NARA n.d. a, n.d. b). Due to his size and position in the center of the vessel, it would have been difficult for him to escape from the submarine in any emergency (FOTH 2004b:5).

Miller

The sixth position in the submarine was filled by a crewman by the name of Miller (Figure 2.17). Little has yet been learned of him, not even his first name. At first, it appeared that he may have been the second man from the German Artillery reportedly added to the crew after the departure of Alexander (1902b:173); however, Alexander (1898) mentioned in a letter that he knew Miller, suggesting the man had been recruited before Alexander left the team. Carbon isotope analysis indicates Miller was a relatively recent immigrant from Europe. Forensic analysis also concluded he was between 40 and 45 years of age and stood 5 ft. 8 in. (173 cm) in height (Jacobsen 2004). Owsley noted he was a heavy smoker and carried his wooden pipe with him inside the submarine (FOTH 2005a:4). He had had a hard life, as evidenced by healed fractures to his ribs, leg, and skull. Not surprisingly, he showed early stages of arthritis (FOTH 2005a:4).

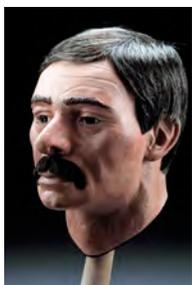


Figure 2.17. Facial reconstruction of crewman Miller. His first name is not yet known. (Photo by Chip Clark, courtesy of FOTH)

Quartermaster James A. Wicks

The seventh position in the submarine was filled by an experienced seaman, James A. Wicks (Figure 2.18). Wicks was a native Southerner, born in North Carolina circa 1819. In 1850, he enlisted in the United States Navy at the Brooklyn Navy Yard, New York. He also married that same year and by 1861 had fathered four daughters. He served in the U.S. Navy more than a decade, first as a seaman and later as a quartermaster (FOTH 2005b:4).

When the war began, his wife and daughters were living in Fernandina, Florida, deep in the heart of the Confederacy. Wicks served in the North Atlantic Blockading Squadron, first on USS *Braziliera*, then USS *Congress*. He was aboard this vessel on 8 March 1862, when it was attacked and sunk by CSS *Virginia* at the Battle of Hampton Roads. Wicks took this opportunity to head south and on 7 April 1862,



Figure 2.18. Facial reconstruction of Quartermaster James Wicks. (Photo by Chip Clark, courtesy of FOTH)

in Richmond, he enlisted in the Confederate navy as a seaman. His first assignment was CSS *Indian Chief*, where he was eventually promoted to Boatswain's Mate, before volunteering for Dixon's new crew in October 1863. He apparently took a break from his service on *Hunley*, as he is recorded as volunteering for a raid outside of New Bern, North Carolina, that destroyed the Union ship USS *Underwriter* on 3 February 1864 (FOTH 2005b:5). He returned to his Charleston duties two days later, less than two weeks before *Hunley's* final mission.

Owsley's analysis revealed that Wicks was a large man, standing 5 ft. 10 in. (178 cm) tall, and, like Lumpkin and Miller, was a heavy tobacco user (Jacobsen 2004). Abrams's research of records found that he had light brown hair, blue eyes, and a florid complexion (FOTH 2005b:5). His duties in the submarine included manning the hand crank and also releasing the keel ballast mechanism that was at his feet.

Joseph F. Ridgaway

The eighth and last man in the submarine was Joseph Ridgaway of Talbot County, Maryland (Figure 2.19). He was born in late 1833 to James and Elizabeth Ridgaway (FOTH 2005c:6). James was a sea captain and owner of merchant vessels. Joseph earned his Seaman's Protection Certificate and the rating of seaman at age 16. Like many from his home state, Ridgaway appears to have had Confederate sympathies and enlisted in the Confederate States Navy in Richmond on 29 August 1862. He first appears on the Charleston Naval Squadron's payroll roster in October 1862 and is later removed from regular pay records after 31 October 1863, along with his fellow volunteers from CSS *Indian Chief* (ORN 2.1:317; NARA n.d. a, n.d. b).

Owsley's analysis indicated Ridgaway was 5 ft. 10 in. (178 cm) tall and robust for his height (FOTH 2005c:6–7). He had suffered a broken nose and injured his shoulder, perhaps a result of his occupation. He also used tobacco and his wooden pipe was found nearby with his slouch hat, pencil, and an apparent war souvenir. The last was a copper alloy token or tag with the name Ezra Chamberlin, Company K, 7th Regiment Connecticut volunteers, who entered service on 6 September 1861. Chamberlin was killed at the Battle of Morris Island, South Carolina, in 1863. Abrams noted that since seamen from *Indian Chief* were assigned to picket duty off Morris Island, Ridgaway might have picked it up there or obtained it from someone who was there (FOTH 2005c:6).



Figure 2.19. Facial reconstruction of Joseph Ridgaway. (Photo by Chip Clark, courtesy of FOTH)

Ridgeway took over Alexander’s position on *Hunley* when the engineer was recalled to Mobile (see below). This was a key position of responsibility, in which he would have been accountable for the securing the aft hatch, as well as operation of the seventh crank position, aft pump, and seacock valve. It is likely his extensive seafaring background made him an excellent candidate to take over these duties.

Ridgeway’s story does not end with his loss in *Hunley*, for he had a fellow shipmate from *Indian Chief*, James Joiner, who took news of Ridgeway’s death to the Ridgeway family in Maryland. Joiner became a member of his friend’s family, when he married one of Ridgeway’s four sisters (FOTH 2005c:7).

Training the Crew

Dixon and the new crew of submariners were garrisoned in the town of Mount Pleasant, a small fishing community located along the north shore of Charleston Harbor near the mouth of the Cooper River. Initially, practice runs were conducted in the Cooper River; however, the submarine’s base of operations was eventually moved to Back Bay, a small lagoon located behind Battery Marshall and along the northeast tip of Sullivan’s Island (Figure 2.20). Although Sullivan’s Island often received sporadic cannon fire from the blockade fleet, it was not in immediate danger of invasion (as was the case with Morris Island). Further, it provided a safe anchorage out of sight of the enemy, and access to the sea via a narrow channel known as Breach Inlet. In theory, the crew could conduct operational exercises in the Back Bay during the day, and (weather permitting) covertly slip into the ocean at night via the inlet.

Alexander described the crew’s daily trek to Sullivan’s Island: “We would leave Mount Pleasant about one o’clock P.M., walk seven miles [11.27 km] back to Battery Marshall along the beach—this exposed us to the enemy’s fire, but it was the best walking—take the boat out, and practice the crew for two hours in the Back Bay” (Alexander 1903:748) (Figure 2.21). On nights when seas were calm, *Hunley* was piloted into the open ocean, where the crew practiced submerging and surfacing their vessel. According to Alexander, he and “Dixon . . . would . . . lie down on the beach with the compass between [them], and get the bearings of the nearest Federal vessel as she took her position for the night. [They] would ship up the torpedo on the boom, and, when dark, go out, steering for the ship [they] had marked” (Alexander 1903:748). The crew soon discovered that it was necessary to leave the island during the ebb tide and time their return for peak flood tide. On several occasions, the submarine came so close to U.S. Navy patrol boats operating in the area that they could hear the picket boat crews “talking and singing” (Alexander 1903:748). Occasionally, the tiny vessel and its exhausted crew would not return to Sullivan’s Island until sunrise. During a typical cruise, the submariners “would proceed until the condition of the men, the sea, the tide, the moon, the wind, or the approach of daylight compelled [their] return to the dock. Then [they] would unship the torpedo, put it under guard at Battery Marshall, walk back to quarters at Mount Pleasant, and cook breakfast” (Alexander 1903:748).

Dixon and Alexander were very concerned that the submarine and its crew might be caught at sea during the daylight return to Breach Inlet. Consequently, both men arranged a somewhat unorthodox (and dangerous)



Figure 2.20. Map showing the route from Mount Pleasant (upper left) to Battery Marshall and Breach Inlet (right). (Detail from USCS 1865)



Figure 2.21. View from Fort Moultrie on Sullivan's Island, looking east. Dixon and his men would have passed by here on the way to take Hunley out to sea. (Courtesy of NARA, RG 94, Quincy Adams Gillmore papers)

described.' We soon had the boat to the surface and the manhead opened. Fresh air! What an experience! (Alexander 1902a)

Dixon drilled the new crew throughout November; by mid-December he received orders to engage the enemy as soon as practicable. By the beginning of 1864, the intrepid submariners were conducting missions an average of four nights per week, and covering a distance between six and seven miles (9.66–11.27 km) per excursion (Alexander 1902a). However, strong winds and high seas prevented the boat from venturing far from shore throughout January. Consequently, no Federal vessels were engaged during this time. Dixon's feelings of frustration about not being able to effect an

experiment. Under controlled conditions in Back Bay, the crew would submerge *Hunley* and determine the length of time it could remain under water before their air supply was depleted:

It was agreed to by all hands to sink and let the boat rest on the bottom, in the Back bay, off Battery Marshall, each man to make equal physical exertion in turning the propeller. It was also agreed that if anyone in the boat felt that he must come to the surface for air, and he gave the word 'up,' we would at once bring the boat to the surface.

... Dixon and myself and several of the crew compared watches, noted the time and sank for the test. In twenty-five minutes after I had closed the after manhead and excluded the outer air the candle would not burn. ... Each man had determined that he would not be the first to say 'up!' Not a word was said, except the occasional, 'How is it,' between Dixon and myself, until it was as the voice of one man, the word 'up' came from all. ... We started the pumps. Dixon's worked all right, but I soon realized that my pump was not throwing. From experience I guessed the cause of the failure, took off the cap of the pump, lifted the valve, and drew out some seaweed that had choked it.

During the time to do this, the boat was considerably by the stern. Thick darkness prevailed. All hands had already endured what they thought was the utmost limit. Some of the crew almost lost control of themselves. It was a terrible few minutes, 'better imagined than

attack during this period were expressed in a letter to Henry Willey:

I suppose that you think strange that I have not done any thing here yet, but if I could tell you all of the circumstances that have occurred since I came here you would not think strange of my not having done any execution as yet. But it would take considerable paper and time to relate them to you at present so I will postpone relating them until I see you. But there is one thing very evident and that is to catch the Atlantic Ocean smooth during the winter months is considerable of an undertaking and one that I never wish to undertake again. Especially when all parties interested at sitting at home and wondering and criticizing all of my actions and saying why don't he do something. if I have not done any thing "God Knows" it is not because I have not worked hard enough to do some thing. And I shall keep trying until I do some thing. I have been out-side several times but for various reasons I have not yet met with success. I am out-side every night in a small boat so that there is not a possible for any good night to pass with out my being able to take advantage of it. I have my boat lying between Sullivan's and Long Islands and think that when the night does come that I will surprise the Yankees completely. The Fleet offshore have drawings of the sub-marine and of course they have taken all precautions that it is possible for Yankee ingenuity to invent, but I hope to Flank them yet. (Dixon 1864)

The tight-knit crew's morale was shaken on 5 February 1864, when William Alexander received orders to return to Mobile and construct a breech-loading cannon for the Confederate army. According to Alexander, "This was a terrible blow, both to Dixon and myself, after we had gone through so much together. General Jordon told Dixon he would get two men to take my place from the German Artillery, but that I was wanted in Mobile" (Alexander 1902a). Alexander departed for Mobile the same day. To date, only Corporal Carlsen has been identified as a volunteer from this unit.

While Lieutenant Dixon introduced and integrated Alexander's replacement(s) and waited for January's foul weather to abate, the Federal fleet was gathering information about Confederate submersibles and preparing for an imminent attack. As mentioned above, the depositions of the Confederate deserters—George L. Shipp (ORN 1.15:229–33) and another individual identified only by the surname "Belton" (ORN 1.15:227)—were recorded aboard the Flag Steamer *Philadelphia* on 7 January 1864. According to Belton's testimony, he had worked in the machine shop in Mobile where the boat "American Diver" was built and saw it "in all stages of construction" (ORN 1.15:229). He was later conscripted into the Confederate navy and assigned to a vessel in Charleston. He claimed to have been stationed aboard the receiving ship *CSS Indian Chief*, where he interacted with several of the submarine's crewmen and personally witnessed practice dives under *Indian Chief* and *CSS Charleston* on a number of occasions. In his statement, George Shipp also claimed that he observed "American Diver" make several practice dives under ships in Charleston Harbor, and recounted the removal of the bodies of Horace Hunley and the second crew from the submarine in October 1863 (ORN 1.15:231).

On 7 January 1864, Rear Admiral John A. Dahlgren, Commander of the South Atlantic Blockading Squadron, received a transcription of Belton and Shipp's testimony from their interrogation officer. The same day, he issued the following orders to the blockade fleet:

I have reliable information that the rebels have two torpedo boats ready for service, which may be expected on the first night when the water is suitable for their movement. One of these is the 'David,' which attacked the *Ironsides* in October. . . .

There is also one of another kind, which is nearly submerged and can be entirely so. It is intended to go under the bottoms of vessels and there operate.

This is believed by my informant to be sure of well working, though from bad management it has hitherto met with accidents, and was lying off Mount Pleasant two nights since.

There being every reason to expect a visit from some or all of these torpedoes, the greatest vigilance will be needed to guard against them.

The ironclads must have their fenders rigged out and their own boats in motion about them.

A netting must also be dropped overboard from the ends of the fenders, kept down with shot, and extending along the whole length of the sides; howitzers loaded with canister on the decks and a calcium for each monitor. The tugs and picket boats must be incessantly upon the lookout, when the water is not rough, whether the weather is clear or rainy. (ORN 1.15:226–227)

Hunley's Final Mission

Toward the middle of February 1864, the weather began to moderate. Shortly thereafter, Dixon and the submarine crew initiated a new series of nighttime sorties from Breach Inlet. Just before sundown on Wednesday, 17 February 1864, Dixon presumably obtained bearings for nearby blockaders (as he had with William Alexander) and selected the nearest target. The logbook of the nearby *USS Canandaigua* captured the relative positions the blockading ships moored off Sullivan's Island that evening: "February 17, 1864—Bearings of vessels at sundown: *Wabash*, S. $\frac{3}{4}$ E.; *Mary Sanford*, N.N.E.; *Housatonic*, N.N.E. $\frac{3}{4}$ E.; *Paul Jones*, N.N.E." (ORN 1.15:332). Although it is difficult to ascertain exactly where each vessel in the fleet was positioned, the bearings provide an approximation of their overall formation. The squadron formed an "L," with *Canandaigua* comprising the apex of the right angle. *Housatonic*, *Mary Sanford* and *Paul Jones* were positioned in a line to the northeast of *Canandaigua*; *Wabash* was to the southeast and located farther out to sea.

As the sun set at 6:07 P.M., the moon emerged high in the evening sky. The moon was waxing and approximately 79% of its visible surface was illuminated (USNO, n.d.). Winds were reportedly out of the northwest at 7 to 16 knots, the sea was calm, and the sky clear. At sunset the air temperature was 44°F (6.67°C); the tide was ebbing to the southwest at approximately 1 to 3 knots (DON 1863–64, 1864a). Dixon probably would have preferred to attack on a moonless night, but realized that the propitious weather might not last long enough for another attempt. As the submarine was propelled toward the nearest blockade vessel, its crew may have contemplated which vessel they were attacking, and whether this mission, like so many before it, would end before they could carry out a successful

engagement. On that particular night, however, the crew of *Hunley* managed to avoid federal picket boats and propel their tiny craft within striking distance of the nearest blockader, USS *Housatonic* (Figure 2.22).

The steam sloop-of-war *Housatonic* was launched at the Charlestown Navy Yard on 20 November 1861. It had an overall length of 207 ft. (63.09 m), a depth of hold of 16 ft. 10 in. (5.13 m), and a maximum beam of 38 ft. (11.58 m). Its maximum displacement was 1,240 tn. (1,126 t). When fully loaded, *Housatonic* drew 7 ft. 7 in. (2.31 m) at the bow and 9 ft. 7 in. (2.92 m) at the stern. The warship's single four-bladed propeller was powered by two horizontal 42 in. (1.07 m) Isherwood direct-acting steam engines. It was armed with a single 100-pounder Parrott rifle, three 30-pounder Parrott rifles, one XI-inch Dahlgren smoothbore cannon, two 32-pounder smoothbores, two 24-pounder Howitzers, one 12-pounder Howitzer and one 12-pounder rifle. Two additional 32-pounder smoothbores were added to its complement of armament in 1863 (ORN 2.1:104).

The Commander of *Housatonic*, Captain Charles Whipple Pickering, was born in Portsmouth, New Hampshire, on 23 December 1815. He was appointed midshipman on 1 May 1822, when he was only six years old (Marvel 1996:12). He was promoted to lieutenant and attached to the U.S. Navy's Pacific Squadron on 8 December 1838. He served as executive officer of USS *Cyane* and was present at the bombardment of Greytown, Nicaragua, in 1854. On 14 September 1855, he was promoted to commander, and from 1859 to 1861 was stationed near Key West, Florida. He advanced to the rank of captain on 15 July 1862, and commanded the warship USS *Kearsarge* in the Mediterranean and West Indies. While under Pickering's command, *Kearsarge* failed to engage a single Confederate warship. His inability to intercept enemy ships on

the high seas prompted Secretary Welles to transfer him to the South Atlantic Blockading Squadron. It was during this assignment—in spring 1863—that he was given command of *Housatonic*.

Aside from periodic instances when the fleet would fire on enemy coastal fortifications or give chase to blockade-runners, blockade duty for Union sailors was largely uneventful. Dahlgren's message warning the fleet of an imminent attack by one or more enemy torpedo boats changed the attitude of most blockader crews from malaise to one of excitement and/or anxiety. Some individuals serving aboard Union vessels prepared for the worst. Acting Master Joseph W. Congdon recounted:

As our information concerning their plans was very reliable, we naturally expected to go skyward sooner or later. With that in view, we concluded that if it were a possible thing, we would take our valuables with us on the journey. So before turning in each night, each one of us officers would attach a line to our valuables and lead the line up through the hatch on deck, making it fast and handy so that when the time did come for us to leave, we could clutch our lines, haul up our valuables and take them along with us just as easily as rolling off a log. (*Historic Nantucket* 1980:28–29)

Pickering obeyed Dahlgren's instructions to the letter and took extra precautions to protect his ship against a potential submarine attack. As night fell, Pickering ordered hammock netting to be deployed around *Housatonic's* hull below the waterline as a measure to foil subsurface attacks. He also ensured that the vessel could quickly slip its moorings and



Figure 2.22. Wash drawing of the United States Sloop-of-War *Housatonic* by R. G. Skerrett (1908). (NHHC Photo Archives #NH 53573)

initiate evasive maneuvers in the event of an enemy assault. A small detachment of sailors was placed near the shackle holding the anchor chain. The anchor shackle was fitted with a wooden pin so it could be easily discarded, and the ship's engines were set in reverse. Additionally, the stokers in the boiler room maintained a steady head of 25 lb.⁴ (11.34 kg) of steam in the boilers between 6 A.M. and 6 P.M. so that the engines could be started immediately. Pickering also ordered *Housatonic's* crew to maintain a vigilant watch at all times.

The night of 17 February was clear and frigid. "It was a cold night, just making ice," according to Congdon (*Historic Nantucket* 1980:30). That evening, six armed lookouts were positioned around the perimeter of the ship. Four men were assigned to slip the anchor chain on the fore-castle and an additional man was positioned near the alarm gong in the stern of the ship. The forward watch consisted of two armed sentries (one at each cathead) and the four men assigned to the anchor chain. Acting Master's Mate Louis A. Cornthwait supervised this group. The stern watch was commanded by Quartermaster James Timmons and consisted of a pair of sentries posted on the quarterdeck. The third pair of armed guards was posted on the gangway amidships and was supervised by the watch commander or Officer of the Deck. The Officer of the Deck, Acting Master John Keyes Crosby, was positioned on the bridge. *Housatonic's* bridge was an elevated catwalk just forward of the vessel's smokestack. From this elevated position, Crosby could maintain contact with the fore and aft watches as well as the two lookouts on the gangway. Each lookout was armed with a rifled musket and all were prepared to fire on any unfriendly vessel that approached the ship. Additional personnel were assigned to the ship's battery (guns). On the night that *Housatonic* was attacked, Crosby recalls that "[t]he battery was all cast loose . . . with side tackles hooked in the fighting bolts . . . [and] the balance of the watch [number unknown] were at the guns armed as at quarters" (DON 1864a:0499). The sole task of the man stationed at the ship's gong was to sound the alarm and fire rockets should the order be given.

Crosby began his watch at 8:00 P.M. The sea was calm, the sky was clear, and a light cold breeze blew from the northwest. He recounts that "the weather was clear, very bright moonlight" (DON 1864a:0501). Archival sources indicate that the first person to spot the approaching submarine was a young African American landsman named Robert F. Flemming. Flemming was posted on the starboard bow and recalled seeing something unusual just prior to the attack:

I saw something approaching the ship broad off the starboard bow, about two ship's lengths off, and reported it to the Officer of the fore-castle. He told me it was a log. I then told him this was not floating with the tide as a log would, but moving across the tide. He still thought it was a log so I called the lookout from the Port side [Landsman C. P. Slade] to see what it was. When the Officer of the fore-castle saw this other lookout coming over he looked at the object through his glasses and then ran aft. (DON 1864a:0544–0545)

The officer that Flemming refers to, Acting Master's Mate Lewis A. Cornthwait, reported:

[At] about 8:45 P.M. the lookout on the starboard cathead reported something adrift on the water, about two points on the starboard bow, and 100 yards [91.44 m] distant. I then made it out with my glasses and it looked to me like a log with two lumps as large as XV inch shell boxes on it, about ten feet apart. There was a break of the water forward, and aft and between these two lumps. As soon as I saw it, I ran aft and reported it to the Officer of the Deck, who was on the bridge, and his glass turned in the direction of this object. (DON 1864a:0524)

At almost the same moment, Crosby raised his glass and reported seeing "something on the water, which at first looked to me like a porpoise, coming up to the surface to blow. It was about 75 to 100 yards [68.58–91.44 m] from us on our starboard beam, the ship heading N.W. by W. ½ W. at the time" (DON 1864a:0491–0492). Uncertain of the object's identity, Crosby summoned Timmons to the stern and asked if he could see it. Timmons looked in the direction indicated by Crosby but claimed that all he could see was a tide ripple on the water. Moments later, *Hunley* turned toward *Housatonic* and increased speed. Crosby raised his glass a second time and noticed that the submarine "was coming towards the ship very fast. I gave orders to beat to Quarters, slip the chain and back the engine" (DON 1864a:0493). Within moments, the ship's gong was sounded and the anchor chain was slipped.

Housatonic's cooper, George Kelly, was on the fore-castle as *Hunley* approached the warship: "I saw something on the water looking like a capsized boat . . . about three points on the starboard bow, about 75 yards [68.58 m] distant, moving astern nearly parallel with the keel" (DON 1864a:0558). As Quarters were sounded, Kelly moved aft toward his assigned position at the aft pivot gun. When Kelly arrived at his station at

4 This measurement is not the same as pounds per square inch; steam is measured in pounds of water used to make the equivalent amount of steam, hence a pound of steam is equal to a pound of water.

the forward end of the gun's starboard port, he "saw this object again, about fifteen yards [13.72 m] from the ship, making a sort of circle towards the starboard quarter" (DON 1864a:0559). Immediately after the alarm was sounded, *Housatonic's* Executive Officer, Lieutenant L. J. Higginson, arrived on the bridge and questioned Crosby. Pickering soon followed Higginson to the bridge and repeated the order to slip the chain and back the engine. He also gave the order to open fire on the object.

With the captain on the bridge, Crosby departed and went forward to make sure *Housatonic's* anchor chain had been slipped. Higginson moved aft to the sentry positioned on the starboard quarter. He later recounted, "I... saw something resembling a plank moving towards the ship at a rate of 3 or 4 knots; it came close alongside, a little forward of the mizzen mast on the starboard side. It then stopped, and appeared to move off slowly" (DON 1864a:0530). The sentry, Landsman John Saunders, had tried to shoot at the submarine twice but his rifle had misfired both times. Higginson grabbed Saunders' musket, took his place on the horseblock, quickly re-primed the weapon, and fired as the submarine started to move away. He was not the only person firing at *Hunley* with small arms during the attack. As the submarine moved away from *Housatonic*, Congdon claimed: "I discovered this Wild Cat and immediately opened fire from my revolver, but did not have the opportunity of using all the chambers" (*Historic Nantucket* 1980:30).

As members of *Housatonic's* crew discharged small arms at the submarine, Pickering made his way from the bridge towards the stern; en route, he procured his double-barreled shotgun from the ship's clerk, Charles O. Muzzey. Pickering quickly assumed Higginson's position on the horseblock along the starboard quarter rail and fired his weapon. He then stepped down and moved to the port side of the mizzenmast, where he issued additional commands to the engine room (DON 1864a:0580).

Seconds later, *Hunley's* torpedo exploded. The effect of the black powder charge on *Housatonic's* hull and crew was immediate and catastrophic. According to Congdon:

The explosion was terrific, tearing a hole in the side of the ship large enough to drive a horse and cart through. I was raised several feet skyward but came down unharmed and somewhat bewildered, expecting of course that our magazine, containing some 5 ton [4.54 t] of powder would explode and that would end the affair. Fortunately for us, it did not. (*Historic Nantucket* 1980:29)

Crosby later recounted, "The explosion started me off my feet, as if the ship had struck hard on the bottom.

I saw fragments of wreck going up into the air. I saw no column of water thrown up, no smoke and no flame" (DON 1864a:0501).

When the torpedo detonated, *Housatonic's* engine was engaged but had not yet established enough momentum to move the vessel away from its mooring. According to Third Assistant Engineer James W. Holihan, the explosion disabled the engine:

I heard the gong beat for Quarters, and gave orders to have everything ready for starting the engine. Immediately three bells were struck, and I gave orders to open the stop valves and back the engine. The engine had made about ten or twelve revolutions, at the rate of about thirty per minute, before I heard the crashing of timbers... I was standing by the throttle valve and was staggered by the shock, and the engine commenced turning so rapidly I closed the throttle valve, supposing some part of the machinery had given way. (DON 1864a:0549–0550)

Housatonic's gun crews were also unable to respond effectively during the attack. Although all of the ship's cannon were armed and ready to fire when the attack occurred, the gun crews could not bring their weapons to bear on a target so close to the ship. Ensign Charles H. Craven was below decks when the alarm was sounded. Craven commanded the ship's starboard battery of four 32-pounder guns. He immediately made his way topside when he heard the call to quarters. As he rushed to his post he spotted the submarine approaching *Housatonic* from a distance of approximately 30 ft. [9.14 m]. Craven fired three shots from his revolver before he reached his post. Craven later testified that he:

Tried, with the Captain of No. 6 gun to train it on this object...; I had nearly succeeded, and was about to pull the lock string when the explosion took place. I was jarred and thrown back on the topsail sheet bits, which caused me to pull the lock string and the hammer fell on the primer but without sufficient force to explode it. I replaced the primer and was trying to catch sight of the object in order to train the gun again upon it, when I found the water was ankle deep on deck by the main mast. I then went and assisted in clearing away the 2nd Launch. (DON 1864a:0505–0506)

Nearly every man aboard was thrown to the deck by the force of the explosion. However, those on the quarterdeck fared much worse. Muzzey, and four others

were killed in the explosion. Pickering himself was badly injured: "I...was blown into the air the next instant from where I stood on the Port side abreast of the mizzen mast. I found myself in the water, about where I stood previous to the explosion, amongst broken timbers, the debris of panel work, and planking. I succeeded in getting into the mizzen rigging, very much bruised" (DON 1864a:0581).

Most of the remaining crew followed their captain's example and scrambled into the ship's rigging as the vessel sank. One minute after the explosion, *Housatonic's* stern touched bottom. The crew frantically attempted to free the vessel's remaining lifeboats as its bow slipped beneath the water. As *Housatonic* sank, it listed hard to port, swamping two of the lifeboats before they could be freed from their davits and sending several crewmen into the icy water. Because the ship sank in only 28 ft. (8.53 m) of water, "the sheepholes of the lower rigging at the waters edge" were accessible to crewmembers—a fortunate circumstance that probably saved several lives (*Historic Nantucket* 1980:30). Congdon describes the turmoil that ensued as *Housatonic* sank: "When the water reached the furnace fires, it made a roar even worse than the explosion, so that nearly everyone was overboard for a while . . . Some of the crew in the excitement had divested themselves of their wearing apparel and started to swim somewhere. When they discovered that our masts offered a place of refuge, they swam back to the rigging and posed as Living Pictures in their primitive state...." (*Historic Nantucket* 1980:30).

Two of *Housatonic's* launches were successfully deployed before the vessel sank. The first of these headed for USS *Canandaigua*, which was the nearest friendly ship and clearly visible from *Housatonic*. The second launch, commanded by Crosby, remained behind to assist men who had gone into the water. Once this task was completed, Crosby rescued Pickering from the mizzen rigging and then made for *Canandaigua*. That ship's logbook records the events that followed:

At 9:20 p.m. discovered a boat pulling toward us. Hailed her and found her to be from the *Housatonic*. She reported the *Housatonic* sunk by a torpedo. Immediately slipped our chain and started for the scene of danger, with the *Housatonic's* boat in tow. At the same time sent up three rockets.... At 9:30 p.m. picked up another boat from the *Housatonic*, with Captain Pickering on board. At 9:35 arrived at the *Housatonic* and found her sunk. (ORN 1.15:332)

Meanwhile, the survivors of *Housatonic's* sinking waited anxiously in the rigging for *Canandaigua* to rescue them. Fleming, the young seaman who initially

spotted *Hunley*, later claimed to have observed a flash of light just as *Canandaigua* arrived: "When the 'Canandaigua' got astern, and lying athwart of the 'Housatonic', about four ship's lengths off, while I was in the fore-rigging, I saw a blue light on the water just ahead of the 'Canandaigua', and on the starboard quarter of the 'Housatonic'" (DON 1864a:0546–0547).⁵

Captain Joseph F. Green, commander of *Canandaigua*, dispatched his ship's launches and ordered the removal of *Housatonic's* surviving crew from the rigging. The following excerpt from *Canandaigua's* logbook describes the rescue effort and its results: "at 9:35, discovered her sunk with her hammock nettings underwater; dispatched all boats and rescued from the wreck 21 officers and 129 men. There are missing, and supposed to be drowned, the following-named officers and men: Ensign Edward C. Hazeltine, Captain's Clerk Charles O. Muzzey, Quartermaster John Williams, Second-Class Fireman John Walsh, Landsman Theodore Parker" (ORN 1.15:328).

In the aftermath of its engagement with *Housatonic*, *Hunley* earned distinction as the first submarine to sink an enemy ship in combat. However, its victory was short-lived. Dixon and his crew failed to return to Sullivan's Island. Federal forces were enraged by the loss of *Housatonic*, as evidenced by the average rate of artillery fire into Charleston, which increased five-fold within 24 hours of the attack. Colonel Laurence M. Keitt, Commanding Officer of Sullivan's Island, recorded the number and frequency of Federal ordnance directed at the city between 10 February and 20 February 1864:

Feb. 10, "nothing"
 Feb. 11, "15 shots fired at City"
 Feb. 12, "4 shell thrown in City by Enemy"
 Feb. 13, no federal activity listed
 Feb. 14, "3 at City by Enemy"
 Feb. 15, "2 shells fired at Sull. Isl."
 Feb. 16, "Nothing"
 Feb. 17, "13 shell fired at City"
 Feb. 18, "86 shot fired at City by Enemy"
 Feb. 19, "94 shots fired by enemy at the City"
 Feb. 20, "106 shots fired at City"

(Keitt 1864)

The blockade fleet was shocked by the sudden turn of events. Dahlgren sent the following dispatch to

⁵ While blue, red, green, and white lanterns were a standard part of night signaling, they were distinct from "blue lights," which were bright, chemically-produced signals, generally burning in a wooden cup with a handle, used by both Union and Confederate forces in this period (Jenkins 1861:159–60). It is impossible to know if Fleming was referring to a blue light type signal or a fainter light with a blue tint, as he would have used the same phrasing in each case.

Secretary Welles two days after the attack: "The Department will readily perceive the consequences likely to result from this event; the whole line of blockade will be infested with these cheap, convenient, and formidable defenses, and we must guard every point" (ORN 1.15:329). He went on to suggest that Welles supply the blockade fleet with its own fleet of submersibles: "I am inclined to the belief that in addition to the various devices for keeping the torpedoes from the vessels, an effectual preventive may be found in the use of similar contrivances. I would therefore request that a number of torpedo boats be made and sent here with dispatch" (ORN 1.15:329). Dahlgren's desire to learn more about Confederate submersibles is apparent in the closing sentence of his letter to Welles: "I desire to suggest to the Department the policy of offering a large reward of prize money for the capture or destruction of a 'David;' I should say not less than \$20,000 or \$30,000 for each. They are worth more than that to us" (ORN 1.15:330).

The Confederate garrison at Breach Inlet reported witnessing a signal from *Hunley* the night of the attack. It is possible that these men saw the same blue light reportedly observed by Flemming from *Housatonic's* rigging, or perhaps the rockets fired from *Canandaigua*. Convinced that the light was a signal from the submarine, they answered it and awaited the tiny vessel's return. Two days later, there was still no sign of Dixon and his crew. Battery Marshall's garrison commander, Lieutenant Colonel O. M. Dantzer, thinking that the submarine might have drifted north, waited until 19 February before filing the following report:

LIEUTENANT: I have the honor to report that the torpedo boat stationed at this post went out on the night of the 17th instant (Wednesday) and has not yet returned. The signals agreed upon to be given in case the boat wished a light to be exposed at this post as a guide for its return were observed and answered. (ORN 1.15:335)

Confederate authorities in Charleston anxiously awaited news of the missing submarine and its crew. However, after another week passed, hope diminished for the vessel's safe return. It was unclear whether *Hunley* had been captured or lost at sea. It was difficult to even verify whether the submarine had successfully accomplished its mission. News of the attack finally reached Charleston on 27 February. The crew of a Federal picket boat captured the previous evening related the story of the destruction of *Housatonic* to their captors. On 29 February 1864, an article in the *Charleston Mercury* described the loss of the Union blockade ship:

An official dispatch was received from Colonel ELLIOT at Fort Sumter, on Saturday, conveying the gratifying news that one of our picket boats, commanded by boatswain SMITH, had captured a Yankee picket boat containing one officer and five men. The prisoners have arrived in the city. Their accounts of the success of the pioneer of our fleet torpedo boats are really exhilarating. They state that the vessel sunk off the harbor on the night of the 16th, and reported lost in a gale, was the U.S. steamer *Housatonic*, carrying 12 guns and three hundred men, and that she was blown up by our torpedo boat.

... As a practical and important result of this splendid achievement, the prisoners state that all the wooden vessels of the blockading squadron now go far out to sea every night, being afraid of the risk of riding at anchor in any portion of the outer harbor.

An article printed in the *Charleston Daily Courier* the same day added: "This glorious success of our little torpedo boat, under the command of Lieut. Dixon, of Mobile, has raised the hopes of our people, and the most sanguine expectations are now entertained of our being able to raise the siege in a way little dreamed of by the enemy."

Eventually, the Confederates learned that, in addition to destroying *Housatonic*, the crew of *Hunley* avoided capture after the attack. Despite these good tidings, Dixon and the other members of the submarine's crew never returned to tell their tale. Ultimately, the optimism expressed by the *Charleston Daily Courier* was short-lived, as Federal forces advanced throughout the South during 1864 and ultimately defeated the Confederacy. After *Housatonic's* loss, the blockade fleet stationed off Charleston was never successfully challenged by rebel torpedo boats again. The siege of Charleston was never lifted, the blockade was never broken, and on 17 February 1865, precisely one year after *Hunley's* successful attack, General Beauregard abandoned the city (ORN 1.16:369).

The fate of the submarine and its crew of pioneering submariners was the subject of debate and conjecture for years after the vessel's disappearance. Theories abounded: some speculated that it was mortally damaged by the attack and perished with *Housatonic*; others hypothesized that the vessel and its crew were swept out to sea during a gale that arose shortly after the engagement. Although many individuals and institutions searched for the tiny pioneering vessel, *H. L. Hunley's* final resting place would not be discovered for 131 years.

3. Environmental Context

M. Scott Harris and Robert S. Neyland

The marine environment encompassing the *H. L. Hunley* site underwent several transformations over the course of 14 decades as a result of the interactions of geological, physical, chemical, and biological processes. While the wreck eventually stabilized after its burial beneath the seafloor, reconstructing how that came about provides important information for archaeological interpretation and conservation planning. To completely understand *Hunley's* overall context, including artifact distribution and level of preservation, it is critical to interpret the complexities of site formation processes and their variability through time. The site developed over five critical phases: 1) the span of time prior to the submarine's deposition on the seafloor; 2) a

period of complete exposure of the sunken hull within the water column; 3) the burial process; 4) complete encapsulation of the submarine within the seabed; and 5) excavation and recovery.

Data acquired during the *H. L. Hunley* and *USS Housatonic* surveys in 1996, 1998, and 2000 have all contributed to the environmental analysis (Murphy 1998; Hansen et al. 2000; Conlin 2005). Research also included analysis of archival data for tides and currents, historic charts, geophysical remote sensing, and sediment coring, as well as visual observations made by project staff. Natural and anthropogenic alterations to the coastal zone—and the nearly infinite number of variables associated with them—played an important



Figure 3.1. The *Hunley* site was located approximately 4 nautical miles (7.4 km) from the entrance to Charleston Harbor. Barrier islands are a significant feature of this part of the North American Atlantic coast. (Basemap from Esri et al., annotated by H. G. Brown, NHHC.)

role in the development of site conditions prior to, during, and after the submarine sank. Analysis of these alterations provides insight into the physical site and the assemblage of materials and artifacts associated with it.

The *Hunley* wreck site was discovered approximately 4 nautical miles (7.4 km) ESE of the entrance to Charleston Harbor at a depth of 8–10 m (26.25–32.81 ft.), depending on the tide, and buried beneath roughly 1 m (3.28 ft.) of sediment (Figure 3.1). The geology in the area is composed of a shallow, heterogeneous substrate resulting from a complex heritage. It was influenced by the availability and distribution of sediments within the marine system, long- and short-term sedimentary evolutions of the area, and the deposition and burial of the submarine itself. Building on an understanding of the site context for both *Hunley* and *Housatonic* provided by prior studies, a preliminary model of site formation was developed by considering the regional physiography, including the local barrier island systems, geological framework, and the impact of biological processes and human alterations to the environment.

Regional Background

Physiography

The modern coastline in and around the Charleston area separates two distinct physiographic provinces: the lower coastal plain and inner continental shelf. The lower coastal plain, known locally as South Carolina's Lowcountry, is a low and terraced region that originates 20 km (12.43 mi.) inland and drops in elevation from approximately 9 m (29.53 ft.) above mean sea level (MSL) to sea level at the coast. The emergent marine and estuarine terraces that characterize this zone were formed in response to successively lowered sea levels and repeated transgressions tied to glacial and interglacial periods throughout the Pleistocene Epoch (ca. 2.6 million to 11,700 BP). Due to ancient drainage patterns along the South Carolina lower coastal plain, the presence of terraces and poor drainage associated with this region, and the number of local sea-level changes, rivers are restricted almost entirely to Coastal Plain areas and are characterized by low annual discharge. This form of drainage reduces average annual river discharge to amounts significantly less than that commonly associated with larger

regional drainage systems. These larger systems are associated with rivers that originate in the Sand Hills, Piedmont, Blue Ridge, or Appalachian mountain chains. Rivers that empty into Charleston Harbor and its associated estuaries drain only the lower and middle coastal plains; consequently, freshwater discharge to the upper reaches of the estuaries is limited and seaward-reaching river delta formation is effectively eliminated. A small amount of freshwater discharge originates through aquifers, and surface recharge is likely on the barrier islands and along nearshore sections of the inner continental shelf. Currently, the Cooper River discharges into Charleston Harbor 151 m³/s (Hughes 1994); by contrast, the Santee River to the north of Charleston Harbor and North Edisto River to the south have annual river discharges of 323 m³/s and 74 m³/s, respectively.

Major regional physiographic features within the immediate vicinity of the *Hunley* site include active barrier islands, wide estuaries, Charleston Harbor, and a series of small inshore inlets (Figure 3.2). Moderate wave energy and mesotidal tide range (approximately 2 m [6.56 ft.]) around Charleston Harbor has, over time, influenced the development of an abundance of deep inlets and a large, protected harbor within the barrier island system.

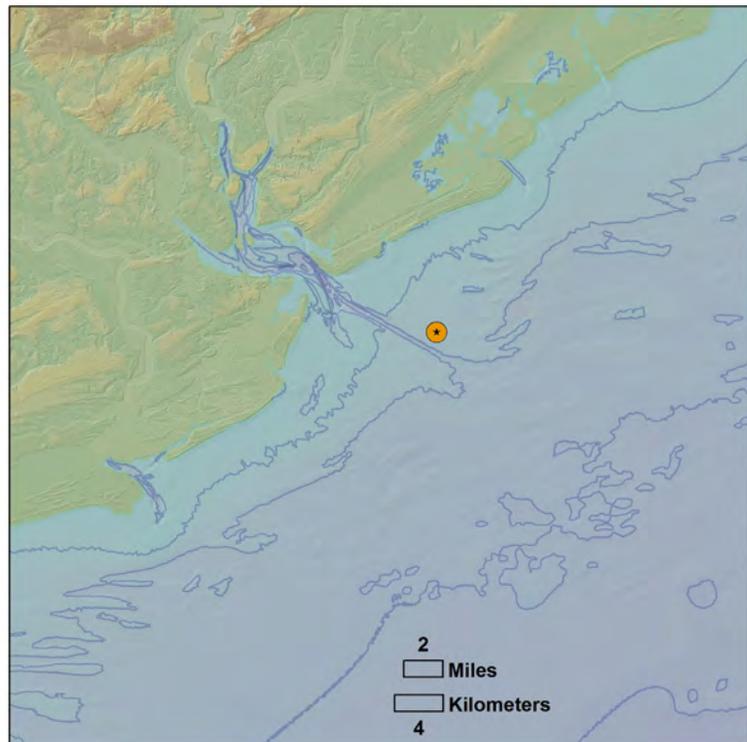


Figure 3.2. Regional physiography of the area surrounding *Hunley*. The lower coastal plain and modern coastal environments are being submerged as the inner continental shelf expands to the northwest during sea level rise. The ancient deposits extending beneath the shoreline are exposed in the areas around the site (denoted with orange dot). (M. Scott Harris)

Five km (3.11 mi.) offshore, the active shoreface gently dips to a depth of approximately 8 m (26.25 ft.) below sea level; between 6 and 8 km (3.79–4.97 mi.) from shore, the seabed steps down again to approximately 10 m (32.81 ft.) below sea level. Seabed ridges attached to the shoreface are common to the north and south of the site, particularly off Folly Island and Isle of Palms. Along the approximate 8 m (26.25 ft.) water depth contour, shoreface-attached ridges are not present and major seafloor features are largely oriented parallel to shore. Channel throats extend from the barrier islands straddling the shoreface inlets for a distance of approximately 1 to 2 km (0.62–1.24 mi.). Associated ebb-tidal deltas extend offshore for a distance of 1 to 5 km (0.6–3.11 mi.); these features create large masses of sediment that accumulate along the continental shelf.

Harbor Entrance Changes

Prior to the 1880s, Charleston Harbor’s entrance was a difficult and circuitous path for ships to negotiate when entering or leaving port. At the time, the harbor’s large ebb-tidal shoals and delta extended approximately 3 km (1.86 mi.) offshore, at which point they were forced south due to predominant longshore currents. Thus the primary entrance to the harbor developed well south of Morris Island (Figure 3.3). To improve navigation into the harbor, a pair of stone jetties was constructed between 1877 and 1895 (Moore 1981:32–36).

The harbor entrance was thereby confined to a channel that extended directly offshore from the deepest portions of the harbor, resulting in a channel that extends to the southeast roughly 3 mi. (4.83 km)

to an offshore water depth of approximately 14 m (45.93 ft.). As current and wave patterns shifted around this new obstruction, the harbor’s sediment discharge and accumulation shifted north to a zone directly offshore from the harbor entrance.

Barrier Island Systems

The present day coastline is dissected by a series of inlets that separate classic mesotidally-dominated barrier islands (Hayes 1979). Moderate tidal range and moderate to low wave energy has created a series of classic drumstick-shaped barrier island complexes in this region. Backed by expansive salt marsh and tidal creeks, these barrier islands are separated by deep to shallow tidal inlets that, although locked in general position, have active ebb tidal channels that migrate frequently (Harris et al. 2005). The closest inlets to the *Hunley* site are Lighthouse Inlet to the south and Breach Inlet to the north, separated by the entrance to Charleston Harbor (see Figure 3.1). These inlets tend to be relatively shallow when compared to the Stono Inlet and Dewees Inlet systems, both of which are the dominant sandy sediment masses in the region. Marsh systems and shallow lagoons are responsible for retaining and releasing fine-grained sediments to the coastal ocean. Infrequent large-scale discharges from the inland rivers are the only means by which fine-grained sediment is discharged onto the continental shelf. These sediment dynamics influence the outer reaches of the ebb tidal deltas and their associated shorelines. Shoreline changes associated with barrier islands and inlet positions also provide a means by



Figure 3.3. Charleston Bar in 1864 (left) and in 1899 (right). The primary route to access the main shipping channel is indicated with a blue arrow. (Details from USCS 1864 and USCGS 1899)

which sediments are supplied or removed from the barrier islands and coastal systems.

Geologic Framework

The Hunley site is situated on the inner continental shelf, along the western margin of the North Atlantic basin and is underlain by a thick wedge of predominantly marine, fluvial, and paralic (coastal) sediment deposits, which have accumulated since the Jurassic period. Near to the surface, three dominant geologic units underlie this region, all of which are internally heterogeneous and known to crop out in the vicinity of the site (Weems and Lewis 2002; Harris et al. 2005) (Figure 3.4). The seafloor comprises a modern Holocene wedge inshore and exposed Pleistocene mud and sand just offshore. Partially indurated (cemented or lithified) deposits characterize the seabed in depths greater than 12 m (39.37 ft.). Older Tertiary units tend to be composed of semi-consolidated, phosphatic and foraminiferal sands and siltstones that form ledges and expansive hard grounds in water depths greater than 9 m (29.52 ft.) below MSL. Pleistocene units deposited during one of several of the last interglacial periods are often composed of dense sticky mud (often misstated as marl or clay) and sand-filled fluvial and tidal channels. This dense estuarine mud crops out in water depths between approximately 4 to 10 m (13.12–32.81 ft.) below MSL and create a gentle platform or step that extends from beneath the modern offshore barrier island system. The third dominant geologic system is a Holocene sediment wedge that includes modern estuaries, barrier islands, ebb tidal deltas, linear rippled scour depressions, and offshore sand waves (Harris et al. 2005).

Within the immediate vicinity of the site, the dominant geologic strata at or near the seafloor range in age from the Tertiary period to modern (Figure 3.5). Cenozoic deposits, primarily comprising Tertiary, Pleis-

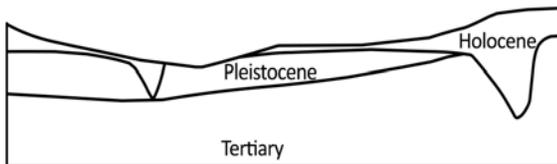


Figure 3.4. A schematic representation of the stratigraphy beneath the site. The near surface units consist of three major depositional units or systems, each being quite heterogeneous in its sedimentological nature. Older Tertiary and Pleistocene deposits commonly crop out at the seafloor in this area, and shell material at the seafloor may be modern or ancient reworked material. (Diagram by M. Scott Harris)

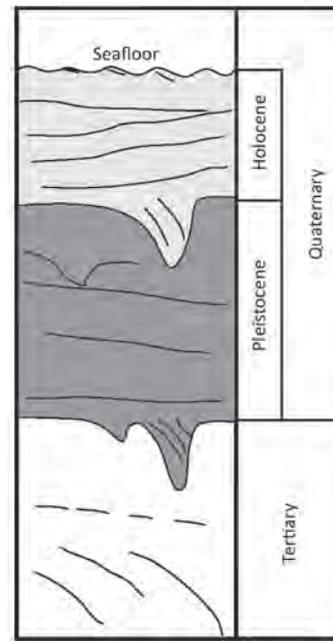


Figure 3.5. A generalized stratigraphic column of the area immediately surrounding the site. The Holocene sediments range from non-existent on the shelf to very thick in ancient paleochannels. (Diagram by M. Scott Harris)

tocene, and Holocene materials, underlie the shallow nearshore continental shelf off Charleston. The older Tertiary strata consist of dense marls, foraminiferal sands and partially consolidated siltstones. These deposits crop out of the seafloor along a zone east of the 10 m (32.81 ft.) isobath. Younger Pleistocene-aged materials overlie the Tertiary deposits in an unconformable layer, and generally crop out of the seafloor between the 3 m (9.84 ft.) isobath (contour located inshore of the site in Figure 3.2) and the 10 m (32.81 ft.) isobaths (contour just east of the site). These Pleistocene deposits consist of unconsolidated sands, shelly sands, and muds created during former transgressive events.

Most of the localized stratigraphic exposures on the seafloor are composed of Cooper Marl (Tertiary), undifferentiated Tertiary shelf deposits, estuarine and marine Pleistocene units, and the modern Holocene sheet and wedge. These exposures are dependent on geologic heritage and modern sediment erosion-deposition patterns. Human intervention on the coastal system caused by construction of the jetties contributed to the creation of a sedimentary mass outside the outlet of the channel.

In the modern Holocene system, sediments generally consist of fine to very fine sands interspersed

with mud and shells, but frequently accumulate in un-conforming sediment combinations in response to varying environmental conditions. Materials at the seafloor, although recently deposited, may contain fossil shell and microfaunal constituents which behave as sediment particles in the modern system, creating a mix of both modern and ancient grains in the same sediment. One study of shell in beach sediment along the Atlantic coast of the United States found that approximately 60% of shell in beach sediment date from the Pleistocene (Wehmiller et al. 1995:326).

Biologic Framework

Biological processes can cause physical and chemical alterations to the environment that can either preserve or destroy cultural materials. Organisms can attach to or encrust the surfaces of artifacts, consume wood and other organics, burrow through and disturb soft overlying sediment, and remove oxygen creating an anaerobic environment. The type of potential biological activity relies on the sediments present, subsurface water flow, the local climate regime, and physical oceanographic processes acting in the area. This biogeochemical system created through the interaction of biological constituents on a system can potentially influence the acidity of a site and the oxygen content of the surrounding materials and hence the state of preservation of cultural materials on the sea floor.

Site-Specific Analysis

Ultimately the state in which the submarine was recovered is related directly to the materials encasing it, the mechanisms that emplaced those materials, and the environmental variables in temperature and chemistry imposed on it through time. In general, elements of the marine environment that have influenced the preservation potential of the hull and its associated artifacts include a variety of physical, chemical, and biological processes. These processes, in conjunction with natural and anthropogenic materials within the marine realm, comprise a series of complex interactions that acted to preserve materials and their respective archaeological contexts.

Conditions at the Time of Sinking

Understanding conditions on the night of the sinking provides an important basis for the interpretation of *Hunley's* resting position and the subsequent processes affecting the site. Wind and tidal current information for the night of 17 February 1864 is difficult to obtain.

Newspapers, during that time, did not publish regular weather reports or tidal information. The best information regarding environmental conditions at the time of the attack comes from USS *Housatonic* crewmembers' accounts and entries made in USS *Canandaigua's* log.

During the court of inquiry concerning the attack, a number of crewmembers testified as to the weather and sea state. While there are some minor discrepancies in the details, the overall picture is one of a clear, cold night with moderate winds.

Acting Master John K. Crosby stated: "The wind was about NW by N; force 3. The tide was setting to N.E., about one knot per hour; the weather was clear, very bright moonlight" (DON 1864a:0501). Similarly, Ensign C. H. Craven recalled: "The sky was clear, with few clouds; little or no sea on; the weather good and the moon and stars shone clearly; a moderate wind from Northward and Westward" (DON 1864a:0512). Acting Master J. W. Congdon testified that "[t]he weather was fine, clear and bright moonlight; the sea was quite smooth; the wind was light and I think it was about N.N.W." (DON 1864a:0521).

General estimates for depth of water at the time of sinking range from 25 to 28 ft. (7.62–8.53 m). Congdon testified about the depth of water at *Housatonic's* anchorage, that "[t]here was about twenty-five feet [7.62 m] at low water, and she sank at about half flood" (DON 1864a:0518). According to Lieutenant F. J. Higginson, "the sea was smooth; wind about N.W. force 2; it was about low water, and there was about 28 feet [8.53 m] of water at her anchorage at low water" (DON 1864a:0537). Captain C. W. Pickering recalled the anchorage to be "26 or 27 feet [7.29 or 8.23 m] at low water; it was a pleasant, moonlight night, with a fresh breeze and very cold; about half ebb tide, and 28 or 29 [8.53 or 8.84 m] feet of water" (DON 1864a:0584).

On 7 March 1864, at the conclusion of the inquiry, the court acknowledged the following facts:

That the U.S. Steamer 'Housatonic' was blown up and sunk . . . at about 9 o'clock P.M., while lying at an anchor in 27 feet [8.23 m] of water off Charleston S.C. . . . The weather at the time of the occurrence was clear, the night bright and moonlight, wind moderate from the Northward and Westward, sea smooth and tide half ebb, the ship's head about W. N. W. (DON 1864a:0588)

A 9:00 P.M. entry in *Canandaigua's* log for the evening of 17 February 1864 states the wind was from the NW at force 4 (DON 1863–4). The air temperature was recorded to be 44° Fahrenheit (6.7°C) at 6:00 P.M.

The wind speed designation "force" refers to the Beaufort Wind Scale developed by Admiral Sir Francis

Beaufort in the early 19th century. The original scale was a qualitative estimate based on the effects of wind acting on the sails, with no quantitative measurement of wind speed. Wind of force 1 was designated as light air with just enough force to give a “well-conditioned man-of-war” steerage. By the Civil War, the Beaufort Wind Scale had been modified to reflect wind speed, with force 1 a wind speed of 1 to 3 knots, force 2 a wind speed of 4 to 6 knots, force 3 a wind speed of 7 to 10 knots, and force 4 a wind speed of 11 to 16 knots.

Housatonic crewmembers reported the wind at the time of the attack as force 2 and force 3. Onboard *Canadaigua*, the six o'clock wind speed entry was force 3 and the nine o'clock entry was force 4. With *Canadaigua* slightly over a mile away from *Housatonic*, one would not expect a significant difference in the wind speed. It appears that the wind speed was building as the evening progressed. Crewmembers onboard *Housatonic* may recall the calmer wind speed of the early evening, before the attack. Given the differing accounts, *Canadaigua's* entry was probably more accurate.

Housatonic crewmember Crosby recalled that the tide was falling to the northeast at about one knot per hour. Additional crewmembers' accounts place the tide somewhere between half ebb and low water. Tide or tidal current data for the precise time of the attack does not survive; however, an 1856 U.S. Coastal Survey chart contains a current rose from a position roughly one mile (1.6 km) west of the site, which shows the first quarter ebb flowing northeast, but the second and third quarter ebb currents turning southeast, the direction of *Hunley's* orientation on the seabed (Figure 3.6). It is possible

that Crosby was mistaken and was recalling the tide from earlier in the evening, prior to the attack. If it was running northeast at the time of the explosion, *Hunley* may have initially drifted in that direction, then been pushed southeast as the current shifted, provided they managed to stay afloat for some time afterward. The final position of *Hunley* almost directly east of *Housatonic* may support this interpretation.

Once on the seabed, the submarine became part of a complex system of physical processes that would both alter it and protect it over the next 14 decades.

Physical Processes

Coastal and estuarine processes influenced by climate are the dominant regional forces that acted on the *Hunley* site. These include coastline tidal exchanges, wave action and movement across the continental shelf, general wind fields, storm history, and sea level rise. Archival sources that record these attributes exist for much of the latter half of the 20th century; however, far fewer data are currently available for the years spanning 1864 to 1940. Consequently, modern analysis and interpretation of the physical geological record recovered from the site complemented or, in some cases, acted as a proxy for data from historical records.

Climate: Temperature and Precipitation

Hunley came to rest in waters located within the humid subtropical region of the western North Atlantic basin. Precipitation and temperature data have been collected for this area (identified as South Carolina Region 7 by NOAA) since 1895 (NOAA 2004). Between 1895 and 2000, the average recorded temperature in this region was 18°C (65°F). Average high and low temperatures ranged from 27°C (81°F) in July to 9°C (48°F) in January. Precipitation amounts averaged 122 cm (48 in.) annually, generally in the form of rainfall. Single-year precipitation amounts ranged between a minimum and maximum of 70 cm (27.56 in.) and 180 cm (70.87 in.), respectively. The Charleston area receives more precipitation during the summer months due to thunderstorms and tropical events (tropical

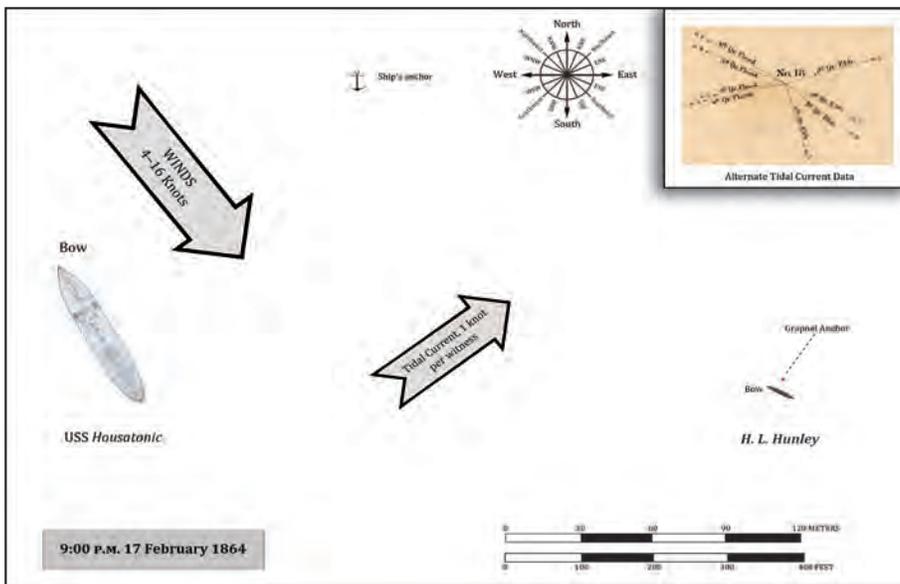


Figure 3.6. The positions of the *Hunley* and *Housatonic* wreck sites are shown in relation to the directions of wind and current at the time of the sinking. (Diagram by Alicia Massey and H. G. Brown; contains detail from USCS 1856)

depressions, tropical storms, and hurricanes). Monthly rainfall amounts peak in March due to the passage of spring fronts. Precipitation affects stream and river flow and hence outgoing tides, sediment transport, and channel erosion. Offshore sedimentation is in part due to increased sediment transport. Changes in channels, either incision or filling, can result in movement of areas where sediment had previously accumulated.

Temperature influences sedimentation through its effects on vegetation growth, as vegetation affects water run-off, river flow, and sediment transport. The dense vegetation of marshes and forests of coastal South Carolina is the product of the warm temperatures and humid climate. Much of the region's rainfall is absorbed prior to it entering the river system. Flood events can result in excessive amounts of sediment transport and offshore deposition.

Winds, Storms & Hurricanes

The Appalachian Mountains have a strong influence on the prevailing surface wind direction. The prevailing winds tend to be either from the northeast or southwest with average surface wind speeds between 6 and 10 m.p.h. (9.66–16.09 kph). Cyclones occurring during the winter months usually pass to the south of the mountains and the winds are generally from the southwest but shifting to the northeast as they move out into the Atlantic. In summer, winds are from the south or southwest from the Gulf of Mexico. Autumn winds are from the northeast due to the effect of the mountains in forming the southern edge of the predominant continental high pressure pattern. This weather system moves southward along the eastern seaboard, fostering northeast winds circulating in a clockwise fashion. The Bermuda High can also contribute to air stagnation, usually during the summer. It is the semi-permanent subtropical high pressure area in the North Atlantic that moves east and west with varying central pressure. Displaced westward during the Northern Hemispheric summer and fall, the center is located in the western North Atlantic, near Bermuda.

Tropical weather systems, including hurricanes, frequently pass over the region. A density plot of tropical storms and hurricanes reveals that approximately thirty-five recorded systems struck the region between 1864 and 2000 (Figure 3.7). Of these, two—an unnamed storm in 1893 and Hurricane Hugo in 1989—had the strongest recorded winds and inflicted the

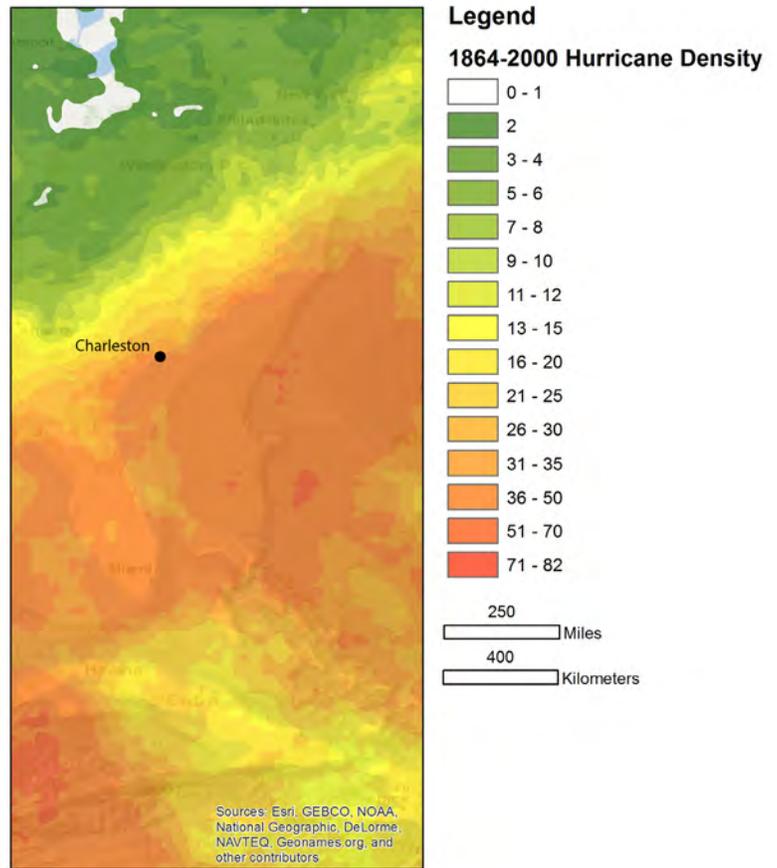


Figure 3.7. Number of hurricanes affecting the South Carolina area between 1864 and 2000. Positional data from NOAA compiled into a trackline density map for the region at 0.5-degree blocks. (Basemap by Esri et al., processed by M. Scott Harris)

most damage. Nor'easters, strong low pressure storm cells that develop off the East Coast, are typically not as powerful and frequent in the southeastern United States (especially when compared to those that strike the northeastern coast); however, their effect can be destructive, especially if a storm contains high winds for an extended period of time. One example of a Nor'easter that detrimentally impacted the Charleston area is the 1962 Ash Wednesday storm, which devastated the entire eastern seaboard.

Other severe weather systems, including short-lived thunderstorms, fast-moving tropical storms and hurricanes, and extratropical cyclones, are frequent along the South Carolina coastline during the spring, summer, and fall months. The most important influence on this coastline from storms is the interaction of the wave base on the seafloor, increased current flow along the coastline, and erosion of the near shore environment. It is possible these events increased sedimentation over the site, as evidence indicates sediment accumulation there with no periods of site erosion (Marot and Holmes 2005).

Coastal Processes: Tides, Currents, and Waves

Dominant coastal processes that act upon the area surrounding the *Hunley* site are sea level rise, tides and tidal currents, and waves. These processes all interact to move the sediment from various sources and sinks. The Charleston area experiences a mixed semidiurnal tidal range. This includes a spring tide range and tidal extreme measuring approximately 1.7 m (5.58 ft.) and 2.4 m (7.87 ft.), respectively (NOAA 1993). Offshore waters near Charleston typically exhibit slightly smaller tidal fluctuations; however, these fluctuations can undergo a rapid increase (or decrease) due to heavy winds, changes in barometric pressure, or surges associated with approaching storms. Because the tidal bulge passes through the waters off Charleston twice a day, local currents reverse on a daily basis. This creates two current surges for each tide, or four changes per day.

Historic charts combined with records of shipboard observations provide an understanding of the tides as they existed in the harbor in the late 1850s (Figure 3.8). Slight variations in the ebb tidal shoals surrounding the natural harbor entrance would affect local tidal flows, but the overall patterns, prior to the jetty installation,

should have been fairly consistent. The tidal wave—and subsequent tidal currents generated by it—responded to seafloor conditions present around a large ebb delta. Detailed bathymetry was conducted at several points along the harbor’s multiple entrance channels (USCS 1858). Unfortunately, offshore observations, when available, were not comprehensive enough to complement the bathymetric data recovered inshore.

Installation of the jetties drastically changed the overall configuration of Charleston Harbor. As a consequence, tidal currents in the region have also changed, modifying the sediment dynamics. Over time, the alterations in these local tidal currents influenced the erosion and deposition of sediments in offshore zones, shifting the overall ebb tidal shield to the north and east over the *Hunley* site. By the end of the 19th century, the system reached a state of quasi-equilibrium with new hydrodynamic forces that were imposed on the existing environment. Likewise, dominant ebb and flood tides and tidal currents responded to the modified system. Sediment accumulations that normally would have been deposited at the mouth of the harbor and trending southward were now transported farther offshore, with

some being forced to the north, within reach of the site, and some distributed south of the harbor entrance, influenced by the dominant wave climate and longshore currents (Figure 3.9).

Currents are integral to offshore sediment transport and the higher the current speed, the more sediment will be transported. This is particularly true for the larger and heavier sand grains and coarse shell. Current-transported sediment is influenced by the upward and/or settling velocities of the current flow. Individual particles of sediment vary in suspension within the flow, based upon size and weight and the force of the upward velocity on grains versus the force of the settling velocity. Currents offshore of Charleston under normal conditions are 10 to 26 cm/sec (.019–0.51 knots) during flood and 36 to 102 cm/sec (0.70–1.98 knots) during ebb currents. Flood usually occurs in a southerly direction and the ebb in a northeastwardly direction (NOAA 2005).

Compared to other regions in the United States, average wave size in the waters off Charleston

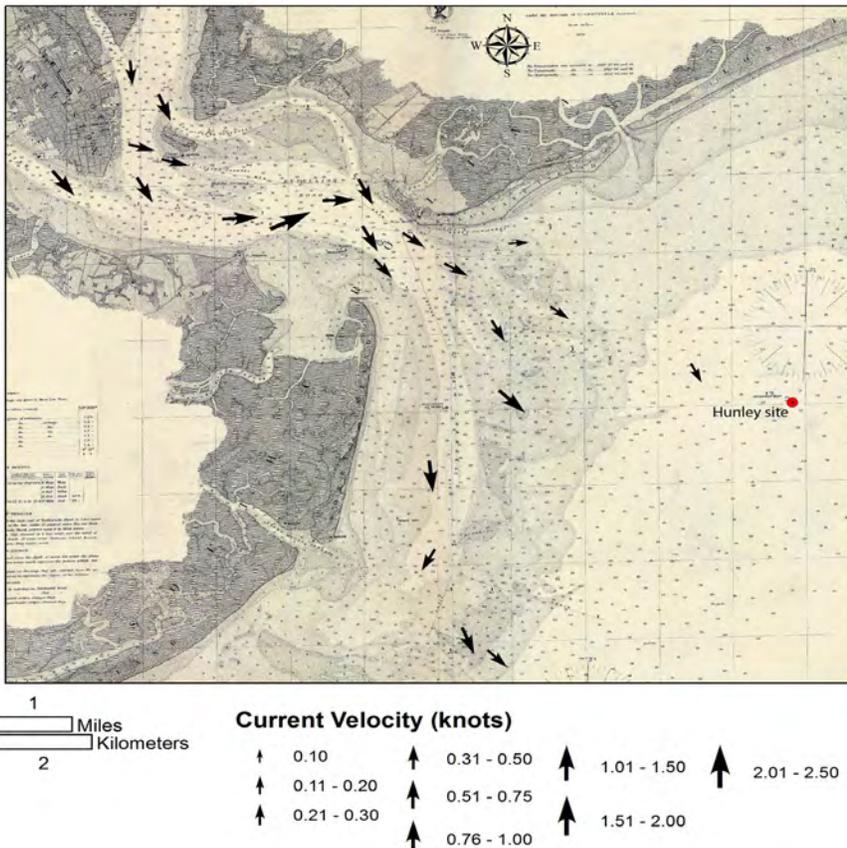


Figure 3.8. The fourth quarter ebb current flow in the vicinity of the Charleston Harbor entrance depicted on 1870 Coast Survey chart (USCS 1870), with currents extracted from 1856 Coast Survey chart (USCS 1856). (Map annotations by M. Scott Harris).

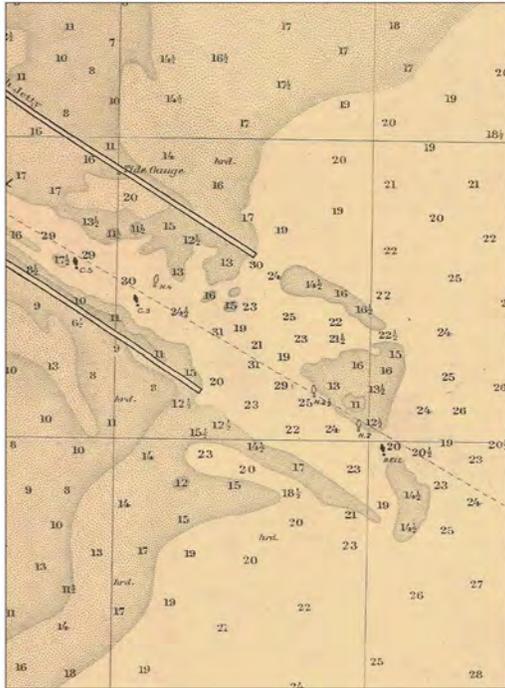


Figure 3.9. Sediment distribution at the mouth of the jetties in 1900, showing build-up of delta-like conditions extending east toward the Hunley site. (Detail from USCGS 1900)

are relatively small. This is largely attributable to the considerable length, width, and shallow depth of the continental shelf located to the east of the *Hunley* site. Significant wave heights recorded off Charleston between May 1980 and December 1993 measured 1.3 m (4.27 ft.) (with a 5-second period) on average (NOAA 1998). Seafloor shears, when combined with significant wave heights and the relatively shallow depth of the wreck, results in fine sediment transport along the seafloor when wave height surpasses approximately 0.5 m (1.64 ft.).

Sea Level Rise

When available, tidal gauge records are the best measure of sea level change for a particular region. Charleston, a large port city, has maintained a water level recorder in its harbor since approximately 1900. However, discrepancies exist in these data, including variations caused by potential dampening and sharpening of tidal measurements during storms and increased fresh-water runoff conditions. Offshore tidal records, when compared to those of Charleston Harbor, reveal a strong correlation between the two data sets. In addition, a comparison of data collected from the Charleston Harbor and Isle of Palms tidal gauges indicates very little variation between inshore and offshore sites. Consequently, the Charleston Harbor tidal record can be used as a proxy for offshore measurements.

Sea levels around Charleston have risen approximately 0.3 m (1 ft.) since 1900 (Hicks 1978; Hicks et al. 1983). Using the trend back from 2000 to 1900, an extrapolated rise of slightly more than 0.4 m (1.3 ft.) is calculated. There is a record of strong sea level variation for the area, related to decadal changes in average barometric pressures and shifts in storm frequency. Many of these alterations relate directly to large-scale climatological changes that have occurred in the North Atlantic during the past 136 years. Sea level rise can cause long-term changes in coastal accretion and erosion patterns (Kana et al. 1984).

Sediment Load

In addition to the jetties, another case of human alteration of the environment, specifically to the river drainage systems, may have increased the sediment load at the site. The diversion of the Santee River into the Cooper River for the generation of hydroelectric power in the late 1930s (completed in 1941) resulted in the unintended increase of current flow, sedimentation, and shoaling in Charleston Harbor (Kjefvre and Greer 1978). This led to intensified offshore sedimentation as well as more frequent dredging in Charleston Harbor. To mitigate these periodic dredging requirements, a rediversion canal was implemented and completed in 1985, sending most of the water flow back through the original Santee riverbed (Bradley et al. 1990:374–75).

Historical Bathymetric Analyses

Bathymetric charts that depicted pre- and post-jetty conditions were georectified to modern landmarks in the geographic information system ArcGIS 8.2. The georectification process required adjustments in longitude and latitude. Longitude exhibited the largest ordinate shift. Landmarks on the older charts shifted westward approximately 250 m (820 ft.). By contrast, adjustments in latitude rarely exceeded a few tens of meters. All of the landmarks' locations shifted north. A systematic analysis of depth soundings depicted on the georectified charts identified the general bathymetric changes surrounding the *Hunley* site. According to an 1864 chart (1863–5 bathymetry), water depth varied from 7.0 to 8.5 m (23–28 ft.) within 500 m (1,640 ft.) of the site. Recent (1997) charts depict much the same in terms of water depth, but since local sea levels have risen over 1 ft. (0.30 m) since 1864, it appears that at least an additional foot of sediment accumulated on the seabed around the submarine between 1900 and 1997. Based on basic depositional trends, it appears that approximately 1.0–1.5 m \pm 1 m (3.28–4.29 ft. \pm 3.28 ft.) of sediment accumulated in this area from 1864 to 1997.

Model of Site Formation

Hunley sank to the seafloor well north and east of the natural, pre-jetty ebb-tidal shield of Charleston Harbor. Analysis of sedimentological and geological data recovered during the initial phase of the submarine's recovery, combined with information gleaned from historic and modern hydrographic charts, depth measurements, ^{210}Pb analyses, and loci of encrusting organisms on the hull's exterior, has enabled the development of two possible burial sequences. It is important to note that—in theory, at least—the thin Holocene sediment cover that characterizes the continental shelf surrounding the site should have prevented the submarine's complete burial. Under normal conditions, the hull would have settled only 0.5 to 1.0 m (1.64–3.28 ft.) into the natural sand sheet; consequently, a sizable portion of the upper half of the submarine would have been exposed to the water column during the past century and a half. However, data derived from marine macrofauna (encrusting corals) on the hull, taken in conjunction with sediment accumulation rates at the site prior to excavation, suggest that the submarine remained buried from the end of the 19th century until its discovery in 1995. These findings are consistent with sediment transport that resulted from the creation and completion of jetties after the Civil War.

There are two possible burial sequences (Figure 3.10).

Scenario 1 relies heavily on the presence of a scoured seafloor, with very little to no Holocene sedimentation at the site, and the submarine coming to rest directly on the dense Pleistocene mud bottom. Areas of exposed dense mud are not uncommon on the seafloor off the Charleston coast today, and charts from before the jetty installation show many readings of hard bottom rather than shell in the vicinity of the sinking site (USCS 1864). In this scenario, the submarine was gradually buried by accumulating sediment, primarily due to increased sediment load from the jetties. Scenario 2 is the most likely and is supported by bathymetric analysis and chart data, combined with existing sea level data. In this scenario *Hunley* came to rest on a thin Holocene sand layer, and was subsequently buried by a combination of the submarine's natural tendency to settle into the sand, as it was scoured by currents and tidal action, and the gradual shift in the Charleston Harbor ebb-tidal delta. These events likely occurred simultaneously; the settling of the hull into the seabed was probably complete by the time the ebb-tidal shield had completely shifted northwards. It is interesting to note that had *Hunley* settled on the seabed approximately 50 m (164 ft.) farther to the southeast, it may have been buried 2–5 m (6.56–16.40 ft.) deeper in bottom sediment. This is because it would have come to rest in the sands of an ancient paleochannel rather than the dense Pleistocene mud layer common to the region.

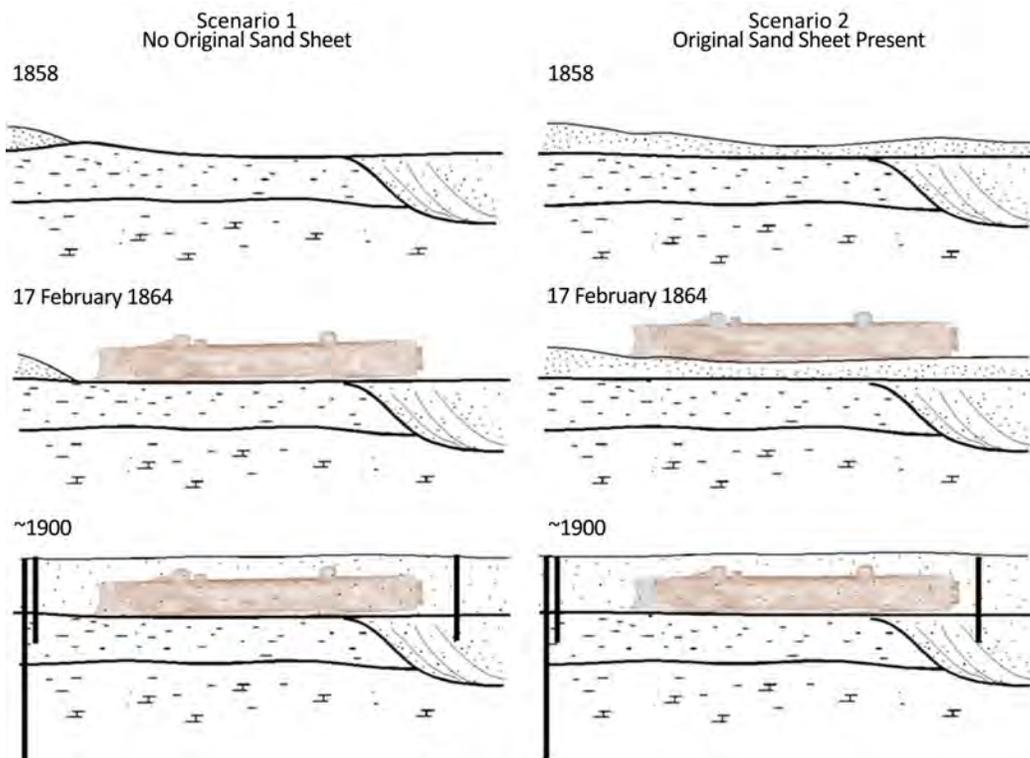


Figure 3.10. Two potential models of site formation. (Image by M. Scott Harris)

4. Previous Investigations

Harry Pecorelli III

Contemporary Salvage Attempts (1864)

After the sinking of USS *Housatonic* and subsequent disappearance of *H. L. Hunley*, a marine diver in service with the U.S. Navy, William Churchill, led a search for the submarine. He convinced his superior, Lt. Commander A. W. Johnson, to request permission from Rear Admiral Dahlgren to salvage *Housatonic* and uncover the torpedo boat (Quinn-Smith 2009:9). Having heard rumors about the submersible, Churchill was eager to see if he could find it. Dahlgren wanted to find *Hunley* to further the Navy's submersible program and gave permission for Churchill to carry out his search in May 1864.

Churchill filed a final report on 27 November 1864 claiming that weather conditions had prevented him from fully salvaging *Housatonic*. His report went on to explain that "I have also caused the bottom to be dragged for an area of 500 yards [457.20 m] around the wreck, finding nothing of the torpedo boat. On the 24th the drag ropes caught something heavy (as I reported)" (ORN 1.15:334). He sent a diver down to examine it, but discovered it was only some rubbish on the seabed. In 2002, archaeologists discovered a grapnel anchor dating from the 19th century in the same Pleistocene mud on which *Hunley* rested and only 5 m (16.40 ft.) from the hull (see Chapter 11). While no lost grapnel was specifically mentioned by Churchill, it may have been connected with his search efforts. It is also possible the object was simply lost from one of the many other ships active in the vicinity during or after the war.

An article in the 1870 Charleston *Daily Republican* claims that *Hunley* had been discovered within the wreck of *Housatonic*. The boat was supposedly found with the remains of all if its occupants still inside. This false report likely originated from diving activities related to the demolition of Civil War-era wrecks around Charleston harbor; however, no further work was carried out to confirm the alleged discovery (Chaffin 2008:209). The matter seems to have been put to rest when work was done between 1908 and 1909 to lower the profile of the wreck, which was considered a

hazard to navigation. Newspaper reports on the project, as well as the final report from the U.S. Army Chief of Engineers, included no indication that *Hunley* had sunk there (Conlin 2005:43–44).

Early Claim (1970)

In November 1970, Edward Lee Spence (1995:37) found a "cylindrical object which formed an unnatural shelf or ledge in the sand" with "raised marks of hand hammered rivets." He requested permission from the General Service Administration (GSA) in 1974 to salvage the wreck, but was denied due to historic preservation laws: "In view of the legal questions involved concerning the Antiquities Act and the formulation of the guidelines previously mentioned, we are holding in abeyance the issuance of any contracts covering the raising of sunken vessels" (Herman 1974).

The Navy was also notified of his discovery during this process. Believing he had discovered *Hunley*, Spence filed papers on 7 July 1981 with the U.S. District Court for the District of South Carolina Charleston Division to claim *Hunley* (Civil Action #80-1303-8). However, the find was never authenticated by any government agency or independent archaeologist on site. During the interceding decade, Spence published several articles advertising his claim to the public. Several proposals were made for expeditions to confirm the identity of this wreck, including one that was to be led by National Geographic.

It is possible that Spence's target was actually a sunken navigation buoy that once might have marked the wreck of *Housatonic* and was documented in 1999 when magnetic anomalies surrounding the sunken ship were investigated (discussed below). The iron buoy was partially exposed, with a curved side rising a few inches above the sea floor, and was of riveted construction. *Hunley* was constructed with rivets flush to the outside

surface, while Spence described feeling raised rivets, a feature present on the buoy. In addition, lead isotope analysis of sediment samples around *Hunley's* hull shows that once it was buried it had not been uncovered after its initial burial until the 1995 discovery (Moore 1998:160–61). While Spence's coordinates, published on his website, are known to be within several hundred meters of *Hunley's* actual location, both the buoy and *Housatonic* lie within this radius as well. This combination of factors makes it likely that Spence discovered the buoy, and not *Hunley*, in 1970.

First NUMA Search for *H. L. Hunley* (1980)

Author Clive Cussler founded the organization National Underwater Marine Agency (NUMA) in 1978 for the sole purpose of locating America's historic shipwrecks. In 1980, NUMA initiated a comprehensive search for *Hunley* in the waters off Charleston, South

Carolina. The search began with an extensive investigation of archival sources. These records helped Cussler's group establish two high probability search areas (Figure 4.1). Operating on the assumption that the submarine made it back to shore, NUMA developed one search area in shallow waters just offshore of Breach Inlet. The second search area was established on the assumption that the submarine suffered damage during the attack on 17 February 1864, and was located in the vicinity of the wreck of *Housatonic*.

NUMA deployed a proton-precession magnetometer (in conjunction with a Loran positioning system) from a rubber zodiac boat and surveyed a 1 mi. (1.61 km) wide by 3 mi. (4.83 km) long zone parallel to the beach at Breach Inlet. The search area near the wreck of *Housatonic* measured 2 mi. (3.22 km) wide by 2.5 mi. (4.02 km) in length. All survey operations associated with the latter survey zone were conducted aboard NUMA's research vessel. A total of four anomalies were detected during investigation of both survey areas. One anomaly, discovered in the Breach Inlet survey area, was disregarded because it lacked the magnetic intensity expected of a large iron object like

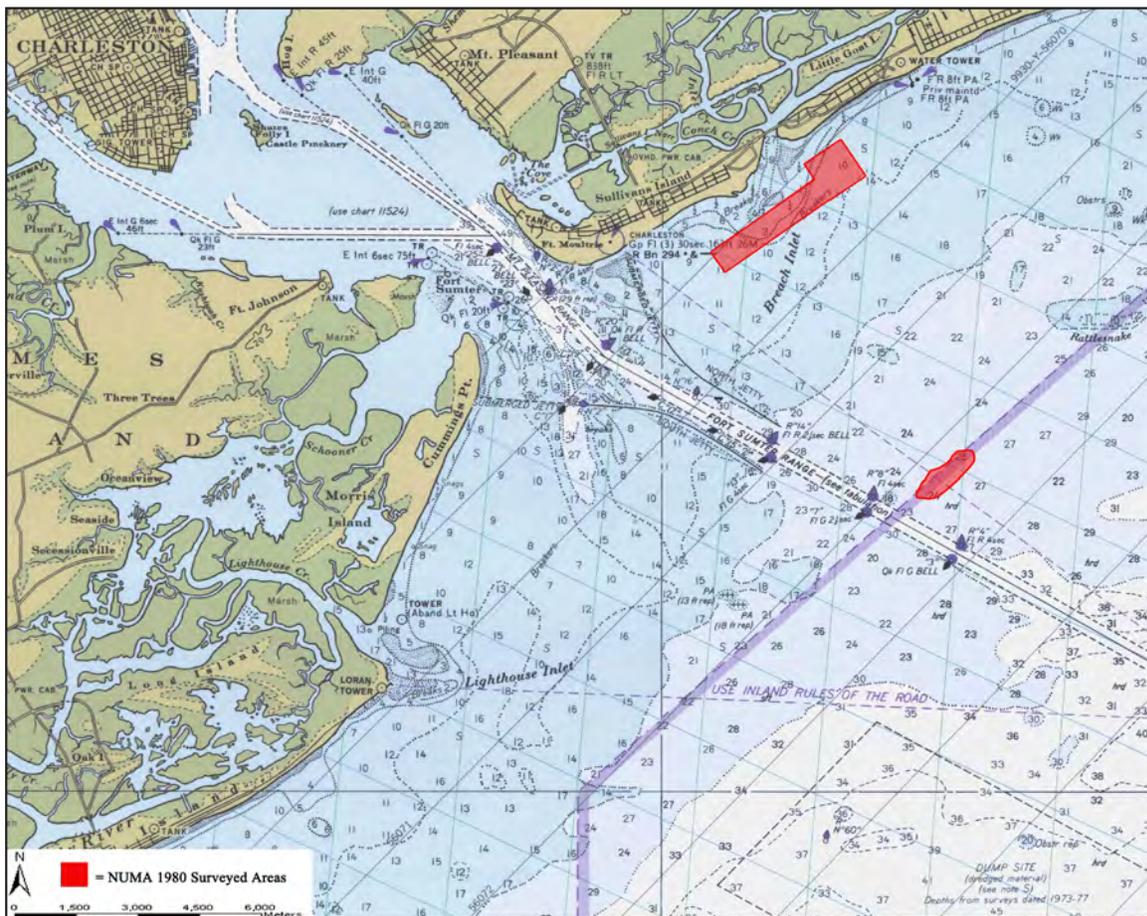


Figure 4.1. Map showing Charleston Harbor and 1980 NUMA search areas. (NOAA Chart 11521, annotated by Alicia Massey, NHC)

Hunley. The remaining anomalies were detected in the offshore survey area. These were later determined to be scattered ferrous objects associated with *Housatonic* (Browning and West 1982).

Second Search for *H. L. Hunley* (1981)

NUMA researchers returned to Charleston in June of 1981 to continue the search for *Hunley*. The new survey was conducted in conjunction with the South Carolina Institute of Archaeology and Anthropology (SCIAA), and expanded to encompass a rectangle 3 mi. (4.83 km) wide by 5 mi. (8.05 km) long (Figure 4.2). The new area extended from Breach Inlet to an area immediately southeast of the wreck of *Housatonic*. Due to time restrictions, NUMA was forced to reduce the original 15 sq. mi. (38.85 km²) search area to 8 sq. mi. (20.72 km²). The 1981 survey employed the use of two separate teams; one was solely responsible for remote-

sensing operations, while the other consisted of divers that attempted to identify the targets acquired by the remote-sensing team.

The NUMA/SCIAA team surveyed the search area by establishing multiple transect lines parallel to the beach spaced at 30 m (98.43 ft.) intervals. The survey team positioned all transects and anomalies with a Motorola Mini-Ranger III line-of-sight pulse radar tracking system. The Mini-Ranger system incorporated the use of two onshore transmitters—each placed at a known location—and a receiver station on the survey vessel. The Mini-Ranger console, located at the crew’s headquarters, computed the position of the survey vessel as it operated offshore. Course corrections were radioed to the survey vessel by CB radio, which increased the accuracy with which each survey lane was executed.

Ferrous targets were detected using an Elsec proton magnetometer. The magnetometer sensor was towed 50 ft. (15.24 m) behind the survey vessel. As magnetic anomalies were detected, the verbal message “target” was radioed to the Mini-Ranger operators onshore. The operators in turn assigned and plotted coordinate

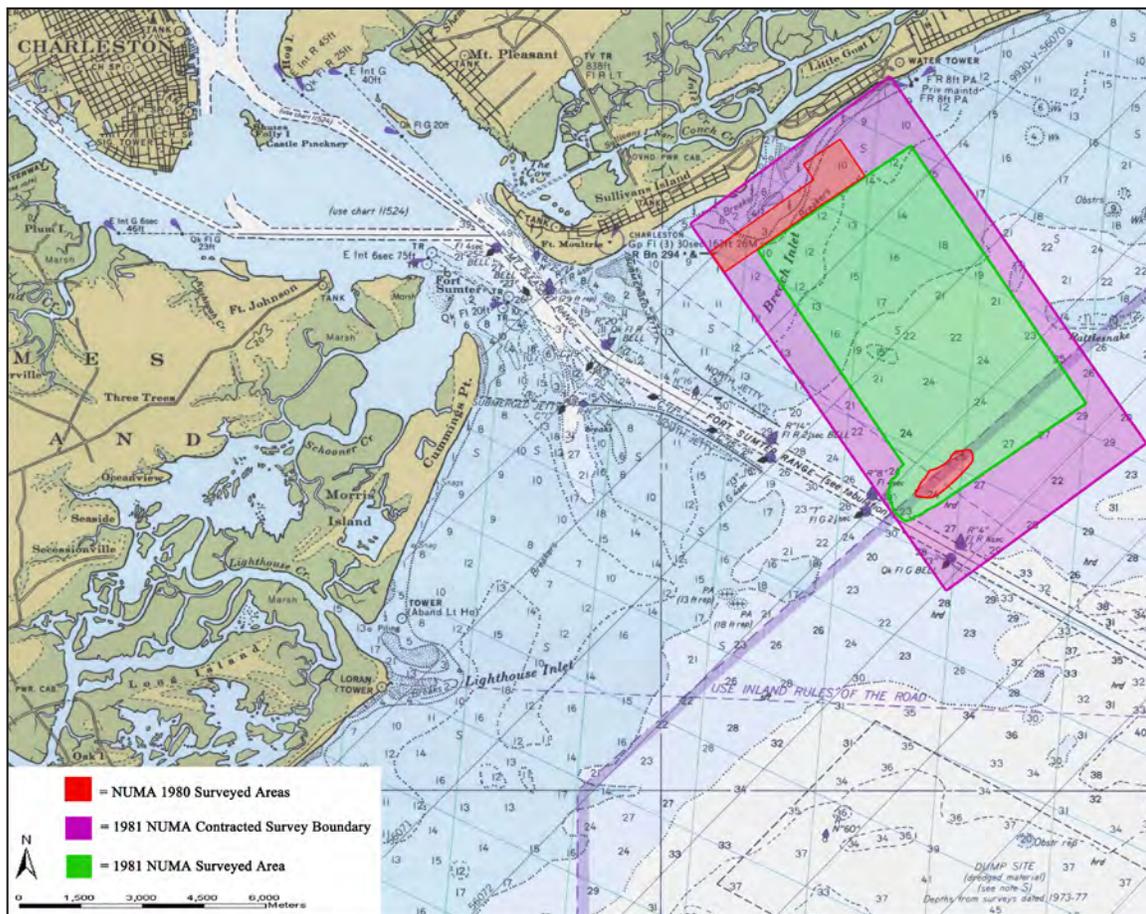


Figure 4.2. Map showing Charleston Harbor and 1981 NUMA search areas. (NOAA Chart 11521, annotated by Alicia Massey, NHHC)

data for each locality. A total of 19 magnetic anomalies were recorded using this system. Of these, seven exhibited the magnetic intensity expected for *Hunley* (Hall 1995:6).

The dive team employed a combination of the Mini-Ranger system and a Schonstedt Instruments gradiometer to position the dive vessel in the vicinity of each target. Initially, divers would investigate a target to determine whether portions of it were exposed above the seabed. In instances where the target was completely buried, divers probed the bottom with 6 ft. (1.83 m) steel rods to determine its shape, size, and material type. If an anomaly exhibited characteristics consistent with those anticipated for *Hunley*, the sand overburden covering it was removed with an airlift. Of seven targets exhibiting the expected magnetic intensity, four were investigated. The four targets were individually identified as: 1) the remains of *Housatonic*; 2) a 20th-century wooden vessel; 3) a buried wooden vessel of undetermined date; and 4) a torpedo-shaped iron cylinder. Divers were not able to identify the iron cylinder but determined that it was not *Hunley*. During the target investigation phase of the survey, the dive team conducted 57 dives, totaling 39 hours and 25 minutes.

Third Search for *H. L. Hunley* (1994)

NUMA teamed up with SCIAA for a second time and returned to Charleston in 1994. The primary focus of this survey was to further investigate the seven targets located during the 1981 survey. NUMA relocated six of the seven targets; a shrimp trawler had moved the seventh from the area during the intervening period (Hall 1995:7). The shrimpers that reportedly snagged this object were unable to identify it.

As soon as the six targets were relocated, NUMA resumed remote-sensing operations. Equipment used during this phase of the search included a Geometrics 866 proton-precession marine magnetometer and a 531-T 500 kHz Klein side-scan sonar. A NavStar Differential Global Positioning System, used in conjunction with Coastal Oceanographics HYPACK survey software was used to position targets and acquire data. The HYPACK system enabled NUMA to establish pre-planned parallel survey lines using 100 ft. (30.48 m) lane spacing, significantly expanding the 1981 survey area.

SCIAA underwater archaeologists were responsible for identifying the six targets located during the 1981 survey. All targets were deeply buried in the seabed and required extensive probing. A thick shell lens buried approximately 3 feet (0.91 m) below the bottom hampered the probing process. Initially, SCIAA archaeologists thought that the shell lens represented a solid object; consequently, many of the targets were disre-

garded as potential *Hunley* candidates because probing gave the appearance that they were much larger than they actually were. However, SCIAA staff did partially excavate and expose one of the targets and determined that it was the remains of a wooden vessel (Hall 1995:8).

Discovery of *H. L. Hunley* (1995)

Throughout the spring of 1995, Clive Cussler employed Ralph Wilbanks and Wes Hall to continue searching for *Hunley*. When not working on other contract obligations, Wilbanks and Hall surveyed an ever-expanding portion of Charleston Harbor. During one magnetometer survey, they detected a sizable target. The magnetic signature produced by the anomaly was similar to what Wilbanks expected from *Hunley*. Wilbanks and Hall enlisted the aid of Harry Pecorelli III to investigate the target. On 3 May, Wilbanks anchored his survey vessel *Diversity* over the target locale. As the junior member of the team, Pecorelli was first in the water. The object that produced the large magnetic signature was an early 20th century ship's windlass covered with anchor chain. Wilbanks, Hall, and Pecorelli, after identifying this anomaly, reviewed notes from the 1994 survey and decided that they should properly identify the targets located during the 1980 and 1981 field seasons, rather than expanding the search area.

Wilbanks and Hall selected the target with the most likely magnetic signature. Wilbanks approached the target from three different directions and marked the strongest magnetic intensity with a buoyed concrete cinder block. Once *Diversity* was anchored over the anomaly, Pecorelli went down to locate and identify it. Pecorelli was attached to one of the marker buoys by a search line and began probing toward the other marker buoys. He pushed a ¼ in. (0.64 cm) diameter stainless steel probe 3 ft. (0.91 m) into the sand, where a dense layer of shell stopped it. Working the probe through the shell layer, Pecorelli detected a metallic surface. Next, he probed side-to-side and front-to-back to determine the orientation of the object. It was cylindrical, with an approximate width of 4 ft. (1.22 m) and length of 35 ft. (10.67 m).

Water visibility on site ranged from zero to 1 ft. (0.30 m) and a moderate current was present. Pecorelli located a portion of the object that was the least deeply buried and stuck the probe in the sand next to it to mark it. After securing the search line to the probe, he followed the search line back to the marker buoy and up to the boat. Returning to the site with a water induction dredge, he excavated a conically-shaped test unit, and exposed a 1 ft. (0.30 m) diameter portion of the surface of the object before the need arose to

resurface and change scuba cylinders. On the next dive, Hall expanded the hole to an approximate diameter of 3 ft. (0.91 m). Enlargement of the excavation area exposed the forward hatch, snorkel box, and a portion of the port diving plane. Identification of these features confirmed that the anomaly represented the remains of *Hunley*. Fortunately, the initial test excavation was placed immediately adjacent to the most diagnostic features on the submarine's hull. The unit was quickly backfilled and the team returned to shore.

On 7 May 1995, Wilbanks, Hall, and Pecorelli returned to the site to document their discovery on videotape. Wilbanks had contacted Clive Cussler the previous evening, and Cussler requested that the find be substantiated on film. The team re-excavated the test unit and videotaped the forward hatch, snorkel box, and the port diving plane (Figure 4.3). The video evidence was presented two weeks later at a press conference held at the Charleston Museum.



Figure 4.3. Screen capture from NUMA's 1995 video footage of the site. Distinguishing features such as the snorkel box helped build confidence that the vessel was indeed Hunley. (Courtesy of NUMA)

The remote sensing survey located the remains of the two vessels as well as a number of smaller, nearby ferrous objects (Murphy 1998:60). Although these latter targets were not investigated at the time, their close proximity suggested a possible association with one or both wreck sites, and were slated for further investigation (discussed below). Immediately following the conclusion of the remote sensing survey, underwater archaeologists from SRC, SCIAA and NHC excavated and exposed the entire upper surface of the submarine in order to confirm the vessel's identity as well as collect data on its physical condition and surrounding environment. Additionally, project archaeologists wished to acquire preliminary data that addressed *Hunley's* site formation processes.

USS *Housatonic* Site Assessment and Investigation (1999)

In the summer of 1999, archaeologists from NHC, SRC, SCIAA, and the U.S. Geological Survey conducted a limited investigation of the buried remains of *USS Housatonic*. The project commenced with a series of 3 in. (7.62 cm) diameter vibracore sediment samples collected from the seabed in the immediate vicinity of *Housatonic* and *Hunley*. Following the sampling phase of the project, the multi-agency team conducted a remote sensing survey to complement the results of the 1996 survey. The new survey focused primarily on recording site-specific seismic and sonar data. Using an Applied Acoustic AA200 sub-bottom profiler system, Edge Tech Geo-Star FSSB CHIRP system, and Edge Tech 272 TD side-scan sonar, data was collected from a variety of points throughout the entire engagement site.

Ground-truthing operations located the remains of *Housatonic* beneath approximately 6 ft. (1.83 m) of sediment (Conlin 2005:66–67). Archaeologists using water jet probes delineated the wreck site. In addition,

***H. L. Hunley* Site Assessment (1996)**

In May 1996, the National Park Service's Submerged Cultural Resources Unit, now the Submerged Resources Center (SRC), Naval Historical Center (NHC), and SCIAA conducted a site assessment of the *USS Housatonic/H. L. Hunley* engagement site (Murphy 1998). This assessment served two purposes: 1) to confirm NUMA's 1995 discovery of *Hunley* and; 2) determine its state of preservation and gather information to assist those responsible for planning its management and possible recovery.

The assessment began with a comprehensive remote-sensing survey that encompassed the area comprising both the *Housatonic* and *Hunley* sites. The survey utilized a variety of equipment, including a Geometrics G-876 proton-precession magnetometer, Marine Sonic Technology side-scan sonar with a 600 kHz towfish, differentially corrected Trimble Navigation Accutime II GPS, and an EdgeTech X-Star digital sub-bottom profiler.

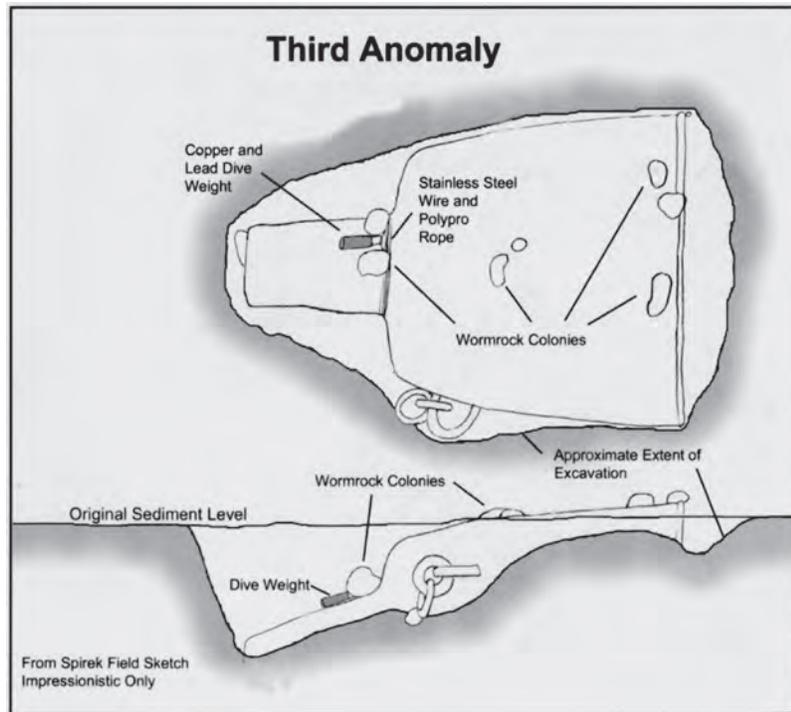


Figure 4.4. Diver sketch of possible sunken navigation buoy between USS *Housatonic* and *Hunley* sites. (Murphy 1998:78)

three test trenches were excavated at specific points on the wreck where significant structural remains and archaeological features were anticipated to be present. Numerous diagnostic artifacts were recovered during excavation of these trenches.

In addition to work at the *Housatonic* site, the team investigated the two nearby magnetic targets located in 1996. The first target, dubbed “Anomaly #3,” was situated midway between the two wrecks, and appears to be the remains of an old navigation buoy (Figure 4.4). This object was partially exposed above the seafloor and a preliminary excavation revealed it to be a large, roughly cylindrical, riveted iron object, approximately 7 ft. (2.13 m) in length with a maximum diameter of 8.58 ft. (2.62 m) (Conlin 2005:78–80). A dive weight and cable were found wrapped around the narrower portion of the object, buried just under the mud-line,

an indication of previous activity by divers on the site. While historic charts indicate the *Housatonic* wreck was marked by a nun buoy beginning in 1901 (USCGS 1900, 1901), followed by a bell buoy between 1906 and ca. 1912 (USCGS 1906, 1912, 1914), the anomaly does not conform to either of those buoy types. U.S. Coast Guard Historian Dr. Robert Browning reviewed the data and found the object most resembled the remains of a gas or gas-and-whistle buoy from the 1920s or early 1930s. Due to the site’s proximity to the shipping channel, it is likely the buoy was struck by a vessel, and drifted toward the *Hunley-Housatonic* site as it sank (Browning, pers. comm.). It is possible this is the same cylindrical object identified as *Hunley* by Lee Spence, described above. The second target, documented as Anomaly #4, was identified as a small Admiralty-type ship’s anchor with open-link chain (Conlin 2005:80–81).

5. Project History

Robert S. Neyland

After its discovery, there was almost immediate interest in recovering *Hunley*. State authorities and maritime archaeologists were concerned over the wreck site being looted. The Navy and the recently-formed South Carolina Hunley Commission (SCHC) agreed to keep the coordinates secure and confidential. Shortly after the discovery and at the request of Senator Ernest Hollings (D-SC), a Regulated Navigation Area (RNA) was created around the site. This prohibited anchoring, salvaging, dredging, and diving. A commitment was made by the General Counsel of the Navy Steven S. Honigman to Senator Strom Thurmond (R-SC), then Chairman of the Senate Armed Services Committee, to protect the site from unauthorized visitation (Neyland and Amer 1998:7).

In order to honor this commitment, the Navy's Space and Naval Warfare Systems Command (SPAWAR) Atlantic placed security video and infrared cameras on Sullivan's Island Lighthouse. These were monitored by base security at Naval Weapons Station Charleston.

If a violation was observed, the base security would alert the U.S. Coast Guard (USCG) Sector Charleston, who then would send out a USCG boat to investigate (Neyland 1998).

These procedures were successful in keeping interlopers off the site. However, that was not a viable long-term solution for managing the site. With rumors spreading of high cash rewards being offered for parts of the submarine, increased concern over looting prompted the Navy to investigate options for safely recovering the vessel, which represented a unique and significant milestone in naval history (Dudley 1998). Determining what happened to the submarine and the crew and returning the remains to Charleston also influenced the decision to recover the submarine. The story of the submarine and its crew is closely tied to South Carolina's history. *Hunley* had become part of the City of Charleston's identity and a Civil War icon, which stimulated the drive for its recovery.



Figure 5.1. Friends of the Hunley board members, staff, and volunteers at the Warren Lasch Conservation Center in North Charleston. (Courtesy of FOTH)

Course to Recovery: Partners and Agreements

The state and federal jurisdiction over *Hunley* was resolved and a Programmatic Agreement (PA) was signed in August 1996 (Neyland and Amer 1998). The PA stipulated the roles of the principal state and federal agencies involved in the *Hunley* recovery and provided the administrative way forward. The parties to the agreement were the SCHC, which was created by the South Carolina State Legislature with members appointed by both the legislature and the governor, and the South Carolina State Historic Preservation Office (SHPO), which was under South Carolina Archives and History Division. Parties on the federal side included General Services Administration (GSA), Department of the Navy represented by Naval Historical Center (NHC, now Naval History and Heritage Command), and the Advisory Council for Historic Preservation (ACHP). In summary, the PA provided agreement between the consulting parties and the framework for undertaking the recovery of *Hunley* while providing the highest standard of protection under the National Historic Preservation Act (16 U.S.C. 1470).

The agreement required anyone wishing to investigate or raise *Hunley* to submit detailed and adequate plans for the endeavor. The personnel involved in any such effort had to be qualified underwater archaeologists and conservators. Hull and artifact stabilization and conservation had to be provided for before any recovery effort could commence. The human remains would be treated with dignity, respect, and honor. The SCHC would be given the lead on preparing a plan for burial of the crew. All proposals would be reviewed by those party to the PA and by a committee, designated the *Hunley* Oversight Committee (HOC), made up of professionals and experts in the fields of underwater archaeology and conservation, including representatives from the Department of the Interior, GSA, the National Oceanic and Atmospheric Administration (NOAA), the Smithsonian Institution, and ACHP.

The submarine and associated artifacts would remain federal property and the Navy as the federal property manager would oversee their disposition to the appropriate institution via loan agreement. In turn, the federal agencies agreed that the artifacts could remain in South Carolina on indefinite loan as long as they were professionally curated and preserved in compliance with federal standards (36 CFR 79). SCHC would manage the intellectual property to defray the cost of recovery and preservation. The Navy was not obligated to any funding by the agreement, although the federal government would eventually contribute a significant level of funding through the DOD Legacy Resource Management Program for both the recovery and conservation.

Friends of the Hunley

The Friends of the Hunley, Inc. (FOTH) was created in 1997 as a 501(c)(3) corporation by the SCHC, which also appointed all board members (Figure 5.1). That same year, Warren Lasch agreed to be chairman at the encouragement of South Carolina state senator Glenn McConnell, SCHC Chairman, and Rear Admiral William L. Schachte Jr. USN (ret), a governor-appointed member of the commission. FOTH's mission as stated in their director's handbook was to procure charitable donations for the raising, restoration, and preservation of the *Hunley* submarine, manage and expend procured funds as needed to advance the raising, restoration, and preservation of *Hunley* and related artifacts, and to perform all necessary or desirable actions, incident to the above-stated purposes.

The board consisted of both voting directors and non-voting ex officio members. The initial board of directors totaled eight and included Chairman Lasch; George Bell of Bultman & Bell Insurance; Clive Cussler of NUMA; Robert Evans of the law firm of Sterne, Agee & Leach, Inc.; the Honorable Harry Hallman, Mayor of Mount Pleasant; Dr. Charlie Peery, Charleston obstetrician and owner of a rare Confederate naval collection; City of Charleston Mayor Kenneth Riley; and Greenville businessman James D. Cockman. Ex officio members included Senator Thurmond; Representative Floyd Spence (D-SC-2); and Ted Turner, President and CEO Time Warner, Inc. (Tapp 1999:i-3). Lasch, with the help of Schachte and Thurmond, recruited Dr. Robert S. Neyland, Head of Underwater Archaeology at the NHC, in 1998. The Navy agreed to allow Neyland to work on the project through the South Carolina Department of Archives and History (SCDAH) on loan under the Intergovernmental Personnel Act. As Project Manager, Neyland assisted SCHC and FOTH in project planning and personnel recruitment.

Ultimately, FOTH would be integral to the recovery and preservation of *Hunley*, particularly through its ability to manage and expend money and negotiate contracts. Lasch brought considerable business acumen to the organization. His leadership was essential to keeping both the recovery operation and the renovation of the building that would become the conservation laboratory on schedule.

Hunley Oversight Committee

The *Hunley* Oversight Committee (HOC) was developed from a working group formed by the Navy in 1995, shortly after the discovery of *Hunley*, in response to a number of recovery proposals that very quickly began to circulate after the news was announced. The body was primarily intended to assist in peer review of these documents.

The first working group meeting was held on 22 August 1995 to discuss the draft programmatic agreement and methods of public and state involvement, which at that time included both the states of South Carolina and Alabama. The group also reviewed the two proposals for recovery described below. Both were lacking in sufficient details and were submitted prior to the conclusion of negotiations regarding ownership and management. Present at the meeting were Navy representatives Dr. William S. Dudley, CDR Joseph Thomas, Robert R. Rossi, CAPT James K (Otto) Orzech, and Neyland. The National Park Service (NPS) was represented by E. C. Bearss and Kevin Foster. ACHP representatives included Valeria DeCallo, Druscilla Null, and Ralston Cox. The federal owner of the property, GSA, was represented by Property Division personnel Bill Tesh and Dona Gamble. Other federal officials were Dr. Paul F. Johnston, Smithsonian Institution; Ole Varmer, NOAA; and Caroline M. Zander, Department of Justice. In addition, peer reviewers included Bruce Terrell, NOAA Sanctuaries and Reserves Division; Dr. John Broadwater, NOAA USS Monitor National Marine Sanctuary; Colin Wagner, GSA Federal Preservation Office; Dan Lenihan, NPS-Southwest Regional Office; and Dr. Donny L. Hamilton, Nautical Archaeology Program Texas A&M University. These agencies and many of the same individuals would also participate in the review of the final *Hunley* recovery and conservation plans.

Two proposals were submitted in 1995 hard on the heels of *Hunley's* discovery, both of which were reviewed by the working group. The first was submitted by the SCIAA, which pointed out it was the state's regulatory authority for underwater antiquities and, as such, its role required it to ascertain the location and manage sites within state waters (Leader 1995). Subsequent review of the coordinates, however, proved the site lay in federal, not state, waters. This proposal was still in the preliminary phase, as the recovery method was not outlined in detail, and reviewers had concerns about the chosen conservation methods and that no secure sources of funding had been established. No revised document was submitted by the organization. The second proposal was submitted by the Rescue Company of Rescue, Virginia, in September 1995. The plan included specialists in maritime archaeology, conservation, corrosion engineering, salvage, forensic anthropology, and history. Although relatively brief, it was a multifaceted approach that included all aspects of the project as well as fundraising and exhibition. Nevertheless, it lacked the level of detail required to fully approve the project. In addition, with the PA still in preparation, the authorizing parties were not yet in a position to commit to a way forward.

When the PA was finalized, the working group became known as the Hunley Oversight Committee, though it remained an informal advisory body of federal

subject matter experts directed "to provide guidance on the management of the *Hunley*" (DON 1996). From its very outset, the committee provided valuable expertise and insight in reviewing further proposals received by the Navy, and it continued to help shape the recovery plans with their advice, questions, and concerns.

Laying the Groundwork: Studies and Plans

Originally it was thought that the way to proceed would be to generate a Request for Proposals (RFP) and publish the RFP in the federal register to entice contractors and appease competing groups. However, there was no precedent for the recovery of a Civil War submarine and many unknowns were evident regarding its state of preservation and the safest method for lifting it, as well as what to do in regards to conservation and excavation of the submarine's interior once it was brought to shore. It was also apparent that even if proposals were submitted, it would be difficult to evaluate them without some basis for understanding what options were realistic. What was needed was a feasibility study that would determine the parameters for a recovery system.

Option Study

The Navy's Supervisor of Salvage (SUPSALV) had an indefinite delivery contract with Oceaneering Advanced Technologies, a division of Oceaneering International, Inc. (OII) for maintenance and development of the Navy's deep-water remotely operated vehicles and advanced engineering services. Neyland worked with SUPSALV and Leonard Whitlock, OII's program manager on this contract, to facilitate the *Hunley* recovery option design study, which was supported by DOD Legacy Resource Management funding. Steve Wright of OII was assigned to the study. Initial discussions concerning design options were conducted with NHC UAB personnel and NPS archaeologists Dan Lenihan and Larry Murphy.

OII's "Preliminary Study for the Recovery of the H. L. Hunley," submitted in August 1999, was fundamental to the mission. It provided a systematic evaluation of all potential lift methods with a recommended best option, as well as an important cost analysis to the rough order of magnitude (ROM). It was not intended to be a final plan but to provide a guide as to the best option for recovery and the basis for initiating an RFP. OII eventually was requested to fully develop this plan in order to meet a 2000 recovery goal set by the SCHC and FOTH,

but at the option study stage was not pre-selected as the final contractor.

The study made some basic assumptions: 1) the wreck was intact; 2) the site was limited to the immediate area such that extensive archaeological excavation would not be required; 3) the submarine's hull would be self-supporting during the lift; and 4) there would be a sufficient weather window to conduct the operation safely. A variety of standard recovery methods was considered. The site was shallow enough for a cofferdam, but this was ruled out due in part to the expense, but also the risk of drying out well-preserved organic artifacts and the vulnerability of the exposed site to potential hurricanes. Capturing and lifting the submarine within its surrounding sediments was considered infeasible due to the risk of soil fluidization, based on the analysis of sediment cores taken around the site. There were additional concerns about the total weight of such a load. Raising the vessel using flotation devices would be difficult to control given the active surface conditions at the site. The study ultimately recommended that a rigid space frame structure be built to contain *Hunley*. The frame and submarine would be lifted directly off the ocean floor by a crane deployed from a derrick barge or heavy lift boat. *Hunley* would then be transported by barge to Charleston for off-loading and transfer to the conservation facility.

ROM costs were estimated to be \$2,270,200 for 66 days at sea, which would comprise the excavation, rigging, and lift of the submarine. The study had several follow-on recommendations to aid in further planning: the preparation of a 3D model of the wreck for pre-engineering the lift system, obtaining an accurate wall thickness for the submarine, and preparing a more detailed recovery operations plan (OII 1999a:ii-18). Under the direction of Neyland, hull thickness data was collected in early November 1999 (see Chapter 8), and OII used this data to conduct a finite element analysis (FEA) to help predict potential stresses and critical failure points on the hull (see Chapter 9).

Conservation Planning for H. L. Hunley

In conjunction with planning the recovery itself, the project team had to secure an appropriate venue for the conservation and display of the submarine. With no ready-made facility available in the Charleston area, a state-of-the-art conservation laboratory had to be built and outfitted in time to receive *Hunley* as soon as it was raised. To assist with laboratory design, FOTH contracted with the firm of Davis & Floyd Engineering, Inc. of North Charleston, South Carolina, who would manage the design bid of the laboratory. With the assistance of Neyland and conservator Paul Mardikian, Davis & Floyd staff visited conservation laboratories at

Parcs Canada in Montreal, Jefferson Patterson Park and Museum, Maryland, and Texas A&M University Conservation Research Laboratory, College Station, Texas. The information gathered from touring these facilities and talking with the conservators was beneficial to the design team.

With a solid understanding of laboratory requirements in place, the search for an appropriate location for *Hunley's* conservation was narrowed down to two possibilities—a new wing at the Charleston Museum, which would require design and construction, or Building 255 at the former Charleston Naval Shipyard in North Charleston, which had been built as a Navy warehouse but never occupied, due to closure of the shipyard by the Base Realignment and Closure Commission in 1996. As discussions progressed between SCHC and Charleston city and county officials, it was determined that Building 255 would be the best location for a conservation laboratory, since the structure was already built, it was located in an industrial area with access to the Cooper River, and had the requisite floor load capacity for supporting the conservation operation. It was apparent that an expansion of the Charleston Museum, which was adjacent to a historic residential area in downtown Charleston, would require public hearings and new construction would likely not be completed in time for the targeted 2000 recovery date. SCHC Chairman Senator McConnell noted that by renovating the warehouse building, it could also serve as a permanent conservation facility with a longer term benefit to the State of South Carolina. This decision would allow each building to be more effectively designed in accordance with its function and location. The renovation of an existing building would allow recovery and conservation to proceed at an efficient pace. Being in an industrial park would also be more suitable for the conservation process and make it easier to estimate the conservation cost. The location also reduced the transport and handling requirements for the submarine, since it was accessible to nearby piers, and the shipyard cranes, which were on railways, could be used to transfer *Hunley* directly from the barge to the building. The Charleston Museum was still considered as the final repository for exhibit and could then focus on building an exhibit wing dedicated to *Hunley*.

Laboratory design and modification of Building 255 was accomplished through the help of several conservators: Dr. Hamilton, who was contracted with for an overall conservation methodology study and report with ROM cost (Hamilton 2000); Betty Seifert of Maryland Archaeological Conservation Laboratory, who was contracted to prepare a cost analysis for the initial laboratory set up; Claire Peachey of NHC via NPS; and Dr. Jonathan Leader of SCIAA. Building renovation and laboratory outfitting were estimated to be \$2 million and were scheduled to be completed to receive

Hunley by April 2000. Detailed costing for transforming the empty warehouse into a conservation facility was estimated at \$1,036,300, and the initial outfitting of the laboratory at \$843,154. In comparison, the preliminary cost of recovery was estimated to be \$2,405,250. Thus the project was heavily front-end loaded, with the costs totaling \$4,284,704. The long-term conservation, curation, and public interpretation of *Hunley* and its associated artifacts were estimated to cost an additional \$5 to \$10 million over the following ten years (Neyland 1999). Davis & Floyd was selected to design and oversee the renovations. The facility, completed in time for the recovery, was dedicated as the Warren Lasch Conservation Center (WLCC) in August 2000, in honor of the FOTH chairman, who was the principal force behind overall project funding.

Hunley's interior excavation posed a dilemma. *Hunley* was sealed with both hatches closed, which were presumed to be fastened from the inside. It was determined during the 1996 survey and the 1999 testing that the submarine was completely filled with sediment. The submarine's interior dimensions were confined, with a height of only 4.5 ft. (1.37 m) and a width of 4 ft. (1.22 m), and the interior space was taken up with the hand crank, benches, ballast tanks, pumps, and other machinery. This would further restrict the archaeologists' ability to excavate efficiently. How to get into the submarine was as yet an unresolved problem and, once in, excavating would be a complicated and slow process.

Since excavation protocols were still in development, plans had to be made to keep the submarine and its contents stable until they were ready to begin work. In addition, there was concern that fragile organic materials could deteriorate due to bacterial and fungal activity or dry out during the course of the excavation, which was expected to take place over six to twelve months. To prevent the degradation, several options were considered, including total submersion in water, pumping out and refilling the tank daily; refrigeration of the entire submarine and its contents; or use of an inert gas. In the end, it was decided to utilize a large tank of water chilled to a temperature slightly above freezing, to better preserve organic materials and slow the corrosion rate of the iron. The chilled water would be used during archaeological excavation and afterward as a storage medium, until chemical or electrolytic treatment commenced. Recovery and delivery into the chilled water tank had to be a seamless, single process, one in which the lifting frame and the tank worked as two parts of a whole. OII was requested to prepare the design for the tank and plan *Hunley's* delivery and installation therein.

In addition to the tank, the laboratory was equipped with extensive space for small artifact conservation, an x-ray unit, a chilled room for storing organics

and human remains, and a photography area (see also Chapter 7). There was also a darkroom, but the advent of digital photography ultimately limited its utility. The facility was designed to be one of the best-equipped conservation laboratories in North America.

Conservation Symposium

In November 1999, a symposium was held in Charleston to consider the recovery, excavation, and conservation of *Hunley*. The meeting brought together an international group of authorities experienced in the conservation and handling of large iron and steel artifacts from underwater archaeological sites around the world. Ten experts were invited to present papers on their research, participate in discussions regarding *Hunley*, and critique the methods proposed for raising and treating it (Appendix A). These included Drs. Michael McCarthy and Ian MacLeod of the Western Australia Maritime Museum, presenting work with sunken submarines as well as the recovery and conservation of the steam engine from SS *Xantho*; Martin Dean of the University of St. Andrews, on the submarine *Resurgam*; Dr. Donny Hamilton of Texas A&M University, on the conservation of large iron artifacts; Peter Lawton of Treadgold Industrial Heritage Museum, on the conservation of HM Monitor *M33*; Paul Mardikian, senior conservator of the *Hunley* project, on conserving the Blakely cannon from CSS *Alabama*; Curtiss Peterson of the Rescue Corporation, on the conservation of USS *Monitor*; and Drs. Donald Johnson and William Weins of the University of Nebraska, on corrosion and metallurgical research on USS *Arizona* (Figure 5.2). In addition, three papers were presented to update the participants on the previous work conducted on *Hunley* from Neyland, Murphy, and Leader. OII also presented their recovery plan, including the results of the FEA they commissioned, and received important critical feedback.

The main areas of concern participants raised about OII's plan were:

- Maintaining sufficient water for the interior and exterior of the hull during transport, so no damage would be incurred through drying;
- Preparing for the possibility of a significant breach in the hull in the areas that had yet to be exposed, both in terms of hull structure and preventing loss of interior contents;
- Keeping the concretion encasing the hull intact and free of cracks during recovery and transport;
- Ensuring that the additional stress of the lift would not cause the submarine to collapse under its own weight, particularly if rivet strength was significantly compromised.

Water loss during transport was found to be related to the condition of the concrete. If cracks in the concrete could be minimized, this would limit the loss of interior fluids and silts. Some time was spent discussing methods to prevent cracking through elaborate techniques such as consolidation under water, a plastic sheath filled with argon gas, or even a coating of water-retaining gel with sodium carbonate like that used during transport of the *Xantho* engine. It was agreed, however, that it was best not to introduce chemicals into the hull at this stage and that, without any of these measures, 12 hours out of the water would likely only result in some minor cracking, which would be better for the wreck than leaving it in situ indefinitely. OII also discussed its plans for patching any hull breaches, if encountered.

There was a question about whether the submarine would experience increased rates of corrosion during the excavation, and should cathodic protection be employed in situ until it could be raised. However, this process posed a risk of altering the microenvironment inside the hull and would result in more loss of concrete by drilling into the hull plates to attach anodes.

Concerns regarding structural integrity centered on ensuring proper support for the entire submarine, the potential for rivet failure, and the risk of deflection of the hull under the strain of the water and sediment trapped inside. Some were concerned about the reliability of the ultrasonic tests conducted on corroded and concreted wrought iron.

Conservation-related topics were also discussed at length, including proposed methods for gaining access

to the interior without damaging it, issues related to handling human remains, and potential treatments for the hull once excavation was complete. The reviewers were able to shed light on gasses that had developed in the interior, which were encountered during the ultrasonic thickness tests. These were identified as hydrogen, methane, and nitrogen, a common result of reduction and corrosion processes in an anaerobic environment. It was important to be aware the excavation team might encounter more and that it should be sampled for future conservation planning.

These discussions reflected the participants' considerable experience with large iron artifacts and contributed to the improvement of the overall recovery plan. OII implemented several changes to their plan (discussed below), while another company represented at the event, International Archaeological Lifts (IAL), developed an alternate plan based on the ideas and concerns raised at the symposium.

Two Proposals

The two proposals in contention for the recovery contract came from OII and IAL. One centered around a direct lift, while the other favored lifting *Hunley* within its surrounding sediment matrix. Both ideas had been considered from the beginning, and expert opinion varied on the potential success of each method and the likely effects on the submarine. Both submissions were thoroughly reviewed by the HOC.



Figure 5.2. Presenters at the Hunley Conservation Symposium, from left to right, Donny Hamilton, Peter Lawton, Donald Johnson, William Weins, Robert Neyland, Ian MacLeod, Larry Murphy, Paul Mardikian, Martin Dean, Michael McCarthy, and Curtiss Peterson. (Courtesy of FOTH)

Oceaneering International Inc.

As the firm that had conducted the preliminary study for the recovery of *Hunley*, Oceaneering had detailed knowledge of the project and its unique difficulties and was therefore asked by FOTH and the SCHC to prepare a proposal. Their method relied on proven salvage methods, calling for the use of “an all welded steel tube box truss with bolt on bearing seats and a removable sling support system incorporated with load cells for data acquisition” (OII 2000a:2). This large metal structure would be custom built to accommodate the known dimensions of the hull. The truss would be lowered to the seabed, above the wreck, where it would be supported by two rigid cylindrical piles. With the truss anchored in place, divers would excavate around and underneath the submarine to allow the placement of a series of slings suspending the vessel from the truss (Figure 5.3). This method would maintain the same orientation of the hull at which it had been resting since its deposition, protecting it and its contents from sudden shifts, which could result in damage or loss of archaeological context. A crane would then lift the truss and submarine from the seabed and onto a barge for transportation back to shore, whereupon it would be immediately installed at the WLCC. The recovery was scheduled for May, June, and July based on historical weather data, which pointed to optimum conditions of calm seas and less chance of storms in that period.

OII provided a very detailed account of equipment needed, personnel involved, and time table. Diving operations would be mounted from a vessel secured at the site with a permanent

four-point mooring system. This vessel would be mobilized at the Port of Charleston with operations personnel loading diving and excavation equipment, and lifting structures. All stationary equipment such as pumps, dive trailers, and decompression chamber would be welded to the deck of the diving platform.

An archaeological dive team would coordinate with OII divers to excavate around the hull, document and recover artifacts, and rig the truss. The time table was based on a 24-hour operation for both dive teams, to maximize effort and reduce time at sea.

The proposed excavation would encompass an area approximately 40 ft. (12.19 m) wide by 130 ft. (39.62 m) long by 4 ft. (1.22 m) deep. Such a broad area allowed for slope stabilization, diver safety as excavation depth increased, and placement of the suction piles. The goal was to expose one third of *Hunley*, leaving the remaining sediment in place for support until the truss was positioned. All sediment excavated from around the hull would be screened using a custom-built series of sluice boxes mounted on the deck of the dive platform. The hull would be documented by archaeologists before rigging the slings.

Foundation support for the truss and *Hunley* would be provided by suction piles. This type of pile, designed for mooring oil rigs in deep water, requires less penetration than those driven into the seafloor and can be placed accurately. They could be installed with limited vibration and other disturbances to the archaeological site and removed with relative ease. Complete removal of the piles would facilitate a magnetometer survey for small iron artifacts associated with the site after *Hunley* was removed.

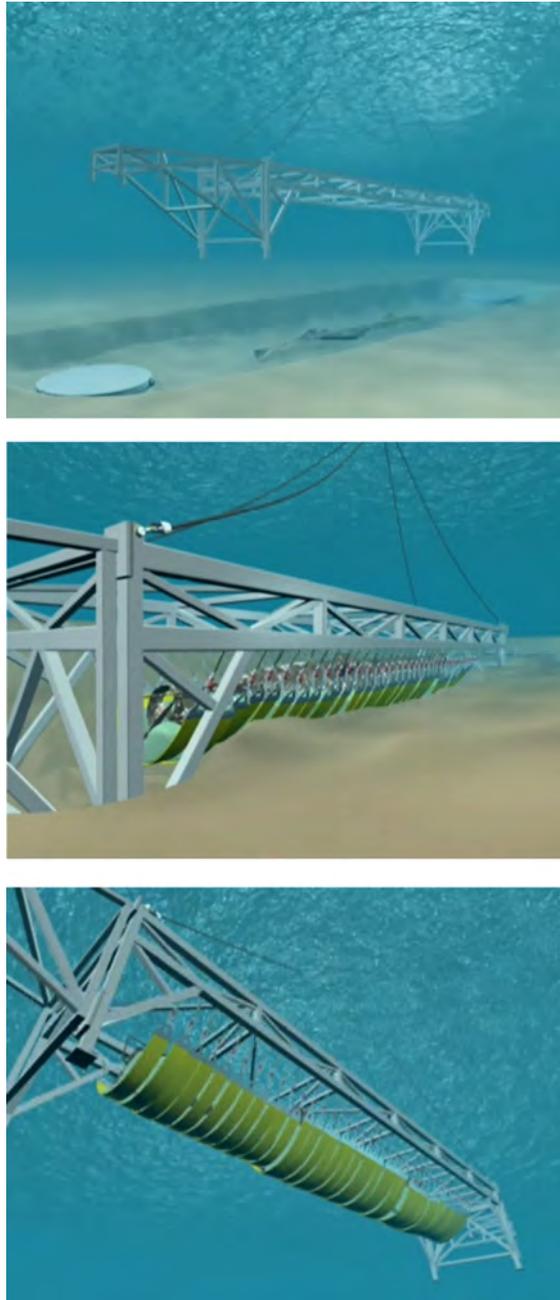


Figure 5.3. Oceaneering created a digital animation of their proposed lift method, demonstrating how Hunley would be rigged in slings beneath a custom-built truss and raised by crane. (Courtesy of OII)

The slinging of the submarine would begin at the bow, removing just enough sediment to place and tension one sling at a time. The process would continue from bow to stern, thus ensuring the weight of the vessel would be smoothly transferred from the surrounding sediment to the truss. The slings would be lined either with foam or neoprene pads to conform accurately to the shape of the hull and prevent hull weight from resting on vulnerable external component. If necessary, OII divers would measure and fit support materials to protect hull features such as the diving planes, keel weights, and conning towers from the rigging elements. Load cells would be placed on the starboard side all of the slings to measure the load on each one. Data from the cells would be monitored by a topside engineer, who, through radio communication, would direct the divers tensioning each sling. This system would measure total weight of the load on the truss and provide an alarm if loads shifted during the recovery. It was also designed to be used during the conservation phase.

The lifting process was reversible and could be aborted. The truss could be returned to its position on the piles, and it would not be necessary to remove the submarine from the slings in case of a hurricane or other severe weather event. The truss was designed to withstand such forces, and by packing the area inside the truss with sandbags, the submarine could be made secure, with an estimated completion time of 12 hours.

Changes Based on Reviewer Concerns

One of the chief concerns raised was that the port side of the hull, subject to stress from the weight of the interior sediment, might warp due to deterioration of the hull plates or rupture due to corroded rivets. This deformation hypothesis was based on the FEA conducted for the hull filled with sand, which would exert an outward force once the sedimentary matrix was removed. Based on this data, the proposal was amended to include an additional set of slings that would be rigged over the port side and attached to the truss on the starboard side. These would be tensioned to fit snugly against the hull to prevent port-side distortion but not to provide an inward force against the port side (see Figure 9.8).

There was considerable discussion of sling spacing among the symposium participants. Since there was concern over the loss of artifacts from inside the hull, OII originally proposed connecting all the slings along their edges to provide continuous coverage beneath the vessel in order to contain anything that might fall out. However, this would interfere with the ability to adjust tension on each sling with precision, which was vital for the prevention of torsion and deflection of the hull. Therefore, the plan was finalized to include slings

that were spaced closely together to provide maximum structural support with the flexibility to distribute the load as needed. A semi-permeable membrane would be slung beneath the whole truss to catch loose pieces, should any breaches be discovered in the hull before lifting.

International Archaeological Lifts

Following the conservation symposium, International Archaeological Lifts, LLC, a Mississippi corporation, developed and submitted their proposal for the recovery of *Hunley*. It was the project of Robert M. Adams of International Archaeological Consultants and Steve James of Pan American Maritime, LLC, a subsidiary of Pan-American Consultants, Inc. of Tuscaloosa, Alabama. Both Adams and James were experienced underwater archaeologists. The third underwater archaeologist, Richard Swete, also had extensive experience. Their engineering team consisted of Jimmy L. Laurence of Laurence and Associates of Corpus Christi, Texas, and William P. Ogletree, a licensed engineer with 46 years of experience in marine and naval engineering. Also on board were Michael Garvey and Ted Price, owners of Crane Company in Columbia, South Carolina, which lifted and moved the 18th century Brown's Ferry shipwreck remains for SCIAA. Rounding out the IAL team was Stevens Towing Company, the largest barge company in Charleston, South Carolina.

IAL introduced their proposal at a 20 December 1999 meeting hosted by the Charleston Museum. They expressed several concerns with the OII plan and put forth a safer method of recovery. Their concerns with the truss lift method were numerous, including:

- The removal of sediment from around the hull might lead to a hull breach from the weight of the sediment inside the hull, which was not structurally designed for such a load;
- The degraded condition of the rivets could increase the likelihood of a hull breach, causing the hull to open like a zipper along the submarine's longitudinal strakes, forcing the bottom half to separate from the top half;
- There was inadequate provision for the comprehensive collection of artifacts outside of the submarine and there would be a lack of archaeological data collection by using commercial divers;
- There was too much potential for damage to protruding hull features, particularly the propeller and rudder assembly, which would be exposed during a truss lift;
- If there were any exposed holes or breaches in the hull, interior sediments and artifacts would drain out, particularly under the stress of going through

the water-air interface, when the slings might stretch and increase pressure on the structure.

Overall, the group thought the OII plan posed significant danger to the submarine and artifacts, with a real potential for catastrophic failure.

In their proposal, IAL quoted the original *Hunley* site assessment: “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 sediments” (Murphy 1998:120). In accordance with this guidance, they planned to use a lifting cradle with hydraulically actuated plates that would capture the vessel and surrounding sediments and deposit the full load into a watertight lifting tray, which would be transported to the laboratory and house the subsequent excavation.

Prior to implementation, the three known magnetic anomalies in the vicinity of the site would be located and removed. They would then excavate an area around the submarine 56 ft. (17.07 m) in length, 20 ft. (6.10 m) in width to a depth not to exceed 7 in. (0.18 m) below the upper part of the submarine. Two guide towers would be installed, one forward of the bow, one aft of the stern, to help position and secure the lifting cradle. These were to be constructed of Y-shaped large round pipe, with 6 × 6 × 2 ft. (1.83 × 1.83 × 0.61 m) footings that would be filled with ballast for stability. The towers could be adjusted vertically and laterally as needed for aligning the cradle.

The lifting cradle would then be positioned over the wreck and steel reinforced plates pushed underneath the submarine, angled at 45°, powered by hydraulic rams. The operation would begin with two opposing plates positioned at midships, and then plates forward and aft of the central plates would be set and closed. The cradle would be equipped with partitioned ballast tanks, which would be inflated until positive buoyancy was achieved. With the cradle thus floating, it would be tethered to the guide towers and floated over the lifting tray, positioned several feet away. While maintaining positive buoyancy, the cradle would be winched down into the tray and securely shackled. After retracting the plates, the cradle would be moved clear, and the lifting tray, now with submarine and surrounding sediments, raised and placed on the deck of the recovery platform for transport to the conservation facility.

IAL mentioned several advantages to their proposal, including sound structural engineering principles, no direct contact with the submarine, and uniform support of the vessel, which would maintain its stability even if its structural integrity had been compromised through the loss of rivet strength. There was no danger of artifacts being lost through a hull breach, the rudder

and propeller assembly would be supported in their exact position, and all fluids would be retained. The method addressed many of the concerns raised at the conservation symposium, and allowed the project to remain highly visible to the public by allowing them to view the excavation in an aquarium environment. The group also offered to demonstrate the lifting technique in advance and stressed that the procedure was fully reversible—the vessel could be stopped and reversed at any time during the recovery (Adams 1999:13). An added benefit was the cost, coming in at \$1,000,000 less than the projected recovery costs of OII’s plan (Adams 1999, elec. comm.).

Wade Logan, IAL’s Charleston attorney, indicated prior to the group’s presentation that the plan disclosed proprietary information, including some 14 possible patents, and since the document would be subjected to public review, certain information could not be shared. Adams gave the presentation to members of the SCHC and *Hunley* recovery team, but stated the illustrations would be left out of the submitted written proposal. However, since many of the specific details about the equipment to be used were not available for review, it was difficult for reviewers to judge the proposal.

The IAL plan met several of the initial criteria that had been recommended after the 1996 survey—recovery of the submarine without compromising archaeological integrity, along with the surrounding sediment as well, so that the submarine and its environs could be excavated in controlled conditions ashore. It went further than the criteria in suggesting the submarine be put in an aquarium-like environment where its excavation could be conducted by divers and witnessed by the viewing public. They planned to do the trial test on 20 May 2000 to demonstrate the feasibility of their proposed method, with a recovery date timed for Memorial Day, 29 May 2000. Overall, the group believed their method closely fit the preferred method given by NPS.

Hunley Oversight Committee Review

As stated above, the HOC reviewed both proposals extensively. The IAL team was considered highly experienced on an academic and technical level. Their method was attractive since it would enable archaeologists and conservators to study anaerobic site formation processes on an iron hull in a controlled environment. However, the committee was unable to evaluate details of the proposal since much of it was withheld due to proprietary concerns. How the plates would be closed and locked into place, how much force this would take,

and their possible inability to lock securely would be detrimental to *Hunley* and the surrounding archaeological context. There were concerns over pushing rams blindly into the sediment, which could damage artifacts and destroy site information, since magnetic data indicated that there were likely ferrous artifacts outside the hull. No weights were given for the lifting tray and its contents; therefore it was not possible to determine crane and barge requirements or floor load requirements for the WLCC. Reviewers also expressed concern that this technology had never been demonstrated.

Perhaps one of the most significant concerns was that of sediment fluidization, as indicated by the analysis from geotechnical engineers. Sediment fluidization, or soil liquefaction, is a phenomenon that occurs when a saturated soil is put under stress and subsequently loses strength and stiffness. In the case of sediment below sea level, which is saturated with water between the grain spaces, the applied stress increases the pore water pressure. The water then attempts to flow out from the sediment to zones of low pressure. There was a real chance that the sediment inside the lifting cradle or lifting tray could liquefy, causing the hull to lose all support and sink to the bottom of the structure. Other concerns were the possibility of an asymmetrical lift due to bottom suction and the unpredictability of buoyancy lifting, especially with currents running 1 and 1.5 knots on site. Finally, the lifting tray did not appear to leave enough room for archaeologists to excavate the sediments, they would be unable to monitor the condition of the submarine in the matrix during the ramming operation or during lift and transport, and excavation in an aquarium might be unsuitable for a site with human remains.

HOC's review of the OII plan also raised some concerns. The questions were more specific to details of the plan, since OII had provided not only the concept but a comprehensive plan. Many of the reviewers' questions were similar to those expressed by the symposium participants. The slings were scrutinized as to their level of adjustability and spacing, as well as the ability of the foam-filled bags to fully support the weight of the hull. The reviewers felt more attention needed to be paid to the proper support of the conning towers and stern assembly. They sought assurance that the recovery vessel would be moored in such a way to prevent damage to the site, and that the suction piles were strong enough to perform as needed. There was concern over the effects of wave surge on the submarine and truss during the lift and the potential for longitudinal flexing of the hull.

From an archaeological perspective, reviewers wanted clarification on how the magnetic anomalies near the hull would be investigated. They also wanted to be sure of containment of artifacts should any spill from the submarine and that the capacity of the sluice

boxes was sufficient for proper artifact collection. It was stressed that all excavations immediately around the hull should be conducted by archaeologists, and that perhaps they should also supervise the placement of the truss.

HOC's recommendations included excavating bow and stern areas prior to positioning the truss, recording the hull sections prior to sling placement, and possibly using a rubber molding compound to hold weak hull areas in place and at the same time mold hull features. Some suggested using sacrificial anodes to protect the hull from deterioration during the excavation. Others felt it would perhaps be worthwhile to spend more time studying the lift methods and postponing the project.

The committee recommended OII's proposal, but wanted their final concerns addressed. All in all, the OII plan was believed by the Hunley Research Center to be based on a sound understanding and interpretation of the results gathered by the last archaeological campaigns" (Mardikian 2000, elec. comm.) Mardikian preferred the OII plan since the process could be "basically controlled and daily monitored." A representative of the NHC's Underwater Archaeology Branch deemed the engineering plans to be satisfactory from an archaeological perspective and recommended that, when adequate funding was in place, recovery of *Hunley* should proceed.

Response to Reviewers' Concerns

Rivets

Concerns over the strength of the rivets holding the plates together was primarily based on one rivet sample taken during the ultrasonic thickness survey, which was found to be completely degraded. The FEA provided several different scenarios for rivet failure. OII used the lowest factor in which their system would work, basing calculations for their recovery system on at least 10% rivet strength. Some of the reviewers shared IAL's concern. Lawton (2000, elec. comm.) thought the rivets should be assumed to have zero strength and to test them not only for shear but eccentric extension as well. Others, such as Johnson (2000), did not believe that one rivet failure was evidence that the others would fail as well. In running the FEA model, it was determined that as rivet strength values reached 10%, anything lower was beyond the failure range, and calculations would be the same for any lift. Only 1 of the 22 rivets sampled was completely deteriorated, and although it was advisable to look at the worst case scenario, the rivets, plates, and concretion layer were expected to be stronger than what was modeled. In addition, NASA engineers gave an independent review and confirmed the results of the FEA model (HRC 2000).

Hull Deflection

There were also questions about possible deflection of *Hunley's* hull. The OII plan hypothesized a possible 1 in. (2.54 cm) deflection over the 50 ft. (12.19 m) length of the truss. In particular, the proposal made no mention of what greater deflection would do to the hull and its protective concretion. OII answered that attempting to create a structure that would reduce the deflection to zero would create additional problems of fabrication and design time, cost, and weight. A small amount of deflection was inevitable, as was recognized at the *Hunley* Conservation Symposium. A taut wire system that would be connected to surface readout tensiometers was also proposed by OII to monitor any stresses on or deformation of the hull in real time. If it was discovered at any time that the hull was being contorted by the lift, the project could be aborted by the project director.

Other Concerns

While some felt a longer planning phase was warranted, the decision to raise *Hunley* in 2000 was justifiable due to the threat of looting and active ongoing corrosion (although occurring at a relatively slow rate). It was hypothesized that the rivets were corroding at a faster rate than the hull itself and, if too much time passed between the engineering plan and recovery, the technical aspects of the lift would become more difficult. Concerns about artifact displacement were addressed by proposing to sling a semi-permeable membrane underneath the submarine, which would allow water to drain but trap any loose artifacts. Large breeches in the hull would be covered and plugged prior to lifting, and a sprinkler hose system would keep the hull wet during transport. Closer sling spacing was

also initiated, with the assurance that the foam bags would expand to fill the spaces in between (HRC 2000).

Since the entire vessel had not yet been exposed, there were some concerns over properly preparing for these unknowns, including the weak stern, the protruding diving planes, the missing torpedo spar, and the known magnetic anomalies close to the hull. These concerns were allayed by scheduling archaeological investigations of these areas during the month prior to the lift, with a plan for locating and removing artifacts as necessary.

OII Plan Selected

The end result of the considerable review of both proposals was an endorsement by the HOC of the OII recovery plan. The IAL submission did not have enough details, and while the technology was innovative, it was also risky. OII provided a detailed and well-thought-out document based on proven methodology. Dudley (2000) officially notified the SCHC of the Navy's approval OII's proposal on 30 March 2000.

The period of planning and review that eventually preceded the recovery of *Hunley* and construction of the conservation facility was a laborious but thorough and necessary process. It was accomplished in a relatively short time, beginning in the spring of 1999 and wrapping up by the beginning of the next year, allowing for the commencement of fieldwork in May 2000 and completion of the WLCC in time for the lift in August 2000. The review by experts in the disciplines of archaeology, conservation, materials science, and ocean engineering was an important step in the development of recovery and conservation plans, allowing for the anticipation and prevention of many potential hazards.

6. Recovery Planning

Robert S. Neyland

Recovery Mission

Three priorities were established for the *Hunley* recovery operation. First was the safety of all project personnel whether in the water, on the work platform, in transit to and from work, or off duty. Safety off the job was as important as while on duty. Absences due to illness or injury would affect the ability to field the required diver teams. Diver personnel were selected based on their archaeological and diving skills and were organized into diver teams that complied with American Academy of Underwater Scientists (AAUS) regulations. The second priority was the recovery of all cultural materials and archaeological information pertaining to *Hunley*, the 17 February 1864 sinking, and its subsequent burial for 136 years. The third priority was the preservation of all archaeological data intact, without damage to the submarine or the integrity of the crew compartment. All of the project pre-planning stipulated that the submarine was to arrive at the conservation laboratory as well-preserved as it was when found within the sea bed. "If at any time during recovery, the submarine is suffering damage, destruction of cultural material, loss of archaeological information, or the integrity of the vessel and intact submarine hull and its machinery are jeopardized, the recovery will be immediately aborted" (Neyland 2000:4). Warren Lasch, Chairman of the Friends of Hunley (FOTH), stated many times during the planning and operation, "We have only one chance to do it; we have to do it right the first time." This position would be put to the test when the original barge slated to perform the lift was found to be too unstable (see Chapter 10). To the credit of all involved, despite the additional costs it would incur, the decision was made to temporarily stand down until a stable platform was obtained.

Recovery Operations Team

The recovery operation was both an engineering and scientific project and required individuals with

diverse talents, including scientists, engineers, commercial divers, and equipment operators. The main functions of the operation were divided between the *Hunley* Archaeological Team (HAT) and the commercial contractor Oceaneering International, Inc. (OII), all under the overall direction of a single project director (Figure 6.1). HAT consisted of archaeologists from federal, state, and private sectors. Federal agencies included the Submerged Resources Center (SRC) and Fort Sumter National Monument (FSNM), both of the National Park Services (NPS), and NHC's Underwater Archaeology Branch (UAB). State agencies consisted of the South Carolina Institute of Archaeology and Anthropology (SCIAA), College of Charleston, and the South Carolina Department of Archives and History (SCDAH). HAT also included a number of independent contractors and consultants. (A complete listing of all recovery operation personnel can be found in Appendix B). The OII commercial contractor's team included an engineer and project manager from Advanced Technologies Division of Upper Marlboro, Maryland, and commercial diving personnel from the Gulf Coast Division, Morgan City, Louisiana. Other major commercial contractors included Tidewater Marine, LLC of Amelia, Louisiana, and Titan Maritime Industries, LLC.

A number of other entities participated in the project either through donation of their services and equipment or as contractors hired for their unique abilities. (Appendix C provides a complete listing of the companies who provided essential services.)

Project Leadership

All recovery personnel, whether federal, state, or contractor, worked under the sole direction of Dr. Robert S. Neyland, *Hunley* Project Director, who was also the principle investigator (PI). The project director reported directly to the Honorable Glenn McConnell, Chairman of SCHC; Dr. William S. Dudley, Director of NHC; and Warren Lasch, Chairman of FOTH. Authority for all

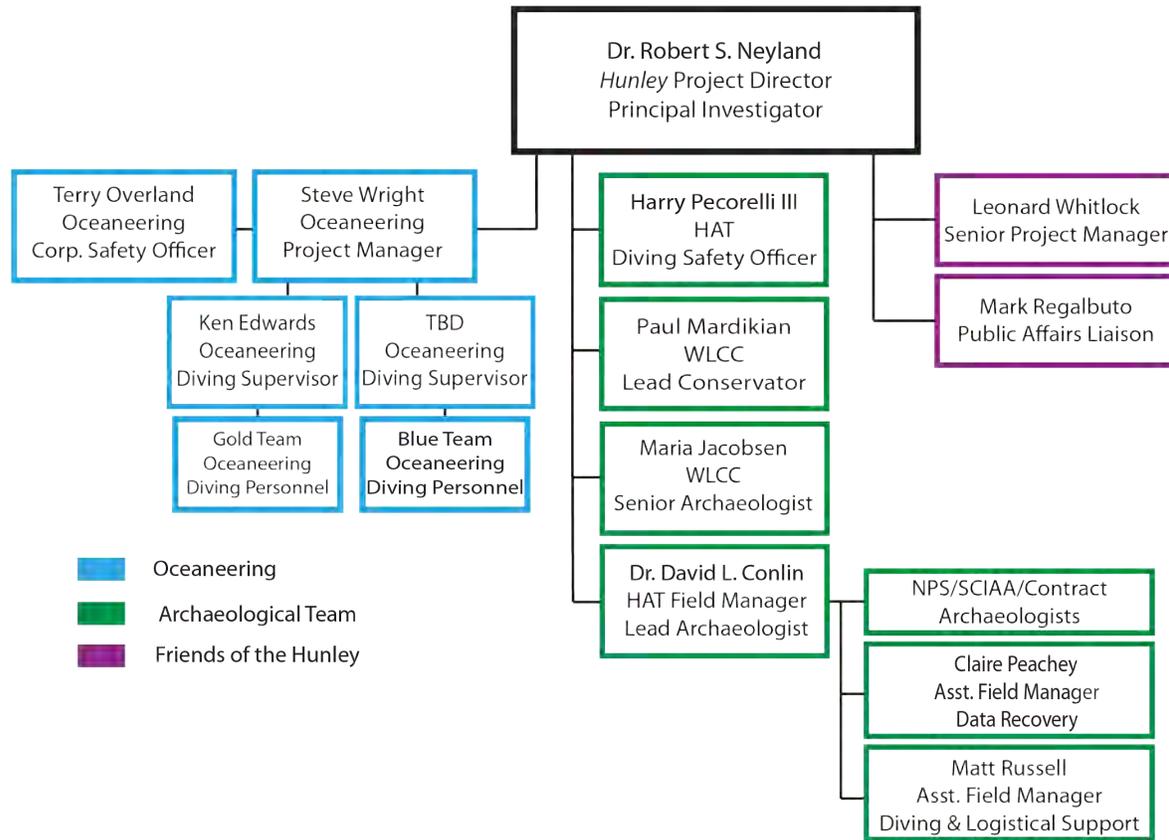


Figure 6.1. The project consisted of personnel from multiple sources organized under a single project director. (Chart by Emily Haver, NHHC)

aspects of the project rested with the project director and included archaeological operations, engineering operations, press coordination, site security, and safety. The PI’s responsibilities included the authority to halt, slow, or change work, if continued activities posed an immediate or future danger to project personnel, *Hunley*, its archaeological information, and/or the human remains on board the submarine. Neyland was able to use his discretion to delegate responsibilities and authority to other key project personnel. The PI had the unique position of being able to represent both the Navy and the State of South Carolina on the project and thus provide a unified chain of command during the recovery.

HAT Personnel and Organization

HAT daily operations were organized under a field manager, with two assistant field managers, a project photographer, two equipment managers, and a diving safety officer. Dr. David L. Conlin of the National Park Service was field manager and was the next in charge of the entire operation when the Project Director was not on site. The field manager’s duties were to oversee

HAT diving, logistics, work schedules, archaeological research, and data collection. He reported directly to the project director and coordinated with OII’s project manager to develop daily work schedules and coordinate the work between the two teams. The field manager was not responsible for work assignments for OII personnel. Likewise OII’s project manager did not assign work to HAT personnel.

In a project of this scale, internal communication was a vital factor in its success and was built into the organizational structure. The field manager developed the daily work plans and provided them to the project director 24 hours prior to beginning each day’s work along with daily reports on the overall activities of the preceding day. This system of reporting worked well until the operation went to a 24-hour operation with two 12-hour shifts. In addition, both the HAT field manager and OII project manager provided weekly reports. HAT’s reports summarized the week’s work, the status of data collection, photography, and diving logistics, pointed out any and all deficiencies in data collection and logistics, made recommendations for correcting deficiencies, and outlined the work to be accomplished in the current week. These reports allowed the project director to see if the mission was ahead, behind,

or on schedule, and brought to light any potential problems that required addressing. The field manager and his two assistant field managers also assisted with drafting weekly press releases.

The assistant field manager for logistics (AFM-L) was Matt Russell, reporting directly to the field manager. He was responsible for organizing the daily dive schedules, structuring work so that it accomplished the goals of the project director and field manager (Figure 6.2). He oversaw the daily and weekly work plans and worked closely with the other assistant field manager to facilitate data collection. He also worked closely with the diving safety officer in maintaining dive and work safety.

Also reporting directly to the field manager was the assistant field manager for data collection (AFM-DC), Claire Peachey. Her role involved overseeing data collection and management, including tracking all individual daily reports, the weekly reports of the project director and field manager, the photo field log, artifact sheets, and artifacts (Figure 6.3). While data collection was every archaeologist's responsibility, the AFM-DC had the responsibility to review each HAT member's reports and request that incomplete or insufficient work be redone. She could also reassign team duties

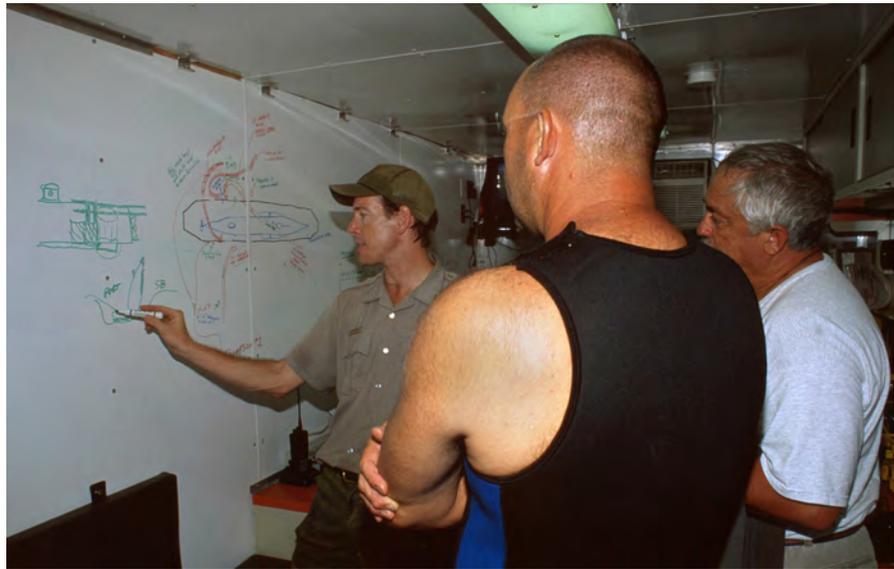


Figure 6.2. Assistant field manager for logistics Matt Russell (left) briefs James Spirek and Ralph Wilbanks on the day's dive objectives. (Courtesy of FOTH)

in order to ensure that data was being correctly logged and cataloged by all archaeologists. HAT team members David Whall and Brett Seymour also assisted Peachey with photographing artifacts. Her duties required custody of the artifacts and samples, and overseeing their proper handling in storage until they and their accompanying records were transferred to the WLCC. She and the senior archaeologist coordinated with one another and maintained a database that inventoried and registered the location and status of artifacts, samples, and other records.

When the project director was absent from the site, the field manager assumed the role. In the absence of both the project director and field manager, command fell to the AFM-L, followed by the AFM-DC. All the commercial and private contractors reported to one of the archaeologists. This chain of command was established to maintain the scientific mission of the recovery project and to prevent salvage from taking precedence over the archaeology.

Other key HAT personnel included Brett Seymour of the NPS, who oversaw all underwater still and video photography for the project, documenting archaeological work both under water and on the surface, as well as archaeological features as designated by project management. He was responsible for ordering and maintaining all project video and photo equipment and coordinating with media teams working on the project. Stills were primarily shot in 35mm color slide and black and white negative film, with limited use of digital, which had not yet reached a resolution comparable to film. Video was recorded with a Canon GL1 3CCD miniDV digital camcorder. Seymour maintained the photographic log, providing copies to the AFM-DC,



Figure 6.3. Claire Peachey, assistant field manager for data collection, finds a dry corner in which to document an artifact prior to transport. (Courtesy of FOTH)

and analyzed coverage to ensure all archaeological aspects of the project were properly documented. Chris Amer of SCIAA provided assistance as needed. Personal photography was discouraged as interfering with the work of the project photographer and the overall work schedule. Also, by limiting the number of individuals taking photographs, FOTH could control the quality of images released to the media. However, as the project neared recovery day, these stipulations were found increasingly onerous to maintain and individuals were allowed to take personal photographs as long as they were for personal use only.

Ralph Wilbanks, private contractor, and Joe Beatty, SCIAA, were assigned the duties of equipment managers. Their responsibilities were to ensure that project equipment such as pumps and boats were serviced and operational at all times. They coordinated repairs and preventive maintenance with AFM-L. As it turned out, Steve Wright of OII also became responsible for maintaining one of the crew boats. It was affectionately nicknamed "Little Elián" after the Elián González affair in the news at that time and the fact that the passengers sometimes felt the need of rescue due to its handling in adverse weather conditions.

Harry Pecorelli III was the HAT diving safety officer. His responsibility was the safety of the archaeological dive team and in the performance of his duties he had the authority to halt a proposed dive, abort a dive, and remove individuals temporarily or permanently from active duty on a dive team. In matters of safety, he did not have to request the concurrence of a higher authority. As collateral duty he was responsible for overseeing overall project safety and safety of HAT members both below and above the water. This included boat safety as well, ensuring that boats were properly equipped and operated safely. Time permitting, he assisted with equipment maintenance. He reported directly to the project director on matters of safety. In his absence, dive safety duties rested with the field manager and his assistants.

While the HAT and Oceaneering diving safety officers were responsible for ensuring safe diving practices during recovery, ultimately all project personnel were responsible for safety as well. All divers were expected to assess the diving situation and evaluate conditions and tasks against their own knowledge of their skills, abilities, and readiness to dive. Project personnel could at any time opt out of a dive for health or safety reasons. While off duty, personnel were requested to conduct themselves in a manner that would not impede their ability to work.

Richard Guobaitis, M.D., and Larry Raney, M.D., both with the Medical University of South Carolina, volunteered their services as emergency medical physicians and agreed to be on 24 hour call during the operation. They were provided copies of medical

records for all diving personnel. Although there were no dive-related injuries, they were called upon at times concerning the health of project personnel and helped to keep everyone safe and healthy.

Hunley Senior Project Manager/Recovery Operations Monitoring

Leonard T. Whitlock, a private contractor, was hired by FOTH to be the *Hunley* senior project manager. As a program manager at Oceaneering Advanced Technologies, he was instrumental in developing the engineering plan for the *Hunley* lift and bringing OII on board as the engineering firm for the operation. After leaving the company to start his own consulting firm, he was subsequently hired to assist with the logistics of the recovery side of the operation. His expertise in all aspects of ocean recovery operations and his industry contacts were indispensable to the project. This was particularly true when it became apparent the project would have to locate another lifting platform. Whitlock traveled to the Dominican Republic to personally inspect the barge *Karlissa-B* and negotiate the contract with Titan for its use. He also assisted the project director with monitoring the recovery operations, scheduling of resources, and budgetary versus actual tracking. In addition, he maintained the action item list, provided diving support to HAT, was a VIP liaison, advised on security issues, and helped with public relations and media coordination. He reviewed and provided status reports of daily activities, weekly reports, expenditures, and management of resources. His background also made him an excellent liaison between HAT and OII personnel.

Oceaneering Project Management

Oceaneering's team was led by project manager Steve Wright, who oversaw the implementation of the OII contract and supervised all of their personnel and equipment. Under him were assistant project manager Doug Dawson, diving supervisor, Ken Edwards, and lead engineer Perry Smith, who designed the recovery system and storage tank. OII's 12 man team included 6 divers, 3 tenders, 2 supervisors, and 1 superintendent. Wright also oversaw the fabrication of the lifting truss and suction piles with the assistance of Smith. He supervised the mobilization and demobilization of the work platforms *Marks Tide* and *Karlissa-B*. He became the principal captain of the small crew boat used to transfer personnel from shore to the work platforms. He reported directly to the project director or his designee, providing weekly reports, and coordinated diving and recovery activities with the HAT field manager (Neyland 2000:9–10).

Senior Archaeologist

Two other key personnel who were part of the scientific team were senior archaeologist and senior conservator. Both participated in the recovery operation, however, their primary responsibilities involved outfitting the conservation laboratory, which was being constructed as the recovery was underway. As senior archaeologist, Maria Jacobsen was HAT's primary on-shore scientific contact, and was tasked with monitoring incoming communications at the *Hunley* Research Center (see below) and at the conservation laboratory. In this capacity she was liaison with the primary construction contractor, Davis & Floyd, and their sub-contractors, gave coordination and oversight for change orders, oversaw the installation and operation of equipment, and provided regular status briefings to the project director (Figure 6.4). She and the senior conservator conducted building and equipment inspections and equipment operations training on the major systems (mechanical, electrical, security, etc.). She also assisted office manager Darlene Russo with coordinating phone and computer services for the new building. While all this was in progress, she also finalized the research design for the upcoming laboratory-based excavation of the interior of the submarine. She developed sections pertaining to the study of site



Figure 6.4. Senior archaeologist Maria Jacobsen inspects progress on the renovations at the conservation facility. (Courtesy of FOTH)

formation processes, hypotheses, objectives, procedures, and equipment requirements. She was also primary liaison with the Smithsonian forensic team and experts in the field in developing a comprehensive forensic protocol.

Senior Conservator

Senior conservator Paul Mardikian addressed all aspects of conservation of the submarine and its associated artifacts. As part of the outfitting of the conservation laboratory, he purchased all necessary chemicals and supplies for the new facility. As mentioned above, he reviewed and inspected work by Davis & Floyd and their sub-contractors. He assisted with any conservation issue that occurred during the recovery, providing on-site expertise as needed, and coordinated with the AFM-DC to provide supplies for stabilizing and storing the artifacts in the field. He oversaw the collection of specific data pertaining to the chemical parameters of the environment of the submarine on the sea bottom. As artifacts and samples were recovered and transported from the archaeological site to shore, he took charge of all artifacts and samples and secured them in the conservation laboratory. During this time, he also worked to develop the overall *Hunley* conservation plan and was tasked with preparing a report on the subject.

Logistics

Shore Support Facilities

The shore facilities included the *Hunley* Research Center (HRC), an office located at 94 Wentworth Street provided by the College of Charleston, the new conservation laboratory (WLCC), and the *Hunley* Recovery Command Post. The HRC was the primary office space for the project for the year leading up to the recovery and while the conservation laboratory was being renovated. Russo supervised this office and managed employees and interns. HAT and OII personnel used this office as well until the WLCC was ready for occupation. The command post was located in an office trailer placed directly behind Fort Moultrie and adjacent to the NPS boat landing used by field personnel. The conservation laboratory under construction was a warehouse building on the former Charleston Naval Shipyard that was undergoing a \$2 million renovation while the recovery project was gearing up and underway (see Chapter 7). Primary renovation was scheduled for completion in mid-May, but the actual occupation of the building did not occur until June. After renovations, the HRC offices were relocated to the new facility.



Figure 6.5. U.S. Coast Guard Cutter Yellowfin was the largest of the security vessels providing an escort for the barge carrying Hunley to North Charleston. (Photo by Captain James Hoffman, USN)

Security

The security plan for the recovery project was designed and implemented by the South Carolina Department of Natural Resources (SCDNR), Marine Law Enforcement Division. Major Alvin Taylor of the SCDNR Marine Law Enforcement Division coordinated security efforts with the Charleston County Sheriff's Office, Charleston Police Department, and the U.S. Coast Guard (USCG). Security was broken into two phases: Phase I, providing safety for the divers and site protection leading up to the raising of the submarine, and Phase II, the security of the submarine and transportation to WLCC. In Phase I, the SCDNR kept unauthorized boats out of the work site by establishing a boating exclusion zone mirroring that Regulated Navigation Area established by USCG. The area was marked with USCG buoys. Law enforcement officers from SCDNR, Charleston County, and Charleston City monitored the area on a regular basis and the *Hunley* recovery team was provided 24-hour access to an officer as needed. Phase II was initiated twelve hours in advance of the lift. After *Hunley* was raised, transport to shore was safeguarded by a moving security escort of nine vessels, including USCGC *Yellowfin* and others provided by SCDNR, Charleston County, and the City of Charleston (Figure 6.5). An additional two boats were assigned to the offload site at Pier Zulu, located at the former Naval Shipyard, to ensure that traffic was kept to a minimum. Radio communication was via hand-held units supplied by Charleston County marine police.

Media Plan

It was apparent from the beginning that, during the recovery, release of information to the media required accuracy, continuity, and an unbreakable line of communication. The Public Affairs Liaison (PAL) was established as the single point of contact with the media and thus, the general public. To fill this role, FOTH contracted the services of Mark Regalbuto and his firm, Advent Media. A strict media plan was developed to ensure that the media could not access information or make requests of decision-makers without going through the PAL, so as not to undermine his credibility and ability to manage the press. The PAL would first consult with the project director before making commitments to the press.

As part of the media plan, a written statement was prepared by the project director that outlined his concerns in regards to safety and guidelines for access and required all media requests be addressed to the PAL. In addition, a media kit was prepared that included a CD-ROM with 10 images, a videocassette of the animated recovery method and design, and other pertinent information. The South Carolina Press Association assisted with the project by verifying press members' credentials.

The newly outfitted WLCC was selected as the best site to hold press conferences and was equipped with the proper staging for both press and staff. A press communication center was also established there in a visitor conference room that was fully equipped with phones, fax, and computer access. The auditorium at



Figure 6.6. Oil project manager Steve Wright, with his dog Bosun, gives an authorized interview concerning the engineering aspects of the project. (Courtesy of FOTH)

Fort Moultrie was selected as an alternate site for the press briefings, should the conservation laboratory not be available.

The decision when to hold press briefings and generate releases was dictated by the amount of new information to be disseminated. However, it was determined that a weekly briefing would be necessary, particularly during key stages of the recovery effort. The official commencement of the fieldwork, anchoring of the pylons, lowering of the truss, and eventual lift would all potentially require more frequent, even daily briefings. Fridays were found to be best for releasing new information, as they would allow newspaper articles and news reports to be made by reporters for the weekend editions. The local newspaper, *Charleston Post & Courier*, requested the project director give daily briefings to its primary reporters, Schulyer Kroft and Brian Hicks.

The press releases were sent out by fax and handed out at the briefing. The releases were the written, synthesized version of the live briefing and did not differ greatly in content. This was to ensure that the press received a consistent and clear message and to limit the transmission of inaccuracies. The initial information

for the release was generated by the project staff and provided to Neyland for review, editing, and approval. The press release was also assessed by John Hazzard V, who was legal advisor to the SCHC and communicated with FOTH. The PAL then reviewed the draft for grammatical errors and formatting, and sent it back to Neyland and Hazzard for final review. Each release had to be signed off by, in order: (1) Project Director, (2) FOTH Executive Director, (3) PAL, and (4) Project Director for final approval.

Official spokespersons were assigned based on their areas of expertise and limited to one person per topic in order to provide clear and precise information, a consistent voice and a regular contact for the press. They were:

- Robert Neyland—Overall *Hunley* Recovery Operation and Archaeology
- Leonard Whitlock—Recovery Engineering
- John Hazzard V—Friends of the Hunley
- Senator Glenn McConnell—South Carolina Hunley Commission
- Maria Jacobsen—*Hunley* Research Center and Warren Lasch Conservation Center

These were the only people designated as official project spokespersons. Other HAT and OII team members were allowed to speak as project participants about their own personal experiences and areas of expertise, but did not identify themselves as official spokespersons (Figure 6.6). When recovery team members and other project personnel were asked questions outside the scope of their expertise or knowledge, they were to refer the media to the appropriate spokesperson.

All of the state and federal agencies involved with the project received press releases via broadcast fax. These principally included the NPS-SRC, NPS-FSNM, NHC, SCIAA, College of Charleston, SCDAH, USCG, and City of Charleston.

Public outreach during the project was a success. The media and the public were eager for information and followed the progress of the recovery closely. The proximity of the site to shore allowed media and VIPs to visit and receive project briefings as well as obtain video and photographs. Information was disseminated effectively through regular briefings and at public media events. The project's news releases were clear, consistent, and accurate.

There was extensive project planning and coordination with local, state, federal, and private entities. The time that went into planning paid off with the successful recovery operation and delivery of *Hunley* to its new home at the WLCC.

7. Warren Lasch Conservation Center

Robert S. Neyland, Paul Mardikian, and Maria Jacobsen

The selection and outfitting of the conservation facility for *Hunley* occurred in parallel with the development of engineering and archaeological plans for recovery. Conservation was known to be the largest long-term project cost and probably the most difficult to estimate in terms of cost and time. It was understood from the beginning that the submarine could not be recovered without having a suitable conservation laboratory to receive it.

While the Charleston Museum was originally considered to house the facility, ultimately a 46,000 sq. ft. (4,274 m²) warehouse at the former Charleston Naval Shipyard was selected (see Chapter 5). Building 255 was still relatively new and had never been occupied either before the closure of the base or under its subsequent proprietor, the State of South Carolina Redevelopment Authority (RDA). The lease could be obtained from the RDA at an insignificant cost. Initially a 7-year lease was acquired but it was decided that a 30-year lease, which would cover the life of the building, would provide a full return on the state's investment (SCHC 2000). Renovation of an existing building allowed both recovery and conservation planning to move forward at a faster pace and saved on construction expenditures—in this case, it could be renovated within six months. The renovation and laboratory outfitting was carried out by the engineering and architectural firm Davis & Floyd, Inc. The State of South Carolina allocated a total of \$3,000,000 in funds designated for the *Hunley* facility (SCHC 2000). In addition to the state funds, the Friends of the Hunley (FOTH) received several substantial donations of services and equipment from private corporations and individuals (Mardikian 2004:138).

Building 255 had several advantages over the Charleston Museum as a conservation facility. It had in place the necessary industrial services and structural requirements including compressed air lines, electrical service of 120, 208, and 480 volts, and water and wastewater lines of adequate capacity to handle the volumes required by a large conservation process. The floor load capacity of 650 p.s.f. (3,173 kg/m²) was sufficient for supporting the tank of water containing *Hunley*. At that

time *Hunley*, sediment, water, and lifting frame were estimated to be more than 60 tn. (54.4 t). The building was large enough for laboratory space, artifact storage, shops, storage, and offices. It could also accommodate the installation of overhead cranes needed for raising, lowering, and moving the submarine. The location was suitable for the dirty and industrial nature of the conservation process, whereas the Charleston Museum was located in a residential area that might require special exemptions from the city building codes.

In developing cost estimates for retrofitting the building and conservation laboratory requirements, several conservators were consulted concerning necessary equipment and operating costs. These included Dr. Donny L. Hamilton from Texas A&M University; Betty Seifert, Head Conservator at the Maryland Archaeological Conservation Laboratory; Dr. John Leader of the South Carolina Institute of Archaeology and Anthropology; Claire Peachey of the Naval Historical Center; and Paul Mardikian of FOTH. The combined efforts of these conservators and archaeologists were essential to outfitting a state-of-the-art marine archaeological conservation laboratory and in estimating conservation costs for fund raising.

The conservation laboratory construction was underway by December 1999 with an anticipated completion date of 28 April 2000, in time for the *Hunley's* recovery to proceed, well within the initial six-month estimate. Davis & Floyd had the design lead and oversaw five principal sub-contractors. These were local firms with the exception of Mid-Atlantic Crane and Equipment Company, who installed the crane support systems. C. R. Hipp was hired to develop the process piping, mechanical, and plumbing systems. Utilities Construction Company would be in charge of the electrical work. Dave Matthews of Harbor Town Construction would conduct the building renovations and site preparation work. Division 5, based in Hollywood, South Carolina, would fabricate the chilled water tank according to the design produced by Oceaneering (OII), the company also orchestrating the lift of the submarine itself. This construction would be monitored

by OII engineer Perry Smith. Greg Beasley was assigned as the Davis & Floyd contract administrator. During a 28 February 2000 meeting of the South Carolina Hunley Commission (SCHC), Beasley stated that half of the renovations were completed and the entire project was on schedule for completion. The majority of the laboratory construction was completed and installation was underway for the analysis equipment, fume hoods, darkroom, cold storage unit, x-ray equipment, and the laboratory furnishings (SCHC 2000).

Some demolition was necessary to install windows that would allow natural light into the work area. This would facilitate the delicate work on artifacts. Window glass was chosen that would exclude ultraviolet light. The Canadian Conservation Institute tested the glass to ensure it filtered the appropriate wavelengths. In the warehouse area where the chilled water tank was constructed, a new loading dock was installed with a roll-up door sufficiently large to allow *Hunley*, suspended in the recovery truss, to enter and be placed underneath the overhead cranes. Outside of the building, security fencing, holding tanks, and associated piping for water and chemicals were installed (SCHC 2000; Mardikian 2004:139).

Wet Laboratory

The renovated conservation laboratory included space for separate wet and dry work areas. The former was located in a large warehouse bay area directly inside the exterior roll-up door, which was already equipped with a floor drain. This roughly 14,000 sq. ft. (1,300 m²) space could accommodate the treatment tank that would house *Hunley* during the excavation of its interior and the subsequent conservation of the hull, as well as additional work space. Large loose hull components, such as the torpedo spar, could be stored and treated in the bay area in their own individual, customized tanks (Figure 7.1). There were two overhead cranes in this area that could manipulate heavy objects in the work area as well as directly over the *Hunley* tank.

Chilled Water Tank

A large steel tank was designed to contain both the *Hunley* and the truss in a fresh water environment during the initial period of examination and the following excavation phase. In order to protect the organic materials inside, it had to be capable of chilling the water enough to slow decomposition. During the excavation phase, the water was kept at an optimal 43.3°F (6.3°C). To provide work space around the submarine and truss, the inner dimensions were 55 ft.

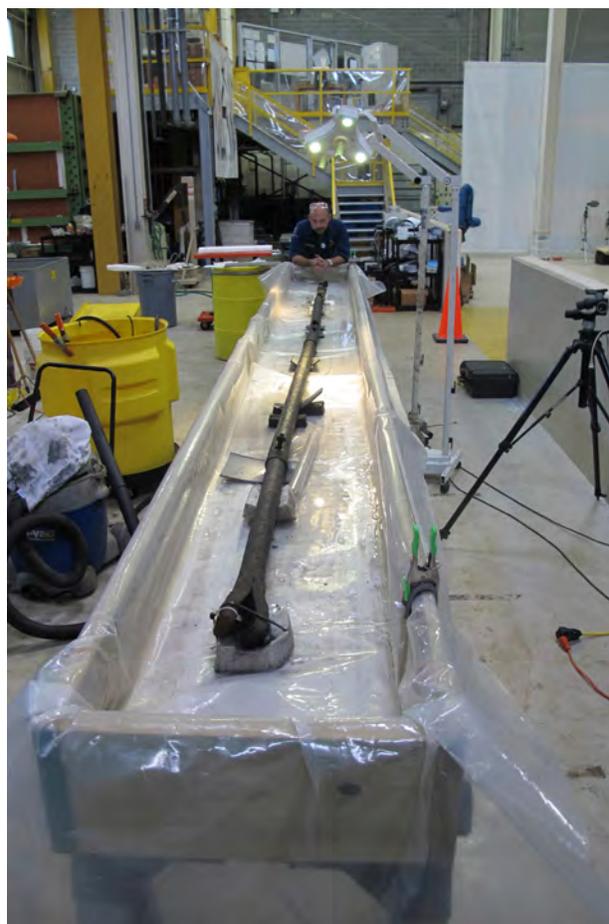


Figure 7.1. The bay area of the wet laboratory held a variety of custom treatment tanks, such as this unusually long one built to hold *Hunley*'s torpedo spar. (Courtesy of FOTH)

(16.76 m) long, 18.5 ft. (5.64 m) wide, and 10 ft. (3.05m) high, for a total of 10,175 cu. ft. (288.12 m³), with a maximum capacity of 76,109 gal. (288,104 L) or 317.58 tn. (288.12 t) of water (see Appendix D for plans). The interior was painted with a chemical resistant coating. Mardikian researched and selected 3M Scotchkote 306, a liquid epoxy coating designed to protect metal and other surfaces from corrosion and deterioration due to a variety of chemicals including sodium hydroxide. Starting from a near-white metal blast-cleaned surface finish, a coat of 10 to 16 mil (0.25–0.41 mm) of epoxy was rolled on, and before completely dry it was followed by the second coat that was sprayed on at a 5 to 10 mil (0.13–0.25 mm) thickness (Mardikian 2000a). Reverse osmosis and deionized water systems were installed for removing chemical ions, particularly chlorides, from the city water.

An elaborate pumping system was developed for chilling and circulating water in the tank and for pumping caustic treatment solutions during the conservation process. At this stage, the builders installed



Figure 7.2. A view of the newly-constructed mezzanine looking down into the treatment tank. (Courtesy of FOTH)

the electrical and pumping systems for both phases, although the conservation treatment would not begin for several years. The initial pumping design included sand filters for water purification, but, after algae problems developed, it was amended to include diatomaceous-earth filters that filter particles to a 20 μm (0.00078 in.) level. A swimming pool skimmer was also added to the southeast corner of the tank to keep the surface of the water clean. The original commercial chiller that was installed failed and had to be replaced. The new one was donated by Aqua Blue Pool and Pentair (Mardikian 2004:144).

The risk from a potential spill if a leak occurred required a 48 in. (1.22 m) high concrete curb to be installed around the tank and bay as a spill retaining wall. This curb had doorways that could be closed with removable doors. The walled-in area encompassed a large general work space, a room for chemical storage, a workshop, an air abrasion room, and showers and dressing room for staff.

It was originally proposed to cover the tank water to improve energy conservation by reducing surface exchange and evaporation loss. A layer of 50 mm (1.97 in.) diameter hollow plastic spheres could be used to create a floating layer over the 1,017.5 sq. ft. (94.53 m^2) surface area of the water. However, this would have impacted both the scientists' and the public's ability to monitor and view the submarine, so this plan was not implemented (Mardikian 2004:140).

Mezzanine

Around the top rim of the chilled water tank, a 1,076 sq. ft. (100 m^2) mezzanine was constructed where the scientists could set up computer work stations and stage for the excavation (Figure 7.2). The mezzanine was

rated at 150 p.s.f. (732.4 kg/m^2) with a 10,000 lb. (4,536 kg) concentrated load (Smith 2000c). An industrial grade touch-screen computer was stationed there to monitor the chemical and physical parameters of the submarine in the truss. The filling and draining sequences could be programmed into this computer. The area also functioned as work space during the excavation to facilitate the removal and temporary storage of artifacts, and as a platform for photography, laser scanning, and hull recording. A rolling bridge was designed to fit over the tank, capable of movement from one end to another, to facilitate excavation and the documentation of the hull. The mezzanine would eventually be the means for bringing visitors to the site to witness the excavation and the submarine. Although not initially intended for tourism, the mezzanine and lab did eventually accommodate this purpose with some modification.

The two 20 tn. (18.14 t) top-running double girder cranes, which were installed over the submarine for its installation, were used during excavation to facilitate the smooth recovery of artifacts and sediment from the submarine and placement onto the mezzanine, or in the case of large items, such as hull plates, directly onto the warehouse floor. The cranes could also support equipment such as an x-ray tube or Cyrax laser scanner. A scissor lift positioned adjacent to the mezzanine was used to lower fragile or heavy artifacts from the mezzanine floor to the lower level, where they could be rolled or carried into the dry lab (Mardikian 2004:139).

Dry Laboratory

The dry laboratory encompassed approximately 9,000 sq. ft. (836.13 m^2) of floor space. This area was constructed with the philosophy of working from wet

and dirty to dry and clean. A roll-up door separated it from the wet lab. Upon entering the area was a cooler for storage of human remains and organic materials. The x-ray cabinet and digital radiograph system were also placed at this end of the lab to document the wet concretions and block lifts of sediment containing human remains, textiles, and artifacts without contaminating the rest of the lab with water or sediment (Figure 7.3). They could then be transferred directly to wet storage in the cooler or the warehouse. FOTH purchased a mobile 300keV x-ray tube that could be used in the cabinet or directly on the submarine. Fuji NDT Corporation donated the digital system, providing state-of-the-art x-ray capability to the project (Mardikian 2004:140).



Figure 7.3. Senior conservator Paul Mardikian inspects the newly-installed digital x-ray unit in the dry laboratory. (Courtesy of FOTH)

The far end of the dry lab area held two climate-controlled storage areas for conserved artifacts, one designed for metal artifact storage and the other for organic materials. Metals would be kept at a lower relative humidity of 30% RH \pm 5% RH, and organics at 50% RH \pm 5%. In the central area of the dry lab were rooms designated for textiles and small organics, analysis, clean work, chemical storage, a darkroom, and several laboratory work tables with overhead fume hoods. An office was also provided for the Senior Conservator as well as a break room and staff restrooms.

A large area of the first floor of the warehouse was left undeveloped and a wall constructed partitioning it from the conservation area. This area would

later be used for a museum and gift shop. The second level of the building was designed for offices and had a ca. 9,000 sq. ft. (836 m²) office floor plan. This was renovated into a suite of offices for archaeological and administrative staff with an SCHC office, a library, drafting area, and a meeting room. The outside area on the rear side of Building 255 required substantial renovation with placement of a concrete pad for a loading dock and six water/chemical storage tanks. All outside piping was electrically heat traced and insulated to prevent freezing.

Cathodic Protection System: Impressed Current

Hunley, in situ off Charleston, was in a low oxygen environment, measured at 1.9 ppm dissolved oxygen and high salinity of 33 ppt chlorides. The iron structure was estimated to be corroding at a rate of less than 0.2 mils (0.0051 mm) per year (Murphy 1998:11). Once recovered, the submarine was placed in fresh water with dissolved oxygen content of approximately 8 ppm. The presence of oxygen is the primary factor contributing to the rate of metal corrosion. Of lesser concern but a contributing factor to differential corrosion is the difference in electrochemical potentials between the submarine's cast- and wrought-iron components. These corrode at different rates resulting in the cast iron potentially being sacrificial to the wrought iron.

During the 1999 *Hunley* Conservation Symposium, the employment of galvanic protection was discussed as a method for preventing further corrosion of *Hunley* during the excavation period. This process usually requires an anode of zinc, aluminum, or magnesium, which have a more negative potential, allowing current to flow to a metal with more positive potential, such as iron. This was highly impractical, however, for to protect the hull and the recovery truss with the required current density of 3.5 A, a total of 50 high-potential 7 × 30 in. (17.78 × 76.20 cm) magnesium anodes each weighing 50 lb. (22.68 kg) would be required. Fifty anode packages would cover 73 sq. ft. (6.78 m²) of the hull. Other problems with galvanic protection included penetrating the concretion to attach the numerous anodes to the submarine's hull, current densities that are difficult to control, and excessive ionic by-products from the anode reactions that would precipitate on the hull and interfere with chloride removal.

Corrosion engineers recommended using an impressed current system, which uses inert anodes and an external electrical power supply to produce current flow of electrons to the metal to be protected, i.e. the submarine (Meier and Mardikian 2004). This method

provided a means of reducing the corrosion rate of the submarine's hull using smaller, less intrusive anodes, and avoided the use of corrosion-inhibiting chemicals that would destroy fragile artifacts in the interior of the hull. The expertise of engineer Craig Meier from Corrosion Control, Inc. (CCI) and electrochemist Steve West from Orion Research Inc. (now Thermo Orion), among others, enabled the conservators to customize the system for *Hunley* to ensure optimal protection.

The impressed current system was installed by CCI and consisted of two 40 ft. (12.19 m) long anodes placed within pre-drilled PVC pipes. The anode selected was 0.125 in. (3.2 mm) diameter wire of inert titanium substrate coated with a layer of plasma-sprayed mixed metal oxide. The PVC pipes protected the anodes from damage and ensured they did not come into contact with the mild steel truss or tank. The anodes were placed parallel to both sides of the submarine to provide the most uniform distribution of current along its full length (Meier and Mardikian 2004:6).

Power for the anodes was supplied by a rectifier unit, which converts alternating to direct current, and feeds it into the submerged anodes. The current discharges off the anodes and, passing through the water, flows through the metal surfaces of the submarine and truss. It then passes out through a negative cable attached to the bow and another on the truss and returns to the rectifier (Figure 7.4). The rectifier, rated at 20 V / 5 A, uses a standard 120 V alternating current to draw 1.6 A (Meier and Mardikian 2004:6).



Figure 7.4. A negative cable for the impressed current system was attached to the bow where the spar was once mounted. A coating of epoxy protected the exposed metal. (Photo by H. G. Brown, NHHC)

One side effect of using impressed current in the presence of chlorides is the formation of chlorine gas (Cl_2) at the anode surface. This is formed when the electrons are stripped from the chloride ions, lowering chloride ion concentrations in the water, and in some cases can be problematic without proper ventilation. In addition, on the surface of the submarine's hull and truss, electrochemical reduction of water and oxygen produce hydroxyl ions and hydrogen ions which evolve as gas, potentially loosening the concretion layer. Any amount of gas produced was relatively small and never presented a safety hazard.

Careful monitoring of the cathodic protection system ensured that conservators maintained a safe and balanced reaction. Six silver/silver-chloride permanent saturated gelled reference cells were placed along the hull for monitoring cathodic protection levels. The level of potential in each reference cell was tracked, using an LC-4 corrosion voltmeter with variable impedance. The rectifier, designed specifically for the project, could automatically adjust the output of the anode in response to detected changes in water chemistry (Mardikian 2004:141–43; Meier 2000:3–4).

Electrolytic Reduction Control System

Once the excavation of the interior was completed, the original conservation plan called for use of electrolytic reduction, a well-established method for stabilization of large archaeological iron pieces. Therefore, although it would be years before *Hunley* was ready for this chemical phase, the wet laboratory was built with the necessary infrastructure for generation and distribution of the electrolyte, in this case a solution of sodium hydroxide (NaOH), sometimes known as caustic (Figure 7.5). Plans included a smaller tank referred to as the electrolysis tank that would fit inside the chilled water tank, which would then become a spill containment tank. Six cylindrical 15,000 gal. (56,781 L) fiberglass holding tanks, 12 ft. (3.66 m) in diameter with a height of 18 ft. (5.49 m), with mixing agitators were set up outside the building for mixing and holding the treatment solution. These could also be used to neutralize solutions as needed. The pumping system included a 300 gal. per minute (GPM) (1,136 LPM) suction pump powered by a 5 hp 115/220 volt, 1,750 rpm electric motor, 240 gal. per day (GPD) (908 LPD) caustic and 240 GPD (909 LPD) acid pumps. A dedicated industrial standard PC operated the control system for the pumps, valves, tanks, and water filtration systems. The electrolysis tank, however, was removed from the building plans to save money during the construction

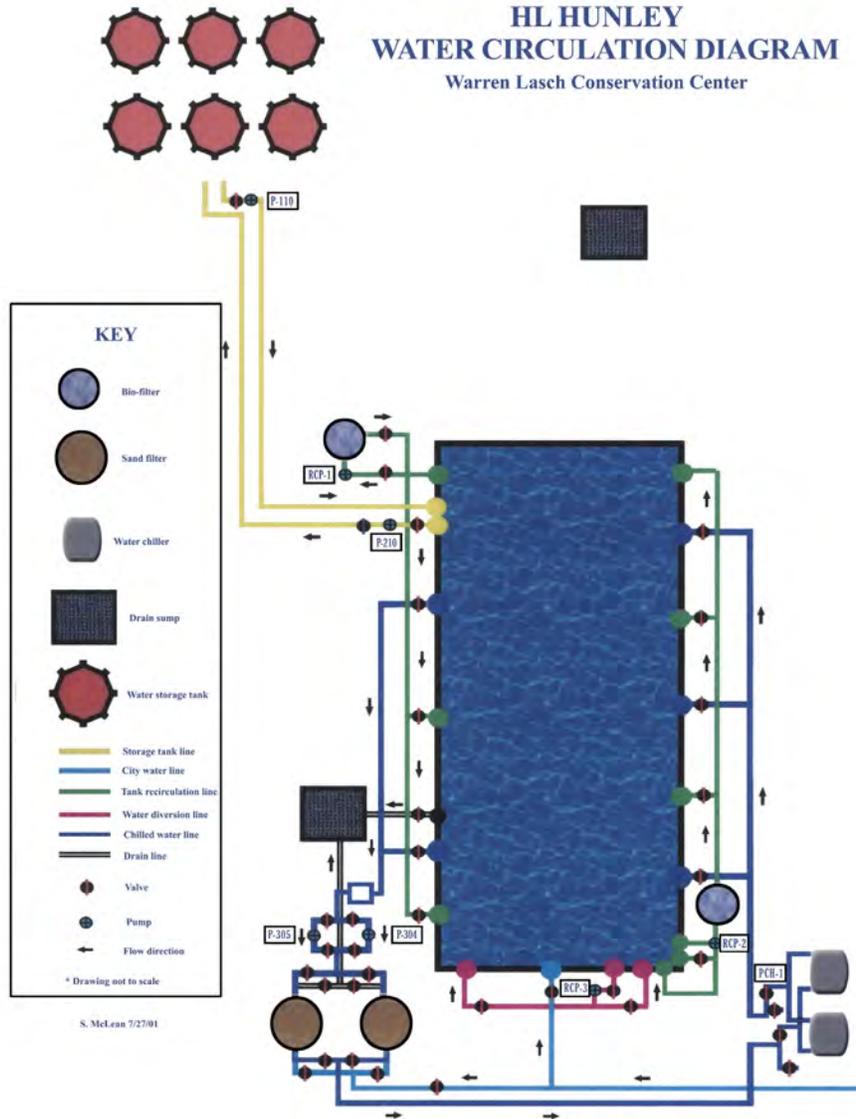


Figure 7.5. Design specifications for the piping system for treatment solution. (Diagram by Shea McLean, courtesy of FOTH)

phase, with the intention to construct it at a later date. Ultimately, the conservation plan was changed to a chemical-based passive soaking treatment, and the electrolysis tank was not required.

Treatment Solution

Preparation of the caustic solution was designed to be controlled by a combination of manual and automatic operations. The operator chooses from the PC control terminal the type of water needed for the solution (deionized or reverse osmosis), the desired tank level, and fill sequence. If required, the control

system starts the reverse osmosis (RO) system. To prevent overflowing, each tank has a level indicating controller (LIC) to track the interior liquid level and indicate when the filling sequence is complete. Once the fill level is reached in any tank, the RO unit automatically shuts down and the control valve returns to the closed position. If after a period of five minutes, all LICs indicate the tanks are not full, the control valve opens and, if required for the solution, the RO unit restarts until tank indicators again show they are full; then the RO stops and the valves close (Davis & Floyd 2000).

The operator then completes the solution by adding NaOH to the specified mixing tank until the desired pH

is reached. The tank agitator starts and operates continuously until transfer of the electrolyte to the treatment tank is complete. A caustic metering pump introduces the chemical into the mixing tank, monitored by a pH sensor and analytical controller. This system contains manual overrides and has the capability to manually conduct a quick-fill. If, during the caustic addition sequence, a high level alarm point is triggered, the pump and solenoid both shut off. Sensors also detect high pressure and low levels, shutting off the pump and solenoid as needed. The control system continuously monitors the pH and temperature in each tank. When the predetermined pH level is attained, the metering pump shuts down and the control valve returns to the closed position. The water is allowed to sit for 15 minutes, known as "dwell time," and if the pH has fallen below the predetermined level, the system restarts and corrects it. Once the pH is reached and remains constant, the control system indicates the solution is prepared and ready for transfer to the treatment tank (Davis & Floyd 2000).

Treatment Tank

The system was designed to allow any chemical solution into the treatment tank only after an operator manually measures the pH and enters the values in the control system for record keeping and to ensure safety. The operator then initiates the fill sequence from the control terminal. The system's safety features deactivate the transfer pump if at any point during the transfer the LIC on the holding tank indicates that the pre-determined low level is reached, or the treatment tank reaches the high level shutoff.

Solution in the treatment tank is continually monitored for temperature, pH, conductivity, dissolved oxygen and chloride level. This data is stored and available to the operator for records and planning purposes. The instruments for monitoring these parameters were donated by Orion Research and Rosemount Analytical. The instruments provide data directly to a Rockwell Automation industrial touch-screen computer donated by McNaughton-McKay. The software for the computer was designed by W. R. Riggs & Associates, Inc. The filling and draining sequences are pre-programmable and do not require manual operations. The system could be monitored from offsite by the conservators through an internet connection. Finally, the DC power supplies that provide current for electrolysis are controlled at a set current based on predetermined settings. Exhaust fans operate continuously while the DC power supply is operating, exhausting hydrogen gas and other fumes originating from the tank (Davis & Floyd 2000; Mardikian 2004:139). The operator can make additions to the solution in the treatment tank by

performing a makeup water sequence from the central computer. The solution can also be transferred temporarily from the treatment tank to a holding tank to allow access to the submarine.

Chemical Disposal

Further infrastructure was developed to adjust the pH of the solution to allow for safe disposal through the city's sewer system. The Pretreatment Discharge Permit required a pH of 6.5 to 9.5. Solutions under or above the required pH range had to be either increased by addition of NaOH or decreased with addition of nitric acid (HNO_3). Before disposal the solution required testing by an independent laboratory and, once approved, released into the sewer at a rate of 25 GPM (95 LPM) (Mardikian 2004:139).

To prepare the chemical solution for release, the operator selects a specific holding tank for acid addition and pH neutralization, and the liquid is pumped into it from the treatment tank. Once the solution is in place, HNO_3 from the acid pump is introduced into the holding tank until the requisite pH is reached. The tank agitator runs continuously during the acid addition and until the draining sequence is initiated. The control system continuously monitors pH and temperature in each tank throughout the dumping process. Although much of the system is automatic, an operator's input is required to drain the neutralized solution to the sewer (Davis & Floyd 2000). During the acid addition and dumping process, if either the high level or high pressure alarms are activated, the pump stops automatically.

Final Outfitting

The laboratory renovation was scheduled to be completed by 28 April, but testing and construction items were still being resolved into July. Mid-Atlantic Crane had a 15-day delay in installation of the cranes due to a shortage of steel, the delivery of which was impeded by weather. There also had to be a change order to strengthen the crane support system. By 12 April, the *Hunley* team was working extensively with Davis & Floyd to finish the laboratory renovations and testing the equipment. Most of the construction and laboratory outfitting was completed during May 2000, although by 27 May, Davis & Floyd contractors were still working on a punch list of unfinished items or ones in need of repair (Jacobsen 2000a, 2000b; Mardikian 2000c). Repairs and final punch list items continued to be worked on through June, with electrical and cooler problems to be corrected, as well as repairs to the tank's coating. Window and roof leaks occurred during

a 27 June storm and had to be repaired (Mardikian 2000d).

As the date of initiating the recovery work drew closer, all of the plumbing, circulation, and deionized and RO systems still required testing. The chilled water tank was leak-tested and the pumping and fill cycles were tested. It was found to take four hours for a complete fill sequence. Also, the darkroom, fume hoods, and sinks had not been checked to see if they were functioning properly. Painting, electrical work, compressed air, and safety equipment such as eyewash stations still required finishing or installation. The mezzanine and tank bridge had not been completed and Smith still needed to check the work. All of the necessary chemicals, storage containers, supplies, and analytical equipment had to be obtained prior to recovery. Bill Williams of Newco arranged for a borescope at no cost (Caperton 2000). Fiberoptic lighting for the *Hunley* tank was obtained through The Schneider Company of Columbia, SC. This consisted of two 40 ft. (12.19 m) long sections of waterproof Optiance A200 Accent Light fixtures containing twenty 3.5 in. (8.89 cm) diameter fixtures (Jordan 2000). Radiation safety certification had to be obtained through the South Carolina Department of Health and Environmental Control (DHEC) and FOTH staff trained in the operation of the x-ray unit and radiation safety. The laboratory also had to purchase and install phone and security systems. Lists of chemicals kept in the conservation laboratory were provided to the North Charleston Fire Department (Mardikian 2000b).

In addition to completing the initial work, a mechanical and HVAC service agreement was required for maintaining the heating, ventilating, air conditioning, refrigeration, and process equipment. Hipp Mechanical Services, Inc. of Charleston provided the periodic inspections and maintenance service for \$14,355 per year. A crane inspection service agreement was also negotiated with Mid-Atlantic Crane (Beasley 2000). As of 18 July 2000, work on the laboratory punch list was still underway, although with fewer items left than previously. Work was being done to install the lift and to replace the chilling unit that was not working. Although the tank had been filled and drained successfully, water below the pump pickup had to be removed with a shop vacuum.

By this time small artifacts from the excavation were being received into the lab and were handled accordingly (Mardikian 2000e). On 23 June, Bill Williams conducted a radiographic survey of the recovered spar. This involved removing the x-ray tube from the cabinet and establishing radiation safety boundaries. Once South Carolina DHEC had been provided with documentation of this survey along with the operating procedures for the x-ray tube outside the cabinet, they issued a facility registration approval for mobile use of the device (Patterson 2000).

Building Security

Security for the laboratory was a concern once the submarine was inside and artifacts began to be recovered from the excavation of its interior. Any item from *Hunley* had monetary value as a collectible historic artifact. Particular hull components, such as hatches or propeller, would be of high value as would any artifacts from the crew. During working hours the building was monitored by a guard who controlled visitor access and monitored exits. The south entrance was the designated entry point for employees and visitors. This entrance was alarmed and could only be entered with an access card or through communication with a video intercom system. Other entrances on the north, west, and east sides were alarmed, and only used occasionally for specific tasks.

The building was outfitted with an alarm system with card reader access control, which was monitored after working hours by Coastal Burglary Alarm Company. The system initially consisted of four zones configured so that one or more zones could be deactivated while other zones were left alarmed. Motion detectors were installed throughout the building to detect movement and glass break detectors installed to detect entry by breaking through windows. Four outside closed circuit television cameras with pan, tilt, zoom, and low light capabilities monitored the approaches to the building. Imaging was recorded on a VHS video recorder system. The fire system was connected to the alarm system, which caused all alarm-controlled doors to unlock in the event of fire. An auxiliary generator would provide back-up power when there was a power failure, although this was not initially tied into the security system. An 8 ft. (2.44 m) high chain link fence ran the length of the west side of the building along the property line, 12 ft. (3.66 m) from the building. Once *Hunley* was inside the facility, North Charleston Police set up regular patrols and placed a marked K-9 vehicle in front of the building 24 hours a day (SLED 2000a).

On 16 August 2000, a security survey was requested by Senator Glenn McConnell's office. The survey team consisted of Lt. Chip Johnson and Senior Agent Bruce Otterbacker from South Carolina State Law Enforcement Division, Chief Clayton Spradley and Security Specialist Tom Scott from Bureau of Protective Services. They made several security upgrade recommendations. To improve security outside the building they suggested installing motion sensors on the roof, crash barriers on the east side of building, and iron bar window protectors and interior blinds on the laboratory area. They also recommended expanding the 8 ft. (2.44 m) high perimeter fencing to encompass the entire facility with card reader controlled access into the parking area; this area could also be microwave alarmed to activate

the security system if there was an unauthorized penetration of the area. Additional recommendations for exterior security upgrades included:

- Set camera system to record when movement is detected;
- Retain recorded video tapes for 30 days;
- Do not reuse previously recorded video tapes;
- Retain digital copies of all recordings;
- Tie all cameras, recorder, and alarm system into a back-up power system;
- Increase view of camera on northeast corner to cover field of view of both rear doors and east side of building.

Improvements to security inside the building focused primarily on increased monitoring in sensitive areas. Recommended upgrades to the security system included:

- Additional movement sensors in upper portion of the treatment tank area;
- Additional glass breaking sensors on the windows located above the treatment tank on east side;
- Securing the computer and other monitoring/controlling equipment located on the mezzanine;
- Two additional pan, tilt, and zoom cameras in the treatment area such that the rear doors and the computer control system on the mezzanine would be covered;
- Positioning the cameras installed for internet viewing of *Hunley* so as not to disclose any security information;
- An additional camera at south entrance positioned to provide full facial recognition of persons entering the building;
- A camera in the north end of the clean lab area to provide view of laboratory area and any artifacts left out in the workspace;
- Glass breakage sensors in the office area;
- A panic alarm for personnel working in the treatment tank;
- A ringdown telephone at the receptionist desk connected directly to the North Charleston Police Department to expedite response time;
- Upgrading alarm wiring to add resistors to the loop so that the system cannot be bypassed.

Other recommendations addressed the risk posed by those inside the facility. They suggested that one staff member should be given security responsibility for

the building, and that extensive background checks be conducted on all potential employees and volunteers. Permanent security personnel should be hired, and, in that event, a security office should be established and the monitoring equipment moved to that location. This could accommodate an additional monitor and recorder for the camera system, to operate in alarm mode, so that a full screen image of an intruder will be recorded after capture on the camera system.

As the excavation progressed and artifacts began moving to various locations in the building, they recommended developing a bar coding and inventory system for small artifacts that are moved from the storage rooms. They also recommended that public viewing should be conducted in small scheduled groups, tours should be staged in another area separate from the lab and chilled water tank area, with members of the public escorted into the viewing area as a group by a volunteer or employee, and viewing should be through a glass panel. In addition, restrooms, which were shared between public and employee spaces, should be secured on the employee side (SLED 2000b).

Not all of these recommendations were feasible but most were accepted and security was upgraded. In addition, after the gold coin was discovered, a system of maintaining precious items in bank safety deposit boxes was established. The Bureau of Protective Services assigned Officer Jay Griffin to be in charge of *Hunley* security and provided other officers as weekend relief and to police the weekend tours (SLED 2000a).

Conclusion

In summary, the building was renovated and outfitted to become one of the most well-equipped, spacious, and efficient archaeological conservation laboratories in the United States. This was accomplished in record time, four to five months. It was done at the same time the final engineering of the *Hunley* recovery was underway and completed in time for the lift. The submarine was successfully delivered into the building and placed in the fully functional chilled water tank without a hitch. Building the conservation laboratory was a unique and unprecedented experience for the archaeologists and conservators, but also for the engineers, architects, and construction contractors. Building 255 was renamed the Warren Lasch Conservation Center in gratitude for FOTH Chairman Lasch's efforts to advance the recovery and conservation of *H. L. Hunley*.

8. Preliminary Fieldwork

Claire L. Peachey and David L. Conlin

From 27 October through 9 November 1999, a team conducted fieldwork on the *Hunley* site to investigate structural details of the hull and to generate data necessary for OII's recovery plan. The objectives of the short project were many: to take thickness measurements of the iron hull plates, to determine the pattern and condition of the rivets holding the plates together, to assess the extent and nature of corrosion of the metal, to partially investigate the previously unexcavated starboard side of the vessel, and to determine the structural character of the sediment layers adjacent to the submarine. This information was crucial for OII's planning and design of the apparatus that would lift *Hunley* from the seabed, transport it to the laboratory, and support it during many years of conservation treatment.

Team members were NHC archaeologist Dr. Robert Neyland, NHC/SRC archaeologists Dr. David Conlin and Claire Peachey, contract archaeologists Harry Pecorelli III and Ralph Wilbanks, OII project manager Steve Wright, *Hunley* project conservator Paul Mardikian, and Dennis Donovan of Coastal Inspection Services, a specialist in ultrasonic measurement of boiler structures and underwater structures. Both qualitative and quantitative measurements were made to assess the condition of *Hunley's* metal. These included recording surface roughness, testing magnetic pull, measuring electrical conductivity, and measuring hull thickness with metal and ultrasonic probes. During the short project, the team retrieved important technological information about *Hunley*, as well as 36 samples (99-001 through 99-036). The results of the project influenced the final recovery methodology by determining hull thickness and sampling of rivets for corrosion analysis.

As part of the same project, geologists Jim Biddle, Card Smith, and Bob O'Kelly from the U.S. Army Corps of Engineers, Savannah District, drilled a 60 ft. (18.29 m) deep sediment core adjacent to the site from the geological research vessel *Explorer*, captained by Tony Maze. The core was to be used for testing the sediment strength, which would directly affect the nature and size

of the piles needed to support the frame to be used for lifting *Hunley* from the seabed.

Archaeologists conducted dive operations from Wilbanks's 26 ft. (7.92 m) Parker *Diversity* using scuba and Aquacom full face masks with wireless communication for dictating data to the surface. During most of the dives the underwater visibility ranged from 0 to 1 ft. (0–0.3 m).

Sample Area

After reacquiring *Hunley's* location, the entire length of the submarine's upper surface was exposed using a 4 in. (10.16 cm) water induction dredge. In order to have access to the submarine's metal plates and rivets, archaeologists removed patches of the obscuring marine concretion from ten small areas of the surface, approximately 10 × 10 cm (3.94 × 3.94 in.) each. The submarine was completely covered in this extremely hard, precipitated concretion approximately 1 in. (2.54 cm) thick. They used a 3 lb. (1.36 kg) hammer and ¾ in. (1.9 cm) metal chisel to carefully crack and loosen the concretion to separate it from the metal surface. The concretion, though extremely hard, cleaved off the surface relatively easily once it was broken, because of a thin layer of flaky corrosion products between the metal and the concretion.

After deconcreting a small test patch, archaeologists chose another area that might hold construction details. During the 1996 partial excavation and mapping of *Hunley*, the team had observed a distinct depression just forward of the aft hatch on the port side, that was thought to be a vertical seam between two metal plates. This possible seam intersected the horizontal expansion strake, a band of metal added to the original boiler plate structure to increase the size of the submarine (see Chapter 12). Therefore, in 1999, the team chose this seam as a promising area to find rivets and other construction features.

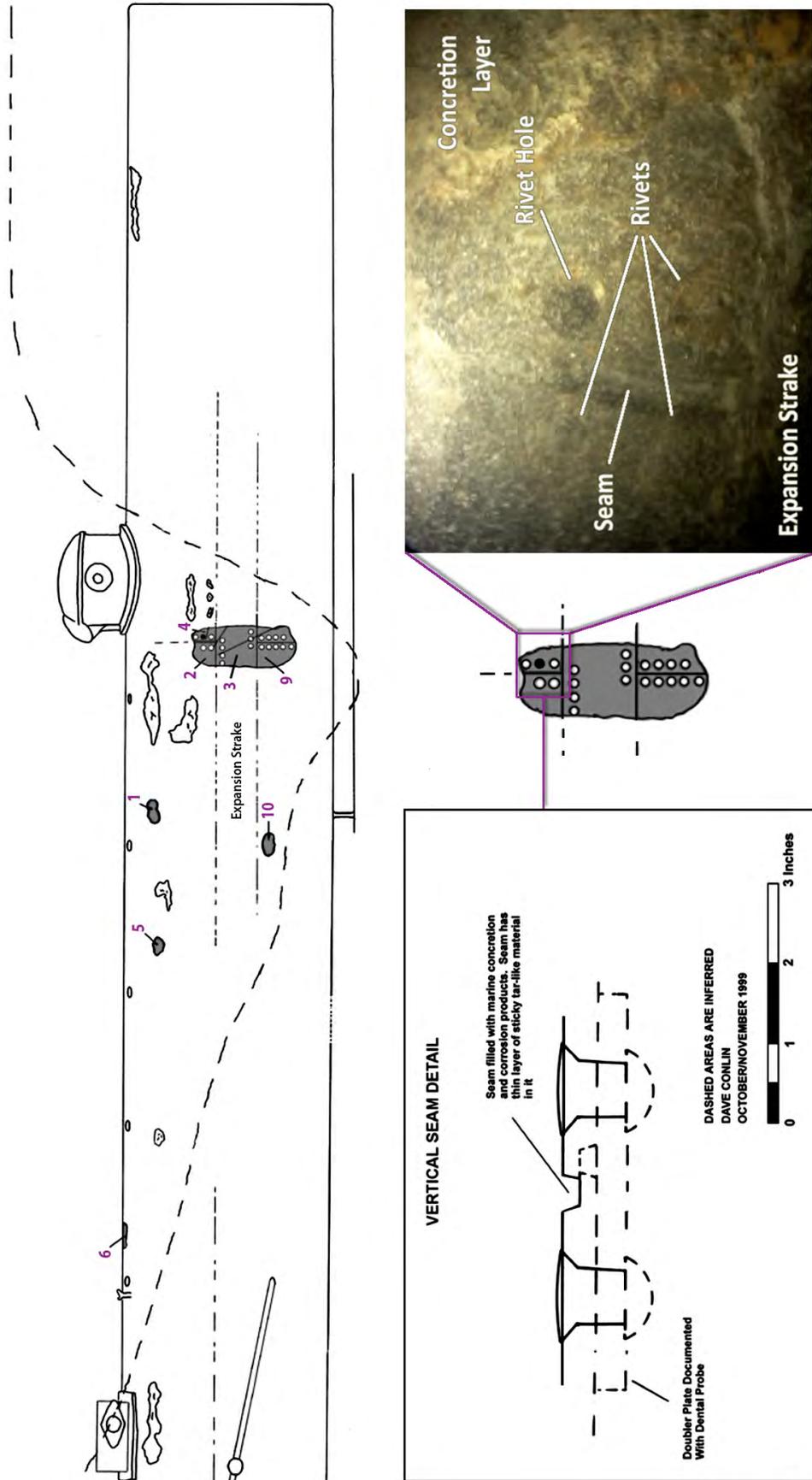


Figure 8.1. Portside view showing thickness testing locations 1–6 and 9–10 (Areas 7 and 8 were located on the starboard side). The area where a vertical plate seam intersects with the expansion strake (photo, lower right) provided a wealth of useful data for the finite element analysis. The missing rivet allowed for limited investigation of the interior seam structure (reconstruction, lower left). (Diagram and photo by David L. Conlin, NPS)

Indeed, this area turned out to hold a wealth of information in an area only approximately half a meter square (Figure 8.1). The depression was found to be a vertical seam between two butt-joined metal plates. The seam was backed by another plate or band of metal of undetermined dimensions. The vertical seam had rivets on both sides of it, both above and below the expansion strake. The expansion strake had rivets along its top and bottom edges where it overlay the edges of the boiler plates.

Because visibility in the muddy water was negligible, Paul Mardikian acquired a dental molding putty (3M Express STD Firmer Set Vinyl Polysiloxane Impression Material Putty #7312) that allowed the team to take detailed molds of the surface of the iron, the rivet heads, and the seams. A diver mixed the two-part putty immediately prior to diving, took it down as a ball, and pressed it firmly onto the surface of the metal. It set in three to five minutes to produce finely detailed molds which recorded subtle features divers could not feel with their fingers. From these, the archaeologists determined that the metal plates (in the areas tested) showed only moderate surface roughness, indicating they might be in a good state of preservation.

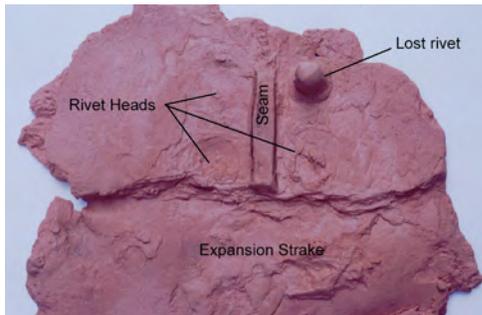


Figure 8.2. Dental putty mold of the seam between two hull plates and the expansion strake. A missing rivet is also represented by the positive impression in the upper right. (Photo by David L. Conlin, NPS)

Rivets

In total, 21 rivet heads were exposed, which were found to be in variable condition. Many could be examined only from the dental putty mold, because they were flush with the metal plate surface and could not be detected by touch (Figure 8.2). The rivet heads had a diameter of approximately 1.063 in. (2.7 cm) and were spaced 2 to 2.25 in. (5.0–5.5 cm) apart, center to center. There appeared to be no difference in the size and spacing of the seam rivets as compared to the strake rivets. All of the exposed rivet heads were lightly corroded, in the form of pitting and metal loss. Two heads were completely corroded away, leaving just a

portion of the rivet shaft surviving. Archaeologists retrieved one degraded shaft using a small flat-head screwdriver and a pair of tweezers. They later sent this rivet to Dr. William Weins at the University of Nebraska, Lincoln, who analyzed it and found it to consist entirely of corrosion products, with no metal remaining (Weins and Makinson 2000). The diameter of the rivet hole exposed was 1.5 cm (0.6 in.).

Expansion Strake

Immediately above the expansion strake, a short length (6.5 cm, 2.5 in.) of the seam was completely cleaned of concretion and found to have an unexpectedly large width of 1.5 cm (0.5–0.625 in.). The depth of the seam was 0.6 cm (0.25 in.), reflecting the thickness of the hull plates at that seam. The plate edges were well preserved, sharp, and slightly beveled. The backing plate exposed at the seam had a slightly tacky surface, which may be traces of a waterproofing material applied either during or after construction.

Time did not permit careful cleaning of the concretion at the top and bottom edges of the expansion strake, so the condition and exact dimensions of those edges could not be determined at that time. However, a rough measurement gave an estimated strake thickness of 0.6–0.7 cm (0.25 in.). During a single rare period of reasonably good visibility, video footage was taken of the newly uncovered features.

Hull Thickness Measurements

A small, L-shaped probe inserted into the hole that had contained the heavily corroded rivet (noted above) allowed direct measurement of the thicknesses of the hull and backing plates in the area next to the vertical seam. Both the upper plate and the backing plate measured 0.31 in. (0.8 cm) each. There was a well-defined gap at the juncture between the two overlapping plates, probably due to corrosion of the plate surfaces. The plate thickness measured in the rivet hole was very close to the thickness measured at the seam, 0.25 in. (0.6 cm).

In order to measure the metal thickness at several widely-spaced, representative points on the hull, including on and below the expansion strake, non-destructive ultrasonic thickness (UT) measurements were performed by Dennis Donovan of Coastal Inspection Services. With this technique, the speed of sound waves traveling through a material can be used to determine the thickness of the material. Each metal has a known velocity based on its grain structure. Therefore, after calibration of the UT transducers for that particular metal, the transducers can measure the

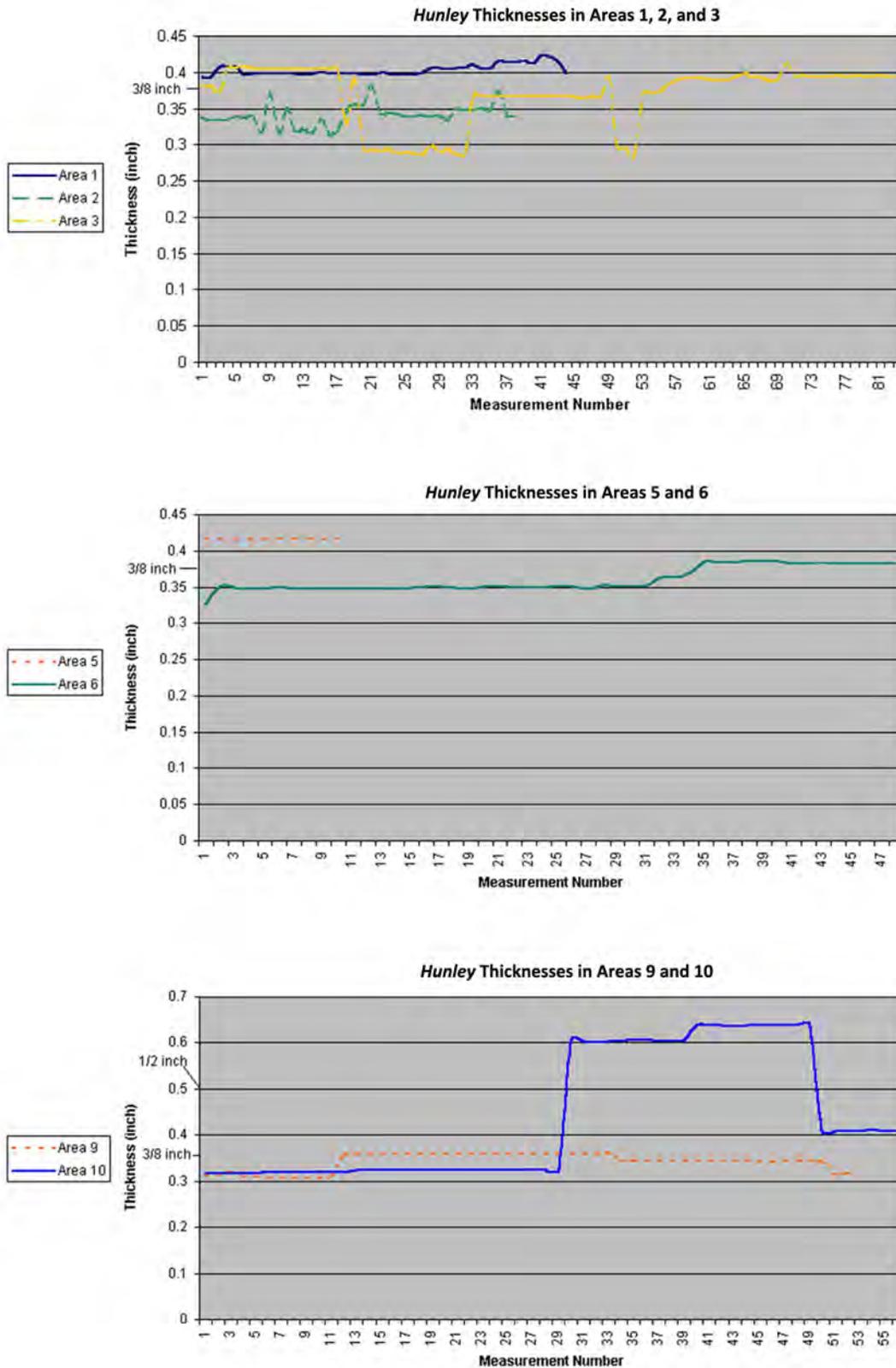


Figure 8.3. Graphs of the ultrasonic thickness readings from the port side of Hunley's hull. (Graphs by David L. Conlin, NPS)

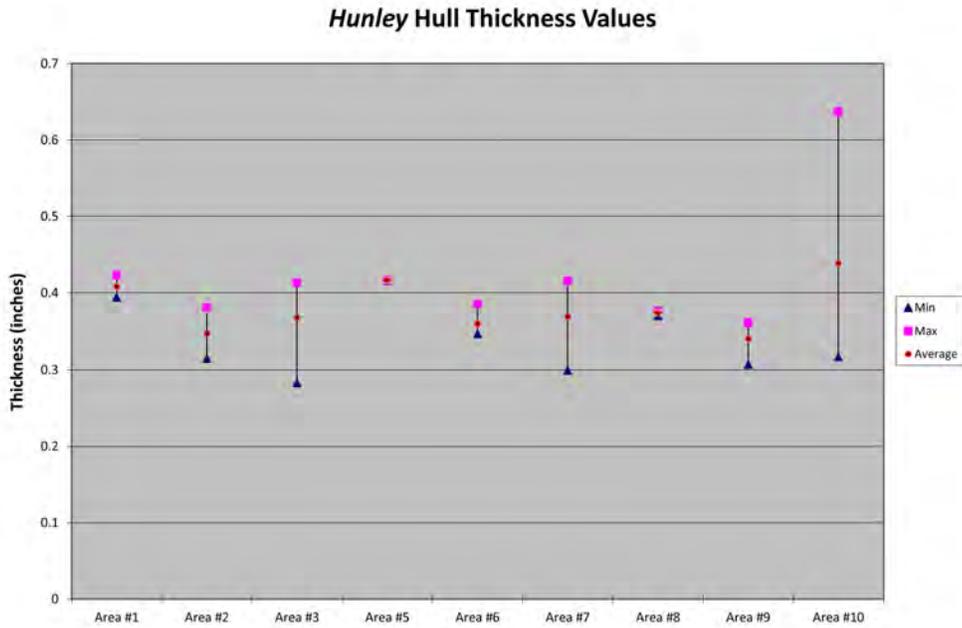


Figure 8.4. Ultrasonic thickness values from nine of the ten test areas on Hunley’s hull. Data from Area 4 was not useable. (Graphs by David L. Conlin, NPS)

time taken for the sound waves to travel from the transducer through the material to the back wall (where an air boundary usually exists), and back to the transducer.

The transducer used was the Auto-V, developed and calibrated specifically for use on cast and wrought iron by Krautkramer Branson of Lewiston, Pennsylvania, manufacturers of UT measurement equipment. It was based on an earlier model developed by the Hartford Steam Boiler Inspection and Insurance Co., Hartford, Connecticut. Because of the irregular, inhomogeneous grain structure of cast and wrought iron, such a custom-designed transducer was needed. The Auto-V had an array of four transducers, two that gather velocity and two that measure thickness; it sampled thickness and velocity four times per second and auto-calibrated with every reading. It used low frequency sound waves, approximately 2 megahertz. To see if it would produce accurate readings on historic iron that had been submerged for more than a century, Branson tested it on a wrought-iron artifact excavated earlier in the year from USS *Housatonic*. The transducer was found to have an accuracy of $\pm 5\%$, confirmed through caliper measurements of the test artifact.

The only way to obtain accurate measurements of hull plate thickness was to ensure the transducer was placed flat against the metal surface. Therefore, the surface had to be smoothed to remove all corrosion and roughness in an area slightly larger than the area of the probe. Archaeologists experimented with several techniques for dressing the hull’s surface. They began with a pneumatic grinder with a coarse grinding wheel but found it too abrasive and difficult to monitor in

the zero-visibility environment. Next, they tried the grinder with a 60-grit sanding wheel but also found it too abrasive. They tested a stiff wire brush and even that was too abrasive. Finally, they settled on hand-sanding the metal surface with 80-grit sandpaper. Although the process was slow, it produced better, more controlled results.

To take the thickness measurement, a diver pressed the probe, which was attached to a cable from the surface vessel, firmly on the smoothed metal surface. Donovan remained on the surface to monitor the ultrasonic instrument and record the results. With

communication gear, he directed the diver to move the probe around on the hull surface until a steady reading was obtained, and then to move it to the next test location. Donovan captured 38 to 83 readings from each of the 10 test locations, except Area 5, from which he captured only 10 readings (Figure 8.3). The thicknesses obtained from the ten areas were quite uniform, averaging 0.34–0.43 in. (8.64–10.92 mm) (Figure 8.4). The range of readings was, however, quite large, with the lowest being 0.283 in. (7.19 mm) (Area 3), and the highest 0.637 in. (16.18 mm) (Area 10). As an experi-

Table 8.1. Mean Thickness of Hull Plates

| AREA | MEAN THICKNESS (IN.) | NUMBER OF DATA READINGS | RANGE |
|---------|----------------------|-------------------------|-------|
| Area 1 | 0.403 | 44 | 0.029 |
| Area 2 | 0.340 | 38 | 0.066 |
| Area 3 | 0.368 | 83 | 0.130 |
| Area 4 | not determined | | |
| Area 5 | 0.417 | 10 | 0.001 |
| Area 6 | 0.360 | 48 | 0.059 |
| Area 7 | 0.369 | 47 | 0.117 |
| Area 8 | 0.374 | 47 | 0.007 |
| Area 9 | 0.341 | 53 | 0.050 |
| Area 10 | 0.439 | 56 | 0.320 |

ment, divers took probe readings from Area 4 without surface preparation, but the data was not useable.

The mean measurements (in inches) from each area are listed in Table 8.1. These values correspond to $\frac{3}{8}$ in. (9.53 mm) rolled iron boilerplate. The smaller thickness values may have been due to loss of metal through corrosion, and the larger values may reflect corrosion product buildup or the presence of additional metal such as a backing plate.

Qualitative Hull Assessment

To assess the residual metal content of the submarine components in a general, qualitative manner, archaeologists performed a simple test of magnetism. They found that a 6 cm (2.36 in.) diameter disc-shaped magnet was strongly pulled when placed near the bare metal surface of the hull plates, and could be removed only with difficulty.

To further assess the condition of the metal in a qualitative way, archaeologists measured electrical continuity between different areas of the hull. Electrical continuity would indicate that the metal components were still in contact, not completely separated by non-metallic corrosion layers. Divers took measurements with a standard ohmmeter modified by attaching long cables between the meter and the probe tips. Results showed that there was electrical contact between adjacent metal components, for example between different rivets and between the rivets and the plates. This indicated that although some rivets may have been completely corroded away, others were in good metallic condition. Measurements taken from more widely separated areas on the submarine did not register continuity, which possibly indicated a discontinuity in the structure, but also may have been due to lack of good contact with the probe tips. Some readings taken on adjacent areas of the same plate did not register continuity, indicating that negative results were suspect. Positive results must also be regarded cautiously, as electrical continuity requires only one point of metallic contact, and is not indicative of overall metallic content and structural coherence. This basic test was perhaps most instructive in confirming metallic content of the rivets, as this had been a question of some concern.

Sediment Samples

The poor condition of the rivet adjacent to the seam provided the unexpected opportunity to take several samples of sediments from the interior of the submarine, through the empty rivet hole. Samples were

taken by pushing 12 mm (0.47 in.) outer diameter rigid plastic tubing (Tygon) into the sediment, which filled the submarine at this level. These samples were placed in a freezer and were used for later microbiological analysis.

Following the ultrasonic measurements, the deconcreted portions of the hull metal surface were covered with an epoxy product, Ameron Devoe Devclad 182 Splash Zone Barrier Coating, to prevent prolonged exposure to the oxygenated seawater, which would accelerate corrosion. The product proved difficult to use for this specific application. The epoxy did not readily adhere to the metal surface, requiring divers to pile sandbags over each patch until it hardened.

To backfill the site at the end of the project, sandbags were positioned around all protruding features such as the forward cutwater, hatches, and the snorkel box. Reversing the dredging process, spoil from the dredge was used to rebury the submarine.

Conclusion

This preliminary work at the site provided valuable data about the submarine's state of preservation and structural integrity. From a very short, but focused, research effort utilizing novel techniques such as dental molding compound and existing expertise for corrosion analysis and UT thickness measurement on a non-standard material (wrought iron), the team was able to produce concrete, scientifically-based information that was key in developing and shaping recovery methodologies.

First and foremost, the research indicated that the hull plating had sufficient thickness (at least in the measured areas) to support the weight of the hull during recovery—particularly during the stresses of the transition from water to air—when lifted from the bottom. The complete disintegration of one of the rivets during the examination was of considerable concern, as it indicated differential corrosion of a key structural element; however, the apparent soundness of adjacent rivets mitigated those concerns a great deal. Finally the indications from probing through the rivet hole that the hull was likely completely (or almost completely) full of sediment provided important evidence regarding the presumed weight of the submarine for recovery planning and also gave the team confidence that these sediments provided some internal support to the hull that would not have been there if the submarine was empty.

In summary the work informed the Hunley Oversight Commission's evaluation of the two recovery proposals, and formed the basis of the finite element analysis used by the engineers to design appropriate lift equipment and procedures.

9. Engineering

Heather G. Brown

The recovery of the submarine *Hunley* represents a level of complex engineering that is rarely associated with an archaeological project. Equipment adapted from oil drilling and marine salvage technologies was applied to the recovery of a fragile, 136-year-old vessel, requiring a degree of delicacy not generally required in commercial industries. Working closely with archaeologists and conservators, the Oceaneering (OII) team developed a plan that surpassed all expectations and resulted in the safe and successful raising and transportation of an invaluable piece of American history.

Several distinct challenges were faced by the engineers planning the lift. First, unlike the competing International Archaeological Lifts plan, the OII plan called for exposing the vessel and recovering it with gear that would come into direct contact with the hull (see Chapter 5). The concretion layer that had developed on the submerged iron was hard and relatively scratch-resistant, but also brittle, so protecting this layer from impact or stress fractures during the lift was important. In addition, during its time on the seabed, the vessel had gradually filled with sediment, making the internal load on the structure much higher than it was designed to bear, particularly when out of the water. It was, therefore, necessary to distribute this additional burden carefully and evenly over the hull to prevent breakage, cracking, or distortion. Tests had also indicated that rivet strength had been compromised, at least in some areas, leading to concerns that the hull plates would separate under the added pressure during the lift (Weins and Makinson 2000).

Second, the submarine had settled on the seabed canted an estimated 45° to starboard. The post-recovery plan was to excavate the interior of the vessel under controlled conditions in the laboratory in hopes of finding out what caused it to sink. This would require a detailed forensic investigation, including recreating the order of deposition of all internal elements. To ensure all possible evidence remained undisturbed, it was necessary for the vessel to maintain its in-situ position during and after transport. Any shifting of position could potentially alter

the interior relationship between the contents or disrupt the stratigraphy of the sediment layers.

Finally, the lift method required that the submarine be slung beneath a large metal frame, or truss. This system required the truss to rest stably on the seabed for a period of several weeks while the hull was being rigged. To provide such a stable platform, a structure needed to be installed in the sea floor without damaging the site. Archaeological experts reviewing the proposed plans expressed concern that vibration from driving piles into the ground could adversely affect the site. In addition, traditional metal piles are normally left behind after use; however, this would have left a strong metal signature that would disrupt further magnetometer survey of the site after the removal of the vessel.

To address these issues, a number of the lifting components were designed and built specifically for the recovery. While customized for the size and shape of *Hunley*, the general design of the equipment and

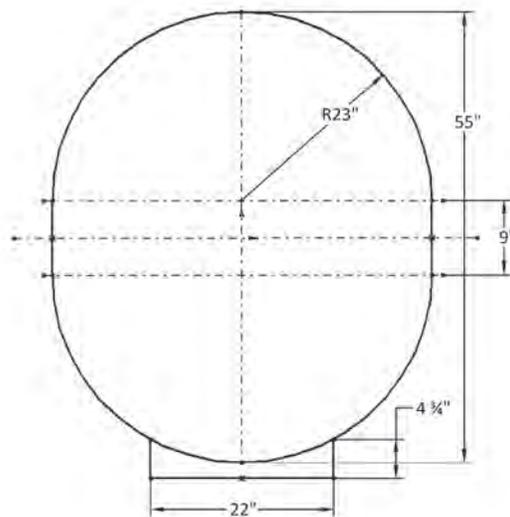


Figure 9.1. Cross section of hull based on measurements taken at the site in 1996. (OII 2000a:31)

adaptations made for the hull's protection may provide a useful model for future archaeological recovery operations.

Finite Element Analysis

In order to design the equipment for the lift, the engineers needed to conduct a structural analysis of the hull based on finite element modeling. This method of modeling the behavior of an object or a system under various hypothetical stresses provided valuable parameters for planning load distribution and support structures, as well as identifying critical areas of potential failure. In particular, they wished to test the inherent strength of the hull and to project how much the hull would move once its weight was transferred to the slings. To perform the analysis, engineers ideally needed to know:

- Dimensions, including shape and hull thickness;
- Material properties including modulus of elasticity, yield, and ultimate strength of all parts;
- Rivet details, including size and pitch;
- Density and amount of contained material.

As the geometric shape of an object is an essential factor in finite element analysis, a cross section was developed based on measurements taken during the 1996 survey (Figure 9.1). Described as “obround,” the main body of the hull has two parallel sides with a semi-circular top and bottom (OII 2000a:28). Hull thickness data was gathered during the preliminary fieldwork in November 1999 (see Chapter 8). The hull was made of wrought-iron plate, which varied somewhat in thickness, but a minimum average thickness was calculated at 0.340 in. (8.636 mm) for use in the model (OII 2000a:29).

The material properties had to be supplied based on the known properties of wrought iron. The size, pitch, and spacing of the rivets were recorded during the November 1999 expedition. The material inside

was assumed to be sand, and an applied pressure for submerged wet sand of 0.5 p.s.i. (0.345 bar) was used (OII 2000a:36).

Based on the rivet analysis conducted in 1999, risk of rivet failure was deemed high. A number of models were generated using different rivet strengths, primarily by altering the elastic modulus and elemental thickness of the hull. The models showed that even at an 80% reduction in rivet strength, there was little chance of rivet failure as long as the hull remained uniformly loaded (OII 2000a:52). As a result, the recovery plan was amended to include additional slings that wrapped around the unsupported top portion of the central hull area to minimize movement and to apply a uniform pressure to the hull (see Figure 9.8).

Recovery Frame (Truss)

The primary component built for the recovery was the frame, which would cradle the hull and bear its load. Described by the engineers as “an all welded steel tube box truss,” this was a long rectangular metal frame from which *Hunley* would be suspended in slings (OII 2000a:2); it was also fitted with legs high enough to provide ground clearance for the hull once on land (Figure 9.2). The OII design team was led by engineer Perry Smith, and fabrication was performed by Able Iron Works of Charleston, South Carolina.

The frame was designed using the dimensions of the hull gathered during the 1996 site assessment: 39 ft. 5 in. long (12.01 m) (without propeller and rudder assembly), 3 ft. 10 in. (1.17 m) wide, 4 ft. 3 in. (1.30 m) high (Murphy 1998:76). Built to accommodate the hull and slings with a span broad enough to support the vessel at its in-situ orientation, the frame was 50 ft. (15.24 m) long, 10 ft. (3.05 m) wide, and 10 ft. (3.05 m) high. Based on the reported dimensions, the hull volume was estimated at 400 cubic ft. (11.33 m³) (OII 2000b:App. E). From this, the weights of both the hull and the sediment/water load contained within it were calculated (Table 9.1). Applying a 150% margin of

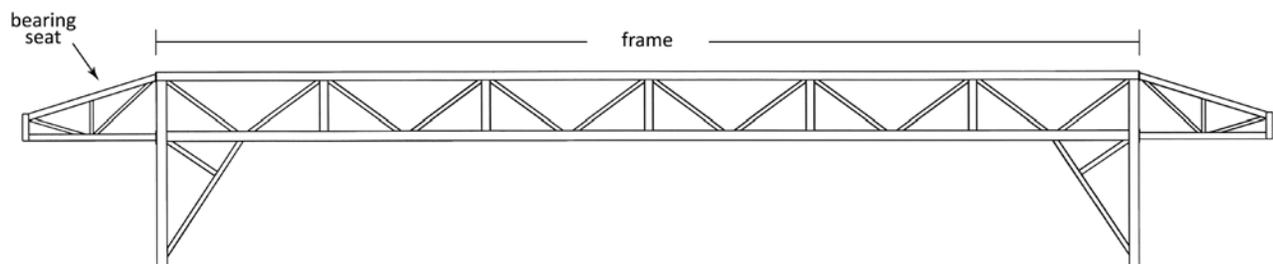


Figure 9.2. Side view of the construction plan of the recovery frame with bearing seats attached. (After OII 2000b:App. F)

Table 9.1. Gravity Load Data

| Component | Estimated* | | Estimated with Error Margin** | |
|-----------------|------------|--------|-------------------------------|--------|
| | lb. | kg | lb. | kg |
| Hunley (hull) | 23,975 | 10,875 | 25,000 | 11,340 |
| Sediment Load | 34,500 | 15,649 | 50,000 | 22,680 |
| Truss Dead Load | 22,000 | 9,979 | 22,000 | 9,979 |
| Total | 80,475 | 36,503 | 97,000 | 43,999 |

* Source: OII 1999b

** Source: OII 2000b:App. E

error to the live load for safety, the truss was designed to accommodate a gravity load of 75,000 lb. (37.5 tn., 34.02 t) (Smith 2001).

The total weight of the hull, contents, and frame needed to be within the capacity of the two cranes that would be used to install the vessel in its tank at the conservation lab, which were rated to 20 tn. (40,000 lb.; 18.14 t) each (STI n.d.:1). To minimize the weight of the frame itself while maintaining maximum bearing strength, it was constructed of a combination of rectangular and square steel hollow structural sections of ASTM A500 Grade B steel (Smith 2001). The bottom braces, from which the submarine would hang, were the most robust, at 8 × 6 × ½ in. (20.32 × 15.24 × 1.27 cm). The legs were 6 × 6 × ½ in. (15.24 × 15.25 × 1.27 cm), while the diagonal and cross braces ranged from 3–5 in. (7.62–12.7 cm) square and ¼–⅝ in. (0.64–0.95 cm) thick (OII 2000b:App. E). The finished frame, without the bearing seats (discussed below), weighed 17,730 lb. (8,042 kg) (Smith 2000b).

From an engineering perspective, the structure had to fulfill two roles—while rigged to the suction piles under water it was a long span truss, but on the surface, supporting the submarine on its legs, it was a braced frame (Smith 2001). As part of the long span truss, a bearing seat, roughly triangular in profile view, was welded to each end of the frame (see Figure 9.2). The pieces would anchor the frame to the piles in the seabed, creating a level and stable environment for rigging the slings. Once the lift was completed, the bearing seats would be removed, as they were no longer needed and could not fit within the storage tank at the conservation laboratory. The full span of the truss with the bearing seats in place was 62.5 ft. (19.05 m).

The top chord plan utilized vierendeel panel openings, a structural style that eliminates cross bracing, to allow better access for the divers (Smith 2001) (Figure 9.3). Chevron braces along the sides were added to withstand lateral forces from currents, wind, and vessel motion, as well as horizontal forces from the gravity load of the submarine in the slings. The bracing design was so effective that the total displacement of

the bottom brace after the lift was 0.625 in. (1.59 cm) over 50 ft. (15.24 m) (Smith 2001). Ultimately, the frame could remain stable in a current of up to 2 knots or winds up to 100 mph (161 kph) and “withstand to 2 g vertically, 0.2 g longitudinally and 0.4 g laterally” (Smith



Figure 9.3. A view of the top of the frame in the chilled water tank. The wide openings provided by the vierendeel structure maximized diver access to the submarine during the recovery process. (Courtesy of FOTH)



Figure 9.4. The soaker system designed to keep the hull wet during transport utilized ordinary sprinklers and pumped seawater. At left are the burn marks left from removing the bearing seats. (Photo by Rand Pixa, courtesy of FOTH)

2001). It would be safe during storm surges associated with hurricanes, and, in the event of such a storm developing, the frame could remain in place on the seabed and provide some level of protection for the submarine, even if only partially rigged.

Another important consideration in the frame's design was the fact that it would remain submerged in the conservation tank during the full duration of the interior excavation of *Hunley*, as well as in a chemical solution during the conservation phase, an estimated 8–10 years. Therefore, all welds had to be made watertight to prevent corrosion, and a corrosion-resistant coating compatible with the electrolyte applied to the entire exterior surface of the frame. Two coats of Sherwin-Williams Dura Plate 235 epoxy were applied after an SSPC-10 surface preparation (Smith 2001). The straight lines and flat surfaces of the hollow structural sections made both processes more efficient and economical (STI n.d.:2).

To keep the submarine wet during transport to the laboratory, a soaker system was installed on the truss (Figure 9.4). While this system was relatively simple, consisting of ordinary lawn sprinklers installed along alternate cross braces, connected to hoses supplied with seawater, it was thorough and easy to install quickly. *Hunley* was out of water for a total of 9.5 hours, during which time it was never allowed to dry out.

Suction Piles

A stable support foundation was required to support the truss on the seabed while the slings were being rigged. The engineers selected suction piles for this purpose. It was a proven technique developed for mooring deep-water oil rigs and had been safely in use

by oil companies for some time. As discussed above, this style of piles could be installed without vibration, and could be easily removed so as not to interfere with future magnetometer investigations of the site.

Suction piles are hollow, metal cylinders, or caissons, closed on the top with a valve through which water can be pumped out. They are placed on the seabed and allowed to sink into the seabed under their own weight (known as self-weight penetration), which forms a seal that will enable the development of differential pressure once the pump starts. This pressure drives the caisson smoothly into the seabed until the caisson has reached desired penetration depth. Once set, the upper surface, or caps, of the piles act as table tops to support the ends of the lifting truss. The caissons are removed simply by reversing the pump, channeling water into the caisson, forcing them up out of the seabed, where they can be lifted back to the surface by crane.

All suction piles are individually designed for their specific use. Two of the primary factors to consider during the design process are the soil composition and the required holding capacity. The latter had already been calculated for the truss design and came to approximately 75,000 lb. (34,019 kg). Sediment properties were gathered from the 60 ft. (18.29 m) core samples taken by the Army Corps of Engineers during the November 1999 investigation. For predominantly clay-based sediments, suction piles are generally long and narrow, while for sandy sediments they tend to be as wide as they are high (Delft 2006). Analysis of the cores allowed for the calculation of skin friction, which in turn determined the depth of penetration required. In the case of *Hunley*, another factor was the shallow water depth, which called for a large pile cap area, thus

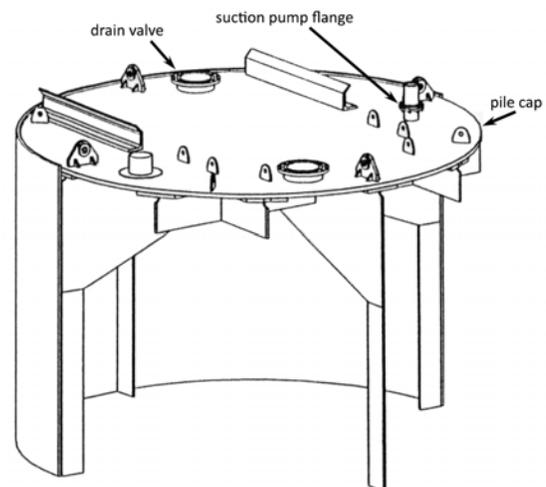


Figure 9.5. Three-dimensional cutaway view of caissons designed to support the recovery frame. (Oll 2000b:App. D)

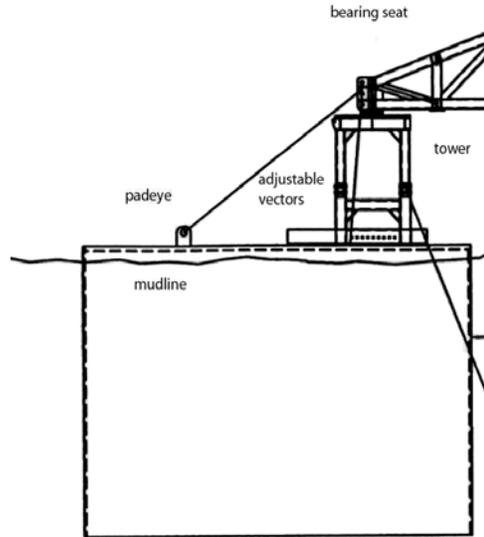


Figure 9.6. Profile of suction pile as installed, with adjustable tower table for the bearing seat. (OII 2000b:App E.)

the diameter of the pile needed to be wider than the penetration depth (Smith 2001). The caissons designed for the *Hunley* by Delmar Systems, Inc. of Broussard, Louisiana, were 12 ft. (3.66 m) deep and 18 ft. (5.49 m) in diameter. They were made of 1.5 in. (3.81 cm) thick ASTM 572 steel with internal bracing (OII 2000b:App. D) (Figure 9.5).

The pile cap was equipped with two 16 in. (41 cm) diameter drain valves, a 4 in. (10.16 cm) diameter suction pump flange and padeyes for attaching lifting cables, features common on most suction piles. For the *Hunley* lift, a specially-designed adjustable tower was added to receive the bearing seats of the truss (Figure 9.6). These platforms, 13 ft. (3.96 m) long by 3.5 ft. (1.07 m) wide, could move vertically ± 12 in. (0.30 m) for



Figure 9.7. Fully rigged suction pile being lowered into the water. Depth markings can be seen down the side of the pile wall at left. (Courtesy of FOTH)

a total of 24 in. (0.61 m); horizontally they could move 15 in. (0.38 m) parallel toward and 24 in. (0.61 m) away from the submarine (Smith 2000a), thereby allowing for a limited margin for error in placing the piles.

The suction piles were marked with depth indicators so they could be monitored by divers during the installation process. A dry land training exercise was performed with the recovery equipment so that potential problems could be anticipated and corrected. For installation, the caissons were rigged topside, then lowered by crane to the seabed and guided into place by divers (Figure 9.7). The seabed was prepared in advance, with an area approximately 20 ft. (6.1 m) in diameter and 5–6 ft. (1.52–1.83 m) deep excavated down from the mudline to receive the caissons, to ensure stability. The divers also monitored the evenness of pile caps and penetration rates during suction operations.

Once in proper position, divers closed off the flooding valves with blind flanges to prepare the pile for pumping the water out of the pile. A submersible pump was installed on the pump flange and suction operations commenced. One OII diver monitored the pile penetration depth while a second monitored the pump from the pile cap during water evacuation. Pump pressure, gauge pressure, pile level, and penetration depth were continually monitored. The penetration rate, calculated using 10 p.s.i. (0.69 bar) and 500 GPM (1,893 LPM), was expected to be 3 in. (7.62 cm) per minute for a total of 48 minutes to suction down each pile (Smith 2000a). In practice, the total time was closer to 60 minutes.

The piles were removed with no complications on the day after the lift. Divers attached lifting cables to

the pile, and a pump attached to the suction pump flange. With the crane applying constant pressure to the cables and the pump reversed to flood the caisson, the skin friction of the sediment was overcome and the pile pulled free of the seabed. Both piles were raised to the surface and placed on the deck of *Karlissa-B*, leaving the seabed clear of intrusive structures.

Slings

The use of flexible nylon slings to support the submarine provided even distribution of weight along the whole system while allowing for individualized padding and rigging of each segment of the hull. By excavating only a short length of the hull at a time, each sling was set and tensioned to support the vessel in the exact position in which it was resting in the seabed.

The slings were custom made for the recovery by LiftAll of Landisville, Pennsylvania, in conjunction with Southern Weaving of Greenville, South Carolina. Since the slings would be supporting the vessel for the next decade to come, they were designed with strength, flexibility, and endurance in mind. Nylon was chosen since it would not deteriorate in a sodium hydroxide solution, the electrolyte proposed for use during *Hunley's* conservation phase (OII 2000a:16). The primary slings, 32 in all, were rigged beneath the vessel to support its weight, and were 12 in. (30.48 cm) wide, spaced on 15 in. (38.10 cm) centers (OII 2000b:9). They had an estimated working capacity of 16,000 lb. (7,258 kg) and 6% stretch when fully loaded for a maximum stretch of 1 in. (2.54 cm) (OII 2000a:16). Woven into the fabric at regular intervals along the edges were 1 in. (2.54 cm) square holes protected by grommets that could be used

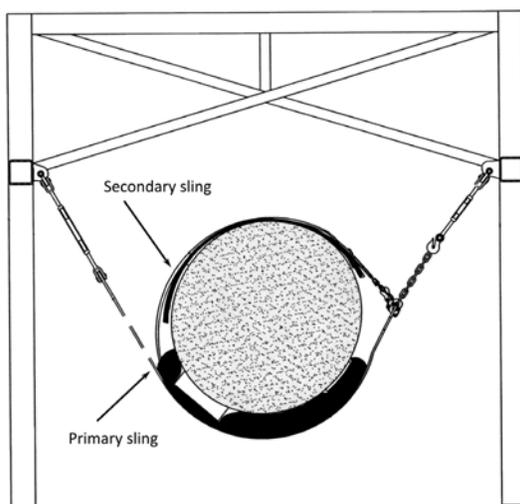


Figure 9.8. Diagram showing proposed placement of secondary slings for added stability. (OII 2000b: App. F)

to attach padding elements if necessary. The slings were hung from the bottom braces of the frames using 12 in. (30.48 cm) turnbuckles on the port side and 6 in. (15.24 cm) versions on the starboard side, allowing for precision tensioning. The turnbuckles had a minimum working load of 5,200 lb. (2,359 kg) each (OII 2000a:16).

A set of six secondary slings, 8 in. (20.32 cm) wide, were rigged over the top of the hull between the conning towers (Figure 9.8). These slings were a response to concerns about weak rivets. The slings wrapped around the main body of the hull to counteract any circumferential, or hoop, stress it might undergo. They were attached low down on the port side to the primary slings, then across the hull to the starboard sling rigging, where they were attached with turnbuckles and tensioned just enough to compress the neoprene pad below.

Compliant Support System

The slings alone were not sufficient to fully conform to the shape of the hull. The varying curves, uneven concretion surface, and protruding elements of the hull all posed difficulties for safely supporting the load. A combination of neoprene padding and polyurethane foam was used to ensure the vessel rested comfortably in the slings without any shifting or uneven pressure. The principal method of stabilizing the vessel was a compliant support system based on the use of self-hardening foam that was molded to the shape of the hull to provide support as needed. At the time the system was proposed, an appropriate substance for use under water had not yet been identified. Mike Gatto, of NCS Supply, a frequent supplier to the U.S. Navy, recommended Froth-Pak polyurethane foam. Manufactured by Flexible Products, Co., a subsidiary of Dow Chemical, this two-part foam is injected into a mold and hardens in place. Several days of testing were required to determine the product's effectiveness under water and to develop a delivery system. Up to that point, there had been little success using polyurethane foam in this environment due to water restricting the exothermic reaction of the polymerization process (Drukenbrod 2000). OII needed to determine:

- 1) How effectively an off-the-shelf, two-part polyurethane foam can be applied underwater;
- 2) Effects of hydrostatic force on the cured foam's properties;
- 3) Expansion rate and compressive force of the foam due to the chemical reaction of the components within a confined space during the set-up period;
- 4) Dimensional stability of the foam, mixed at a set pressure, then brought to the surface. (OII 2000b:App. H).



Figure 9.9. Members of the engineering team practice fastening a vinyl bag to a sling in land-based trials. (Courtesy of FOTH)

The tests proved the Froth-Pak product would work well in the conditions at the site. They then had to develop a delivery system to get the liquid foam in place against the hull before it began to harden, a window of only a few minutes. Vinyl bags were developed to contain the foam. They would cover the length of the side of the sling that would be in contact with the hull, and were attached to the slings with cable ties via grommets prior to filling (Figure 9.9).

As a two-part foam, two hoses had to run from the surface, down to the divers below, where they would meet at a diver-operated nozzle. When the vinyl bag was in position, the diver would inject the foam, which then expanded to conform to the hull's shape. To ensure that the vinyl bags were not overfilled and damaged, a one-way relief valve was built into the opposite end of the bag from the fill valve. In practice, due to the restricted visibility, divers would often have to rely on counting for so many seconds to know when the bag was at capacity.

Some protruding areas of the hull required more customized support, in particular, the starboard diving plane. Support material for this area consisted of steel standoff blocks fabricated specifically for each sling station along the plane. These standoff blocks diverted the weight of the submarine and interior load around

the projecting hull elements and prevented the rigging from making contact with them.

The compliant support system proved 100% successful. It could be deployed relatively easily and it set up quickly despite the underwater environment. It held the submarine exactly in position not only during the initial recovery and transport, but maintained its shape and firmness during the subsequent eleven years in the tank, until the vessel was rotated upright in 2011 (Jacobsen 2012 elec. comm.) (Figure 9.10).

Load Cells

Each sling station on the truss was equipped a load cell, wired to the starboard turnbuckle (Figure 9.10). These devices measured the amount of load on each sling at all times and relayed the data to the computer that was used for monitoring the loads topside.

OII engineers calculated that the lifting force should be less on the ends of the submarine than in the center. Based on this model, the weight apportioned to each sling could be calculated, resulting in a tension value for that sling. After the foam was installed and allowed to harden, divers took up the tension on the slings via the turnbuckles, as directed by topside personnel, to reach the necessary strain values. Once the submarine was completely slung, the graphical sling tension display on the load-cell monitor screen was bell-shaped (Figure 9.11). Throughout the entire recovery operation loads on all slings were monitored and adjusted as required.

The load cell system was also utilized during the conservation phases of the project. Individual slings could be loosened for conservation considerations and then re-tensioned to original value. During this phase, slings often needed to be removed temporarily to allow access for excavation of the interior as well as for thorough documentation of the outer hull.

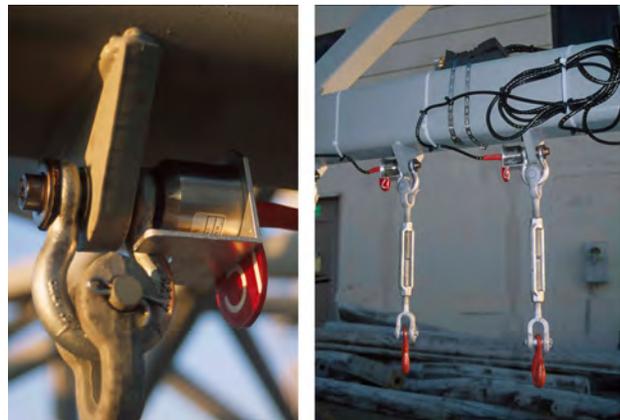


Figure 9.10. Turnbuckles in place on the frame with load cells rigged. (Courtesy of FOTH)

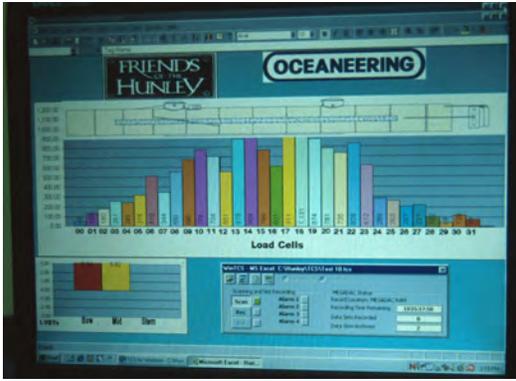


Figure 9.11. Display of weight distribution on the load cells supporting Hunley. (Courtesy of FOTH)

Deflection Monitoring

Vertical deflection along the hull's longitudinal axis was monitored during excavation and sling installation. An LVDT (linear variable displacement transducer) system tied in with the load cell data acquisition process recorded deflections in the hull during sling installation. Three LVDT's were installed on truss panel points above *Hunley*; one each at the bow and stern and one at the center of the hull. The center and stern transducers, however, failed to work properly during sling operation. Therefore, the two malfunctioning units were replaced with simple vertical rods, which rested on the hull surface and would move freely up or down if the submarine shifted (Figure 9.12). Manual vertical measurements of the rods were then recorded to measure any deflection of the hull. Deflections

recorded throughout the slinging operation were less than 0.5 in. (1.27 cm).

Conclusion

The use of experienced engineers is somewhat of a luxury in the archaeological field, but it proved critical to the success of the mission. Their knowledge was essential not only during the design phase, but on site as well, for the proper application of the complex systems and the ability to solve unexpected problems quickly, limiting project delays. Working on site also allowed the engineers to gain a better understanding of the unique requirements of archaeological recovery.

The engineering team concluded that the suction piles were well suited for this type of recovery (OII 2000b:7). The dead weight of the piles and stable crane made them relatively easy to set. Strong currents and winds were not a problem. The piles suctioned down and propelled out with no unexpected occurrences. Truss end and pile table mating reactions were lower than anticipated. Potential problems, such as pile overturning and short-term settlement, did not materialize. The sling system, including load cells, foam system, and secondary rigging, also performed as intended. Overall, no damage to the hull was detected by the archaeologists resulting from the recovery operations.

The safe recovery of this unique piece of American cultural heritage could not have been accomplished without thorough planning, expert design and fabrication of components, and mutual respect between the engineers and archaeologists.



Figure 9.12. Linear variable displacement transducers (LVDTs), left, were planned for monitoring any longitudinal displacement of the hull. Two LVDTs were replaced with rods for manual monitoring (right). (Courtesy of FOTH)

10. Excavation and Recovery

Claire P. Peachey, Harry Pecorelli III, and Robert S. Neyland

The decision to remove *Hunley* from its original context on the seafloor necessitated a comprehensive archaeological excavation to collect as much data as possible before that context was lost. The archaeology and preservation methodology developed required forethought equal to that of other project components. With expensive work platforms, and a massive engineering and diving component, it was important to communicate the research goals clearly to all project participants to maintain a successful collaborative team. Six primary research objectives were therefore established (Table 10.1).

Field operations began on 5 May and ran until 9 August, with a hiatus between 24 June and 16 July. Sediment samples were taken and environmental conditions recorded before excavation commenced. An area of approximately 90 × 40 × 5 ft. (12.19 × 27.43 × 1.52 m) was excavated, centered on *Hunley*. All sediment was screened for cultural material. More than 500 artifact and sample numbers were assigned.

The site was recorded in detail and mapped before the vessel was removed from the seabed. The diving strategy called for a division of labor with the *Hunley* Archaeological Team (HAT) conducting the hull documentation and artifact recovery, and commercial divers from Oceaneering (OII) undertaking the excavation of trenches for the suction piles, placement of recovery structures, and rigging. A total of 73 days were spent on site. HAT conducted 410 dives for a total of 971 hours 31 minutes under water. Total man hours for the team, including dive time, was 10, 276 hours. Total man hours for OII was 2,376, of which roughly half were spent under water. Combined personnel averaged 26 people at one time, including divers, supervisors, and surface support. Despite the challenging sea conditions, only a total of two diving days were lost to bad weather (Figure 10.1).

The submarine *H. L. Hunley* was successfully raised and transported to the Warren Lasch Conservation Center (WLCC) on 8 August. This feat was accomplished through many long hours both above and below water and the ability of the Friends of the Hunley (FOTH) to

overcome some daunting problems, including changing recovery platforms in the middle of the project. Despite the inevitable logistical difficulties encountered on a project of this size, coordination between the two teams was effective and efficient, resulting not only in the successful recovery of the submarine, but also the collection of significant scientific data.

Table 10.1. Archaeological Research Objectives

| | |
|---|---|
| 1 | Recover any artifacts or loose hull components associated with, or contemporary with, the wreck |
| 2 | Investigate and identify magnetic anomalies adjacent to <i>Hunley</i> |
| 3 | Prepare an overall site plan, plotting the submarine's position in relation to associated loose vessel components and artifacts |
| 4 | Create accurate hull drawings |
| 5 | Acquire biological, geological, and chemical samples |
| 6 | Monitor hull shape for changes during excavation |

Archaeological Objectives

Prior to commencing fieldwork, HAT developed a research design based on the six objectives delineated above. For each one, expectations were described and procedures for handling each case were outlined, as follows.

Artifact Recovery

Three classes were expected to be present at the site. The first class consisted of artifacts directly



Figure 10.1. Operating with decks awash was not uncommon during operations four miles out to sea, but few dive days were lost to bad weather. (Courtesy of FOTH)

associated with the submarine, either having come directly off the exterior of the hull or having escaped from inside, through breaches in the hull. The second class comprised intrusive anthropogenic materials deposited around the hull as it became buried. These would represent a variety of sources, including debris from *Housatonic's* wreckage, flotsam and jetsam from the Union blockaders or blockade runners, and materials washed out to sea from shore. The third class was intrusive material from a later time period deposited over the site by fishermen, storms, tidal activity, and other sources. All three classes would be mapped and documented with equal thoroughness, since even intrusive material could provide data relating to site formation processes.

Loose Hull Components

Since the bow and stern had not yet been exposed, the likelihood of finding disarticulated hull components had to be considered. These two areas were known to house some of the more delicate external features, such as the rudder, spar, and propeller shroud, which might have been damaged or come loose at the time of the sinking or during the subsequent period of exposure on the seabed. Surveying with a marine magnetometer had revealed that magnetic anomalies were present in the area around the submarine, particularly

in the area of the bow. The excavation plan called for any disarticulated components to be mapped and removed by HAT archaeologists prior to the recovery. The decision whether to remove partially disarticulated pieces, if encountered, would be made on a case-by-case basis, guided by the needs of the artifact.

Magnetic Anomalies

Magnetometer data generated during the remote sensing phase of the 1996 survey disclosed that *Hunley* produced a multiple component anomaly consisting of a single 400 gamma positive and two 200 gamma negatives (Figure 10.2). Murphy (1998:88) noted that: "*Hunley*, basically a cylinder, would be expected to produce a dipolar (single positive and negative components) magnetic anomaly. The dual negative aspect of the anomaly indicates a possibility that there may be additional material southwest of *Hunley's* bow." In addition, 1999 work on *Housatonic* and related magnetic features of the *Hunley/Housatonic* engagement site demonstrated that magnetic anomalies of very low duration and intensity were not ghosts, but were the results of physical structures buried in the seabed. For example, a six-gamma target referred to as the "fourth anomaly" turned out to be a small anchor (possibly a kedge) and chain buried three feet under the silt line (Conlin 2005:80). As a consequence, the three areas identified as A, B, and C, located within 75 ft. (22.86 m) of *Hunley*, were suspected to contain cultural items associated with the submarine. The research design called for these areas to be excavated prior to the commencement of lifting operations.

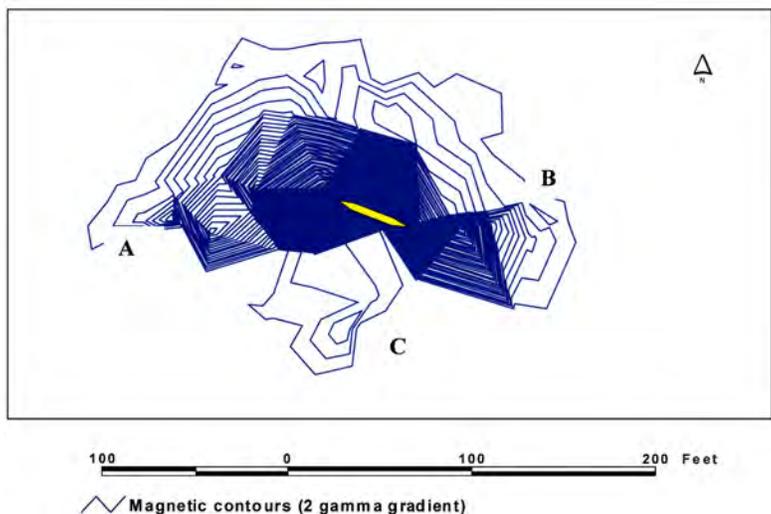


Figure 10.2. Magnetometer readings around the *Hunley* site. (Detail from Murphy 1998:60)

Site Plan

An overall site plan containing the submarine, loose hull components, and artifacts associated with the hull was planned. The site plan would document the orientation of the submarine and its degree of list. All materials recovered would be positioned based on direct measurement to datum points placed around the submarine's hull. Primary datum points were planned for the bow and the stern, with secondary datum points to be added as needed. Measurements of x, y, and z positions were required of all artifacts, loose hull components, and samples recovered. Once the OII lifting frame was in place, the frame itself could be used as a backup system of measurement, as it was, in effect, a large metal grid with a precise rectangular shape to which datum points could be readily added.

Hull Measurement and Drawings

During the 1996 survey, the exposed areas of the hull were measured and mapped, and one cross-sectional view was drawn (Figure 10.3). Following the 1999 hull survey, in which thickness measurements were taken, additional information, such as the expansion strake width and two seams for hull plates, was added to the original field drawing. This corrected field drawing

would serve as a baseline map during the final excavation. As part of the excavation plan, time was allotted to check the drawing for accuracy and add new hull construction features as they were located. During this time the hull would also be inspected for damage that may have occurred at the time of sinking, such as holes in the hull from gun fire and torpedo blast. While much of this data was expected to be available after the recovery, it was important to collect it in situ, as a baseline against which to check for changes in the hull after installation in the laboratory. In addition, in the event of damage or destruction during the lift, this would serve as the only complete set of hull measurements from the intact site.

Sampling

Important information could be gained through macro- and micro-biological, geological, and chemical sampling. Collection of this type of data was considered relevant to understanding the sequence of events surrounding the processes of site formation, hull and artifact preservation, and the creation of micro-environments inside the submarine. Information concerning the environmental conditions outside the hull was an important dataset for evaluating conditions found on the interior of the submarine. These data would have

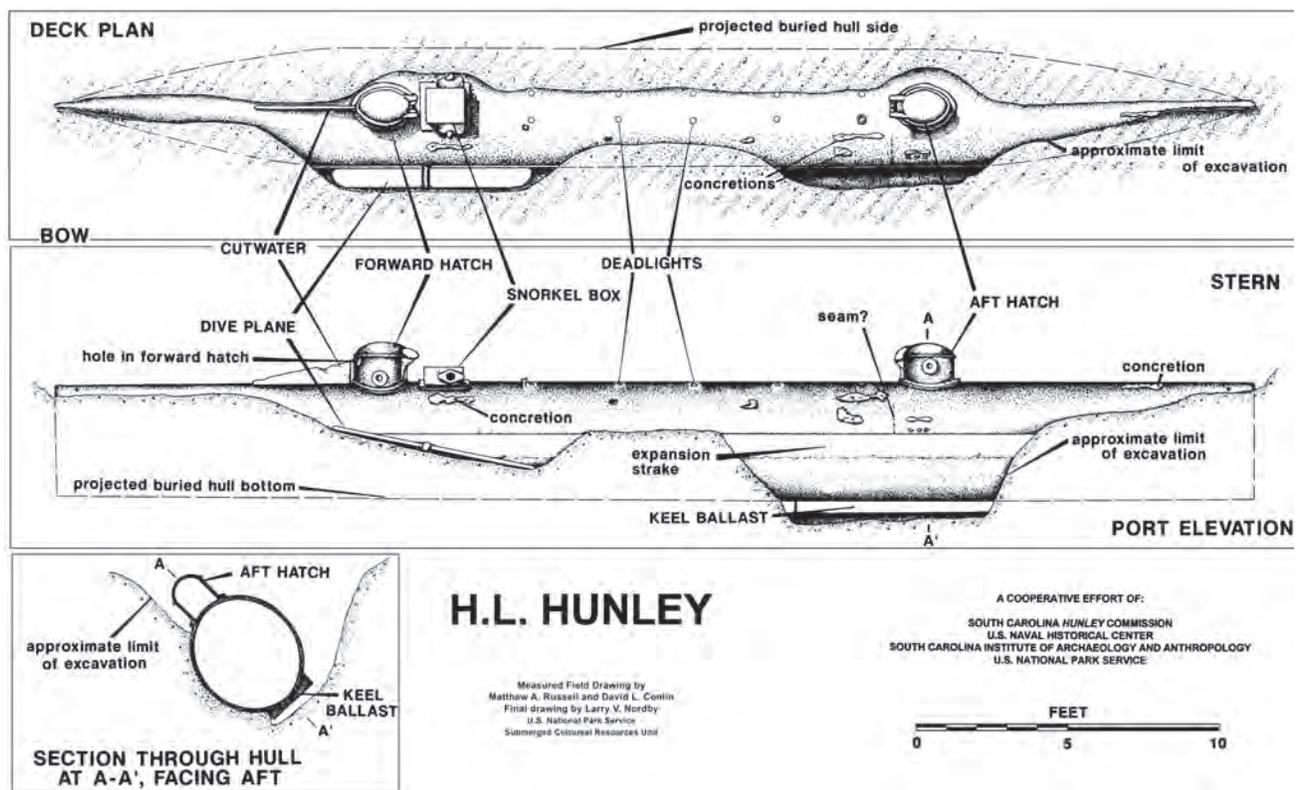


Figure 10.3. Site plan developed based on the 1996 investigation. (Murphy 1998:77)

direct application in finalizing conservation operations for the hull and in assessing the probable state of preservation of small artifacts and potential human remains within the submarine. Some of this information could also be used in predicting the state of preservation and depositional history of other shipwreck sites. Documentation of sedimentary stratigraphy in the matrix surrounding the vessel was also planned in order to disclose the presence and extent of scour areas or the condition of the sea bottom at the time of *Hunley's* sinking.

Hull Shape Monitoring

A system for monitoring changes in hull shape during the excavation was developed in conjunction with the engineering design. The load cells designed by OII for use on the slings would detect any changes in load weight and provide information on any sign of localized hull distortion (see Chapter 9). A backup system of measuring overall longitudinal or lateral distortion was also considered. One option consisted of using a taut wire system of measuring overall circumference of the hull. This could be monitored visibly by divers or hardwired to an instrument on the surface that would measure any increase or decrease in tension. A second option was to use a computerized acoustic hull measurement system called SHIPSHAPE, which was developed for the Navy. This employed transponders and receivers placed on or around the hull that would monitor for changes in its position or shape. SHIPSHAPE also allowed for the integration of hull line drawings, once acquired, into the computer program. As discussed below, due to difficult conditions at the site, the SHIPSHAPE system was not used; the load cells provided sufficient data.

Equipment and Procedures

With the objectives firmly in place, equipment was acquired, personnel allocated, and the details of where and how the excavation would proceed were ironed out. One month was scheduled for excavation prior to beginning the rigging process. Based on known dimensions of the hull and the space needed for setting the suction piles, a perimeter around the wreck was planned to be 40 ft. (12.19 m) wide and 130 ft. (39.62 m) long. It was estimated that an area this large was needed to provide adequate working room for the engineers and to limit extensive infilling of excavated areas during the off hours.

The site would be subdivided, with the team from OII excavating the outer 10 ft. (3.05 m) on each long side,

and the HAT divers working within the 20 ft. (6.10 m) central section containing the submarine (see Figure 10.11). Both teams were to use dredges and screen all materials removed. Due to concerns about possible spillage of internal components from potential holes at the bow and stern, it was determined that only HAT divers would work in the sections closest to the hull until it came time to rig the slings.

The excavation strategy began by removing the sandbags and overburden along the top of the vessel, where prior work had already taken place. The bow and stern components were excavated next, to provide enough time to alter the recovery plan should any significant breaches be discovered and to design any custom supports that would be needed during the lift. With the surrounding sediment taken down to a the level of the keel along the length of the port side and approximately halfway down on the starboard, operations were stopped for the placement of the truss. After a one-month delay in operations while a new lift platform was acquired (see below), the truss was then lowered in place, and excavation began beneath the hull in 24 to 36 in. (0.61–0.91 m) increments as the slings were rigged. During the delay, sandbags were packed around the exposed portion of the vessel for protection, but they also served to delineate the areas that had not yet been excavated from infilled material.

Dive Operations

As mentioned above, the dive team was divided into two groups, scientific divers from HAT and commercial divers from OII, with both groups operating simultaneously. All divers are listed in Appendix B. Initially, operations ran 12 hours a day, but increased to 24 hours in late July as the rigging phase commenced. Due to equipment restrictions, dives were limited to two divers per team at any one time. Each team generally conducted three dives per day during the initial phase of excavation, and six during the extended phase. All diving operations, with the exception of underwater photography, were conducted using surface-supplied air.

Surface-supplied diving had numerous advantages over scuba. *Hunley* was located in 8–10 m (26–33 ft.) of water, depending on the tide. At this depth, divers could remain on the bottom for five hours and thirty minutes. A diver averaging one hour per scuba tank would have to return to the surface and change tanks six times, whereas a diver using surface-supplied air could remain on the bottom for the entire time. Each surface-supplied diver had an individual tending the umbilical hose (Figure 10.4). This link to the diver eliminated the possibility of being swept from the site by the current and drifting away without being noticed. The helmet also contained a speaker and microphone, enabling diver-

to-surface and diver-to-diver communication. A diver could request a tool and have it sent down on the umbilical hose without having to return to the surface. With the lifting truss and all of the accompanying metal hardware in place, the *Hunley* site became an overhead-hazard working environment and the dive helmets provided necessary head protection. One drawback to using the surface-supplied system was the risk of entanglement. Divers had to constantly monitor their umbilical hoses in the restricted visibility where datum pipes, the lifting truss, and other divers' umbilical rigs all became snag hazards.

All archaeologists not yet certified in surface-supplied diving participated in a rigorous training course designed to familiarize them with the project equipment. Conducted by Von's Diving Services of Westwood, California, the dive training included tending protocol, diver-to-surface communication, emergency procedures, open water search and recovery, and equipment cleaning and maintenance.

Both dive teams conducted operations from the same mobile command trailer. Project protocol, however, necessitated that HAT and OII keep their dive operations separate, sharing only the air compressors. OII used a dive manifold designed in-house,

while HAT used an Amron AMCOMMAND II portable manifold. Both teams used Kirby Morgan Superlite 17 helmets.

HAT divers followed the diving standards established by the American Academy of Underwater Sciences (AAUS) to ensure maximum protection of scientific divers from accidental injury and/or illness. The OII team adhered to the guidelines established by the Occupational Safety and Health Administration designed for to safeguard the U.S. commercial diving industry. In the event of a diving emergency, a double lock recompression chamber was on site at all times (Figure 10.5).

Dive Platforms

During the first phase of excavation, dives were conducted from the 750 tn. (680 t) *Marks Tide*, a 180 ft. (54.86 m) supply ship owned by Tidewater Marine of

Amelia, Louisiana (Figure 10.6). It was moored over the *Hunley* site on a four-point mooring system and acted as the main base for diving support and dredging operations. This vessel allowed easy access to the water; divers could simply step off the deck into the water and return to the deck by climbing a ladder. Facilities included an air-conditioned trailer for the OII team, air compressors and dredge pumps for both dive teams, the



Figure 10.4. Senior project manager Leonard Whitlock tends to diver and field manager David Conlin. (Courtesy of FOTH)



Figure 10.5. Hyperbaric chamber being readied for loading onto Marks Tide. (Courtesy of FOTH)



Figure 10.6. Marks Tide moored over the site. (Courtesy of FOTH)

sluice boxes for OII's team, and an artifact storage area. Sleeping quarters were also available for team members. Working in conjunction with *Marks Tide* was a 125 tn. (113.4 t) floating crane barge supplied by Detyens Shipyards, which would accomplish the heavy placement of the suction piles, recovery truss, and lift *Hunley* in its truss for transport to Charleston.

After the excavation was well underway, it was found that the crane barge did not possess sufficiently stable dynamics in offshore seas to safely conduct the lifting of the suction piles or truss without endangering *Hunley* and personnel on the crane barge. It was determined that only a self-elevating, or jack-up, vessel could meet the requirements for the safe lift of *Hunley*. After looking at location and availability of vessels that met project requirements, *Karlissa-B*, a six-legged jack-up from Titan Maritime Industries, was chosen based upon availability, cost, and arrival time in Charleston (see below).

The second phase of excavation was therefore conducted from *Karlissa-B* (Figure 10.7), which was 170 × 80 ft. (51.82 × 24.38 m), and when jacked up above the water, had a deadweight capacity of 4,245 tn. (3,850 t). All portable equipment, including trailers, compressors, and pumps were relocated to this platform upon its arrival in July. With the deck of the vessel approximately 30 ft. (9.14 m) above the water, divers had to be lowered into and raised from the sea using a winch-operated lift platform, or stage. To keep the HAT and OII dredge pumps and water screens closer to the site they had to be placed on a separate supply barge.

Additional Support Vessels

The 52 ft. (15.85 m) stern trawler *Anita*, owned and operated by the South Carolina Department of Natural Resources (SCDNR), was made available as a dive platform during the first two weeks of fieldwork, prior to the arrival of *Marks Tide*. It also provided further assistance and transport periodically throughout the



Figure 10.7. Karlissa-B in place over the site along with the supply barge, which housed the dredge pumps. The truss prior to installation is visible on the supply barge. Suction piles had already been placed on the sea floor. (Photo by Cramer Gallimore, courtesy of FOTH)

remainder of the excavation. Several additional vessels were chartered during the project, primarily for ferrying crew, including the 26 ft. (7.92 m) *Parker Diversity* owned by Ralph Wilbanks, 47 ft. (14.33 m) *Cole-Be* owned by Groboat's of Morgan City, Louisiana, and 43.5 ft. (13.26 m) *Jeremy* owned by Steve Howard. Finally, a 22 ft. (6.71 m) *Boston Whaler* was supplied by the Navy for a portion of the project.

Dredges

OII used two custom-built 4 in. (10.16 cm) dredge systems to excavate. The dredge systems were powered by two jet water pumps joined together with a manifold to produce up to 1,000 GPM (3,785.4 LPM) of seawater at 200 p.s.i. (13.8 bar). Water from the high-pressure manifold was directed through two venturi devices called inductors, which use high-pressure water to create tremendous suction. The OII divers used two long 4 in. (10.16 cm) diameter rigid-walled hoses, connected to the suction end of the inductors, to excavate sand from the site. The output end of the inductors was connected to custom-built sluice boxes (Figure 10.8). Sand and water blasted into the top of the sluice box and then cascaded over three separate screens with graduated mesh diameters of 2.6 in. (6.6 cm), 1.7 in. (4.32 cm), and 1 in. (2.54 cm). One to two individuals monitored the screens for cultural materials at all times. Materials recovered were collected and placed in water in plastic bags and labeled with the corresponding dredge area. Non-cultural material was cleared from the screens and went into the bottom of the box, which drained overboard through two 6 in. (15.24 cm) rigid-walled hoses.

HAT used a 4 in. (10.16 cm) Keene Engineering water-induction dredge head to excavate the area immediately surrounding the submarine. Water from the on-deck jet water pump manifold was pumped down to the dredge head through a long flexible 2 in. (5.08 cm) diameter fire hose. As sand was sucked, it



Figure 10.8. Sluice boxes designed by OII for screening dredge outflow had three tiers of increasingly smaller mesh. (Courtesy of FOTH)

traveled through a 40 ft. length of 4 in. (10.16 cm) diameter flexible hose and into a large mesh bag. Laundry bags of ¼ in. (0.64 cm) diameter mesh proved to be the easiest to come by and most durable. The dredge spoil, primarily shells and small cultural material, were retained within the bag while sand and silt passed through the mesh holes.

When a spoil bag approached three quarters full, the diver would replace it with a new one. The full bags would be hauled to the surface via a haul line. Once on deck, the contents were emptied onto a plastic tarp and inspected for cultural material. The remaining contents were sorted by material type: macrofaunal, boiler slag, coal, bone, iron concretion, wood, and unknown. The sorted materials were then stored in water in plastic bags and labeled with the corresponding dredge area. Archaeologists brought up any large artifacts either by hand or supported in a plastic box.

Documentation

Direct measurements with metric tapes were taken from primary and secondary datum points to all artifacts, loose components, and major hull features. It was hoped that the acoustic system SHIPSHAPE could be used to augment measurements taken with tapes; however, this did not prove practical, due to the difficult conditions on site.

HAT divers documented the submarine in detail by measuring and sketching features with pencil on sheets of Mylar drafting film duct taped to hard plastic boards; this was frequently hindered by limited and zero visibility conditions. Finished drawings were sprayed with Krylon clear acrylic lacquer after they were rinsed and dried, and each record was assigned a consecutive log number. One team member transferred relevant sketches to the overall site map. HAT documented larger

artifacts in situ with trilateration or triangulation, and if visibility allowed, by sketching and video.

To record the shape of the hull in situ, prior to each sling installation, archaeologists cast the exterior hull profile. The procedure consisted of encircling the hull with two layers of 4 in. (10.16 cm) wide resin-soaked fiberglass cloth from DuraPower Products Inc. (Pipe & Hose Repair Kit "Air" Activated Fiberglass Tape). After overlaying and tightening the two wraps with a piece of ⅝ in. (1.59 cm) three-strand polypropylene rope, another wrap was applied with a third piece of cloth. Once hardened, divers removed the fiberglass profile by making a single diagonal cut near the bottom of the submarine and lifting the profile off. Once on the surface, the profiles were reassembled and traced onto paper (Figure 10.9). Using a digitizing tablet, these tracings were entered into the computer drawing program AutoCAD.



Figure 10.9. From left, Randy Burbage, Senator McConnell, and Robert Neyland examine fiberglass profile taken by divers. (Courtesy of FOTH)

Artifacts

All artifacts had their provenience mapped prior to recovery. The original plan called for each artifact to be photographed, video documented, and drawn in

situ as visibility allowed. Visibility was generally very poor, however, so photography and videography were extremely limited. The assistant field manager, Claire Peachey, or a designated archaeologist under her oversight was on deck to receive the artifacts, assess their state of preservation, and insure they were secure and stable. When necessary, field conservation and stabilization was initiated prior to their being transferred to the conservation laboratory.

HAT kept an artifact log, assigning a unique number beginning with the "HL" prefix to each artifact, group of artifacts, or sample. Each artifact or lot was labeled with a Tyvek tag and stored in seawater in stackable, lidded plastic boxes of various types and sizes. Where necessary, archaeologists placed artifacts in polyethylene self-seal bags, wrapped them in polyethylene foam, or provided other protection. They catalogued all excavation material on artifact or sample record sheets as appropriate, sketching significant artifacts on Mylar drafting film, usually at 1:1 scale unless the objects were too large to fit.

Loose components were treated as other artifacts: photographed, drawn, assigned an artifact number, and mapped into the site plan. Any minor elements that were loose but still attached to the submarine's hull were carefully removed, with special attention paid to minimizing damage to the concretion layer surrounding the hull. The option to leave some loose material in place was considered; however, due to the extensive coverage of the slings this was impractical. In addition, damage could be better controlled by a planned removal than by letting it break off under its own mass and inertia.

Artifacts were transported to the conservation laboratory approximately once a week, weather permitting. In one case, several fragments of rope were brought in on the day they were recovered and placed directly into frozen storage due to their extreme fragility. The assistant field manager or her designee prepared a transfer form for each batch of artifacts or samples leaving the field site, which was countersigned by the

receiving party, either the senior conservator or the scientist conducting sample analysis. A collection specialist was in place under the senior conservator, whose responsibility was maintenance of the overall artifact inventory and database, and was accountable for the location of all artifacts at all times.

Field Operations

The first phase of operations involved delineating the site and establishing datum markers for mapping. Six yellow, 32 in. (81.28 cm) steel buoys were deployed from *Anita* to define the perimeter of a no-entry zone surrounding the *Hunley* recovery area. These buoys were marked with dusk-to-dawn yellow flashing lights and elevated aluminum radar reflectors. Four large mooring buoys were also put in place by the U.S. Coast Guard in preparation for the arrival of *Marks Tide* (Figure 10.10).

Working from *Diversity* and the Navy Boston Whaler,



Figure 10.10. USCGC Madrona prepares to deploy the four mooring buoys used to secure Marks Tide safely without risk of damage to the site. (Courtesy of FOTH)

a small contingent of HAT archaeologists marked *Hunley's* bow and stern with weighted buoys, using previously recorded GPS coordinates. HAT, using scuba, relocated and exposed the upper surface of the submarine. A perimeter was then set up using a combination of 0.25 in. (6.35 mm) braided poly line and lengths of 1.5 in. (3.81 cm) diameter Schedule 40 PVC pipe. First a centerline was established along the top of the submarine,

extending 13.5 m (44.29 ft.) out beyond either end. By triangulating off the centerline, divers were able to place 5 ft. (1.52 m) lengths of PVC pipe at the corners of the excavation trench, strung with poly line, outlining an area 130 ft. (39.62 m) long by 40 ft. (12.19 m) wide.

With the perimeter defined, HAT used the centerline and the ends of the submarine to triangulate in four permanent datums, two off the port side and two off the starboard side, just outside of the excavation trench. These datums consisted of 10 ft. (3.05 m) lengths of 1.5 in. (3.81 cm) diameter aluminum pipes driven to

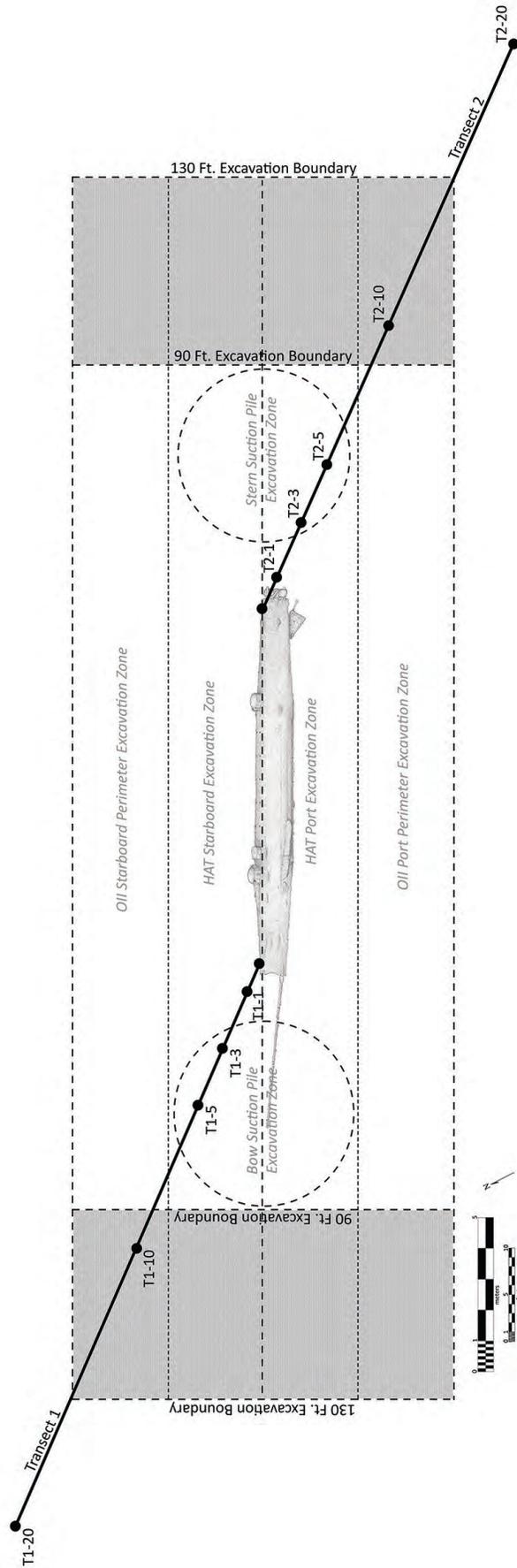


Figure 10.11. Layout of excavation boundaries and sample transects at the site. (Diagram by H. G. Brown, NHC; drawing of Hunley by James W. Hunter III, FOTH)

within 18 in. (45.72 cm) of the bottom. Archaeologists then placed six 10 ft. (3.05 m) lengths of PVC as subdatums in an arced array at each end of the submarine's hull. The twelve subdatums were located 3 m (9.84 ft.) from each end of the submarine and 2 m (6.56 ft.) apart. They were then mapped in using trilateration. These datums and subdatums were used to accurately position cultural material discovered during the excavation.

Pre-disturbance Sampling

Prior to conducting further excavation, HAT took a series of sediment cores and faunal samples, part of the suite of studies to characterize the environment surrounding the submarine. HAT placed two transect lines diagonally off the submarine, one off the bow to the north corner of the perimeter, and the other off the stern to the south corner of the perimeter (Figure 10.11). These transect lines covered areas that had not been disturbed in 1996 or 1999. The purpose of this sampling strategy was to determine if there was any gradient in the biology and sedimentology of the site correlating to distance from the submarine. Using 3 in. (7.63 cm) outer diameter by 1 m (3.28 ft.) long aluminum hand core tubes, divers collected sediment cores along the two transects at 1 m (3.28 ft.), 3 m (9.84 ft.), 5 m (16.40 ft.), 10 m (32.81 ft.), and 20 m (65.6 ft.) from the submarine. Project geologist Scott Harris then immediately opened and sub-sampled all but three of these cores on the deck of *Anita*. Analysis would focus on microbial activity, physical geology, pore water content, and dissolved iron content (see Chapter 13). HAT divers also collected benthic infaunal samples from the same transect points, which were immediately sieved and preserved on deck by marine biologist Dr. Pam Jutte.

The team sampled the backfill sand and the compact mud adhering to the hull concretion to test for microbial activity. Several small sections of hull concretion were collected in plastic bags, which were also analyzed for microbial activity as well as chemical characterization. After removing a portion of concretion, a corroded rivet was found in the bow area of the submarine that could be removed, thus allowing the opportunity to take samples of the interior sediment. Once the rivet was removed, divers inserted a series of clear, rigid plastic tubes into the rivet hole to remove three cores of sediment, which were then transferred to the custody of microbiologist Dr. Pam Morris. In addition, divers captured several samples of the gas bubbles released by deconcreting small areas the hull, using a polyethylene bag; the gas was then transferred immediately to a glass flask closed with a rubber stopper.

Since the closest NOAA buoys to the site were either along the shore or else about 40 km east (Station 41004) of the *Hunley* site, local environmental conditions were not readily available. Therefore, a multiparameter probe from YSI, Inc. was placed on the wreck for 48 hours to collect data that would help give conservators a picture of the range of conditions *Hunley* would be exposed to during the excavation once the sediment was removed. Knowledge of these conditions helped in planning and assessing the post-recovery storage environment for the hull. The device recorded temperature, depth, specific conductance, dissolved oxygen, pH, and oxygen reduction potential (ORP) in 5-minute intervals (Appendix E).

Anomaly Investigation

The three magnetic anomalies that had been identified during earlier survey work on the site were located and investigated by HAT divers during this preliminary set-up period to assess their significance and potential incorporation into the dive plan. Using a handheld magnetometer, each anomaly was pinpointed. Archaeologists removed sediment down to the level of the source of the metallic signature using a jet probe. The source of one anomaly was not rediscovered, and the others were found to be concreted ferrous can fragments at depths significantly shallower than that of *Hunley*. These anomalies were therefore deemed unrelated to the submarine and no alteration to the excavation plan was required.

Corrosion Potential and Continuity Studies

Steve West of Orion Research visited the site on 16 and 17 May 2000, to perform ORP and electrical continuity tests on the iron hull plates. The purpose of this was to indicate the extent of corrosion of the metal. West also measured the pH and ORP of two sediment samples collected immediately adjacent to the submarine. His report, listing the equipment used and a step-by-step account of the measurements, is provided in Appendix F.

West performed the ORP measurements by modifying flat-surface, combination platinum probes (6.25 mm/0.25 in. diameter) to operate underwater. HAT divers cleared concretion from small areas of the hull surface using a hammer and chisel to reveal the iron plate surface; these areas were relatively smooth, but were not polished to remove corrosion and create a clean metallic surface as they had been for the ultrasonic thickness measurements. Two divers each placed one probe at different points on the hull surface, and West operated the pH/mV meter on the boat deck

and directed the team through voice communication, while other personnel handled the cables leading from the meter to the underwater probes (Figure 10.12). The divers first held Probe 1 at the bow and Probe 2 at the stern. After stable readings were attained, they reversed the positions of the probes, resulting in identical readings. They usually had to gently move the probe around on the hull surface until a stable reading was attained, indicating that contact between the probe and hull was not optimal, even though the flat-surface probes were of a small diameter. The dive team was successful in recording several readings. West determined from these readings that the corrosion potential at the bow of *Hunley* was -379 ± 2 mV vs normal hydrogen electrode (NHE), while that at the stern it was between -320 and -363 mV vs NHE.

West then connected the same probes to a Fluke multimeter to perform continuity tests on the hull. Divers once again placed the two probes on the patches of cleaned hull plate surface at some of the same locations as above, primarily to test continuity between the bow and stern and between amidships



Figure 10.12. Steve West monitors instruments during corrosion potential studies conducted at the beginning of the excavation. (Courtesy of FOTH)

and the vessel ends. The continuity readings were erratic and inconclusive, leading West to conclude that either poor continuity existed between the different sections of *Hunley's* hull or that poor contact was made between the probes and the hull surface. These results were similar to those obtained in 1999.

Overall it was determined that the corrosion potential and oxygen levels were relatively low on site, indicating a slow corrosion rate on the seabed, but showed the need for an impressed current protection system once in the laboratory tank, where readings pointed to a markedly increased corrosion rate (Mardikian 2004:141).

Site Excavation

The arrival on site of *Marks Tide* on 13 May with the full team of HAT and OII divers signaled the commencement of the primary excavation effort. The initial rectangular 130 × 40 ft. (39.62 × 12.19 m) excavation perimeter was subdivided lengthwise by securing two lengths of poly line 10 ft. (3.05 m) inside of either long edge of the rectangle. As per the excavation plan, the outermost zones, which had a much lower probability of containing cultural material, were excavated by OII. The central area immediately surrounding the submarine where the highest density of culturally significant material was expected was excavated by HAT. Twenty days into the excavation it became apparent that the teams were not going to be able to excavate the entire length of the area in the allotted time, due in part to infilling of sediment over of time, which necessitated periodic re-excavation. The site perimeter was therefore reduced by 20 ft. (6.10 m) at either end, resulting in an excavation zone of 90 ft. (27.43 m) by 40 ft. (12.19 m) (see Figure 10.11). This area was still large enough to accommodate the suction piles, and, based on analysis of dredge spoil already collected from the perimeter areas, was considered adequate to locate any cultural material associated with the wreck.

After removing the overburden along the top of the vessel left from previous investigations on the site, divers concentrated on exposing the bow and stern of the vessel to evaluate their state of preservation. The top of the propeller and shroud were exposed on 19 May, and it was noted that the rudder was not in position. A large hole in the starboard side of the stern was encountered on 20 May, and three days later another, smaller, hole was found in the bow, also to starboard. Divers packed both with sandbags to stabilize and prevent loss of any interior contents over the course of the excavation. They would be further reinforced prior to the lift as part of the slinging process (see below).

Spar excavation

The largest unexpected feature was encountered on 24 May, by HAT diver Chris Amer as he was continuing the assessment of the bow. It quickly became clear that he had discovered the spar that had deployed the torpedo and that it was still fastened to the submarine. Previous investigations had not revealed this feature, which was thought to have been attached at the top of the bow, and initial engineering plans were based on its absence. HAT archaeologists, however, had considered the possibility that it could be present at the site, possibly detached from the vessel as a result of the sinking event.

Further exploration by project director Robert Neyland revealed the surviving end approximately 16 ft. (5 m) from the bow. Over the next few days the spar was completely excavated and documented, showing the piece to be securely attached to the hull, bolted to the base of the bow casting with a Y-shaped clamp-like fitting (Figure 10.13). One single bolt through the casting held this fitting to bow, the bolt head on the starboard side and the threaded end and nut to port. Measurements were taken to determine the angle of the spar to the submarine. It extended forward bending slightly to port from the centerline with no discernible elevation, although later measurements did detect a rise of approximately 3° as it moved away from the bow.

Due to the overall length of the spar, it could not be accommodated within the truss arrangement planned



Figure 10.13. The torpedo spar in its original position attached to Hunley's bow. (Courtesy of FOTH)

for the lift. In addition, being so long and slender, it would have been extremely vulnerable to damage if lifted with the submarine. Therefore it was decided to detach the spar and recover it separately from the hull. To determine how best to remove the spar, HAT divers mapped the bolt and nut, but important details were obscured by concretion. Therefore, on 30 May, senior conservator Paul Mardikian came to the site to deconcrete the fitting and make a mold of the bolt and nut assembly (Figure 10.14). Based on his findings, it was decided that the only way to remove the spar would be to cut through the bolt securing it to the yoke. On 2 June, HAT began cutting on the bolt with a hack saw blade. This work was extremely slow because of the difficulty in inserting the blade between the yoke and spar and working in zero visibility. The cutting



Figure 10.14. Mold of bolt (A) and recovered bolt (B) used to attach spar to main body of the hull. (Courtesy of FOTH)



Figure 10.15. Hunley's torpedo spar was removed from the bow and raised separately to protect it from damage. (Courtesy of FOTH)

effort was continued by several dive teams. Eventually it was decided to attempt to put a socket and breaker bar wrench on the 1.5 in. (3.81 cm) nut and see if some pressure would break the bolt at the cut. Several large sockets were supplied by Jerry Franks of Charleston International Ports, LLC (a company owned by Warren Lasch). One diver increased the leverage on the wrench with a cheater bar and attempted to turn it counterclockwise while a second diver tapped on the socket with a sledge hammer. Unexpectedly, after this effort the bolt did not snap, but the nut backed off the threaded end of the bolt with very little damage to either component. The threads on both were still in working condition after 136 years! However, the bolt still stubbornly held the spar to the submarine. Attempts with a punch and hammer, gear puller, and hydraulic jack failed to move the bolt. Oll manufactured a custom-made wrench and divers eventually were able to get the bolt to move with this, shearing it at the point where the initial cutting had been made over the previous three days.

Oll welders customized an I-beam as a support system for raising the spar, and lowered it by crane to

the seabed, where divers positioned it alongside the artifact to minimize the distance it had to be moved. The metal of the spar had completely corroded through in some places, revealing that, with the exception of the first few feet from the yoke, it was tubular rather than solid. The worst corrosion was found approximately 80 cm (31.50 in.) from the tip, where the connection was too tenuous to survive a change in position. Therefore the distal end was lifted separately. Both sections were placed in the cradle, which was then moved to the starboard corner of the excavation area and left on the sea bottom safely out of the way of ongoing dredging operations. Neoprene padding was secured to the spar with cable ties and plastic bags were placed over the hollow ends to help preserve them and to keep supporting mud in place. A long metal rod (HL-0463) that had also been discovered on the site was placed in the cradle as well, and the whole load was secured in place with ratchet straps. On 13 June, the spar was raised. A Charleston Harbor Pilot boat came alongside the *Marks Tide* and the first major component of the submarine was lowered onto the deck and safely transported to the WLCC (Figure 10.15).

Rudder and Other Artifacts Recovered

Excavation in the stern area continued to exposed the propeller and shroud. On 30 May, as the excavation at the stern reached the bottom of the vessel, a large flat concretion was discovered. This turned out to be the rudder, which had unshipped and slipped beneath the hull. The piece was documented, protected with sandbags, and left in situ until the submarine was completely slung and supported within its straps. It was recovered on 4 August and submerged in wet storage in a child's wading pool on the deck of *Karlissa-B*, until it was transported to the WLCC on the day of the submarine recovery.

In addition, the aft cutwater was found on the starboard side near where it had been attached to the aft conning tower. The snorkel tubes were found on 23 May about halfway down the hull on the starboard side, between the snorkel box and forward hatch. Aft of this area, another iron rod-like piece was found. It was held to the hull by its concretion and turned out to be a section of rectangular bar that connected to the propeller shroud. Near the bottom of the starboard bow, several fragments of rope and some wood pieces were recovered. Two large iron concretions with distinctive clamp-like shapes were found forward of the bow. Several of the smaller pieces were removed from the site by 10 June, but the larger pieces were protected with sandbags and left in place while hull documentation was completed, and not raised until after the truss was placed.

Lift Preparations

With the bow and stern exposed and evaluated, and the port side fully cleared, it was nearing time for the installation of the suction piles and placement of the lifting truss. During the initial weeks of the excavation, the OII dive team had been working to prepare the 20 ft. (6.10 m) diameter areas forward and aft of the vessel to receive the piles. To accommodate the longitudinal angle of the sub, depth of excavation at the bow was approximately 6 ft. (1.83 m) and 5 ft. (1.52 m) at the stern. The bow section could not be completed, however, until the torpedo spar was safely out of the way. On 31 May, as Neyland and his team worked to detach the spar, HAT field manager David Conlin and assistant field manager Matt Russell took on the challenge of determining exactly where the engineers needed to place the suction piles on the seabed.

Million-Dollar Measurements

For the truss to be properly centered over *Hunley*, the suction piles had to be placed in precisely the right position. Divers, therefore, needed to set targets on the seabed to help guide them into place. Since the success of the recovery hinged on the placement of these targets, the crew jokingly referred to them as the “two million dollar points.” The first step was to determine the geometric longitudinal centerline of the wreck as it lay on the seabed. This would represent the center of gravity at its post-depositional angle and would need to align perfectly with the center of the truss for correct positioning in the slings.

Despite near zero visibility conditions, the dive team was able to determine the geometric centerline by recording offsets from the architectural centerline of the vessel. They first measured the vertical height of the stern (124 cm; 48.82 in.), then divided this number in half, locating a point 62 cm (24.41 in.) down from the natural top of the stern. They then dropped a plumb bob at this point, and measured a perpendicular offset to the top of the stern. This process was repeated at the bow, and both resulted in an offset of 42 cm (16.54 in.) (Figure 10.16). A reference point taken from the top of the stern or bow, which were the most practical landmarks on the site, could then be shifted to port 42 cm (16.54 in.) to locate the vessel’s resting centerline. The data also allowed the team to accurately calculate the vessel’s angle of repose, originally estimated at 45°, to be 47.36° relative to the horizontal plane.

With the offsets calculated, Conlin and Russell were ready on the following day to measure in the center points for the suction piles, which needed to be 70.5 ft. (21.49 m) apart to accommodate the length of the truss. The points were measured using trilateration from two

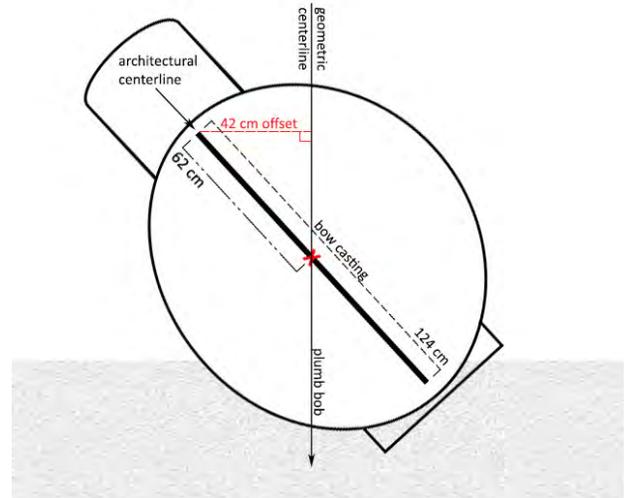


Figure 10.16. Measurements taken to determine the geometric centerline of the hull as it lay on the seabed. (Diagram by H. G. Brown, NHHC)

datum points at the bow and two at the stern, using a tape measure, carpenter’s level and plumb bob. Both points were marked with PVC stakes and then checked against each other and the vessel. The distance between stakes was 70.58 ft. (21.51 m), giving a total linear error of just 1 in. (2.54 cm), with a lateral error of 0.39 in. (1 cm). With the adjustable tables on the suction piles, this error would be inconsequential.

A small surface buoy was set at the center of each pile excavation site, providing a visual target for the crane operator to use when setting the piles. Divers installed 30 in. (76.30 cm) diameter buoys 10 ft. (3.05 m) off bottom and 25 ft. (7.62 m) out from the pile center, to act as deadmen supports for the divers to guide the piles into correct rotational position. The buoys’ anchors, 200 lb. (90.72 kg) clump weights, were buried 4 ft. (1.22 m) below the natural bottom using an induction dredge jet in order to maintain stable positions. With the markers set and the torpedo spar safely stowed, the site was ready for the engineers to take the lead.

Operations Delayed

On 6 June, with the site cleared and ready for action, the floating crane barge, which had been donated by Detyens Shipyard, was brought out to the recovery site to set the suction piles and lower the recovery truss. The donation of this crane was anticipated to save the project approximately \$200,000. However, the barge was designed primarily for harbor use, not open ocean operations. As it was towed off shore by a tugboat, the crane exhibited a great deal of pitch in the open water.

After anchoring on site, tests of the block and tackle indicated that even in moderate seas of 2 ft. (0.61 m) the crane hook would move approximately 4–8 ft. (1.22–2.44 m) vertically. This movement could transfer a significant amount of force to the truss and submarine, well over the 2 *g*'s the truss legs were built to withstand. In addition, when swinging the crane, it became apparent that when loaded it could easily topple over mid-swing. The crane also had a very slow lifting speed, which would pose a risk during the initial phase of the lift. With the barge moving up and down in the swell, a slow crane speed could result in the submarine impacting with the seabed during first few feet of the lift. Wright and Neyland, with input from Billy Bergeron of Delmar, decided to abort the use of the floating crane due to excessive risk to the submarine and the safety of the crane operator and others on that platform. While this would delay the project substantially, as no further work could be done until a safe recovery platform was located, all the parties—South Carolina Hunley Commission, Naval Historical Center, Friends of the Hunley, Oceaneering, and Delmar—agreed that it was the only responsible way to proceed.

When the recovery options had been studied initially, it was determined the best crane platform would be a self-elevating vessel, often called a jack-up barge. These have steel legs called spuds that can be extended down to the sea floor and, by continuing to extend the spuds, it can lift itself completely out of the water, into the air. No longer affected by the sea state, a crane can operate from the platform with extreme precision. In early plans, a jack-up barge had been proposed but was not selected due to availability and expense concerns in the face of Detyens Shipyard's offer. It was difficult to locate one of a suitable size with a crane meeting the required lifting capacity. While common in the Gulf of Mexico, none were available on the east coast of the United States. The high expense of bringing one from the Gulf or from overseas would increase the overall cost of the project. Nevertheless, it was the safest option for the successful recovery of *Hunley*.

Two suitable platforms were found, one in the Dominican Republic and the other on the Gulf Coast of Florida. Transport time to Charleston varied, the Florida vessel taking the longest to arrive because it would have to go around the Florida peninsula. Also, if it encountered bad weather it would have to go into port and wait until the weather improved—all at the expense of the project. It also required that a safe harbor be provided for it in Charleston, which could be difficult since the legs were too tall to fit under the Cooper River bridges. This vessel was also only a three-legged jack-up, whereas the other candidate had six legs.

The vessel in the Dominican Republic, *Karlissa-B*, was considered the best choice due to its construc-

tion, proximity, and cost. Formerly a U.S. vessel, it was, however, currently working under the Belizean flag and could not conduct a salvage lift in the United States without violating the Jones Act of 1920. In order to perform the *Hunley* recovery, Titan offered to reflag their vessel back under the United States, a procedure almost unheard of once a U.S. vessel has become foreign flagged. Once reflagged, *Karlissa-B* would be allowed to lift the submarine, but provisions of the Jones Act still prohibited its use to transport cargo into an American port. Although discussions were held with U.S. Customs about whether *Hunley* should appropriately be considered cargo, it was determined the submarine could not be transported to shore on *Karlissa-B*. Thus the submarine and truss would be placed on the same barge that had transported the suction piles and truss to the site. This change to the recovery plan resulted in a 32-day project stand down as well as increasing project costs.

The decision to change lifting platforms meant that *Marks Tide* was no longer needed. Captain David Fontaine and crew were all extremely disappointed, for the *Hunley* had come to mean more to them than just another job. After the exposed portions of the hull were protected with sandbags and all equipment removed from the site, on 22 June, dive operations were halted and *Marks Tide* was sent back to the Gulf of Mexico. The crew boat was also released back to Groboat's. On 13 July, *Karlissa-B* got underway from the Dominican Republic, going through the reflagging process while in transit.

During the interim, the site continued to be monitored by USCG and video surveillance equipment on the Sullivan's Island lighthouse. In addition, personnel from U.S. Navy Special Boat Units 20 and 22 were assigned to help provide security for the project. They did morning and evening visits to the site and in one case ran a dive boat away from the site.

Resumption of Operations

As the lift platform approached Charleston, dive operations recommenced on 17 July from the new crew boat *Jeremy*. A small team of four HAT divers went to the site and dredged out the sand and mud that had filled in the previously-excavated trench around the hull to make ready for the suction piles. All of these dives were conducted using scuba. *Karlissa-B*, towed by the oceangoing tug *Elsbeth III*, arrived in Charleston on 21 July and went into Detyens Shipyard for mobilization. Over the next two days all of the dive equipment formerly on *Marks Tide* was refitted and loaded on board. On 24 July, *Karlissa-B* was towed to the *Hunley* site and positioned southwest of the submarine. This was not without some problems as the harbor tugs found that the large *Karlissa-B* was not easy to control

in the open ocean. Several of their lines broke during the offshore operation and some damage occurred to *Karlissa-B*'s hull when one of the tugs collided with it. As the difficulty became apparent, a call was made to Great Lakes Dredging, a company performing dredging operations in Charleston Harbor, who had a larger seagoing tug in the area. This tug tied on to *Karlissa-B* and was able to successfully position her over the site.

A 110 ft. (33.53 m) materials barge was towed to the site and secured on a four-point mooring to the northeast side of *Hunley* (see Figure 10.7). This platform held heavy equipment such as pumps, screens, and generators for the dredging operations, which were welded to the deck. The barge also carried the suction piles and the lifting truss. In addition, the barge was used as a crew staging area. Dive operations, however, were conducted from the deck of *Karlissa-B*. Crewmembers would board *Jeremy* at the Fort Moultrie dock on Sullivan's Island and travel forty minutes. Once on site, they would either offload onto the materials barge and transfer by personnel transfer basket (called a "Billy Pugh" after the manufacturer) attached to the crane, or access *Karlissa-B* directly by *Jeremy* reversing engines and holding the stern against the jack-up barge's ladder (Figure 10.17). Both methods of transfer had some risk factors, either being hoisted high into the air by a crane or maneuvering from the pitching deck of the boat onto the barge's ladder.

Normal, surface-supplied dive operations resumed on 24 July. Due to the delay caused by changing lifting platforms, dive operations were stepped up to a 24-hour schedule. Hurricane season was rapidly approaching and no one wanted to experience the frustration of covering and evacuating the site. In the event of a hurricane evacuation, the entire exposed portion of the submarine was to be covered with sandbags. The James Island fire department had generously provided the project with hundreds of sandbags, which remained at the ready on shore. Two 12-hour shifts were adopted that affectionately became known as the day crew and the night crew, with one crew always trying to outdo the other.

Placing the Piles

With the positioning markers for the caissons still in place from June, and the infill removed from the footing areas, the placement of the suction piles could begin immediately. One OII diver remained in the water to set each pile and maintained contact with the surface diver control operator, who in turn directed the crane operator. Topside OII personnel positioned the pile by adjusting attached lines running through bottomed deadman braces and rotating it into proper orientation for it to mate with the truss end seat.



Figure 10.17. Team members transferred from the crew boat to *Karlissa-B* via a crane-lifted Billy Pugh. (Courtesy of FOTH)

At 3:30 A.M. on 25 July, *Karlissa-B*'s crane placed the first suction pile 6 ft. (1.83 m) forward of *Hunley*'s bow, with a placement error of 3 in. (7.62 cm). At 8:45 that morning, the crane set the second pile aft of *Hunley*'s stern. This one came down 28 in. (71.12 cm) from its target point, outside the acceptable margin of error. In only a few hours it was lifted, shifted, and rotated, and by mid-afternoon it was placed on its target point, 5.75 ft. (1.75 m) aft of the stern.

Over the course of the night, the flanges and pumps were rigged, and the caissons were suctioned down into the seabed. Optimal pile depths were calculated, taking into consideration the fact that the bow was approximately 1 ft. (0.30 m) lower than the stern, the resultant angle of the truss, and the adjustability of the slings. As a result, the bow pile was set approximately 3 ft. (0.91 m) below the top of the bow, the stern approximately 3.5 ft. (1.07 m) below the top of the stern.

Safety during the pile installation operation was maintained through proper communication, strict adherence to proper procedures, and verification that all performance requirements were met. In addition,

equipment inspection and function tests for all gear and deck equipment were carried out prior to installation.

Once the piles were fully set, archaeologists excavated in the areas where the lifting truss legs would extend into the sand. At 1:30 in the afternoon of 26 July, the lifting truss was lowered over *Hunley*; however, the area had not been sufficiently excavated to accommodate the truss legs, so the truss stood several feet above the suction piles. OII divers removed approximately 2 ft. (0.61 m) of stiff clay from beneath the truss legs, and the truss was set firmly on top of the suction piles, ready for final alignment. Although the process of aligning the truss with the piles took longer than expected, two days later, OII divers were able to place the first of the lifting slings beneath the submarine.

Rigging the Slings

With the truss secured to the tops of the suction piles, HAT divers began to excavate, starting at the bow, beneath the submarine in preparation for placing the lifting slings. To avoid having a portion of the submarine hanging unsupported in the water column, archaeologists only excavated enough sediment to place two to three slings at a time, approximately 2–3 ft. (0.61–0.91 m). Work was now hampered overhead by the truss and all of the accompanying sling turnbuckles. In the restricted visibility, entanglement hazards were everywhere, making it difficult for the dive team to keep their umbilical hoses free (Figure 10.18). Nevertheless, the process went smoothly, and divers excavated and cast exterior hull profiles prior to each sling installation (as described above) without incident.

Following the profile casting, OII divers placed the slings for that section beneath the submarine and secured them loosely to the turnbuckles on the truss. Next, vinyl bags cable-tied to the inner surface of the lifting slings were injected with expandable foam, which, when filled, fit the submarine's lower exterior contour perfectly (see Chapter 9). Bill Youmans of Flexible Products and Michael Gatto Jr. of NCS Supply were on board the *Karlissa-B* during the initial foaming process to ensure all went smoothly (Figure 10.19). The foam set up in approximately two minutes. Once the foam was in place, the OII team then began tensioning the lifting sling. An OII engineer monitored the computer load-cell display from *Karlissa-B* and directed OII divers as they tightened the turnbuckles in accordance with the load distribution plan devised by Perry Smith.

Before the lift could be initiated, the holes in the hull had to be patched to prevent loss of material from the interior of the submarine. In addition to the two discovered in late May, there was a third in the forward conning tower, which had come to light with the submarine's discovery in 1995. The largest hole, at the stern,



Figure 10.18. Diver working around the forward conning tower with truss beams directly overhead. (Courtesy of FOTH).

spanned several sling stations and required patching before the slings could be set. It was covered with a large neoprene pad, which was held in place by four 6 in. (15.24 cm) wide ratchet straps. A strongback of angle iron was placed along the port side near the top to hold the ratchets away from the hull surface. The strongback extended aft beyond the stern to provide additional protection and rigging support to the propeller shroud (Figure 10.20). When the patch was complete, the slings were filled and tightened in place. The two smaller holes were patched after the slings were in place, the bow hole with neoprene and the conning tower with filled with expandable polyurethane foam. The slinging process was completed on 4 August. A total of 32 slings supported the submarine.

The submarine, once free of the bottom, swayed gently in its cradle with the flow of the ocean tides. The day of the lift was then scheduled for 8 August, since weather projections, which were being closely monitored, were for optimum conditions. This waiting period also provided enough time to accommodate the public and press that wanted to view the raising.



Figure 10.19. Bill Youmans, Michael Gatto Jr., and Mark van Emmerick demonstrate the foam setting up around an object. (Courtesy of FOTH)

Divers spent the remaining days removing any intrusive material and installing the secondary slings designed to reduce circumferential stresses (see Chapter 9). Intrusive material, including loose cotter pins and misplaced tools, were collected and removed. This step would be very important when, following *Hunley's* recovery, underwater archaeologists returned to the site with a magnetometer to look for additional small iron objects whose magnetic signature had been obscured by the iron mass of the submarine (see Chapter 11).

During this brief hiatus in the work, Smith raised concerns about the bobbing movement of the materials barge that would carry the truss and submarine. When first brought to the site, this barge rode low in the water from the weight of the truss and piles. However, once freed of this heavy load, it began to bob cork-like in the waves. The apparent danger was that, as the truss and submarine were being lowered, the barge could suddenly rise upward and impact the truss with sufficient force to crush a leg and possibly damage the submarine from the impact. A 2 ft. (60.96 cm) rise due to the waves could equate to a 2 *g's* of force on the truss. This issue was resolved in two ways simultaneously. Leonard Whitlock, the senior project manager, researched how partially flooding the barge's three separate internal compartments would affect overall stability. The procedure was tested ashore on an identical barge located at Detyens Shipyard with guidance from a naval architect on the amount of flooding needed in each compartment to maximize stability. With the proper fill levels determined, partial-

flooding was successfully implemented on the materials barge at the site. Care had to be taken to flood the compartments equally to maintain stability.

At the same time, a visit was made to a representative of Great Lakes Dredging, the company that had helped with positioning *Karlissa-B*. Their dredging operation used a large hopper barge to carry the dredge spoil to a designated offshore disposal site. They donated the services of the hopper barge and two seagoing tugs to create a temporary breakwater during the lift.

Every possible precaution was taken to ensure a safe recovery. Law enforcement from SCDNR, USCG, and Charleston and Mount Pleasant marine police organized a security zone around the recovery site and a

moving security zone down the Cooper River to the former Charleston Naval Shipyard (see Chapter 6). Once *Hunley* was transferred to shore and transported by crane to the WLCC, North Charleston police would take over security. They would also maintain security for *Hunley* and VIPs while it was being installed in the tank in the laboratory.



Figure 10.20. A patch was placed over the starboard stern hole to ensure no loss of interior contents. (Photo by Rand Pixa, courtesy of FOTH)

Raising the Hull

The recovery date was planned as an event for the public and press, as there was a great deal of interest in and excitement about the project. As the meteorologists had predicted, 8 August was perfect, a sunny and calm day with waves of 1–1.5 ft. (30.48–45.72 cm). All archaeologists, divers, engineers, and other personnel arrived on *Karlissa-B*, both to help with the lift and to witness the event. The two individuals who guided the whole operation, Senator Glenn McConnell, Chairman of the South Carolina Hunley Commission, and Warren Lasch, Chairman of the Friends of the Hunley, were present on site before dawn. Two additional vessels arrived on site shortly after dawn. The Fort Sumter tour boat *Spirit of Charleston* carried VIPs and supporters of the project, while the local charter vessel *Carolina Clipper* carried all the press and media personnel. *Spirit of Charleston* was given the privileged position of being closest to the point of lift. The press boat was a bit further off but had an expansive view of the lift operation. *National Geographic* personnel and contractors, as well as local *Charleston Courier* reporters Brian Hicks and Schuyler Kroft, were the only media on *Karlissa-B*.

The large hopper barge from Great Lakes Dredging was towed to site and held in position by the two tugs (Figure 10.21). However, it also became apparent that the 102 ft. (31.01 m) long *Spirit of Charleston*, which was stationed very close to the recovery barge, would act as a breakwater as well. The interagency security team, including the 87 ft. (26.52 m) USGC cutter *Yellowfin*, established a perimeter around the site. The security zone proved necessary as the number of private boats, including kayaks and jet skis, was estimated at 600 vessels.

Preliminary dives were done by both OII and HAT personnel. OII detached the umbilical that uploaded the load cell data and accomplished the final rigging for the lift. After a final check on the truss rigging from underwater, Perry Smith communicated that the truss and sub were ready for the lift. Smith then moved away from site to the safety of the diver's stage. At 8:39 A.M. *Hunley* emerged from sea and slowly spun on the cable to give a full view to eager spectators (Figure 10.22). The submarine was met by the sound of cheering and boat horns. Steve Wright timed the setting of the truss on the materials barge perfectly with the rise and fall of the



Figure 10.21. Aerial view of the raising of Hunley, showing disposition of vessels around *Karlissa-B*. (Photo by Cramer Gallimore, courtesy of FOTH)

waves. As soon as it touched down, the crane slacked the cable and OII personnel began chaining the truss down and welding its legs to the deck of the material barge. A quick inspection determined that the lift had gone perfectly, with no apparent leaks or damage to the hull. Mardikian immediately began setting up the sprinkler system to keep the hull wet during transport.

Neyland, Whitlock, and Wright monitored the lift from the materials barge, since setting the truss and submarine on it would be the most critical part of the lift. Lasch and McConnell were the first to transfer over to the barge. Eventually all OII and HAT personnel transferred to the materials barge for a triumphant return of *Hunley*. As soon as the truss was safely secured to the barge, a tow was attached to two McAllister Towing & Transportation tugs, *Lewis G. Seabrook* in the lead, and *Brooklyn McAllister* behind for added maneuvering control. As the tow got underway, the security zone closed around the tugs and barge to clear a path among the many boats and maintain a safe perimeter.

As the historic submarine made its way into the Cooper River, it was accompanied by several hundred private boats (see Figure 16.1). Other than a private boat running out of fuel, there were no incidents and the moving security zone worked flawlessly. Thousands of people turned out at Ft. Moultrie on Sullivan's Island and thousands more lined the shores of Charleston and Mt. Pleasant. The traffic over the Cooper River Bridge came to a standstill and people got out of their cars to view the sight. The procession moved flawlessly to Charleston Naval Shipyard and arrived at Pier Juliet at 2:30 in the afternoon (Figure 10.23). OII personnel then



Figure 10.22. The submarine H. L. Hunley begins its journey back to Charleston after 136 years. (Photo by Travis Bell, courtesy of Travis Bell Photography.)

set to work removing the bearing seats from the truss with a cutting torch in preparation for its placement into the tank. With the truss prepared, it was lifted by one of the shipyard portal cranes and carried to the WLCC, where it was transferred to an overhead crane inside the conservation building (Figure 10.24). The truss was then lifted, carefully positioned over the tank, and slowly lowered inside. The submarine was safely in the tank by 6:15 P.M. and Mardikian immediately began filling it with water. From recovery to placement in the tank, transport had lasted a total of 10 hours. Once inside the tank, the rigging was removed from the truss and the tank filling sequence was initiated. Conservators ensured hull was kept wet during the four hour procedure. Over the next 24 hours the tank water was chilled from 20° C (68° F) to 10° C (50° F). The only period the submarine had not been kept wet was during the transfer from the pier to the laboratory tank.

On the following day OII personnel began removing the suction piles from the seafloor. They were placed on a barge and transported to the shipyard. *Karlissa-B* was then towed from the site that evening to a

Detyens Shipyard pier in North Charleston. On August 10, OII and HAT teams began demobilizing *Karlissa-B* and rigged the mooring anchors for recovery.

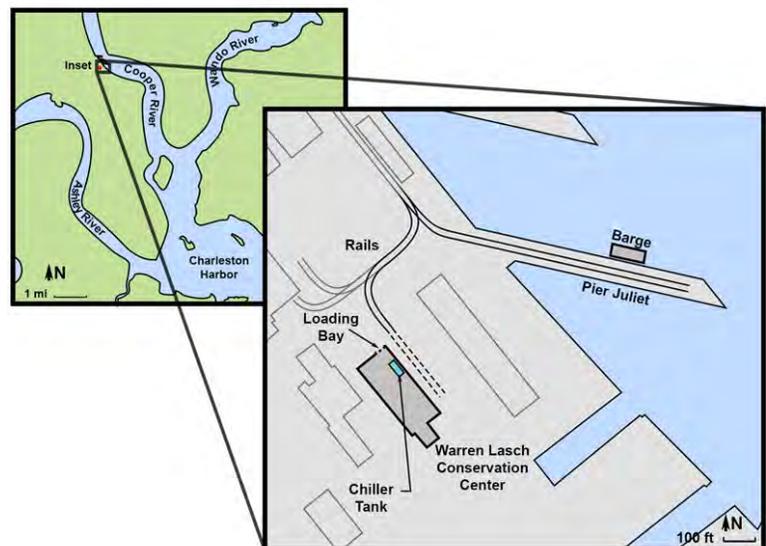


Figure 10.23. The barge carrying Hunley was towed up the Cooper River to Pier Juliet at the former Charleston Naval Shipyard in North Charleston for transfer to the Warren Lasch Conservation Center. (Map by Mari Hagemeyer, NHC)



Figure 10.24. H. L. Hunley on its final leg of the journey, carried by rail-based portal crane to the WLCC. (Courtesy of FOTH)

Conclusion

H. L. Hunley was successfully recovered without any damage or loss of archaeological information. As planned, the submarine maintained hull integrity and never deviated from its original starboard list, as it had rested in the sea bottom for 136 years. The teamwork of archaeologists, engineers, and others worked exceptionally well. As Senator McConnell was fond of saying, “No slip between the lip and the cup!” The implementation of the engineering design was superb. Even though at times it was said that the recovery system was “over engineered,” this type of planning and execution was precisely what was needed for such a unique and fragile artifact. The recovery operation was carried out without any injuries to the personnel involved. The Friends of

the Hunley would receive three awards for safety the following year from the South Carolina Occupational Safety Council.

Discovery and recovery of famous shipwrecks is always a media event and *Hunley’s* raising was no exception. Providing for the public viewing and media coverage of the recovery, with all the logistical, safety, and security challenges, was a valuable component in generating good will and support for the project. The thoroughness of the recovery planning and professionalism of its execution set the standards for the excavation of the submarine’s interior that would follow and provided a useful template for future archaeological recoveries.

11. Post-Recovery Surveys

Harry Pecorelli III and Heather G. Brown

With the recovery of *H. L. Hunley*, the largest ferrous object at the site was no longer present to saturate magnetometer readings, and the way was clear to re-examine the area. A new remote sensing survey plan was designed to locate and identify any additional iron artifacts that may have been missed during the initial investigation. A preliminary survey was conducted in the area surrounding the submarine's pre-recovery position in 2000, followed by a detailed, diver-based survey conducted by the Friends of the Hunley (FOTH) in the summer of 2002, and final brief site assessment in 2003.

For the primary, 2002 survey, FOTH archaeologists Harry Pecorelli and Shea McLean joined Ralph Wilbanks and Steve Howard of Diversified Wilbanks, Inc. to conduct the investigation. The 10-day field project began on 5 August 2002 and was funded by author Clive Cussler and an American Battlefield Protection Program grant from the National Park Service (Grant No. GA225502101). In 2003, a subsequent survey was conducted to reacquire and excavate the few remaining magnetic anomalies that could not be investigated previously.

Background

During the excavation of the *Hunley* site in June 2000, archaeologists discovered that a portion of the port side of the submarine's propeller shroud and the port shroud attachment bar were missing. Project staff hoped that the missing objects would be discovered during the recovery excavation; however, this significant part of the submarine's architecture was never found. Because project archaeologists had completely excavated the area immediately surrounding the vessel, the pieces were assumed to be located outside of the excavation area. This resulted in the decision to return to the site and conduct additional survey work in hopes of locating the missing elements.

As discussed in Chapter 4, several magnetometer surveys had been conducted in the years leading up to the recovery (Figure 11.1), primarily with the goal of locating the site itself. In 1996, a high resolution survey was conducted by NPS in order to detect any undiscovered material associated with the *USS Housatonic/H. L. Hunley* engagement site (Murphy 1998:53). Lanes were spaced at 10 m (32.81 ft.) intervals for a total coverage area of 400 × 800 m (1,300 × 2,600 ft.) (Murphy 1998:56–58). The main anomalies noted at the time, an anchor and a buoy, were at least 100 m (328 ft.) distant from the submarine, with many closer objects masked by the signature of the hull itself (Figure 11.2). The data collected was entered into GIS software where it could be easily compared to post-recovery survey data.

Immediately after the recovery in 2000, the area where *Hunley* had been was resurveyed by Diversified Wilbanks. Several targets were acquired that had not been detected in the 1996 survey. These had the potential to be either materials left behind from the excavation or targets not captured in 1996 due to the strength of *Hunley's* magnetic signature. To determine the nature of the most significant targets, a diver-based survey was necessary.

Methods

All 2000 and 2002 survey and dive operations were conducted from the vessel *Diversity*, which was launched at the Wild Dunes Marina and Boat Landing and docked at the NPS Fort Moultrie's floating dock on the north side of Sullivan's Island.

Surface Survey

A 100 × 100 m (328 × 328 ft.) area surrounding the submarine's pre-recovery position was surveyed with a Geometrics 881 cesium magnetometer operated at a ½

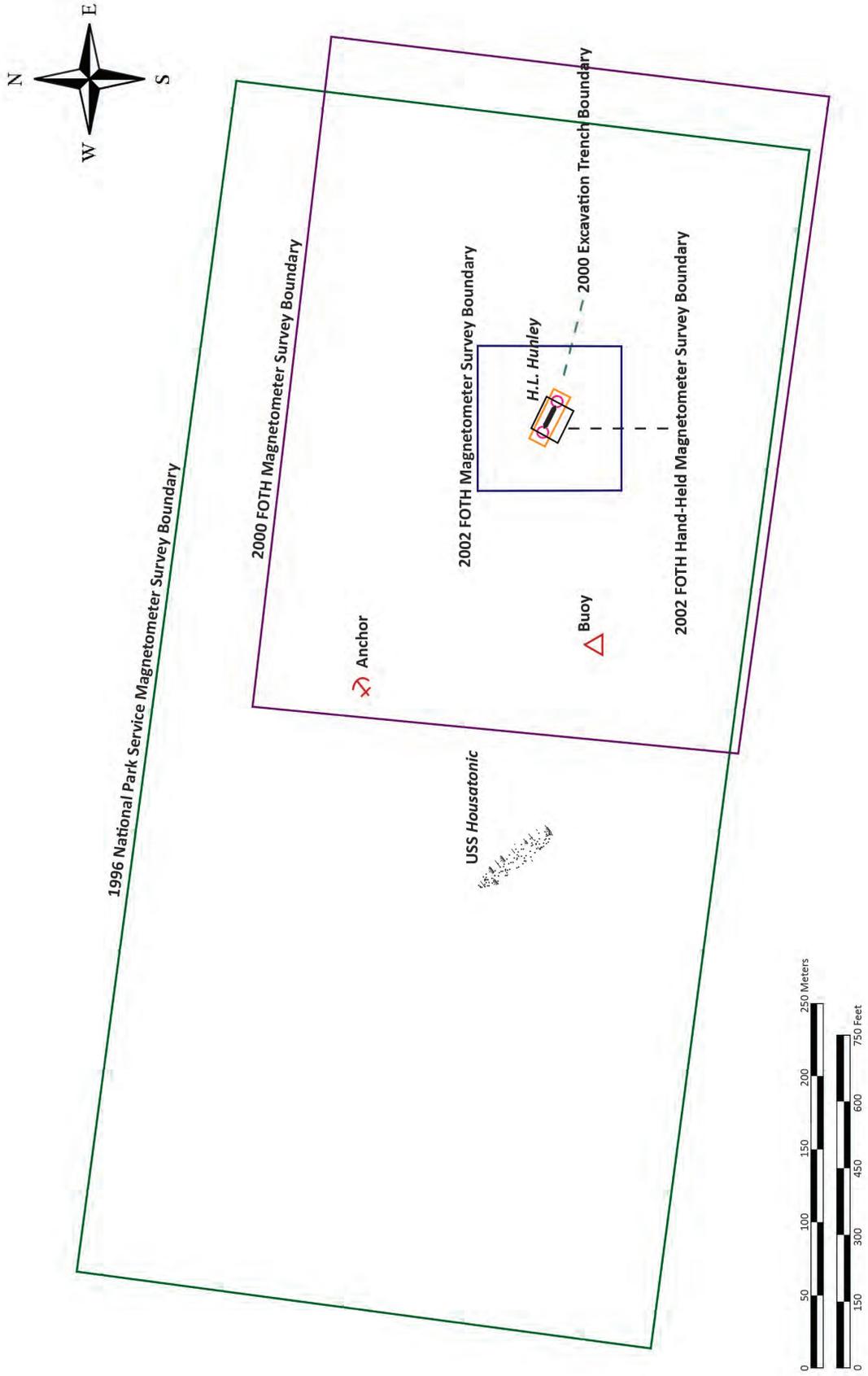


Figure 11.1. Boundaries of 1996, 2000, and 2002 surveys.

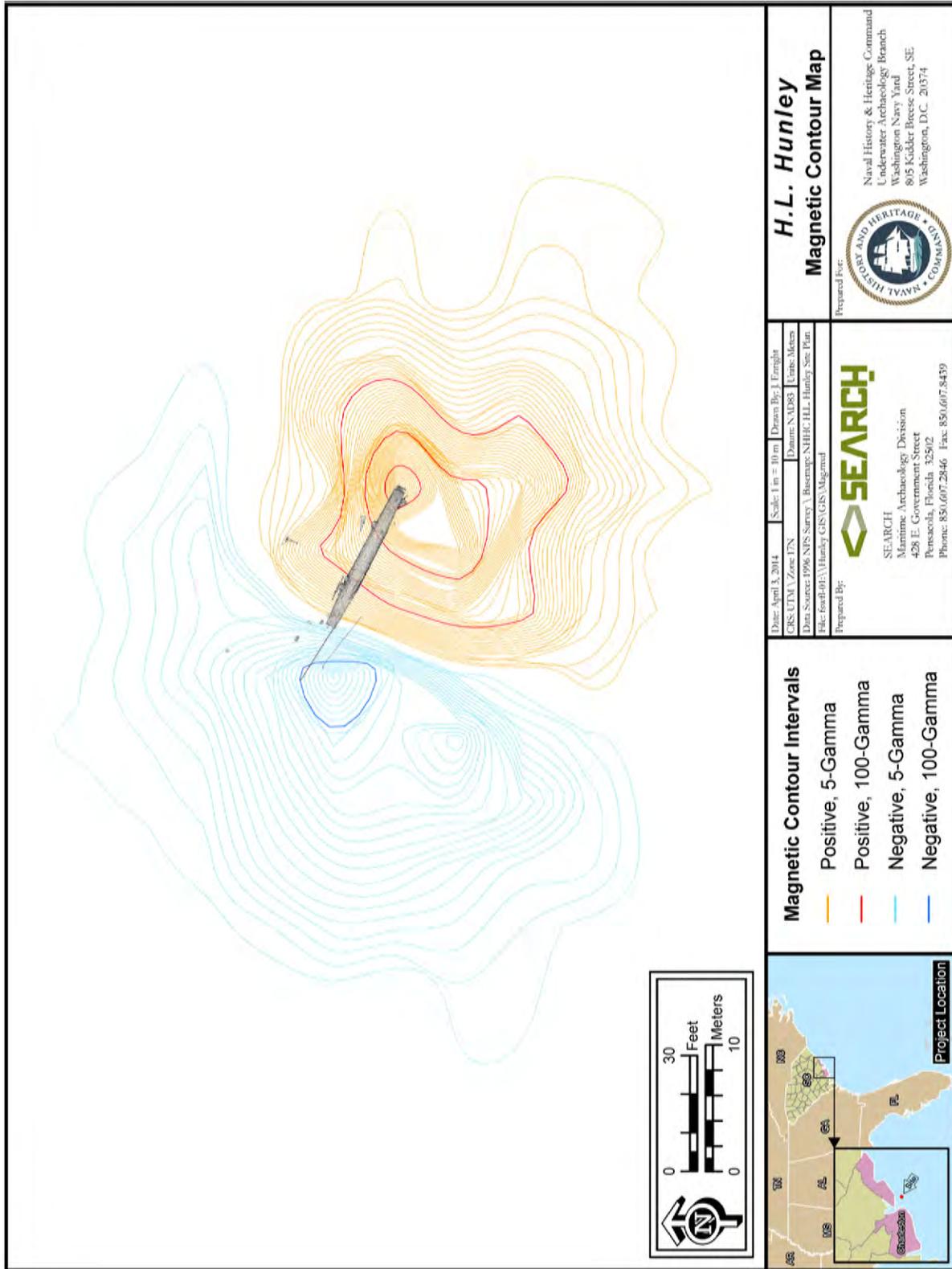


Figure 11.2. Magnetometer data from 1996 overlain on the post-recovery site plan. Deeply buried material, such as the grapnel anchor and cutwater, did not show distinctive signatures in the shadow of the readings from the hull.

second sample rate. The magnetometer was towed at a boat speed of four knots. Ten transects spaced at 10 m (32.80 ft.) intervals were surveyed. Sea conditions at the time of the survey dictated that all ten lanes were run in the same south-to-north direction.

Diver Survey

Upon completion of the surface survey, the team conducted a diver-based, hand-held magnetometer survey to collect higher-resolution data from the area surrounding the submarine's pre-recovery position. The initial survey area was 25 × 12 m (82.10 × 39.37 ft.). Using a survey-grade global positioning system, the team placed weighted buoys on the north and east

boundary corners of the recovery site to establish the northern boundary line. Archaeologists then used fiberglass reel tapes to physically mark the south and west boundary corners. All corners were marked with 1 m (3.28 ft.) lengths of 1 in. (2.5 cm) diameter schedule 40 PVC pipe. These PVC pipes were driven into the seabed so that only 15 cm (6 in.) remained exposed above the bottom. Lanes were then established at 2 m (6.56 ft.) intervals and strung with ⅜ in. (0.95 cm) diameter poly line. In the restricted visibility environment surrounding the site, physical lanes proved necessary to help guide the divers conducting the survey.

The 300 m² (3,229 sq. ft.) area was first surveyed by divers using the same magnetometer used in the surface survey. Archaeologists held the cable end of the magnetometer sensor and pushed it backwards—fin end

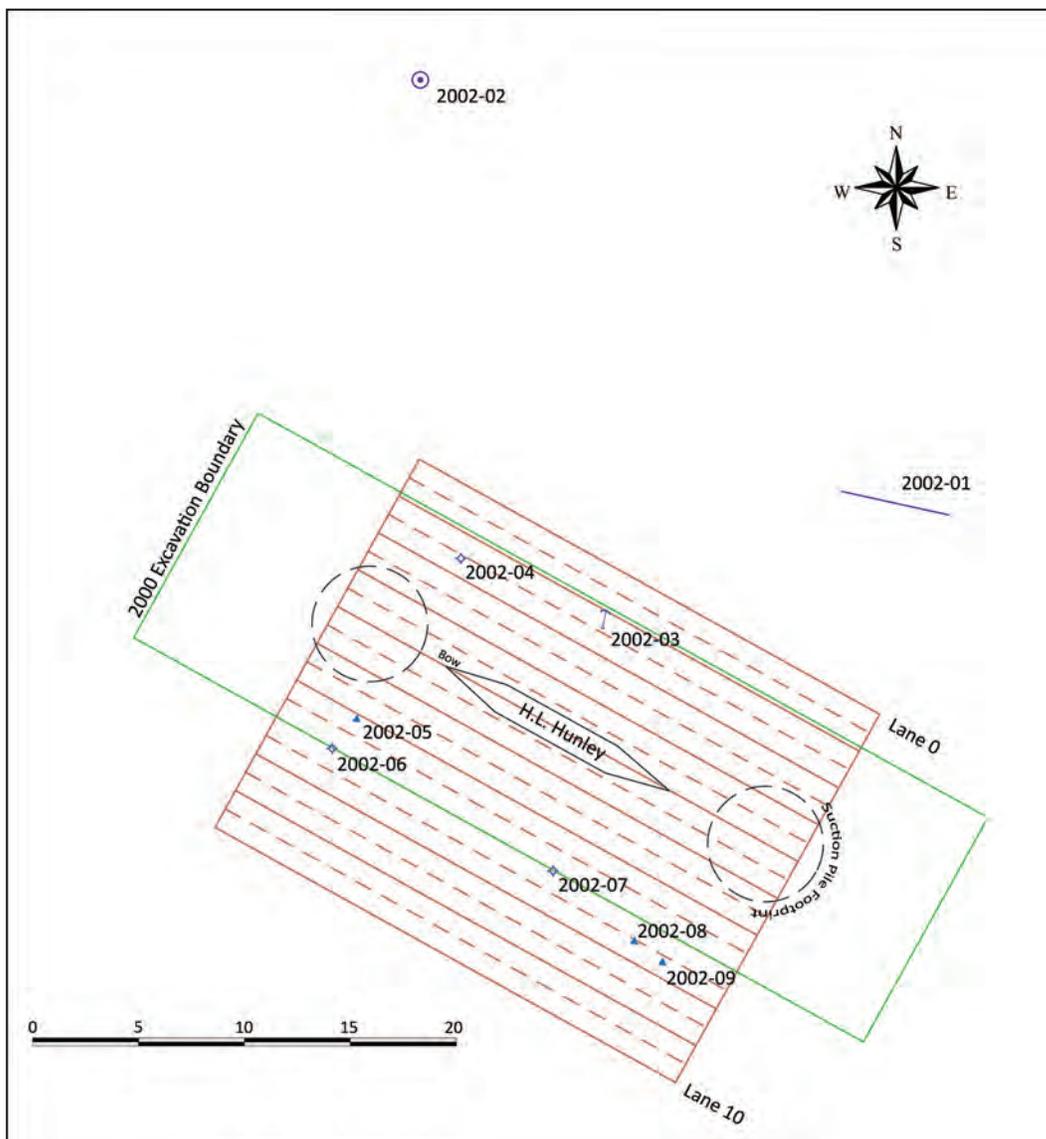


Figure 11.3. Area of hand-held magnetometer survey over original position of H. L. Hunley wreck.

Table 11.1 Magnetometer Targets Investigated in 2002–2003

| Target | Distance (m) | Direction | Gamma (γ) | Identification |
|---------|--------------|-----------|-----------|---------------------------|
| 2002-01 | 20 | NE | 100+ | Steel fence post |
| 2002-02 | 25 | N | 5+ | Mushroom anchor (19th c.) |
| 2002-03 | 5 | N | 40+ | Grapnel anchor (HL-2917) |
| 2002-04 | 6 | NW | n/a | Aluminum datum pipe |
| 2002-05 | 5 | SW | 12+ | Dive knife |
| 2002-06 | 8 | SW | n/a | Aluminum datum pipe |
| 2002-07 | 6 | S | n/a | Aluminum datum pipe |
| 2002-08 | 9 | S | 150+ | Iron can fragments / wire |
| 2002-09 | 10 | S | | Iron can fragments / wire |

first—along every other transect. While this technique produced better-than-average results, problems with data acquisition frequently arose whenever the sensor wobbled from side to side. Water currents also seemed to affect the quality of data; for example, transects that traveled with the current produced better results than those that ran contrary to it. Archaeologists marked all objects with a 1 m (3.28 ft.) length of ¼ in. (1.91 cm) diameter yellow fiberglass rod.

Each transect was then re-surveyed using a hand-held Quantro Sensing Discovery Plus proton-precession magnetometer operated at a 2.5 second sample rate. This technique produced very accurate results, and enabled project staff to identify objects that exhibited less than a meter (3.28 ft.) of magnetic influence. Due to the improved results, several targets were discovered very close to the initial grid boundaries. As a result, the grid was expanded to 20 m (65.62 ft.) wide, with lanes 0, 8, 9, and 10 added to the initial 1–7 (Figure 11.3). The entire grid was resurveyed at 1 m (3.28 ft.) intervals, ensuring extremely thorough coverage of the area.

Following the magnetometer survey, archaeologists replaced each of the fiberglass markers with a buoyed cinder block and began probing the surrounding area with a 3 m (9.84 ft.) long, ¾ in. (1.91 cm.) diameter water jet probe powered by an 11 horsepower water pump. No objects were detected with the jet probe. After probing operations were completed, archaeologists inserted a 3 m (9.84 ft.) long section of 1 in. (2.54 cm) diameter PVC in the seabed next to each of the target positions. These posts served as a vertical guide for subsequent dredge excavations. Archaeologists employed the use of a 4 in. (10.16 cm) diameter water induction dredge to excavate a conically shaped test unit around each PVC pipe.

Once exposed, each target’s position was recorded relative to the survey grid and assigned coordi-

nate values in Universal Transverse Mercator, North American Datum 1983, Zone 17 north. These items were subsequently recovered and transported to the Warren Lasch Conservation Center (WLCC) in North Charleston for conservation and analysis.

Findings

A total of seven targets were identified as cultural material in the 2002 survey, while two additional targets required a visit the following summer to locate and identify (Table 11.1). Two of the targets were discovered during the surface survey. The first (2002-01) had been noted originally in the 2000 post-recovery survey and was relocated approximately 20 m (65.62 ft.) north of the site. At 100+ gamma magnitude, it had the potential to mask smaller signals nearby, and archaeologists were deployed to recover it. The object was identified as a 5.26 m (17.33 ft.) long section of 1.5 in. (3.81 cm) diameter fence pipe left over from the recovery project. It was one of a number of pipes originally intended as a component of the sub-datum network developed for the submarine’s recovery (see Chapter 10). These pipes had proven too difficult to drive into the seabed and were either recovered or abandoned on site. A 5+ gamma ferrous object (2002-02) was also detected approximately 25 m (82 ft.) north of the site. Time limits prevented investigation of this target until the 2003 survey (discussed below).

The diver survey resulted in the discovery of three of the original 1.5 in. (3.81 cm) diameter aluminum primary datum poles used to delineate the 2000 excavation trench boundary (2002-04, 2003-06, 2003-07). Each datum pole still protruded approximately 40 cm (15.75 in.) above the sand. In addition to the site

datums, archaeologists discovered the original ¼ in. (0.64 cm), three-strand synthetic line that delineated the boundary of the site. Portions of the line were buried as deep as 30 cm (11.81 in.) below the seabed.

In addition, four iron objects were discovered within the survey area. One target (2002-05), a 12+ gamma ferrous object detected 5 m southwest of the bow position, could not be pinpointed by divers and was added to the 2003 survey (see below). Two targets proved to be small iron fragments and wire, buried 10 to 20 cm (3.94–7.87 in.) below the surface of the sand (2002-08, 2002-09). These iron fragments varied in size, although they averaged approximately 0.2 cm (0.08 in.) in thickness, and all had a slight curvature to them, consistent with the can fragments recovered from many locations around the site during the 2000 excavation (see Chapter 15). They were transported to the WLCC for documentation then discarded. Similar fragments were also detected at shallow depths during the pre-recovery magnetometer survey conducted in 2000 (see Chapter 10), and may be a relatively common feature in the sediments close to the outflow zone of Charleston Harbor.

The most significant discovery during the 2002 survey was a five-tined iron grapnel anchor (Target 2002-03; Artifact HL-2917), found roughly 5 m (16.40 ft.) north of *Hunley's* original midship position. The anchor shank was located 1.8 m (5.91 ft.) below the seabed; three of the tines were partially dug into a 10 cm (3.94 in.) thick shell lens. The center of its tined end was

buried 1.8 m (5.91 ft.) below the seabed and located 14 m (45.93 ft.) from the southern end of lane one. The ring at the end of the shank was positioned 13.9 m (45.60 ft.) from the southern end of lane one. The grapnel's lower half was heavily concreted with large shells from the shell lens in which it was embedded, which appears to be part of the same shell layer that was found surrounding the bottom of the submarine during the 2000 recovery excavation. The grapnel's shank was oriented level with the bottom, with the attachment ring pointing toward the forward hatch of the submarine (197°). The ends of the grapnel tines were flattened to form flukes. The grapnel has an overall length of 85 cm (2.79 ft.) and exhibits attributes consistent with 19th century manufacture (see Chapter 15). Given its depth of burial and its general characteristics, it is likely this anchor was deposited on the site at some point close to or soon after *Hunley's* loss. It is possible it was lost during attempts to locate *Hunley* or during salvage work on the *Housatonic* wreck.

2003 Site Visit

In 2003, the FOTH team returned to the site for one last offshore survey and limited excavation. The purpose of the survey was twofold: 1) investigate the nature of certain magnetic anomalies discovered near the site during the 2000 and 2002 remote sensing surveys;

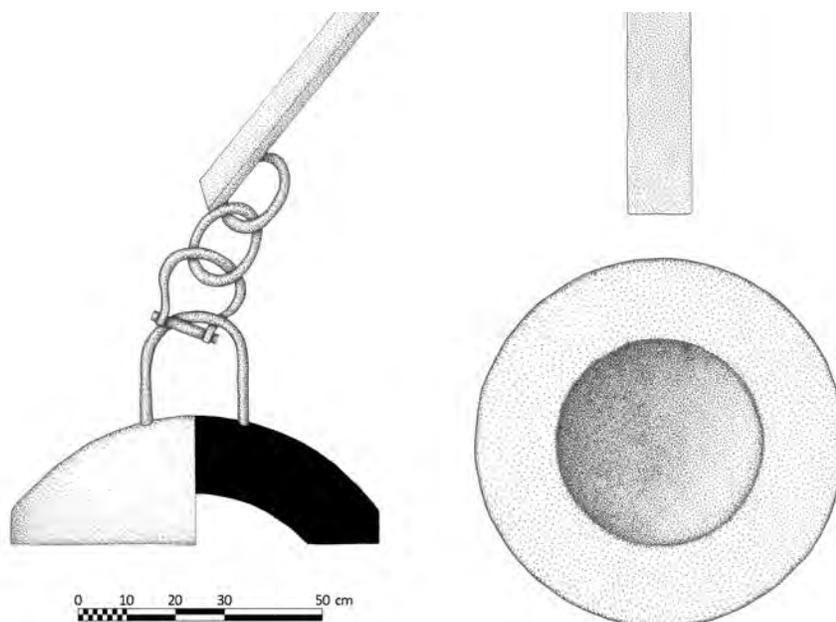


Figure 11.4. Illustration from diver notes of the mushroom anchor and length of chain discovered near the *Hunley* site and left in situ. (Drawing by James W. Hunter III, courtesy of FOTH)

and 2) ensure that no ferrous objects were missed that could be associated with the wreck site. This survey paved the way for removing maritime restrictions at the battle site that had been in place since the submarine's discovery.

No objects were found that are believed to be associated with *Hunley*, but Target 2002-02 may be roughly contemporary with the submarine. It was a large, convex iron object weighing an estimated 250 lb. (113.4 kg), located approximately 25 m (82 ft.) north of *Hunley's* original position on the seabed. The object, which was 30 in. (76.2 cm) in diameter and 7 in. (17.78 cm) thick, most likely represents a buoy weight of the type sometimes referred to as a mushroom anchor or sinker. Attached to the top of the convex side was an 8 in. (20.32 cm) iron chain fastened to a metal bar. Only a portion of the bar and chain assembly was exposed, but its buried length extended at least 50 ft. (15.24 m) from the point where it disappeared into bottom sediment. Since the object was found on the same shell lens that the submarine once rested on, it is likely that it, too, dates to the Civil War era. Because this type of weight was commonly used for anchoring not only buoys but also submerged mines during that period (Schiller 2011:190), the dive team refrained from following the chain all the way to its end. The exposed

portion of anchor, bar, and chain were documented in situ and reburied. Scaled drawings were made based on the divers' notes (Figure 11.4).

Target 2002-05 was also found buried 1.5 m (4.92 ft.) below the seabed and identified as a modern diver's knife embedded in a sandbag. During the excavation of *Hunley*, sandbags were placed on the site to protect the exposed areas of the hull during excavation. Just prior to the submarine's recovery, the sandbags were removed from the site. To simplify the process, divers cut open each one, discharged its contents, and brought it to the surface. It appears that one of the divers lost his knife in the process and was unable to locate it in the restricted visibility around the site. The effectiveness of the hand-held magnetometer survey was demonstrated by project archaeologists' ability to locate such a relatively small object within the vast area comprising the *Hunley* site.

The 2000, 2002, and 2003 surveys were an important follow-up to the recovery. They provided additional data regarding possible activities occurring after the sinking of *Hunley*, such as the U.S. Navy dragging for the submarine (see Chapter 4), and reassured the archaeologists that the recovery had been as thorough as possible in locating all of the cultural material from the sinking event.

12. Site Description

Heather G. Brown, Michael Scafuri, and Harry Pecorelli III

The submarine *H. L. Hunley* was buried beneath approximately 3 ft. (0.91 m) of sediment. An area 90 × 40 ft. (27.43 × 12.19 m) was excavated around it, and the sediment screened for artifacts. The vessel rested at an angle of approximately 47° to starboard, with the bow angled approximately 0.5° downward. The majority of the sediment was sand mixed with organic concretion and shell. The bottom of the vessel and part of the starboard side were embedded in a stiff mud topped with a tough shell lens.

A total of 341 artifact lots and 167 samples were collected. From the screened sediment, shells and natural concretions were discarded, while coal, boiler slag, wood fragments, fish and animal bones, and metal concretions were retained (Table 12.1). Samples were primarily sediment, but gas, metal, and water samples were also collected. Larger artifacts, such as hull components and concretions, were recovered by hand, while smaller materials were retrieved from dredge spoil. For a complete list of materials recovered, see Appendix G.

No formal trench designations were assigned, but the site was subdivided into regions based on location and excavation teams—the starboard and port sections directly adjacent to the hull that were excavated by the *Hunley* Archaeological Team (HAT); the starboard and port sections 10 ft. (3.0 m) out from the hull that were excavated by divers from Oceaneering International (OI); and the two holes for the suction piles, approximately 6 ft. (1.8 m) forward and aft of the hull (see Figure 10.11). These were all excavated down to the dense mud/shell layer in which the bottom of the submarine was embedded.

All artifacts were measured in by triangulation using a combination of fixed datum points and key points on the hull itself. The geographic position of the hull was pinpointed with GPS readings on the bow and stern. As per the research design, a three-dimensional site plan was created with the locations of significant artifacts and loose hull components using Rhinoceros software. A two-dimensional site plan was generated from this data and drawn by James Hunter (Figure 12.1).

Table 12.1. Number of Artifact Lots Collected by Material Type

| Organic | | Inorganic | |
|-----------------------|-----|-----------------------------------|-----|
| Bone | 17 | Ceramic | 3 |
| Caulking | 1 | Glass | 5 |
| Coal | 58 | Metal - fragments/concretions | 104 |
| Coral | 1 | Metal - hull components | 14 |
| Nutshell | 6 | Miscellaneous - modern materials | 9 |
| Rope | 2 | Miscellaneous - natural materials | 5 |
| Wood | 48 | Slag (boiler) | 65 |
| Unidentified Material | 3 | | |
| Total | 136 | Total | 205 |

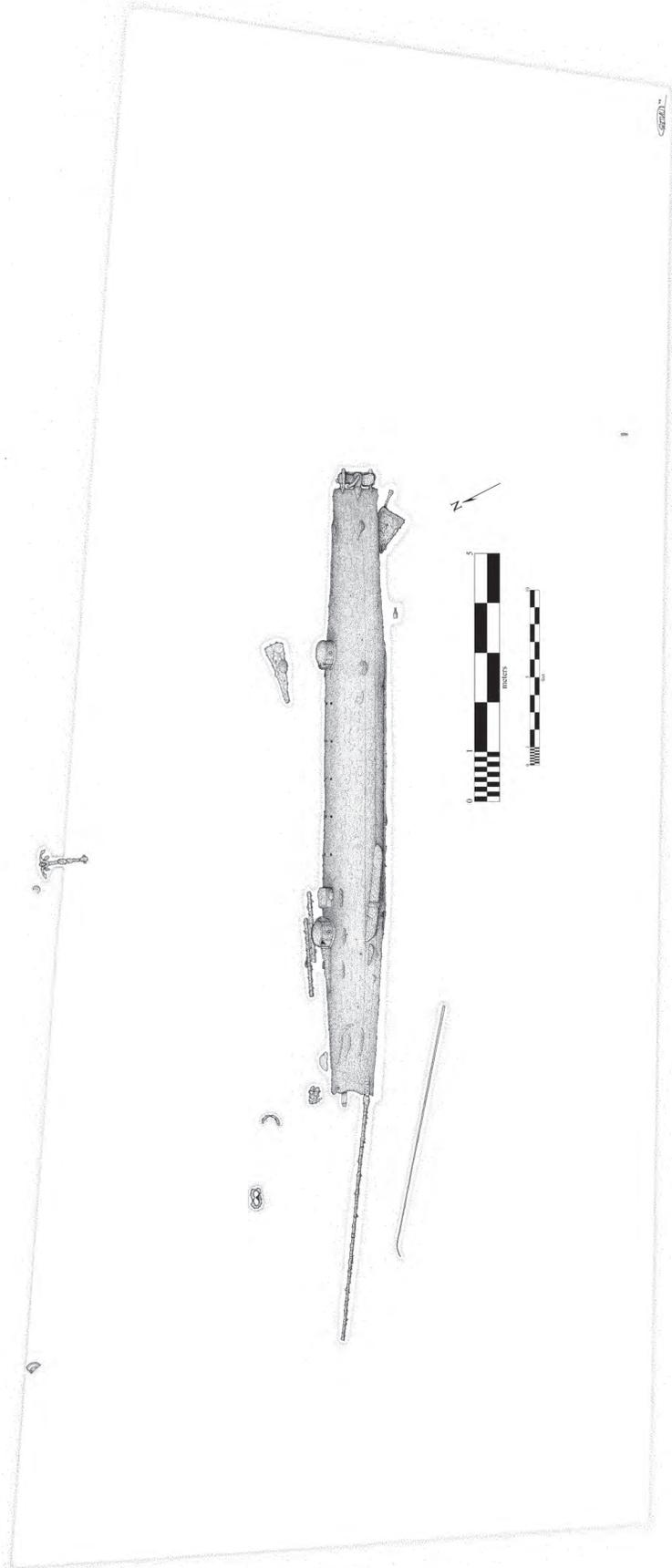


Figure 12.1. The site plan was created using triangulated measurements of artifact positions, which were plotted in three-dimensional software. A two-dimensional plan was then drawn by hand. (Drawing by James W. Hunter III, Courtesy of FOTH)

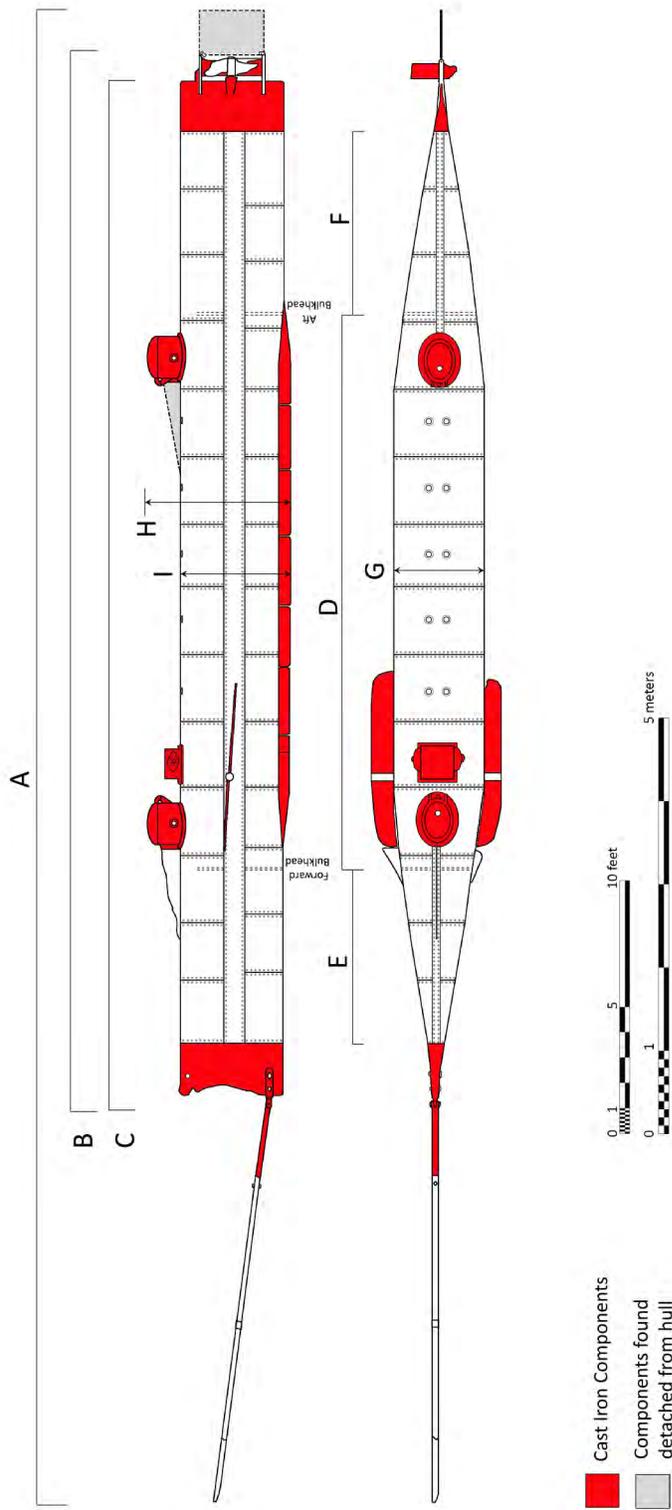


Figure 12.2. Plan and profile views of Hunley. Letters indicate significant measurements included in the text. For larger version, see foldout at the end of the volume. (Source drawing by Michael Scafuri, courtesy of FOTH; adapted by H. G. Brown, NHHC)

Hull

The most significant “artifact” recovered from the site was the hull itself, designated HL-0708 (Figure 12.2). While many features had been revealed during the 1996 site investigation, the complete exposure of the hull revealed its full dimensions for the first time. It was covered in a layer of concretion that varied in thickness, but was usually no less than 1 cm (0.39 in.). All measurements given below include the concretion layer, unless otherwise specified.

Structurally, the hull can be divided into five basic sections: the main body, primarily made up of wrought-iron hemispherical plates, which comprised the crew compartment; bow and stern sections made up of tapering wrought-iron quarter plates, which housed the fore and aft ballast tanks; and the cast-iron bow and stern pieces and their associated assemblies, including the weapons system forward, and the propeller and rudder aft.

Other external features include two conning towers on top of the vessel providing access to the fore and aft ends of crew compartment. An apparatus known as a snorkel box was mounted on top just behind the forward conning tower to allow for the admission of air into the interior. Two long blades, or diving planes, were mounted on the sides, at about center height of the body, just aft of the forward conning tower. An iron torpedo spar was attached to the bottom of the bow casting. The submarine was weighted with an external cast-iron keel made up of eight distinct blocks bolted to the bottom of the hull.

Hunley would have had an overall length of approximately 59 ft. (17.97 m) from the forward tip of the spar to the aftermost point of the rudder (A). An explosive charge would have been mounted at the end of the spar until its deployment against another vessel, in this

case *USS Housatonic*. From the forward end of the spar attachment tang to the aftermost point on the rudder attachment (B), *Hunley* has a length of 41.375 ft. in. (12.61 m). The hull measures 40.063 ft. (12.21 m), from the forwardmost point on the bow to the aft-most point on the stern (C). The spar attachment tang extends 12 cm (4.72 in.) forward of the extreme end of the bow. The propeller and shroud extend 27.8 cm (10.94) aft of the aftermost point on the stern.

The overall height of the submarine (H), from the hatch top to the bottom of the keel weight, is 5.58 ft. (1.70 m). The height of the hull at the center of the crew compartment (I), including the keel weights, is 4.25 ft. (1.293 m). Its maximum width (G) is 3.625 ft. (1.10 m).

Main Body

The center portion of *Hunley's* hull was found to be made of a series of six pairs, or courses, of hemispherical plates, for a total of twelve plates. All plates are joined along the edges with single-riveted butt joints underlain by a butt strap, and riveted along the bottom edges to an expansion strake that ran down the center along both sides. Three plates are 82 cm (32.25 in.) in width, two are 81 cm (31.875 in.) and one is 76 cm (29.94 in.), with an average thickness of 0.6858 cm (0.27 in.).

The two expansion strakes are approximately 35.93 ft. (10.95 m) long (not considering taper), 8.625 in. (0.22 m) wide, and appear to be constructed from a single length of rolled wrought-iron plate per side, although that cannot be confirmed until deconcretion of the hull has been completed. The average thickness is 0.90 cm (0.36 in.), but there may have been some metal loss due to erosion prior to burial. The addition of expansion strakes to the sides of the submarine's hull increases its interior headroom and gives the compart-

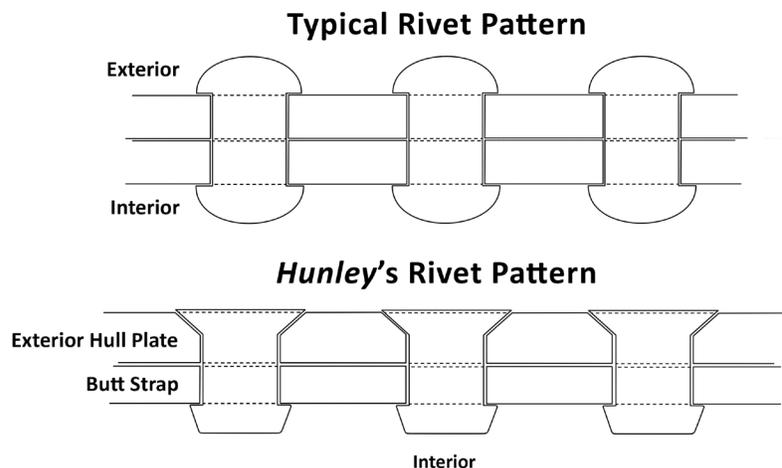


Figure 12.3. Diagram of the riveting style used on *Hunley* compared to the more standard industrial riveting method common at the time.

ment a somewhat elliptical shape, formally known as “obround” (see Figure 9.1).

All rivets along plate boundaries are flush-riveted, or countersunk, a relatively uncommon style for the period. This means that each rivet hole in the submarine’s main assemblage was beveled to allowing the top of the rivet head to fit level with the exterior surface of the hull plate (Figure 12.3). The rivets average 1.25 in. (3 cm) in diameter and are spaced approximately 2.125 in. (5.5 cm) on center.

Crew Compartment

The crew compartment (D) is located in the center of the hull and begins just forward of the forward conning tower. It terminates at a point slightly aft of the aft conning tower. Internally, it is defined by bulkheads at each end, which are composed of two pieces, perpendicular to the tapering hull. This results in a slightly V-shaped top profile and two distinct length measurements. From the top center of the bulkhead, the overall length is 22.56 ft. (6.88 m). From the top corners, the overall length is 22.64 ft. (6.90 m).

Light entered the crew compartment through five pairs of 6.1 cm (2.375 in.) diameter glass deadlights set into the top of the upper hull plates. Each port is spaced 10.5 cm (4.13 in.) from *Hunley*’s centerline to the center of the glass. All but one of the deadlights appears undamaged; the exception—located on the starboard side of the submarine in the fourth set of ports aft of the forward conning tower—is cracked. The source of this damage remains undetermined.

Conning Towers

The crew entered the vessel through two elliptically shaped, cast-iron conning towers, which consist of a relatively short vertical wall or hatch coaming and a hinged hatch cover (Figure 12.4). The conning towers measure approximately 60 cm (23.62 in.) fore-and-aft and 41.8 cm (16.46 in.) wide, including the concretion layer. They rise approximately 39.74 cm (15.66 in.) from the top of the hull. A small lip or flange surrounds the base of the tower where it is attached to the hull plates.



Figure 12.5. Top of aft hatch cover after deconcretion. The glass from the deadlight was removed and conserved separately. (Photo by Johanna Rivera, courtesy of FOTH).

The hatch covers are shallowly dome-shaped and fit inside the hatch coaming, sealing closed over a rounded lip. Both hatches open toward the center of the submarine’s crew compartment. The aft hatch cover is 56.7 cm (22.32 in.) in length, 38.5 cm (15.16 in.) wide, and ranges from 12 to 15 cm (4.72–5.91 in.) high. *Hunley*’s builders placed a single glass deadlight in each hatch cover, along the centerline, but closer to the hinged side, centered approximately 18 cm (7.09 in.) from the hinged edge (Figure 12.5). Two hinge arms, part of the casting, extend from the cover, approximately 16 cm (6.30 in.) apart, and align with two hinge arms cast into the coaming. The hatches were secured from the inside, with no external latch or handle.

Several glass viewports are situated in each hatch coaming. Both conning towers have a viewport in the starboard and port sides. Those in the forward tower are low down near the bottom of the coaming, approximately 12 cm (4.72 in.) above the top of the hull (measured to the bottom of the glass). Those in the aft tower are up near the top of the coaming. The bow tower also has two ports facing forward on either side of the cutwater, toward the top of the coaming. All viewports are made up of a flange 4 in. (10.16 cm) in diameter holding a glass insert averaging 2 in. (5.08 cm) in diameter and 0.31 in. (0.8 cm) in thickness.

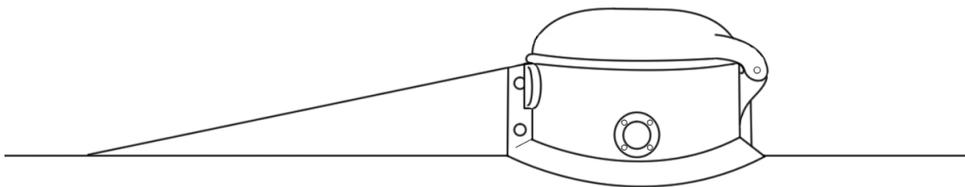


Figure 12.4. Idealized view of the forward conning tower with cutwater and intact forward viewport. (Diagram by Mari Hagemeyer, NHHC).

Bow and Stern Quarters

At either end of the crew compartment, the sides of the hull begin to taper sharply toward the bow and stern (E and F). The forward tapered portion is 3.04 m (9.97 ft.) long; the aft tapered section has an overall length of 3.08 m (10.11 ft. in.). While the taper begins with the panels holding the conning towers, the majority of these two sections were divided off from the crew compartment via a partial bulkhead. The space fore and aft of the bulkheads acted as ballast tanks, providing for the intake or expulsion of water to control the submarine's depth in the water column. Only the submarine's width is affected by the taper, as the vessel height remains relatively constant over its entire length.

The tapering at each end is completed over a series of four narrowing courses made up of 4 wrought-iron quarter plates each, for a total of 32 quarter plates. The quarter plates are flush riveted along all edges, with the sides butt joined, in the same fashion as the central, hemispherical plates. The top and bottom of the panels are lap joined to the expansion strake at center height, and to metal strips called strongbacks along the top and bottom of the vessel. Like the expansion strake, the strongbacks are located on the exterior of the vessel, covering the seams between the plates. The quarter plates are affixed to the cast-iron pieces at the bow and stern using a single-riveted lap joint, with the quarter plates placed over the casting.

Bow Casting and Spar Assembly

The submarine's builders achieved the knife-like edges that characterize the bow and stern by casting them out of iron. The bow casting measures approximately 63 cm (2.07 ft.) in length. At the point where it is riveted to the quarter plates, it is approximately 19.7 cm (7.75 in.) wide and tapers to a point approximately 2–3 cm (0.79–1.18 in.) wide. There is a significant amount of scour erosion along the forward edge, making precise measurement difficult (Figure 12.6).

A hole penetrates the upper forwardmost portion of the bow casting laterally. With concretion, it measures approximately 5 cm (1.97 in.) in diameter, but a larger dimension is expected once the hull has been deconcreted. It is 6.3 cm (2.48 in.) from the top of the casting, and 18 cm (7.09 in.) from the surviving forward edge. An iron bolt laterally penetrates the casting immediately beneath the

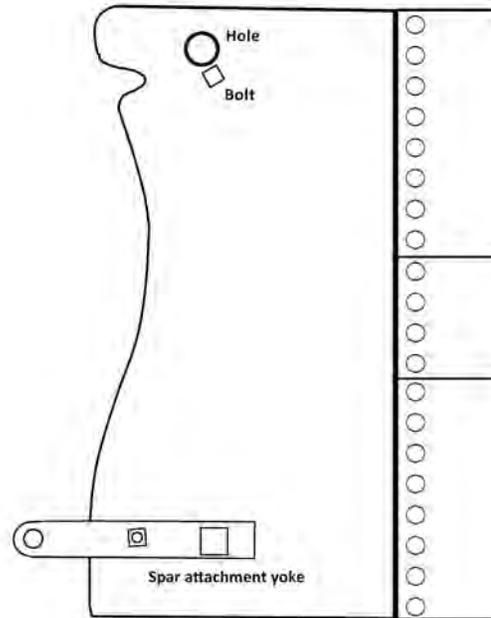


Figure 12.6. Portside view of the bow casting, showing deterioration of leading edge (rivet spacing approximate). (Diagram by Mari Hagemeyer, NHHC).

hole. The bolt head, approximately 5 cm (1.97 in.) square, is on the port side and does not rest flush against the side of the casting, but protrudes roughly 6 cm (2.36 in.) (Figure 12.7). This suggests there is an object missing that was once held in place by this piece of hardware. There is evidence of another lateral through hole, approximately 12 cm (4.72 in.) down from the top of the casting, that has been partially eroded away along the forward edge leaving an indentation

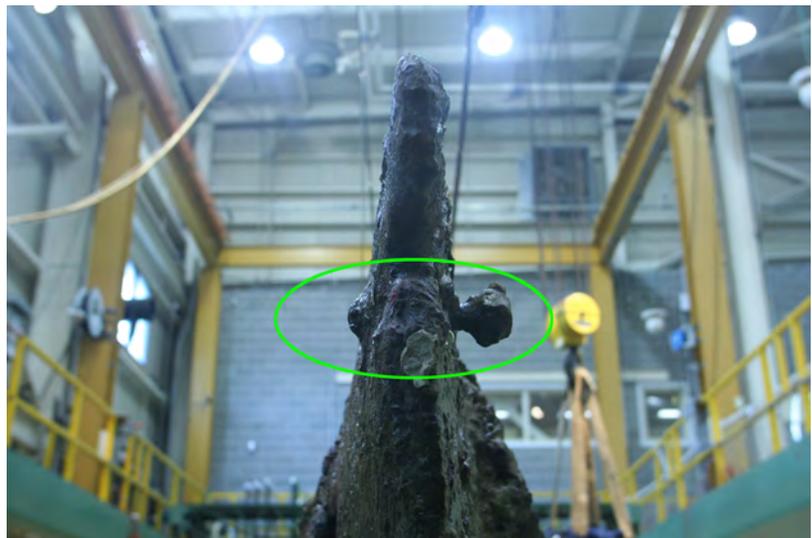


Figure 12.7. A substantial bolt laterally penetrates the bow casting. (Photo by H. G. Brown, NHHC).

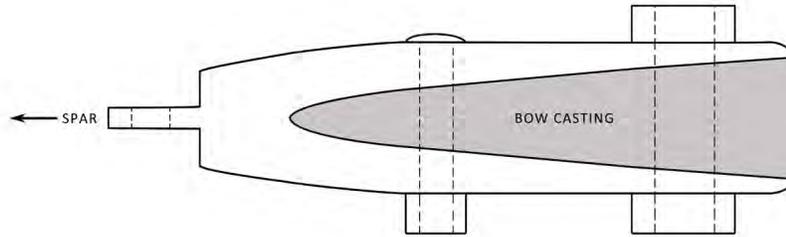


Figure 12.8. Spar attachment yoke based on measurements taken prior to deconcretion. (Diagram by H. G. Brown, NHHC)

approximately 4 cm (1.57 in.) deep. This hole and the surviving bolt are likely mounting points for hardware used to hold a rigging boom in place (see Chapter 14).

At the bottom of the casting, a Y-shaped cast-iron yoke with a square tang extending forward is bolted to the bow, 13.8 cm (5.43 in.) from the base of the submarine's prow (Figure 12.8). The yoke fits over the casting and is held in place by two through bolts, approximately 16 cm (6.30 in.) apart on center. The tang protrudes approximately 12 cm (4.72 in.) beyond the bow, and is 6.5 cm (2.56 in.) high, and 6.2 cm (2.44 in.) wide before it narrows to 2.7 cm (1.06 in.) wide to receive the spar. The yoke arms are 33.5 cm (13.19 in.) long, 7 cm (2.76 in.) high, and taper down from 3.2 cm (1.26 in.) thick at the bow to 1.5 cm (0.59 in.) at the after ends.

The tang held a multi-component iron spar, still bolted in place when excavated, with a preserved length of 4.89 m (16.05 ft.) (Figure 12.9). Heavily concreted, it was recovered in two pieces, the longer portion attached to the bow, and the shorter end, 69.73 cm (27.45 in.), still in its original position but deteriorated to the point that it separated from the rest of the spar.

Once deconcreted, conservators discovered the spar was originally made up of three distinct pieces. The first is a solid, cast-iron rod, 1.075 m (3.53 ft.) long and 5.68 cm (2.24 in.) in diameter, bifurcated at the proximal end to fit over the tang at the forward end of the yoke. A single bolt penetrated both pieces horizon-

tally to secure the spar while providing a pivot point for raising and lowering it. The distal end narrowed to 4.8 cm (1.89 in.) diameter for the final 14.5 cm (5.71 in.) so it could be inserted into the rolled wrought-iron pipe or tubing that made up the remainder of the spar and bolted in place. The first section of tubing is 1.8 m (5.91 ft.) in length, and the second, 2.15 m (7.05 ft.) long. They were joined together with a 6.4–6.6 cm (2.52–2.6 in.) iron coupling, for a total hollow length of 3.96 m (12.99 ft.). At the tip of the spar, conservators found a fragment of copper sheathing from the torpedo it carried bolted to the iron, indicating the preserved spar length is very close to its original length (FOTH 2013:4).

Stern Casting, Propeller, and Steering Assembly

The stern casting, like that of the bow, is also solid cast iron, 63 cm (24.80 in.) long, 123 cm high (48.43 in.), widening to approximately 19.7 cm (7.76 in.) where it meets the quarter plates, and attached to the stern quarter plates with a single-riveted lap joint (Figure 12.10). One lateral hole near the top aft portion may correspond in size and shape to that in the bow casting, but it is currently too concreted to know for certain. Two longitudinal openings, or glands, were cast through

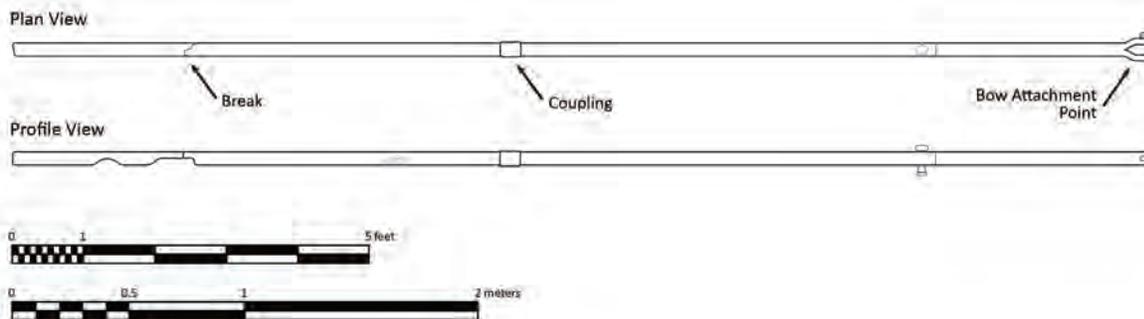


Figure 12.9. Outline of spar showing main sections and surviving hardware. (Diagram by Amanda Quinn, NHHC)

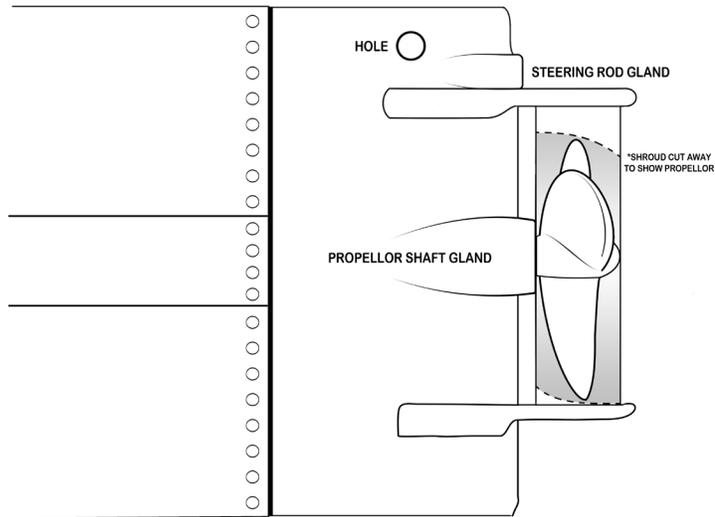


Figure 12.10. Idealized port-side view of stern casting (rivet spacing approximate). (Diagram by Mari Hagemeyer, NHHC).

it to accommodate the propeller shaft and the steering rod. The steering rod gland begins 16 cm (6.30 in.) from the top of the casting, and is approximately 8.5 cm (3.35 in.) in diameter at the after edge. Concretion extends several inches beyond the after edge of the casting, suggesting that a small portion of the steering rod may survive. The propeller shaft gland begins approximately 55 cm (21.65 in.) from the top of the casting and is approximately 15 cm (5.91 in.) in diameter at the after edge of the casting. The propeller hub appears to rest flush against the gland, but details are currently obscured.

Seven of the submarine's eight-man crew turned an iron crankshaft attached to a roughly 69 cm (27.165 in.) diameter, three-bladed cast-iron propeller. The blades had a maximum width of approximately 19 cm (7.48 in.) and a thickness of 2–3 cm (0.79–1.18 in.). An iron shroud originally surrounded the propeller, of which only just over half survives, primarily on the starboard side. It measures approximately 20 cm (7.87 in.) wide and 1.5 cm (0.59 in.) thick, with a diameter of approximately 76.6 cm (30.16 in.). The shroud was mounted to the stern casting with a pair of Y-shaped yokes similar to, but smaller than, the one used to secure the spar to the bow casting. The dimensions of the arms, as estimated through the heavy layer of concretion, are 20 cm (7.87 in.) long and 5 cm wide (1.97 in.). The yoke arms meet aft of the stern casting and extend into a flat, horizontally-oriented iron bar or bracket, approximately 6 cm (2.36 in.) wide and 2 cm thick (0.79 in.), to which the shroud was fastened. The end of each shroud bracket continued beyond the after edge of the shroud to provide a means for mounting the rudder (Figure 12.11). Only the lower mounting point appears to have survived, though this will be clearer once the conserva-

tion phase is completed. The surviving portion of the upper bracket extends 27.5 cm (10.83 in.) beyond the after edge of the stern casting, while the lower bracket extends 30 cm (11.81 in.).

Attached to the starboard side of the shroud was one of two long rectangular iron bars that originally connected to the top edge of the expansion strake about 2 m (6.56 ft.) forward of the aft end of the stern casting and likely helped prevent the propeller from fouling. It was heavily concreted and still tenuously



Figure 12.11. Propeller as exposed by loss of the port side of the shroud. The brackets holding the shroud also provided mounting points for the rudder. (Photo by H. G. Brown, NHHC)

connected to the hull, but inverted, so the after end was positioned forward of the aft conning tower, about 80 cm (31.50 in.) below the centerline of the vessel. In its concreted state, it measures 1.78 m (5.84 ft.) in length, 3.0 to 3.6 cm (1.8–1.42 in.) in width, and 1.49 cm (0.59 in.) thick. The forward end of the bar showed evidence that it had been pulled forward, deforming the metal where it attached to the hull. The piece was detached from the hull during excavation and recovered separately (HL-0660). The corresponding port bar was not present.

At some point following the wrecking event, *Hunley's* iron rudder (HL-0686) became unshipped from its position behind the propeller and came to rest beneath the stern end of the hull, where archaeologists located it, roughly 70 cm (27.56 in.) forward of its original position. The rudder is approximately 78 cm (30.71 in.) high, 53 cm (20.87 in.) wide, and ranges in thickness from 0.65–0.75 cm (0.26–0.30 in.) after deconcretion. It is possible there was some overall metal loss, suggesting the original material may have been a standard $\frac{3}{8}$ in. (0.95 cm) iron plate. After deconcretion, many important features of this piece came to light (Figure 12.12). Two iron pieces are fastened to either side of the top and bottom corners of the rudder, which appear to be part of the hardware that attached the rudder to the propeller shroud mounts. Both were broken off along the edges of the rudder, so evidence of the attachment joint itself is not present. The upper piece is at an angle of approximately 45°. The oblong hole was found in the center, approximately

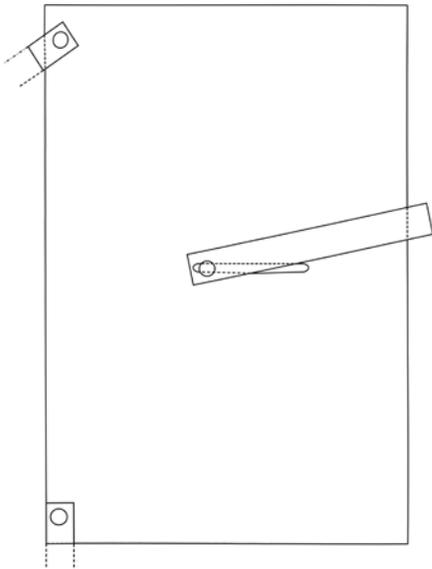


Figure 12.12. Idealized view of surviving elements of the rudder (HL-0686), port side. Attachment points and steering hardware do not survive. (Diagram by Mari Hagemeyer, NHHHC)

8 cm (3.15 in.) long and 1 cm (0.39 in.) wide, that is original to the piece. There is an iron strap on each side, bolted or riveted together through the hole. These likely connected to a vertical steering arm aft of the rudder and could move fore and aft in the hole as the rudder changed position (see also Chapter 15).

Other External Features

Diving Planes

The submarine's two cast-iron diving planes are located beneath the snorkel box. They served as the primary control surfaces for directing the vertical movement of the submarine in the water column. Both are mounted along the approximate horizontal centerline of the hull, on opposite sides of the vessel (Figure 12.13). Each diving plane measures approximately 2 m (6.56 ft.) in length, and range in width from 25 to 31 cm (9.84–12.20 in.) due to erosion and concretion. They are 2.3 cm (0.91 in.) thick. While the starboard plane was found in a level position, the port plane was inclined slightly upward.

Fixed fins or skegs are located forward of the diving planes to protect the leading edge. They measure 40–42 cm (15.75–16.53 in.) in length where they attach to the hull, and project horizontally 18–20 cm (7.09–7.87 in.) at the widest point. The port skeg lacks the well-defined triangular shape of the starboard one—this is very likely the result of the submarine's list to starboard, which exposed the upper port side of the submarine to prolonged sand abrasion while protecting its counterpart.

Air Exchange Systems

A raised box was attached to the top of the crew compartment, 20 cm (7.87 in.) aft of the forward conning tower. This cast-iron component, known as the air box or snorkel box, incorporated two adjustable iron pipes that allowed the exchange of fresh air into the crew compartment while the submarine operated just below the water's surface (Figure 12.13). It is 40 cm (15.75 in.) on each side and 21 cm (8.27 in.) tall. The remains of two packing glands are located on the port and starboard side of the box. The packing glands housed the two pipes, or snorkel tubes, that could either lie flat against the hull or be positioned vertically while submerged. As with the conning towers, a small lip or collar surrounds the box to aid in mounting the piece to the hull. Further details on the joints used will be clear once the deconcretion process is completed.

Portions of both tubes were recovered, though neither is fully intact. They were found along the starboard side of the hull, parallel to each other, but

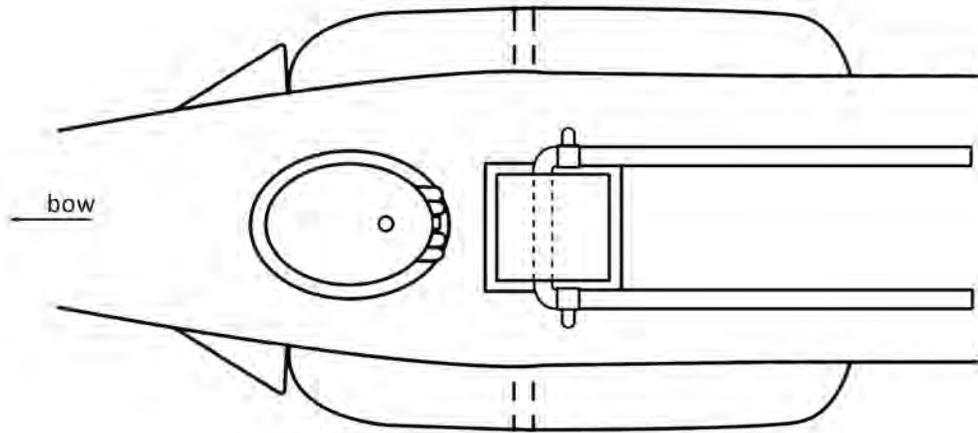


Figure 12.13. Idealized plan view showing position of diving planes and their protective skegs, in addition to the forward conning tower and snorkel box. (Diagram by Mari Hagemeyer, NHHC).

offset approximately 65 cm (25.59 in.), with the outer tube further forward. They were roughly 70–80 cm (27.56–31.50 in.) below the top of the hull, in the dense shell layer encasing the lower portion of the submarine. The aft end of the outermost tube was 9 cm (3.54 in.) starboard of the hull, and the forward end 39 cm (15.35 in.) to starboard. As the plating is beginning to taper inward at this point, it appears the tubes came to rest roughly parallel to the hull. The preserved length of the first tube (HL-0616) is 140 cm (55.12 in.); the second tube was recovered in two adjoining pieces (HL-0614, HL-0615) for a total length of 148.5 cm (58.46 in.). Both have an inside diameter of 4.1 cm (1.61 in.). There is evidence that both ends of the snorkels were threaded.

Cutwaters

Two cutwaters were originally positioned on the top of the hull along the centerline, each abutting the forward side of one of the conning towers. These triangular sheets of metal tapered down forward to the top of the hull, most likely to prevent fouling of the conning towers and their viewports (see Figure 12.4). The aft cutwater (HL-0555) became dislodged from the hull following *Hunley*'s loss and was discovered lying to

starboard of the submarine during the recovery project. It measures 1.6 cm (0.63 in.) thick, 112 cm (44.09 in.) long where it attached to the hull, and extended vertically 22 cm (8.66 in.) up the leading edge of the hatch coaming. The bow cutwater is of comparable dimensions.

Keel

The submarine's keel is made up of a series of eight cast-iron blocks affixed to the bottom exterior surface of the hull (Figure 12.14). An additional small wooden wedge was inserted between the fifth and sixth blocks. Together, these blocks run approximately the length of the crew compartment over a distance of 22 ft. (6.71 m). The forwardmost and aftermost keel weights (KB1 and KB7) taper sharply at each end and are fitted carefully to match the curvature of the underside of the hull. Both are 124.5 cm (49.02 in.) long at the centerline, 11 cm (4.33 in.) thick, with an average width in the non-tapering portion of 55.5 cm (21.85 in.). KB1 weighs 237 kg (522.50 lb.). The remaining blocks are rectangular and smaller, with most (KB2–KB5) running 78 cm (30.71 in.). One block, KB6, is only slightly shorter at 77 cm (30.31 in.), while KB1A is considerably smaller

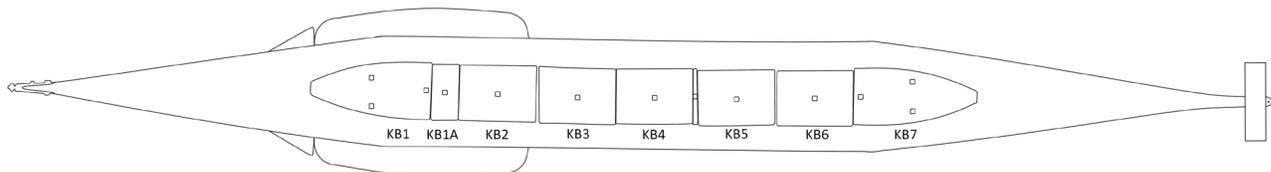


Figure 12.14. Layout of keel weights, based on 3D data collected prior to deconcretion. All blocks are cast iron, and the small wedge between KB4 and KB5 is made of wood. (Diagram by Mari Hagemeyer, NHHC).

at 28 cm (11.02 in.). Together they vary in width from 54 cm (21.26 in.) to 58 cm (22.83 in.). All average 11 cm (4.33 in.) thick.

According to historical sources, *Hunley's* keel weights were designed to be unbolted from inside the crew compartment if the submarine took on an excessive amount of water ballast. Theoretically, the submarine would be able to resurface once rid of the extra weight created by these ballast blocks. Square bolt heads are clearly visible in the center of nearly all the keel blocks, supporting the presence of this design feature. In practice, the system did not work very well, as evidenced by the loss of the submarine's second crew in October 1863 (see Chapter 2).

Condition

Upon recovery, the hull was entirely covered in a concretion layer that varied from approximately 1 cm (0.39 in.) thick to as much as 10 cm (3.94 in.). Some areas that demonstrate thicker patches of concretion encase small intrusive objects that came to rest against hull and became concreted to it. This certainly happened in several cases with tin cans (see Chapter 15). It is also possible these areas represent additional hull components that were dislodged from their original position or features that protrude from the hull.

The glass from all but one of the deadlights was not fully concreted and was visible to divers upon the submarine's discovery. Most of the viewports in the conning towers were only partially concreted over, although those on top of the hatches and one on the forward conning tower were completely covered (Figure 12.15).

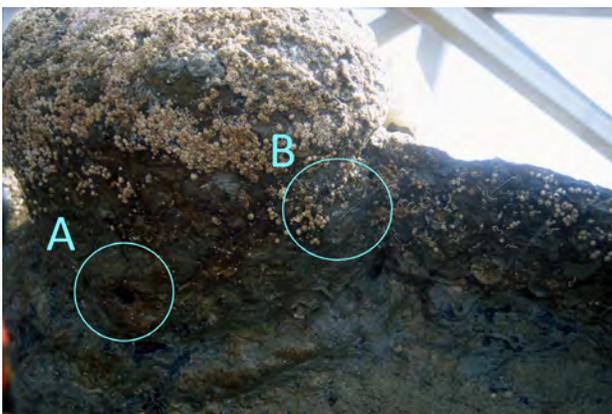


Figure 12.15. The viewport (A) on the starboard side of the forward conning tower was partially exposed, while the forward viewport (B) was completely covered. Remains of star coral colonies are densely packed over the top of the hatch. (Courtesy of FOTH).

Large areas of the hull were also covered with marine growth, the most distinctive being the white remains of colonies of star coral (*Astrangia danae*) and the horse oyster (*Ostrea equestris*) (Murphy 1998:150–51). The upper areas preserved more evidence of colonies growing on the hull itself, while the lower areas, in the region of the Pleistocene mud layer, were covered in a thick shell/mud conglomerate. A few areas were relatively smooth with minimal shell coverage, such as portions of the bow casting (Figure 12.16). This apparent lack of colonization may be the result of high energy water flow during the period prior to the vessel's burial (see Chapter 13).



Figure 12.16. Horse oyster shells can be seen at the top of the port side of the bow casting, but the area below has been worn smooth by hydrodynamic forces. (Photo by H. G. Brown, NHHC).

Holes in Hull

As excavation progressed, a total of three significant hull breaches were recorded. The first, in the forward conning tower, had already been discovered during the 1996 site investigation (Figure 12.17). It is roughly 10 cm (3.94 in.) high in the center, and 11 cm (4.33 in.) at its widest point, close to the hatch cover. This area once held the forward, portside viewport. Original speculation was that this damage was caused by small arms fire from *Housatonic* (Murphy 1998:80), and this possibility cannot be ruled out, based on tests conducted at the Warren Lasch Conservation Center.

The other two holes are located along the starboard side, one near the bow, one near the stern, both in the vicinity of the boundary between the cast-iron ends and the wrought-iron plates. These appear to have developed after the submarine had settled into its final position, as a result of a complex interaction of erosion and corrosion processes (see Chapter 13). The bow hole



Figure 12.17. Hole in the forward conning tower encompassing the total loss of the port viewport (Courtesy of FOTH).

is trapezoidal in shape, measuring 27.4 cm (10.79 in.) at its widest point and 26.6 cm (10.47 in.) high (Figure 12.18). It begins 26.5 cm (10.43 in.) from the top of the hull, and 57.7 cm (22.72 in.) aft of the surviving edge of the bow casting.

The stern hole is somewhat ovoid in shape, beginning 3 cm (1.18 in.) down from the top of the vessel and 32 cm (12.60 in.) forward of the after edge of the stern casting (Figure 12.19). It measures approximately 90 cm (35.43 in.) at its widest point with a maximum vertical expanse of 50 cm (19.69 in.). It crosses the boundary between the stern casting and the aftermost starboard top quarter plate. The steering rod can be seen through the upper third of the opening, running horizontally along the vessel's centerline.



Figure 12.18. Hole in bow, along boundary between wrought- and cast-iron components. Deterioration of the leading edge of the casting is also visible at right. (Photo by H. G. Brown, NHHC).

Other Damage

Several of the protruding elements of the vessel also showed damage, most notably the rudder, which was fully detached from its mounting. The hardware connecting the steering rod to the rudder was also not evident. Possibly related is the damage to the propeller shroud, which is almost entirely missing on the port side, and is torn on the upper quarter on the starboard side with the forward edges bent upward (Figure 12.20). This type of damage is less likely to have been part of the natural degradation of the hull, and may be related to the initial explosion, subsequent search attempts, or simply an accidental anchor snag. The disarticulation of the starboard shroud attachment bar and loss of the port attachment bar may be related to the same event or events that damaged the shroud.

Another anomaly is the arrangement of the diving planes. Designed to move in parallel to each other, maintaining the same angle of inclination, the planes are now out of sync with one another. The starboard diving plane is positioned exactly along the vessel's horizontal axis, in line with the skeg. The port diving plane, however, is inclined slightly upward, its forward edge approximately 3 cm (1.18 in.) above its skeg, yet it does not appear bent (Figure 12.21). It is possible the port plane was snagged by a passing anchor at some point, or that the prolonged pressure from the ebb current on the exposed plane gradually pushed it up in relation to the starboard plane, which was protected by being planted in the Pleistocene mud layer. Further research, after deconcretion is complete, may shed light on the cause for this apparent discrepancy.

Several areas of the hull show degradation from erosion in the post-depositional environment. The leading edge of the bow casting, as mentioned above,



Figure 12.19. The largest hole was at the stern near the top, crossing the boundary between the wrought- and cast-iron components, causing the loss of several rivets and exposing the steering rod. (Courtesy of FOTH)



Figure 12.20. Damage to the top starboard quarter of the propeller shroud. (Photo by H. G. Brown, NHHHC).

was reduced from its initial straight vertical line to a concave profile. In addition to the two holes on the starboard side, the outer front edge of the port diving plane is worn down. This is the most significant area of erosion on the port side of the hull. The starboard hatch attachment arm on the aft hatch shows noticeable metal loss, particularly on the bottom side.

Surrounding Sediment Matrix

Due to its excellent preservation, very few artifacts in the surrounding sediment were directly related to *Hunley*. Despite several holes, no objects from inside the submarine were found outside the hull. A number of loose hull components were recovered, primarily from the starboard side or beneath the stern. Intrusive artifacts included contemporary glass and ceramic wares, as well as modern items such as a standard brass screw (HL-0393) and even a plastic astronaut figurine (HL-0525). Material from intervening periods was also collected, including early 20th century ceramics and a 5 m (16.40 ft.) long galvanized rod, discovered in the lower layers on the port side. A possible explanation for the rod is that it was lost during previous surveys for *Hunley*, which got close to the magnetic anomaly but failed to recognize it (Browning and West 1982; Hall 1995).

All sediment from the dredging operations was carefully screened. It contained a mixture of shells, wood fragments, coal, and slag. While shell was discarded, the latter three categories were retained for analysis. Coal, slag, and wood were found in all areas of excavation. There were noticeable clusters of these materials around the starboard bow and beneath the propeller at the stern, trending to starboard (see Chapter 13).



Figure 12.21. The port side diving plane is in a slightly raised position. (Photo by H. G. Brown, NHHHC).

The majority of loose hull components were located in the starboard HAT trench, the only exception being the rudder, which was found under the stern, spanning the port/starboard dividing line. Fewer artifacts were found on the port side, but much of the ceramic assemblage was found there. The port area, however, was extensively disturbed during the prior excavation in 1996 (see Figure 13.5). At that time, sediment was removed from the central area between the conning towers in a wedge shape down the port side to the keel and was not screened. Therefore, artifacts found in the port midships area may have come from backfilled sediments. The bow and stern areas were not disturbed prior to the 2000 field season.

Wood

The wood fragments consisted of a combination of naturally occurring branches and sticks, along with heavily weathered or eroded fragments that appear to have been part of man-made objects (Figure 12.22). Of this material, none could be linked directly to the submarine. Harbor outflow may account for much of the material. Several larger wooden pieces were found closer to the submarine, including a barrel cant (HL-0587), which represent material culture, but could not be tied directly to the submarine.

One long, thin piece (HL-0505) was found adjacent to the starboard side of the bow. Roughly trapezoidal in cross section, the piece is 68 cm (26.77 in.) long, 10 cm (3.94 in.) wide and 6 cm (2.36 in.) high (see Figure 15.22). One end is well preserved with a clear diagonal cut, while the other is heavily worn by teredo damage. Two cut marks run perpendicular to the grain along the wider side, approximately 27 cm (10.63 in.) from the cut end. The possibility that this was part of the spar boom



Figure 12.22. Sample of a wood lot collected from dredge outflow during the excavation. This material did not prove diagnostic. (Photo by H. G. Brown, NHHHC).

was investigated, but deemed unlikely after comparing the dimensions of the piece to those of the brackets that would have held it in place.

Coal and Slag

Coal and coal slag were found in abundance around the site (Figure 12.23). This material was collected from the dredge outflow, weighed and counted. While it did not originate from *Hunley* itself, some may have been transported from the nearby *Housatonic* wreck. The material varied greatly in size, and, in the case of slag,

density. The distribution of this material was plotted and compared to other environmental data to help reconstruct the post-depositional processes affecting the site (see Chapter 13). The most noticeable clusters of coal and slag were found under the propeller and immediately to starboard, at the very bow down around the spar, and along the starboard forward quarter, particularly below the hole in hull. Some was even found inside the hull, carried in with the rest of the sediment as the interior gradually filled.

Concretions

Another common material present at the site was metal concretion, particularly in thin flake form. Some of these flakes may have been related to the hull itself, but there is evidence to suggest that many of these pieces, found at a variety of depths and sometimes quite distant from the hull, are remnants of tinned iron or steel cans. These fragments are generally slightly magnetic, but with little metal surviving, and gently curved profile. On many, the outer surface had an irregular or rough, granular texture, while the interior surface was smooth and black with occasional orange iron staining or an iridescent, cellophane-like film.

At least sixteen lots of iron fragments can be confirmed as cans, primarily due to shape and the presence of lead solder, a common component of cans until the late 20th century (Table 12.2).¹ Seven of these were found through radiography to be complete or nearly complete: HL-0427, HL-0653, HL-0654, HL-0700,

1 American manufacturers began voluntarily eliminating lead from cans in the 1980s, but it was not formally prohibited until 1995 (21 CFR 189); however, designs successfully isolating a can's contents from contact with exterior solder had developed by the early 20th century.



Figure 12.23. Typical collection of slag (left) and coal (right) collected from sediment surrounding Hunley. (Photos by H. G. Brown, NHHHC)

HL-3288, HL-3667, and HL-3678 (Figure 12.24). Fifteen additional lots consisting of small fragments and no lead have also been classified as cans based on their shape and texture, but no diagnostic features remain. While this material is not directly related to *Hunley*, as with the coal and slag, an examination of the distribution of the cans has contributed to a reconstruction of the post-depositional processes at the site (see Chapter 13).

Ceramics and Glass

Very little ceramic or glass was recovered from matrix surrounding the submarine. In all, only five glass and three ceramic artifact lots were found. Of these, three were found to starboard of the hull, five to port. Only one, a stoneware bottle (HL-0661), was fully intact. None could be directly tied to *Hunley*, although one group of glass fragments (HL-0506) was reconstructed

Table 12.2. Iron and Lead Concretions Identified as Historic Cans

| ID # | Surviving Elements | Provenience |
|---------|---|---|
| HL-0413 | 11 pcs, largest 7.2 × 4.6 × 0.9 cm; including two end pieces of hole-and-cap style | Starboard of aft hatch, down near metal rod [HL-0660] |
| HL-0427 | Cylindrical object in 9 pieces; circular bottom and some walls intact in main piece | Starboard side, near propeller, shell layer |
| HL-0468 | 29 pcs, largest 6.7 × 5.0 × 1.7 cm; some pieces of lead solder | Starboard side of stern suction pile area. |
| HL-0485 | 19 pcs, largest 7.0 × 4.8 × 1.6 cm; some lead solder remaining; may be related to HL-0468 | Stern suction pile hole, between starboard subdatum S1 and S2 |
| HL-0617 | 1 pc iron concretion with strip of lead solder; 3.6 × 1.9 × 1.2 cm | Starboard bow aft of Sling 5, excavating around snorkel tubes HL-0615 and HL-0616 |
| HL-0627 | 1 pc, concave, 5.1 × 4.4 × 1.7 cm; loose lead solder along curved edge | Under hull for slings 6-7 after jetting - probably fell in from above |
| HL-0644 | 4 pcs, largest 5.4 × 5.4 cm; lead solder strip, folder over | Port, under keel between slings 18-19 |
| HL-0653 | Fragile, cracked cylindrical concretion. h. 20 cm, d. 14 cm (with concretion); lead 0.3 × 0.1 cm | Concreted to underside of keel in midships area. |
| HL-0654 | Slightly flattened cylinder in 3 pcs; h. 28 cm, "long" d. 28 cm, "short" d. 20cm (based on oblong shape of can) | Concreted to port side of keel, directly on side/bottom junction |
| HL-0678 | 15 pcs, largest 6.7 × 5.0 × 1.2 cm; lead solder on lip preserved on several fragments | Starboard stern, aft of sling 25 |
| HL-0681 | Lead ring, max. diam. 4.8 cm, int. diam. 3.5 cm, th. 0.1 cm w/o concretion | Starboard stern, aft of sling 25 |
| HL-0682 | Lead strip with frags of iron concretion adhering, triangular cross section | Starboard stern, aft of sling 25 |
| HL-0700 | Complete cylinder preserved approx. 11 cm diameter and 14 cm tall | Starboard side of extreme stern edge, 66 cm down from top of stern |
| HL-3288 | Complete cylinder with lid (and cap) survive; bottom not intact | Removed from iron conglomerate HL-0582, off starboard bow |
| HL-3667 | Complete but flattened cylinder with preserved vented cap and side seam | Concreted to center of keel block 6; removed during conservation phase |
| HL-3678 | Upper or lower half of a complete cylinder; preserved rim and side seam; flattened | Concreted to starboard side of plate CB6 near the expansion strake; removed during conservation phase |

and identified to be a 19th century U.S. Navy condiment bottle, which could have come from *Housatonic*. The remaining lots in this category were only fragments. Most pieces recovered represent items of late 19th or early 20th century manufacture (see Chapter 15).



Figure 12.24. A radiograph of HL-0653, showing diagnostic seams that confirm identification as a tinned iron can. (Courtesy of FOTH).

Conclusion

The archaeological data collected at the site provided valuable supplementary data to the environment analysis (Chapter 13). The presence and positions of scour pockets on the starboard side of the submarine were initially noted by divers and could be roughly delineated based on the mapping of cultural material around the submarine. The condition of the hull itself also served as document attesting to the conditions encountered in the years after its sinking.

Access to the entire submarine, even in its concreted state, allowed for a more detailed analysis of *Hunley's* features and construction, particularly in the face of the disparate historical accounts that could only be confirmed or refuted by data from the submarine itself (Chapter 14). There are still many questions to be answered, but the preliminary data reported above provide an important starting point for future studies of this remarkable vessel.

13. Site Analysis

M. Scott Harris, Heather G. Brown, Robert S. Neyland

Analysis of the geologic and archaeological data collected at the *H. L. Hunley* site provided additional means by which to interpret both the events of the submarine’s loss and its post-depositional context and preservation environment. Building on geologic data collected prior to the recovery, many of which are discussed in the National Park Service reports (Murphy 1998, Conlin 2005), geologist Scott Harris used samples collected immediately prior to the recovery to reconstruct the depositional history of the site. His conclusions were supported by an examination of the fauna at the site as well as the distribution of artifacts that collected around the submarine as it was slowly encased in the seabed.

Site Geology: Survey and Sampling

Data: Types and Sources

A variety of geologic data sources, including acoustic sub-bottom profiles, drill cores, vibracores, pound cores, and the observations of divers working on site, were collected and analyzed at various stages during the recovery project. During the 1996 season, the site was surveyed with a marine magnetometer, side-scan sonar, and sub-bottom profiler. In addition three hand-driven cores were taken—two adjacent to and one directly over *Hunley*. Two radioisotope studies of cores collected near the submarine were conducted in conjunction with macrofaunal analysis of encrusting organisms on the submarine’s hull. The results were revealing: ²¹⁰Pb studies indicate that only the upper few centimeters of sediment covering the submarine have been disturbed in the last century (± 20 years) (Murphy 1998:158–62).

In May 1999, the United States Geological Survey Center for Coastal Geology and Regional Marine Studies collected high resolution sub-bottom profile data, and 500 kHz side-scan sonar over the area of the *Hunley* and *Housatonic* wrecks. A series of 20 ft. (6.1 m) long

vibracores was taken—five near *Hunley* and three near *Housatonic* (Hansen et al. 2000). Yet another series of cores had to be taken by the United States Army Corps of Engineers (Savannah District) to gather information to be analyzed by soil engineers to determine the size and depth of the piles to be placed.

All of the sediment samples collected during the surveys were analyzed for textural variability following the conventions of Wentworth (1922) and the Udden-Wentworth scale (Figure 13.1) (Wentworth 1922). This is the scale typically used in the United States to define classes of particles by size such as colloid, sand, clay, silt, gravel, pebble and even boulder. These can have further graduations from very fine, fine, medium, and coarse. Textural analyses were performed on sediment samples collected from the cores using standard sieve (Krumbein 1932) and pipette (Creager and Steinberg

| | | | |
|-------------|------------------|------------------------------|-----------|
| granules | | 4 mm | -2 ϕ |
| very coarse | S A N D | 2 mm | -1 ϕ |
| coarse | | 1 mm | 0 ϕ |
| medium | | $\frac{1}{2}$ mm 500 μ m | 1 ϕ |
| fine | | $\frac{1}{4}$ mm 250 μ m | 2 ϕ |
| very fine | | $\frac{1}{8}$ mm 125 μ m | 3 ϕ |
| silt | | $\frac{1}{16}$ mm 63 μ m | 4 ϕ |
| clay | M U D | $\frac{1}{256}$ mm 4 μ m | 8 ϕ |

Figure 13.1. The Udden-Wentworth scale provides a standard comparative scale for clastic sedimentary materials based on grain diameter. Both metric and ϕ ($-\log_2$ of mm) scales are provided for reference.

1963) methods. Samples were also viewed under a microscope to determine primary composition and mineralogy. Following consultation with the project's principal investigators, the decision was made to not conduct iron analyses of the pore waters. This decision was based on the probability of cross-contamination from water flow along the outer edge of the pound core during the elapsed time after the sample was collected.

Three dominant stratigraphic layers characterize the portion of the continental shelf where the *Hunley* site is located (Harris et al. 1994) (see Figure 3.5). Prior studies indicate a definite and distinguishable series of strata that exist in the local Charleston area, although the internal organization of these strata is often heterogeneous in nature (Harris et al. 1994; Gayes et al. 1998). The oldest of these layers consists of Tertiary aged marls and semi-consolidated sedimentary strata. The younger layers contain various back-barrier and shelf deposits of Pleistocene age that were deposited when sea levels were higher. The youngest layer, created during Holocene (modern) times, consists of multiple layers of sand, mud, and shells, in a variety of combinations. The distribution of the Holocene and Pleistocene units is scattered, creating regional strata that exhibit an extremely heterogeneous configuration. In general, recent sand and occasional mud layers exist over semi-consolidated Pleistocene muddy sands and sandy muds (estuarine and shelf deposits). These sediments in turn overlie the dense Tertiary marls, muds, and limestones (Popenoe et al. 1987; Harris et al. 1994; Weems and Lewis 2002).

Macrofaunal specimens taken during the 1996 survey consisted of colonies of Star Coral (*Astrangia danae*) and Horse Oyster (*Ostrea equestris*). The size of the coral and oyster colonies indicated that the upper portion of *Hunley* remained exposed for a period of 10 to 15 years, was gradually buried, and once completely buried was not exposed again until its discovery. Pollen was also sampled from the sediment around the submarine and revealed primary arboreal pollen types consistent with what would be expected had the submarine been buried within 20–25 years of sinking (Murphy 1998: 147–67). Despite the large number of tropical storms and hurricanes that have passed through the region since 1864 (see Figure 3.7), the submarine remained completely buried within a significant “cap” of sediment following its loss. Consequently, very little post-depositional impact—natural or otherwise—affected *Hunley* following its burial.

Sediment Sampling During Recovery

At the beginning of the 2000 recovery season, ten pound cores were collected from the *Hunley* site along two previously undisturbed transects during diver operations. Divers recorded the position of each pound core

by measuring with a line and tape pulled from the stern and bow of the submarine (see Figure 10.11).

Each pound core was collected by the following method: project staff utilizing surface-supplied or scuba diving equipment used weighted slide hammers to drive standard 3 in. (7.6 cm) aluminum irrigation pipes into the seafloor. Water-extraction holes drilled at equal intervals along each aluminum pipe were covered with Teflon tape to reduce sample contamination; black plastic tape was placed over these holes to increase the overall strength of the device during the coring process (Figure 13.2). A core catcher was installed at the base of each tube to hold sediment in place while the tube was removed from the seafloor and lifted through the water column to the deck of the research vessel.



Figure 13.2. Drs. Pam Morris and Scott Harris prepare cores for sampling. (Courtesy of FOTH)

Rivets were drilled to release the core catcher, and sediment was extruded onto a plastic gutter for sample collection. Samples were taken from the base of the core first; subsequent material was obtained from each successive overlying sediment layer. The distance from the base of the core to the sediment-water interface was calculated as follows: the total core length was established as the bottom depth and the “zero” depth marker coincided with the seafloor. Water samples were collected from each pound core with a sterile syringe and placed in sterile Nalgene containers. Bacteriological samples are extremely sensitive to outside contamination; consequently, these specimens were collected from each core prior to the textural analysis sampling process. This ensured that no additional contamination of sediment by oxygen and/or bacteria occurred while each core was being sampled in the field.

Sediment samples that consisted primarily of sand- and gravel-sized particles were sieved using standard sieving methods. Those that contained an abundant percentage of mud (<63 μm [0.0025 in.]) were analyzed with a pipette method that determined the amount

Table 13.1. Pound Cores Taken from around the H. L. Hunley in May 2000

| CORE ID [^] | Total Length | From | | Sample Type ^{^^} | Sample Number | Other | Method | Mean (mm) | Mean (phi) | Sorting | | | % mud | % silt | % clay | | |
|----------------------|--------------|-------------|---------------|---------------------------|------------------|-------|--------|-----------|------------|-------------|-------|-------|-------|--------|--------|------|--|
| | | Bottom (cm) | Seafloor (cm) | | | | | | | (std. dev.) | Skew | -ness | | | | | |
| T1-1 | 5 cm | 0-5 cm | 2.5 cm | S ** | HL 0270 | | s | 0.12 | 3.01 | 0.76 | 0 | 8.59 | 0.2 | 93.2 | 6.6 | | |
| | | | | W* | HL 0258 | | | | | | | | | | | | |
| | | | | W* | HL 0259 | | | | | | | | | | | | |
| T1-3 | 20 cm | 20 cm | | W* | HL 0260 | | | | | | | | | | | | |
| | | | | S ** | HL 0273 2A, 2B | | s | 0.11 | 3.18 | 0.89 | 0.22 | 5.67 | 0.1 | 86.7 | 13.2 | | |
| | | | | S ** | HL 0272 3A, 3B | | s | 0.12 | 3.03 | 0.85 | 0.06 | 7.7 | 0.4 | 90.1 | 9.6 | | |
| | | | | S ** | HL 0271 5A, 5B | | s | 0.16 | 2.61 | 1.29 | -1.24 | 5.9 | 4.9 | 87.3 | 7.8 | | |
| | | | | W* | HL 0261 | | | | | | | | | | | | |
| T1-5 | 30 cm | 20 cm | 10 cm | W* | HL 0262 | | | | | | | | | | | | |
| | | | | W* | HL 0263 | | | | | | | | | | | | |
| | | | | S ** | HL 0274 6A, 6B | | s | 0.11 | 3.18 | 0.89 | 0.22 | 5.67 | 0.1 | 86.7 | 13.2 | | |
| | | | | S ** | HL 0275 7A, 7B | | s | 0.14 | 2.83 | 1.02 | -1.43 | 9.24 | 2.4 | 91.1 | 6.5 | | |
| | | | | S ** | HL 0276 8A, 8B | | s | 0.14 | 2.84 | 1.12 | -1.13 | 7.38 | 2.5 | 88.3 | 9.2 | | |
| | | | | W* | HL 0264 | | | | | | | | | | | | |
| | | | | W* | HL 0265 | | | | | | | | | | | | |
| | | | | S ** | HL 0277 9A, 9B | | s + p | 0.09 | 3.41 | 2.41 | -1.12 | 2.57 | 15.8 | 19.4 | 64.8 | 64.8 | |
| | | | | S ** | HL 0278 10A, 10B | | s + p | 0.09 | 3.43 | 1.36 | -0.76 | 4.31 | 1.8 | 64.5 | 33.7 | 33.7 | |
| | | | | S ** | HL 0279 11A, 11B | | s | 0.15 | 2.78 | 0.94 | -1.2 | 9.02 | 1.1 | 93.7 | 5.2 | | |
| T1-10 | 35 cm | 30 cm | 20 cm | S ** | HL 0280 12A, 12B | | s | 0.12 | 3.07 | 0.88 | -0.35 | 8.01 | 0.6 | 89.6 | 9.8 | | |
| | | | | W* | HL 0266 | | | | | | | | | | | | |
| | | | | S ** | HL 0281 13A, 13B | | s | 0.13 | 2.92 | 0.94 | -0.64 | 8.51 | 1.3 | 90 | 8.7 | | |
| | | | | S ** | HL 0282 14A, 14B | | s | 0.11 | 3.14 | 1.42 | -0.85 | 4.58 | 3 | 72.5 | 24.5 | | |
| | | | | W* | HL 0267 | | | | | | | | | | | | |
| T1-20 | 20 cm | 10 cm | 10-20 cm | W* | HL 0268 | | | | | | | | | | | | |
| | | | | W* | HL 0269 | | | | | | | | | | | | |
| | | | | S ** | HL 0283 15A, 15B | | s | 0.12 | 3.06 | 0.9 | -0.18 | 7.43 | 0.6 | 88.7 | 12.7 | | |
| | | | | S ** | HL 0284 16A, 16B | | s | 0.13 | 2.9 | 0.82 | -1.25 | 11.05 | 0.7 | 94.8 | 4.5 | | |
| | | | | S ** | HL 0285 17A, 17B | | s | 0.15 | 2.75 | 0.72 | -1.33 | 13.67 | 0.8 | 96.6 | 2.6 | | |
| T2-1 | 25 cm | 30 cm | 20 cm | W* | HL 0267 | | | | | | | | | | | | |
| | | | | W* | HL 0268 | | | | | | | | | | | | |
| | | | | W* | HL 0269 | | | | | | | | | | | | |
| | | | | S ** | HL 0283 15A, 15B | | s | 0.12 | 3.06 | 0.9 | -0.18 | 7.43 | 0.6 | 88.7 | 12.7 | | |
| | | | | S ** | HL 0284 16A, 16B | | s | 0.13 | 2.9 | 0.82 | -1.25 | 11.05 | 0.7 | 94.8 | 4.5 | | |

SITE ANALYSIS

| CORE ID ^Δ | Total Length | From | | Sample Type ^{ΔΔ} | Sample Number | Other | Method | Mean (mm) | Mean (phi) | Sorting (std. dev.) | Skew -ness | Kurtosis | % gravel | % sand | % mud | % silt | % clay | |
|----------------------|--------------|-------------|---------------|---------------------------|---------------|----------|--------|-----------|------------|---------------------|------------|----------|----------|--------|-------|--------|--------|--|
| | | Bottom (cm) | Seafloor (cm) | | | | | | | | | | | | | | | |
| T2-3 | 25 cm | 0-10 cm | 20 cm | W* | HL 0316 | | | | | | | | | | | | | |
| | | | 10 cm | W* | HL 0317 | | | | | | | | | | | | | |
| | | | 15-25 cm | S** | HL 0326 | 18A, 18B | s + p | 0.11 | 3.21 | 1.5 | -0.68 | 3.8 | 2.8 | 65.4 | 31.8 | 28.2 | 3.5 | |
| | | | 5-15 cm | S** | HL 0327 | 19A, 19B | s | 0.14 | 2.79 | 1.22 | -1.1 | 6.44 | 3.2 | 86.6 | 10.2 | | | |
| | | | 0-5 cm | S** | HL 0328 | | s | | | | | | | | | | | |
| T2-5 | 25 cm | 20-28 cm | 20 cm | W* | HL 0318 | | | | | | | | | | | | | |
| | | | 15-25 cm | S** | HL 0329 | | s | 0.16 | 2.68 | 1.22 | -1.07 | 5.66 | 2.7 | 89.8 | 7.4 | | | |
| | | | 5-15 cm | S** | HL 0330 | | s | 0.14 | 2.85 | 1.17 | -0.75 | 6.11 | 1.9 | 85.9 | 12.1 | | | |
| | | | 0-5 cm | S** | HL 0331 | | s | 0.18 | 2.48 | 1.26 | -1.24 | 5.9 | 4.9 | 89.2 | 5.9 | | | |
| | | | | | | | | | | | | | | | | | | |
| T2-10 | 50 cm | 0-10 cm | 40 cm | W* | HL 0319 | | | | | | | | | | | | | |
| | | | 30 cm | W* | HL 0320 | | | | | | | | | | | | | |
| | | | 20 cm | W* | HL 0321 | | | | | | | | | | | | | |
| | | | 10 cm | W* | HL 0322 | | | | | | | | | | | | | |
| | | | 40-50 cm | S** | HL 0332 | | s | 0.12 | 3.04 | 0.88 | -0.15 | 7.23 | 0.3 | 89.9 | 9.8 | | | |
| | | | 30-40 cm | S** | HL 0333 | | s | 0.14 | 2.81 | 0.76 | -1.44 | 13.15 | 0.7 | 96.1 | 3.2 | | | |
| | | | 20-30 cm | S** | HL 0334 | | s | 0.13 | 2.91 | 0.82 | 0.08 | 7.87 | 0.2 | 92.4 | 7.4 | | | |
| | | | 10-20 cm | S** | HL 0335 | | s | 0.14 | 2.81 | 0.9 | -0.79 | 9.09 | 0.9 | 92.6 | 6.5 | | | |
| | | | 0-10 cm | S** | HL 0336 | | s | 0.15 | 2.72 | 1.45 | -1.17 | 5.2 | 7.2 | 80.5 | 12.3 | | | |
| | | | | | | | | | | | | | | | | | | |
| T2-20 | 45 cm | 40-45 cm | 40 cm | W* | HL 0323 | | | | | | | | | | | | | |
| | | | 30 cm | W* | HL 0324 | | | | | | | | | | | | | |
| | | | 20 cm | W* | HL 0325 | | | | | | | | | | | | | |
| | | | 35-45 cm | S** | HL 0337 | | s | 0.13 | 2.96 | 0.97 | -0.76 | 8.42 | 1 | 89 | 10 | | | |
| | | | 25-35 cm | S** | HL 0338 | | s | 0.12 | 3.1 | 0.89 | 0.24 | 6.07 | 0.2 | 87.7 | 12.2 | | | |
| | | | 15-25 cm | S** | HL 0339 | | s | 0.15 | 2.78 | 0.98 | -1.13 | 8.12 | 1.1 | 93 | 5.9 | | | |
| | | | 5-15 cm | S** | HL 0340 | | s | 0.14 | 2.86 | 0.95 | -0.56 | 8.07 | 0.9 | 90.7 | 8.4 | | | |
| | | | 0-5 cm | S** | HL 0341 | | s | 0.14 | 2.86 | 1.11 | -1.04 | 7.65 | 2.7 | 86.9 | 10.4 | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |

^Δ T1-3 refers to transect one, three meters away from H. L. Hunley hull
^{ΔΔ} S = Sediment Sample; W = Pore Water Sample
* depth from base of core
** 0 is at seafloor, higher numbers are below sediment-water interface
"Other" refers to samples collected by P. Morris of MUSC, Ft. Johnson Campus
N/R = no recovery

of silt (4–63 μm [.00016–.0025 in.]) and clay (<4 μm [.00016 in.]) in each (both methods are described in detail in Lewis and McConchie 1994). All numeric data were entered and analyzed through a sediment analysis program that utilizes the moment methods (see Friedman 1979). Percentages of the following attributes were calculated for each sediment sample: gravel, sand, mud, mean (ϕ), mean (mm), sorting, skewness, and kurtosis (Table 13.1).

Approximately 30 g (1.06 oz.) of sediment were sampled from each bag and placed in 50 mL (1.69 fl. oz.) Pyrex beakers to obtain the wet sample weight of each core. These sediment samples were dried in a Fisher Scientific Isotemp oven at approximately 60–70° C for 24 hours and then weighed to obtain the dry weight of each sample.

Sediment samples that consisted primarily of sand were wet-sieved with distilled water through a #230 (63 μm , 1/16mm [.0025 in.]) U.S.A. Standard Testing Sieve. Muds that washed through the sieve were not collected; their loss recorded the amount of mud (grains smaller than 63 μm) in the sample. Washed sediment was placed back into 50 mL (1.69 fl. oz.) Pyrex beakers and dried for 24 hours in an Isotemp oven at 60–70° C (140–158° F).

Each dried sample was weighed and the percentage lost due to wet sieving was calculated to determine its mud content. Grain size was documented in phi (ϕ), a unit based on the diameter of individual grains relative to 1 mm. These samples were sieved through a series of -1 ϕ to 4 ϕ sieves at 1/2-phi intervals using an RX-86 sieve shaker for 10 minutes. Each was then removed from the sieve screens and sediment weights were obtained for each phi interval.

Samples with a high mud content were analyzed in two phases. The entire sediment sample was washed (wet sieved) with distilled water through a #230 Standard Testing Sieve measuring 63 μm (1/16 mm). Silts and clays that were washed through the sieve were collected in a 1,000 (33.81 fl. oz.) mL graduated cylinder and set aside. The remaining material was placed back into a 50mL Pyrex beaker and dried for 24 hours in an oven at 60–70° C (140–158° F) to obtain the weight of sediment greater than 4 ϕ .

Using the Stokes equation for settling particles (Craeger and Steinberg 1963), the liquid portion of the sample was analyzed by taking samples from suspension. Because of differing settling velocities of various particle sizes, muddy water samples collected at various times from the same depth in the column can be used to calculate suspended sediment concentration. The slurry was placed in 1,000 mL (33.81 fl. oz.) settling tubes and stirred to obtain even dispersal of silts and clays. A pipette was inserted 10 cm (3.94 in.) below the water's surface so that a 25 mL (0.85 fl. oz.) aliquot, or portion, of muddy water could be collected for analysis.

The sample obtained immediately after the stirring process was used to determine the amount of silt in the water; another sample collected 120 minutes later was used to determine the amount of clay. Each of the 25 mL (0.85 fl. oz.) aliquots was placed in a separate pre-weighed 50 mL (1.69 fl. oz.) beaker and dried for 24 hours in an Isotemp oven at 60–70° C (140–158° F). The resulting dried samples were weighed to determine the mass of sediment that had not settled below the 10 cm (3.94 in.) level.

Results

Textural analyses were performed on bulk sediments collected from the pound cores (Table 13.1). Raw sieve and pipette measurements were derived utilizing standard moment methods for mean (first moment), standard deviation (Table 13.2; second moment), sorting (Table 13.3; third moment), and kurtosis (fourth moment). Additionally, calculations for the percent gravel, percent sand, and percent mud were determined for each individual sample.

Cumulative frequency diagrams were plotted to help visualize differences between the distributions of sediment grains (Appendix H). Overall, sediment grain

Table 13.2. Values and Description of the Standard Deviation (Sorting Parameter, 2nd moment)

| | |
|-----------------|-------------------------|
| < 0.35 phi | Very well sorted |
| 0.35 – 0.50 phi | Well sorted |
| 0.50 – 0.71 phi | Moderately well sorted |
| 0.71 – 1.00 phi | Moderately sorted |
| 1.00 – 2.00 phi | Poorly sorted |
| 2.00 – 4.00 phi | Very poorly sorted |
| > 4.00 phi | Extremely poorly sorted |

Table 13.3. Values and Description of the Skewness Parameter (3rd moment)

| | |
|---------------|------------------------|
| > +0.30 | Strongly fine skewed |
| +0.30 – +0.10 | Fine skewed |
| +0.10 – -0.10 | Near symmetrical |
| -0.10 – -0.30 | Coarse skewed |
| < -0.30 | Strongly coarse skewed |

size ranged from 0.09 in. (3.41 ϕ) to 0.18 in. (2.48 ϕ) mean grain size. Standard deviations (such as those produced by sorting) ranged from 0.76 ϕ (well sorted) to 2.41 ϕ (poorly sorted). Skewness ranged from -1.54 ϕ (strongly coarse skewed) to 0.24 ϕ (finely skewed). The majority of the samples fell within the coarsely skewed range. Trends for mean grain size, standard deviation, and skewness have been plotted for each sediment core to highlight the compositional variability within each (Appendix I). The sample group included both modern and fossil shell remains, the condition of which ranged from pristine to highly abraded. Calcareous (shell) material tends to comprise the overall gravel content of the assemblage. Thirty examined samples, with the exception of T1-10 (depth 0–10 centimeters), contain organics and mica. In general, the texture of seafloor materials was highly variable and ranged from 2 to 24% mud at the seafloor/water column interface (averaging approximately 10%). Down-core trends in texture ranged from fining to coarsening to generally heterogeneous.

Diver Observations

A pit profile was generated during excavation based on diver observations relayed via two-way communication between the geologist and diver (Figure 13.3). Sediments observed in the profile closely resembled those identified in the vibrocores.

The types of sediments identified during diver operations exhibit attributes—including textural parameters, faunal assemblages, and arrangement—that are typical to the region encompassing Charleston Harbor. The three-dimensional arrangement of strata appears normal, and few recognizable trends were observed among the shallow cores. In general, textural parameters indicate that most materials deposited in the vicinity of *Hunley* were the result of reworking of sediments deposited across the ebb-tidal delta of Charleston Harbor’s entrance. This process resulted in the overall presence of lag deposits consisting of sands and very sandy mud.

Discussion

The composition of sediment cores analyzed during the *Hunley* recovery project exhibit similarities to cores recovered from the seafloor in and around Charleston Harbor during previous scientific investigations (Gayes et al. 1998). By contrast, internal lithologies vary from site to site. Each of the four aforementioned moment parameters enables geologists to describe the distribution of sediment grains based upon the mean grain size of the sample. In addition, these parameters provide some measure of the processes involved in the deposi-

tional history of site sediments. The overall fine-grained nature of these sands is typical, and likely resulted from a lack of coarse-grained sediment in the source area.

The presence of coarse skewness—not necessarily coarse-grained sediment—indicates that a general lag deposit was created at the site. A lag deposit typically results from the winnowing away of fine materials from sediments during depositional processes. Although there is strong indication that fine-grained material intercalated (formed in distinctly alternating layers) into the site’s coarser sediments after deposition, comprehensive analyses suggest that the sediments that characterize the site are the result of an overall accumulation of sediment and subsequent winnowing of that sediment into a lag deposit.

Distinct stratigraphic boundaries, delineated by a marked increase in the percentage of mud as opposed

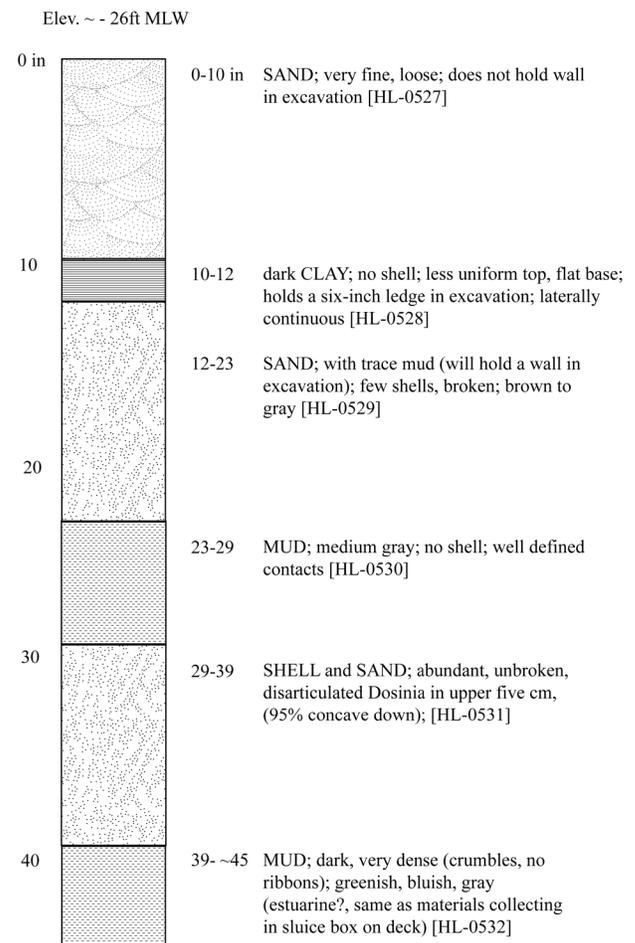


Figure 13.3. Excavation profile measured from seafloor, approximately 2.5 ft. (0.76 m) above stern, 20 ft. (6.10 m) astern and 10 ft. (3.05 m) starboard. Description provided by diver (H. Pecorelli) to geologist (S. Harris) through seafloor communication and post-dive interviews. Samples collected within distinct beds.

Table 13.4. Benthic Infaunal Sample Analyses by Transect and Distance from Submarine

| Category* | | | | | | | | | | | | |
|---------------------|-------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Species Abundance | 62 | 45 | 46 | 53 | 64 | 90 | 73 | 125 | 78 | 69 | 36 | 77 |
| Species Richness | 14 | 16 | 8 | 9 | 17 | 16 | 9 | 10 | 10 | 11 | 9 | 12 |
| Shannon (H') | 2.001 | 2.3 | 1.634 | 1.306 | 2.416 | 1.738 | 1.07 | 0.79 | 0.927 | 1.143 | 1.662 | 1.433 |
| Evenness (J') | 0.758 | 0.83 | 0.786 | 0.594 | 0.853 | 0.627 | 0.487 | 0.343 | 0.403 | 0.477 | 0.756 | 0.577 |
| Percent Polychaetes | 73% | 69% | 83% | 74% | 58% | 68% | 88% | 93% | 94% | 93% | 86% | 90% |
| Percent Amphipod | 6% | 0% | 0% | 4% | 9% | 16% | 3% | 1% | 3% | 3% | 3% | 0% |
| Percent Mollusk | 3% | 2% | 0% | 6% | 9% | 8% | 3% | 2% | 0% | 0% | 0% | 4% |
| Percent Other Taxa | 18% | 29% | 17% | 17% | 23% | 9% | 7% | 4% | 4% | 4% | 11% | 6% |
| Percent Silt/Clay** | n/r | 6.6% | 9.0% | 9.2% | 6.7% | 24.5% | n/r | 3.9% | 10.2% | 10.0% | 12.3% | 9.1% |

* Species distribution analyses were generated using BiodiversityR (Kindt & Coe 2005) in R (R Core Team 2013).

** Based on top 15 cm of sediment samples or nearest measured equivalent (0–5 or 0–10 cm) from Table 13.1; a weighted average was used to combine two samples of uneven sizes (*italics*).

to other sediment types, were noted in some of the longer core sections. The presence of mud layers within the seabed is not surprising, as they are quite common and scattered throughout the region. Most appear to be the result of the late 19th century redirection of the harbor ebb-tidal delta into the area immediately surrounding the *Hunley* site.

No textural trends (with respect to the distance along a coring transect originating at the submarine) were observed, nor were any distinct trends down the length of the core observed. Project scientists were able to develop a close estimate of the amount of coarse sediments and shell material that had accumulated around the submarine since its loss. However, the scattered nature of the sedimentary body precluded identification of any specific trends that deposited these materials on site. This lack of trend does not discount diver observations, but rather it demonstrates the heterogeneous nature of the shelf outside the hydrodynamic influences of a large object on the seafloor.

Faunal Samples

An abundance of marine macrofauna was identified within the sediment samples taken by Harris, who provided a general characterization of the species he encountered. Approximately 61% of the samples contained *Spisula solidissima* (surf clam) shell halves and/or broken shells belonging to this particular species. Other marine macrofauna species observed within the 31 sediment samples include the following: four *Ensis directus*, one duck clam, one tube worm, one ark shell, one bryozoa cluster, three echinodea, one *Crassostrea virginica*, two *Divaricella quadrasulcata*, two gastropods,

and one piece of material tentatively identified as slag from burnt coal. Other broken and unidentifiable shells comprised 68% of the sample group.

Samples specifically targeting benthic infauna were taken during the 2000 recovery operation by Pam Jutte, biologist with SCDNR, and reveal a range of invertebrates. Two replicate samples were taken along the same transect lines as the sediment samples, at points adjacent to the hull and 1 m, 3 m, 5 m, 10 m, and 20 m from the hull on both transects. They were collected using a core 7.6 cm (3.00 in.) in diameter and 15 cm (5.91 in.) deep, for a sample volume of 680.47 cm³ (41.55 cu. in.) in order to be comparable to other studies already conducted in the region (Jutte et al. 1999, Van Dolah et al. 1992, 1994). The samples were sieved through 0.5 mm (0.02 in.) mesh and all macrofauna and sediments retained on the sieve were preserved in a 10% buffered formalin solution with rose bengal stain. The family, genus, and, where possible, species of individuals present in each sample were identified and counted (Appendix J).

Several measures of benthic communities were calculated for each sample location based on combined counts of the replicate samples (Table 13.4). The samples were also assessed by percentage of polychaetes, amphipods, and mollusks in conformance with other benthic studies in the region (Van Dolah et al. 2004, 2006, 2013). Environmental data collected over a 48-hour period at location T1-0M resulted in a mean temperature of 21.72 °C (71.10 °F) and a mean pH of 8.13. The mean dissolved oxygen content over a 24-hour period was 6.39 mg/L.

The most abundant taxon present overall was Polychaetes, a class of marine annelid worms commonly referred to as bristle worms because of the many fleshy protrusions. Polychaetes are a robust and wide-

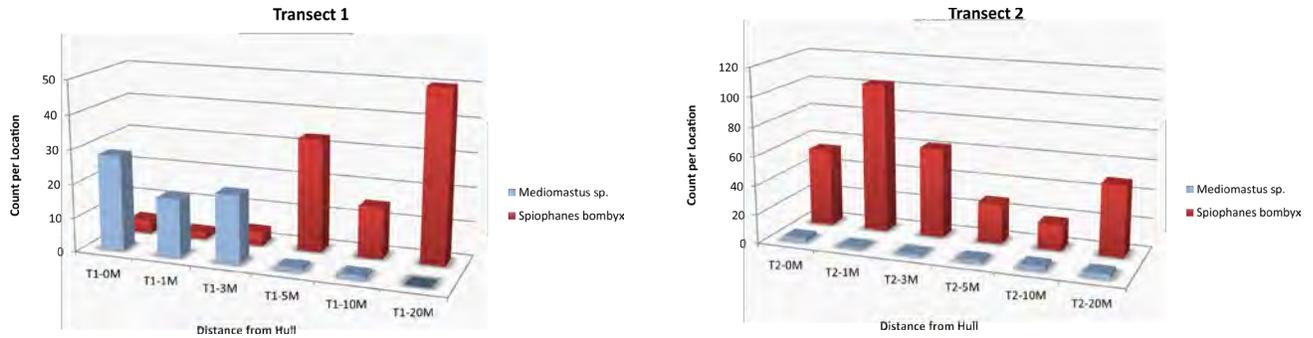


Figure 13.4. Distribution of *Mediomastus* sp. and *Spiophanes bombyx* counts along Transects 1 and 2 shows no statistically significant pattern. (Graphs by H. G. Brown, NHHC)

spread class, with more than 10,000 species. The most populous species present among the *Hunley* samples, *Spiophanes bombyx*, is of this class, with a total of 444 individuals identified. This widespread bristle worm, also known as the Bee spionid, lives in tubes that protrude slightly from the seabed and feeds on suspended particles in the water column as well as deposits (Dauer et al. 1981). On transect 1, the species was most abundant beginning 5 m from the hull, while on transect 2 there was no significant increase or decrease in relation to distance from the hull.

The second most populous group was the genus *Mediomastus*, also of the class Polychaetes. Another common worm, this genus is found throughout the world, except in areas of extreme high latitude, and is generally found in shallow sandy-mud and muddy environments (Warren et al. 1994). Along transect 1, individuals were more populous within 3 m of the hull, and became much sparser further away, thus reversing the trend demonstrated by *Spiophanes bombyx* (Figure 13.4). There was, however, no significant pattern of distribution along transect 2.

Six species of amphipods were represented. Organisms in the order Amphipoda are malacostracan crustaceans identified by the absence of a carapace, a laterally compressed body, and appendages that differ unlike the isopods in which all the thoracic legs are similar. Amphipods range in size from 1 to 340 millimeters (0.039 to 13 in.) and are mostly detritivores or scavengers. Only one species of the order Isopoda was found. Isopods are relatively small crustaceans with seven pairs of legs of similar size and form, bodies that are usually (but not always) flattened dorso-ventrally, and a reduced carapace that covers only the head.

Bivalves and gastropods, representatives of the largest marine phylum, Mollusca, were both observed in the samples. Two species of bivalves and three species of gastropods were noted. Bivalves are a class that includes both marine and freshwater mollusks, such as clams, oysters, and mussels, which possess a

hinged shell and laterally compressed body. Gastropods include snails and slugs and are the most highly diversified class in the phylum. They thus exhibit a high degree of variability in anatomy, reproduction, and behavior. Those animals with shells usually have only one and were formerly known as univalves

Overall, these fauna do not seem to have affected the condition of *Hunley* to any significant extent. Burrowing animals could have the effect of aerating the shallow sediment to a limited extent. However, once the submarine became buried by 3 or more feet (0.91 m) of sea floor sediment they would have had no effect. This is also supported by the lead isotope analysis, which did not reflect any disturbance from either hydrodynamic forces or bioturbation.

Microbial Analysis of Sediment from Cores and Hunley Interior

Sediment samples taken from both outside and inside the submarine were analyzed by Dr. Pam Morris to see whether different types of iron reducing bacteria (FeRB) were present at the site based on variations in a specific region of their 16s rDNA. Since these bacteria can affect the integrity of the metal, the analysis would help inform conservation planning, influencing the specifics of the treatment applied to the submarine. The research was carried out at the Department of Biology, Grice Marine Laboratory at the College of Charleston. Some genetic analysis was conducted on the samples by Jeremy Goldbogen (Appendix K). Samples were taken from all sediment cores taken along Transects 1 and 2 except T1-0M and T2-0M. Additional samples were taken from inside the submarine during the hull thickness and rivet sampling survey.

To select for FeRB, sediment samples were introduced into a goethite media under anaerobic conditions prepared from a mixture of hydrolyzed $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, and 5M KOH. This was then incubated for eight

months, after which a volumetric reduction of the Fe (III) matrix to the more compact Fe (II) structure was noted. Nucleic acids were then extracted and amplified using polymerase chain reaction (PCR) with a set of universal eubacterial primers that target the V9 323-bp region of the 16S rDNA. Extraction and amplification were achieved in all samples except 3m. Successful PCR products were then analyzed using denaturing gradient gel electrophoresis. The genetic analysis revealed that a variety of different FeRB were present in the samples. The presence of FeRB in samples up to 20 m (65.62 ft.) from the hull indicates that the FeRB occurs naturally in the sediment.

Site Formation Processes

When reconstructing the processes that have affected a site over time, multiple lines of evidence must be examined, including sediment stratigraphy, artifact distribution, current and wave action, regional storm history, and human activity at the site. The insights gained from understanding the post-depositional processes that affected the hull can allow investigators to separate what hull damage was directly related to the sinking from what came after, over century beneath the sea. Using evidence derived from the hull condition, distribution of artifacts, and surrounding sediment, a general picture of what

took place after *Hunley's* loss can begin to take shape. The primary lines of inquiry include how soon after the sinking was the submarine buried, how and when it canted roughly 45° to starboard, and at what point were the disarticulated hull components lost.

The largest factor affecting the site was the excavation itself. Based on records from the submarine's initial discovery in 1995 (Hall 1995), the site investigation in 1996 (Murphy 1998) and HAT's site visit in 1999, the sediment directly above the hull was disturbed in order to identify and assess the vessel (Figure 13.5). The full length of the top was exposed in 1996 along with the port side down the level of the diving plane, except one section near the aft conning tower that went down to the keel. The dredged material was not screened. Care was taken to minimize dredging around the bow and stern, where it was believed the most fragile elements would be found, and along the starboard side for fear of undercutting the support keeping the hull in position (Murphy 1998:17). In 1999, excavators attempted to stay within the previously disturbed area, but did need to expose a roughly 2 m (6.56 ft.) length along the starboard side to acquire vital engineering data for the recovery (see Chapter 8). Overall, the loss of context was kept as minimal as possible, and the matrix around the lower levels of the submarine remained intact except for the small section of keel port side. Despite the extent of prior disturbance, trends in the sediment matrix were still discernable.

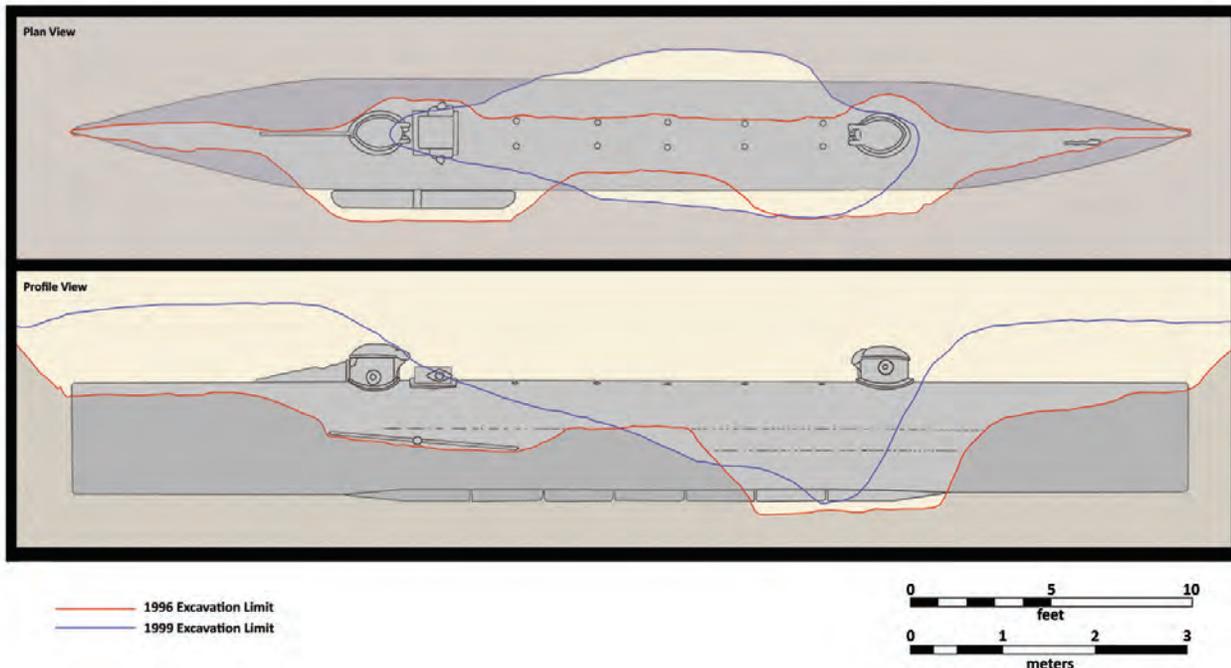


Figure 13.5. Areas of sediment disturbed during the initial assessments of H. L. Hunley. (Diagram by H. G. Brown, NHHHC)

Artifact Distribution

By examining where intrusive material came to rest around the vessel, the hydrodynamic forces that affected them can, in part, be reconstructed. Anthropogenic material collected at the site can be divided easily into classes based on different characteristics that affect their behavior on the seabed. Coal and slag behave in a similar fashion to naturally occurring sediment, functioning essentially as gravel-sized particles introduced from a variety of source locations surrounding the site. Ceramics and glass are relatively dense and, when fragmented, nearly flat, making long-distance transport less likely without a high-energy event to move them. Tin cans are denser than the surrounding environment, but their cylindrical shape facilitates post-depositional surface movement. Finally, the pieces that became disarticulated from the hull represent the largest and densest objects found at the site, and the only ones that can be traced with certainty back to their original position.

Coal and Slag

As discussed in Chapter 12, the sediment around *Hunley* contained a significant amount of coal, coal slag, bone, shell, and wood, mostly in small particle form. The shell was considered non-diagnostic and not retained for study. The bone specimens represented a mixture of marine and terrestrial animals. At least three mammal bones were found to have probable cut marks characteristic of butchering and likely represent discarded food waste originating either from passing ship traffic or washed out from the harbor through the jetty system. The material was spread throughout the site, with no distinctive clustering.

Most of the wood was in small fragments, too small or damaged to assess whether they were natural or from a man-made object. In addition, establishing provenience for this material was difficult as some of it may have washed in during the dredging process. While some was no doubt contemporaneous with *Hunley's* sinking and burial, there was no reliable method of ascertaining exactly what percentage. The two closest sources of contemporary worked wood were the wreck of *Housatonic* and the Stone Fleet. Reports on early salvage efforts indicate that *Housatonic's* wooden components deteriorated rapidly, primarily due to marine borers, and that by the 1870s work focused on recovered scrap metals, such as copper bolts (Conlin 2005:189–90). Such salvage activity could have dislodged fragments of the weakened wood and set them loose in the water column. In December 1861, a collection of old, wooden vessels, known as the Stone Fleet, was sunk across the main shipping channel south of the *Hunley* site to disrupt Confederate access to the

port. These deteriorated quickly and may also have contributed to the amount of worked wooden debris in the area.

The most abundant intrusive organic material in the sediment matrix surrounding the hull was coal and coal slag. As a particulate matter, its behavior is similar to natural sediment, but since its grain size is larger than the surrounding sand and mud, it provides a class of heavier particulate matter to study. The heavier materials require higher energy to initiate suspension or bedload transport, and sink more readily through unconsolidated fine material. It was also introduced into the seabed roughly contemporaneously with the wreck, functioning to a limited extent as a particle tracker. It is not ideal, however, because the original position of the material when it was introduced into the system cannot be determined.

This material is relatively common in the seabed off Charleston, and is frequently found in core samples taken in the area, particularly around dredge spoil areas and shipping lanes. Coal usage increased with the expansion of steam power in first half of the 19th century, and coal-powered steamships plied the coastal Atlantic waters in abundance well before and after the advent of the Civil War. Nevertheless, the extensive blockade enforced by the U.S. Navy represents a significant period of increased steam traffic in the area.

Slag, sometimes referred to as clinker, is the waste material produced from burning coal, and is generally a silica-based, vitreous material that varies widely in composition and density depending on the source coal and conditions in the furnace. There was a grate below the fire through which the pieces of slag would fall, whereupon it was collected and discarded. In the case of steamships, this meant “tossed overboard.” To calculate exactly how much slag was deposited on the seabed off Charleston by the blockading squadron is an impossible task—the amount of slag produced by any one ship varies greatly depending on the size and characteristics of the engine, the quality of coal used, the temperature of the furnace, the distance traveled, the sea conditions, and a number of less quantifiable factors.

Between 24 December 1861 and 1 July 1865, a minimum total of 132 Union vessels spent some period of time on blockade duty off Charleston, Bull's Bay just to the north, or Stono Inlet to the south (Figure 13.6). The maximum number reportedly present at one time was 43 on 15 February 1865, immediately prior to Charleston's surrender on the 18th of that month (ONR 1.16:244–46). On average, 20% of the vessels present at any one time were sailing vessels, which produced a relatively minor amount of slag from their galley stoves and any smithing operations they might perform on board. The rest of the fleet was divided into classes, the largest ships being 1st class, down the smallest 4th class

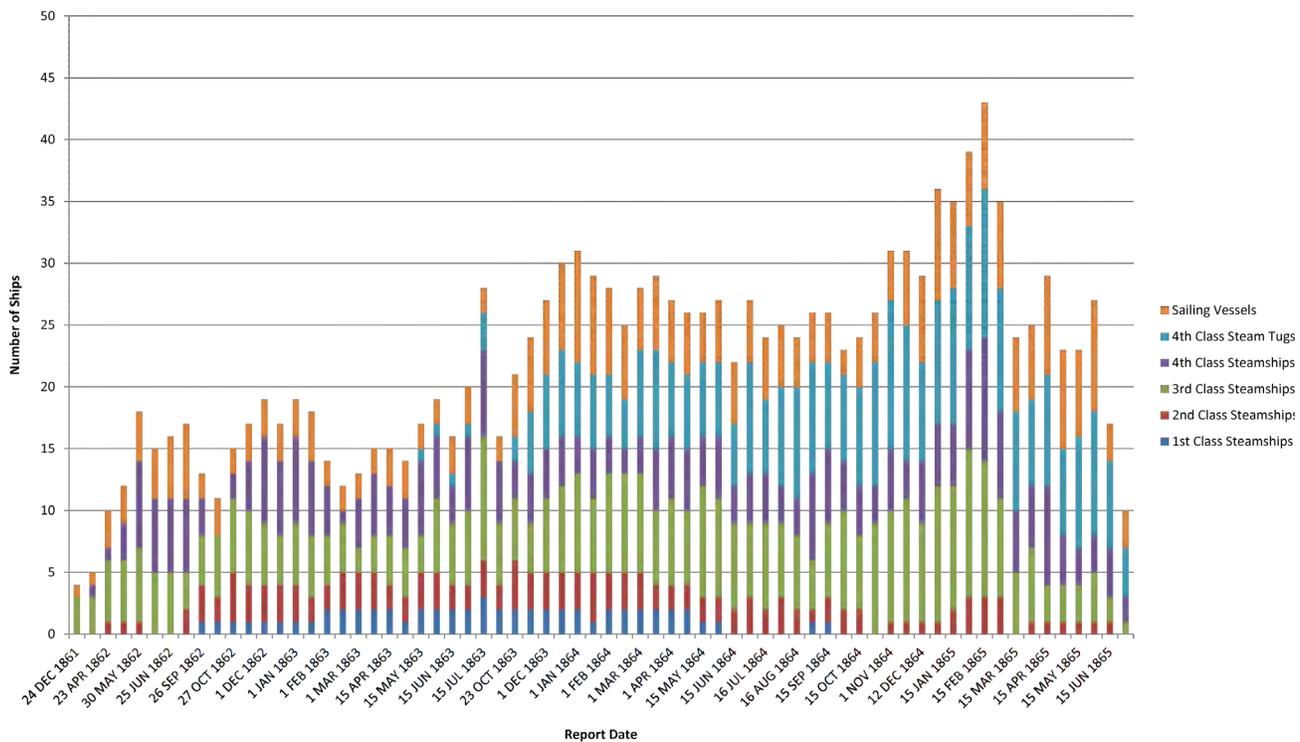


Figure 13.6. Number of U.S. Navy vessels on station off Charleston, Stono Inlet, and Bull's Bay, based on periodic reports from the commander of the South Atlantic Blockading Squadron. See Appendix M for complete listing of vessels. (Graph by H. G. Brown, NHHC)

vessels. Most of the ironclads were 3rd class vessels, and their accompanying tugs were 4th class.

Two cases can help give an indication of how much coal was used, and how much ash discarded, while also highlighting the shortcomings of the data. Steam logs for two vessels that participated on the blockade were examined, although not for the period of the blockade itself (DON 1858, 1865). USS *Wabash*, a 301.5 ft. (91.90 m) screw steamer, with a displacement of 3,274 tn. (2,970 t), a crew of 523, and 46 guns, was considered a first class vessel. USS *James Adger*, a 215 ft. (65.5 m) sidewheel steamer with a displacement of 1,151 tn. (1,044 t), a crew of 120, and 8 guns, fell into the second class.

Wabash spent the summer of 1858 in the Mediterranean. Between 8 June and 29 September the engines consumed 2,524,224 lb. (1,262 tn.; 1,145 t) of coal and dumped 376,282 lb. (188 tn.; 171 t) of coal ash into the sea. These figures reflect a considerable number of days actively cruising. However, many of the blockading vessels spent little time actively traveling, but rather stayed at anchor, only shifting positions closer to shore at night, and relocating out of gun range at day break. Thus the tonnage of waste produced may not be comparable to that produced by ships on blockade duty. The data do show that *Wabash* discarded approximately 15% of the original weight of coal consumed into the sea as waste. This is a figure that varies widely

from ship to ship and even between batches of coal. For example, the log shows that during the first half of the period, they were dealing with an inferior batch of coal that produced approximately 18% waste; they then refueled in Gibraltar with Welsh coal, a high quality steaming coal, and their waste percentage dropped to 12%. Despite the variation, these figures can be used to develop a range of expected waste material produced based on their average consumption. We also know that during the war years, the blockading squadron burned almost exclusively anthracite, since it burned without producing tell-tale smoke that might have given away their positions, and thus the variation in waste percentages, at least within an individual vessel's records, might have been significantly less during that period.¹

The surviving steam log from *James Adger* covers the period of 2 October to 31 December 1865, and records time spent in and around Colón, Panama, as well as at least one return cruise to Cartagena, Columbia. In this period, *James Adger* consumed 681,420 lb. (341 tn.; 309 t) of coal and dumped 186,980 lb. (93 tn.; 85 t) of ash from the boiler, producing an average of 27% of the original fuel in waste material. For a period of 8 days, the engine room kept up a head of steam,

¹ Anthracite was also preferred due to its higher density, providing more heating units per volume of stowage, and its superior hardness, making it less prone to crumble and deteriorate during transport and stowage (Nicolls 1904:305).

but the vessel did not travel. During this period, they consumed an average of 7,013 lb. (3,181 kg) of coal per day, and produced an average of 2,048 lb. (929 kg) of ash per day. This is an excellent proxy for blockade duty, since vessels frequently had to keep the boilers hot and the steam up to maintain readiness to chase and intercept blockade runners. As discussed in Chapter 2, standing orders on *Housatonic* were for the engine room to maintain 25 pounds (11.34 kg) of steam in the boilers throughout the night, the best time for blockade runners to try and make it through the fleet (DON 1864a:0534).

Using factors garnered from the steam logs, as well as several references to coal consumption in official correspondence, an estimated use of coal for a full day of steaming was developed as follows: 1st class—32 tn. (29 t); 2nd and 3rd classes—22 tn. (20 t); 4th class—15 tn. (13 t); tugs—8 tn. (7 t). *James Adger* consumed approximately 15% of its normal rate on days it maintained a head of steam with no travel. Thus, reducing each class's daily consumption by this factor, and multiplying by the total number of vessels of each class on station each day, a minimum of 58,000 tn. (52,617 t) of coal would have been burned off the coast of Charleston between 24 December 1861 and 1 July 1865. If one assumes an average of 15% of that was converted to ash, then, at the very least, roughly 8,700 tn. (7,893 t) of material was deposited on the seabed outside of Charleston Harbor during the war years.

In addition to this, there was slag deposited during normal ship traffic before and after the war, slag from the inner harbor that worked its way out to sea through normal processes of sediment transport, and slag from dredge spoil taken from the inner harbor and dumped outside the bar. These quantities, unfortunately, are impossible to estimate, but doubtless contributed to the material that came to settle around the *Hunley* site as the vessel was slowly buried.

Unburned coal was also found in the matrix surrounding *Hunley*. There are several ways coal found its way into the seabed. Very small pieces, often found at the bottom of coal storage bins, were frequently generated through the wear and tear of shoveling and stowing the material. These small pieces could fall through the grate in the bottom of the firebox and end up in the ash pit without being consumed. Larger pieces generally found their way into the sea through shipwreck or spillage. *Hunley's* victim *USS Housatonic*, for instance, went down with a significant quantity of coal on board, some of which, no doubt, found its way to the submarine's resting place. Blockade runners that were run ashore by Union forces were often plundered and their less valuable or portable contents, including coal, tossed about on the beach (e.g. Daly 1968:142). In such cases, some of this coal was likely caught up in the sediment transport system and made its way offshore.

There was occasionally also loss at sea during refueling. During the blockade, coaling ships came directly out to the vessels at their stations and transferred the fuel on the open sea, where conditions were not always stable. Such an incident was recorded in the steam log of *Wabash*, when 6,720 lb. (3,048 kg) of coal was "lost overboard in consequence of rough weather" while coaling in Marseilles (31 August 1858).

Twelve coal samples, four from the *Housatonic* site and eight from the *Hunley* site, were sent to Rod Hatt of Coal Combustion, Inc., Versailles, Kentucky, for analysis (Appendix L). Of these, only six were viable, three from *Housatonic* and three from *Hunley*. All three of the former were identified as anthracite, consistent with U.S. Navy practice for the period. Of the *Hunley* samples, one was anthracite of similar physical and chemical characteristics to those from *Housatonic*. The second sample was identified as medium volatile bituminous coal, and the third as low volatile bituminous coal, both of which were commonly found in the eastern Appalachian Mountains.

A total of 32.29 kg (71.19 lb.) of slag and 14.33 kg (31.59 lb.) of coal was collected from sediments excavated around *Hunley*. Using the Udden-Wentworth scale of grain size (see Figure 13.1), the pieces recovered ranged from fine gravel (-2 to -3 ϕ) to cobble (-6 to -8 ϕ) in size. Because pieces were recovered by hand, primarily from dredge screens, materials smaller than -2 ϕ were not collected. Once recovered, coal and slag were separated into lots based on the excavation position in relation to the hull as recorded by diver observation, resulting in somewhat generalized provenience. In analyzing the data, the lots collected immediately following the one-month hiatus were omitted; these represent material that washed in from the surrounding area during the work stoppage, and slipped down through the sandbags left on site to protect the hull. A small percentage of the overall material most likely washed in during the excavation process, but the majority was found in situ.

All selected lots were plotted in ArcGIS to show distribution by count of coal and slag separately (Figure 13.7 and Figure 13.8). A polygon was created for each lot, based on reported size and position of each dredging area. The number of coal and slag pieces for each lot was distributed evenly over the area of the corresponding polygon. This method, therefore, does not take into account variations in weight for each piece, instead focusing on relative abundance and position relative to the wreck. Since much of the sediment along the centerline and the port midships region were disturbed during the 1996 and 1999 field seasons, it is not surprising that these areas contained a relatively small amount of coal and slag. However, the area below the level of the top of the hull on the starboard side was not disturbed during the earlier excavations. Similarly,

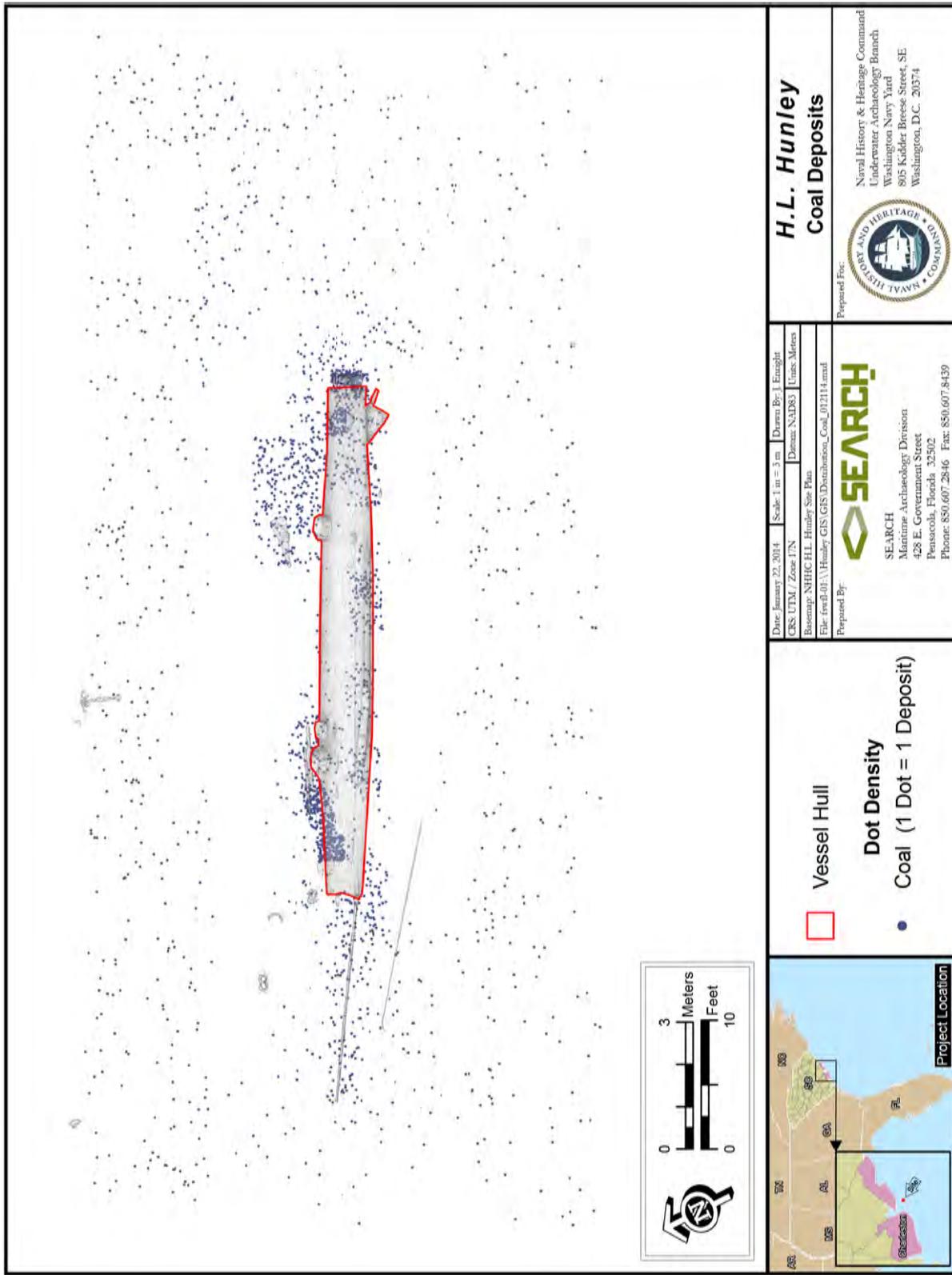


Figure 13.7. Distribution of coal around the Hunley site based on raw counts. White patches represent areas where data was not collected.

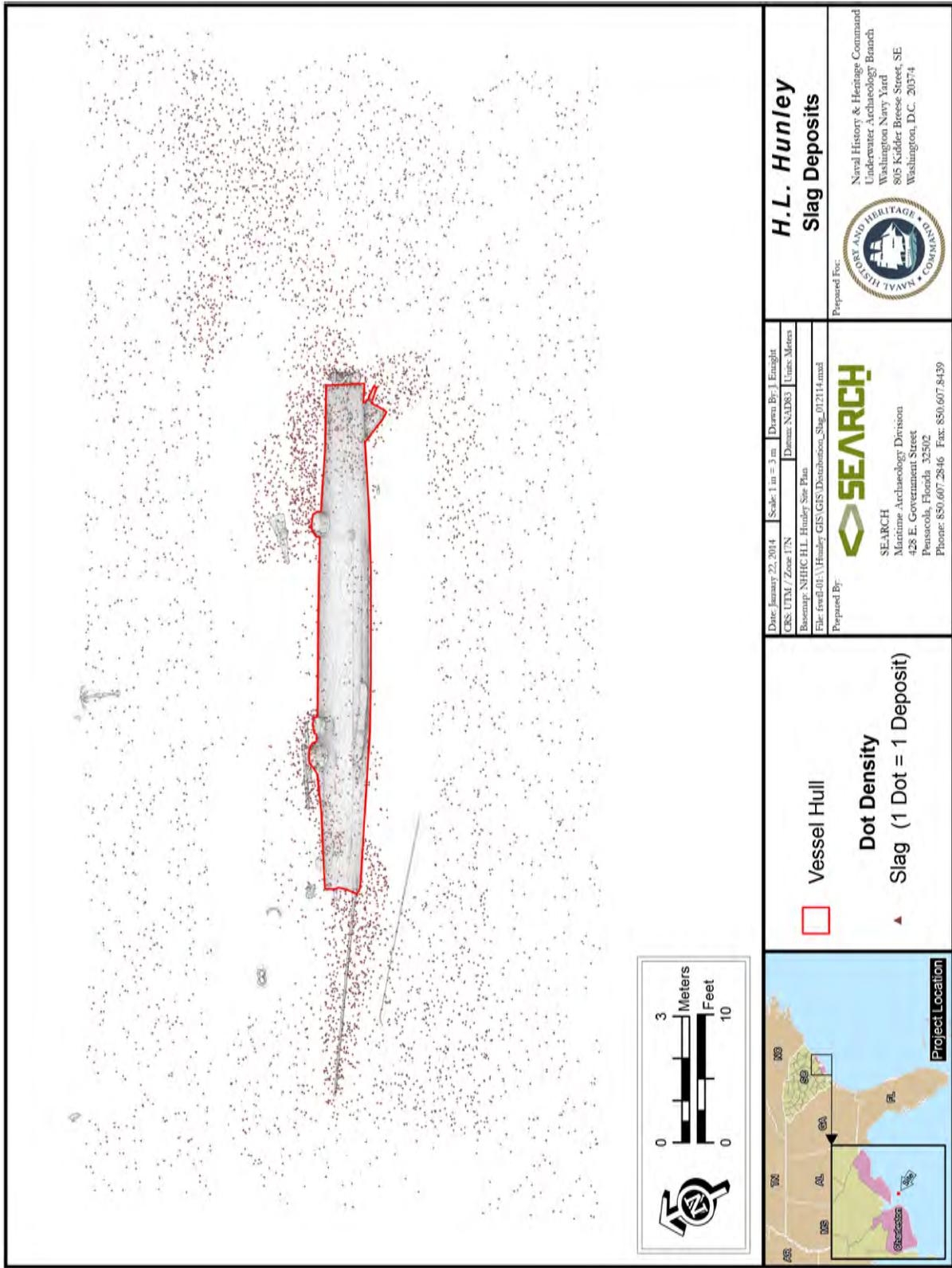


Figure 13-8. Distribution of slag around the Hunley site based on raw counts. White patches represent areas where data was not collected.

the deeper levels along the port side were largely undisturbed, particularly at the bow and stern.

The areas of densest concentration were found to be below and just to starboard of the stern, along the path of the spar, and starboard of the bow below the level of the top of the hull. Several areas were revealed to have had minimal data collection, primarily along the boundaries between the HAT and OII excavation areas; these two sections were left relatively intact in the form of a raised, berm-like area until late in the excavation, at which point the focus was primarily on preparing the hull for lifting. Comparing the two plots, it is evident that the denser coal collected lower down into scour pockets close to the hull, while the slag, which tended to be lighter, was more widely distributed.

There also appears to be an area of moderate density east of the hull, stretching roughly 5 m (16 ft.) eastward from the stern scour pocket. This may represent residual particles that began to settle as the turbulent waters around the scour pockets began to slow further from the submarine. However, due to the gaps in data, this trend cannot be verified.

Ceramics and Glass

The distribution of ceramic and glass is somewhat haphazard (Figure 13.9). The density of bottle glass is generally between 2.4 and 2.8 g/cm³ and ordinary ceramics of the type found at the site are in a similar range, making both likely to sink through fine sand layers. The wide, flat shapes of dish fragments such as

HL-0448 and HL-0451 are more resistant to transport either as suspended or bedload, suggesting they were either deposited nearby originally, perhaps as trash from a passing ship, or were transported during a very strong storm event. A ceramic bottle (HL-0661) was found close to the stern on the port side, and may have rolled from the south or southwest and become blocked by the submarine. Two other glass fragments were found in this area, a base (HL-0662) and wall shard (HL-0675). If these two were part of a larger whole when originally deposited, they may also have rolled into *Hunley* and become trapped.

The whiteware fragment HL-0451 has a stamped date of 1912, making it the only intrusive artifact with a known *terminus post quem* for deposition (see Chapter 15). It was found above the level of the top of the hull, suggesting a relatively stable sediment depth covering *Hunley* by the second decade of the 20th century.

Tin Cans

Another class of cylindrical artifact common to the site is the tinned iron can. With a density of 7.85, iron is even more likely to work its way down through unconsolidated fine sand layers. The addition of a lead (11.34 g/cm³) or lead/tin (8.8 g/cm³) solder increases the overall density of the can. However, its hollow cylindrical shape also lends itself to ease of transport along the seafloor. With one open end, it must eventually fill up with sand and become buried, but it is impossible to predict how long this would take.

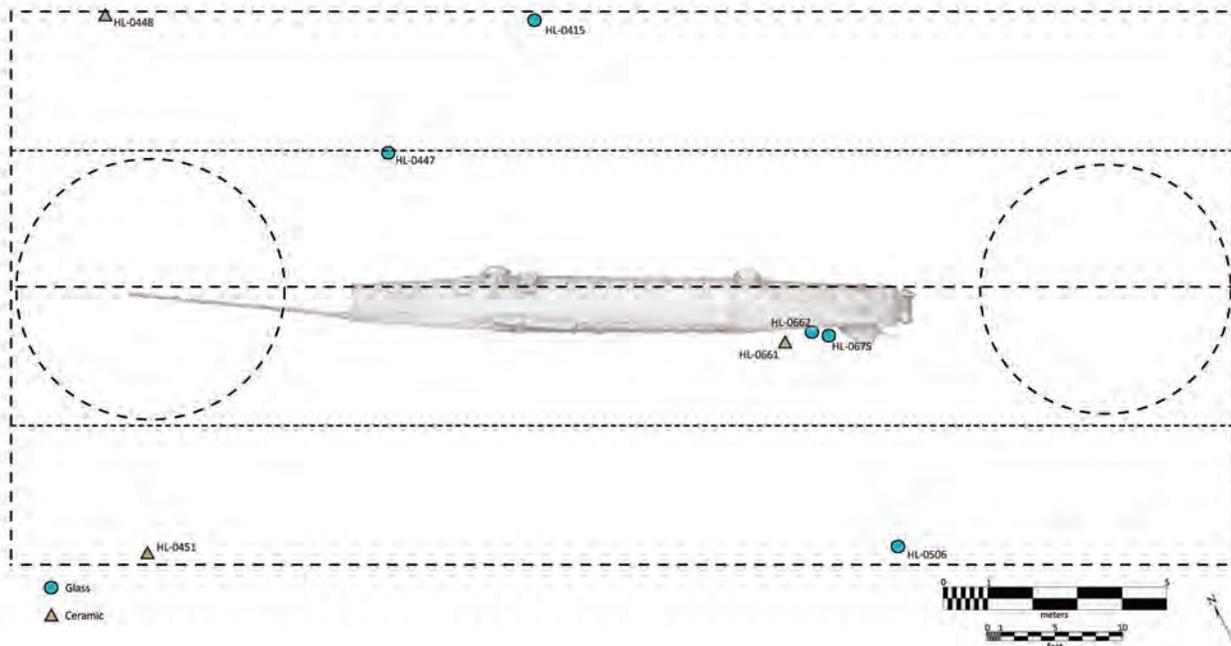


Figure 13.9. Positions of ceramic and glass artifacts recovered from the wreck site. (Site plan by James W. Hunter III, annotated by H. G. Brown, NHHHC)

Of the cans that were identified at the site, most were fragmentary in nature but often found in small clusters, indicating they had come to rest relatively whole and then broke down as the thin iron wall corroded. Seven were nearly complete, though in some cases slightly flattened. Of these seven, four were concreted to the hull on or near the keel along the port side (HL-0653, HL-0654, HL-3667, HL-3678). The other two were found to starboard of the hull, one at the bow (HL-3288) and one at the stern (HL-0700). HL-3288 had become concreted to an iron bracket from the hull (HL-0582) and also had trapped a small wooden handle fragment (HL-3289) inside it. Three were identified from the stern suction pile area, from various depths, primarily starboard of the hull, and two from the bow suction pile area. Overall, the material clustered to starboard of the bow and the stern, with a third cluster along central portion of the port side (Figure 13.10).

Most of the cans were relatively low down in the matrix, starting about halfway down the vessel height down to the dense shell layer. The level of preservation of the complete cans suggests they were buried relatively quickly and did not experience subsequent periods of significant exposure, while the fragmented cans may have had longer or intermittent periods of exposure to the water column.

The collection most likely represents a wide variety of dates and products, none of which were directly associated with *Hunley*. However, a few cans can be roughly dated by their technological features to the late 19th century (see Chapter 15).

Hull Components

Although the submarine remained remarkably intact for over a century in the seabed, many of the exterior components became disarticulated from the hull, either through natural processes or human interaction. These include the rudder (HL-0686), its mounting hardware and steering gear; both shroud attachment bars, only one of which was found (HL-0660); the cutwater from the aft conning tower (HL-0555); both snorkel tubes (HL-0614, HL-0615, HL-0616), and two apparent mounting brackets from the bow (HL-0526, HL-0582). Knowing their point of origin makes these pieces valuable in reconstructing the forces in play around the submarine prior to its burial.

Most of the disarticulated components came to rest to starboard of the hull, close to their original location (Figure 13.11). The starboard shroud attachment bar never detached fully from the hull, but was apparently bent forward while the metal surface was still exposed, as it was found concreted to the hull in several spots along its length. The event that caused this displacement may be related to the damage on the starboard side of the propeller shroud.

The rudder was found directly beneath the stern, along with one concretion (HL-0683), which appears to be part of one of the shroud attachment bars or steering assembly (HL-0683). It was lying diagonally across the center line, approximately 1 m (3.28 ft.) forward of the after edge of the propeller shroud, with the port side upward and the top corner of the leading edge toward bow. It is possible that the rudder fell off through gradual

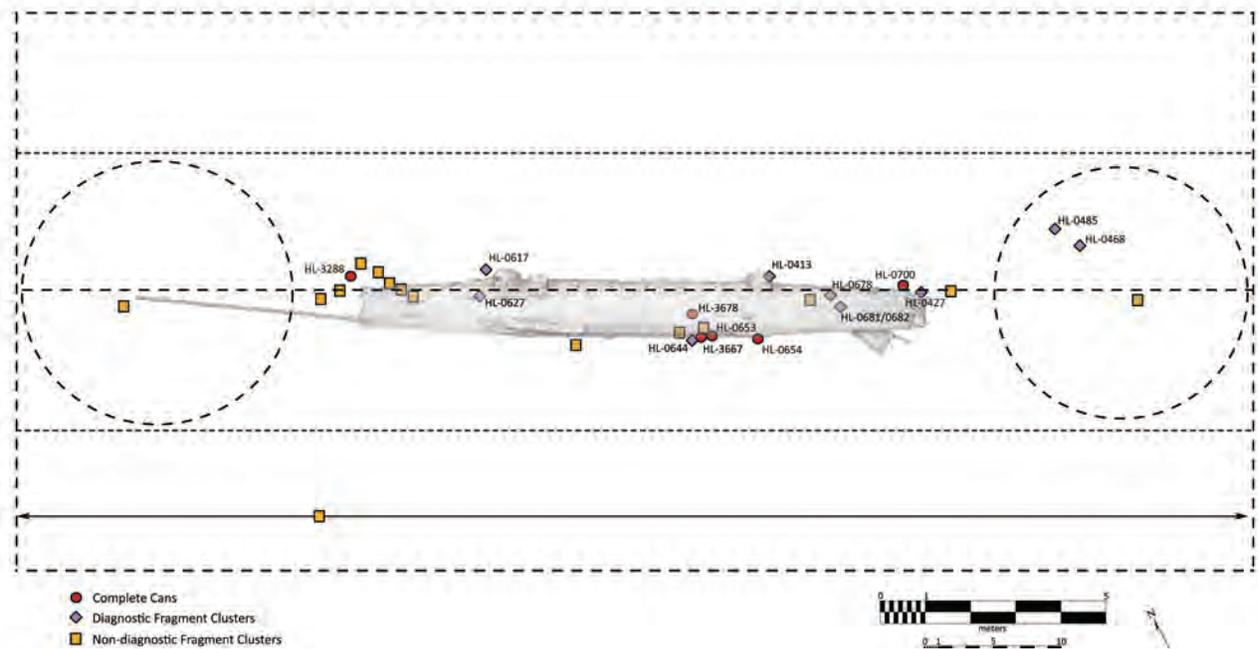


Figure 13.10. Positions of complete, partial, and fragmentary cans recovered from the wreck site. (Site plan by James W. Hunter III, annotated by H. G. Brown, NHHC)

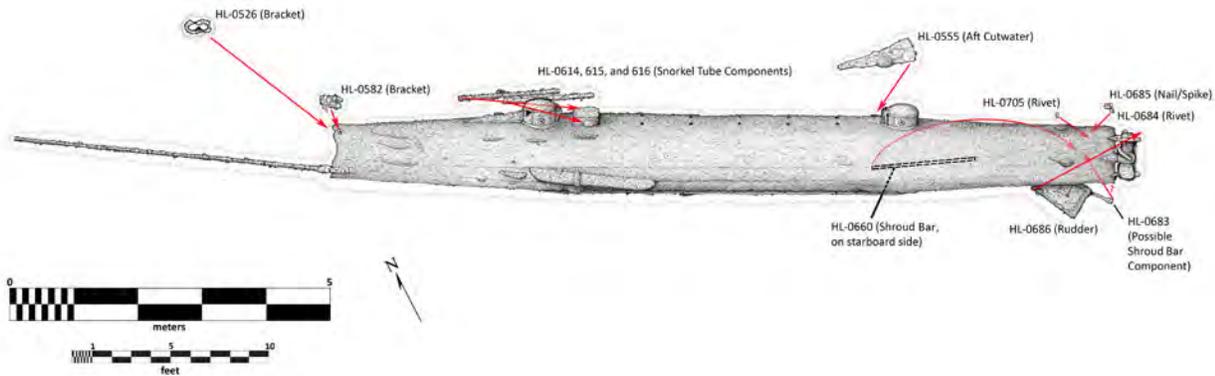


Figure 13.11. Site plan showing locations of the disarticulated components, with red arrows indicating their point of origin. Due to the steep cant of the wreck, the shroud attachment bar (HL-0660) appears to be beneath the hull in this view. (Site plan by James W. Hunter III, annotated by H. G. Brown, NHHC)

deterioration of the mounting points, and it migrated forward as it scoured down to the Pleistocene mud layer. Due to its weight (38.3 kg [84.44 lb.]) and flat profile, however, it is possible natural hydrodynamic forces were not enough to have pushed it so far out of position.

Another scenario is that the damage to the steering assembly also involved the rudder itself, although the piece shows minimal damage. The mounting brackets show no deformation but do appear to have snapped cleanly off rather than eroding gradually, while the steering arms concreted to the rudder show deformation at the trailing edge trending upward and to starboard. If the port side of the propeller shroud and the steering rod were pulled away by a snagged anchor traveling northward, the rudder might have been wrenched off to starboard and come to rest slightly forward and to starboard of the stern while *Hunley* was still upright. Once it canted over to its 47° position, it then covered the rudder, which had already settled down to the mud layer.

The cutwater was found approximately 61–76 cm (24–30 in.) starboard of the hull roughly northeast of its original position, with its port side down. There does not appear to be any deformation of the metal, suggesting the piece corroded along its attachment points and fell off the submarine naturally. Since the forward cutwater remained solidly in place, however, it is possible additional force was required to dislodge it. There is a small section of metal loss along the hypotenuse, but it is difficult to determine whether it was caused by corrosion or an impact event.

The snorkel tubes were found parallel to the hull, forward of their original position. These elements did not show any sign of damage from external forces, and likely corroded naturally, most likely at the point where the wrought-iron tubes connected to the cast-iron snorkel box, where a galvanic cell would have

formed. The fact that the port snorkel tube came to rest to starboard of the hull indicates that they came loose after the hull canted to starboard. The apparent movement toward the bow suggests that a northward flow dominated their deposition.

The bow brackets show an unusual distribution pattern. The after bracket was bent about halfway down one arm, and both arms broke off around the fastener holes; however, it came to rest very close to its original position, 35 cm (13.78 in.) starboard and 5 cm (1.97 in.) forward of the bow. The forward bracket was found disarticulated from the hull, approximately 2.0 m (6.56 ft.) forward and 1.4 m (4.59 ft.) starboard of the bow, but with its fastener in place and no sign of metal deformation. The through hole for this bracket was compromised at some point, either through erosion or breaking from impact or strain, a possibility that can't be more fully examined until the hull is deconcreted. Given the damage to the aft bracket and the position of the forward bracket, it is likely that the boom, or possibly rigging elements attached to the boom, was snagged after deposition, pulling the hardware away from the bow northward.

Hull Erosion

The hull itself showed significant areas of metal loss that are directly tied to the flow of water and suspended sediment around it. The leading edge of the bow casting, formerly a straight vertical edge, was worn into a scallop shape. Even the nut holding the spar on to the bow was heavily worn (Figure 13.12), attesting to the strong flow along the port side of the bow. The skag in front of the port diving plane was also somewhat eroded, and it is possible the diving plane itself was pushed upward out of horizontal alignment from the currents flowing

around the bow. The port side of the stern does not demonstrate such severe erosional damage, although the rounded edge of the broken propeller shroud attests to some flow-related wear.

A study conducted at the Warren Lasch Conservation Center took an in-depth look at the two holes on *Hunley's* starboard side and linked them to scour (Jacobsen et al. 2012). Analysis of the sediment inside the hull revealed that these two holes were not formed as a result of the sinking, but formed much later. There were several factors that contributed to an accelerated degradation rate in these areas. Both holes formed along the boundary of the cast-iron end caps and the wrought-iron plates, a likely environment for the formation of a galvanic cell. This natural corrosion system was enhanced by the turbulent flow around the bow and stern, which pelted the hull surface with granular material as it pushed past. Controlled laboratory studies on metal plates of similar consistency to *Hunley's* wrought iron tested rates of corrosion, erosion, and combined erosion-corrosion processes. It was found that

[t]he mass loss rate for the plate exposed to erosion-corrosion is 18 and 10 times greater than plates exposed to corrosion and erosion conditions. The primary reason for this is probably due to the constant removal of surface oxide layers, thus exposing the underlying metal and leading to accelerated mass loss. (Jacobsen et al. 2012:44)

Essentially, the continual abrasion of the hull appears to have prevented the formation of a protective concretion layer in an area already predisposed to an increased corrosion rate due to contact between two different metals. Both holes are near the top of the hull,



Figure 13.12. Erosion is evident on the outer surface of the nut that connected the spar to the hull at the base of the bow casting on the port side. (Courtesy of FOTH)

which may give an indication of the depth of the submarine's initial burial, as the lower hull seems to have been protected from these effects, perhaps by its list to starboard.

Scour and Burial

Scour is a phenomenon involving the interaction of moving water, sediment, and an object in contact with the seabed. The object, in this case *Hunley's* hull, obstructs the current flow, causing the water to slow down as it approaches, then speed up as it pushes around and over. The dynamics of scour are complex and even with detailed environmental data can be difficult to predict. However, understanding the general behavior of scour is important in interpreting the disposition of artifacts at the site.

As velocity slows on the incident side of the obstruction, causing some deposition of suspended load, pressure increases; on the lee side, pressure drops significantly and velocity rises, increasing lift force. In addition, the direction of flow is severely disrupted, and the relatively laminar flow becomes turbulent. Horseshoe vortices develop on the incoming side of the obstruction that wrap around the ends of the obstruction, and wake vortices form on the lee side (Rory Quinn 2006:1420). These forces can cause localized erosion of the seabed resulting in hollows or pockets of sediment loss that extend away from the wreck, usually in the direction of current flow. The direction and size of these pockets are determined by many factors, including the shape of the object, the direction of the currents, wave action, and the composition of the seabed.

Idealized projections of scour zones outlined for a simplified ship shape were generated by Rory Quinn (2006:1423). These take into account unidirectional, bi-directional, and rotary flow with the object at various angles to the flow direction (Figure 13.13). The area around *Hunley* is characterized by a rotary current, where the direction of current rotates in a clockwise direction over the course of the tide cycle. Therefore, one might expect uniform scour around the base of the submarine. However, since the duration and speed of the rotary current is asymmetrical, some characteristics of bi-directional current could be expected.

The site development history is further complicated by the fact that there were two distinct phases of predominant tidal direction during the period when the submarine was on the seafloor. At the time *Hunley* sank, the ebb tide set roughly northeastward (ca. 73°) at the beginning of the cycle, but quickly circled round to southeast by east (ca. 120°–130°) for the second quarter and part of the third, tailing off to south by east by the final quarter (USCS 1856). The flood tide ran in two primary directions—west by south (ca. 256°–259°)

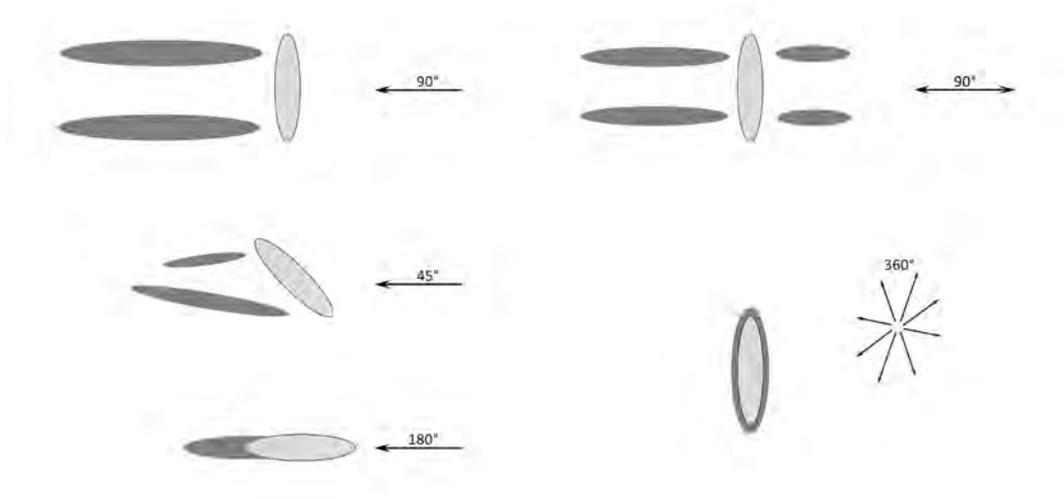


Figure 13.13. Generalized scour patterns for unidirectional current striking a shiplike object at 90°, 45°, and 0° (left), and 90° bidirectional and rotary current (right). (After Rory Quinn 2006:1423)

for the first half and west-northwest (293°–303°) for the second half of the cycle. Thus scour pockets would most likely have developed around the base of the submarine, with larger extensions trending roughly southeast of the stern and west to west-northwest of the bow (Figure 13.14, top). The construction of the jetties altered the dominant currents, which were described in 1900 as follows: “Off the bar the flood current sets 3 hours southwestward, then westward, and the last hour

northwestward. The ebb for the first 3 hours sets north-eastward, then eastward, and for the last hour south-eastward” (USCGS 1900:78) (Figure 13.14, bottom). In addition, the ebb flow was now noticeably stronger than the flood (Conlin 2005:140). Scour pockets arising from tidal currents that developed after the influence of the jetties, therefore, would be expected to trend roughly northeastward around the vessel ends, with a deposition zone trailing off eastward.

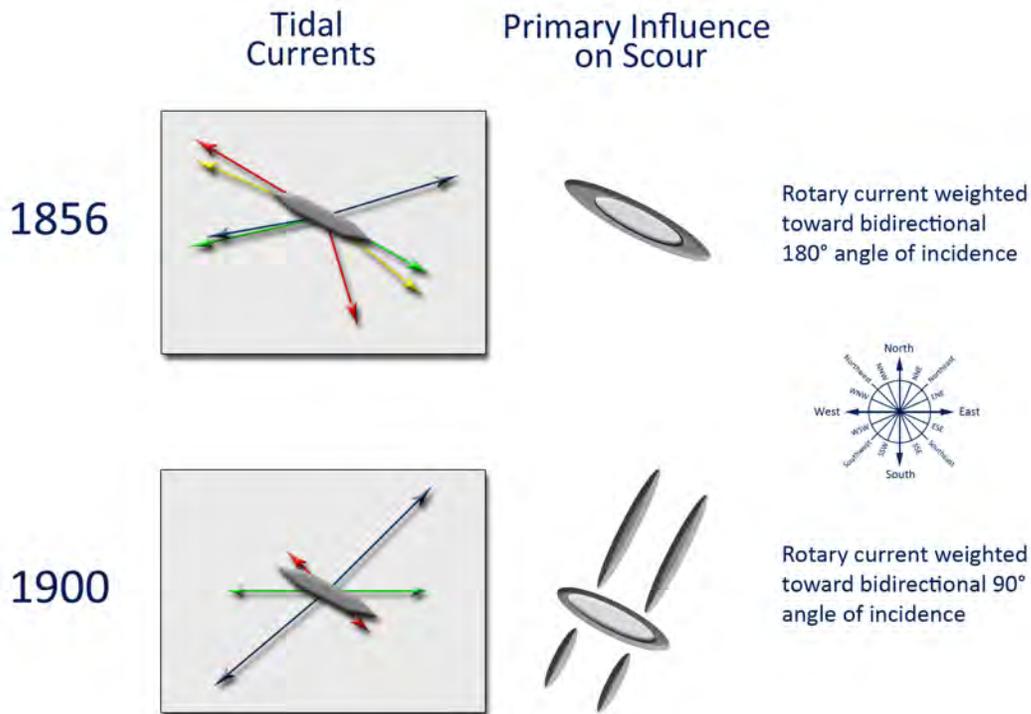


Figure 13.14. Idealized projections of how the tidal current affected scour around Hunley both before and after construction of the jetties at the harbor entrance. (Diagram by H. G. Brown, NHHC)

Studies on cylindrical mines in fine sands off Martha’s Vineyard, however, identified wave action rather than tidal currents as the primary driver of scour on the mines (Traykovski et al. 2007). Wave energy off Charleston is generally low due to the breadth and shallow slope of the continental shelf in that area (see Chapter 3), but severe storms can significantly increase wave height, period, and direction in the short term, increasing scour around an obstruction. A large storm-related scour pocket developed at shipwreck site 31CR314, believed to be *Queen Anne’s Revenge*, in North Carolina after the passage of Hurricane Bonnie in 1998. The pocket developed northwest of the site, in contradiction to the natural longshore current coming from the northeast, and had not yet filled in by the time of publication (McNinch et al. 2006:298–99). Reburial at this site may have been slowed by the site’s position in an active ebb-tidal delta.

As discussed in Chapter 3, a number of tropical storms and hurricanes passed close to the *Hunley* site in the 50 years following the sinking. The earliest hurricane to have affected the site was in June 1867, which made landfall just east of Charleston as a Category 1 storm (NOAA n.d. a). In September 1874, a Category 1 hurricane developed in the Gulf of Mexico and traveled northeastward, with the eye passing very close to Charleston on its way past (Partagás and Diaz 1995:40–41). Another storm made landfall southwest of Charleston as a Category 1 in September 1878 (NOAA n.d. a). Two small hurricanes made landfall near the South Carolina coast in 1881, one to the southwest and one to the northeast, but only one, which hit northern Georgia heading west, had severe effects in the Charleston area (Partagás and Diaz 1996:11–17). In 1885, a storm came up from the south, making landfall near Beaufort, South Carolina, likely as a Category 2 hurricane, and turned northeast reaching Charleston as a Category 1 or 2, and heading up the coast toward the Carolinas (Mayes 2006:48–60). Two hurricanes hit in 1893, one in August, the other in October. The first was the strongest event to hit Charleston in the period under review and became known as the Sea Islands Hurricane. It traveled off the Florida coast northward and made landfall just south of

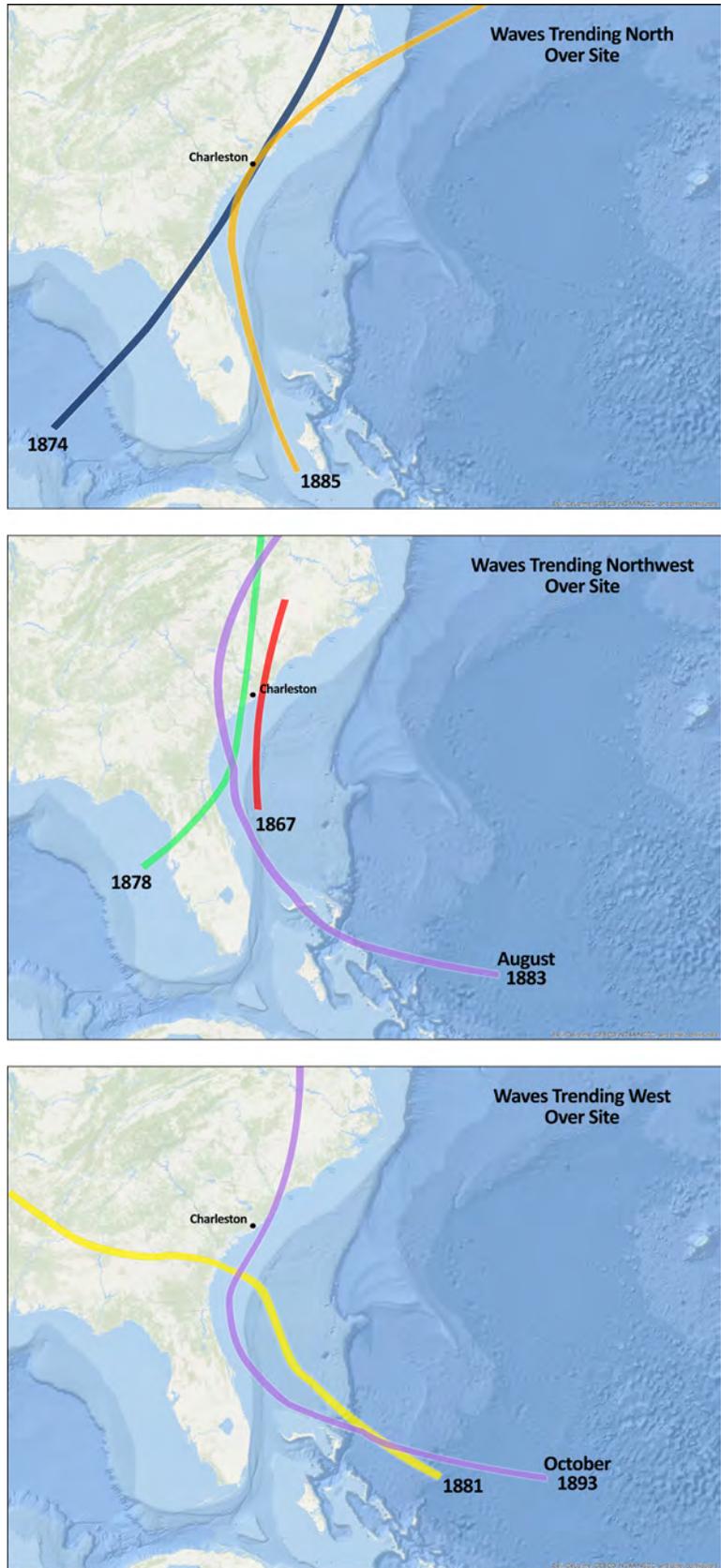


Figure 13.15. Hurricane activity affecting Charleston in the late 19th century, clustered by probable dominant wave direction. (Basemap from Esri et al., annotated by H. G. Brown with data from NOAA NHC)

Savannah, Georgia, as a Category 3, devastating the coastal island communities (NOAA n.d. a). The storm continued northward straight through central South Carolina, leaving Charleston on the stronger, eastern side of the storm (Mayes 2006:63). The hurricane of October 1893 approached from the south, making landfall likely as a Category 3 at Bull's Bay, just north of Charleston, and therefore it did not have as damaging an impact as the previous hurricane of that year (Mayes 2006:69). Given that wave directions during a hurricane do not correspond directly with wind direction, but are influenced by the direction of the storm's movement, and that the significant wave heights are more intense in the right forward quadrant of the system (Ochi 2003:53–59), one would expect the strongest wave activity to have trended to the north in 1874 and 1885; the northwest in 1867, 1878, and August 1893; and the west in 1881 and October 1893 (Figure 13.15).

As long as the wreck remained proud of the surface, scour pockets caused by storms remained exposed and open to alteration by changes in hydrodynamic conditions. Over time, however, they filled in, until both the submarine and the scour pockets were fully buried. This was a gradual process, with alternating periods of scouring and infilling. The Martha's Vineyard mine study demonstrated that after the course of a year, one test mine, which was 2 m (6.56 ft.) long and 0.533 m (1.75 ft.) in diameter, and its scour pocket were fully buried and overlain with a 10 cm (3.94 in.) layer of fine sand (Traykovski et al. 2007:157). The scour pockets contained a higher percentage of silts and clays (35%) than the surrounding seabed (3%) (Traykovski et al. 2007:157). Sediment suspension and scour at the test site, which was 11–12 m (36.09–39.37 ft.) in depth, were primarily linked to high wave events. The authors observed that fine particles settled into the scoured areas after the wave event ceased, but were subsequently washed out by peak tidal currents; however, over a series of these events there was ultimately a net gain of accreted material in the scoured area (Traykovski et al. 2007:163). Since periods of high energy waves at the site were most common in winter, infilling generally occurred afterward, "during a period when the seasonal waveheight envelope was decreasing" (Traykovski et al. 2007:158). Prior to burial, the mines reoriented themselves over the course of several weeks into a position perpendicular to the direction of wave propagation and eventually rolled into the scour pit that developed on the lee side, contributing to the rapid rate of burial (Traykovski et al. 2007:159). This was facilitated by their cylindrical shape. Due to its weight and the flat keel, it is unlikely *Hunley* shifted orientation after coming to rest or rolled into a scour pit.

Another factor in burial is liquefaction of the bed, which develops with increased pore water pressure, causing heavy objects to sink into the substrate.

Wave action is the primary cause of liquefaction in saturated soil, although it can also result from earthquakes, shocks, and motions of structures under cyclic loading (Sumer and Fredsøe 2002:447–48). The higher pressure initiated by the flow on the incident side of *Hunley* may have increased sheer stress enough to cause liquefaction of the surficial sand layer, leading to the submarine settling down to the compact Pleistocene mud. However, it is also possible seismic waves from the Charleston Earthquake of 1886 liquefied the substrate. The epicenter of this quake was 29 km (18 mi.) northwest of the *Hunley* site, with a meizo-seismal area of roughly 50 × 35 km (31 × 22 mi.) trending NE, putting *Hunley* well within the affected area (Stover and Coffman 1993:348–49). If the submarine had not yet subsided into the seabed by this point, it is likely this event would have completed the task.

Discussion

There are a number of unknown factors that make reconstructing the sequence of events affecting *Hunley* difficult. The submarine likely came to rest on a shallow layer of Holocene fine sand, but there is also a chance the Pleistocene mud layer was exposed at the time (see Chapter 3). It may also have landed on an even keel or come to rest immediately at the 47° angle found during excavation. Based on Chapman's painting, which shows the boat resting on its keel blocks with no side supports, it appears the vessel could rest easily in an upright position. Evidence from the inside the hull indicates that the vessel was upright when the hole in the forward conning tower was made, but, based on sediment accumulation, the vessel was canted over very early in the post-depositional time scale (Jacobsen et al. 2012).

The submarine came to rest at a heading of 297°. Despite differing testimony about the tide state at the time of the explosion, the Court of Inquiry determined it was at ½ ebb (DON 1864a:0588), putting it directly in line with the wreck's centerline, suggesting the vessel was drifting sternward with the ebb current when it went down. In this orientation, scour pockets would have formed predominantly to the bow and stern, in which case the pockets would not have been a significant factor in the burial process. As currents altered in response to the jetties, the dominant northeastward ebb would have struck the hull at a roughly perpendicular angle, causing scour pockets to form starboard of the bow and stern trending nearly parallel.

Actual scour pockets at the site were identified close to the hull by divers during the excavation at the bow and stern, where they noted a change in sediment characteristics and increased artifact density. In a fine sand environment, an increase in silts and clays into the 30–40% range has been noted above as characteristic

of infilled scour pockets. Of the samples analyzed by Harris, T1-10, T1-20 and T2-3 match these characteristics. Since the depth of these samples is above the level of the submarine, if these are the result of scour, it most likely occurred after *Hunley* was buried, caused by small-scale obstructions that are no longer present. We cannot discount the possibility that these developed in response to equipment used during the work done at the site in 1996 or 1999.

Without an array of sediment samples around the site taken at hull depth, the scour pockets were primarily identified by clusters of heavy anthropogenic materials. These arise when heavier objects, transported as part of bed load, get trapped in scoured depressions, either by settling into the newly deposited fine sediments or simply being too heavy to be lifted back out during the next high energy event. Artifact density beneath and to starboard of the stern was particularly noticeable to divers, and was also evident in the coal and slag distribution map (see Figure 13.16). Another area of density was apparent starboard of the bow, in the vicinity of the eroded hole in the bow casting. The high incidence of cans at the bow suggests that they rolled in with the ebb tide and could not overcome the incline to keep moving. It is also possible the angle created by the hull's starboard list increased the propensity to trap larger materials. The distribution of glass and ceramics shows that the relatively flat fragments are randomly distributed, but the complete or partially cylindrical material collected against the port side of the stern.

The distribution of artifacts along the port side is scanty and limited primarily to bottles and cans very low down near the keel of the vessel. A narrow band of scour directly adjacent to and surrounding the hull likely developed soon after deposition under the initial rotary current conditions, and may have provided a zone for trapping glass bottles and cans. However, based on the positions of the disarticulated hull components and the coal and slag, it appears that seasonal storm activity or the post-jetty, northeast- to east-setting ebb tidal current had more impact at the *Hunley* site than the predominant wave direction, which runs from east northeast to southwest, which would have initiated scour erosion to port of the submarine.

The overall pattern revealed by artifact density suggests two asymmetrical scour pockets trending to starboard of the hull. The smaller one was located along the bow quarter, but did not extend fully beneath the hull. The larger one encompassed the stern, with an area of density directly beneath the hull, and trending roughly northward, with a zone of increased coal and slag deposition trending eastward. This asymmetrical pattern is mirrored in the erosion-corrosion holes on the starboard side, also products of the hydrodynamic action around the hull—the stern hole is nearly three times longer than that at the bow. The direction and

orientation of the pockets, which were found only on the starboard side and trended toward each other, suggests the primary driver of scour was unidirectional wave action roughly from the south, which is consistent with the dominant wave forces generated during the hurricanes of 1874 and 1885 (Figure 13.16). This timeframe coincides with the advent of increased sediment load collecting around *Hunley* from the jetty outflow. It is tempting to conclude that the submarine must have been fully buried prior to the Sea Islands Hurricane of 1893 with its dominant northwest-trending wave action; however, there are too many variables in the behavior of individual storms to make a conclusive determination in that regard.

The relative lack of anthropogenic material in the starboard midships area suggests that the two pockets did not remain exposed long enough to converge before they filled in. This rules out the possibility that *Hunley's* starboard list came from rolling into a scour pocket the way the mines studied at Martha's Vineyard did. The sharply angled zones of greatest intensity may have been influenced by the hull shape, with the very narrow ends initiating a sharper angle of scour than the blunt or rounded ends more commonly modeled for studies.

The hull most likely had tipped over at the latest by the earthquake of 1886. The starboard shroud attachment bar appears to have been damaged prior to the rotation of the hull, since it would have been very difficult to swing it 180° forward with the starboard side angled toward the seabed. The condition of the stern assembly suggests that it was snagged while the submarine was still upright, breaking the steering rod and vertical steering arm, unshipping the rudder, and damaging the attachment bar. This might have occurred as early as November 1864, when William Churchill used the drag ropes to search for *Hunley* (see Chapter 4). He reported snagging on something heavy, although, upon further examination, divers found only "a quantity of rubbish" (ORN 1.15:334). This type of event may have pulled the hull over to starboard, or initiated a slight lean that was augmented later through scour or liquefaction.

If there was a sand layer present when *Hunley* came to rest, it was unlikely to have been deep enough to bury the submarine. The complete burial was dependent on an overall increase in sediment load brought about by the jetty construction. The cans concreted to the bottom of the keel can be roughly dated to the last two decades of the 19th century, coinciding with the construction period and provide additional evidence that the vessel had tipped over by then. The intact condition of these cans suggests a relatively quick burial after deposition, with little or no post-depositional exposure or disturbance, consistent with the burial model discussed in Chapter 3 and supported by the lead isotope analysis (Marot and Holmes 2005) and biological assessment (Murphy 1998:148–51).

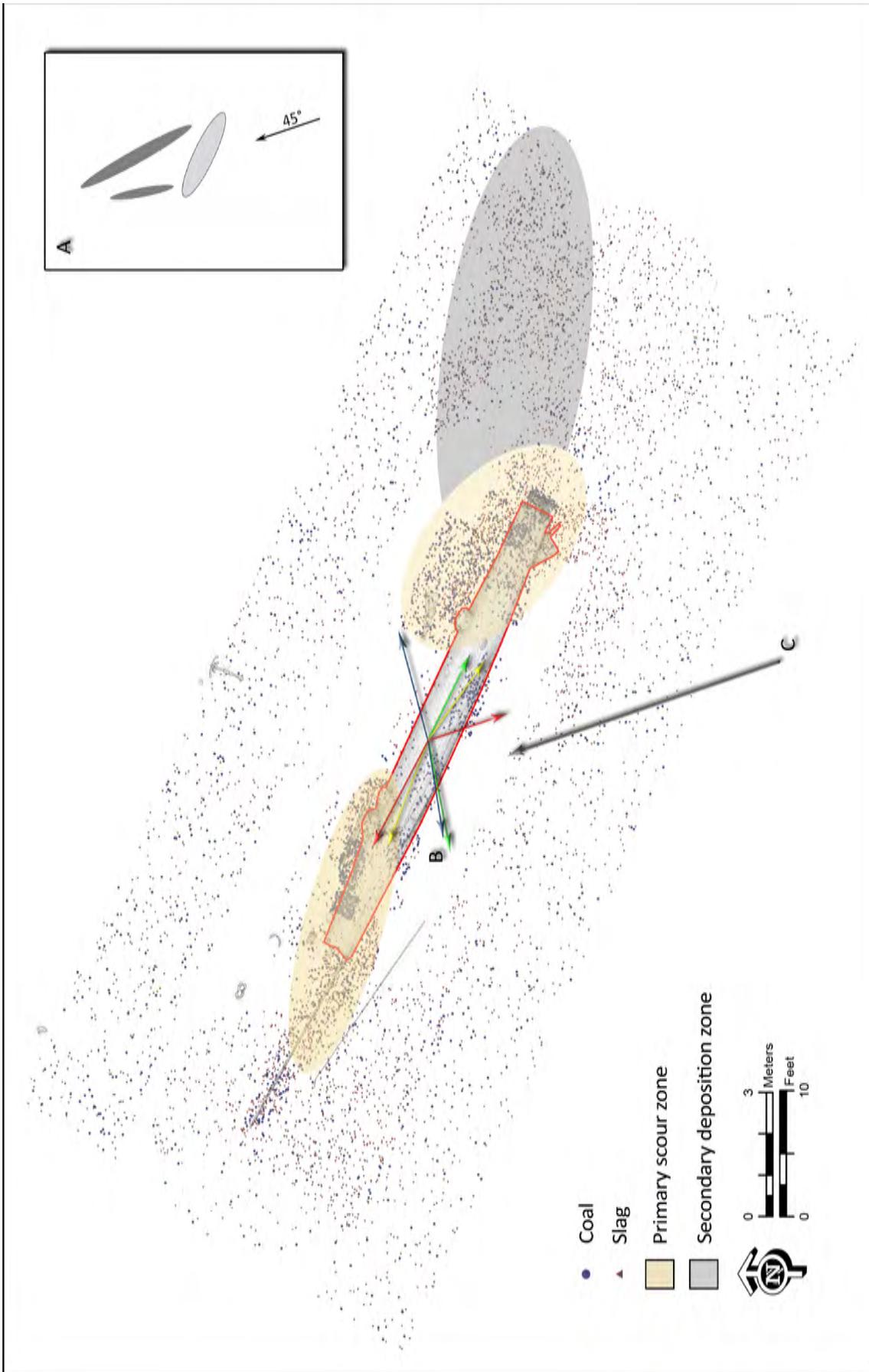


Figure 13.16. Idealized projections demonstrating asymmetrical, convergent scour pattern similar to those identified at the Hunley site are based on an angle of incidence of approximately 45° (A). Comparing 1856 current data from a nearby station (B) shows no vectors that correspond to the projected angle of incidence (C) required to generate the documented scour areas, suggesting storms coming up from the south may have been a significant factor in the formation of the site. (Coal and slag distribution map provided by J. Enright, SEARCH Maritime Archaeology Division, annotated by H. G. Brown, NHHHC)

14. Hull Analysis

Heather G. Brown and Robert S. Neyland

With the submarine safely placed in controlled laboratory conditions, a closer examination of the hull was possible. This allowed for the first time, a detailed comparison between the historical descriptions of the hull and the actual vessel itself. While a comprehensive analysis must wait for the completion of the hull deconcretion and a full examination of data collected from the excavation of the interior of the vessel, a number of observations can be made about *Hunley's* design and construction. A closer look at the hull in conjunction with known accounts as well as other submarines of the period can clarify the historical record, provide insights into the surviving features of the vessel, and help identify possible missing features.

Historical Sources

Prior to the submarine's rediscovery, many attempted to reconstruct the vessel based on historical sources.

These fall into several categories: descriptions by those involved with building or operating the vessel; accounts by eyewitnesses or those who interviewed someone involved with *Hunley*; and diagrams and illustrations.

The primary publicly-available description of *Hunley's* construction and its significant features came from William Alexander (see Chapter 2). A mechanical engineer in the Confederate army, he was assigned to work on the submarine project when it was still in Mobile. At the turn of the century, in order to set the increasingly muddled record straight, Alexander published an article in a number of periodicals (1902a, 1902b, 1902c, 1902d), in which he gave both the operational history of the vessel as well as some dimensions and construction information. Some have been critical of this account because of inaccuracies in dates and dimensions, caused by committing the details to paper nearly four decades after the fact (Chaffin 2008). Nevertheless, his overview of the various components of the hull and how they worked have generally proved consistent with archaeological findings and his insights

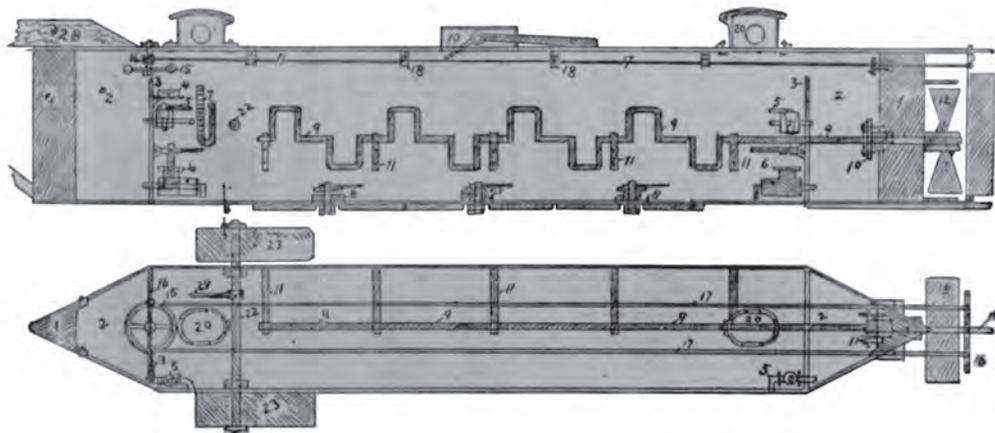


Figure 14.1. Published drawings of H. L. Hunley based on sketches by William Alexander (ORN 1.15:338)

as to the purpose behind the design of certain features must be given some credence. It was the primary source upon which most models were built until the vessel was found in the 1990s.

Another detailed account, not widely available until recently, was given to officers of the Royal Navy by James McClintock in 1872, and is on file at the British National Archives in London. McClintock, the only surviving member of the initial building team, met secretly with British officers in Halifax, offering to build them a submarine along similar lines as *Hunley* but correcting critical deficiencies. The dimensions he supplied in describing *Hunley* were more accurate than Alexander's, but the description of its construction and operation is not as thorough. His analysis of the problems *Hunley* experienced is illuminating in regard to the submarine's capabilities and limitations. It must be noted that, according to Alexander (1902e), McClintock did not have much direct operational experience with *Hunley* and thus his observations likely pertain primarily to *Pioneer* and possibly *Pioneer II*.

Most eyewitness accounts give rough estimates of dimensions, and describe the obvious features of the vessel without getting into too much detail. Nevertheless such narratives occasionally offer a piece of information lacking or not featured prominently in the aforementioned accounts, generally influenced by the writer's personal interest. These sources include an 1863 letter from Confederate officer George Gift, who helped haul the submarine out of the water in Mobile and put it on the train to Charleston (Turner 1995); an article by G. W. Baird (1902), an engineer with the U.S. Navy who interviewed McClintock after the war; a narrative by Simon Lake (1899, 1918) based upon a discussion with former *Hunley* crewmember and survivor of the second sinking, Charles Hasker; an article by C. L. Stanton (1914), former lieutenant in the CSN and shipmate of Lt. Payne on the *Chicora*; and an interview with D. W. McLaurin, member of the 23rd Alabama Volunteers, stationed on Sullivan's Island, who was asked to go aboard one day "to help adjust some machinery" (*Confederate Veteran* 1925).

An interesting unpublished summary of a description by eyewitness William G. Mazyck of Charleston was also brought to light soon after *Hunley's* recovery by Patrick McCawley, an archivist at South Carolina Archives and History Center. In 1957, G. Robert Lunz sent a letter to the archive describing a meeting he had in 1935 with Mr. Mazyck (Lunz 1957). As a boy, Mazyck had seen the submarine up close in Charleston and even managed to get a look inside. His account (Appendix N) was remarkably accurate, particularly given he was nearly 90 years old at the time, with measurement estimates coming surprisingly close to documented figures. His descriptions of some of the components, e.g. "an ordinary cistern hand pump," help

modern researchers recognize what components of the vessel were similar to or adapted from technology in everyday use.

Several diagrams of the vessel were generated over the years, which show both the overall shape and exterior features of the vessel, along with the basics of its interior layout and functional aspects of the propulsion system and pumps. These include drawings by Alexander from the early 20th century, adapted and published by the U.S. Navy (Figure 14.1); a sketch by Baird (1902:846) based on his discussions with McClintock, although Alexander (1902e) claimed this represented the boat McClintock built in New Orleans; and a drawing by Lake (1899). There was also a sketch developed by McClintock (1872) for his meeting with the Royal Navy (1872) and annotated by several of the officers there, that purports to be a representation, not to scale, of the submarine that sank *Housatonic* but substituting an engine instead of a hand crank. It

While these diagrams do convey the overall concept of the submarine and many of its significant features, they do not allow the viewer much insight into the many small alterations made to ordinary technology to accommodate life in a cramped, underwater environment, nor to see what innovations were developed for the vessel. Many things were taken for granted by the creators of the diagrams, or considered unnecessary for communicating a basic understanding of how the boat worked.

The most valuable image documenting the exterior of *Hunley* is the painting by Conrad Wise Chapman, a Confederate soldier and artist who painted a series of scenes based on sketches he made during his army service (Figure 14.2). It has proven remarkably accurate when compared to features documented archaeologically and may prove the best source for identifying possible features lost during or after the sinking. In addition, a study for the painting, dated 2 December 1863, survives and shows details, particularly in the steering system, that are not as clear in the oil (see Figure 14.10). Many later depictions, including the watercolor wash by R. G. Skerrett published as a frontispiece in the *Official Records of the Union and Confederate Navies* (ORN 1.15), were adapted from Chapman's work, but significant inaccuracies were introduced in each iteration (Figure 14.3).

Two other important images are drawings of *Pioneer*, from after it was dragged from Lake Pontchartrain and documented by U.S. Navy staff. One was the schematic enclosed in Fleet Engineer Shock's report based on work by Second Engineer Alfred Colin (see Figure 2.5). The other was a pencil sketch with several detail views captured by Ensign David M. Stauffer in March 1865 (see Figure 2.6). This eyewitness documentation provides a unique opportunity to examine design changes between the prototype and the final vessel.



Figure 14.2. Oil painting by Conrad Wise Chapman depicting H. L. Hunley in Charleston. (Courtesy of The Museum of the Confederacy, Richmond, Virginia)

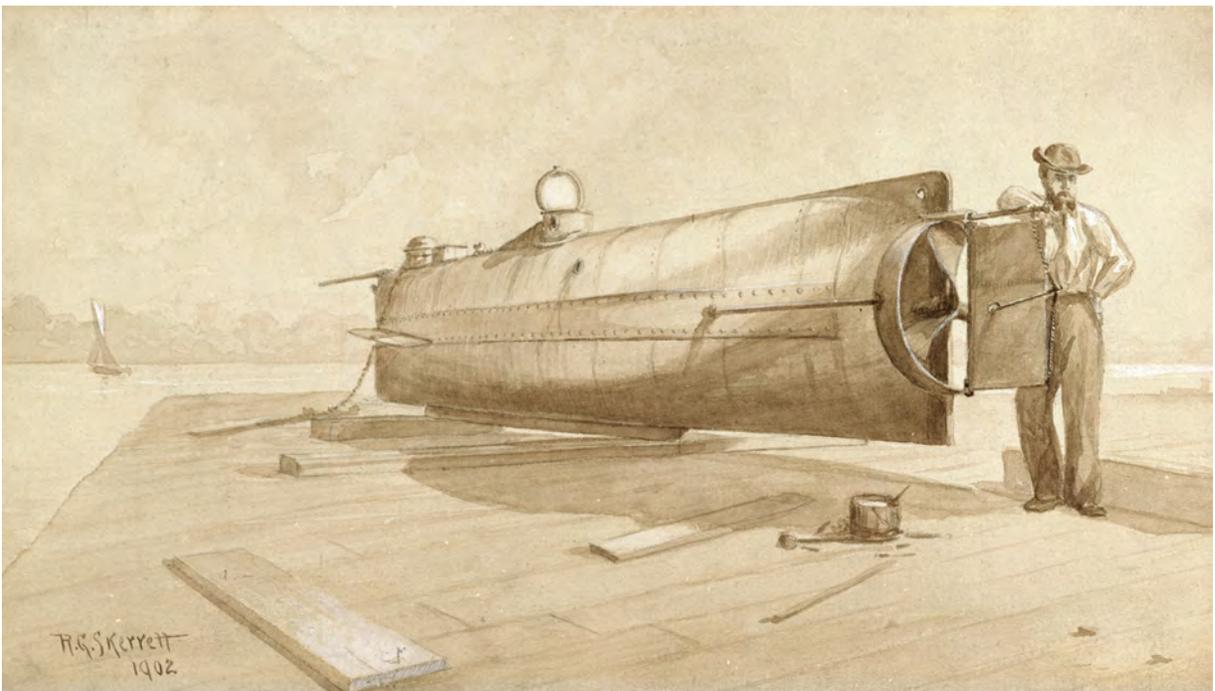


Figure 14.3. Sepia wash drawing produced by R. G. Skerrett in 1902 based on Chapman's painting. Aside from the obvious increase in scale, representational errors include a round, rather than oval, hatch cover; placement of the shroud attachment bar in the center of the expansion strake; and a chain running from the steering rod to the rudder arm, rather than a solid metal piece. (Courtesy of Navy Art Collection, NHHC)

Archaeological Parallels

Three other American-made submersible craft survive from the 1860s that are available for study. As a group they help to show the range of innovation happening during this period of rapid development and experimentation. These vessels fall into two general categories based on function—the diving bell sub and the closed-capsule sub. The former developed from the stationary diving bell, already in use since at least the 17th century, and is based on the need to allow people to enter and exit while it is submerged. These vessels were primarily designed for salvage and aquacultural operations and, in war time, for sabotaging enemy shipping or clearing defensive obstructions. They generally had a hatch opening in the bottom and required a method for pressurizing the air inside to keep it from flooding. Interior space was optimized in these vessels at the expense of traveling speed and streamlined hull design.

The closed-capsule vessel type remained fully sealed while submerged, with its primary application limited to underwater attacks on enemy vessels via towed or spar-mounted explosives. These vessels tended to optimize speed and handling over interior space. A hydrodynamic hull was particularly important since they were hand powered, requiring maximum efficiency in cutting through the water to cover any significant distance.

The earliest surviving Confederate submersible is likely the unidentified submarine recovered from Lake Pontchartrain in 1878. Now housed at the Louisiana

State Museum, it was originally thought to be *Pioneer*, although this has since been discounted based on comparison to drawings of *Pioneer* made by Colin. While its true identity has not been established, the Louisiana State Museum vessel most likely dates to the early period of the Civil War, before New Orleans fell to Union forces in 1862 (Wills 2000:187).

The vessel was fully documented by Richard Wills (2000) in 1999. It is a closed-capsule submersible, propelled by a manually-operated crankshaft connected to an axially mounted four-bladed propeller (Wills 2000:138). Measuring 20.17 ft. (6.15 m) in length, 3.21 ft. (0.97 m) in beam (Wills 2000:109), it is about half the length of *Hunley*, and has a length to beam ratio of 6.3:1. The hatch cover and possible conning tower do not survive, but the preserved height of the hull is approximately 6 ft. (1.84 m) (Wills 2000:109). The interior has been partially filled with cement, and, at the time of documentation, the vessel was mounted on large cement stands, limiting access to data concerning the keel and lower extremities (Wills 2000:108).

On the Union side, *Intelligent Whale* was designed by Scovel S. Merriam and construction was begun in 1863, in hopes of selling it to the U.S. Navy (Figure 14.4). After a complicated series of ownership and builder changes, it was finally granted an official trial for the Navy in 1872, although based on stories from owner Oliver Halsted's family, it was in working order in 1866 (Hitchcock 2002:83ff). The trial was deemed unsuccessful and the vessel remained unused at the Brooklyn Navy Yard until the yard's closure in 1965, whereupon it was moved to the Washington Navy Yard, and finally



Figure 14.4. *Intelligent Whale* on display at the New York Navy Yard, photographed on 27 July 1915. (NHHC Photo Archives #NH 53244)

to the National Guard Militia Museum of New Jersey (Hitchcock 2002:105–110). It was fully documented by Peter Hitchcock (2002) between 1996 and 2002.

This is a diving-bell type submersible, propelled by a manually-operated central crank shaft connected to a three-bladed propeller, and equipped with compressed air and two rectangular access hatches in the bottom at midships. It measures 29.02 ft. (8.85 m) in length to the aft end of the propeller shaft, with a maximum breadth of 7.25 ft. (2.21 m) and a height at midships of 6.98 ft. (2.13 m), resulting in a length to breadth ratio of 4:1 and a length to height ratio of 4.16:1 (Hitchcock 2002:113). A small conning tower rises 11.75 in. (29.85 cm) from the top along the centerline, just forward of midships (Hitchcock 2002:131). A report on the trial states the boat could be operated by six people, but could hold up to thirteen people, although Hitchcock believes that would have been a very tight squeeze (Hitchcock 2002:3–4, 102).

The last parallel is *Sub Marine Explorer*, designed by German immigrant Julius H. Kroehl (Figure 14.5). Construction began in 1864 with hopes of persuading the U.S. Navy to adopt his vessel design for use against Confederate forts and harbors (Delgado 2006:245–46). Navy interest, however, did not develop, and the boat was completed with backing from the New York-based firm Pacific Pearl Company, who shipped it to Panama in 1866 to work the dwindling pearl beds in the area (Delgado 2006:247). In or around 1869, it was abandoned on the shores of Isla San Telmo, Panama, where it remains today. The site, whose history had been lost over time, was first brought to the attention

of Dr. James Delgado in 2001. He subsequently identified the vessel, then organized a team to document it between 2004 and 2008 (Delgado 2006, 2012).

Another diving-bell submersible, *Sub Marine Explorer* was propelled by hand most likely by a single operator at the crank (Delgado 2012:199). It was 36 ft. (10.97 m) in length, with a maximum breadth of 10 ft. (3.05 m) and width at the keel of 8 ft. (2.44 m), resulting in a length to breadth ratio of 3.6:1 (Delgado 2006:235). Vessel height was reported as 10.54 ft. (1.99 m) (Delgado 2012:189), but access to the bottom levels was limited due to its partial burial in a surf zone. A conning tower, 1.42 ft. (0.44 m) high, remains along the centerline, although the hatch cover has been lost (Delgado 2006:236).

Despite various levels of disrepair and deterioration, these vessels allow access to a level of knowledge unavailable in the historical documents. Sketches and plans do not fully record metallurgical processes, construction techniques, and the everyday work of the engineers that can only be found in the material remains of the vessels themselves.

Analysis of Features

Based on Alexander's statement that *Hunley* was made from "a cylinder boiler which we had on hand," it has been implied over the years that the vessel must have been relatively makeshift and rudimentary (e.g. Mazet 1942:665). However, once *Hunley* was



Figure 14.5. The remains of Julius Kroehl's *Sub Marine Explorer* on a beach in Panama. (Photo by Todd A. Croteau for the Historic American Engineering Records, National Park Service, available from Library of Congress, HAER-CZ-5-2)

recovered and closely examined, it became apparent that its hull was much more than just a modified boiler shell. A great amount of skill, ingenuity, and labor went into adapting contemporary technology for the deadly and unforgiving environment of the open sea. The wartime environment limited access to resources, forcing the mechanical engineers to the utmost of their creativity to complete a working weapon of war.

Hull Design

The designers of underwater vessels in the late 19th century faced many challenges. They gained insights from anywhere they could—the naval architecture of surface ships, published accounts of previous attempts by other pioneering submariners such as Bushnell, contemporary knowledge of physics and mechanical engineering, and, in some cases, even from the bodies of sea creatures.

There are several factors that must be considered in a successful submarine design. In order for a vessel to remain upright while fully submerged, its center of gravity must fall below its center of buoyancy. There must also be accommodations for making it stable at the surface. To travel efficiently through the water, it must minimize drag. And it must retain sufficient interior room for crew, activities, machinery, and ballast tanks, while still allowing the crew to move inside without upsetting longitudinal stability. Balancing all these needs is a challenge and one that was resolved differently by the various designers of early submarines. While 19th century designers did not have the benefit of decades of advanced engineering studies to guide them, there are several features of *Hunley* that represent the beginning of that journey.

Shape

Many studies have been conducted since the advent of long-range submarines on the ideal hull shape for minimizing drag, thereby providing the most efficient movement through water (Arentzen and Mandel 1960; Friedman 1984; Burcher and Rydill 1994; Joubert 2004). Current opinion is that this is a cigar-shaped vessel, with a rounded, elliptical bow and parabolic stern gradually tapering aft to a point at the stern, with a length to beam ratio in the range of 6:1 to 7:1, exemplified most notably in USS *Skipjack* (SSN-585) built in 1956 (Burcher



Figure 14.6. USS *Skipjack* (SSN-585) utilized a parabolic bow and gradually tapering body that is hydrodynamically ideal but costly to produce. (NHHC Photo Archives)

and Rydill 1994:105–6, Joubert 2004:17–18) (Figure 14.6). Since such a form calls for a constantly varying diameter, even modern builders frequently adopt a parallel midbody form to save construction costs and time (Burcher and Rydill 1994:106).

The *Hunley* team's original design, *Pioneer*, incorporated a parallel midbody with a circular cross section (McClintock 1872). The most geometrically ideal shape for bodies under pressure is the sphere; however, given the spatial limitations imposed, a cylinder is the most practical alternative as it experiences relatively uniform pressure while providing adequate interior space for functional requirements. This concept was well known to 19th century engineers, as it lay behind nearly every boiler design in use (Wilson 1875:7ff). For *Hunley*, the circular cross section was altered to obround in order to add 7.5 in. (19.05 cm) in height, but a parallel midbody was retained. This is an early example of a longstanding quandary for submarine designers—accommodating the needs of the vessel's occupants and functions, while maintaining, as much as possible, an efficient hydrodynamic shape. *Hunley* was not expected to go to depths requiring significant pressure resistance, which, along with the relatively small scale of the boat, likely contributed to the success of this design; an elliptical cross section was attempted in the early 20th century and failed due to insufficient strength (Friedman 1984:19).

Other submarines from the period also deviated from the ideal (Figure 14.7). *Intelligent Whale* came closest to achieving a cigar-shaped hull, with a constantly varying shape that reflects care and expense

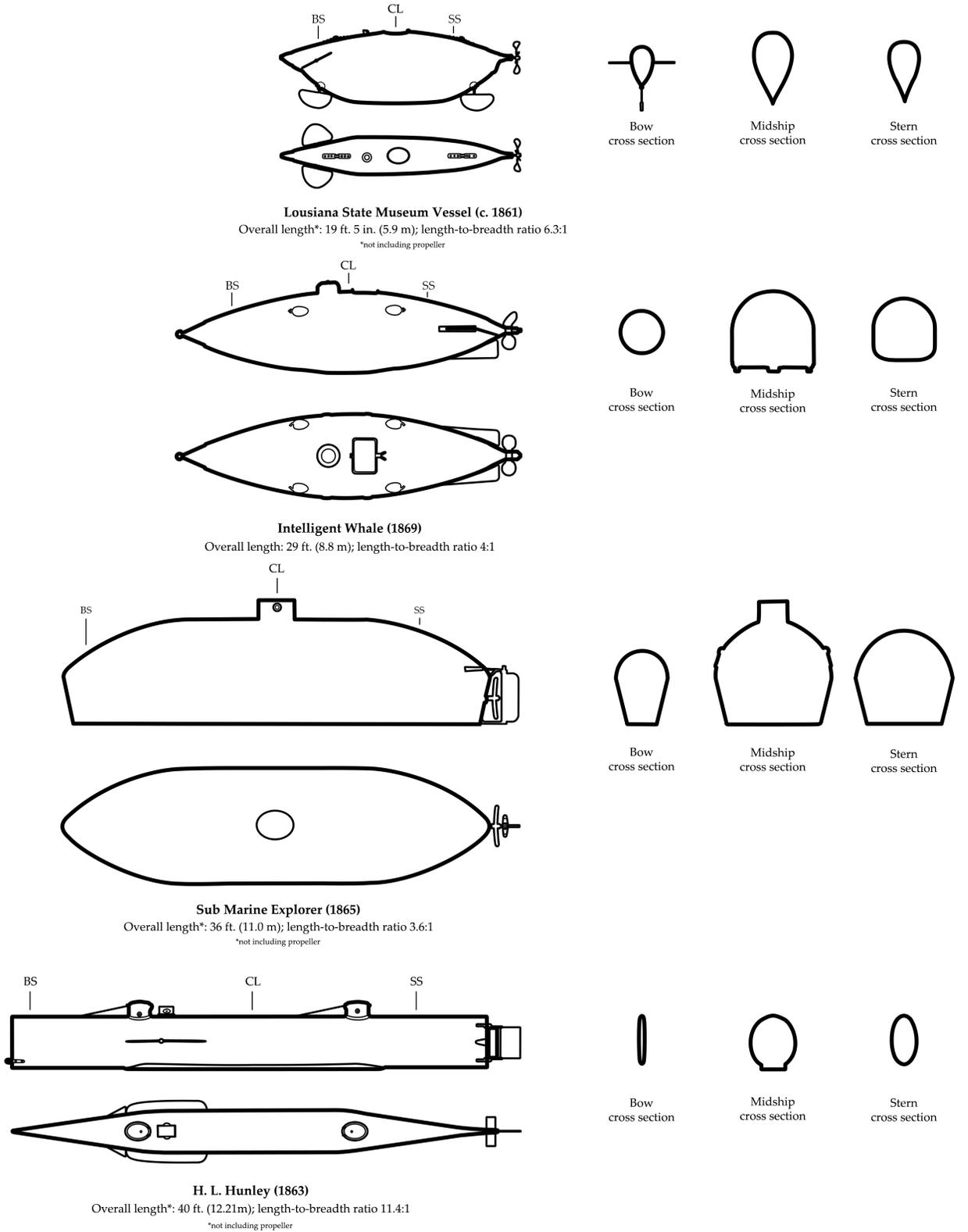


Figure 14.7. Relative sizes and shapes of surviving American submarines built in the 1860s. (Diagram by Mari Hagemeyer, NHHC)

in its construction. However, in order to incorporate its diving bell function, it had a wide, flat bottom at midships, and relatively flat sides for a large section of the midbody. *Submarine Explorer* incorporated a parallel midbody, with a curved top, but a wide, flat bottom and flat, angled sides to accommodate several diver access ports. This allowed for maximum workspace inside the vessel, but reduced hydrodynamic efficiency. The Louisiana State Museum vessel shows the most irregular, almost organic shape, with elongated, flat sides that taper gradually over the length of the crew compartment, then curves in quickly as it heads to the stern. The cross section is shaped like a teardrop, with a semicircular top that transitions into a deeply plunging V-shaped bottom. This asymmetrical design most likely was an attempt to solve the underwater stability issue, increasing the area below the center of buoyancy and providing space for ballast as low down as possible; however, it must have severely increased its drag. It is interesting to note that Lake (1918:153) felt the Louisiana State Museum Vessel, while seriously over-weighted, “should have been very stable . . . and could have been successfully navigated had she been properly ballasted.”

The bow and stern also presented a challenge to designers of this new type of vessel. Lessons from surface ships at the time suggested that a sharp bow was best for speed. Adapting that concept to a body that was completely submerged seems to have resulted in an instinct for cone-shaped ends. *Intelligent Whale*, the Louisiana State Museum vessel, and *Pioneer* all had conical ends. *Hunley's* designers, however, learned from the experience with *Pioneer* that the conical ends were not ideal for handling underwater, due to severe longitudinal instability (Baird 1902:846). McClintock (1872) described their first vessel as “faulty in shape” and reported that the second vessel was built with square sides “to obtain more room as well as to correct the faults of the first Boat.” He also noted that the shift to wedge-shaped ends was intended to “make her Easy to pass through the water” (McClintock [1871]). Time would eventually prove that a rounded cylindrical bow would have been more efficient hydrodynamically; however, *Hunley's* wedge-shaped design was an improvement over the conical ends. The fleet submarines of World War II also used a similarly shaped bow as it aided running on the surface, a requirement for early long-range subs that needed to recharge their batteries by running their diesel engines above water.

While an ideal hull form reduces resistance of a vessel's motion through water from form drag, another source of resistance is skin friction drag (Burcher and Rydill 1994:104). The best way to reduce this is by minimizing hull surface area, and therefore is somewhat at odds with the demands made by the hull form itself; however, skin friction can also be reduced by main-

taining as smooth a surface as possible and avoiding discontinuities (Burcher and Rydill 1994:104).

Hunley's designers accomplished this by using countersunk, or flush, rivets. This was not a new idea—iron surface ships had been constructed with flush rivets as early as the 1840s (Quinn 2010:91). Smith (1861) specified use of flush rivets in his call for submarine designs, and both *Intelligent Whale* and *Submarine Explorer* also employed them. They were not frequently needed in boilers, but were used in areas where appendages, such as manholes, needed to be attached to the outer shell (Shock 1880:144–45; ITC 1902:315). As countersinking rivets increases construction time, their use represents a conscious design choice. Further examination of the deconcreted hull may reveal other measures used to smooth the outer plating, such as polishing marks or traces of paint.

Another measure for eliminating discontinuities was the use of edge-to-edge, or butt, joints. Butt joints were very common in boilers of the period, and the skills needed to create snug, watertight joints between plating would have been well known to *Hunley's* builders. Early iron shipbuilders tended to use lap joints, as they were found to be stronger in the face of the rough conditions at sea and required less metal usage than their edge-joined counterparts (Claxton 1845:23). However, the early submarines were designed for use in nearshore environments, where turbulent surface conditions were not as much of a concern. With the limited hand-power of these early vessels, minimizing drag was a more important consideration.

Of the other submarines of the period, *Intelligent Whale* used butt joints and flush rivets, speaking to the designer's attempt to optimize the vessel for efficient movement under water. The plates on the Louisiana State Museum vessel were lapped toward the stern and, while the rivets were nearly flush, it appeared that this was “due to differential corrosion” (Wills 2000:123). Lap seams would have been faster to construct, and, given its small size and consequent low motive power, might not have slowed the vessel significantly. The plates comprising the top shell of *Submarine Explorer* were lapped and double riveted, a robust construction consistent with its use as an underwater work platform that did not need to move quickly (Delgado 2006:239).

It is important to note that “resistance due to appendages no matter how streamlined and carefully executed, approaches and may exceed, 50% of the bare hull resistance” (Joubert 2004:16 citing Daniel 1983). Thus, features such as *Hunley's* two conning towers, the snorkel box, and the diving planes, which could not be omitted from the design, were significant forces of resistance to forward motion. No amount of surface smoothing could counteract that; nevertheless, the designers clearly made an effort to balance the forces of drag as much as possible while maintaining functionality.

Materials

Hunley's hull was made up primarily of $\frac{3}{8}$ in. (9.53 mm) wrought-iron plate. With the nascence of the American steel industry just beginning at the outbreak of war, iron was still the primary industrial material of the 1860s. The physical demands of temperature and pressure on boiler shells required both tensile strength and ductility, and as few slag inclusions as possible. Wrought iron was the best material for the job, and, when produced well, boiler plate was the best quality iron available. Even plate manufactured specifically for ships was considered inferior (Wilson 1875:32).

Gauges of boiler plate generally ran from $\frac{1}{4}$ in. (0.64 cm) to $1\frac{1}{4}$ in. (3.18 cm) thick (Shock 1880:214). Both *Pioneer* and *Pioneer II* were constructed of $\frac{1}{4}$ in. (0.64 cm) plate (McClintock 1872). It is not clear whether *Hunley's* increased thickness was a design choice or an issue of materials availability. Thinner plate was easier to form into to custom shapes. Thicker plate, however, would improve strength, an important consideration for a vessel 33% longer than its prototype; however, the overall weight would also increase. This weight gain was offset by power attained from the additional crank stations, possibly even resulting in a net gain in propulsive efficiency. No accounts survive about the characteristics of *Pioneer II*, which was nearly as long as *Hunley* but with the thinner shell, that might shed any light on the builders' choice of thicker plate.

A variety of thicknesses are represented in the other submarines of the period. The Louisiana State Museum vessel was made up of $\frac{1}{4}$ in. (0.64 cm) plate, similar to *Pioneer*, also built in New Orleans. Given the unusual teardrop shape of this vessel, thinner plate may have been desired for ease of customization, but would also have made the hull lighter. *Intelligent Whale* was made of $\frac{1}{2}$ in. (1.27 cm) plate (Hitchcock 2002:127), a

challenging thickness for the complex curvature the designers achieved. *Submarine Explorer* consisted of several different plate thicknesses, the thickest ($1\frac{1}{4}$ in. [4.45 cm]) at the bottom, and the thinnest ($\frac{1}{2}$ in. [1.27 cm]) at the top, thus building a low center of gravity into the very shell of the vessel itself (Delgado 2012:190–94).

The Boiler Question

Many secondary accounts of *Hunley* have repeated Alexander's description of the submarine's hull being built from a cylindrical, riveted boiler that was cut in half longitudinally and expanded at the center with a strip of iron to increase the height of the vessel. He is the only person directly connected on *Hunley* to state this outright. McClintock makes no mention of it, and other accounts simply state that it was made from boiler iron (Stanton 1914:398, *Confederate Veteran* 1925, Lunz 1957). Gift, when directing his correspondent to envision *Hunley*, says only "imagine a high pressure steam boiler," but does not assert it was actually built from a pre-existing one (Turner 1995:6). Baird (1902:845), who helped measure *Pioneer* after its recovery by Union forces in New Orleans, described that vessel as being "built of iron cut from old boilers."

Recycling plates from a used boiler shell would have posed several problems, including the potential for weak points, particularly around used rivet holes, and inconvenient placement of pre-existing holes for access points and other accessories (Figure 14.8). These would not have been insurmountable, however, and in the face of a shortage of materials, might have been worth addressing. Once the hull has been fully deconcreted, it may be possible to determine if the plates were recycled by examining evidence such as patched

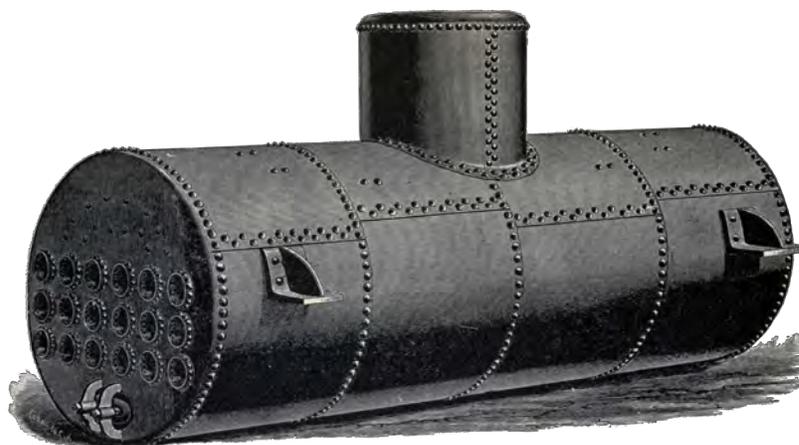


Figure 14.8. This flue boiler from Hutton (1897:443) provides an example of the number and position of rivets penetrating a typical boiler plate, making reuse challenging.

holes, manufacturer's stamps (if found), tool marks, and metallurgical composition.

Boiler construction involved some of the most skilled engineers and the highest quality materials available at the time. Shells needed to be watertight, withstand large amounts of pressure, and maintain structural integrity in the face of intense heat and intermittent cooling cycles. The many tales of makeshift repairs and worn out materials should not obscure the fact that the underlying technology was far from rudimentary and crude. Successful recycling of such materials in the face of wartime shortages should be seen as a credit to the engineers' resourcefulness in a time of need rather than a slight to their skills. Several additional features of *Hunley*, discussed further below, reflect adaptations of boiler technology.

Conning Towers

The idea of a raised compartment that offers the pilot a forward view both above and below the waterline was not a new concept when *Hunley* was built. Early submarine designs such as Bushnell's *Turtle* and Robert Fulton's *Nautilus* included this feature, although it is not clear from drawings exactly how they were constructed. The conning towers that survive on *Hunley*, therefore, represent some of the earliest surviving examples of what would become one of the most distinguishing features of a submarine.

Drawings of the original *Pioneer* show that the pilot house was a separate, raised box forward, while the access port was an ovoid opening with a lower profile aft. The combination of the two features into a single component provided higher freeboard for the access hatch, helping to prevent water from getting into the vessel while the crew entered and exited. It also reduced the number of openings, and thereby possible points of leakage, in the hull. Both the Louisiana State Museum Vessel and *Sub Marine Explorer* combined the access port with the pilot house. *Intelligent Whale* separated them, but both were located close to midships, where the vessel was at its widest to accommodate its diving bell features (Hitchcock 2002:135).

William Mazyck described *Hunley's* hatches as "hinged smoke-stack covers" (Lunz 1957), but Hasker noted they were "much the same as a boiler manhole" (Fort 1918), from which they were clearly adapted. Access for cleaning the interior of boilers was required for the longevity and safety of the equipment. They were commonly oval-shaped, which allowed for the cover to be passed through the hole and fastened on the inside of the boiler, a common arrangement to deal with the outward pressures being exerted on the cover. In addition, to reduce stress on the shell, designers aimed for the smallest opening possible that would

still admit a person. According to mechanical engineer Frederic Hutton (1897:416):

Measurements show that the average man is fourteen inches on the axis of the longest dimension through the articulations of the hip-joints with the pelvic bone. The shoulder dimension, though naturally larger, is flexible and contractile, and any man can pass through a hole through which his hips will pass. The dimension at right angles to the line through the hip-joints is normally less than the other, and is a flexible one when it is not less. Hence the manhole received an elliptical shape with its long axis 14, 15, or 16 inches long, and its short axis 9, 10, or 11 inches, or four or five inches less than the other.

While *Hunley's* hatches are larger than this (roughly 21 × 15 in. [53.34 × 38.10 cm]), ease of access was likely more of a consideration than stress reduction for the submarine. Another adaptation for the vessel was the orientation of the hatch. Oval hatches were usually positioned with the long axis running laterally across boilers to minimize strains across the grain on boiler plates under pressure (Hutton 1897:418); however, on *Hunley* they were placed longitudinally, likely due to space restrictions on the narrow hull, as well as being more hydrodynamic. The conning towers on the Louisiana State Museum vessel and *Sub Marine Explorer* were also oval-shaped, with the same longitudinal orientation as on *Hunley*, while the designers of *Intelligent Whale* opted for round, perhaps because it was not being used as an access port.

The glass viewports were likely an adaptation from shipbuilding, where watertight openings in the hull for light and air had been common features for many years. Remnants of similar viewports were found in *Submarine Explorer's* conning tower, 4 in. (10.16 cm) in diameter (Delgado 2006:236). *Intelligent Whale's* conning tower held four small ports, 4.5 in. (11.43 cm) in diameter (Hitchcock 2002:131–33). The similarity in size may reflect some level of standardization present in the shipbuilding industry.

Of the three other surviving submarines, all had only a single conning tower, located at or near midships. The double conning tower design of *Hunley*, while increasing drag, was a necessary accommodation to improve ease of access for the greater number of men aboard. Only *Sub Marine Explorer* had a comparable crew capacity. This vessel had a much larger conning tower (5 ft. [1.52 m] on its long axis), facilitating loading of both men and gear, as well as housing piping for the interior pressurized chamber. In addition, in case of emergency, the access ports in the bottom could be used for emergency egress in most cases.

On *Hunley*, two triangular sheets of wrought iron, dubbed cutwaters, were attached to the forward face of each conning tower, tapering down forward. They were most likely added to prevent fouling of the conning towers and their viewports. This feature does not appear in either drawing of *Pioneer*, suggesting it was developed in response to situations experienced in the field. The use of a towed torpedo may have posed an additional fouling risk. None of the three other surviving submarines of the period show evidence of such a feature. The diving bell submarines may have relied on divers for their anti-fouling needs.

Keel

As discussed above, the main method for keeping a submarine upright in the water column is to keep the center of gravity low. Even today, submarines are built with the heaviest materials as low down as possible in the hull, and often additional ballast is needed to attain proper trim (Burcher and Rydill 1994:40–42). *Hunley's* builders created a system of cast-iron weights that fit together along the underside of the hull to resemble a keel. As such, it is not a structural element like a traditional keel, but primarily functions as ballast. The estimated total weight of all eight keel blocks is roughly 2,740 lb. (1.37 tn.; 1243 kg), providing substantial transverse righting action, particularly at the surface, where wave action could have been problematic. The external placement kept the weight as low down as possible, and provided several added benefits: it maximized interior space for crew activities; it provided a stable, flat platform for transporting or working on the submarine out of the water; and it allowed for the weights to be dropped from the hull in case of emergency.

The concept of releasable external weights can be found as early as *Turtle*, which carried a 200 lb. (91.72 kg) lead weight on a 40–50 ft. (12.19–15.24 m) line that could be dropped by the pilot, enabling him “to rise instantly to the surface, in case of accident” (Bushnell 1799:304). McClintock and Watson also hit upon this type of safety mechanism early on, as Baird (1902:846) reports that *Pioneer's* keel, which was made up of five lengths of railroad iron, was detachable from inside. The concept was carried over into *Hunley*, which was equipped with a system of T-headed bolts that could be unscrewed by the men at the cranks (Alexander 1902b:165–66). There are, however, no accounts of the feature being used successfully. Based on examination after the second sinking, it was noted “[t]hey tried to release the iron keel ballast, but did not turn the keys quite far enough, therefore failed” (Alexander 1902b:169). Drawings showing three levers in the floor of the submarine, attested archaeologically, may indicate there was an attempt to improve the release mecha-

nisms after this incident. The irregularities in shape of some of the keel blocks may reflect the insertion of new castings to accommodate new release levers.

The main drawback of an external, flat-bottomed keel is the addition of drag (Burcher and Rydill 1994:107). The castings on *Hunley* reflect an effort to make it as streamlined as possible, with the fore and aft blocks molded with a smooth, rounded taper. This would have been an improvement over the more rudimentary, rectangular keel on *Pioneer*.

Hunley's keel system was unique among its contemporaries. The Louisiana State Museum vessel, the only other closed-capsule submarine, has only a small internal keel, approximately 1 × 2 in. (2.54 × 5.08 cm), which seems to have functioned more as a traditional framing element and did not provide a significant source of weight (Wills 2000:122). The vessel appears to have relied on the teardrop hull shape to lower its center of gravity. As a diving bell submarine, *Sub Marine Explorer* was entirely flat on the bottom, incorporating a single cast-iron keel plate 1.75 in. (4.45 cm) thick, with a maximum length of 34.4 ft. (10.49 m) and maximum breadth of 8 ft. (2.44 m) (Delgado 2006:235, 238). By using very thick plating at the base, the builders were able keep the center of gravity low while maximizing area available for diver hatches.

The closest comparison to *Hunley's* design was *Intelligent Whale*, which did have a central, keel-like piece, 12 in. (30.48 cm) sided and 4 in. (10.16 cm) molded, that ran a length of 9 ft. (2.74 m) along the centerline between its two diver access ports (Hitchcock 2002:122). There were also two 8 ft. (2.44 m) long longitudinal skids, 4 in. (10.16 cm) square, outside the two access ports (Hitchcock 2002:123). They were incorporated into the bottom plate, possibly as a single casting, and provided much needed basal weight as well as a platform to help stabilize it on land. The elements were not detachable, and with three separate protruding elements, the drag would have been increased significantly.

Diving Planes

One of the challenges early submarine designers faced was controlling the vessel's position along the z axis. Many designers turned to inspiration from fish and marine mammals and, in the case of *Hunley*, they chose to develop a horizontal control surface mimicking the functionality of pectoral fins (Alexander 1903:746). As this was not a feature surface ships had to contend with, there was little by way of precedents for deciding on a fin shape and position, or even what to call it. The different names applied in the various eyewitness accounts attest to the novelty of the feature—fins (Alexander 1902a, Fort 1918, Lunz 1957), wings

(McClintock 1872), vanes (Baird 1902:845), blades (Alexander 1903), flanges (Stanton 1914), and hydroplanes (Lake 1918).

Modern studies have determined that these control surfaces, or diving planes, are best positioned toward the bow, forward of the neutral point, at low speeds (below approximately 2 knots) and at the stern for faster speeds (Burcher and Rydill 1994:168–69). Early designers were forced to experiment, taking into consideration hull shape, interior configuration for control mechanisms, and the functional needs of the vessel. *Hunley's* designers chose 6.5 ft. (2 m) long, narrow blades that were mounted just aft of the forward conning tower. Given the speeds achieved by *Hunley*, this placement was probably ideal for handling, though it meant the transverse rod around which they pivoted obstructed easy access to the crank stations from the forward conning tower (Fort 1918:459). The planes were mounted asymmetrically, with the portion aft of the pivot point roughly 11 in. (28 cm) longer than the forward section. This appears to have been an intentional design choice, since the planes are depicted with an exaggerated asymmetry on the Royal Navy sketch from the meeting with McClintock. The proximal edge of the planes follows the outline of the hull as it narrows forward of the axis and the fore and aft exterior corners are rounded, suggesting an attempt to make them more streamlined for smooth running.

This was a shift from *Pioneer*, which, based on both historical sketches, had relatively short diving planes, mounted along the leading edge. They are also depicted as having been mounted low down on the body rather than at the central axis, where they would have provided equal benefit while diving and rising (Burcher and Rydill 1994:179–80). Given the difficulties in control caused by the conical ends, the designers may have decided that, in addition to the change in hull shape for *Pioneer II*, longer diving planes placed higher up would improve control. The trailing edges on *Pioneer* appear to have been squared off, or nearly so, which may indicate they were inefficient, since the corners were rounded off on *Hunley*.

Of the three other surviving submarines of this period, two utilized horizontal control surfaces, while the third, *Sub Marine Explorer*, relied solely on its ballast tanks for vertical positioning (Delgado 2012:195). The Louisiana State Museum vessel had two roughly semicircular diving planes that rotated around a central shaft positioned in the forward third of the vessel (Wills 2000:152). *Intelligent Whale* incorporated diving planes into the stern assembly, where they were placed perpendicular to the rudder just forward of the propeller, with the leading edge mounted on a horizontal shaft passing through the stern ballast tank, and the proximal edge tapered to follow the curve of the hull (Hitchcock 2002:164–67). The wide variety of shapes and positions

represented in these three vessels attests to the difficulties designers faced in optimizing their vessels for the undersea environment.

One additional feature found on both *Pioneer* and *Hunley* was a fin-like projection mounted to the hull in front of the planes. These prevented fouling of the blades in a similar fashion to a skeg on a rudder. The diving planes on *Intelligent Whale* were also equipped with similar protective fins (Hitchcock 2002:167). They do not appear in any of the sketches of *Hunley*, which tended to highlight the components directly involved in submarine operations. Smaller, utilitarian features such as these skegs reflect the more practical adjustments designers made based on their experience with the operation of their craft.

Overall, *Hunley's* diving planes were a precursor to the control surfaces still in use on submarines today; however, they had not yet reached their optimal form. McClintock reportedly “found that, in practice, he got better results by placing the ‘pectoral’ vanes near the center of displacement; that his purpose was as well, and easier served, by sinking or rising bodily on an even keel as by diving” (Baird 1902:847). Alexander (1902c:86) also noted it was easier to surface by expelling water ballast rather than by elevating the diving planes. Their length in relation to the total length of the hull may have exceeded requirement, doubtless increasing drag and perhaps making handling difficult, as just a small shift in the control rod shaft would have led to a significant change in plane application. This sensitivity may have been a contributing factor in *Hunley's* first sinking, as one report claimed that it was caused by the pilot stepping on the diving plane control lever (Fort 1918:459). The planes were also less important once the vessel was refitted with a spar mounted torpedo and no longer expected to dive below enemy ships.

Bow and Stern Casting Holes

The 2 in. (5 cm) diameter hole in the upper portion of the bow casting may have been used as an attachment point to secure a mooring or tow line. A similar hole exists in the aft casting and was depicted in Chapman's painting. Neither hole is mentioned in textual accounts of *Hunley*, although we know that it was frequently towed (ORN 1.15: 334–35). In the drawing from McClintock's meeting with the Admiralty, there is a small circle depicted in the bow casting that most likely represents this hole, but there was no label or explanatory text.

Most other submarines from the period had sturdy brackets, or rigging eyes, riveted to the top of the hull that could function as a tow or mooring point. The Louisiana State Museum Vessel was equipped with two rigging eyes, one toward the bow and the

other toward the stern. They were made up of 30 in. (76.20 cm) lengths of iron strap, bent at the halfway point to form a semicircular eye 1.5 in. (3.81 cm) in diameter, bolted to the hull plating along the longitudinal centerline (Willis 2000:134). The eye section was deliberately smoothed and rounded to prevent damage to lines (Willis 2000:134).

Intelligent Whale has a 6.5 in. (16.51 cm) diameter ring affixed to the tip of the nose cone, as well as a rigging eye, made up of a 12 in. (30.48 cm) iron strap bent to form a 3 in. (7.62 cm) eye in the center, riveted to the top along the longitudinal centerline of the hull, between the second and third frames aft (Hitchcock 2002:137–40). A similar piece may have been present toward the bow, based on surviving penetrations in the plating. Hitchcock points out that the piece was “most likely used for mooring purposes and was not intended as a lifting point, as the rivets would not [have] been able to support the weight of the vessel” (Hitchcock 2002:140). *Sub Marine Explorer* had four iron rings, 6 in. (15.24 cm) in diameter, mounted in brackets at the top of the bow and stern quarters (Delgado 2012:194). As with *Intelligent Whale*, these rigging points do not appear to have been strong enough to lift the vessel out of the water, so must have been limited to mooring and possibly towing functions (Delgado 2012:194).

A rigging eye similar to the ones on *Intelligent Whale* and the Louisiana State Museum vessel appears in Stauffer’s sketch of *Pioneer* and was labeled “Fastening for Towline.” There is no evidence for such hardware on *Hunley*, although this cannot be confirmed until deconcretion is complete. However, there are also no signs of rigging eyes in the Chapman painting, suggesting this feature was deliberately omitted by *Hunley*’s builders. If so, it may have been an attempt to minimize snag hazards or reduce drag. Since cast iron

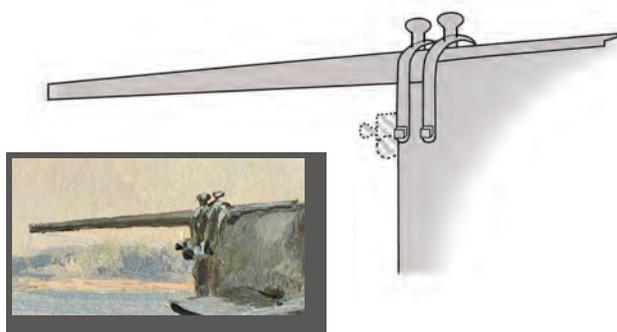


Figure 14.9. Two iron brackets recovered from the site most likely correspond to bow hardware depicted in Chapman’s painting. Based on the painting, additional hardware may have been affixed to the leading edge of the bow (Diagram by H. G. Brown, NHC. Inset: detail from H. L. Hunley by Conrad Wise Chapman, courtesy of the Museum of the Confederacy, Richmond, Virginia)

was generally more brittle than wrought iron, it seems risky to have incorporated a function so high in tensile stress into the body of the vessel itself. Also, securing a tow line so far from where the crew could reach is not practical; however, the loss of *Pioneer II* during a tow with no hands aboard, suggests the submarine was towed empty, in which case a line at the bow would not have been problematic.

Two iron shackles were recovered from near the bow and were most likely part of the hardware used for an upper boom that functioned as part of the weapons system (discussed below). The Chapman painting shows two pieces apparently affixing the boom to the bow casting (Figure 14.9). The remains of a second hole is visible along the eroded remains of the leading edge of the bow casting. Further analysis after deconcretion may be able to determine if one or both holes were part of the original casting or if they were added later. If inherent to the casting, it is possible that the hole was designed as a rigging element and later coopted into service for the new spar torpedo system.

Propeller and Shroud

Alexander (1902a) stated that *Hunley* was equipped with an “ordinary propeller”—in this case, a three-bladed, cast-iron screw propeller roughly 27 in. (69 cm) in diameter. While there was much experimentation in propeller design during this period, most of that was in relation to large vessels with steam engines that induced a good deal of strain on the propeller, joints, and shaft. For smaller vessels, a three-bladed propeller was very common (Peabody 1912:84).

All of the comparable surviving vessels of the period also had a single axially-mounted screw propeller at the stern. The Louisiana State Museum vessel, *Sub Marine Explorer*, and *Pioneer* all had four-bladed propellers, while *Intelligent Whale* had three (Table 14.1). The fact that *Hunley*’s designers reduced the number of blades from *Pioneer* suggests there was an advantage to such a change, although the complexity of factors influencing propeller design, including blade area, pitch, and position relative to the hull, make it difficult to speculate what improvement was achieved. Analysis currently being undertaken at WLCC in conjunction with the University of Michigan’s Naval Architecture and Marine Engineering department may provide insights into this question.

Hunley’s propeller was surrounded by a metal ring, or shroud, which according to Alexander (1902b:166) served to protect the blades from snagging, as well as from damage if struck by passing debris or underwater obstruction. A note on the Royal Navy sketch from the meeting with McClintock (1872) indicates the ring also helped “prevent the disturbance of the Water

Table 14.1. Comparison of Early Submarine Propellers

| <i>Pioneer</i> | 4 | n/a | 48 |
|-------------------------------|---|-----|------|
| <i>Hunley</i> | 3 | 27 | 43 |
| Louisiana State Museum Vessel | 4 | 36 | 38.5 |
| <i>Intelligent Whale</i> | 3 | 40 | 87 |
| <i>Sub Marine Explorer</i> | 4 | 42 | 120 |

Sources: Hitchcock 2002:161; Wills 2000:142; Delgado 2013:199

from being seen, should the boat be working near the surface.” In addition to the shroud itself, there were also two additional metal bars that extended from the sides of the shroud back to the hull, connecting at the top of the expansion strake that would guide loose objects away from the shroud and the suction at the propeller. These may also have protected the shroud from damage and stabilized it during operation, if the sides were subjected to torque under the hydrodynamic forces of the propeller action.

The designers of *Intelligent Whale* took similar precautions by surrounding the propeller with a sort of protective iron cage or basket (Hitchcock 2002:140). No such accessory survives on the Louisiana State Museum vessel, but there was much damage to the propeller area before the vessel was documented. Drawings of *Sub Marine Explorer* also do not include any similar feature; however, the relatively wide stern and the proximity of the propeller to the hull may have afforded sufficient protection from damage, and the ability of divers to exit the hull while submerged allowed for the clearance of snags without surfacing.

The drawings of *Pioneer* show no shroud around its propeller, suggesting that the feature was added to *Hunley* based on experience. It is possible that the twin steering rods on *Pioneer* provided some level of protection from snagging. The long, sharply tapered ends of both vessels left the propeller relatively exposed compared to vessels such as *Sub Marine Explorer*.

Rudder

The rudder was the least well-documented of *Hunley's* exterior features. In most diagrams, even those by McClintock and Alexander, the rudder was depicted with a height to length ratio of approximately 4.2:1. Only Chapman's painting and sketch come close to capturing its true ratio of 1.5:1. This may be indicative of the relatively small consideration they gave to rudder design. The simplicity of a flat, rectilinear piece of metal must have remained unquestioned, as

no special mention was made in any narrative of its design features. While this period saw the advent of balanced rudders on naval vessels such as USS *Monitor*, such innovation, designed to reduce the stresses on the steering gear, was primarily focused on large steam-powered ships (Thearle 1877:368–70). The simple unbalanced rudder, mounted along the leading edge, was sufficient for the speeds achieved by *Hunley*.

No rudder has survived intact on any of the archaeologically comparable vessels, no doubt a consequence of the vulnerability of the exposed position. Based on historical sources and archaeological evidence, *Intelligent Whale* had a rudder mounted below the hull, forward of the propeller, mounted to a shaft that penetrated the hull vertically, so the cable and pulley system that controlled it could be situated inside the vessel (Hitchcock 2002:129, 161–64). Such a position would also provide some protection to the rudder by the hull itself and the propeller cage, located aft of the rudder.

The Louisiana State Museum vessel had two small, roughly semicircular rudders, one at the bow and one at the stern, mounted along the centerline low down below the level of the propeller, just above the keel (Wills 2000:119). Such a design is reminiscent of a fish's pelvic and anal fins, and shows a shift in concept away from surface ship design. Such placement also left the rudders vulnerable to damage from below, although this might not have been a large concern in the relatively even, muddy bottom of Lake Pontchartrain.

The rudder on *Sub Marine Explorer* was lost but archaeological evidence shows that it was controlled using cables connected to a yoke (Delgado 2012:198–99). Based on historical records, the original intent was to use James Cathcart's design of a propeller that rotated on a universal joint instead of a true rudder, but this apparently did not work well, and was replaced (Delgado 2012:196–98). The new rudder was mounted aft of the propeller on fixed brackets extending aft above and below the propeller, and was controlled by two horizontal steering rods to port and starboard of the centerline connected to a yoke on top of the rudder shaft (Delgado 2012:199). Thus this rudder is most

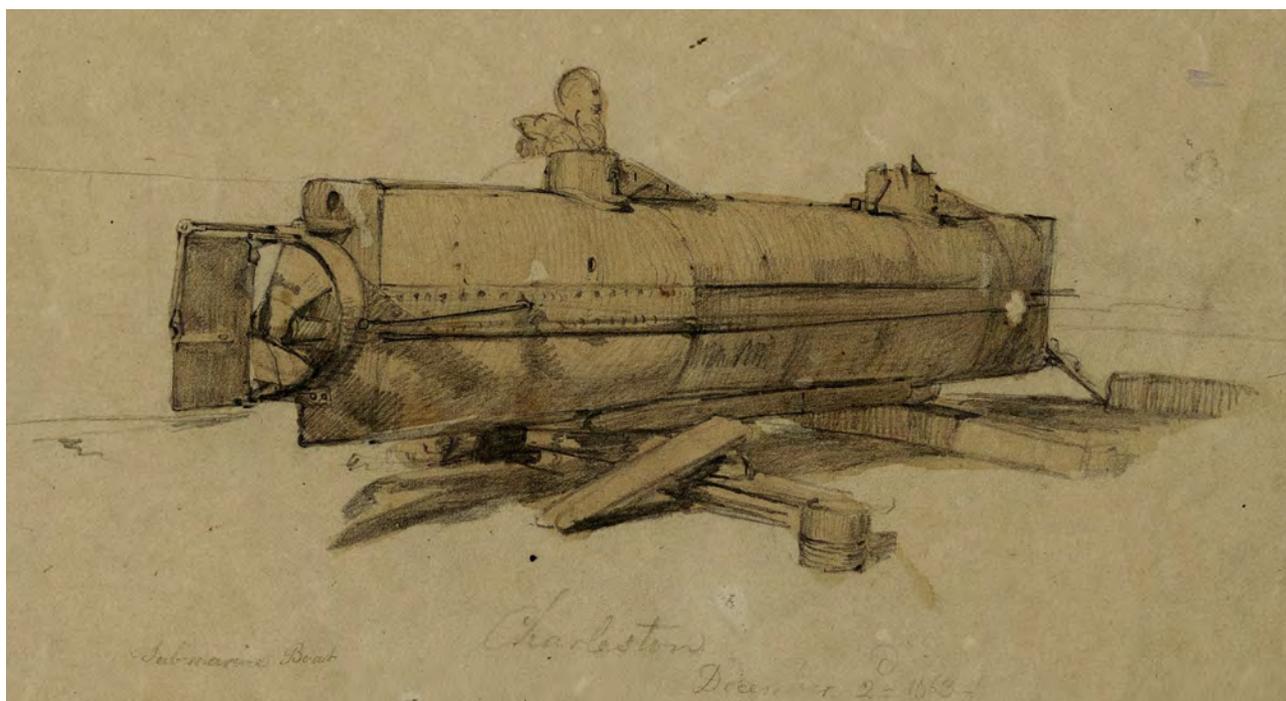


Figure 14.10. This sketch by Conrad Wise Chapman shows Hunley with the forward hatch removed and possibly smoke coming from the aft hatch that may represent the submarine being cleaned and refitted after the second sinking. This is the clearest depiction of the rudder assembly that has been found. (Sketch of of H. L. Hunley, V.41.49.190, The Chapman Collection, The Valentine, Richmond, Virginia)

similar to that of *Hunley*, although the dual steering arm configuration is actually closer to *Pioneer's* design.

Hunley's horizontal, single-shaft rudder control mechanism was unique among the vessels compared. A steering shaft penetrated the stern casting just above the upper propeller mounting bracket, extending aft of the propeller to the top of the rudder. Based on both the Chapman sketch and the McClintock drawing, the steering rod resolved into a ball joint connected to a vertical metal arm that descended aft of the rudder, which in turn reached an additional joint that was attached to a pair of parallel horizontal arms that joined together through a horizontal slot roughly in the center of the rudder (Figure 14.10). These paired arms were preserved, concreted to the rudder itself, but the remaining hardware is missing, with the possible exception of one concretion (HL-0683), found near the stern and similar in shape to the preserved arms. It is interesting to note that there appears to be an error in Chapman's painting at this point, namely the presence of an additional metal arm that is depicted running from the central joint to the bottom of the rudder, a piece that does not appear in his original sketch for the painting and does not make sense mechanically.

Hunley's complex rudder mechanism was an evolution from *Pioneer*, which had two parallel steering rods extending from the top of the hull meeting at a yoke mounted to the top of the rudder shaft. The conical shape of *Pioneer* necessitated the exposure

of a significant length of the steering rods in order to position the rudder aft of the propeller, increasing the risk of damage. The dual rod system, while simpler to design, was more vulnerable to damage.

Rudder position is also an important factor in propulsion efficiency. It has been noted that "[m]ounting forward of the propeller produces a noise-producing wake from each control surface, affecting smooth propeller behavior" (Joubert 2004:31). In both *Hunley* and *Pioneer*, the rudder was mounted aft of the propeller, the ideal position for that component. Only *Sub Marine Explorer* had a similar position for its rudder, and only after the original propeller design failed. The other two contemporary submarines mounted the rudders closer to the hull, reducing exposure of the blade itself as well as its control components. In the case of *Intelligent Whale*, with only a single rudder blade below and forward of the propeller, propulsion may have been adversely affected. For the *Hunley* team, the risk of placing the rudder outside of the protected lee of the stern area must have been outweighed by the gains in performance.

Snorkel Box

A method for replenishing air inside the vessel while submerged was a new feature that could not simply be adapted from known naval architecture or

boiler features. One solution was a floating hose that ran from submarine to surface, as attested by an 1861 defense directive issued after a failed submarine attack on USS *Minnesota* in Hampton Roads: "Or should it pass outside the net, the tube which floats on the surface to supply the inmates with air would be caught on the A spars and the supply of fresh air cut off, causing suffocation" (ORN 1.6:393). A short iron stack survives on top of the Louisiana State Museum vessel forward of the hatch, which may have been part of a floating hose system, possibly aided by some sort of bellows device to draw in air (Wills 2000:161–62). *Intelligent Whale* may have used this system in addition to the compressed air it carried for its diving bell function (Hitchcock 2002:155). *Sub Marine Explorer* also had the benefit of compressed air, but, beyond that, had a pump to spray a mist of sea water that was intended to purify the air on the principal that the water would absorb the "carbonic acid gas" in the cabin and release the oxygen it contained (Delgado 2012:203–4).

The drawing of *Pioneer* in Shock's letter shows two compartments, between the crew section and ballast tanks, identified as being for compressed air. This contradicts Baird's (1902:846) account in which he claims McClintock reported the occupants "might have remained several hours under water without being seriously inconvenienced and without any storage of air." It is possible compartments were initially built for compressed air, but were found to be unnecessary or unworkable. No other means of providing external air is visible in the surviving drawings of *Pioneer*.

By the time *Hunley* was built, the design team had incorporated two iron pipes, or snorkels, that could be raised and lowered from inside while submerged, to introduce fresh air from the surface. Instead of having the pipes laterally penetrate the hull plates and cross the crew compartment, a raised box was installed just aft of the forward conning tower, where they would not interfere with interior access while remaining close to the pilot's station. The snorkels could either lie flat against the hull or be positioned vertically to allow the exchange of fresh air into the crew compartment while the submarine operated just below the water's surface. If McClintock's claim that no additional air was needed in *Pioneer*, the system may have been added to combat the air consumption of a much increased crew complement combined with the longer running distances required for an attack upon the blockade.

Alexander included the feature in his drawing for the Navy, labeled "air box," although he positioned it erroneously midway between the two conning towers. The air system was omitted from Lake's drawing (1899), Baird's drawing (1902), and, most importantly, McClintock's drawing (1872) and description ([1871]), suggesting that the snorkel system was a late addition to the design, developed after McClintock's close involve-

ment with the project. Alexander made no mention in his account of how well the system worked in practice.

The two snorkel tubes were recovered from the site, and found to be roughly 5 ft. (1.52 m) in length and threaded at both ends. This accords with both Alexander (1902b:166) and Hasker (Fort 1918:459), who both stated they were 4 ft. (1.22 m) long. However, at least two eyewitness accounts estimated their length at 10 ft. (3.05 m): Gift, who encountered the boat in Mobile (Turner 1995:7), and Mazyck, who saw the boat when it first arrived in Charleston (Lunz 1957). This suggests that longer tubes may have been used originally. Since both ends were threaded, the design team may simply have coupled two lengths of pipe, as they did later with the spar. Baird (1902:847) stated "the boat was easily managed under water, and, when submerged 10 feet [3.05 m], she was not sensibly affected by the surface." Thus snorkel tubes that allowed ventilation at this depth may have seemed ideal in theory, but not in practice. It is tempting to infer that the tubes were shortened after Beaugard required the boat to be used at the surface rather than submerging it (see Chapter 2). However, as Hasker's account from August 1863 predates that order, the shorter tubes appear to have been in use soon after the vessel reached Charleston. The crew may have found that running at a depth of 10 ft. (3.05 m) was not necessary in Charleston Harbor, or perhaps, as with other aspects of the vessel, the longer tubes were more of a potential snag hazard than a benefit. Nevertheless, the fact that the short tubes were found with *Hunley* seems to indicate that the air system was not entirely abandoned and that, despite his orders to remain at the surface, Dixon kept the tubes ready for at least shallow submergence in case of emergency.

Weapon System

Delivering a killing blow from beneath the surface in a closed-capsule submarine was a challenge that often seemed easy to solve on paper, yet proved very difficult in practice. Problems with successful execution hindered the willingness of naval authorities to accept submarines as a viable weapon of war for many decades. The earliest offensive strategy for underwater boats, such as that of Cornelis Drebbel, may have depended on boring through an enemy hull from below causing it to take on water and sink (Mersenne 1644:208), although others interpret original accounts to construe an explosive ram (Harris 1997:11). Bushnell's *Turtle* was designed to allow men to screw a keg of black powder with a timed detonator to an enemy's hull without opening or leaving the submarine. Due to copper sheathing, strong currents, and other factors, operators repeatedly failed at this task, and use of the submarine was discontinued (Bushnell 1799). Fulton's

original design for *Nautilus* involved positioning the submarine beneath the enemy vessel and driving a metal spike with an eye into the hull; as *Nautilus* pulled away, a rope, threaded through the eye, would drag a torpedo against the ship, which would explode on contact (Parsons 1922:26–27). In a later report, however, Fulton says the submarine vessel was not intended to “go under or near the vessels which are to be attacked,” but rather should be used to approach an enemy anchorage secretly and “there anchor her cargo of submarine bombs under water, or leave them to the tide, or use them in any other way which time and practice may point out” (Parsons 1922:67). This suggests that his original delivery method proved less than successful.

According to Baird (1902:845), *Pioneer* was designed to carry a torpedo “of the clock-work type” that would be affixed to an enemy hull using screws that were “gimlet pointed and tempered steel,” similar to Bushnell’s strategy. Surviving sketches show a rack designed to carry the torpedo on top of the vessel, aft of the pilot station and forward of the entry hatch. McClintock reportedly completed several successful tests, blowing up “a small schooner and several rafts” (Baird 1902:845); however, surviving accounts have little to say about the performance of this weapon system. As it was subsequently abandoned by the design team, it was most likely found to be impractical.

A new design was adopted for *Pioneer II* and, subsequently, *Hunley*, which called for the submarine to tow a torpedo. The submarine would submerge and dive under the enemy ship, trailing the floating torpedo behind. The latter would make contact with the hull of the target and explode, while leaving the submarine unimpaired on the opposite side of the enemy vessel and protected from the explosion. There is very little extant information regarding the specifics of the torpedo’s design, such as where the tow line was attached, or how it was deployed, though Alexander (1902b:166–67) recalled that it “was a copper cylinder holding a charge of ninety pounds of explosive, with percussion and friction primer mechanism, set off by flaring triggers . . . [towed] with a line 200 feet [61 m] after her.” Based on the inaccuracy of many other dimensions in his account, however, these details are suspect. Gift, who witnessed a practice run in Charleston, noted “[b]ehind the boat at a distance of 100 to 150 feet [30–45 m] is towed a plank and under that plank is attached a torpedo” (Turner 1995:7). In trials, the towed method successfully sank several test targets without injury to the submarine (Maury 1894:79, Alexander 1902c:83). However, problems with the towed torpedo were manifest during early trials in Charleston. The fault apparently lay with the maneuvering speed of the submarine and the strong currents. Tomb reported that the last time his vessel towed

Hunley with its trailing torpedo they were at risk when the “torpedo got foul of us and came near blowing up both boats before we got it clear of the bottom, where it had drifted” (ORN 1.15:335). Alexander (1902b:167) noted that “in rough water the torpedo was continually coming too near the wrong boat.”

In *Hunley*’s last months of service the weapon system was changed to a spar torpedo. This change was at the direct order of General Beauregard (1878:154), who, after *Hunley*’s second tragic sinking, ordered it to be used as a semi-submersible rather than a submarine and to be fitted with a “Lee spar torpedo,” in a similar fashion to CSS *David* (see Chapter 2). Beauregard was a strong supporter of the use of mines and spar torpedoes, developed by a member of his staff, Captain Francis D. Lee, that were deployed by steam-powered small craft, such as the semi-submersible *David* and the more traditional surface-running CSS *Squib* types.

Prior to the discovery of *Hunley*’s torpedo spar, many thought it was attached to the upper bow. This configuration was shown in Lake’s (1899) drawing, and can be mistakenly interpreted from the Chapman painting, since it shows a short spar or boom attached to the top of the bow and nothing extending from the bottom. Models and illustrations produced prior to the excavation continued to amplify this interpretation. However, makers of the 1999 TNT-produced movie “*Hunley*” accurately positioned the torpedo spar when trials of the full-sized replica made it apparent that the lower spar configuration was the only workable method of deployment (Neyland 2007).

The question was put to rest when the torpedo spar was recovered with *Hunley* in 2000. It comprised three separate parts that combined into an overall length of approximately 16 ft. (4.9 m). The majority of the spar was made up of two lengths of seamed, rolled wrought-iron pipe, joined by a coupling, bolted to a solid cast-iron section (see Chapter 12). One end of the cast-iron section fit over a tang mounted to the bottom of the bow, where it was attached with a single, horizontal threaded bolt, allowing the spar to pivot up and down as needed.

This arrangement is similar to that described in other accounts of spar torpedoes used by the Confederacy. *David*’s spar was reportedly 14 ft. (4.27 m) long, 3 in. (7.62 cm) in diameter, and made from a boiler tube (Glassell 1877:230, Tomb 1914:168). An officer on the surface vessel CSS *Palmetto State* reported that its spar torpedo extended 20 ft. (6.10 m) from the stem and pivoted upon a “gooseneck” (Parker 1985:327). This length was typical for the surface torpedo boats being put into service in Charleston at this time (Campbell 2000:37). The hollow section of *Hunley*’s spar was likely also made of lengths of boiler tube, as its diameter of 5.68 cm (2.24 in.) is consistent with dimensions of fire tubes from naval boilers of the period (Figure 14.11).

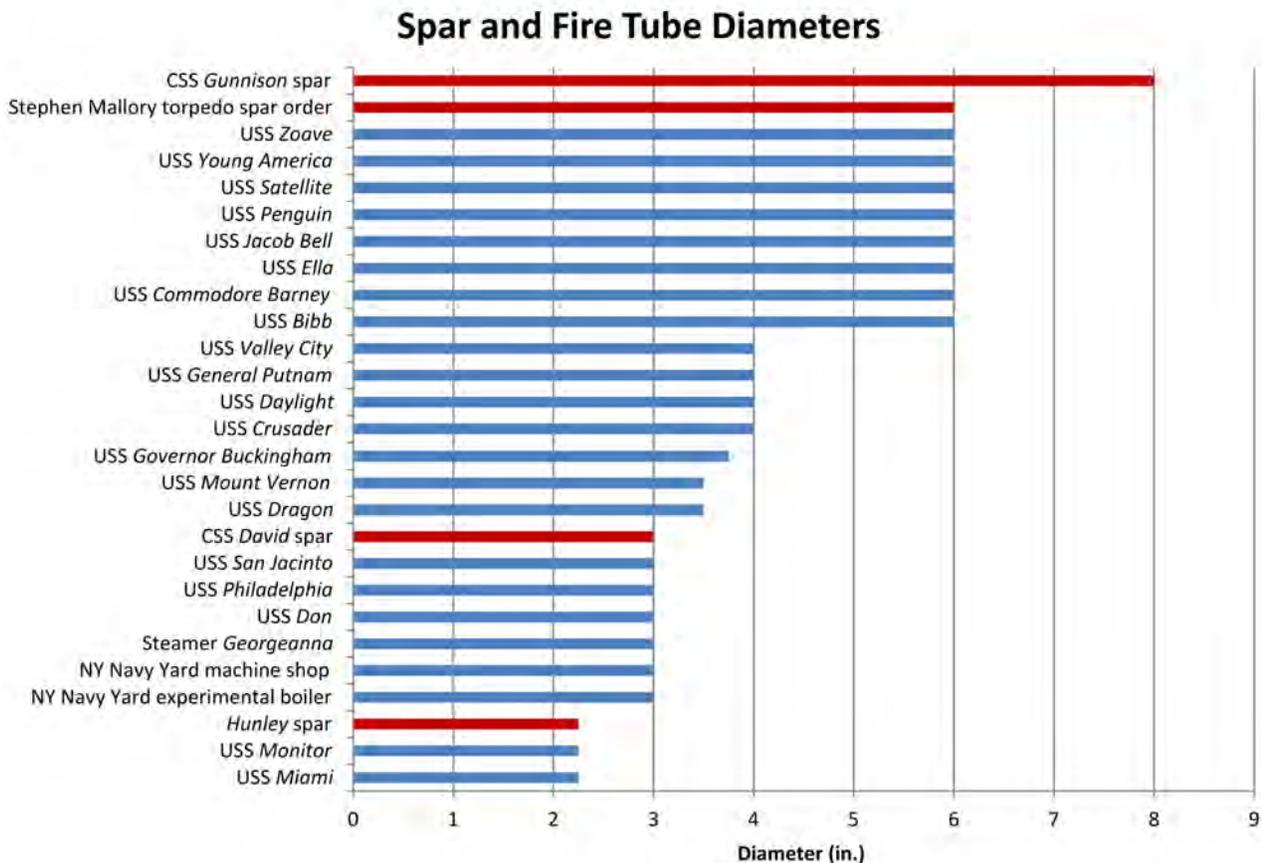


Figure 14.11. Diameters of fire tubes from marine boilers, in blue (Isherwood 1865), compared to known spar diameters, in red (Tomb 1914:168; ORN 1.19:631; ORN 2.2:688).

Of the known spar diameters, *Hunley's* is the smallest, perhaps to reduce weight at the bow or limit drag by lowering surface area. A lighter spar was also desirable for reducing strain on the spar rigging.

Very little survives archaeologically of the rigging that controlled *Hunley's* spar. On *Palmetto State*, an iron davit was used to raise and lower the spar so the torpedo could be carried above the waterline until needed (Parker 1985:327). *CSS David* was equipped with a windlass and lines that allowed the raising and lowering of the spar from the safety of inside (Campbell 2000:66). The *CSS Squib* torpedo vessel type also mounted a spar with a gooseneck arrangement that was adjusted with a line passing over a sheave on top of the stem to a winch inside the boat's cuddy (ORN 1.9:601). This design would have been beneficial in both protecting the torpedo until it was ready for use in an attack and for removal and installation at berth.

Witnesses described a similar arrangement for *Hunley*. McLaurin observed "[t]he torpedo was fastened [sic] to the end of an iron pipe ... which could be extended in front and withdrawn with ease by guides in the center of the boat to hold it in place" (*Confederate Veteran* 1925). Mazyck described it as follows:

On the forward end was fastened a long steel spar 15 to 20 feet [4.57–6.10 m] long. This was stayed to the boat with iron stays. On the end of this spar, the torpedo was carried by means of a hook. On the deck of the boat, just forward of the forward hatch was a reel carrying a steel cable. The distal end of the cable was attached to the trigger of the torpedo. The proximal end, in some manner ran through the deck so that the torpedo could be operated from the inside (Lunz 1957).

Just such a reel or windlass is visible on the Chapman painting, although positioned aft of the forward conning tower, and likely served only to control the spar position, rather than for detonation. While the exact method of detonating the torpedo has not been determined, if a lanyard-activated trigger was used, it is not likely to have been wrapped around a spool, which could delay the transmission of force through the line. The reel's position aft of the conning tower may indicate it had originally been related to the towed torpedo system.

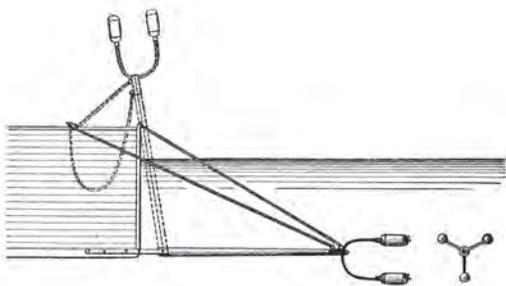


Figure 14.12. A sketch by Francis Lee shows two rigging points, both close to the distal end of the spar (ORA 1.28(2):252).

Images of *David* show rigging points located approximately half to two-thirds of the way along the spar. Lee's sketch of a proposed triple torpedo mount shows the rigging points at the distal end of the spar (Figure 14.12). No definitive rigging points have been found on *Hunley's* spar, but there are several areas of loss in the last meter (3.28 ft.), which could correspond to points where hardware was once attached. If the cable reported by Mazyck was part of the spar rigging, his association of it with the torpedo suggests that the rigging points were near the end of the spar. Once the hull has been fully deconcreted, fittings for spar control may be discovered inside *Hunley*.

One additional component of the spar system was a short spar or boom at the top of the bow, as shown in the Chapman painting, allowing for better leverage and stability in managing the spar. This would likely have had some sort of sheave or roller for rigging lines to pass over smoothly. Two D-shaped metal brackets (HL-0526 and HL-0582) were found near the bow, which may have served to secure the boom to the bow. The arm of one bracket is bent, suggesting that the boom may have been torn off during or after the explosion (see Chapter 15).

Preserved at the extremity of the spar is a portion of the torpedo itself, in the form of a segment of copper sheathing wrapped around the spar and fixed in place with a bolt. Contrary to popular stories of *Hunley* embedding a barbed spear into *Housatonic's* hull and backing away to detonate with a lanyard, this evidence proves that the torpedo exploded directly against the hull. Several successful contact fuses had been developed during the war that would have been reliable alternatives to a manually-triggered system. Even *Hunley's* towed torpedo could have been contact fused as well, despite accounts to the contrary (Turner 1995:7), and may explain Tomb's and Dixon's fear of the torpedo floating into their vessels.

There were two main types of contact fuses utilized for spar torpedoes developed in Charleston. One was based on a sensitive primer developed by General Gabriel Rains using a compound of potassium chlorate, antimony trisulfide, and powdered glass that would

detonate with 7 lb. (3.18 kg) of mechanical pressure (Schafer 1996:75–76). Impact with the side of a hull would depress a plunger against a thin copper cap against the primer, which would ignite the magazine of black powder (Barnes 1869:124). Captain Lee helped develop a highly successful chemical fuse, based on a design by Moritz Hermann Jacobi and utilized by the Russians in the Crimean War (Tucker 2006:257). Lee's fuse consisted of a lead, or, later, brass tube containing a hermetically sealed glass vial of sulfuric acid. Packed around the vial within the tube was a mixture of potassium chlorate, powdered sugar, and fine rifle powder. The tube was capped with a thin, convex-shaped piece of lead that, upon impact, would collapse, break the vial, and release the acid, which would ignite the compound in the fuse and subsequently detonate the torpedo (Beauregard 1878:148–49).

Most spar torpedoes were fitted with multiple detonators distributed around a hemispherical head to increase the chance of the torpedo exploding in case a detonator failed or the angle of impact varied. The torpedo casings were generally made of copper and cylindrical in shape, with a socket at the after end that would fit over a spar (Figure 14.13). Those used in Charleston usually contained between 60 and 100 lb. (27–45 kg) of powder (Beauregard 1878:149).

In the case of *Hunley*, however, another source of torpedo technology was available. One of its investors, Edgar Collins Singer, was part of a group from Texas that made stationary torpedoes on a contract basis for the Confederate army. Sometimes known as the Fretwell-Singer torpedo, it has been described as "perhaps the most successful torpedo used by the rebels during the war" (Barnes 1869:70). The fuse of the Singer torpedo contained a spring-loaded metal rod, held apart from a percussion cap by a pin; attached to the pin by a string was an iron lid on top of the torpedo, which, when dislodged by the current of a passing ship, would fall, pulling the pin with it, releasing the rod into the percussion cap. The Singer team became involved with the *Hunley* team in Mobile, and presumably began adapting their design to a towed torpedo. It may have taken the form as that described by Edmund Ruffin (1989:183) in



Figure 14.13. Drawing of a Civil War-era spar torpedo with multiple fuses distributed around a hemispherical head. (NHHHC Photo Archives #NH 59421)

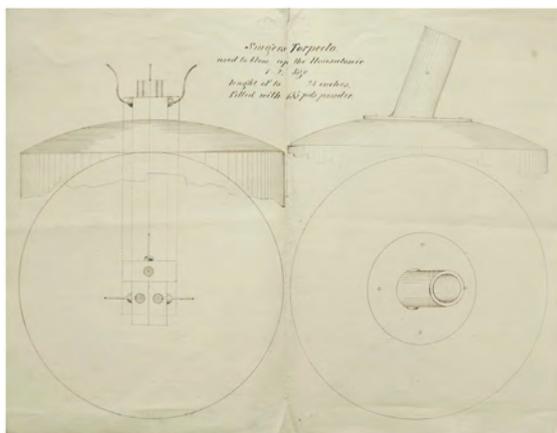
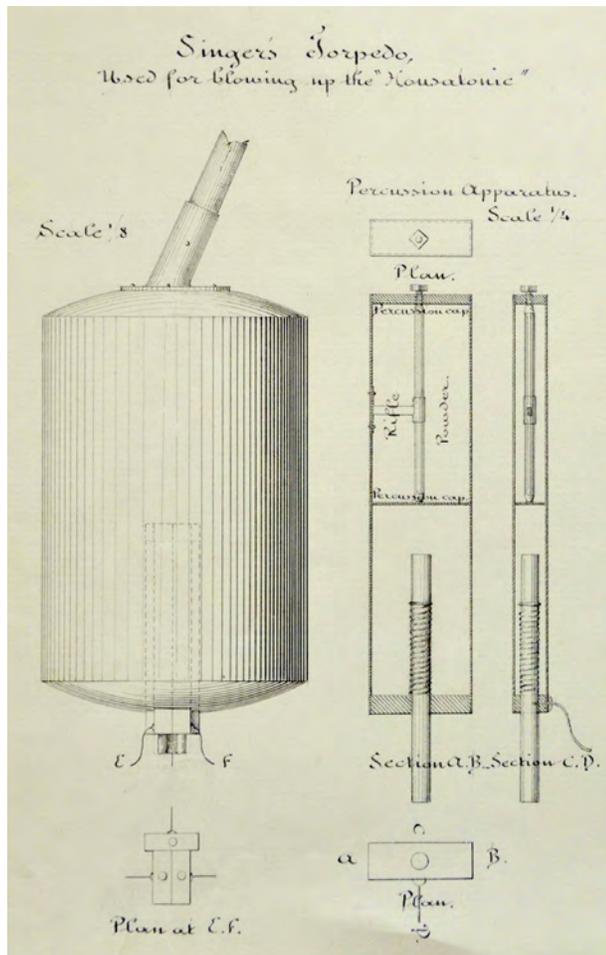


Figure 14.14. Sketch of Singer torpedo adapted for use on a spar. Note letters E and F near the trigger are not annotated. (Courtesy of NARA, RG 94, Quincy Adams Gallimore papers)

October 1863, a “torpedo, in a copper case, cylindrical, with conical ends.” When *Hunley* was rigged to carry a spar torpedo, Singer appears to have adapted his design once again. A drawing was found among Confederate papers at the National Archives labeled “Singer Torpedo Used for blowing up the ‘Housatonic’” (Figure 14.14). It

clearly depicts a spar-mounted, cylindrical torpedo filled with 135 lb. [61.24 kg] of black powder and armed with three spring-loaded fuses mounted in the center of the forward end. It was mounted at an angle, allowing the spar to be lowered below the depth of the submarine, while maintaining the horizontal position necessary for proper contact between the centrally-positioned fuses and the enemy hull. Unfortunately, the key explaining the letters marking the detonators does not survive, so it is unclear whether it was activated by a lanyard, impact, or some other method. Whether *Hunley* was outfitted with this type of torpedo or one of Lee’s on the night it sank *Housatonic* has so far not been determined.

In summary, although questions remain regarding the conversion of *Hunley* to a spar torpedo vessel, evidence points to a design adapted from the spar systems used on Confederate small surface boats and the semi-submersible *David* types. This allowed the spar to be lowered to a depth well below the waterline of the ship, ensuring that the blast would be propelled upward into the enemy hull. With this improved angle of attack, possibly combined with contact fuses, which had already been proven reliable, Dixon and his crew would have been confident of their ability to survive the explosion. Previous trials, as well as evidence from the attack on *New Ironsides* supported this conclusion.

Missing Features

Based on what we know from historical accounts and archaeological evidence, it appears several of the submarine’s external components are still missing. The port side shroud attachment bar, attested in Chapman’s painting, was completely disarticulated from the hull and not found at the site. The steering rod is only preserved for several inches beyond where it emerges from the hull. Additionally, the vertical arm that descended from the end of the steering rod was not found at the site.

The boom that was mounted on the top of the bow, depicted in Chapman’s painting, was not preserved. Its presence at the time of sinking is supported by the two iron brackets and corresponding mounting points found at the bow. A threaded hole in the top of the aft mounting bracket suggested that something was screwed into the material below, which could mean the boom was made of wood. Based on the width of the surviving brackets, it had a diameter of approximately 5 in. (12.70 cm). While the boom served as a rigging point for raising and lowering the spar, little is known about exactly how it was configured. Neither Mazyck (Lunz 1957) nor McLauren (*Confederate Veteran* 1925) made mention of an additional boom. Perhaps the boom was considered part of the whole rigging system and did not merit special note.



Figure 14.15. Detail from Chapman's painting of Hunley showing a reel positioned aft of the snorkel box. (Detail from *H. L. Hunley* by Conrad Wise Chapman, courtesy of The Museum of the Confederacy, Richmond, Virginia)

Another component depicted in Chapman's painting was the aforementioned reel described by Mazyck as being rigged with a steel cable (Figure 14.15). In Chapman's original sketch, there is only a straight rod in the same position, which may have been the mounting point for a separate spool. No reel or rod was attached to the submarine when discovered, nor was one located in the surrounding sediment. Once the hull has been fully deconcreted, it may be possible to tell whether the reel was lost after the sinking or if it had been removed, for some reason, prior to leaving port.

Design Problems

After the war, several of *Hunley's* operational limitations were brought to light. Aside from the obvious drawback of being powered by hand, navigation was very difficult. In a letter to Matthew Fontaine Maury, McClintock described his experience with the compass, "which at times acted so slow, that the Boat, would at times alter her course for one or two minutes, before it would be discovered, thus losing the direct source, and so compell [sic] the operator, to come to the top of the water, more frequent than he otherwise would" (McClintock [1871]). This likely reflects McClintock's early involvement with the project, prior to its oversight by Confederate military, which had more resources and experience in equipping metal vessels with compasses. Alexander (1902c:83) noted that they used an "adjusted compass," suggesting this problem had been addressed sufficiently not to be a concern in Charleston.

McClintock also reported that "when under weigh beneath the surface it is quite impossible to ascertain whether the vessel is progressing" (Royal Navy 1872). He recalled several occasions where "they continued working the crank when all the time the boat was hard and fast in the mud" (Royal Navy 1872). The navy officers he met with seemed to think this would be an easy problem to overcome, again showing the value of

having the resources of a navy involved in the project. Alexander did not comment on this problem, but as the spar-based runs were conducted from the surface, he may not have been unduly hindered by it.

Lake's (1918:152) assessment of *Hunley* was that "she lacked longitudinal stability, and during her experimental trials twice dove head first to the bottom." The true design flaw, in his view, was not the length itself, but the internal water ballast tanks, which were not sealed off from the main body.

If free surfaces exist in the water-ballast tanks, the slightest change from a level keel causes the water to flow to the lower end of the ballast tank. This is apt to augment the inclination still further, and cause the vessel to dive. . . . The movement of the crew forward and aft, or the effect of the sea, which imparts a vertical motion to the water beneath the surface, all tend to destroy both trim and equilibrium to such an extent that many failures have resulted in vessels of this type (Lake 1918:154).

This flaw was also singled out by Alexander (1902e) in his letter to the Navy as the "fatal error in this boat. . . . Had the [bulkheads] been built close up the *Hunley* crew would not have been lost."

Conclusion

Hunley clearly demonstrated the experience the design team gleaned through two previous iterations of their submarine vessel—it was streamlined, better balanced, equipped with anti-fouling devices, and able to function in open sea, not just in harbors or inland waterways. Still, there was a fragile balance between safety and disaster that required expert, careful handling.

By examining the structural changes from *Pioneer* to *Hunley*, one can clearly see development and innovation based on experience gained from many hours in the water. The survival of the U.S. Navy's documentation of the salvaged *Pioneer* has provided a unique opportunity to study the early evolution of submarine design. Even though these boats did not directly influence future builders, such as Holland and Lake, together they provide a glimpse into the minds of late 19th century engineers and their transition from experts adapting their knowledge of boiler technology and surface ship design to authorities in the new field of submarine vessel development. It would have been interesting to see what advances could have been achieved had McClintock succeeded in his post-war goal to build a new submarine.

15. Artifact Assemblage

Shea McLean, Heather G. Brown, Robert S. Neyland , and Ben Rennison

The number of artifacts found during the recovery, a total of 341 lots, was relatively small for an archaeological excavation, especially one that went on for almost three months. Of the artifacts recovered, most were intrusive to the *Hunley* site, representing materials dropped in the area after the submarine's loss or that were carried along the bottom by the current until lodging against the hull or in the scour pockets that formed at the bow and stern. There were a small number of objects that came from the submarine itself, such as the rudder, snorkel tubes, and two metal brackets. Several other finds, including a section of rope and a piece of wood with tool marks, lacked diagnostic features enough to associate them with the submarine, but are consistent with materials that may have been employed on the vessel. All artifacts were brought to the Warren Lasch Conservation Center (WLCC) for cataloging and conservation. The primary diagnostic or potentially diagnostic artifacts are detailed below. A complete list of recovered materials is supplied in Appendix G.

Metals

HL-0378/-0381/-0386/-0428/-0432 — Iron Rod or Hoop

A cluster of concretions were recovered, primarily starboard of the bow, that preserved the original iron, in part, or the hollow mold of a cylindrical rod or wire with a diameter of ca. 0.5–0.6 cm (0.2–0.24 in.). One piece (HL-0432) was consistent in size and composition, but was found near the stern; however it showed a fresh break, suggesting it had been dislodged from its original position. The pieces curve gradually and likely originally formed a ring or hoop. Based on the largest preserved segment (HL-0428), the diameter was approximately 32 cm (12.60 in.) (Figure 15.1). The combined segments form a preserved circumference of roughly 82 cm (32.28 in.), or 81% of the projected total circumference.

The material was found just above the level of the bow, prompting the consideration that it was related to the spar rigging system. However, one would expect braided cable there, rather than solid iron. In addition, the thickness of the metal is too robust for wire, suggesting the piece acted as a stationary strengthening component. It seems unlikely that a solid iron hoop was employed anywhere on the exterior of the submarine. The metal is similar in gauge to a bucket handle, or bail, but those are semicircular, and the surviving pieces form almost an entire ring. Bails for canning jars involve a more complete circle around the neck, but generally are on a smaller scale than represented here. While its original use may never be learned, it is most likely that the object is intrusive to the site.

— HGB



Figure 15.1. Radiograph of HL-0428, the largest fragment of a heavily concreted curved iron rod. (Courtesy of FOTH)

HL-0463 — Galvanized Rod

A long, cylindrical, unidentified metal object was discovered just 1.5 m (4.92 ft.) to port of *Hunley's* bow, resting at an angle, from approximately 22 to 60 cm (8.66–23.62 in.) below the top of the hull (Figure 15.2). It has an overall preserved length of 4.97 m (16.31 ft.) and is composed of two sections of hollow metal rod joined together with what appears to be a modern cylindrical bolt or screw with a square head. The artifact's narrower section terminates in a shallow (approximately 25°) bend that does not appear intentional. Both sections of rod are approximately the same length, but have different diameters. The smaller section has a maximum preserved exterior diameter of 1.4 cm (0.55 in.); the larger section is consistently 2.2 cm (0.87 in.) in diameter for its entire length.

When recovered, the artifact was completely encased in a hard, thin matrix of gray corrosion products. To observe features obscured by concretion, conservators at the WLCC took x-ray images at four different points along its length. These included both ends and the area where the artifact's two sections are joined. Radiographs revealed a number of significant attributes that assisted project archaeologists in their analysis of the item. For example, each end of the artifact is threaded, drilled holes are present at two locations along its length, and 65.35 cm (25.73 in.) of the proximal end of the smaller component is loosely recessed into the larger section. The large diameter section has an overall length of 2.95 m (9.68 ft.), an interior diameter of 1.70 cm (0.67 in.), and an average wall thickness of 0.10 cm (0.04 in.). The interior diameter of its threaded end is 1.60 cm (0.63 in.)—the exact size of a standard $\frac{5}{8}$ in. threaded male pipe fitting. The narrow component is slightly shorter, with a preserved overall length of 2.68 m (8.79 ft.). It has an interior diameter of 0.91 cm (0.36 in.), an average wall thickness of 0.20 cm (0.08 in.),

and its threaded end exhibits an interior diameter of 0.34 cm (0.13 in.). Again, the threaded end compares favorably with a standard pipe fitting—in this case a $\frac{5}{16}$ in. male attachment.

Three sets of drill holes are present on the artifact. One set is located on the smaller-diameter section, immediately adjacent to the point where both components meet, and corresponds to holes drilled in the large-diameter rod. These holes have a preserved diameter of 0.66 cm (0.26 in.) and contain a small, square-headed metal pin with a preserved diameter of 0.48 cm (0.19 in.). The pin fastens the two sections of rod to one another. The remaining set of holes is located 13.26 cm (5.22 in.) from the small rod's proximal (obscured) end. It presumably would have held both sections together when the smaller section was pulled out to extend the overall length of the artifact. A band of rust around the circumference just below the joint may indicate where a clamp or bracket once held the rod in place (Figure 15.3).

Initially, project staff believed that the artifact was made of copper and may have been associated with the submarine's spar assembly. This was based primarily on its provenience (immediately adjacent and parallel to the spar) and the resemblance between its concretion layer and copper sulfide corrosion products. However, elemental analysis using x-ray fluorescence (XRF) revealed that its surface composition is approximately 2% lead, 4% iron, and 94% zinc. This indicates that HL-0463 was manufactured from galvanized steel.

The concept of coating ferrous objects with zinc to protect the iron from corrosion, known as galvanization, was developed more than 250 years ago. The most common process for doing this in the 19th century was "hot-dip galvanizing," a process of dipping the object into a molten zinc bath. Hot-dip galvanizing

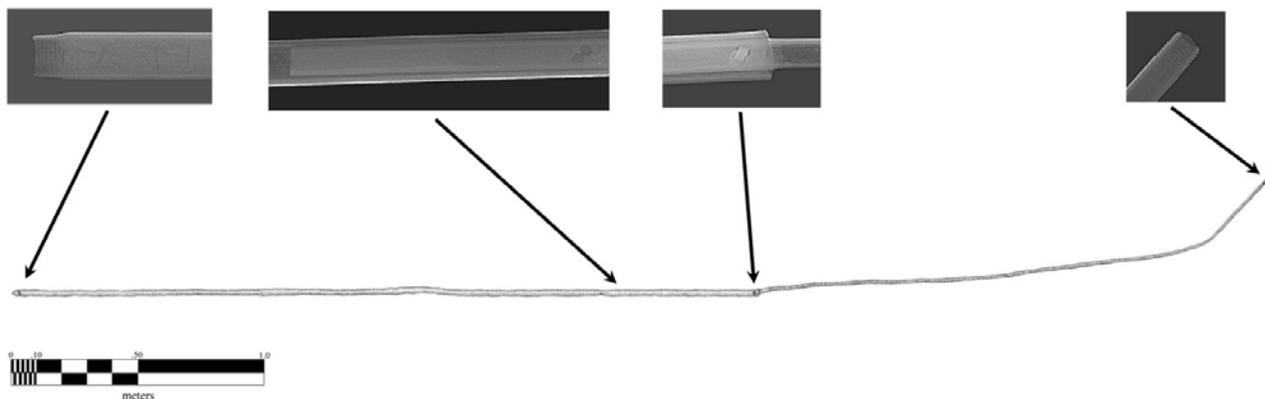


Figure 15.2. Galvanized steel rod found near the submarine's bow. Radiographic images show structural points of interest. (Illustration by James W. Hunter III)



Figure 15.3. Photograph of the joint shows a band of rust indicating the position of a possible clamp or bracket. (Photo by Michael Scafuri, courtesy of FOTH)

was first patented in France in 1836, but only became possible on an industrial scale after effective processes for cleaning iron and steel surfaces were developed (Habashi 2003). By the 1850s, the technique had been adopted in the manufacture of some of Great Britain's earliest telegraph cables (Celoria 1978). After 1890, hot-dip galvanization was a mainstay of the steel industry in the United States. Electroplating was also developed early, but was not practical on a commercial scale until the early 20th century (Bonney 1905:191). A hot vapor-based process called sherardization was patented in 1902 (Patent US701298 A).

Currently, the identity of the artifact remains unclear; however, attributes of its manufacture and construction revealed by radiographs strongly suggest that it is modern intrusive debris and not associated with *Hunley*. In overall appearance, it most closely resembles two sections of modern pipe that were modified into a single, adjustable object. The telescoping function suggests that it might have been a fishing outrigger, but the lack of any hardware for running line is problematic. It may have been electrical conduit for a deck light or other instrument. The previously unsuccessful surveys for *Hunley* undoubtedly involved probing in an attempt to locate magnetic anomalies, and it is also possible this object was used as an impromptu probe by divers, though its depth of burial suggests it may have been lost closer to the beginning of the 20th century.

— SM

HL-0526 — Bracket

A largely intact wrought-iron, D-shaped bracket assembly was discovered buried in coarse sand approximately 2.35 m (7.71 ft.) northwest of the upper edge of the starboard bow. It is composed of multiple components, including two straps, a round-headed rivet and a square-headed pin. The bracket has an overall length of 29.3 cm (11.54 in.) and a maximum width of 13.3 cm (5.24 in.). The straps comprising the bracket range in width between 2.4 and 6.3 cm (0.94–2.48 in.), depending on their level of preservation. The preserved thickness of each strap ranges between 0.4 and 1.1 cm (0.16–0.43 in.).

The flat nature of the metal points to its use as a bracket rather than a shackle, which would have had rounded edges to allow rigging lines to pass smoothly through it. Project archaeologists hypothesize that this piece of hardware, in conjunction with another, similar piece (HL-0582, below), probably held *Hunley's* wooden boom in place along the upper surface of the bow. A semicircular depression located along the forward upper extremity of the bow is most likely the remnants of a hole through which the bracket's iron pin was inserted and affixed to the submarine's hull (Figure 15.4). The bracket is closed, with no breaks or distortions, indicating the piece remained in place on the hull until erosion of the bow casting compromised the integrity of the hole through which it was attached (Figure 15.5).

Two fasteners bind the straps together and complete the bracket. The largest is a wrought-iron pin that has an overall length of 17.1 cm (6.73 in.) and a maximum preserved of 3.1 cm (1.22 in.). The head of the pin appears square in profile, exhibits a maximum



Figure 15.4. Project staff hold bracket HL-0526 against its hypothesized position on the submarine's bow casting. Note the square-headed fastener or nut for bracket HL-0582 immediately beneath the hole in the bow casting. (Detail of photograph by Susanne Grieve, courtesy of FOTH.)



Figure 15.5. Forward spar assembly bracket (HL-0526). (Illustration by Bruce Thompson.)

width of 4.6 cm (1.81 in.) and a maximum preserved thickness of 2.0 cm (0.79 in.). Conversely, the pin may be round-headed and have a threaded end to which a square-shaped nut is affixed. Ferruginous concretions and mineralized deposits obscure the point at which the pin, square-headed head or nut, and bracket strap meet; consequently, an accurate assessment of the pin's construction is presently impossible. A small 2.3 cm (0.91 in.) long round-headed rivet holds both straps together at the apex of the bracket. The rivet has a maximum preserved diameter of 2.0 cm (0.79 in.) and appears to have been peened on both ends to hold it in place. According to Bruce Thompson (pers. comm.), the bracket's construction attributes suggest that it was assembled by one of the following two scenarios:

A) Two wrought-iron straps with 2.5 cm (1 in.) diameter holes cut into the face of one end were forged together, and further secured with an iron rivet. The rivet head was located on the exterior surface of the strap, while the peened end rested against the interior surface. This composite strap was then bent on an 11.2 cm (4.41 in.) diameter round to form a U-shape. A square-headed pin was then inserted through the end holes and peened over on the outer strap surface.

B) The construction process was exactly identical to that outlined above, except that a round-headed pin was inserted through the end holes (in place of a square-headed pin) and a square nut used to cinch the straps in place.

A cut or gash approximately 2.0 cm (0.79 in.) long is visible on the surface of the peened side of the pin. This damage may have occurred at the time of the engagement (i.e., debris from the explosion caused by *Hunley's* torpedo glanced off the pin, marring it). Conversely, it may have occurred at some point following the submarine's loss and deposition on the seafloor. The mark does not appear to have been intentionally produced at the time the bracket was constructed.

— SM

HL-0555 — Aft Cutwater

A flat triangular shaped piece of heavily concreted wrought iron was identified as the submarine's aft cutwater, a piece that was originally mounted along the centerline of the hull, attached to the leading edge of the aft conning tower to prevent fouling (Figure 15.6). The artifact was discovered forward of the aft hatch, 100 cm (39.37 in.) below the top of the hull on the starboard side. The piece became dislodged from the hull following *Hunley's* loss and was discovered during the excavation.

At its longest point, the piece measures 108 cm (42.52 in.), it is 26 cm (10.24 in.) high where it abutted the conning tower. The surviving length of the hypotenuse is 106 cm (41.73 in.), but there is some metal loss along this edge, particularly at the end that was in contact with the conning tower, and there is a semi-



Figure 15.6. Starboard side of aft cutwater (HL-0555). Bolts A and B likely functioned as rigging points. (Photograph by Paul Mardikian, courtesy of FOTH)

circular area of loss about halfway down its length. The average thickness of the metal plate is 0.80 cm (0.315 in.). The bottom corner of the cutwater was cut away to fit over the seam where the conning tower attached to the hull plate. A bolt or rivet hole survives approximately halfway down the back edge to assist in the mounting of the piece to the hatch coaming.

Two through bolts are attached to the object along the midline of the cutwater. The bolts are positioned (A) 32 cm (12.60 in.) and (B) 83 cm (32.68 in.), respectively, aft of the forward end of the piece. Bolt A stands off 5.4 cm (2.13 in.) from the starboard surface, and originally stood off 5.74 cm (2.26 in.) from the port side, although 3.7 cm (1.46 in.) of that is preserved only as a silicon cast. The head of bolt A measures 1.3 cm (0.51 in.) in diameter, and the attached nut measures 2.64 x 2.82 cm (1.04 x 1.11 in.) with a thickness of 1.3 cm (0.51 in.). Bolt B protrudes from the starboard side and is bent aftward, with a length of 4.91 cm (1.9 in.). Its head measures 1.0 cm (0.39 in.) in diameter. Project archaeologists believe the aft bolt point may have been used to hold the aft hatch cover open by a section of chain or rope. The forward bolt may have also been used for this purpose, although access to it from inside the submarine would have been restricted by the open hatch cover. It may have also have been a mounting point for a stay or other hardware related to the original towed torpedo design. The object is still in conservation limiting a closer inspection at this point.

—BR

HL-0582 — Bracket

A fragmented and heavily degraded wrought-iron bracket, similar in size and construction to HL-0526 (see above), was located in coarse sand immediately adjacent to the extreme forward end of *Hunley's* starboard bow. It comprised the majority of a

ferrous concretion that also contained a tin can (HL-3288) and a wooden tool handle (HL-3289). The artifact has an overall preserved length of 24 cm (9.45 in.) and originally had a maximum width between 13 and 14 cm (5.12–5.51 in.). Unlike HL-0526, HL-0582 appears to have been formed from three wrought-iron straps. These components were welded or otherwise joined together on either side of the bracket, near its apex. One arm of the U-shaped strap is bent outwards—likely the result

of violent action—and increases the maximum the distance between the strap ends to 20.6 cm (8.11 in.) (Figure 15.7). The composite strap that comprises the bracket exhibits a preserved width ranging between 2.5 and 7.4 cm (0.98–2.91 in.), and a maximum preserved thickness of 1.3 cm (0.51 in.).

Neither of the fasteners observed on HL-0526 is evident on HL-0582; however, the remnants of two 2.4 cm (1 in.) diameter fastener holes are located near the base of the composite strap. These holes presumably held the iron pin that affixed the bracket to the hull. A wrought-iron bolt similar in size and appearance to the large iron pin on HL-0526 is affixed to *Hunley's* upper bow structure. Based on the aforementioned attributes, project archaeologists believe that this bolt marks the location on the submarine where the bracket was originally attached.

A 1.7 cm (0.67 in.) diameter circular hole is located slightly off center from the apex of the bracket. The hole contains four 0.2 cm (0.078 in.) threads and would have accepted a threaded bolt of the same size. The purpose of this bolt is presently unclear; however, it may have penetrated the wooden support boom to help secure it in position against the upper surface of *Hunley's* bow. The reason why this bracket held a threaded bolt and the other a peened rivet remains an open question.

There is clear evidence that the bracket was badly damaged either during, or after, the submarine's loss. The bent strap arm and broken fastener holes both strongly suggest that the piece was violently wrenched from its original position. This hypothesis is further reinforced by the bracket's iron pin, which remains firmly attached to the hull. Whatever removed the piece from the submarine exerted enough force to bend the strap and break the holes through which the pin was inserted, but was not strong enough to remove the pin from the hull.

— SM

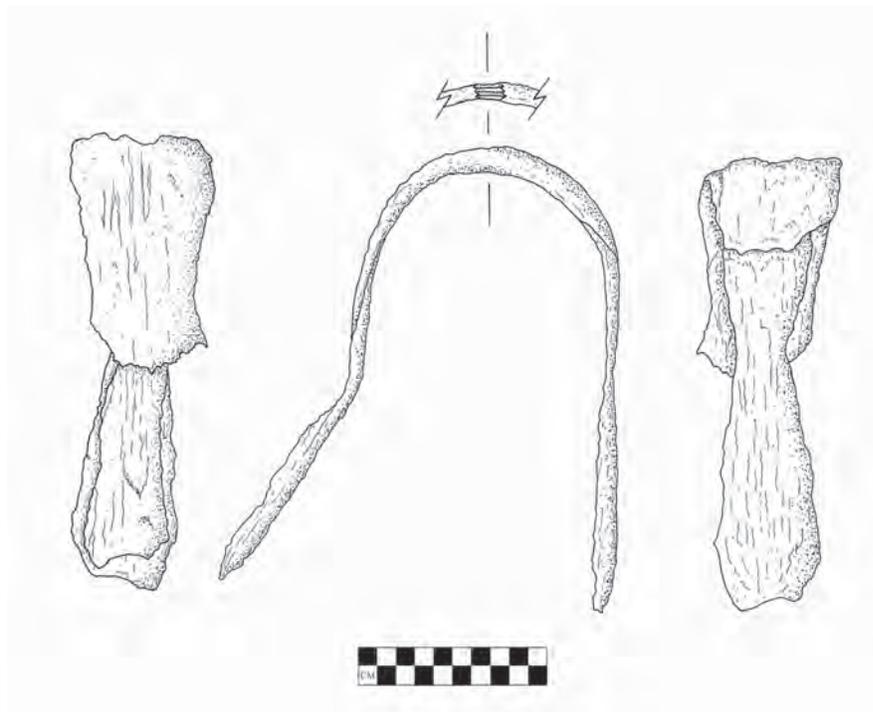


Figure 15.7. Aft spar assembly bracket (HL-0582). (Illustration by Bruce Thompson.)

HL-0614/HL-0615 and HL-0616 — Snorkel Tubes.

Three sections of heavily degraded wrought-iron pipe were discovered on the starboard side of the submarine lying approximately 80 cm (31.50 in.) below the top of the hull and 39 cm (15.35 in.) to starboard (Figure 15.8). Based upon their size, shape, and composition the items have been identified as sections of the air intake and exhaust pipes formerly connected to the snorkel box (see Figure 12.13).

Artifacts HL-0614 and HL-0615 appear to be from one piece of pipe that broke into two sections after disarticulation from the hull. The two sections measure 66.5 cm (26.18 in.) and 82 cm (33.07 in.) respectively. HL-0616 measures 140 cm (55.12 in.) as one whole

section. Each of the sections is cylindrical in shape and has open ends that were completely filled with sediment when discovered. The exterior surfaces were heavily covered in marine concretion. Once this was removed it became apparent that both ends of each pipe were threaded. Their interior diameters measure 4.1 cm (1.61 in.) and they correspond with the two mounting points that can be clearly discerned on the snorkel box. It is likely that the tubes became disarticulated from the submarine after it came to rest and canted to starboard, since both pipes were found to starboard of the hull.

—BR

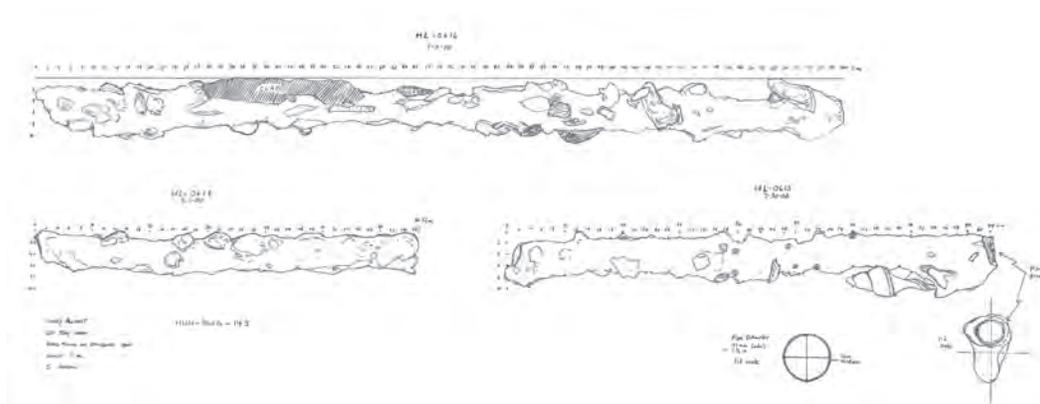


Figure 15.8. Field drawing of snorkel tubes showing their heavily concreted state. (Illustration by Shea McLean, courtesy of FOTH.)



Figure 15.9. Paul Mardikian holds starboard shroud attachment bar (HL-0660) in corresponding port position on a full-scale print of the submarine. (Photo by Philippe de Vivies, courtesy of FOTH)

HL-0660 — Shroud Attachment Bar

A long, thin metallic concretion was found roughly parallel to the starboard side, connected to the hull at one end, just forward of the aft stern hole, near the top edge of the expansion strake. The detached end terminated 14 cm (5.51 in.) forward of the aft conning tower. Due to the fragility of the connection point, the piece was detached from the hull prior to lift. The concretion was removed to expose a long, flat iron bar or strap, measuring 1.78 m (5.84 ft.) in length, 3.0 to 3.6 cm (1.8–1.42 in.) in width, and 1.49 cm (0.59 in.) thick (Figure 15.9). The edges of the artifact show signs of deterioration.

The object was identified as the starboard shroud attachment bar, originally running from the propeller shroud to the expansion strake near the seam of the second and third quarter plates from the stern. Labeled as “Shroud Guard” in the sketch from McClintock’s (1872) meeting with the British Admiralty, the piece was apparently designed to prevent fouling of the propeller and damage to the shroud. It may also have provided some lateral stability to the shroud, which was mounted to the stern at the top and bottom.

At some point after sinking, the piece was detached from the shroud and bent forward nearly 180°, deforming the metal at the point of attachment to the hull plating. Given its final position, it seems unlikely that this could have occurred after the submarine’s tilting to starboard. The surviving length is too short to reach the propeller shroud and no adjoining piece was found adjacent to its final position, suggesting that a

portion of the bar broke off during the initial incident that pulled the attachment bar forward on its axis.

—HGB

HL-0683 — Length of Iron Bar

A heavy concretion was found at the starboard side of the submarine, near the aft stern hole. The concretion was removed to reveal a section of flat, wrought-iron bar, most of which was preserved metal (Figure 15.10). One end contained a void from which a polyurethane cast was made. The artifact measures 46 cm (18.11 in.) in length, with a maximum thickness 0.6 cm (0.24 in.). The width tapers from 3.5 cm (1.38 in.) at its widest point to 2.2 cm (0.87 in.) at the cast end. The wider end tapers sharply to a rounded point, though whether this was its initial shape or a result of post-depositional processes is difficult to determine. No fastener holes or other attachment points were found.

Conservator Paul Mardikian (2014 pers. comm.) noted that the x-rays did not show the usual distinct demarcation of the original surface of the object and that the concretion layer closely conformed to the areas of damage and metal loss. He suggested that the object might have suffered some damage after it had begun to concrete, and subsequently a new concretion layer formed over resulting areas of fresh metal exposure. The end recovered through casting shows evidence of elongation, possibly reflecting a deformation related to its disarticulation from the submarine.

The piece is consistent in width with the starboard shroud attachment bar (HL-0660), although it is 0.89 cm (0.35 in.) thinner, so it does not appear to be the missing adjoining piece of that component. The piece may be related to the rudder steering assembly, but it is less than 1 cm (0.39 in.) narrower than the various wrought-iron pieces concreted to the rudder (HL-0686). While its original position on the submarine cannot be determined, its material and shape is consistent with elements from *Hunley* and likely was associated with the steering assembly.

—BR/HGB



Figure 15.10. Cast of a wrought-iron bar (HL-0683) found near the rudder. (Photo by Virginie Ternisien, courtesy of FOTH)

HL-0684 — Rivet Head

A small ferrous concretion was found 80 cm (31.50 in.) below and 27 cm (10.63 in.) to starboard of the top of the stern. Its overall size is 7.3 × 5.0 × 5.0 cm (2.87 × 1.97 × 1.97 in.). X-rays revealed that the concretion contains the remains of an iron rivet head and partial shaft (Figure 15.11). The maximum preserved width is 2.37 cm (0.93 in.) and maximum preserved length is 1.83 cm (0.72 in.). Its size and the flattened mushroom shape are consistent with *Hunley's* hull rivets as they appear on the interior surface of the hull plates. Positioned almost directly below the hole in the stern, this piece most likely originated from the seam between the cast-iron stern piece and the upper starboard quarter plate. As the metal deteriorated from the erosion-corrosion processes affecting the stern (Jacobsen et al. 2012), the rivet was dislodged and deposited on the seabed. See also HL-0705.

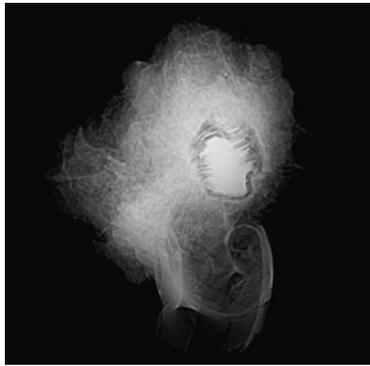


Figure 15.11. Radiograph of concreted rivet (HL-0684). (Courtesy of FOTH)

—HGB

HL-0685 — Iron Spike

A small ferrous concretion was found 80 cm below and 30 cm to starboard of the top of the stern. Its overall size was 14.0 × 9.0 × 6.5 cm (5.51 × 3.54 × 2.56 in.). Based on x-ray imaging, it was determined that no original metal survived and a polyurethane cast was

made of the void (Figure 15.12). The preserved shape proved to be a rectangular shafted spike with a square head with a raised dome in the center. The surviving length of the shaft is 12.5 cm (4.92 in.), although it appears the tip was broken off. The square head is approximately 1.4 × 1.4 cm (0.55 × 0.55 in.). The rectangular shaft is consistent with late 18th to late 19th century production. This type of spike is ideal for use in wood; however since no other hardware from the rudder has yet been found, its use as part of the rudder assembly was considered. This was ultimately ruled out, as the moving joints would require cylindrical hardware. The spike is more likely intrusive, possibly from the wooden-structured *Housatonic*.

—HGB

HL-0686 — Rudder

The rudder was discovered directly beneath the stern of the submarine, lying diagonally across the keel line. It was heavily concreted with a large amount of shell encrustation (Figure 15.13). Its overall measurements, after deconcretion, are 78 × 53 × 0.6–0.75 cm (30.71 × 20.87 × 0.26–0.30 in.) and it weighs 38.3 kg (84.44 lb.). The rudder is of a flat rectangular shape and made of a single piece of wrought-iron plate, most likely originally $\frac{3}{8}$ in. thick, the same gauge as the hull plating.

The remains of one cast-iron mounting bracket is located on the leading edge of the rudder, 12 cm (4.72 in.) below the surviving top edge, canted at approximately a 45° angle. The bracket arms are 0.6 cm thick on each side of the rudder plate. The bracket body, forward of the rudder's leading edge, is 4.4 cm (1.73 in.) thick and appears to have broken off. Its surviving length is 6.2 cm (2.44 in.). A single rivet or peened bolt, 2.6 cm (1.02 in.) in diameter, secures the bracket to the rudder plate. The remains of a second mounting bracket are positioned vertically along the



Figure 15.12. Cast of a dome-headed spike or nail (HL-0685) found in a concretion near *Hunley's* stern. (Photos by Paul Mardikian, courtesy of FOTH)



Figure 15.13. Port side of rudder (HL-0686) before conservation (left) and after conservation (right). (Photos by M. Scott Harris (left) and Johanna Rivera (right), courtesy of FOTH)

bottom corner of the leading edge, broken off at the bottom edge for a surviving length of 6.3 cm (2.48 in.). It is 4.1 cm (1.61 in.) wide, and the rivet or bolt head is 2.6 cm (1.02 in.) in diameter. The mounting points do not resemble a traditional pintle-and-gudgeon design.

In the center of the rudder is a horizontally-oriented oblong hole, roughly 8.1 × 0.9 cm (3.19 × 0.35 in.). Partially overlapping this are two wrought-iron straps, one on each side, with a surviving length of 33.4 cm (13.15 in.) connected by a rivet or bolt, that extend aft at a slight incline beyond the after edge of the rudder. These straps likely originally pivoted up and down as part of the steering mechanism. The metal at the after end of the straps appears somewhat deformed upward, suggesting the adjoining steering arm was torn away.

While both the mounting brackets and the steering component were all broken, the rudder plate itself shows little damage. The trailing edge has the most loss, including diagonal breaks at both corners. There are numerous semicircular patches of metal loss, the largest of which are one 8.7 cm (3.43 in.) long, 2.4 cm (0.94 in.) down from the surviving top edge, and one 6.6 cm (2.60 in.) long, approximately 17 cm (6.69 in.) up from the surviving bottom edge. The remaining edges, particularly the top and bottom, are well preserved, although there is a roughly rectangular break at the upper forward corner above the top mounting bracket. Both plate faces have many small patches of minor loss due to delamination and pockmarks but none that penetrates the full thickness of the metal.

—HGB

HL-0705 — Rivet Head

A small ferrous concretion was recovered from dredge spoil from the starboard side of the stern, roughly below the hole in the hull plating. Its overall size is 8.3 × 6.0 × 5.0 cm (3.27 × 2.36 × 1.97 in.). X-ray images revealed that the concretion contains the remains of an iron rivet head (Figure 15.14). The maximum preserved width is

2.30 cm (0.91 in.) and maximum preserved length is 1.92 cm (0.76 in.). It is similar in size and shape to the rivet found in HL-0684, but the shaft is more deteriorated and the top of the head is somewhat distorted. Despite poor preservation, the rivet is still consistent with *Hunley's* hull rivets as they appear on the interior surface of the hull plates. As with HL-0684, this piece most likely originated from the seam between the cast-iron stern cap and the upper starboard quarter plate. As the metal deteriorated from the erosion-corrosion processes affecting the stern (Jacobsen et al. 2012), the rivet was dislodged and deposited on the seabed.

—HGB

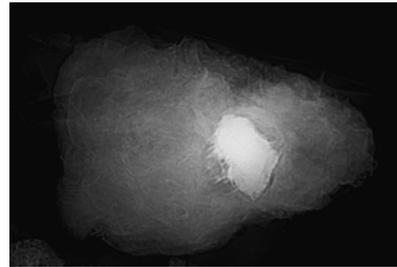


Figure 15.14. Radiograph of concreted rivet head (HL-0705). (Courtesy of FOTH)

HL-2917/HL-2918 — Grapnel Anchor and Iron Ring

During the magnetometer survey that was conducted in 2001, a year after *Hunley* was recovered, the sensor detected a deeply buried magnetic anomaly at the edge of the original excavation boundary to starboard of *Hunley*. Upon investigation, this anomaly was found to be a concretion containing a wrought-iron grapnel (HL-2917) (Figure 15.15). It was embedded in the Pleistocene mud at the same level as the keel. Three of the five arms had been caught in the Pleistocene mud, one of which was distended by at least

7 cm (2.76 in.) and the others had extended above the sea floor (Thompson 2005). The latter arms were heavily concreted with marine growth and were more corroded in contrast to the buried ones, which were better preserved. It appeared as if the anchor had buried three hooks in the mud when it was lost.

The grapnel was located approximately 5 m (16.40 ft.) from the submarine. The shank of the grapnel pointed toward the hull roughly in the direction of the forward conning tower. The grapnel has a shank length of 83 cm (32.7 in.) with lower and middle shaft diameter of 4.1 cm (1.6 in.) and upper shaft diameter of 5 cm (1.97 in.). The hole in the end of the shank that received the iron ring is 2.5 cm (1 in.) in diameter. The ring (HL-2918) has an outer diameter of 11.2 cm (4.4 in.) and inner diameter 8.5 cm (3.36 in.) and thickness of 1.5 cm (0.6 in.). The anchor weighs only 8.1 kg (17.86 lb.).

The curved arms each had a length of 45.7 cm (18 in.) and diameter of 1.9 cm (0.75 in.). Maximum distance between opposing arms is 50 cm (19.69 in.). Only two flukes survived intact, the largest of which had a length of 6.4 cm (2.52 in.) and breadth of 3.8 cm (1.5 in.), and thickness of 1 cm (0.4 in.). The flukes were created by hammering the wrought-iron claw to form two lobe-like protrusions rather than attaching a separate piece of metal for the fluke. The grapnel was forged from wrought-iron bars hammered together to form a single construction. Grapnels, particularly those used for anchors, sometimes have a reinforcement band placed around the lower shank and beginning of the claws for added strength and reinforcement (Jeanne Willoz-Egnor, pers. comm. 2012), though that feature was lacking on HL-2917.

There was no evidence of chain links attached to the ring. Only the iron ring for attaching the rope or chain to the grapnel was found. Although, since the

ring was not intact, it is possible it could have broken away from the chain. A grapnel used for anchoring a boat would possibly require a length of chain to help hold fast to the bottom.

The use of grapnels on ships for anchoring, salvage, and combat is quite ancient. In the 17th and 18th centuries ship's boats were each issued a grapnel depending on the boat's size. The 33 ft. (10 m) longboat of a First Rate ship would have a grapnel of 84 lb. (38 kg) and a 33 ft. (10 m) pinnace one of 56 lb. (25.40 kg). In the 1800s, a 74-gun ship's barge of 32 ft. (9.75 m) would have a grapnel of 84 lb. (38 kg) and the launch of 31 ft. (9.5 m) one of 56 lb. (25.40 kg). Other smaller boats were to carry one each of 40 lb. (18.14 kg) (Lavery 1987:228). There are three types of grapnels mentioned by David Steel in *The Elements and Practice of Rigging and Seamanship* (1794). These consist of boat anchor grapnels, fire and hand grapnels, and creepers (Figure 15.16). Each serves a different purpose:

GRAPNEL, or GRAPPLING, is like a small anchor, with four or five flukes, or claws, used in small vessels or boats to ride at.

FIRE-GRAPNELS resemble the former, are from eighteen to twenty pounds weight, and have strong barbed claws, with a chain to the ring. They are used by fire-ships.

CREEPER is like a small anchor, with four hooks, or claws, used in recovering any thing from the bottom of rivers, &c. (Steel 1794:80)

Boat grapnels are in weight from 112 lb.



Figure 15.15. Five-tined grapnel anchor (HL-2917) and ring (HL-2918) after conservation treatment (Photo by Chris Watters, courtesy of FOTH).

[50.80 kg] to 36 pounds [16.33 kg]. Fire and chain grapnels weigh about 70 pounds [31.75 kg], and bear the same proportion with the hand and chain; grapnels and creepers are made of wrought-iron, and shaped agreeably to the plate. The shanks are round, and have an eye wrought in the upper end, to receive the ring, the ring being put through, and the ends firmly shut together. The shank is left longer than the nett length above, for weldiug [sic] on the claws. Flukes are shut on the extremities of the claws of boat-grapnels, and barbs are made from the solid of fire-grapnels. The claws are welded on to the lower-part of the shank, and spread from the same, at the end, one-third the length of the shank, in boat-grapnels; three-fourths in fire-grapnels; and half the length of the shank in creepers (Steel 1794:82).

Fire grapnels were fixed to the yard arms or thrown by hand to secure the fire ship to its adversary or by other ships to hold the combatants fast for boarding (Falconer 1769:128, 140). The 18th century naval warfare employment of fireships had been out of use for some time by 1864, thus the fire grapnel type would not apply to HL-2917. The exaggerated, barbed flukes of this type were also lacking on the example from the *Hunley* site. It would appear HL-2917 was either a small

boat grapnel or a creeper type used in salvage.

None of the known accounts of *Hunley's* operation mention it carrying an anchor of any form. It is not unlikely that this would have been a recognized need to prevent being swept out to sea by the current. However, deploying an anchor from a vessel with a low freeboard would have caused some risk of swamping. The other possibility for the grapnel is that it was lost by the U.S. Navy during attempts to drag for the submarine (see Chapter 4). Navy records report that the area was dragged for 500 yd. (457 m) around the wreck of *Housatonic* in an attempt to locate the submarine. Although drag ropes reportedly caught something heavy in one instance, the snag was identified by a diver as nothing but debris (ORN 1.15:334).

U.S. Navy ships carried grapnels of various sizes on its ships. The size of these was to be determined by a ratio in relation to the weight of the bower anchor. For a bower over 7,500 lb. (3,402 kg) the ship would have two grapnels each weighing between 140 to 70 lb. (63.50–77.11 kg). In contrast, a ship with a bower less than 800 lb. (363 kg) would require a grapnel of 25 lb. (11.34 kg). Anchor buoys deployed by the ship also required grapnels of from 15 to 10 lb. (6.80–4.54 kg), depending on the size of the bower anchor (DON 1864b:37; 1890:14). Besides recovering lost objects from the bottom, light grapnels were used to locate and detonate mines (Barnes 1869:180; Stotherd 1872:272). They have also been used to anchor fishing nets.

Grapnels used as small boat anchors work best

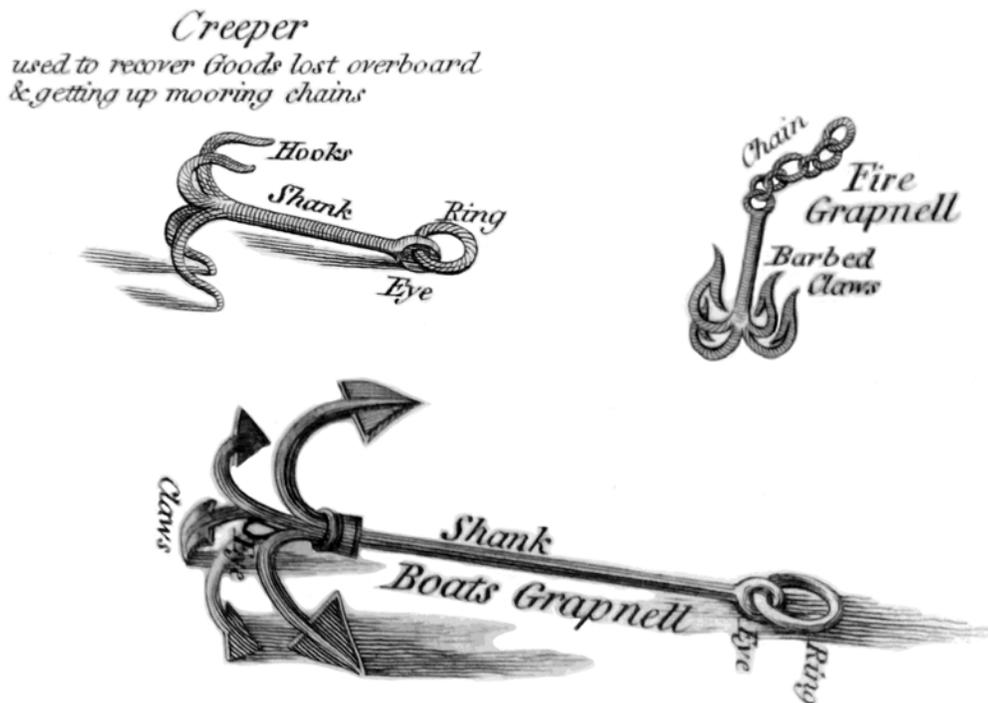


Figure 15.16. A grapnel, fire grapnel, and creeper as illustrated in Steel (1794).

in rocky bottoms or on a beach where they can take purchase in a crevice. Today they are used for boats of not over 3 tn. (2.72 t) displacement, are not considered efficient anchors, and do not work well in sandy or muddy bottoms such as that found in the area of the *Hunley/Housatonic* engagement site (De Kerchove 1961:335; McEwen 2006:190). At roughly 18 lb. (8 kg), HL-2917 seems too light to effectively hold *Hunley* or any boat except one that is very small. In addition, no chain to hold the line down to the bottom indicates it was not used as an anchor. It is likely that it was lost during the Navy's attempts to drag for the *Hunley* and is an indication that the dragging occurred near and perhaps over the submarine. The arms buried in the Pleistocene mud also suggest that there was not a great deal of sediment over this mud layer at the time of loss.

— RSN

Tin Cans

Several complete iron cans, partial cans, and many can fragments were recovered from the sediment matrix surrounding *Hunley*. At least four cans, HL-0653, HL-0654, HL-3667, and HL-3678, were found concreted to the hull itself. The first three of these were found on the port side or bottom of the keel; the last was found on the starboard side, roughly 125 cm (49.21 in.) forward of the aft conning tower, at the level of the expansion strake. HL-0700 was found 37 cm (14.57 in.) starboard of, 15 cm (5.91 in.) forward of, and 66 cm (25.98 in.) below the top of the stern. HL-3288 was found adjacent to the starboard bow.

Historic cans are most easily dated by their labels, which do not survive in this case. Rough periods of production can be gleaned from manufacturing technique, including cap style, seam type, and solder application. In the case of *Hunley* cans, the primary surviving diagnostic features are lead solder and cap style. While canned goods were invented in the late 18th century, their production and distribution increased substantially during and after the Civil War (Busch 1981:97). The earliest cans were assembled by hand, with simple overlapping seams soldered manually (Rock 1984:99). The introduction of machine soldering of side seams in 1883 allowed for smaller, more regular seams (Rock 1984:103).

Cap styles were dictated in part by the can's contents. Dry goods, such as tobacco and coffee could have a simple removable lid that fits over the walls of the can as needed, sometimes called an external friction or slip lid (Rock 1987:10). For liquid and perishable foodstuffs, the hole-and-cap style was most commonly used. In this design, a lid with a ca. 1–2 in. (2.54–5.08 cm) diameter hole in the center was fixed to the body of the can, usually by folding the metal edges over each other and sometimes reinforcing them with solder. The

contents were then inserted through the central hole, which was filled with a smaller cap that was soldered in place. When the contents needed to be heated for proper preservation, a small vent hole was punched in the secondary cap for steam to escape. Once heating was complete, the hole was sealed with a small drop of solder (Figure 15.17). The open top sanitary can, which incorporated a single-piece lid, with or without a vent hole, was introduced in 1904 and had almost completely replaced the hole-and-cap design by 1920 (Busch 1981:98).

Of the cans recovered at the *Hunley* site only four were complete enough to preserve dimensions of the original can; approximate measurements were extrapolated for two additional crushed cans (HL-3667 and HL-3678) (Table 15.1). Due to irregularities in preserved surfaces, measurements were rounded to the nearest eighth of an inch (3.18 mm). Three (HL-0654, HL-0700, and HL-3288) could be clearly identified as vented hole-and-cap cans with machine-soldered side seams. Based on manufacturing style, the cans appear to date between 1885 and 1920. The secondary cap on HL-3288, however, appears to have been hand soldered, placing it in the earlier half of that time range.

Some attempt to record common can sizes and their contents has been made (University of Utah et al. 1992; Rock 1987:76–90); however, dimensions were not standardized until the early 20th century, when cans

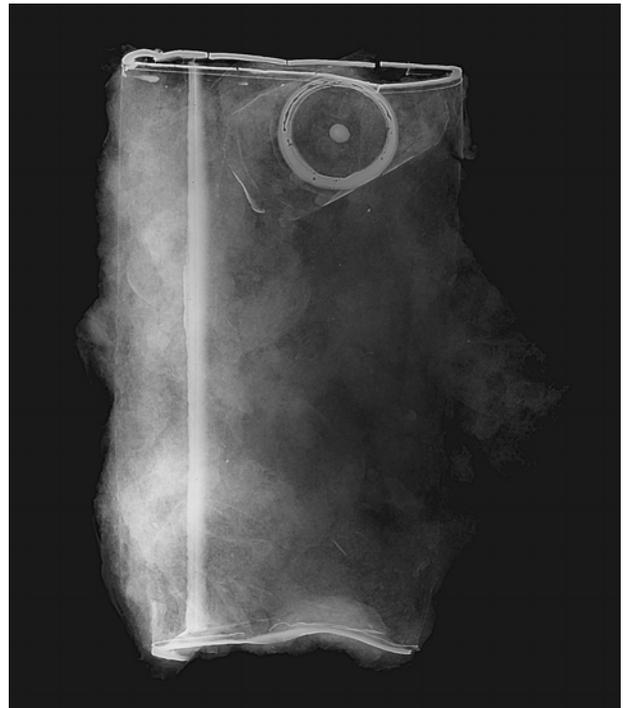


Figure 15.17. A radiograph of the heavily concreted HL-3667 shows a preserved vented cap typical of late 19th century manufacture. (Courtesy of FOTH)

were given numerical designations from smallest to largest. The most common of which were No. 2, No. 2½, No. 3, and No. 10. The dimensions of these sizes were measured to the closest sixteenth of an inch (1.59 mm) and changed somewhat over the years, making identification of unmarked cans challenging. In addition, it can be difficult to acquire measurements on archaeological cans from underwater environments to the precision used by the manufacturers, due to deterioration, concretion, and distortion.

By comparing the dimensions of *Hunley* cans to other known can sizes, we can also see a late 19th to early 20th century date range (Figure 15.18). A group of canned goods recovered from the 1865 wreck of the steamship *Bertrand* in the Missouri River provides comparative size data for cans contemporary with *Hunley* (Petsche 1974). A partial inventory of the collection gives an excellent idea of the types of canned products available at the time (Table 15.2). Based on surviving labels, the majority of the cans were manufactured in Baltimore, Maryland. The vented hole-in-cap cans in the collection generally contained fruit products and frequently came in 2 lb. (0.91 kg) portions, so the can dimensions may have been influenced by a product’s volume per weight rather than desired container size.

It is not until the widespread use of canning machines and the separation of can manufacturers from canning plants in the last two decades of the 19th century that we begin to see the standardization of can

Table 15.1. Dimensions of Cans from the Hunley Site

| Can ID# | Height | | Diameter | |
|---------|--------|-------|----------|-------|
| | in. | cm | in. | cm |
| HL-0653 | 7 7/8 | 20.00 | 5 1/2 | 13.97 |
| HL-0654 | 11 | 27.94 | n/a | n/a |
| HL-0700 | 5 1/2 | 13.97 | 4 1/3 | 11.00 |
| HL-3288 | 4 7/8 | 12.38 | 4 | 10.16 |
| HL-3667 | 9 7/8 | 25.08 | 4 3/4 | 12.07 |
| HL-3678 | 7 7/8 | 20.00 | 5 7/8 | 14.92 |

sizes. A list of standard sizes from 1917 (Rock 1987:92) has been used as proxy data for post-1880 mechanized production. HL-0700 and HL-3288 are within range of standard dimensions (No. 3 [5 1/2]¹ and No. 2 1/2, respectively) from 1917, suggesting post-1880 deposition. HL-0653, HL-3667, and HL-3678, are larger than the standard No. 10, making them difficult to identify, but one is near in size to one of *Bertrand’s* coffee cans.

While it is possible some of the cans found at the *Hunley* site came from the wreck of *Housatonic*, manu-

1 There were three No. 3 can sizes, each with the same diameter but different heights: 4 7/8, 5, and 5 1/2 inches.

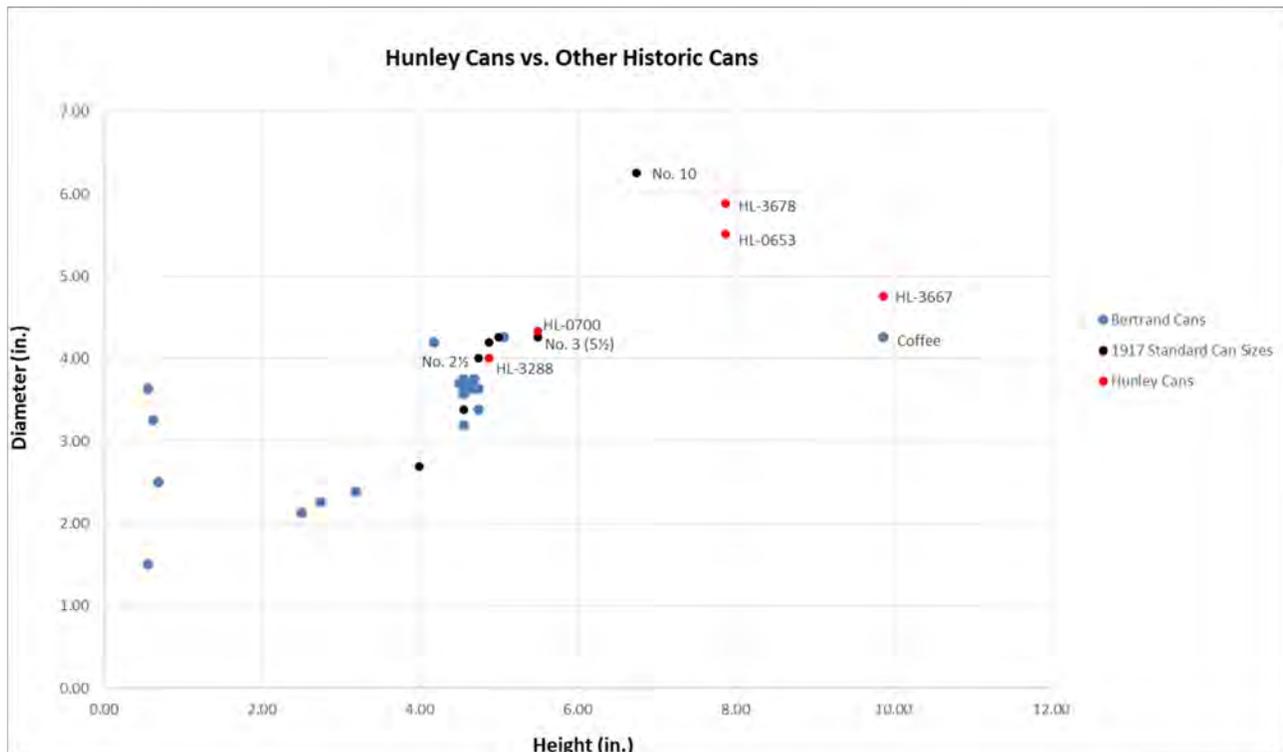


Figure 15.18. Comparison of known can sizes to those found at the Hunley site.

Table 15.2. Canned Goods from the Steamship Bertrand

| Contents | No. Found | Shape | Lid Type | Manufacturer Location | Source |
|-------------------|-----------|-----------------------------|----------|---------------------------------|--------|
| Coffee | 24 | Cylindrical | EFS | Cincinnati, OH | R |
| Cranberry Sauce | - | Cylindrical | HAC | Bridgeton, NJ | R |
| Essence of Coffee | 30 | Cylindrical | EFS | Philadelphia, PA | R |
| Gooseberries | 6 | Cylindrical | VHAC | Baltimore, MD | R |
| Lard | 15 | Rectangular | HAC | - | R |
| Lemonade | 150+ | Cylindrical | EFS | Boston, MA | R |
| Mustard | 7 | Cylindrical | EFS | Boston, MA | R |
| Oyster | 40+ | Cylindrical | VHAC | New York, NY; -Baltimore, MD | R |
| Peaches | 2 | Cylindrical | HAC | - | R |
| Peaches | 4 | Cylindrical | VHAC | Baltimore, MD | R |
| Peaches | 40+ | Cylindrical | VHAC | Baltimore, MD | R |
| Peaches | 15 | Cylindrical | VHAC | - | R |
| Peaches | 20+ | Cylindrical | HAC | Baltimore, MD | R |
| Percussion Caps | 60+ | Cylindrical | EFS | London, UK | R |
| Pineapple | - | Cylindrical | VHAC | Philadelphia, PA | R |
| Sardines | 1 | Rectangular | - | Les Sables-d'Olonne, FR | R |
| Shoe Blacking | 1 | Cylindrical | EFS | - | R |
| Shoe Blacking | 17 | Cylindrical | EFS | Philadelphia, PA | R |
| Shoe Blacking | 14 | Cylindrical | EFS | - | R |
| Strawberries | 2 | Cylindrical | VHAC | - | R |
| Strawberries | 15 | Cylindrical | HAC | Baltimore, MD | R |
| Tomatoes | 1 | Cylindrical | HAC | Baltimore, MD | R |
| Tomatoes | 15 | Cylindrical | VHAC | Baltimore, MD | R |
| Wagon Grease | 30+ | Cylindrical | EFS | - | R |
| Yeast | 600+ | Cylindrical | EFS | Boston, MA | R |
| Cherries | 24+ | - | - | - | P |
| Cod Liver Oil | 72 | Cylindrical/ Rectangular | - | - | S |
| Cream of Tartar | - | - | - | - | P |
| Gunpowder | - | - | - | Saugerties, NY | P |
| Peach Marmalade | - | - | - | Philadelphia, PA | P |
| Pepper | - | - | - | New York, NY | P |
| Pie Fruits | 24 | - | - | Philadelphia, PA | P |

EFS – External Friction Slip Lid; HAC – Hole-and-Cap; VHAC – Vented Hole-and-Cap
Sources: (R) Rock 1987:76–90; (P) Petsche 1974:50–71; (S) Switzer 2013:155

facturing and size data suggest that the cans accumulated around the site in the last two decades of the 19th century. This is consistent with the geological evidence supporting a gradual burial of the submarine as a result of increased sediment load brought in by the construction of the jetties at the mouth of Charleston harbor.

—HGB

HL-3288 — Tinned Iron Can

Only one can, HL-3288, recovered from the *Hunley* site was deconcreted and studied in detail. It was removed from the iron conglomerate recovered from coarse sand immediately adjacent to the extreme forward end of the starboard bow that also contained HL-0582 and HL-3289. The surviving elements of the can consist of very thin and fragile iron partially covered by a mixture of a hard, clay-like substance and ferrous concretion (Figure 15.19). Approximately two-thirds of the can's exterior surface was exposed for documentation purposes; the remainder is still obscured by concretion.

The can measures 12.4 cm (4.88 in.) in overall length, exhibits an average preserved wall thickness of 0.4 cm (0.16 in.), and has base and mouth diameters of 10.1 cm (3.98 in.) and 10.6 cm (4.17 in.), respectively. A radiograph of the artifact revealed the presence of three circular welded rings along its exterior surface (Figure 15.20). Two concentric rings are located at one end, while the third surrounds the opposite end. A single weld line connects the outermost base ring

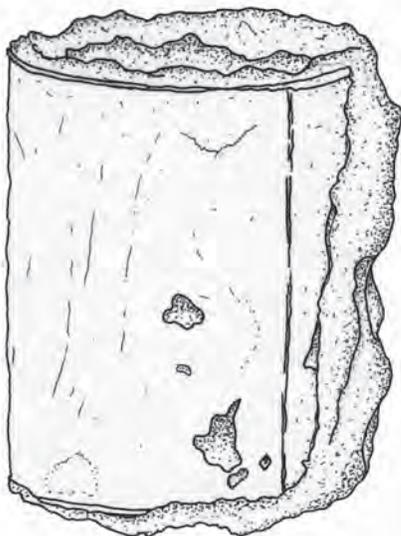


Figure 15.19. Metal can recovered from iron conglomerate HL-0582. (Illustration by Bruce Thompson, courtesy of FOTH.)

to the mouth ring. The regularity of this seam suggests machine production. The cap seam shows two areas of hand solder, suggestive of the use of prefabricated lead solder strips that were curved into a circle and closed by hand, similar to the process described in the 1871 patent of Edward Lang (US Patent 112054). The radiograph also revealed a weld spot in the center consistent with the vented hole-in-cap can design common in the late 19th and early 20th centuries.

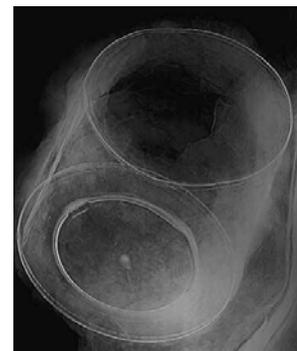


Figure 15.20. Radiograph of metal can HL-3288, showing the locations of specific manufacturing features. (Courtesy of FOTH)

While the can is not directly associated with *Hunley*, its presence in an iron conglomerate that also contained one of the brackets that supported the spar torpedo boom suggests that it is at least contemporaneous with the submarine's loss and subsequent burial in the seabed.

— SM/HGB

Wood

HL-0505 — Wooden Plank

A thick wooden plank was found adjacent to the starboard bow, 42 cm (16.54 in.) below the top, and extending 27 cm (10.63 in.) forward of the bow casting (Figure 15.21). It has a maximum length of 67.3 cm (26.50 in.), maximum width of 12.2 cm (4.80 in.), and maximum thickness of 5.8 cm (2.28 in.). One end is cut at roughly a 35° angle and retains visible cut marks (Figure 15.22). The opposite end is heavily deteriorated, with no original surface surviving. Two parallel scoring marks are present across one face approximately



Figure 15.21. Wooden plank (HL-0505) found close to starboard bow. (Photo by Michael Scafuri, Courtesy of FOTH)



Figure 15.22. Side view showing angled cut (left) and cross section (right) of HL-0505. (Photos by Johanna Rivera, courtesy of FOTH)

27 cm (10.63 in.) from the eroded end. The marks are 3.15–3.9 cm (1.24–1.54 in.) apart. Another, shallower set of scoring marks are found on the opposite face, roughly the same distance from the end and the same distance apart.

Given the object's proximity to the bow, it was important to determine if it could represent a portion of the boom that was originally mounted at the top of the bow casting as part of the spar rigging system (see Chapter 14). The dimensions of the boom were estimated from the surviving brackets (HL-0526 and HL-0582) to be a maximum of 13.3 cm (5.24 in.) wide and 14–15 cm (5.51–5.91 in.) thick. The wooden piece recovered is comparable in width, being only 1 cm (0.39 in.) smaller, but is less than half the expected thickness. Since both faces are reasonably well preserved, it is unlikely this discrepancy can be explained by post-depositional deterioration. In addition, while the score marks might have been caused by some sort of bracket, they are too narrow to have been caused by the brackets recovered at the site, which were 6–7 cm (2.36–2.76 in.) wide. It is therefore likely that this piece is intrusive and not part of the submarine's weapon system.

—HGB

HL-0587 — Barrel Cant

A largely intact wooden staved container component called a “cant” was located immediately adjacent to *Hunley*'s starboard bow (Figure 15.23). Cants are semicircular pieces of wood used in conjunction with “middles” and “quarters” to form the head of a barrel or cask. The artifact has a maximum preserved length of 40.9 cm (16.10 in.), maximum width of 15.6 cm (6.14 in.), and is 2.0 cm (0.79 in.) thick. It is beveled along the edge of its interior surface and exhibits a curved shape that would have corresponded to a set of “croze grooves” located around the periphery of the barrel's interior ends. Croze grooves are V-shaped notches cut into the interior surface of each end of a barrel stave. When a series of staves were placed together to form the shape of a barrel, their corresponding notches accommodated and locked the head of the barrel against the rest of the container.

The cant recovered from *Hunley* was likely part of a three-part head with an estimated diameter of approximately 17 in. (43.18 cm), based on an archaeological rim chart. This is very close to the standard U.S. dry barrel defined in 1915 as having a head diameter of 17½ in. (43.50 cm), a stave length of 28½ in. (72.39 cm), and circumference of bulge of 64 in. (162.56 cm) (15 US

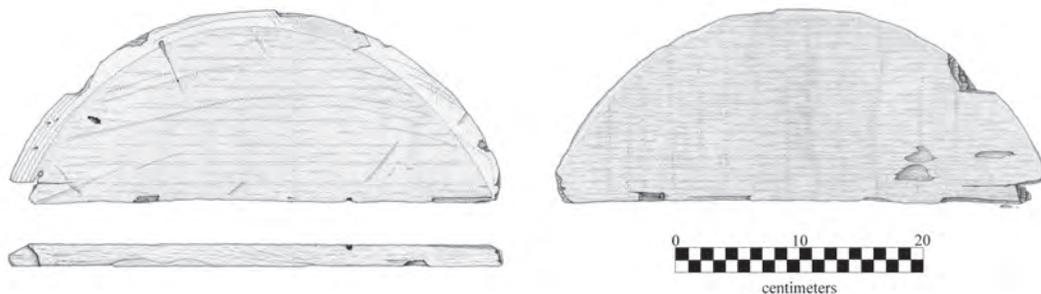


Figure 15.23. Wooden barrel cant recovered near the starboard side of the submarine. (Illustration by James W. Hunter III, courtesy of FOTH)

Code §234). These barrels were intended for fruit (except cranberries), vegetables, and other dry goods. The dimensions were taken from the apple barrel, defined in 1912 (15 US Code §231) and likely in relatively common use before that period.

Barrels and casks were used aboard ships to carry items ranging from water and foodstuffs to gunpowder and nails. Examples of goods packed in barrels from the steamship *Bertrand*, wrecked in 1865, include flour, sugar, beef, pork, pecans, almonds, syrup, china, lamp bases, black powder, nails, and white lead (Petsche 1974:53ff.). In addition to their common role as repositories for shipboard staples and goods, staved containers—especially large water barrels—were stowed in the lowest part of the hold and used as ballast. Once water casks and barrels were emptied of their contents, they were typically reused as storage containers. “Sprung” (damaged or leaky) staved containers were often disassembled and, if the damage to their components was extensive enough, discarded overboard. It is likely this piece was lost off a passing ship, and is intrusive to the site.

— SM

HL-3289 — Possible Tool Handle

A small, cylindrical wooden piece was found embedded in the same iron conglomerate that contained artifacts HL-0582 (iron bracket) and HL-3288 (metal can). Based on its size, appearance, and composition, project archaeologists have tentatively identified it as a wooden tool handle (Figure 15.24). The handle exhibits an overall preserved length of 10 cm (3.94 in.) and maximum and minimum preserved diameters of 2.2 and 1.5 cm (0.87 and 0.59 in.), respectively. A 6.5 cm (2.56 in.) slot passes lengthwise through the approximate center of the artifact and is believed to have once accommodated the tang of an iron implement such as a chisel, file, or awl. The slot is square in profile and retains a maximum preserved width and height of .38 cm (0.15 in.). The exterior surface of the handle is poorly preserved; consequently, its exact identity and

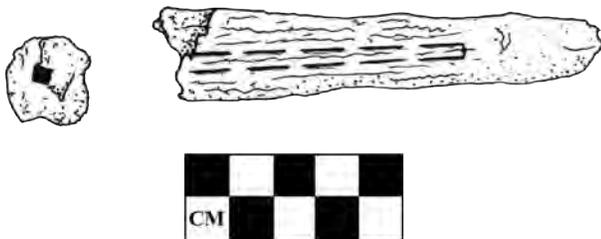


Figure 15.24. Sketch of wooden tool handle (HL-3289) showing socket for tool. (Illustration by Bruce Thompson, courtesy of FOTH)

function cannot be positively ascertained. It is likely intrusive to the site, although its association with the shackle conglomerate suggests a possible (but very tenuous) association with the submarine.

—BR



Figure 15.25. Worn wooden plank with pointed end (HL-0594). (Photo by Johanna Rivera, courtesy of FOTH)

HL-0594 — Wooden Plank

A broken and worn wooden plank (Figure 15.25) was found 77 cm (30.32 in.) aft of and 92 cm (36.22 in.) below the top of the bow, to starboard. The piece measures 65 cm (25.59 in.) in length, 15 cm (5.91 in.) in width and is 1.5 cm (0.59 in.) thick. One end was cut into an asymmetrical V shape, most likely by a saw based on the parallel tool marks. The edges appear beveled, although this follows the grain and may therefore represent natural deterioration. The sawn point measures 6 cm (2.36 in.) and 5 cm (1.97 in.) along each face. The opposite end measures only 2.4 cm (0.95 in.) in width, due to the loss of a longitudinal section of wood along a split in the grain beginning 37 cm (14.57 in.) from the sawn end. Several other splits along the grain are present. No fastener marks were found.

The piece curves gently along its length, similar to a barrel stave; however, the pointed end is not consistent with stave design. It resembles a classic fence picket, but other uses are possible. Association with the upper spar support mechanism is unlikely.

—BR

Other Organics

HL-0581 — Rope Fragment

A piece of natural fiber rope was found 60 cm (23.62 in.) below and 43 cm (16.93 in.) aft of the top of the bow, approximately 18 cm (7.09 in.) to starboard, parallel to the hull. When recovered, the segment was 7.5 cm (2.95 in.) long and 1.3 cm (0.51 in.) in diameter (Figure 15.26). This results in a circumference, while saturated, of 4.08 cm (1.6 in.). The end closest to the bow was frayed, while the after end appeared broken off and most likely was once connected to one of the



Figure 15.26. Fragment of Z-twist rope (HL-0581). (Courtesy of FOTH)

fragments recovered in a separate lot (HL-0585). There was no visible evidence of tar or other preservative. The fragment appears to be made up of yarns Z-twisted into strands, three of which were laid together to form a plain rope in an S-twist; three of these were further closed together to form a cable with a Z-twist. Based on terminology outlined by Sanders (2009:6–9), the rope appears to be a left-laid cablet, or cable-laid rope of “less than 9 inches (229 mm) in circumference.” Cable-laid rope was reputed to have greater resistance to chafing and “were relatively impervious to water, being known as ‘water-laid’” (Sanders 2009:8).

Hemp was the most common material used for maritime cordage in the United States until the late 19th century, when Manila (abaca) began to take over the market. Cotton and flax were also used on occasion, although they were more commonly used ashore. For maritime use, cotton was found to be weaker and more apt to rot (Luce 1877:53). Hemp itself did not stand up well to salt water conditions, and was therefore generally coated in a layer of tar for shipboard use. Untarred hemp, or “white-rope,” was used for lead lines and log lines, as well as ensign and pennant halyards (Luce 1877:49).

This rope cannot be directly tied to the submarine, but it is consistent with production from the period. It cannot be excluded as originating from *Hunley*'s spar rigging. Dixon specifically requested two small batches of cotton rope among his requisitions for supplies for *Hunley* while refitting it after the second sinking; however, the majority of cordage requested was unspecified, suggesting it was hemp (Ragan 1995:87). The fact that the specimen does not appear to have been tarred suggests it was not part of a regular ship's rig, but may have come from a lost line. It is also possible the rope was attached to the lost grapnel (HL-2917) and settled near or became entangled with the hull prior to its being buried.

—HGB

HL-0585 — Rope Fragment

Additional fragments of natural fiber rope, which likely represent an extension of HL-0581, were located approximately 60 cm (23.60 in.) below and 55 cm (21.65 in.) aft of the tip of the bow, 10 cm (3.94 in.) starboard of the hull. Upon recovery, the lengths were approximately 28.5 cm (11.22 in.), 27.5 cm (10.83 in.), and 11 cm (4.33 in.); all were 1.3 cm (0.51 in.) in diameter. There was no visible evidence of tar or other preservative. The composition is identical to that described for HL-0581.

A sample was examined by Susan Heald, textile conservator with the National Museum of the American Indian using a Nikon Eclipse polarizing microscope. Since the rope had been conserved with silicone oil prior to examination, the light was unable to penetrate the fibers well (Figure 15.27). Nevertheless, it was evident that the fibers were not inconsistent with hemp, although several other bast fibers, such as jute and flax, demonstrate similar patterns. Abaca, however, as a leaf fiber, and cotton, as a seed fiber, can be ruled out.

—HGB



Figure 15.27. Sample of rope fiber (HL-0585) examined under cross polarized light. (Image by Susan Heald, National Museum of the American Indian)

Ceramics and Glass

HL-0447 — Bottle Body Fragment

A clear glass shard was found in the starboard OII perimeter trench, roughly in line with the bow of the submarine. It very likely originated from a bottle of indeterminate type and form. It has a maximum preserved length of 5.4 cm (2.13 in.), a maximum preserved width of 4.45 cm (1.75 in.), and is 0.15 cm (0.06 in.) thick. The fragment is curved along both its longitudinal and lateral surfaces, suggesting that it may have once comprised part of the shoulder of a cylindrical bottle. With the exception of a slightly raised straight line at one of its ends, the shard is undecorated. Not enough of the line is preserved to determine what diagnostic attribute, if any, it represents. Two small conchoidal fractures are present on the fragment, as are a small number of gas inclusions (or “seeds”) in the glass body. Its lack of distinct diagnostic attributes precludes a discussion of the artifact’s type, origin, and cultural and temporal affiliation.

— SM

HL-0448 — Yellow Ware Bowl Fragment

A large ceramic sherd was recovered from the starboard OII perimeter trench, roughly in line with the bow of the submarine. The piece makes up approximately one-third of a slip-banded American yellow ware bowl (Figure 15.28). It retains many of the vessel’s important diagnostic attributes, including significant portions of the rim and base, as well as a number of decorative elements. The sherd measures 14.3 cm (5.62 in.) (linear distance) from the bottom of the foot ring to the top of the rim, and has a maximum preserved

width of 26.2 cm (10.32 in.). Its body thickness ranges from 0.6 cm to 1.05 cm (0.24–0.41 in.). A rim chart indicates its original diameter was approximately 30 cm (11.81 in.). The rim is undecorated and has a width and thickness of 2 cm (0.79 in.) and 1.3 cm (0.51 in.), respectively. The base consists of a plain circular foot ring with a beveled interior surface. The foot ring has a maximum thickness of 1.5 cm (0.59 in.) and an estimated diameter of 14 cm (5.51 in.). No diagnostic markings are evident on the preserved portion of the base.

The sherd has a dark, yellowish-brown body with numerous inclusions of various sizes and types. Except where broken, the specimen is completely covered in clear (presumably alkaline) glaze. Three annular bands—two composed of white slip and one of dark brown slip—are located between the lower edge of the rim and the approximate middle of the sherd (Figure 15.29). Both white bands are 1.4 cm (0.55 in.) wide; the brown band is 0.4 cm (0.16 in.) wide. All three bands exhibit areas where the slip was accidentally disrupted or disturbed during the manufacturing process. Although the vessel was likely wheel-thrown, no rill marks are evident on either the interior or exterior surface of the sherd.

American yellow ware is refined earthenware that was first produced during the latter half of the 1820s. By the 1850s, the type was being manufactured in a variety of forms and decorations. Cups, pitchers, and bowls were decorated with a variety of multi-colored slip bands and elaborate slip designs. Other decorative methods employed on yellow ware vessels included molded relief, underglaze painted, finger trailing, and luster. One interesting attribute of yellow ware is that the type was produced in increasingly paler and brighter hues as the 19th century progressed (Leibowitz 1985; Richardson 2001; Sussman 1997).



Figure 15.28. Slip-banded American yellow ware bowl fragment (HL-0448). (Illustration by James W. Hunter III, courtesy of FOTH)



Figure 15.29. Annular decorative bands on the outer surface of HL-0448 show some manufacturing flaws. (Courtesy of FOTH)

Most of the kilns producing yellow ware in the United States were located in New Jersey, Pennsylvania, Ohio, Vermont, New York, and Maryland. The type peaked in popularity during the 1860s and 1870s, but declined shortly thereafter as whitewares began to dominate the ceramics market (Leibowitz 1985; Sussman 1997). Annular slip banding was the first decorative technique employed on yellow ware. The earliest versions were manufactured during the 1840s and produced until at least 1900. The most common forms of yellow ware recovered from the archaeological record are kitchen wares, storage jars, and other utilitarian vessels (Richardson 2001).

— SM

HL-0451 — Whiteware Dish or Bowl Fragment

Approximately one-half of a small, early 20th century white granite (whiteware) ceramic dish or bowl was recovered from the port OII perimeter trench, forward of the bow approximately 2.5 ft. (0.76 m) below the seabed (Figure 15.30). It has an estimated diameter of 14 cm (5.51 in.) and measures 3.8 cm (1.50 in.) (linear distance) from the bottom of the foot ring to the top of the rim. The sherd's body thickness ranges from 0.35 to 0.92 cm (0.14–0.36 in.). The rim is gently everted, scalloped, and decorated along its interior face with a simple molded relief design. No form of decoration is present along the exterior of the rim. At its widest point, the rim has a thickness of 0.4 cm (0.16 in.). The surviving base consists of a plain circular foot ring with beveled interior and exterior surfaces with an estimated diameter of approximately 6 cm (2.36 in.). Two small, concentric 0.05 cm (0.02 in.) thick decorative rings are present on the flat portion of the base. The foot ring has a maximum thickness of 0.75 cm (0.30 in.). Small

dimples, perforations, chips, and other imperfections are present on the surface of the sherd. With the exception of the chips, most of these appear to have been introduced to the artifact during the glazing and firing processes, suggesting that the vessel was one of a number of mass-produced and cheaply manufactured wares.

The sherd is composed of a partially vitrified white earthenware paste with no visible inclusions. Except where broken or chipped, the body is fully covered in clear, shiny glaze that shows no evidence of crazing. Although the vessel was undoubtedly wheel-thrown, no rill marks are evident on either the interior or exterior surface of the sherd. White graniteware evolved from earlier forms of Ironstone and stone china developed in England during the early 19th century. The type was first imported to the United States in the 1840s and, although still manufactured today, declined as a popular ceramic ware by the late 1920s. The classification "white graniteware" is derived from early 19th century shipping invoices, which typically labeled the ware as either "White Glaze" or "White Granite." After 1850, the term white granite or "W.G." became the common

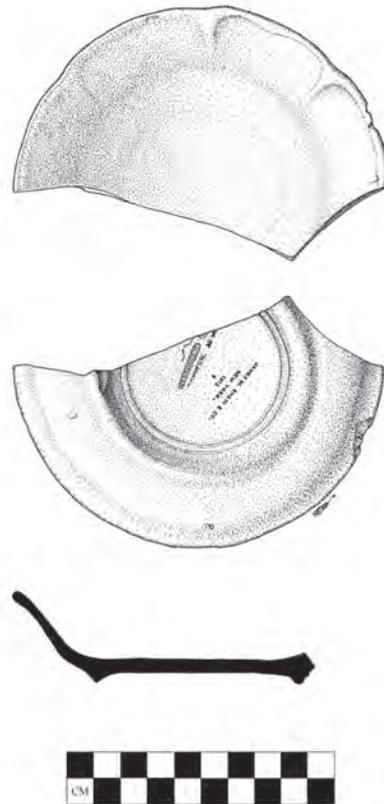


Figure 15.30. White granite ceramic dish fragment (HL-0451). Note maker's mark and distributor's stamp on base of vessel. (Illustration by James W. Hunter III, courtesy of FOTH)

designation for the type. According to Miller (1991:10), white graniteware was the dominant form of whiteware used in the United States between 1850 and 1900.

Two marks are present on the underside of the base and appear to denote both the maker and distributor of the vessel. The maker's mark is impressed in the approximate center of the base. About one-third of the mark is missing and portions of the remainder are partially obscured by glaze. Although incomplete, enough of the mark remains to determine its original complete notation:

GREENWOOD C[HINA]
TRENTON, N. [J.]

"Greenwood China" is a trademark of the Greenwood Pottery and China Company, a Trenton, New Jersey, pottery established in 1861 by William Tams. Tams was an experienced potter from Staffordshire, England who started the company with several investors from the Trenton area. During its heyday, the Greenwood pottery was one of the largest American producers of household and hotel china (Goldberg 1998). It remained in business until 1933. For a short period of time in the 1880s, Greenwood produced famous, high-quality art porcelain known as *Ne Plus Ultra*. The "Greenwood China" trademark was first impressed on the company's ceramic items in 1886 and used until 1910, after which time a different trademark was used (Lehner 1988:180).

The other mark is stamped on the surface of the glaze in red ink. It is located near the inside edge of the foot ring and reads as follows:

JAMES M. SHAW & CO.
NEW YORK
1912
4

James M. Shaw and Company was a New York-based selling agency that operated during the latter half of the 19th century and first few decades of the 20th century. It specialized in the sale and distribution of ceramic items produced by various potteries operating in the United States and England (Lehner 1988:417). Although the company dealt primarily with ceramic tableware, it also distributed a variety of other merchandise, including bedpans and mantel clocks. Interestingly, the year of distribution (1912) for this particular dish occurred two years after the Greenwood Pottery and China Company discontinued its "old" trademark (see above). The purpose of the Arabic numeral four (4) is unclear; it may represent a batch number or designate an individual item in a numbered dinner service or tableware set.

— SM

HL-0506 — Condiment Bottle

Five aqua-colored glass fragments were recovered from dredge spoil from the port OII perimeter trench, roughly in line with *Hunley's* stern and approximately 3.5 ft. (1.07 m) below the seabed. When reassembled, the pieces comprise approximately two-thirds of an eight-sided, Civil War-era United States Navy condiment bottle (Figure 15.31). The fragments include approximately one-half of the bottle body with a complete base; three miscellaneous body shards; and nearly all of the bottle's neck and rim with an attached portion of shoulder. Glass fragments that would have linked the base, body, and neck portions together were not recovered from the *Hunley* site; however, enough of the bottle remains to ascertain its overall dimensions with a reasonable degree of accuracy. The reconstruction process was aided by comparing the *Hunley* specimen

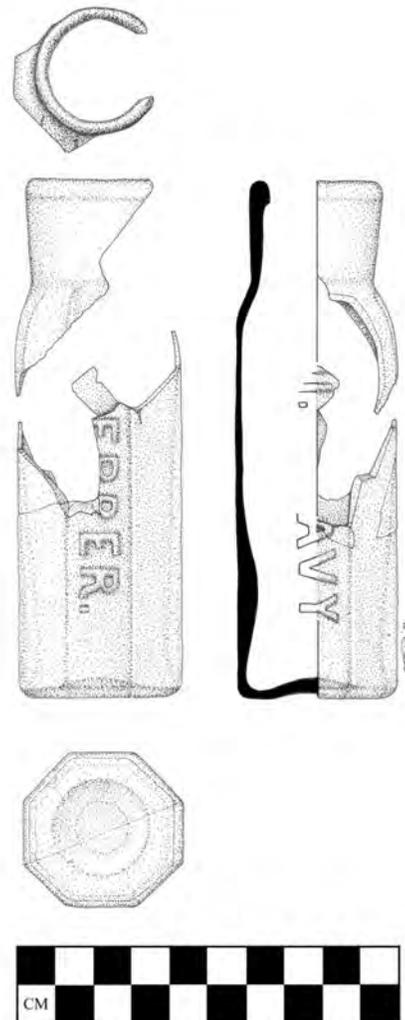


Figure 15.31. Reconstruction of fragmented U.S. Navy condiment bottle (HL-0506). (Illustration by James W. Hunter III, courtesy of FOTH)

with U.S. Navy condiment bottles recovered from the Civil War shipwrecks *CSS Florida* and *USS Cumberland*.

In its reassembled configuration, the bottle has an estimated overall length of 13.55 cm (5.33 in.), a maximum diameter (between flat sides) of 4.3 cm (1.69 in.), and maximum body thickness of 0.5 cm (0.20 in.). It is a relatively straight-sided vessel, tapering only slightly at the shoulder before the base of the neck. At its base, the bottle's neck is 3.15 cm (1.24 in.) in diameter. This opening increases slightly at the rim, which has an exterior diameter of 3.3 cm (1.30 in.) and is 0.5 cm (0.20 in.) thick. The diameter of the mouth (interior) is 2.6 cm (1.0 in.). The base has a maximum diameter (between flat sides) of 3.8 cm (1.50 in.) and thickness of 0.4 cm (0.16 in.). A circular "push up" is located at the bottom center of the base. It is 2.5 cm (0.98 in.) in diameter and has a height of 0.1 centimeter (0.04 in.). Each of the eight panels comprising the sides of the bottle is 10.9 cm (4.29 in.) long and 1.7 cm (0.67 in.) wide.

Centrally located along one of the bottle's eight side panels is the notation "U.S. NAVY" in 1 cm (0.39 in.) tall block letters. The word "PEPPER." is embossed in block letters on the panel on the opposite side of the bottle. A very faint mold seam is visible across the center of the base. It continues upward along opposite sides of the bottle and terminates at the base of the neck. Based on these attributes, the bottle was most likely manufactured by a two-part process. Essentially, the body and base were blown together in a two-part mold, after which the neck was applied with hand tools and altered to conform to the desired bottle shape. Like most other glass bottles manufactured during the 19th century, HL-0506 developed numerous small bubbles in its body as molten glass surrounding pockets of gas in the metal cooled and solidified. While this object did not originate from *Hunley*, it appears to be contemporaneous and may have washed in from the wreckage of *Housatonic*.

— SM

HL-0661 — Bristol-style Stoneware Bottle

A completely intact, American-produced Bristol-style glazed stoneware bottle was discovered near the port side of the submarine's aft hatch (Figure 15.32). It has an overall height of 21 cm (8.27 in.) and a maximum diameter of 7.85 cm (3.09 in.). The base of the bottle is slightly concave and has a diameter of 7.45 cm (2.93 in.). The diameter of the bottle's mouth increases from 0.8 cm (0.31 in.) at the neck to 1.1 cm (0.43 in.) at the rim. The bottle has a double-ring style finish, with a "doughnut-shaped" ring at the lip, which has a diameter of 3.5 cm (1.38 in.) and thickness of 0.9 cm (0.35 in.). Immediately below the rim is a second, smaller ring, or collar, forming a groove with the upper ring that was

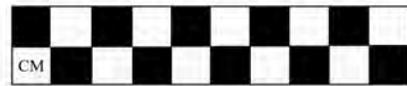
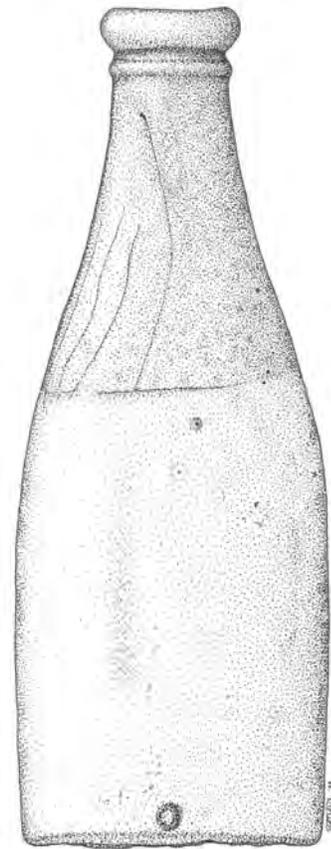


Figure 15.32. Intact American-made Bristol-style glazed bottle (HL-0661). (Illustration by James W. Hunter III, courtesy of FOTH)

used to secure a length of wire or string that held the bottle's cork stopper in place.

The bottom portion of the bottle is white-to-buff colored for approximately one-half to two-thirds of its height. The remaining upper portion is caramel colored—the result of being dipped in a ferruginous (iron oxide) solution prior to final glazing. The entire bottle is covered in a clear, glossy glaze. Portions of the bottle's upper half exhibit areas where the glaze pooled or ran during the manufacturing process. A small (0.6 cm [0.24 in.] diameter) mark in the form of a zero or letter "O" is located near the base of the bottle. Its meaning remains unclear; however, it most likely represents a manufacturer's mark.

William Powell of Bristol, England, invented the Bristol-style glazing process in 1835. It was developed as a substitute for toxic lead glaze and rapidly replaced salt-glazed stoneware and brown slip-glazed pottery. Because of its "clean" white look the type soon became

popular with the British public, who at the time were deeply concerned about sanitation. Within a decade, Bristol-style glazed bottles were being manufactured in North America, where they remained in production until at least 1900 (Noël Hume 2001:324, Richardson 2001, Zug 1986).

According to Noël Hume (1969:80), most American ceramic bottle makers closely emulated the wares produced by their British counterparts in almost every way but overall form. Unlike British bottles, which have a very distinct shape, American versions typically resemble glass beer bottles. British bottles are also usually adorned with the names and trademarks of either their manufacturers or producers—or both. These marks were often stamped in the body of the vessel and then highlighted with dark ink or slip. By contrast, few American wares were marked; those that are exhibit little more than a plain maker's stamp (Noël Hume 1969:80). The most common vessel forms decorated with Bristol-style glaze are preserve/condiment jars or beverage bottles. Most American-produced bottles contained ginger beer, a sweetened carbonated non-alcoholic beverage heavily flavored with ginger, capsicum, or both.

— SM

HL-0662 — Glass Bottle Basal Fragments

Two basal shards from a cylindrical olive green glass bottle (Figure 15.33) were recovered from spoil dredged from around the bottom of the hull on the port side, aft of the aft hatch. The largest specimen comprises approximately 90 percent of the bottle base, as well as a small portion of the bottle's side. It has a maximum preserved height of 2.7 cm (1.06 in.) and diameter of 7.6 cm (3.0 in.). A shallow circular depression or "push up" is located at the bottom center of the base. It is 6.5 cm (2.56 in.) in diameter, exhibits a maximum height of 1 cm (0.39 in.) and is 0.9 cm (0.35 in.) thick. The preserved remnant of the bottle's side has a maximum thickness of 0.6 cm (0.24 in.) and curves slightly to conform to the cylindrical shape of the bottle. Numerous gas inclusions are present throughout the bottle base, and a faint mold seam traverses its bottom exterior surface.

A small, conical 1 cm (0.39 in.) diameter dimple is centrally located on the underside of the push up. Immediately adjacent to the dimple is an embossed symbol that most closely resembles a backwards letter L with a stylized arrowhead at the end of the short stroke. The meaning of the symbol is unclear, but could represent a batch number or other production mark. The presence of the embossed symbol, dimple, mold seam, and relatively smooth uniform push up all indicate that the bottle was manufactured in either an open-and-shut mold or a foot-operated, three-part

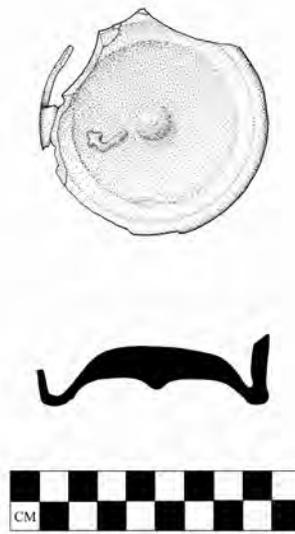


Figure 15.33. Olive green bottle base fragments (HL-0662). (Illustration by James W. Hunter, III, courtesy of FOTH)

mold. Both types of molds were extremely popular worldwide and were used to mass-produce cylindrical bottles from c. 1821 until the early 20th century (Van den Bossche 2001:58).

The other glass shard mends with the bottle base and forms part of the interface between the rim of the base and the side of the bottle. It has a maximum preserved length of 3.65 cm (1.44 in.), maximum preserved width of 1.6 cm (0.63 in.), and maximum thickness of 0.35 cm (0.14 in.). Based on their size, color, and diagnostic attributes, both glass fragments probably originated from a beer or spirit bottle manufactured during the early 20th century.

— SM

HL-0675 — Glass Bottle Body Fragment

An olive green glass fragment, most likely from the body of a cylindrical bottle, was found while dredging on the port side of the submarine around the disarticulated rudder (HL-0686). It has a maximum preserved length of 3.4 cm (1.34 in.) and width of 1.4 cm (0.55 in.). Its maximum thickness is 3 cm (1.18 in.). The shard exhibits a slight curve for its entire length and is heavily riddled with numerous gas inclusions. Its color, thickness, curved shape, and seeded appearance is very similar to attributes exhibited by two glass bottle fragments grouped under artifact number HL-0662 (see above). Additionally, the body fragment was recovered from the same general location as the two base fragments, suggesting that they may have originated from the same bottle.

— SM

16. Conclusions

Robert S. Neyland

H. L. Hunley was successfully raised from the seafloor on 8 August 2000. After 136 years and 6 months, Lt. Dixon and his crew, who had left Battery Marshall, Sullivan's Island, on the evening of 17 February 1864, returned to Charleston, passing Forts Sumter and Moultrie. The submarine and its recovery entourage traveled up the Cooper River to the former Navy shipyard's Pier Juliet, located adjacent to the Warren Lasch Conservation Center in North Charleston (Figure 16.1). *Hunley* was welcomed with public fanfare from the moment it broke the surface, which continued until it completed its voyage. *Hunley* was disembarked from the barge and suspended from the dockyard crane that slowly rolled on rails to the rear of the conservation laboratory, preceded by an honor guard of Civil War reenactors. The recovery was thus part archaeology,

part engineering, and part spectacle. Perhaps this is an inevitable mix for the realization of a myth. *Hunley* had reached iconic status in South Carolina since its loss, but also had obtained a global reputation, for anyone studying submarine development learns about the first such craft to successfully be used as a weapon.

Much of the success of the project can be tied to the level of initial planning. Detailed recovery, stabilization, and conservation plans were all drafted and thoroughly vetted in order for the project to go forward. This allowed for realistic cost estimates and was critical to fundraising. Without first targeting the cost for recovery and conservation it was impossible to implement the fundraising strategy. Even though seed funding was necessary for the planning phase, this initial outlay of money was worth the investment in the long run.



Figure 16.1. *H. L. Hunley* begins its journey up the Cooper River to the Warren Lasch Conservation Center, accompanied by a flotilla of local boaters and cheered on by enthusiastic spectators on shore. (Photo by Cramer Gallimore, courtesy of FOTH)

One of the recommendations from the initial 1996 survey was to have all financing for the recovery, conservation, and curation in hand before the recovery commenced. However, since the project was heavily “front end loaded,” with the concurrent demands of the recovery itself and the outfitting of a conservation laboratory, this expectation was found to be unrealistic. Full conservation would take more than a decade, and curation would be ongoing after that. State and federal fiscal laws do not allow agencies to commit to funding for future fiscal years. For the most part they require moneys to be expended in the year in which they are appropriated. In addition, private donors tend to be reluctant to give large sums of money unless they are assured the project will go through and do not want to give money before it will be expended. Thus financing was in place for the recovery itself and the conservation facility, primarily through public money from federal and state sources, supplemented by donations from private companies, usually in the form of equipment and services, which they found was easier to give than cash. It was impossible, however, to establish a curation endowment, as the recovery and conservation laboratory consumed all of the initial private and public donations. Although the submarine had been initially committed to the Charleston Museum, its final exhibition and curatorial facility was not contractually committed. Without this final decision, it would be difficult to raise funds for the curatorial endowment. Nevertheless, with the high public interest in the project and a long-term fundraising organization in place in the form of the Friends of the Hunley, it was believed that future donations would be enough to finance the ongoing conservation and curation efforts, and the threat to the site was deemed urgent enough that the project move forward with some projected costs initially unmet.

RFPs as a means to resource recovery and conservation assets were not used. They were initially considered, but were impossible to implement without



Figure 16.2. Members of the Hunley recovery team with the submarine in its tank at the WLCC. (Courtesy of FOTH)

the time-consuming process of generating detailed design studies to put out for bid. The use of RFPs for recovery and conservation were therefore abandoned in favor of moving forward with a sole source contract for recovery to ensure meeting the 2000 recovery goal. This work could have been done under an RFP, but it would have been tied into a tightly itemized contract that would leave little flexibility in case of sudden changes to processes or equipment, a common occurrence in large scale maritime projects. In the case of *Hunley*, the change in recovery platform from *Marks Tide* to *Karlissa-B* would have resulted in potentially expensive modifications to the original contract. The construction and staffing of a

dedicated conservation laboratory for *Hunley* made the conservation RFP unnecessary. Overall, the flexibility to assemble a diverse team of experts was an enormous benefit to the project (Figure 16.2).

The method selected for raising *Hunley* proved to be optimal, resulting in a seamless and intact recovery. It provided opportunities for examining the boat and its contents that would have not been available through other recovery methods. Given the extent of the artifacts surrounding the site, as well as the unexpected presence of the spar, which increased the vessel's effective length from 40 ft. (12.19 m) to 56 ft. (17.07 m), the proposed method of encapsulating the submarine with its exterior sediment in a box would have been entirely inappropriate. The loss of context in the perimeter of the site would have been significant. By excavating the surrounding area prior to rigging and lifting the vessel, all artifacts adjacent to the hull were recovered without damage and carefully mapped, allowing for important insights into site formation processes. The care taken to transport the vessel to the laboratory sealed and in its original orientation allowed for the methodical excavation of the interior that has facilitated collection of data shedding light not only how the men of the crew died, but also how they performed their duties in such a difficult environment.

One lesson taught by *Hunley's* recovery and the subsequent research is that during archaeological discovery there will also be discoveries made in the historical records. Interest in *Hunley* led researchers to unearth previously unidentified documents pertaining to the vessel, the crews and designers, and submarine development during the Civil War. Letters from *Housatonic* officer John K. Crosby and even correspondence from Dixon himself were found, as well as other records. Genealogical and forensic research identified the crewmembers, giving them not only names but faces as well. Historical misinformation was corrected, such as the proper position and length of the spar and the total number of crewmen, which proved to be eight, not nine as recorded in eyewitness accounts.

Theories on the Loss of *Hunley*

The chief historical question that is as yet unresolved is why *Hunley* sank. Speculation began immediately after the reported loss, with the two most common early theories being that it was sucked into the hole blown in *Housatonic's* hull or that currents were too strong for the crew to make it back to shore and it was carried further out to sea. In regards to the former theory there was a rumor that during the salvage of *Housatonic*, the submarine was discovered and scrapped with the ship's boilers. All these were categorically proven false by the discovery of the submarine roughly 900 ft. (275 m) east of its victim.

However, the true sequence of events that led to *Hunley's* loss is not so obvious, and only a comprehensive forensic approach can hope to recreate what happened the night of its loss. The excavation and recovery method utilized on the project was designed to collect the most thorough dataset possible to aid in this effort. While the full range of studies has not yet been completed, preliminary evidence from the recovery have allowed us to narrow down the possibilities.

There are six theories that have been hypothesized since the submarine's discovery. The first is that the submarine's hull breached as a result of the explosion. Second is that the crew saw the USS *Canandaigua* approach and decided to submerge and wait on the seafloor for Union forces to disperse but eventually succumbed to the lack of air. There was also speculation that *Hunley* was still at the surface after the attack, but was subsequently struck by *Canandaigua* when it arrived to aid the stranded crew of *Housatonic*. Fourth is that the damage to the forward conning tower was caused by small weapons fire from the deck of *Housatonic*, injuring Dixon and causing the submarine to flood as a result. Fifth, the grapnel anchor found after the recovery led some to suggest that *Hunley's* crew

attempted to hold position against the outgoing tide until the tide changed but were inadvertently pulled under due to the low freeboard of the submarine and lack of buoyancy. Finally, the sixth is that the crew was rendered unconscious after the torpedo explosion and unable to man the pumps or respond to any damage to the submarine.

Evidence from the Recovery

In order to examine these theories more closely, it is important to review several salient details gleaned from the archaeological evidence. First, since *Hunley* was found close to *Housatonic*, it is clear the submarine had to have taken on water and lost buoyancy sometime after the attack on *Housatonic*; otherwise it would likely have drifted far out to sea with the tide, as evidenced by the wind and tide conditions of the night in question (see Chapter 3). Even with only a 1 knot current *Hunley* would have traveled 1 nautical mile in an hour, which is 6,076.12 ft. (1,852.00 m.). The report of *Housatonic* Landsman Robert Flemming states that he saw a blue light, on the surface of the water at the time of *Canandaigua's* approach, approximately 30 minutes after the explosion. It is possible he was referring to the bright chemical flares called by that name (see Chapter 2, Note 4), although it is strange that no one else reported seeing such a light. Perhaps he was mistaken and it came from *Canandaigua* or one of its boats to illuminate an area with the potential for debris or survivors in the water. However, the position at which he reported seeing the light was consistent with *Hunley's* final location, lending more credence to his statement. If he did see just a small blue-colored light, and it did come from *Hunley*, then the submarine must still have been at the surface (DON 1864:0546–0547). Although one report to the Court of Inquiry put the current at 1 knot, Captain Pickering reported half ebb tide, which would have been about 0.5–0.6 knots according to data from the nearest tidal station. The same recording station puts 4th quarter ebb at 0.3 knots. Therefore, without calculating for wind, the submarine adrift at 1 knot of current would have traveled ca. 3,000 ft. (914 m), at 0.5 knots ca. 1,500 ft. (457 m), and at 0.3 knots ca. 900 ft. (274 m) in the time between the explosion and the arrival of *Canandaigua*.

Of the three significant hull breaches found during the excavation, only the missing viewport in the forward conning tower appears to have occurred close to the time of the sinking. Iron fragments and sediment inside and below the forward conning tower suggest the opening occurred while the submarine was still upright, before it settled into its starboard list on the seabed (Jacobsen et al. 2012). Empirical testing has shown that this damage could have been caused by

weapons fire from the crew of *Housatonic*, particularly from rifle fire, and with the submarine running at the surface, the damage might even have been caused by flying debris from *Housatonic*; however, the possibility that it occurred after the sinking cannot yet be ruled out. The loss of the port propeller shroud and attachment bar, as well as the displacement of the starboard shroud attachment bar all appear to have been caused by snagging from a grapnel anchor or other surface-deployed equipment, and this must remain under consideration for the conning tower damage as well. Further analysis of the area after deconcretion is complete may reveal the cause of the damage.

The forward conning tower hatch was found to be slightly ajar when first discovered. Excavation of the interior confirmed that this hatch was not bolted down, although the after hatch was firmly fastened. Since the mechanism used to secure the hatch would have blocked access to the viewing ports, it is currently believed the pilot conned the submarine with the hatch unfastened while operating on the surface so that he could see out. Further analysis of the artifacts found inside may reveal an alternative, temporary fastening method used when the pilot needed access to the conning tower. Another important observation from the interior of the vessel was that there was no evidence of attempting to release the keel weights, as occurred during the second sinking. The after hatch was found to be secured. Also, while the analysis of the pumps is not complete, there is no definitive evidence that the pumps' valves were open to displace water from the ballast tanks. Finally, the presence of the spar, nearly intact with only a slight bend, seems to indicate that direct structural damage from the explosion itself was minimal. The bent bracket for the boom suggests that some external force was applied to it, but perhaps later, as with the damage at the stern, as a result of being snagged by an anchor.

When considering the possible sequence of events from the night of 17 February 1864, it is important to keep in mind the human factor. The causes of *Hunley's* two previous losses have been reconstructed from historical testimony, with human error being a contributing factor in both instances (see Chapter 2). Accounts of the first sinking vary, but Hasker, who was aboard when it went down, stated that Payne became fouled in a line with the hatches still open while the submarine was getting underway and inadvertently depressed the diving plane lever (Fort 1918:459). In the case of the second sinking, in which Horace Hunley was in command, he appears to have failed to close the forward seacock, either prior to or during their planned dive, flooding the forward ballast tank. With the intake valve open, no amount of pumping from the aft pump would have been able to clear the water from the crew compartment. In addition, the presence of an unlit candle

in Hunley's hand indicates there was no interior light for himself and the crew to correct these mistakes. From these events, it is evident that conditions inside the submarine left little time or means to correct problems before they became irreversible.

Analysis of Loss

With these facts in mind, a review of the predominant theories shows that several are less likely than others. The least likely scenario is that *Hunley* was struck by *Canandaigua* as it came to render assistance. Had this been the case, the submarine would likely have suffered massive damage to the hull, possibly even been cut in half. With a draft of 15 ft. (4.57 m) and a propeller of similar diameter, it is unlikely the steamer would have inflicted only the relatively minor damage to *Hunley's* propeller shroud and steering mechanism that was found upon excavation.

The clearest sign of damage to the hull was the loss of the port viewport in the forward conning tower (Figure 16.3). Presuming it did occur prior to the sinking, either as a result of small arms fire or shrapnel, it is problematic because the conning tower was above the surface of the water and Dixon would have had time to block the hole to prevent water from flooding the submarine. However, weather and sea state could also have been a contributing factor. With the wind building from the northwest at the time of the attack and immediately afterwards, and the tide setting to the northeast, seas would have been building with waves that could have thus been lapping over the conning towers. The damage to the forward conning tower alone should not have been sufficient to sink the submarine, provided it stayed above the surface. The hole could have been plugged with a garment or rag to prevent water from



Figure 16.3. What caused the hole in Hunley's conning tower, and when, remain critical questions in reconstructing the sinking event. (Photo by Brett Seymour, courtesy of FOTH)

slopping in while on the surface. If water did get in, it could have been removed with the pumps. Finally, no injuries were observed to Dixon's skeletal remains that might indicate he was a casualty of weapons fire.

In regard to taking the submarine down to wait out the Union rescue operation or for the tide to change, if the damage to the forward conning tower occurred at the time of the submarine's attack, Dixon would not have been able to take the boat down to the bottom to wait or to run the submarine fully submerged. Although the damage might not be a serious problem on the surface it was too large for Dixon to have sealed it securely enough to prevent flooding when underwater. Any damage to the hull that resulted in leakage would likely have prevented him from submerging. Dixon should have anticipated that other ships in the Union fleet could be coming to assist in the rescue or that *Housatonic* would deploy its ship's boats to rescue the crew. Hiding on the bottom until things quieted down on the surface or the tide changed might have been a short-term strategy but an attempt to hide on the bottom could only have been a momentary escape. He had conditioned his crew to submerge until they ran low of oxygen and he knew the limits of their endurance, which would be only an hour or two at most. According to Alexander (1902c:89), they maxed out at two hours and thirty-five minutes on one test, although his figures are not always reliable. If Dixon submerged and everything was functioning normally, he would have had to surface amongst the enemy prior to depleting his crew's air supply. In addition, one would anticipate that, if Dixon had seen the approach of *Canandaigua*, he might attempt to maneuver underwater out of harm's way; however, *Hunley's* final location, so close to *Housatonic* seems to indicate that the submarine had not navigated away from the site under water.

The discovery of the grapnel anchor in 2002 relatively close to the submarine and oriented toward the starboard side led to speculation that the crew of *Hunley* might have attempted to anchor to wait out the Union forces and the ebb tide, but were pulled underneath the water instead. *Hunley* researcher and author Mark Ragan, who pilots small submersibles, related his own personal experience of nearly sinking his submersible by using an anchor. He found that when hoisting on the anchor line he was pulling his vessel under water (Ragan 2012, pers. comm.). In addition, none of the historic accounts of the submarine by Alexander or McClintock mention the deployment of an anchor. Alexander states:

During this time we went out on an average of four nights a week, but on account of the weather, and considering the physical condition of the men to propel the boat back again, often, after going out six or seven

miles, we would have to return. This we always found a task, and many times it taxed our utmost exertions to keep from drifting out to sea, daylight often breaking while we were yet in range. (Alexander 1902a)

This account indicates that they cranked the propeller against the outgoing current, rather than resting at anchor.

In addition, the type of anchor found does not seem an appropriate choice for anchoring the submarine (see Chapter 15). It is of light weight and appears to have lacked any chain between the grapnel and rope. Grapnels anchor better in rocky bottoms and are not the best choice as anchors on a sandy or hard mud bottom, and they also are hard to free from the bottom once they have set. If the vessel was going to anchor, another type other than a grapnel would have been the better choice. The submarine *Intelligent Whale*, for example, used two 350 lb. (159 kg) iron ball anchors that could be dropped directly down and retrieved from inside the crew compartment (Hitchcock 2002:167). Likewise, Confederate torpedoes used mud anchors similar to the one found at a distance from the excavation site (see Chapter 11). In the face of this evidence, the reports that the U.S. Navy dragged for *Hunley* offers a more plausible reason for the grapnel having been lost near the wreck site.

The most obvious place to look for a cause of the sinking was damage from the explosion, in particular a hull breach. The recovery, however, did not reveal a large breach caused by the explosion that led to catastrophic flooding. As mentioned above, the damage to the forward conning tower could have been caused by gunfire or shrapnel from the explosion, but should not have been enough to sink the vessel. However, the concussion resulting from the detonation of the torpedo would have created an underwater shock wave and the force could have been severe enough to damage the hull or the crew. Dixon's watch, which was found to have stopped at between 8:22 and 8:23 that night, suggests that it stopped at the time of the explosion and is evidence of an effect of the concussion. If the explosion stopped the watch it probably also put out the candle flame. It is possible this could have caused distortion or fracturing of the metal components of the hull, allowing water to enter around rivets or seams, and physical injuries to the crew. A slow leak would be consistent with the report that *Hunley* remained at the surface after the explosion. It seems likely the crew would have attempted to stop the leaks and man the pumps, and, if unable to do so, they would have had sufficient time to unfasten both hatches and abandon the submarine to escape. If, on the other hand, the crew was disoriented or disabled by the shockwave, there is a chance slow leaks went unchecked and the boat slowly sank without an attempt to stop it. Recently,

the copper-alloy fill pipe for the forward ballast tank was discovered to be broken at the flange and slightly displaced. If this happened due to the explosion it would have allowed water to enter the submarine. However, it is as yet to be determined if this occurred at the time of the explosion or after. If it occurred as a result of the explosion, why did the crew not attempt to plug the hole or man the pumps?

Given the lack of a proverbial “smoking gun,” it is possible that several smaller problems occurred simultaneously that, when combined, could not be overcome. For example, the concussion from the explosion might have caused some leakage that could have been managed by the crew’s pumping, but additional factors worsened the situation, such as the wake of the *Canandaigua* or an increase in wave height causing additional water to flow through the open forward hatch. Another possibility is that the crew was sufficiently disoriented from the explosive shock wave that they were unable to respond efficiently to the danger of hull leakage. If they lost their interior light and were unable to relight the candle or lantern soon after the explosion, their situation would have been compounded. Longitudinal instability resulting from changes in the metacentric center of balance due to partial flooding could have accelerated the submarine’s journey to the bottom. Finally, if *Hunley* was leaking but submerged to the bottom, such leakage would have increased in response to increases in exterior water pressure on the hull. Once on the bottom no one would have been able to lift the hatches due to outside pressure unless the submarine was completely filled with water. If Dixon was the only one aware of what was happening he might perhaps have broken out the forward viewing port himself in an attempt to equalize pressure by allowing the conning tower to fill, but was unable to lift the hatch to escape. This last still does not explain why the after hatch is securely fastened, and there was no attempt to use the pumps or unfasten the keel weights.

In summation, although it still cannot be definitively stated why *Hunley* was lost, some scenarios can be ruled out or appear to be unlikely. These discounted theories include *Hunley* being struck by the *Canandaigua*, anchoring with the grapnel, and damage alone to the forward conning tower. Submerging to the sea floor to wait out the enemy would have been futile and resulted in having to emerge a short time later among the enemy. Submerging would also not have been possible with the damaged conning tower and an unfastened hatch. If they became trapped on the bottom they would have certainly attempted to remove the keel weights and pump out the ballast. Dixon and the crew being completely incapacitated may be unlikely due to

the distance and position of the submarine from the explosion, which suggests it might not have drifted as far as the half ebb current would naturally have carried it if *Hunley* was still at the surface when *Canandaigua* arrived; however, the unsubstantiated sighting by Flemming may never be proven conclusively.

Future Work

There is still much research and analysis to be done, in particular regarding the pumps and the position of valves to confirm for certain what the crew was doing immediately after the attack and if the crew had attempted to man the pumps or make repairs. Studies are underway in collaboration with the Naval Surface Warfare Center and the University of Michigan to determine the theoretical effects of the explosion on the hull and its crew, as well as the rate of flooding, stability, and performance of *Hunley* under various conditions. With the completion of deconcretion, closer examination of the hull may reveal damage, such as microfractures or distorted rivets, that could shed further light on what forces had the most impact on the submarine.

Future archaeological research at the wreck site might include returning to the site to survey for the piece of the propeller shroud, thus expanding on the 2002 and 2003 surveys. If found, its location and condition might yield information to determine if it was removed by an anchor snag. Likewise, the mud anchor should be relocated, excavated, and recovered to determine if there is any connection to *Hunley* or the attempts to relocate it. Of course additional work could be done on *USS Housatonic*, particularly in regards to the areas of the explosion. The anchor that was located during the previous surveys should be reinvestigated to determine if it is indeed the anchor *Housatonic* was on at the time of the attack.

Challenges still remain for the *Hunley* project. The conservation of the submarine and artifacts has to be completed, as well as funding, designing, and constructing a final exhibition facility that can maintain a stable curatorial environment. In order to answer the many questions concerning *Hunley*’s operation and demise, and bring a successful conclusion to the project as a whole, all of the analysis has to be completed and published in a series of detailed reports. These should be comprehensive explorations of the submarine’s interior excavation, artifacts, crew forensics, and hull architectural studies. These reports should be accessible to the public and scholars. *Hunley*, its science, and its story belong to the American public.

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APPENDIX A

Hunley Conservation Symposium Summary of Proceedings

Hunley Conservation Symposium

In 1999 a symposium was held in Charleston, South Carolina to consider the proposed recovery of the submarine *H. L. Hunley*. The meeting, held from November 18 to 20, brought together an international group of authorities experienced in recovery and conservation of objects similar to *Hunley*. The purpose was to explore issues specific to *Hunley* and exchange ideas on methods of recovery, excavation, and conservation of the submarine. Ten experts were invited to present papers on their research, participate in discussions regarding *Hunley*, and critique methods for its recovery and conservation (Table A1).

Hunley and other similar large iron objects recovered from marine environments pose unique retrieval and conservation problems that few experts have experienced. The group in attendance represented pioneers in the fields of corrosion of iron shipwrecks, in-situ preservation, and conservation. Invitees, their affiliations, and titles of their papers are provided below. Warren Lasch, Chairman of the Friends of the Hunley, welcomed the group and Senator Glenn McConnell, Chairman of SCHC, made the opening remarks.

Other archaeologists, conservators, and interested parties attended the symposium and participated in the question and answer sessions. These included Richard Lawrence, Underwater Archaeologist for the State of

North Carolina, Dr. John Broadwater, Manager of the USS *Monitor* National Marine Sanctuary, Dr. Bradley Rodgers of East Carolina University, and Kate Singley, a conservator of waterlogged artifacts. Other participants included Maria Jacobsen and Paul Mardikian of the Hunley Recovery Team, Steve Wright and Leonard Whitlock both of OII, and Robert Adams, an underwater archaeologist representing IAL, a firm requesting an opportunity to submit a proposal for recovery of the vessel.

The opening presentations were made by Larry Murphy of the National Park Service and Dr. Robert Neyland of the Naval Historical Center. Mr. Murphy reported on data recovered from the *Hunley* archaeological site during a 1996 survey conducted by the National Park Service. The survey provided valuable data with which to make determinations about whether recovery was warranted and how it could be accomplished safely. While corrosion appeared to have been slowed by the stable anaerobic burial environment, their assessment was that corrosion would continue until all the metal in the submarine was eventually lost. None of the areas of the hull that they uncovered appeared to be excessively corroded and overall the hull and hatches appeared solid, sound, and strong. The only damage observed was a hole in the forward conning tower, originally noted by the NUMA team who found the vessel in 1995.

Table A1. Symposium Participants and Presentations

| Participant | Affiliation | Presentation |
|---|--|---|
| Larry Murphy | NPS Submerged Cultural Resources Unit | The 1996 <i>Hunley</i> Assessment |
| Dr. Jonathan Leader | South Carolina Institute of Archaeology and Anthropology | Corrosion Measurements during the 1996 Assessment |
| Dr. Robert S. Neyland | U.S. Navy Naval Historical Center | Work on the <i>Hunley</i> Project, 1996-1999 |
| Dr. Michael McCarthy | Department of Maritime Archaeology, Western Australian Maritime Museum | The Submarine as a Class of Archaeological Site |
| Martin Dean | Archaeological Diving Unit, University of St. Andrews, Scotland | The Second Loss of the <i>Resurgam</i> : Problems in Protecting One of the World's First Steam Powered Submarines |
| Dr. Donny Hamilton | Nautical Archaeology Program, Texas A&M University | Conservation of Large Iron Artifacts: The Sacred and Profane |
| Peter Lawton | Treadgold Industrial Heritage Museum, Portsmouth, England | The Use of Electrolysis in the Conservation of HM <i>Monitor M33</i> (Built 1915) |
| Dr. Ian MacLeod | Department of Materials Conservation, Western Australian Maritime Museum | Case Management of the Conservation of the SS <i>Xantha</i> and How to Avoid Uncontrolled Decay |
| Paul Mardikian | <i>Hunley</i> Research Center, College of Charleston | Conservation of the Blakely Cannon from CSS <i>Alabama</i> |
| Curtiss Peterson | The Rescue Company, Virginia | Conserving the <i>Monitor</i> |
| Drs. Donald Johnson and William Weins. (Co-author John D. Makinson not present) | Department of Mechanical Engineering, University of Nebraska. | Corrosion, Metallurgy, and Biofoul Interactions on USS <i>Arizona</i> |

*PROFESSIONAL PAPERS***The Submarine as a Class of Archaeological Site***Dr. Michael McCarthy**Department of Maritime Archaeology, Western Australian Maritime Museum*

Dr. McCarthy addressed the importance of the archaeological study of submarines. As the person in charge of the 1985 recovery of the SS *Xantho* steam engine and manager of the Japanese submarine *I-124* recovery team, Dr. McCarthy had come to look at them as sites unique in their international character, technology, and culture. By studying factors such as the organization of interior space one can gain insights into how the crew structured their society, which developed within cramped living conditions and isolation. He stressed the universality of the submarine experience that transcends national boundaries and political affiliations. The broader social effects of submarine culture,

such as the impact of base development on communities and the international sharing of technologies, provide new avenues of research. As an archaeological site submarines are unique because of the encapsulation of the site and the potential for preservation of human remains in these tomblike environments. The ethical challenges of how to treat human remains from excavated submarines can be precedent-setting for underwater archaeologists, who rarely encounter these materials at traditional shipwreck sites. McCarthy expressed his belief that the *Hunley* project would become a benchmark and “raise the bar” in maritime archaeology.

The Second Loss of the *Resurgam*: Problems in Protecting One of the World’s First Steam Powered Submarines*Martin Dean**Archaeological Diving Unit, University of St. Andrews*

Martin Dean presented a cautionary tale of what can happen to an historic submarine when left on the seabed. *Resurgam* was built in 1879, designed by the Reverend George Garrett Prasher, who was working on submarines as early as the 1860s, and fabricated by Cochran and Co., boilermakers in Birkenhead. It was lost in 1880 off the northern coast of Wales, just west of Liverpool, while under tow. The story was popular in the area and many had searched for the wreck over the years. *Resurgam* was finally located by chance in 1995 after being snagged by fishermen. The discovery was publicized on television and in local newspapers. Upon Dean’s first visit to the site, the main body of the vessel was relatively intact, though it had at least one large hole and many of its exterior control surfaces were missing; a section of iron straps with wooden cladding lay approximately eight meters away. Within 10 days, a porthole had been stolen, along with several brass control rods, and the steering wheel smashed. An initial survey to record the site was conducted involving local volunteer divers, in hopes of educating divers about archaeological techniques and goals. During this period,

some of the missing pieces were returned to the site, suggesting the educational program was having a positive effect.

An effort to obtain funding for the raising and preservation of *Resurgam* was unsuccessful. The site was designated under the Protection of Wrecks Act, a cathodic protection system was installed to inhibit corrosion, and it was monitored under by a local caretaker, who went out and checked on the site approximately once per month. It was this man who discovered one day that the submarine had been moved. Dean returned to the site and found the vessel now upright instead of canted at 45°, and lay perpendicular to the current instead of parallel; its wooden cladding was all gone, the conning tower caved in on one side, and there were remains of a crude lifting strap beneath the hull. Dean gleaned from this experience that you can never guarantee a wreck’s safety when left on the seabed, and, as he learned from a different site, even 24-hour monitoring could not prevent looting of artifacts. His recommendation was to move *Hunley* to a safe location as soon as possible.

Conservation of Large Iron Artifacts, the Sacred and the Profane

Dr. Donny Hamilton

Nautical Archaeology Program, Texas A&M University

Dr. Hamilton's talk was aimed at ethical concerns involved in the selection of conservation methods for large metal artifacts recovered from underwater sites. He pointed out that archaeological conservators have ethical standards for treating fragile artifacts, which generally advocate caution and reversibility of the conservation process. In his experience, ethics have to be balanced with the need to take decisive action and risks; this is especially true with large iron artifacts such as *Hunley*. Electrolytic reduction (ER), in his opinion, was the only existing process that had a proven track record for conserving iron impregnated with salts. Nevertheless, some conservators still consider the use of ER as "profane" and too dangerous a process to use on significant historic artifacts. He stressed there were many misconceptions about ER, and that it could be employed safely as long as the conservator fully understood how it worked and how to customize the process for the artifact in question. By way of example, he presented the results of several large conservation projects he had undertaken using this technique, including a single 4,000 lb. (1,814 kg) anchor and a 5,000 lb. (2,268 kg) concretion containing two stacked wrought-iron anchors, a cannon, two blocks, and approximately 1,000 smaller artifacts. Artifacts from the 1554 wreck he had

previously treated by electrolysis were still stable 20 years later. He has found that stainless steel vats are not necessary, but mild steel can be a workable and cheaper option, and that sodium hydroxide has the best reduction potential.

He pointed out that some conservators advocate leaving a wreck on the seabed until a better technique was developed; however, based on his experience, and referencing the example presented by Martin Dean, the risk of looting is too great—"[o]nce something has been discovered, it's extremely difficult to keep people off of it."

Conserving *Hunley* would be on a "completely different level, a completely different magnitude, something that's never been attempted in the United States." Among the questions the team needed to consider in planning to apply ER would be: what kind of vat to use, would it be used as the anode, what kind of power supplies, can the vessel be conserved intact or must it be disassembled. With a careful plan in place, use of ER would be a safe and cost-effective conservation option. Hamilton's final advice was "don't over-design, don't over-complicate, and like everything in archaeology and conservation, 95% of it is common sense—the other 5% is science."

Use of Electrolysis in the Conservation of HM Monitor *M33*

Peter Lawton

Treadgold Industrial Heritage Museum

Peter Lawton presented another practical example of the use of electrolysis on a large-scale iron artifact. Lawton agreed with Hamilton "if you have artifacts, you probably need fairly robust solutions to problems." Historic ships such as the SS *Great Britain*, he noted, were falling apart due to overly cautious preservation efforts.

Built in 1915, *M33* is one of only two surviving British World War I warships. It is a monitor-class vessel, 177 ft. (53.95 m) in length and 32 ft. (9.75 m) in beam. After the war, it was converted to a mine layer known as HMS *Minerva*, and then in the 1940s converted again to Hulk *C23* and used in a variety of roles over the ensuing decades. While never sunk, the ship had its engine removed when it became a hulk and remained floating in place for many years. It was acquired by the Hampshire County Council in the 1980s and there was one failed attempt at restoration. The vessel was then

employed as a floating park with two bars and a disco on board. This activity was shut down by Mr. Lawton in 1995 on his first day overseeing the vessel.

When *M33* was placed in dry dock it was found that much of the original metal had completely deteriorated and was held together by rust and attached mussels. Lawton began by pressure washing the hull at 4,000 p.s.i. (276 bar), which in some spots was strong enough to burn holes through badly deteriorated metal, although overall the vessel was found to be relatively sound. Eleven tons (9.98 t) of rust were removed from the bilge. To remove damaging chlorides, Lawton decided on electrolysis. They took metal samples from the ship and tested various anodes to find the best system. The area of the ship Lawton was treating at the time required 100 tn. (90.72 t) of electrolyte solution through which he passed 180 amps, equivalent to only 350 milliamps per square meter.

His success with *M33* resulted in requests to treat other historic British vessels including the SS *Great Britain* and *Cutty Sark*. On both vessels, woven plastic mats developed for greenhouses were adapted to hold the electrolyte, since the former vessel was too structurally unsound to support flooding compartments for treatment, and the latter was required iron frames to be treated without damaging the surrounding wooden hull. In the conservation of all three ships, bacterial attacks

on the original anodes—316 grade steel mesh—were a problem, interfering with the process and eroding the anodes. They eventually switched to platinized titanium mesh with better results. Lawton stated that the potential problem of anode deterioration should be monitored closely in electrolytic treatments of *Hunley*. His recommended electrolyte was sodium carbonate, and he reported no problems with treating dissimilar metals together.

Case Management of the Conservation of the SS *Xantho* and How to Avoid Uncontrolled Decay

Dr. Ian MacLeod

Department of Materials Conservation, Western Australian Maritime Museum

Dr. MacLeod discussed his experience conserving the steam engine from SS *Xantho*, illustrating some of the pitfalls one can encounter dealing with large, multi-component, iron artifacts. The engine is an example of the world's first mass-produced high-pressure marine steam engine, built in 1861 and installed second-hand on *Xantho* in Scotland 1871. The vessel was purchased by Charles Broadhurst for pearling in Western Australia, where it eventually sank in 1872. The wreck was discovered in 1979 and the engine, weighing 7.5 tons, was recovered in 1985.

Among the practical lessons gained from the process of conserving such a large piece, MacLeod emphasized the importance of teamwork between the archaeologists and conservators, pointing out the hardships of working many hours in a wet and cramped environment inside a conservation tank. There is a limit as to how many hours at a time an individual can do this work. His team also discovered that an oxy-acetylene torch could efficiently remove the rock-hard concretion without harm to the underlying metal and speed up the deconcretion process.

The foremost lesson learned after a decade of conservation was that the engine must be disassembled in order to remove the chlorides located in sealed areas and between covered surfaces. After the removal of a flange on the steam pump that had been in electrolysis nine and a half years revealed the presence weeping iron corrosion products, it was decided that the entire engine needed to be disassembled. Some surfaces after disassembly still measured 2,500 ppm chlorides after ten years in electrolysis. MacLeod also warned of the danger of measuring the voltage only on the carbonized outer layer of an iron artifact and not securing direct measurements of the residual metal below the corrosion layers. This led to the development of over-

potential and a strong evolution of hydrogen bubbles, which led to the loosening and loss of the graphitized outer layer. Further investigation revealed that this process was exacerbated by keeping the engine in fresh water in between rounds of electrolysis over the months of deconcretion. By doing this, they were inadvertently washing hydroxide ions out of the interface between the graphitized layer and residual metal, allowing it to become oxidized, thereby loosening the bond between the two zones. The fact that there was no longer a connection between the layers also contributed to the unreliable the surface voltage measurements. He advised avoiding a scenario that involves alternating caustic and fresh water environments on long-term projects. Additionally it was determined that right-angle edges or corners were subject to increased corrosion and therefore more easily damaged during deconcretion and conservation processes.

Several interesting features were found on the interior of the engine that provided clues about the operational and post-depositional history of the vessel. One was the discovery of maghemite corrosion products on the interior surface of a sealed area, which does not normally form on marine iron. Researchers determined that this was a product of the engine's normal operational use. Thus it is important to identify and document all corrosion products on the artifact. There were also two corrosion lines found that were related to water levels trapped inside the engine after the sinking—one attested the vessel's initial position on the seabed, while the other reflected the position in which it settled after the collapse of the ship's superstructure. MacLeod urged *Hunley* excavators to keep a close eye out for details like this, which might be easily overlooked but could actually provide important information.

Conservation of the Blakely Cannon from CSS *Alabama*

Paul Mardikian

Senior Conservator, Hunley project

The Blakely gun was recovered from the wreck of *CSS Alabama* in 60 m (200 ft.) of water off Cherbourg, France. He noted that much of the concretion layer was lost during recovery, which is not ideal from a conservation standpoint. He recommended for future cannon recoveries coating the surface with some sort of silicone prior to the lift and rigging it with a net to keep the concretions together. The cannon, similar to *Hunley*, was constructed of both wrought and cast iron. Its brass tangent sight was also present.

The most difficult aspect of the conservation of the cannon was the removal of a munitions shell lodged inside the chamber. The unexpected discovery forced conservators to change their treatment plan, as no work, particularly no electrolytic reduction, could be performed with the barrel still loaded. A French military demolition team was brought in to help develop a plan to remove the brass fuse from the shell and flush out the gun powder. Conservators took a silicone mold of the fuse, and the demolitions team used the resulting cast to make a custom tool for removing the fuse. After

one year of soaking, the gun was taken to a remote location, for safety purposes, and the fuse successfully removed.

After the shell was made inert, it took several more years to remove sufficient concretion from inside the bore of the cannon to remove the shell and adjacent lead sabot. During this time the gun was put through a series of 2% sodium hydroxide electrolyte baths in order to remove chlorides. Electrolysis was first used to treat just the interior of the barrel, and then it was applied to the entire cannon. When chloride removal was complete, an infrared lamp was used to try the inside of the barrel, and then molecular sieves were applied to fully dehydrate the whole piece. After drying, specific surface areas of the cannon were coated with a surface consolidant (Paraloid B-48N) and then the entire piece received a coating of Owatrol, which can be easily removed with sodium hydroxide. This treatment was selected for its reversibility instead of using the more common method of submerging the artifact in hot microcrystalline wax.

Conserving the USS *Monitor*: Adventures with Big Iron

Curtiss Peterson

The Rescue Company

Curtiss Peterson presented knowledge he and his team gained working with large iron artifacts and hull components from *USS Monitor*, a Civil War ironclad that sank off Cape Hatteras, North Carolina, at the end of 1862. From a conservation standpoint, these types of artifacts make up a class Peterson termed “big iron,” which is more difficult to handle than most artifacts and requires industrial-sized equipment, larger working space, and special safety precautions to protect both the artifact and the conservators.

The anchors were the first large iron object from the site to be conserved, and served as a valuable learning opportunity prior to tackling the hull components. In order to disassemble one anchor, they used a combination of heat, penetrants, and physical force, a process resulting in the destruction of a come-along rated to 4,200 lb. (1,905 kg) and a bent 48 in. (122 cm) wrench. In the end 12 tn. (10.89 t) of press force to successfully separate the two pieces being held together by one bolt and one rivet. Upon disassembly, uncombined

sodium chloride was found in abundance on the previously covered surfaces. This supported the comments from previous speakers that iron objects of multiple components must be disassembled to remove all the salts.

Another example of working with big iron was *Monitor's* propeller. At 9 ft. (2.74 m) in diameter, it was too large to be easily moved, requiring the conservators to constantly consider positioning themselves and not the object. The tank holding the propeller held 1,100 gal. (4,164 l), and was designed to accommodate conservators working inside. The propeller's electrolysis arrangement consisted of a perforated plastic polyethylene pipe containing platinum-coated copper anodes. Current was provided by two cathodic protection power supplies of a type used to maintain pipelines. These power supplies had 12 special circuits for controlling current density thus allowing Peterson to select individual areas to reduce and control current flow. Electrolysis helped remove the concretion, which

came off in large sections of 20 to 50 lb. (9–23 kg). The team found it best to crack the concretion strategically with hammers to prevent it from coming off in pieces so large they might become unmanageable or injure someone. The tank also functioned as an ongoing museum exhibit, drawing several hundred visitors a day, and even thousands on days when the tank was drained. Peterson highly recommended incorporating *Hunley's* conservation into a public outreach environment.

Highlighting his experience with riveted structures, Peterson discussed his working with several hull and deck plates from *Monitor*. In some cases he found that the plate was intact but the rivets had been entirely lost; in other cases, rivet heads survived, but their shanks were gone; and occasionally the hole in the plate around the rivet had enlarged, leaving a rivet in place that was no longer holding the plate. The variation in corrosion was highlighted, Peterson pointing a case where “on the same piece, the rivets were both anodic and cathodic to the structural membrane.” He also noted there was sometimes more significant corrosion along plate edges where plate compression had stressed the metal.

Corrosion, Metallurgy and Biofoul Interaction on USS *Arizona*

Dr. Donald Johnson and Dr. William Weins

Department of Mechanical Engineering, University of Nebraska, Lincoln

Drs. Johnson and Weins presented data on the corrosion studies that have been conducted on USS *Arizona*, a 608 ft. (185.3 m) U.S. Navy battleship sunk during the Japanese attack on Pearl Harbor in 1941. It has been preserved in situ as one of the best known World War II Navy war memorials, but is also a potential environmental problem because of the hundreds of thousands of gallons of oil trapped within its hull. Hull failure due to corrosion is therefore of major concern and research was initiated to determine steel hull thicknesses, materials composition, signs of delamination, biofouling (hard concretion), and the effects of the Pearl Harbor environment on corrosion.

In order to understand the corrosion processes acting on the hull, it was first necessary to assess the metal itself, analyzing its chemical composition and microstructure. Johnson, Weins, and co-author John Makinson examined metal samples from *Arizona's* superstructure, taken from materials salvaged from the wreck immediately following the war, in storage at the Pearl Harbor Naval Base. *Arizona's* hull was confirmed to be plain carbonate steel with a low carbon content of about 0.2%. The metal was also low in sulfur and phosphorous. The steel had been manufactured by the basic

An unexpected surprise was that the propeller's wrought-iron shaft had apparently corroded preferentially to the cast-iron propeller itself, the exact opposite of how wrought iron usually behaves. This unique sacrificial corrosion was evidenced by the build-up of carbonates on the surface of the propeller, which only occurs when the cast iron is in a cathodic relationship to another metal. Research into the manufacture of 19th century wrought iron showed that foundry methods changed during the 1850s and 1860s from sponge manufacturing, in which the metal never becomes a liquid, to puddling. In the latter case, impurities were put into the liquid iron so that it would resemble the traditional wrought iron derived from sponge manufacture. Peterson's assessment is that the propeller shaft consisted of relatively purer iron than is usually expected under the term wrought iron.

In closing, Peterson noted some difficulties in reading electrode potential measurements through encrustation. Measurements were more reliable when the encrustation had been removed. He cautioned the *Hunley* team to pay very close attention to the condition of the rivets.

open hearth process sometime between 1913, when the ship was built, and the 1929-1931 ship refitting. Dr. Weins noted that, as with *Monitor*, corrosion was prevalent around the rivet holes of the sample metal.

The team also measured the ductile-brittle transition temperature, which was found to be high compared to modern standards, but significantly better than some early steel ship plate, such as that from *Titanic*. They then took samples from the submerged hull of *Arizona*. Samples demonstrating significant biofouling were vacuum encapsulated in epoxy and sectioned. The microstructure of the metal was examined and the cross section of the sample characterized using X-ray diffraction (XRD). This allowed them to understand what materials were present all the way from the base metal to the seawater interface.

Dr. Johnson reviewed the main avenues of corrosion and detailed some of the cases encountered with *Arizona* that may have a bearing on *Hunley*. The basic corrosion process has three components: an electrolyte, a metallic circuit, and an anode and cathode. The most obvious source of a difference in potential is galvanic action resulting from different metals, for example copper being cathodic to steel. However, other

factors can result in broad or localized potential differences. On a microstructural level, grain within a metal can act as a cathode, while the grain boundary itself acts as an anode, the principle behind etching metal. Iron carbide (cementite) tends to act as a cathode because it will allow ready evolution of hydrogen, while iron ferrite holds on to hydrogen and will act as an anode. The state of the metal surface is another factor, where clean or smooth areas can be a cathode, while rough areas might act as an anode. Where the metal has been under high stress will be anodic to areas of low stress. In instances where there is only partial or uneven oxygen coverage, contrary to expectation, the high oxygen areas act as cathodes, while low oxygen areas act as anodes.

A sample of steel from *Arizona* showed pearlite, a eutectoid mixture of iron carbide and ferrite placements, in which the carbide tended to act cathodically to the ferrite, resulting in a differential in corrosion rate. Corrosion due to oxygen differential was shown on an iron bolt, where the deterioration began inside a crevice that was anaerobic. In addition to lack of oxygen, crevices and other areas isolated by such things as biofouling or pitting can trap chloride ions, therefore becoming acidic, resulting in an increased corrosion rate. An example of stress corrosion was shown, demonstrating its characteristic branching pattern. This was contrasted to the more linear cracking patterns of both

corrosion fatigue and hydrogen embrittlement.

Johnson addressed the issue of biological effects on the corrosion environment, particularly in relation to bacteria. He noted that in aerobic conditions where bacteria consume oxygen, corrosion rates are independent of the microstructure of the metal. On the other hand, in anaerobic conditions where hydrogen is consumed, corrosion rates become somewhat dependent on the microstructure of the metal and the amount volume of hydrogen evolving from it. After observing that diving activity at the site led to increased evolution of bacteria products, such as H_2S , he hypothesized that the gas volume developed has proportionality to the corrosion rate.

Incorporating the organic materials into their research, Drs. Johnson and Weins took biofoul samples, collected the Fe_3O_4 from the samples from 8 ft. (2.44 m) down to 28 ft. (8.53 m), and using, the weight of iron recovered, calculated an annual corrosion rate in relation to depth. After compensating for corrosion before the attack and for periods out of water while in dry dock, they calculated a total penetration rate incurred between 1913 to 1999 to be 0.2 to 0.25 mils (0.005–0.006 mm) per year. Johnson acknowledged that this method involved a number of assumptions, including that the all of the iron converted to iron oxide was preserved in the biofoul layer.

Conclusion

The papers delivered at the symposium raised many important issues to be considered by the archaeologists, conservators, and engineers who planned and implemented the recovery of *H. L. Hunley*. Since a full-scale symposium may not be feasible for all recovery projects, it is hoped that the inclusion of these papers here will allow future project planners to benefit from their advice and expertise. Many of the projects discussed have been written up in more detail since the conference, and a selection of publications is included below.

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APPENDIX B

Recovery Operations Personnel

HAT (Hunley Archaeological Team)

| | | |
|----------------------|--|-----------------------|
| Dive Team: | | |
| Dr. Robert Neyland | Project Director and Chief Archaeologist | NHC, SCAH |
| Leonard Whitlock | Senior Project Manager | IC |
| David Conlin | Field Manager | NPS |
| Matt Russell | Asst. Field Manager - Diving & Logistics | NPS-SCRU |
| Claire Peachey | Asst. Field Manager - Data Recovery | NPS, NHC |
| Harry Pecorelli III | Archaeologist/Diver/Dive Safety Officer | College of Charleston |
| Paul Mardikian | Senior Conservator | College of Charleston |
| Chris Amer | Archaeologist | SCIAA |
| Joe Beatty | Archaeologist | SCIAA |
| Dan Davis | Archaeologist | IC |
| William Gotts | Archaeologist | IC |
| Wes Hall | Archaeologist | IC |
| Shea McLean | Archaeologist | IC |
| Mark Ragan | Project Historian | IC |
| Drew Ruddy | Archaeologist | IC |
| Brett Seymour | Photographer | NPS-SCRU |
| James Spirek | Archaeologist | SCIAA |
| David Whall | Archaeologist | IC |
| Ralph Wilbanks | Archaeologist | IC |
| | | |
| Surface Team: | | |
| Maria Jacobsen | Senior Archaeologist | College of Charleston |
| Michael Scafuri | Archaeologist | IC |
| Jason Burns | Archaeologist | IC |
| Steve Howard | Crew Boat <i>Jeremy</i> Captain | IC |
| Darlene Russo | Office Administrator | FOTH |
| Samantha Omorsemi | Administrative Support | FOTH |
| Cindy Elgenberger | Administrative Support | FOTH |
| Tristan Amer | Intern | FOTH |
| Terri Henderson | Intern | FOTH |
| Jennings Woods | Intern | FOTH |

FOTH – Friends of the Hunley

IC – Independent Contractor

NHC – Naval Historical Center (now Naval History and Heritage Command)

NPS-SCRU – National Park Service Submerged Cultural Resources Unit (now Submerged Resources Center)

SCIAA – South Carolina Institute of Archaeology and Anthropology

SCAH – South Carolina Archives and History

Oceaneering Team

| | |
|------------------|-----------------------------|
| Steve Wright | Project Manager |
| Doug Dawson | Asst. Project Manager/Diver |
| Perry Smith | Lead Project Engineer/Diver |
| Ken Edwards | Dive Supervisor |
| Clint Allison | Diver |
| Josh Brown | Diver |
| Mike Crago | Diver |
| Todd Groseclose | Diver/Shift Supervisor |
| Chris Hanson | Diver |
| Marcus Harper | Diver/Shift Supervisor |
| Eric Howard | Diver |
| Jeff Ledda | Engineer |
| Benni Martin | Diver |
| Jon Sears | Diver |
| Mark Van Emmerik | Engineer/Diver |
| David Fontaine | Captain, Marks Tide |

Titan Maritime Industries, Inc. (*Karlissa-B*)

| | |
|--------------------|------------------|
| Dan Schwall | Project Manager |
| Colin Trepte | Barge Captain |
| Hank Bergman | Chief Engineer |
| Jenkins Montgomery | Crane Operator |
| Ken Bradford | Crane Operator |
| Oscar Lopez | Jacking Engineer |

APPENDIX C

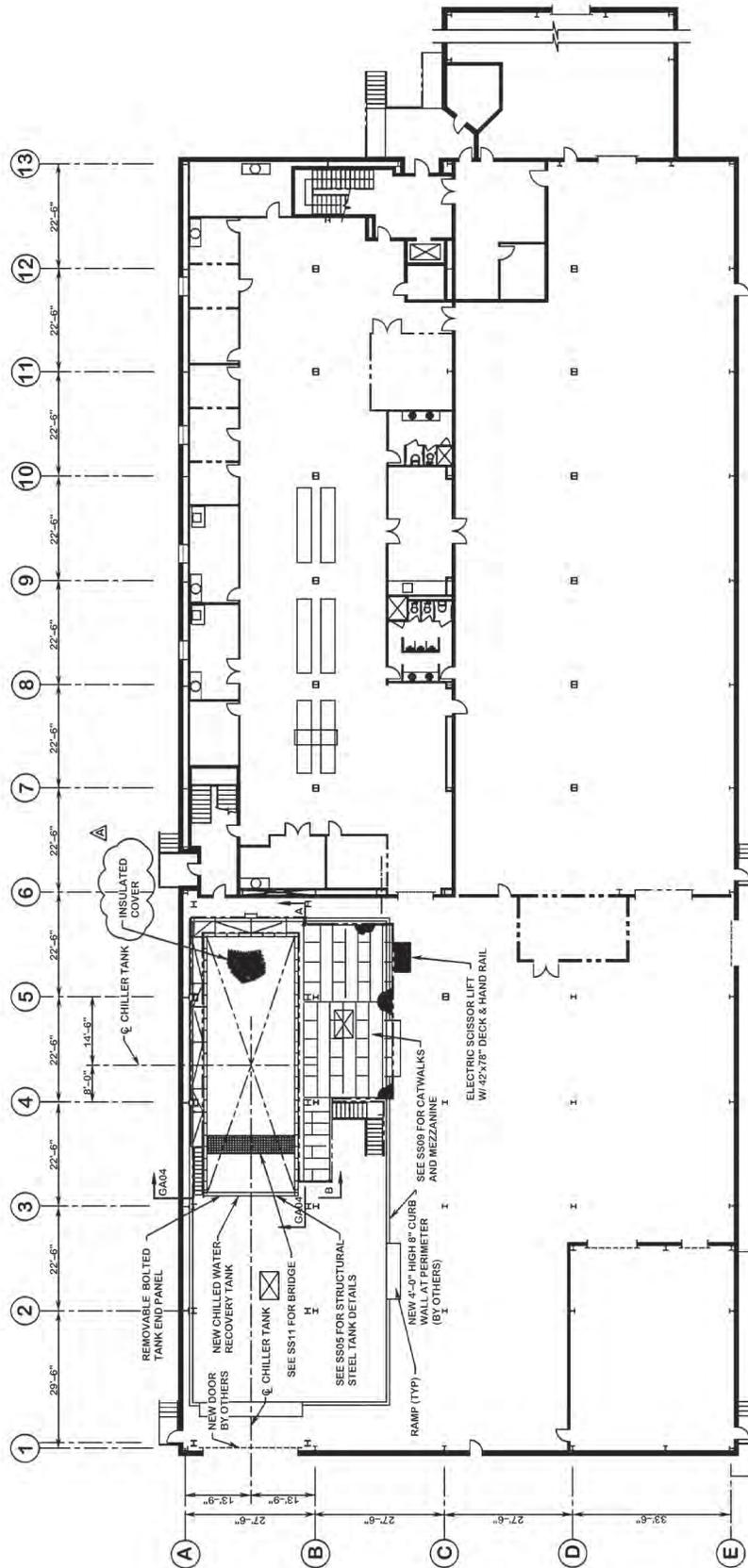
Companies Providing Essential Services to *Hunley* Recovery Operation

3M of Austin
Body Glove International
Bultman/Bell (Greenville, SC)
Carolina Flag & Banner (Charleston, SC)
Celanese Corp
Charleston Museum (Charleston, SC)
Charleston Rigging & Marine Hardware (Charleston, SC)
City of Charleston
Coastal Carolina University
Coastal Inspection Services
College of Charleston
Cortland Cable
Cottage Industry Models
Detyens Shipyards (North Charleston, SC)
Diver Alert Network (Durham, NC)
DuLux Paints (Mount Pleasant, SC)
Fisher Scientific
Froth Pak / Dow Chemical
Ft. Sumter National Monument
Fuji Film
Fuji NDT Systems of Roselle, IA
Krautkramer Branson
Larry Raney (Charleston, SC)
Lou Edens (Mount Pleasant, SC)
Magic Brush (Deland, FL)
Marketing Solutions (Marietta, GA)
Medical University of South Carolina
National Geographic
National Park Service
National PrintFast (Indianapolis, IN)
NCS Supply Inc. (Philadelphia, PA)
Nederman
Newco, Inc. (Florence, SC)
NuVan Technologies (Dallas, TX)
Nycom
Orion Research, Inc.
Phillips Industrial Services (Mt. Pleasant, SC)
Progressive Integrations (Charleston, SC)
Rick Guobaitis
South Carolina Department of Natural Resources
South Carolina Educational Television
Sirisky Marine
Soil Consultants
Stephen Leonard
Suncom
Teleco
Tidewater Marine
Thompson Pump (Summerville, SC)
Turner Network Television (Atlanta, GA)
US Army Corps of Engineers, Savannah
The Wet Shop (North Charleston, SC)
Williams Scotsman
YSI Inc. (Indian Trail, NC)

APPENDIX D

Engineering Drawings

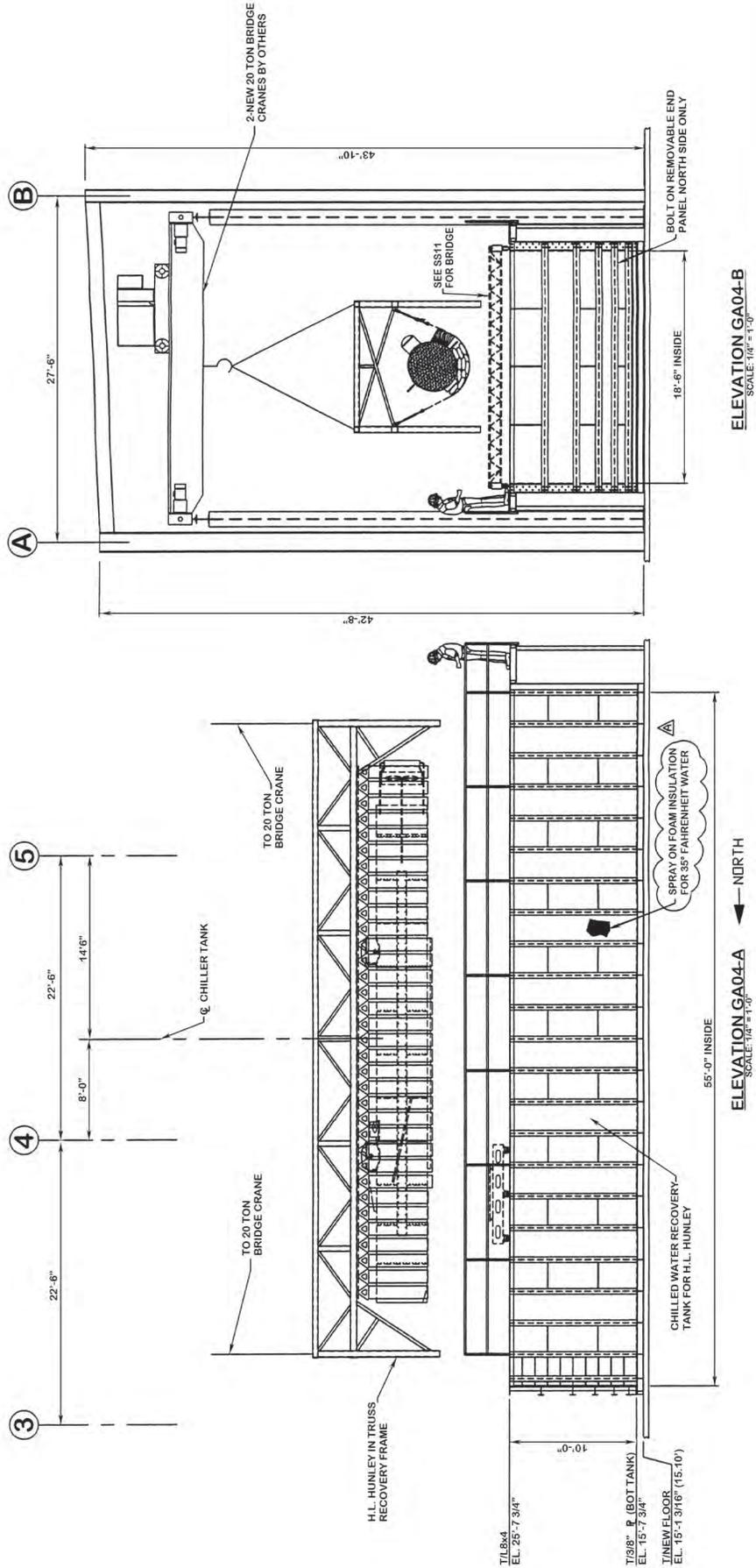
A. Building 255 - First Floor Plan



BUILDING 255 FIRST FLOOR PLAN VIEW GA03-A
SCALE: 3/32" = 1'-0"
← NORTH

OCEANEERING
 OCEANEERING INTERNATIONAL, INC.
 501 PRINCE GEORGES BLVD.
 UPPER MARLBORO, MD 20774

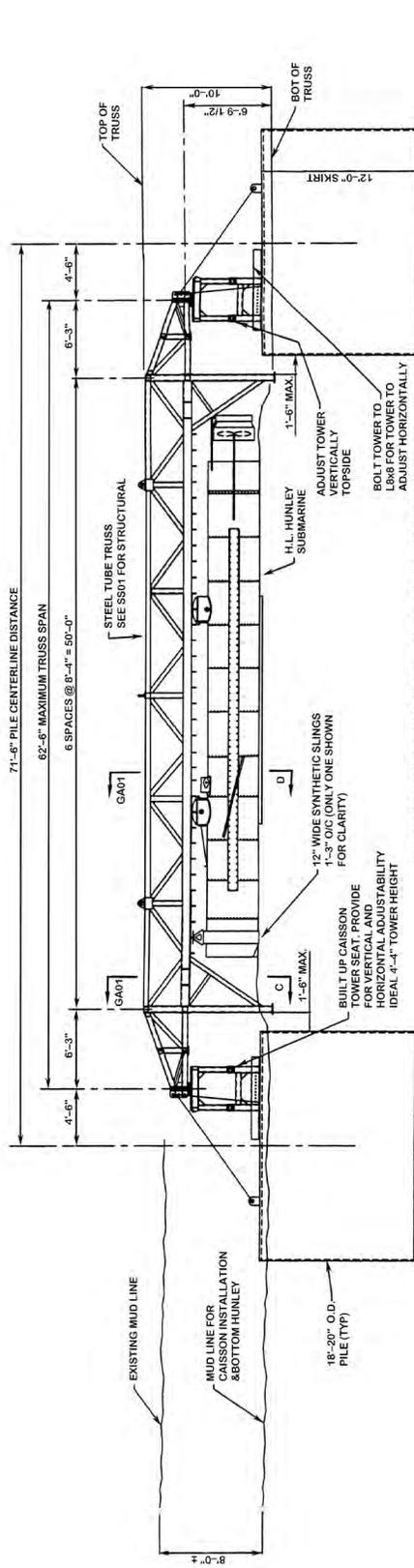
B. Chiller Tank (Elevation)



OCEANEERING INTERNATIONAL, INC.
 501 PRINCE GEORGES BLVD.
 UPPER MARLBORO, MD 20774

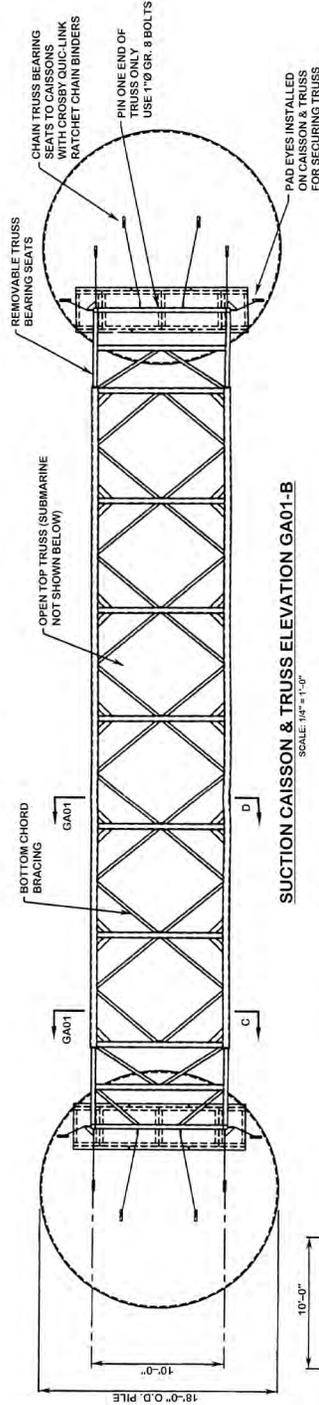
OCEANEERING

D. Suction Pile and Truss (Elevation and Plan)



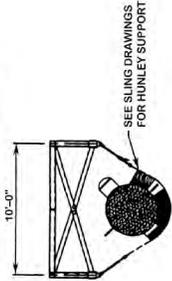
SCALE: 1/4" = 1'-0"

SUCTION CAISSON & TRUSS ELEVATION GA01-A



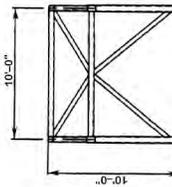
SCALE: 1/4" = 1'-0"

SUCTION CAISSON & TRUSS ELEVATION GA01-B



SCALE: 1/4" = 1'-0"

SECTION GA01-D



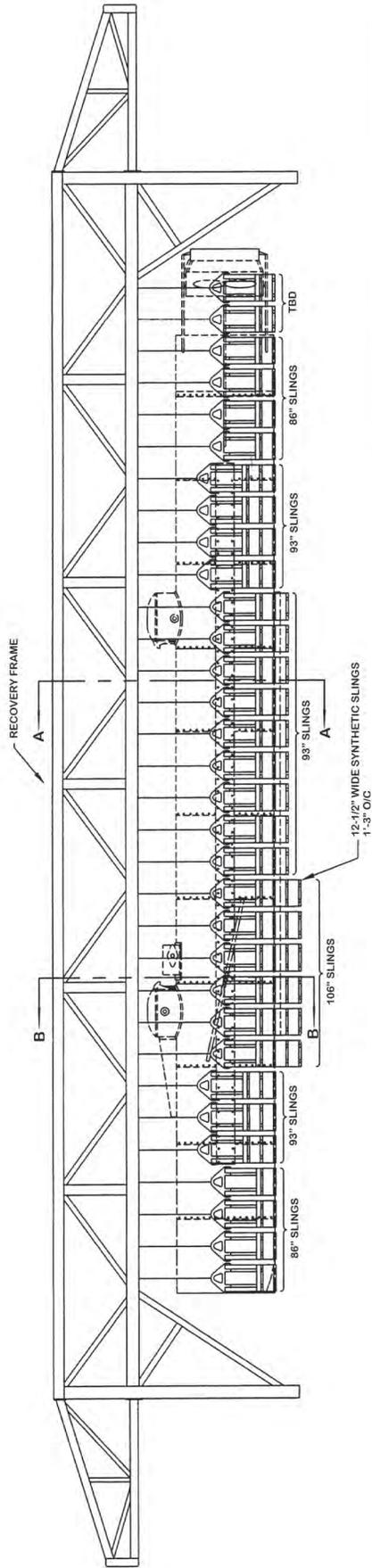
SCALE: 1/4" = 1'-0"

END SECTION GA01-C

- GENERAL NOTES:**
- LOAD CALCULATIONS: HUNLEY DIMENSIONS, PHYSICAL SITE CHARACTERISTICS AND DATA OBTAINED FROM "HUNLEY SITE ASSESSMENT" PREPARED BY THE U.S. NAVAL CENTER FOR MARITIME AND THE S.C. INSTITUTE OF ARCHAEOLOGY AND ANTHROPOLOGY.
 - GRAVITY LOAD DATA:
HUNLEY — 25,000 LBS.
SEDIMENT LOAD — 50,000 LBS.
TRUSS DEAD LOAD — 22,000 LBS.
VOLUME — 400 CF.
 - DYNAMIC LOAD DATA:
CURRENT — 2.0 KNOTS
DYNAMIC — LONG 0.15 G
DYNAMIC — LAT 0.5 G
DYNAMIC — GRAVITY 1.4 G

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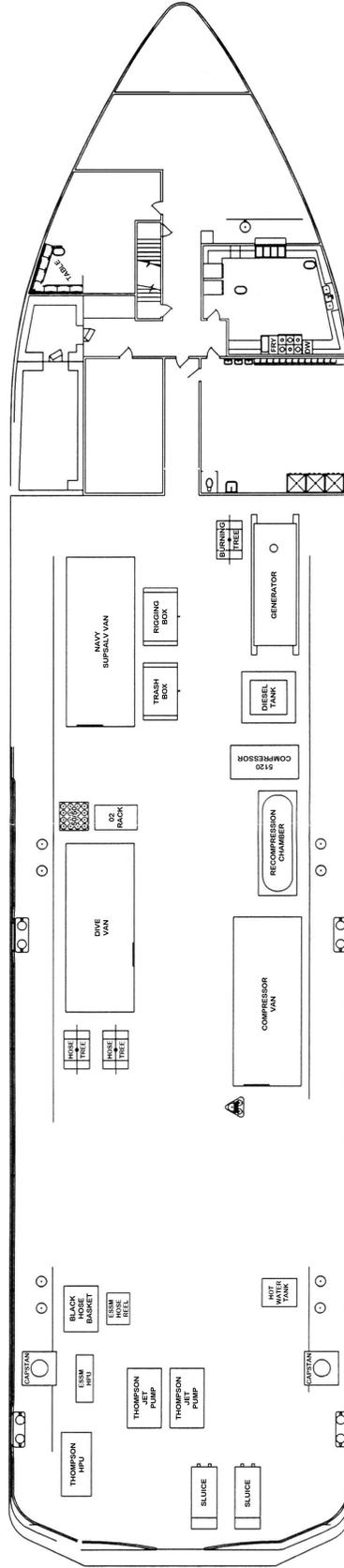
G. Rigging Plan (Elevation)



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RIGGING PLAN ELEVATION

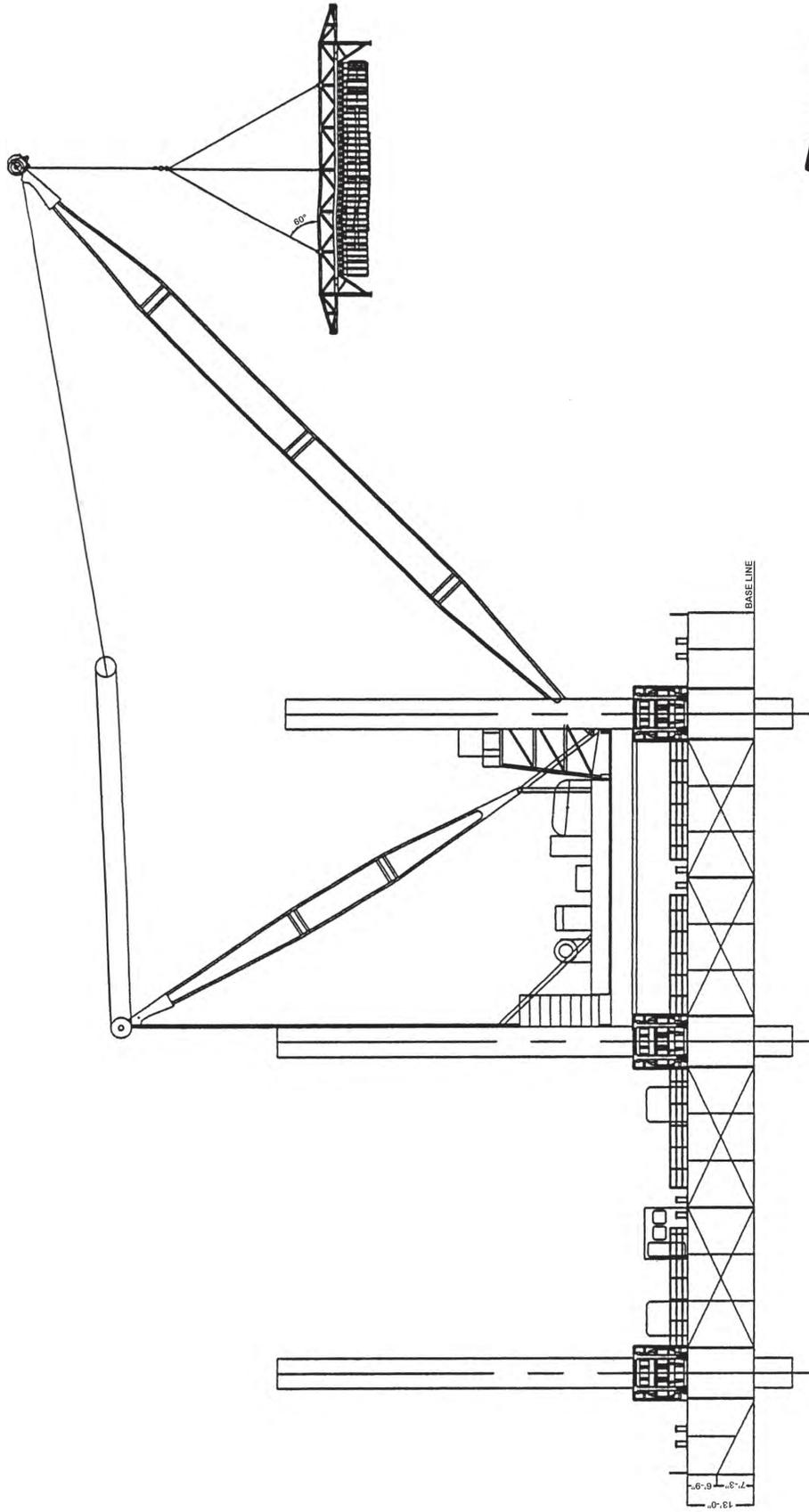
H. Marks Tide Deck Plan



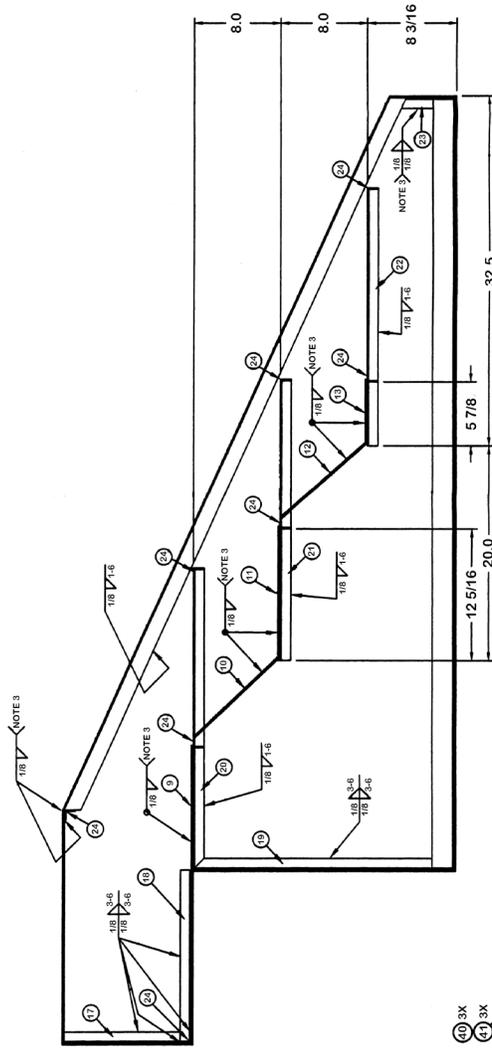
MARKS TIDE DECK PLAN
NOT TO SCALE

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 UPPER MARLBORO, MD 20774

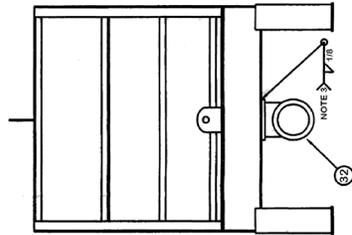
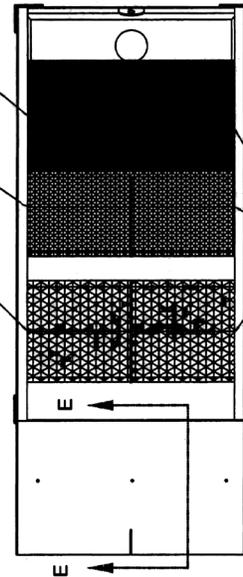
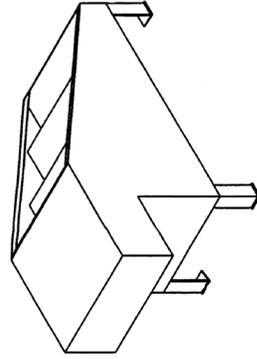
I. Karlissa B (Elevation)



J. Sluice Box



SECTION B-B



SECTION E-E

NOTES:

1. BREAK ALL SHARP EDGES
2. FINISH BLAST & PAINT TO COMMERCIAL STANDARDS, EXCEPT WHERE INDICATED ON SHEET 6.
1 COAT PRIMER & 2 COATS LIGHT GRAY MARINE GRADE EPOXY PAINT APPLIED
IAW MANUFACTURERS RECOMMENDATIONS.
3. WATER TIGHT WELD
4. USE ITEM SHOWN OR EQUIVALENT
5. TREAT THREADS WITH NEVER SEIZE COMPOUND PRIOR TO INSTALLATION.
6. INSTALL ITEM 39 AFTER PAINTING

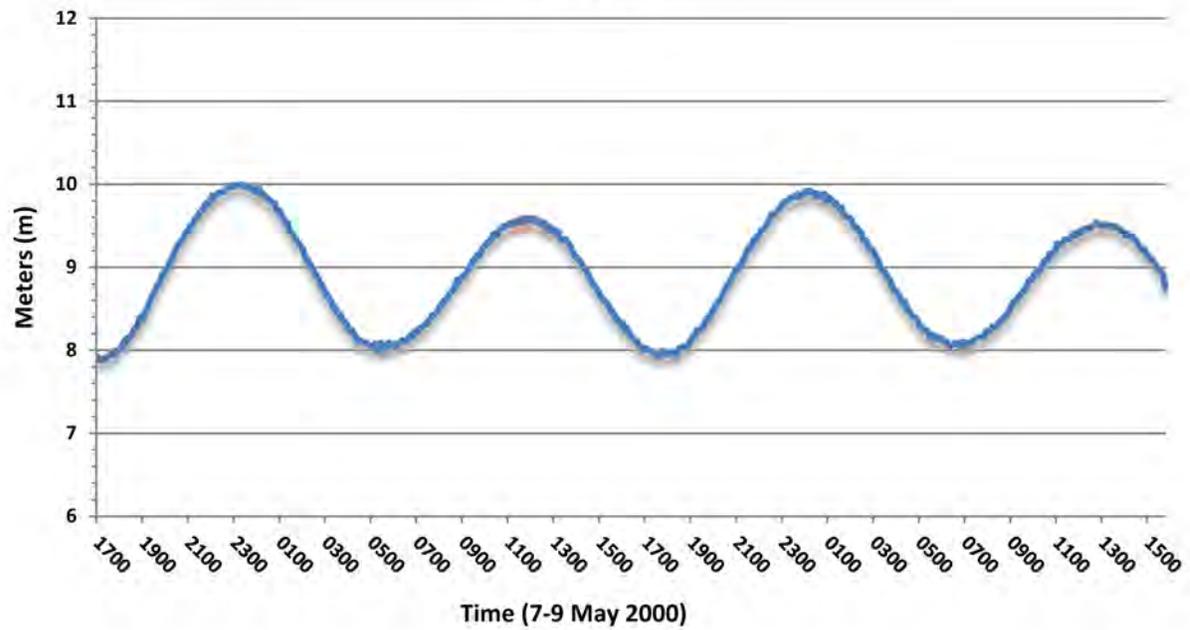
SLUICE BOX-1

OCEANEERING
 OCEANEERING INTERNATIONAL, INC.
 501 PRINCE GEORGES BLVD.
 UPPER MARLBORO, MD 20774

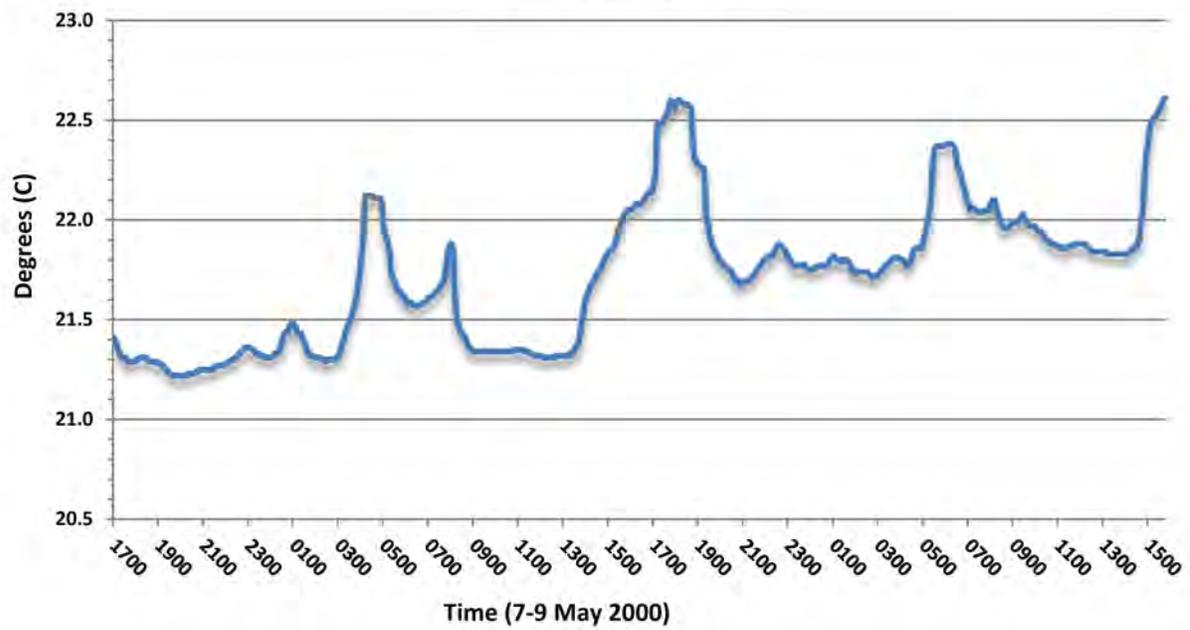
APPENDIX E

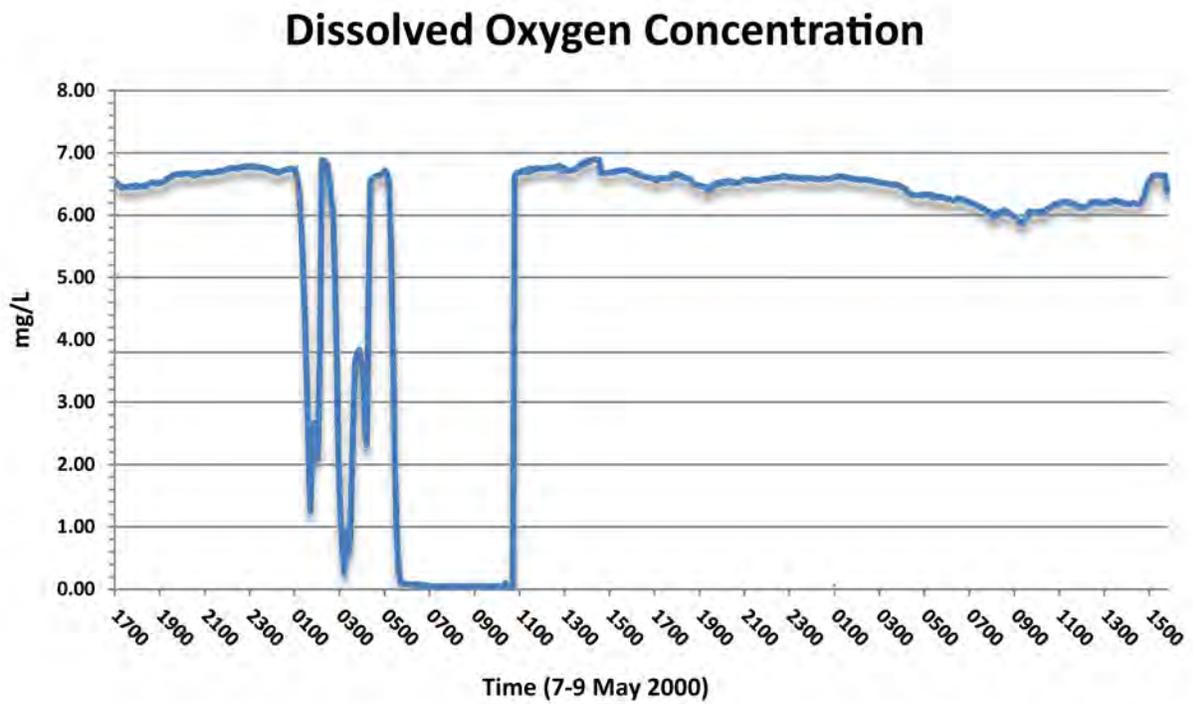
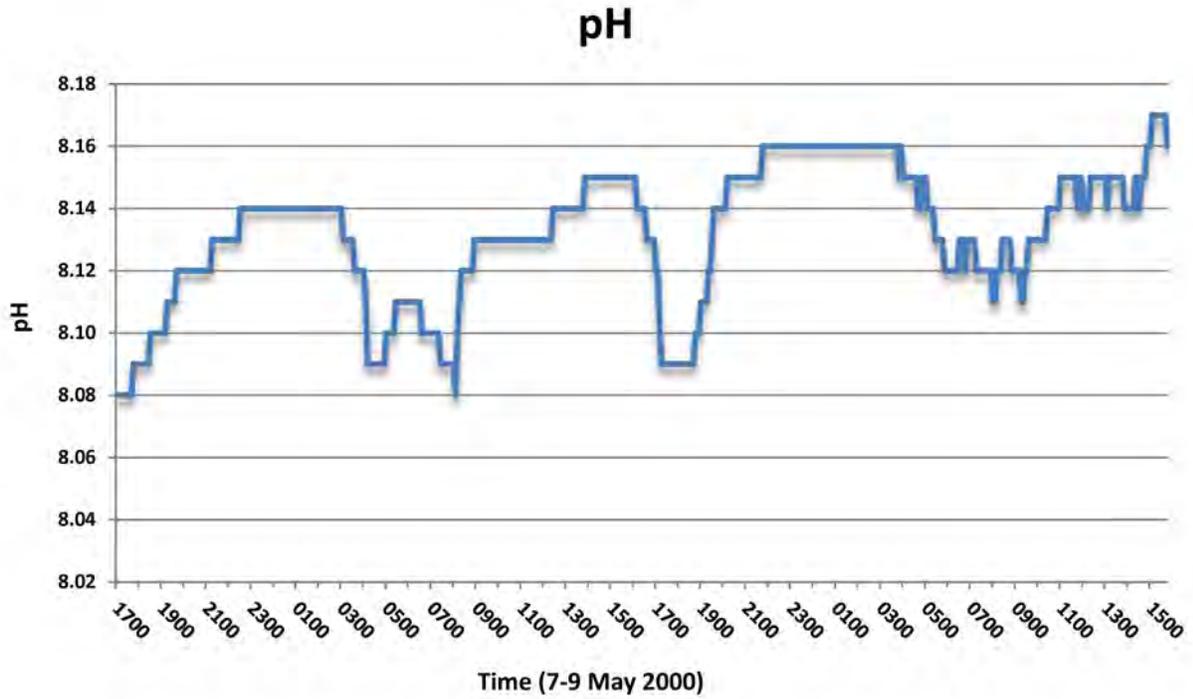
Summary of Environmental Data Collected at the *Hunley* Site over a Period of 48 Hours

Depth

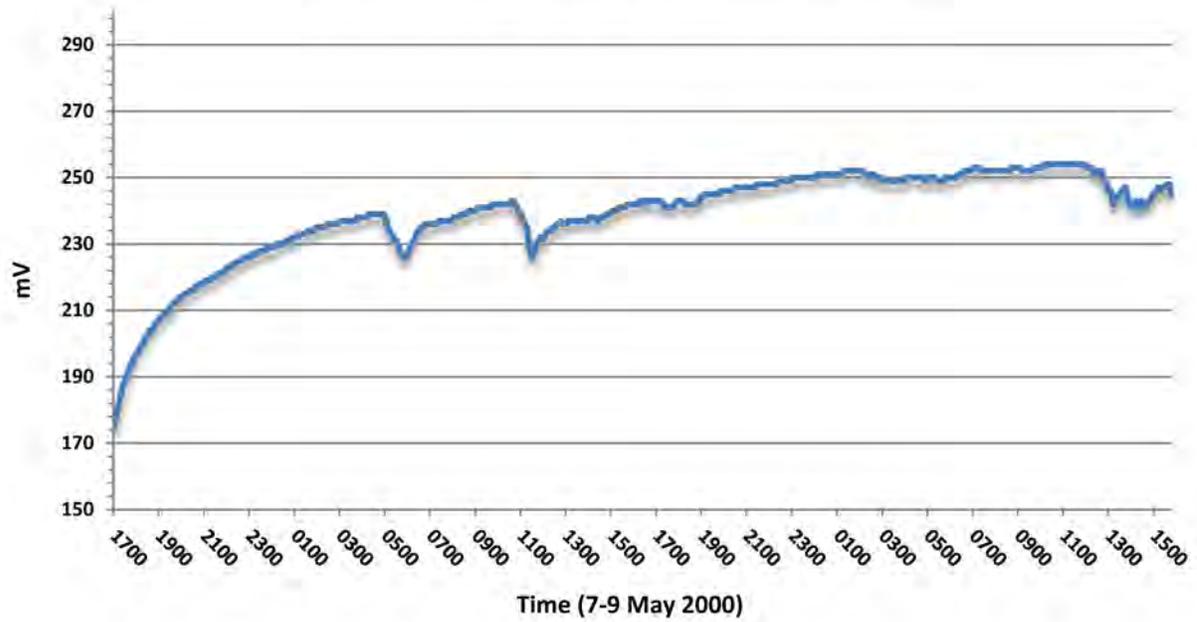


Temperature

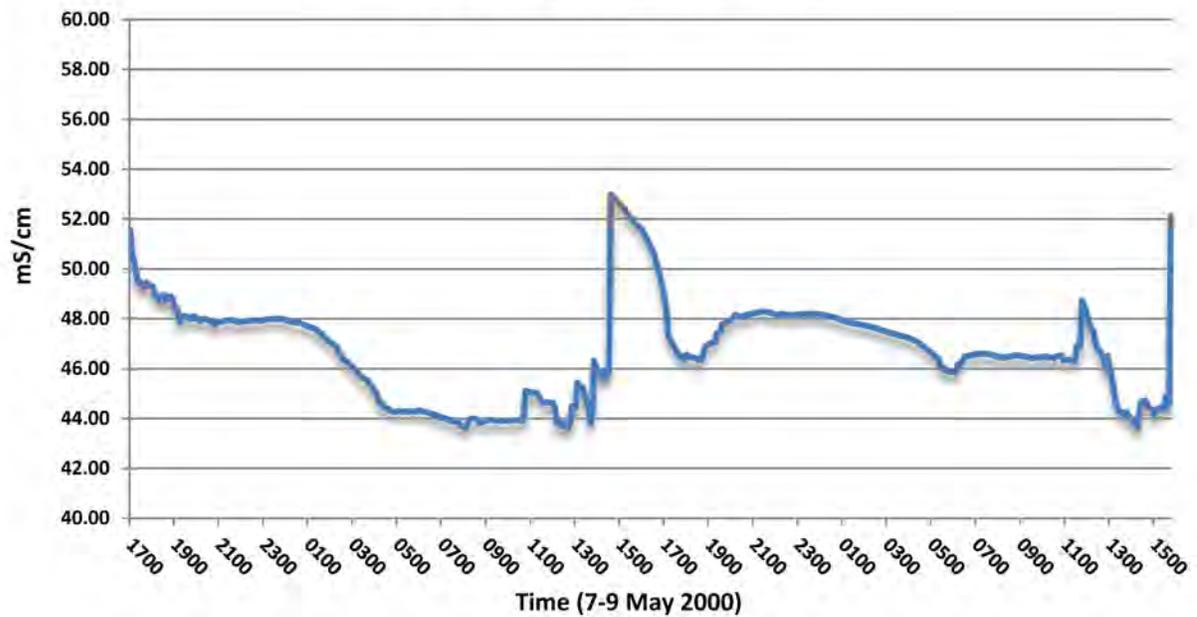




Oxidation-Reduction Potential



Specific Conductance



APPENDIX F

Analysis of Oxygen Reduction Potential of *Hunley* Iron Hull Plates In-Situ

Steve West
Orion Research, Inc.
Beverly, MA

May 17, 2000
Hunley Recovery Site
Offshore, Charleston, SC

Equipment Description

1. Combination Platinum ORP (Oxidation-Reduction Potential) Probes (Qty. 3)

Standard features:

- Orion Model 9179BN ORP Probes
- 6.25 mm dia. platinum pellet sensing half-cell
- Sealed, internal Ag/AgCl reference element with gelled, sat'd AgCl, sat'd KCL electrolyte
- 2 fiber liquid junctions at probe perimeter, 180 degrees apart
- Reference half-cell potential +200mV vs NHE

Modifications

- The 1-meter cables with BNC connectors were replaced with 100-foot cables with waterproof DIN connectors
- The temperature sensor was not installed.
- A chamfer was machined into the epoxy surrounding the platinum element such that the platinum protruded several thousandths of an inch from probe end to ensure contact with the hull of the Hunley.

2. High-Input-Impedance pH/mV Meters (Qty. 2)

Standard Features:

- Orion Model 265A
- pH and direct mV modes
- Waterproof case with DIN waterproof probe connection

3. Fluke Model 833 Multimeter

4. Miscellaneous

- Orion ORP standard solution, Cat. No. 967901
- Banana plug adapters to connect ORP probes to multimeter

Procedures, Results, and Discussion

1. The ORP probe cables were strain-relieved along their entire lengths using 3/16-in. polypropylene line and duct tape.
2. All three probes were tested in Orion ORP Standard (420 mV vs NHE); all read 220 mV, indicating a reference electrode potential of +200 mV vs NHE as expected for sat'd KCL (reference is connected to negative meter terminal, necessitating reversal of sign).
3. Meters and probes were set up on the port-side gunwale walkway.

4. While connected to 265A meters, Probe 1 and Probe 2 were handed to divers Claire and Matt respectively. Coiling and uncoiling of cables was handled by Pam and Leonard topside; communication with divers was relayed by Dave.
5. As divers descended and moved into position, ORP in the ocean water from Probe 1 varied between 184 and 195 (-16 and -5 vs NHE) while ORP from Probe 2 was between 193 and 199 (-7 and -1 vs NHE).
6. Both probes were contacted initially with the bow region of the sub and became immediately stable at -578 and -579 respectively for Probes 1 and 2 (-378 and -379 vs NHE).
7. Probe 2 was relocated to the stern where a noisy reading $-530 \pm 10\text{mV}$ was obtained while Probe 1 maintained a steady reading of $-579 \pm 1\text{mV}$ at the bow (-330 and -379 mV vs NHE).
8. The positions of Probes 1 and 2 were reversed. Probe 1, now at the stern, read $-530 \pm 10\text{mV}$ while Probe 2 read a steady $-579 \pm 2\text{mV}$ at the bow. *Thus the difference in readings [was] a function of the location on the hull, not of the individual probes.*
9. Positions were reversed again and the original readings recovered. Then, after a minute or so of scraping the probe against the hull, quite a stable reading, $-561 \pm 2\text{mV}$ (-361 vs NHE) was obtained from Probe 2 at the stern. This seemed to suggest that making good contact with the hull was more difficult at the stern location and the quality of the contact was varying.
10. To summarize the corrosion potential measurements:
 - *Corrosion potential at the bow of the Hunley was determined to be $-379 \pm 2\text{mV}$ vs NHE.*
 - *Corrosion potential at the stern of the Hunley was determined to be between -320 and -363 mV vs NHE.*
11. Next the probes were disconnected from the 265A pH/mV meters and connected to the Fluke multimeter for continuity tests. When the probes were in the water near the bow and stern, readings fluctuated around 20-30 kohm. (This is not an absurd number. The resistance of a 1-cm cube of typical seawater at 20-25 C is ~ 20 ohm. If the area of each electrode is about 0.25 sq. cm. and the electrodes are about 500 cm apart, the expected resistance would be in the range of, but less than, $20 \times 500 / 0.25 = 40,000$ ohm.)
12. Placing the probes in contact with the sub at the bow and stern caused the readings to drop intermittently to the 0.8 kohm or less range, but only briefly. If conduction through the hull were occurring, poor surface contact was resulting in unreliable readings. When readings were attempted from amidships to the bow and stern respectively, the readings didn't add up. Between the bow and amidships, readings over 1 Mohm were obtained, and between amidships and the stern the readings intermittently dropped to the 0.6 kohm range, but again only briefly.
13. To summarize the continuity measurements:
 - *Either poor continuity exists between different sections of the Hunley's hull, or poor contact was being made between the probes and hull.*
 - *It might be advisable, either while the sub is still on site or when it is in the tank, to try some continuity measurements between spots close together on the hull (a few centimeters apart or less) in order to help diagnose whether poor continuity or poor contact resulted in the unstable, inconclusive readings.*

APPENDIX G

**Catalog of Artifacts
Recovered from the Seabed
Surrounding the Submarine
*H. L. Hunley***

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|-----------|--|--|
| HL-0342 | 5/8/2000 | ME | Iron scale – 38 fragments, modern. All exhibit uniform thickness and appear cylindrical-shaped. | Anomaly 2000-1. |
| HL-0346 | 5/14/2000 | ME/ CC | Metal flakes, thin, probably modern, and metal concretions. Total amount fills ¼ of a 4 × 6 in. plastic bag. | Starboard perimeter zone (10 × 130 ft., 0–5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0347 | 5/14/2000 | SL | Boiler slag – ca. 900 pieces; 3.58 kg | Starboard perimeter zone (10 × 130 ft., 0–5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0348 | 5/14/2000 | WO | Wood fragments. Total amount fills a large plastic bag (9 × 12 in.). | Starboard perimeter zone (10 × 130 ft., 0–5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0349 | 5/14/2000 | CO | Coal – ca. 300 pieces; 1.54 kg | Starboard perimeter zone (10 × 130 ft., 0–5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0350 | 5/14/2000 | CC | Unidentified concretion, possibly natural. Total amount fills a 4 × 6 in. plastic bag. Saved for reference and identification. | Starboard perimeter zone (10 × 130 ft., 0–5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0351 | 5/14/2000 | WO | Wood fragment with remnants of flat faces | 2 ft. from grid, Starboard bow perimeter area. |
| HL-0352 | 5/14/2000 | WO | Wood sliver and four indeterminate wood fragments | In sediment above forwardmost section of bow. |
| HL-0353 | 5/14/2000 | SL | Boiler slag, yellow and red-brown color, iridescent – 4 pieces; 0.02 kg. | In sediment above forwardmost section of bow. |
| HL-0354 | 5/14/2000 | CO | Small fragments of coal – 9 pieces. | In sediment above forwardmost section of bow. |
| HL-0355 | 5/14/2000 | CC | Unidentified concretion. Resembles slag, but possibly natural. Retained for future inspection and identification. | Recovered from sediment at forward section of the bow. |
| HL-0356 | 5/14/2000 | WO | Burned wood fragments, resembling charcoal. Total amount fills ⅓ of a plastic bag (4 × 6 in.). | Starboard perimeter zone (10 × 130 ft., 0–5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0357 | 5/15/2000 | CO | Coal, good condition – 1 large piece; 0.115 kg | Stern, 2 mm abaft aftermost hatch, 0.5 m starboard of vessel centerline, and 0.5 m below mud line. |
| HL-0358 | 5/15/2000 | BO | Bone – 5 individual specimens; one example is broken into 3 fragments and may be an animal pelvic bone. | Starboard perimeter zone (10 × 130 ft., 0–5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0364 | 5/15/2000 | CO | Coal – 30 pieces; 0.12 kg | Stern area, surface of seabed to 3 ft. below datum. Recovered from mesh bag on dredge outflow. |
| HL-0365 | 5/15/2000 | SL | Boiler slag – 145 pieces; 0.53 kg | Stern area, surface of seabed to 3 ft. below datum. Recovered from mesh bag on dredge outflow. |
| HL-0366 | 5/15/2000 | WO | Wood fragments – 13 pieces, largest 5 cm long | Stern area, surface of seabed to 3 ft. below datum. Recovered from mesh bag on dredge outflow. |
| HL-0367 | 5/15/2000 | ST | Stones. Retained for reference and identification. | Discovered throughout excavation area at depths ranging from 0 to 5 ft. below datum. |
| HL-0368 | 5/15/2000 | ME | Iron flakes (2), possibly modern | Stern area, surface of seabed to 3 ft. below datum. Recovered from mesh bag on dredge outflow. |

| Artifact # ^f | Date | Mat. | Description | Provenience |
|-------------------------|-----------|-----------|--|---|
| HL-0370 | 5/16/2000 | CC | Concretion, flat with raised circular section, 4 × 2.5 × 2 cm | Port bow, in sediment between hatch and bow; 0–50 cm below grade. |
| HL-0371 | 5/16/2000 | WO | Wood fragments. Largest piece 8 cm long. | Bow area, surface of seabed to 3 ft. below datum. Recovered from mesh bag on dredge outflow. |
| HL-0372 | 5/16/2000 | SL | Boiler slag – 182 pieces; 0.54 kg | Bow area, surface of seabed to 3 ft. below datum. Recovered from mesh bag on dredge outflow. |
| HL-0373 | 5/16/2000 | BO | Bone – 6 fragments, likely fish | Bow area, surface of seabed to 3 ft. below datum. Recovered from mesh bag on dredge outflow. |
| HL-0374 | 5/16/2000 | CO | Coal – 50 pieces; 0.225 kg | Bow area, surface of seabed to 3 ft. below datum. Recovered from mesh bag on dredge outflow. |
| HL-0377 | 5/16/2000 | CC | Metal concretion – 16 pieces, largest one 5.8 × 4 × 2.6 cm | Bow area, surface of seabed to 3 ft. below datum. Recovered from mesh bag on dredge outflow. |
| HL-0378 | 5/16/2000 | CC | Metal concretion, preserves mold of 5.7 cm length of cylindrical metal object, 5–6 mm diameter. Likely part of HL-0381.* | Bow area, surface of seabed to 3 ft. below datum. Recovered from mesh bag on dredge outflow. |
| HL-0379 | 5/17/2000 | CC | Hull concretion fragments (11), max. thickness 0.8 cm | Bow area, below forward end of cutwater, 20 cm to port side. |
| HL-0380 | 5/17/2000 | CC | Hull concretion fragments (7), max. thickness 1.6 cm | Amidships, along centerline, between 2 nd and 3 rd deadlight aft. |
| HL-0381 | 5/17/2000 | ME/ CC | Iron rod (partial) and concretion preserving mold of rod – 4 pieces. Combined length 40.6 cm. Likely also includes HL-0378, HL-0386, HL-411, HL-0428 and HL-0432.* | Bow area, starboard side of hull. |
| HL-0382 | 5/18/2000 | CC | Concretion – 13 pieces, possible can fragments | Bow area, to starboard of hull, approximately level with end of bow. |
| HL-0383 | 5/18/2000 | CC | Concretion – 2 pieces, possible can fragments | Stern area, abaft end of submarine, moving towards datum stakes. |
| HL-0384 | 5/18/2000 | ME | Unidentified iron fragment, cylindrical, 10.8 cm long. Possible modern welding rod. Bent at one end. | Stern area, abaft end of submarine, moving towards datum stakes. |
| HL-0385 | 5/18/2000 | PA | Paint fragment, red-grey, modern. | Stern area, abaft end of submarine, moving towards datum stakes. |
| HL-0386 | 5/19/2000 | CC | Iron concretion – preserves mold of 4.0 cm length of cylindrical object, 6 mm diameter. Likely part of HL-0381.* | Bow area. Recovered from mesh bag on dredge outflow. |
| HL-0387 | 5/19/2000 | CC | Concretion, possibly natural | Bow area. Recovered from mesh bag on dredge outflow. |
| HL-0388 | 5/19/2000 | SL | Boiler slag fragments of varying sizes – ca. 650 pieces, 3.23 kg | Port perimeter zone (10 × 130 ft., 0–3.5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0389 | 5/19/2000 | SL | Boiler slag – 170 pieces; 1.25 kg | Port perimeter zone (10 × 130 ft., 0–3.5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0390 | 5/19/2000 | WO | Wood fragments. Total amount fills ½ plastic bag (9 × 12 in.). | Port perimeter zone (10 × 130 ft., 0–3.5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0391 | 5/19/2000 | CC | Concretion, possibly natural, and stone. Total amount fills 20% of plastic bag (9 × 12 in.) | Port perimeter zone (10 × 130 ft., 0–3.5 ft. deep). Found in sluice box while sieving dredge outflow. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|------|--|--|
| HL-0392 | 5/19/2000 | ME | Iron flake, 1.5 × 1.1 × 0.2 cm | Port perimeter zone (10 × 130 ft., 0–3.5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0393 | 5/19/2000 | ME | Modern brass screw with slotted head | Sediment along port side of stern cutback. |
| HL-0394 | 5/19/2000 | SL | Boiler slag – 121 pieces; 0.55 kg | Stern area of hull around and to starboard of propeller. |
| HL-0395 | 5/19/2000 | CO | Coal – 25 pieces; 0.145 kg | Stern area of hull around and to starboard of propeller. |
| HL-0396 | 5/19/2000 | WO | Wood fragments – 13 pieces, largest 4.6 cm in length | Stern area of hull around and to starboard of propeller. |
| HL-0397 | 5/19/2000 | CC | Concretion – 2 pieces, largest 7.9 × 5 × 2.7 cm | Stern area of hull around and to starboard of propeller. |
| HL-0398 | 5/20/2000 | CO | Coal – 1 piece; 1.4 kg | Port cutback, stern quarter. |
| HL-0399 | 5/20/2000 | RU | Rubber fragments (2), 1 a partial gasket | Cutback area at starboard amidships. |
| HL-0400 | 5/20/2000 | CC | Concretion – 2 small, roughly circular pieces | Bow area. |
| HL-0401 | 5/20/2000 | CO | Coal – 46 pieces; 0.285 kg | Bow area, starboard side between bow and hatch, excavating forward and to starboard. |
| HL-0402 | 5/20/2000 | SL | Boiler slag – 125 pieces, 0.4 kg | Bow area, starboard side between bow and hatch, excavating forward and to starboard. |
| HL-0403 | 5/20/2000 | CC | Iron concretions (2), largest 3.9 × 2.6 × 1.7 cm | Bow area, excavating to starboard of the hull between the tip of the bow and the forward hatch. |
| HL-0404 | 5/20/2000 | ME | Iron object, cylindrical, 5.4 cm long, .25 cm diameter. No diagnostic features. Possible modern welding rod. | Bow area. |
| HL-0405 | 5/20/2000 | CC | Unidentified concretion, possibly natural | Bow area, starboard side between bow and hatch, excavating forward and to starboard. |
| HL-0406 | 5/20/2000 | SL | Boiler slag – 231 pieces, 0.96 kg | Starboard side of stern, from forward of aft hatch to hole abaft hatch and out to starboard; coming down on iron rod forward of aft hatch. |
| HL-0407 | 5/20/2000 | CO | Coal – 50 pieces, 0.17 kg | Starboard side of stern, from forward of aft hatch to hole abaft hatch and out to starboard; coming down on iron rod forward of aft hatch. |
| HL-0408 | 5/20/2000 | WO | Wood – 23 small pieces | Starboard side of stern, from forward of aft hatch to hole abaft hatch and out to starboard; coming down on iron rod forward of aft hatch. |
| HL-0409 | 5/20/2000 | CC | Concretion, possibly contains an iron nail. Rectangular-shaped object is visible in radiograph. | Starboard side of stern, from forward of aft hatch to hole abaft hatch and out to starboard; coming down on iron rod forward of aft hatch. |
| HL-0410 | 5/20/2000 | CC | Concretion – ca. 50 pieces, from hull surface tests | Around entire periphery of hull within the two inner cutback lines. |
| HL-0411 | 5/20/2000 | CC | Concretion, 5 cm in length, with hollow mold openings at each end. Possibly related to HL-0381. | Stern area from forward of aft hatch, abaft hole aft of hatch, and along starboard side. |
| HL-0412 | 5/20/2000 | ME | Steel spring, modern | Starboard side of stern, excavating down to rod on starboard side. |
| HL-0413 | 5/22/2000 | CC | Iron concretions – 22 pieces. At least one from hole-and-cap can. | Starboard side of stern, excavating down to rod near aft hatch. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|------|---|--|
| HL-0414 | 5/22/2000 | ME | Iron, amorphous chunk | Starboard perimeter zone. |
| HL-0415 | 5/22/2000 | GL | Glass bottle fragment, brown | Starboard perimeter zone. |
| HL-0416 | 5/22/2000 | CL | Clay – 3 pieces; compact mass | Starboard perimeter zone. |
| HL-0417 | 5/22/2000 | CC | Metal concretions – 36 pieces; possible can | Port perimeter strip, 0–3 ft. deep. |
| HL-0418 | 5/22/2000 | SL | Boiler slag – 45 small fragments; 0.115 kg | Starboard side of stern, around rod and concretion. Recovered from mesh bag on dredge outflow. |
| HL-0419 | 5/22/2000 | CO | Coal – 19 pieces; 0.095 kg | Starboard side of stern, around rod and concretion. |
| HL-0420 | 5/22/2000 | WO | Wood fragments – 6 small pieces | Starboard side of stern, around rod and concretion. |
| HL-0421 | 5/22/2000 | BO | Bones – 2 specimens, likely fish | Starboard side of stern, around rod and concretion. |
| HL-0422 | 5/22/2000 | CC | Metal concretion with rectangular void (0.2 × 0.4 cm × 3 cm). Possible nail shaft. | Starboard side of stern, around rod and concretion. |
| HL-0423 | 5/22/2000 | WO | Wood fragments – 9 small pieces | Starboard side of bow above diving plane. |
| HL-0424 | 5/22/2000 | WO | Iron concretions – 3 small pieces | Starboard side of bow above diving plane. |
| HL-0425 | 5/23/2000 | CC | Concretions from hull surface – 10 pieces | Port perimeter zone (10 × 130 ft., 0–3.5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0426 | 5/23/2000 | BO | Bones – 3 specimens, at least one vertebra | Port perimeter zone (10 × 130 ft., 0–3.5 ft. deep). Found in sluice box while sieving dredge outflow. |
| HL-0427 | 5/23/2000 | ME | Iron can – base and partial wall, heavily concreted, and 8 additional fragments. Maximum diameter 16 cm. | Stern area, immediately starboard of propeller at propeller's lower level |
| HL-0428 | 5/23/2000 | CC | Iron concretion – curved with roughly cylindrical cross section; length 31.5 cm, diameter 0.5 cm. May be part of HL-0381 and related pieces.* | Bow area, just to starboard of forwardmost end of bow casting. |
| HL-0429 | 5/23/2000 | CC | Iron concretion, cylindrical, 4.4 cm long, 2.7 cm diam. | Bow area, to starboard of bow near artifact HL-0428 |
| HL-0430 | 7/19/2000 | SL | Boiler slag – 2 pieces; 0.305 kg | Bow area, close to stem. 2–2.5 ft. beneath upper tip of bow casting. |
| HL-0431 | 5/23/2000 | SL | Boiler slag – 1 piece; 0.045 kg | Recovered from within mud matrix inside artifact HL-0427. |
| HL-0432 | 5/23/2000 | CC | Concretion, 6 cm in length, with hollow mold openings at each end, 6 mm diam. Possibly related to HL-0381.* | Port side of hull at the stern and excavating aft from aft hatch. |
| HL-0433 | 5/23/2000 | WO | Wood fragments – ca. 25 pieces; largest 7 cm long | Portside of hull, excavating to port cutback line, bringing down level (approximately to the submarine's expansion strake), bow to stern. |
| HL-0434 | 5/23/2000 | SL | Boiler slag – 249 pieces; 0.81 kg | Portside of hull, excavating to port cutback line, bringing down level (approximately to the submarine's expansion strake), bow to stern. Recovered from mesh bag on dredge outflow. |
| HL-0435 | 5/23/2000 | SL | Boiler slag – 30 pieces; 0.14 kg | Portside of hull, excavating to port cutback line, bringing down level (approximately to the submarine's expansion strake), bow to stern. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|------|--|--|
| HL-0436 | 5/24/2000 | SL | Boiler slag – 72 pieces; 0.345 kg | Starboard side of stern area, immediately around large hole. |
| HL-0437 | 5/24/2000 | CO | Coal – 10 pieces; 0.09 kg | Starboard side of stern area, immediately around large hole. |
| HL-0438 | 5/24/2000 | WO | Wood fragments – 6 pieces | Starboard side of stern area, immediately around large hole. |
| HL-0439 | 5/24/2000 | BO | Bone, possibly tortoise, very hard (fossilized?) | Starboard side of stern area, immediately around large hole. |
| HL-0440 | 5/24/2000 | SL | Boiler slag – 442 pieces; 1.165 kg | Bow area around spar from top of mud to spar surface. Dredge spoil recovered from mesh bag on dredge outflow. |
| HL-0441 | 5/24/2000 | WO | Wood fragments – ca. 15 small pieces | Bow area around spar from top of mud to spar surface. Dredge spoil recovered from mesh bag on dredge outflow. |
| HL-0442 | 5/24/2000 | CO | Coal – 129 pieces; 0.315 kg | Bow area around spar from top of mud to spar surface. Dredge spoil recovered from mesh bag on dredge outflow. |
| HL-0443 | 5/24/2000 | BO | Bone – 2 specimens of unidentified fish species, 1 is a vertebra | Bow area around spar from top of mud to spar surface. Dredge spoil recovered from mesh bag on dredge outflow. |
| HL-0444 | 5/24/2000 | CC | Iron concretion – 2 pieces, largest 6.1 × 3.2 × 1.3 cm | Bow area, above spar, excavating through sediment down to it. |
| HL-0445 | 5/26/2000 | OR | Nut husk fragment (approximately half of entire husk) | Starboard side of stern, between hatch and end (approximately 3–5 ft. along starboard hull), 1–3 ft. deep. |
| HL-0446 | 5/26/2000 | ME | Metal disk-shaped object, possibly lead or zinc alloy. Ext. diam. 3.2 cm; int. diam. 0.8 cm. Heavily mineralized. | Port cutback strip. |
| HL-0447 | 5/27/2000 | GL | Glass shard, clear; 1 thin raised ridge on exterior surface. Curved, possibly from a bottle wall.* | Starboard cutback strip. |
| HL-0448 | 5/27/2000 | CM | Ceramic sherd, large, comprising approximately one-third of a slip-banded American yellow ware bowl* | Starboard perimeter zone, adjacent to forward end of submarine (approximately 1.5 ft. deep in mud). |
| HL-0451 | 5/28/2000 | CM | Ceramic sherd comprising approximately one-half of a small, early 20 th century white granite (whiteware) dish or bowl; retains two maker's marks, which read as follows: "GREENWOOD CHINA TRENTON, N. J." and "JAMES M. SHAW & CO. NEW YORK, 1912 4."* | Port perimeter strip, forward, approximately 2.5 ft. down in mud. May have fallen into hole from above. |
| HL-0452 | 5/28/2000 | SL | Boiler slag – 630 pieces; 2.7 kg | Forward suction pile area, to port and starboard of spar; additional fragments recovered after spar removal. Dredge spoil recovered from mesh bag (HAT) or sluice box (OI) at the end of dredge hoses. |
| HL-0453 | 5/28/2000 | CO | Coal – 81 pieces; 0.76 | Forward suction pile area, to port and starboard of spar; additional fragments recovered during excavation after spar removal. |
| HL-0454 | 5/28/2000 | WO | Wood fragments. Total amount fills about ⅓ of a large (9 × 12 in.) plastic bag. | Forward suction pile area, to port and starboard of spar; additional fragments recovered during excavation after spar removal. |
| HL-0455 | 5/28/2000 | BO | Bones – 4 small specimens, fish; 2 larger specimens, likely mammal: 1 rib, 1 vertebra with possible cut marks. | Forward suction pile area, to port and starboard of spar; additional fragments recovered during excavation after spar removal. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|-----------|---|---|
| HL-0456 | 5/28/2000 | CC | Metal concretions – 9 fragments, thin, some slightly curved; likely from can | Forward suction pile area, to port and starboard of spar; additional fragments recovered during excavation after spar removal. |
| HL-0457 | 5/28/2000 | CC | Metal concretions – 6 small fragments, as least 2 from can | Port side of hull moving out to port, bow to stern. Dredge spoil. |
| HL-0458 | 5/29/2000 | SL | Boiler slag – 176 pieces; 0.97 kg | Excavation area directly around propeller. Recovered from mesh bag on dredge outflow. |
| HL-0459 | 5/29/2000 | CO | Coal – 19 pieces; 0.235 kg | Excavation area directly around propeller. |
| HL-0460 | 5/29/2000 | WO | Wood fragments – 6 small pieces. | Excavation area directly around propeller. Dredge spoil. |
| HL-0461 | 5/29/2000 | OR | Walnut, ½ of shell, heavily abraded | Excavation area directly around propeller. Dredge spoil. |
| HL-0462 | 5/29/2000 | CC | Metal concretion – 1 large piece, possibly from hull tests | Excavation area directly around propeller. Dredge spoil. |
| HL-0463 | 5/29/2000 | ME | Long (5.07 m), cylindrical, metal object possibly associated with the spar torpedo assembly, or intrusive to the site. Fluorescent x-ray analysis revealed that its metallic composition is approximately 2% lead, 4% iron, and 94% zinc, indicating it is made from galvanized steel.* | Discovered just off submarine's port bow in close proximity to the torpedo spar, 1.5 m to port and 25 cm higher than the spar. Aft/large end positioned 1.9 m aft of the bow. |
| HL-0464 | 5/30/2000 | SL | Boiler slag – 603 pieces; 2.49 kg | Stern suction pile area, perimeter line to subdatums, 0–5 ft. depth. Found in sluice box while sieving dredge outflow. |
| HL-0465 | 5/30/2000 | WO | Wood fragments – ca. 60 pieces | Stern suction pile area, perimeter line to subdatums, 0–5 ft. depth. |
| HL-0466 | 5/30/2000 | CO | Coal – 68 pieces; 0.475 kg | Stern suction pile area, perimeter line to subdatums, 0–5 ft. depth. |
| HL-0467 | 5/30/2000 | CC | Metal concretions (6), largest 4.3 × 4.3 × 1.4 cm | Stern suction pile area, perimeter line to subdatums, 0–5 ft. depth. |
| HL-0468 | 5/31/2000 | CC/ ME | Metal concretions – 29 pieces, with thin lead strips on a least five. Likely from soldered can or cans. | Starboard side of stern suction pile area. |
| HL-0469 | 5/31/2000 | BO | Bone – 4 specimens; largest is possible femur from a large animal (pig?), one end cut flat, the other broken. | Stern suction pile area, close to datum array, starboard side; largest fragment recovered approximately 1 ft. below mud line. |
| HL-0470 | 5/31/2000 | CR | Macrofaunal specimen; coral fragment originally misidentified as concretion. | Starboard side of stern suction pile area. |
| HL-0471 | 5/30/2000 | SL | Boiler slag – 43 pieces; 0.185 kg | Port side of stern, around rudder at level of bottom of hull. |
| HL-0472 | 5/30/2000 | CO | Coal – 5 pieces; 0.05 kg | Port side of stern, around rudder at level of bottom of hull. |
| HL-0473 | 5/30/2000 | WO | Wood fragments – 4 small pieces | Port side of stern, around rudder at level of bottom of hull. |
| HL-0474 | 5/30/2000 | CC | Concretion – ca. 40 pieces chiseled from torpedo spar | Spar Y-assembly and nut; all sides. |
| HL-0475 | 5/30/2000 | OT | Three dental putty molds of spar surface and hex-nut | Spar Y-assembly and nut; all sides. |
| HL-0476 | 5/30/2000 | SL | Boiler slag – 64 pieces; 0.53 kg | Stern area, aft and to starboard of propeller. Recovered from mesh bag on dredge outflow. |
| HL-0477 | 5/30/2000 | CO | Coal – 5 pieces; 0.0555 kg | Stern area, aft and to starboard of propeller. Dredge spoil. |
| HL-0478 | 5/30/2000 | WO | Wood fragment | Stern area, aft and to starboard of propeller. Dredge spoil. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|-----------|---|--|
| HL-0479 | 6/1/2000 | SL | Boiler slag – 144 pieces; 0.755 kg | Stern area, port datum S4 to hatch. Found in sluice box while sieving dredge outflow. |
| HL-0480 | 6/1/2000 | WO | Wood fragments – 13 small pieces | Stern area, port side, datum S4 to hatch. Dredge spoil. |
| HL-0481 | 6/1/2000 | CO | Coal – 15 pieces; 0.055 kg | Stern area, port side, datum S4 to hatch. Dredge spoil. |
| HL-0482 | 5/31/2000 | SL | Boiler slag – 60 pieces; 0.595 kg | Stern suction pile area, starboard side, around datums. Spoil recovered from sluice box (OI) or mesh bag (HAT) on dredge outflow |
| HL-0483 | 5/31/2000 | CO | Coal – 7 pieces; 0.11 kg | Stern suction pile area, starboard side, around datums. Dredge spoil. |
| HL-0484 | 5/31/2000 | WO | Wood fragments – 5 small pieces | Stern suction pile area, starboard side, around datums. Dredge spoil. |
| HL-0485 | 5/31/2000 | CC/ ME | Metal concretion – 19 pieces, at least one with lead thin lead strip. Likely from soldered can or cans. | Stern suction pile area, starboard side, near subdatum array, 0–3.5 ft. depth. |
| HL-0486 | 5/31/2000 | CC | Metal concretion from hull surface, 5.8 × 2.8 × 1 cm | Stern suction pile area, starboard side, around datums. Dredge spoil. |
| HL-0487 | 6/1/2000 | OT | Dental putty mold of spar Y-assembly, upper surface | Spar Y-assembly; upper surface. |
| HL-0488 | 5/29/2000 | OT | Unidentified material; black exterior, interior red and black; likely caulking, possible red lead component. 4 joining pieces (28.5 cm), triangular cross section. | Port perimeter strip, 0–3.5 ft. depth |
| HL-0502 | 6/4/2000 | ME | Iron hex-nut removed from spar assembly | Spar Y-assembly, port side. |
| HL-0503 | 6/3/2000 | OT | Dental putty mold of hex-nut from spar assembly | Hex-nut located on port side of spar Y-assembly. |
| HL-0504 | 6/3/2000 | SL | Boiler slag – 1 large piece; 2.115 kg | 1.96 m to port of hull, 35 cm forward of hatch collar center, 1.13 m below top of hull. |
| HL-0505 | 6/4/2000 | WO | Wood, plank-like piece, appears to be cut along two or more sides, 68 × 10 × 6 cm.* | Adjacent to starboard hull at bow. Wood intersected stem 52 cm from top measured diagonally down stern; 42 cm plumb from bow top to wood. Wood extends 27 cm forward of stem |
| HL-0506 | 6/3/2000 | GL | Five aqua-colored glass fragments that, when reassembled, comprise approximately two-thirds of an eight-sided, Civil War-era United States Navy condiment bottle; the fragments include approximately one-half of the bottle body with a complete base; three miscellaneous body shards; and nearly all of the bottle's neck and rim with an attached portion of shoulder.* | Port perimeter strip; 23 ft. forward of the port stern perimeter line, 3 ft. in from port perimeter, approx. 3.5 ft. deep. |
| HL-0507 | 6/2/2000 | ST | Stones (5) | Stern, suction pile area. Dredge spoil. |
| HL-0508 | 6/2/2000 | ME | Iron and brass – 2 fragments, apparently from the <i>Marks Tide</i> fire pump impellor. | Stern, port side, excavating from the propeller to aft hatch along the cutback line. |
| HL-0509 | 6/1/2000 | OR | Unidentified material, sticky and black, possibly tar; 2.9 × 2.9 × 1.7 cm | Stern suction pile area, starboard side, aft of datum array, 0–3.5 ft. deep. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|-----------|---|--|
| HL-0510 | 6/4/2000 | OT | Dental putty mold of bolt head from spar assembly | Bolt head located on starboard side of spar Y-assembly. |
| HL-0511 | 6/5/2000 | ME | Iron bolt removed from spar assembly | Spar Y-assembly, starboard side. |
| HL-0512 | 6/5/2000 | SL | Boiler slag – 411 pieces; 1.65 kg | Stern suction pile area, 20 ft. diameter and 5–8 ft. deep. Found in sluice box while sieving dredge outflow. |
| HL-0513 | 6/5/2000 | CO | Coal – 47 pieces; 0.18 kg | Stern suction pile area, 20 ft. diameter and 5–8 ft. deep. Dredge spoil. |
| HL-0514 | 6/5/2000 | WO | Wood fragments. Total amount fills a large (9 × 12 in.) plastic bag approximately ⅓ full. | Stern suction pile area, 20 ft. diameter and 5–8 ft. deep. Dredge spoil. |
| HL-0515 | 6/5/2000 | BO | Bone – 7 small pieces; primarily fish, but one appears to be a small mammalian rib. | Stern suction pile area, 20 ft. diameter and 5–8 ft. deep. Dredge spoil. |
| HL-0516 | 6/5/2000 | CC/ ME | Metal concretions and lead, likely fragments from soldered can | Stern suction pile area, 20 ft. diameter and 5–8 ft. deep. Dredge spoil. |
| HL-0517 | 6/5/2000 | ST | Stone – piece of limestone, 14.4 × 5.7 × 5.1 cm | Concreted to port side of hull, aft of aft hatch, about half way down. |
| HL-0518 | 6/4/2000 | CC | Concretion – 3 pieces, removed from spar assembly. | Spar, Y-assembly, near starboard bolt head. |
| HL-0519 | 6/6/2000 | PL/ ME | Miscellaneous modern materials (vinyl sticker, plastic, and beer can fragments) | Stern suction pile area, 20 ft. diameter and 5–8 ft. deep. Dredge spoil. |
| HL-0520 | 6/6/2000 | CC | Concretion – 1 pieces, curved, possibly from spar | Forward suction pile area. |
| HL-0521 | 6/8/2000 | WO | Wood – uncut tree limb fragment, 34.4 × 2.39 cm | Discovered floating in aft suction pile hole. |
| HL-0522 | 6/9/2000 | OR | Nut husk, possibly walnut | Forward suction pile area, 20 ft. diameter and 5–8 ft. deep. |
| HL-0523 | 6/8/2000 | SL | Boiler slag – 15 pieces; 0.065 kg | Excavating between hatches and along starboard berm between OI trench and submarine, 0–3 ft. deep. Dredge spoil. |
| HL-0524 | 6/8/2000 | WO | Wood – 9 small pieces, very worn | Excavating between hatches and along starboard berm between OI trench and submarine, 0–3 ft. deep. Dredge spoil. |
| HL-0525 | 6/8/2000 | PL | Plastic action figure; spaceman. | Bottom of stern suction pile area; artifact very likely washed into site. |
| HL-0526 | 6/10/2000 | ME | Wrought-iron shackle or bracket associated with spar torpedo assembly; nearly complete.* | Approximately 2.7 cm forward and to starboard of bow. Artifact located within forward suction pile excavation area. |
| HL-0534 | 6/11/2000 | WO | Wood – 1 unworked piece, possible root, 42 × 7 × 9 cm | Forward suction pile area. |
| HL-0535 | 6/10/2000 | SL | Boiler slag – 126 pieces; 1.365 kg. | Forward suction pile hole, 20 ft. diameter and approximately 5–8 ft. deep. Found in sluice box while sieving dredge outflow. |
| HL-0536 | 6/10/2000 | CO | Coal – 51 pieces, 0.97 kg | Forward suction pile hole, 20 ft. diameter and approximately 5–8 ft. deep. Found in sluice box while sieving dredge outflow. |
| HL-0537 | 6/10/2000 | WO | Wood fragments. Total amount fills a large (9 × 12 in.) plastic bag approximately ¼ full. | Forward suction pile hole, 20 ft. diameter and approximately 5–8 ft. deep. Found in sluice box while sieving dredge outflow. |
| HL-0538 | 6/10/2000 | BO | Bone – 9 fragments; colors vary, possibly due to presence of calcareous marine deposits | Forward suction pile hole, 20 ft. diameter and approximately 5–8 ft. deep. Dredge spoil. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|-----------|--|--|
| HL-0539 | 6/10/2000 | CC | Metal concretion with broken end revealing a thin, flat iron object. Likely fragment of a can. | Forward suction pile hole, 20 ft. diameter and approximately 5–8 ft. deep. Dredge spoil. |
| HL-0540 | 6/11/2000 | OR | Organic object, roughly spherical (1.4 cm diameter); possibly a nut or seedpod | Forward suction pile hole, 20 ft. diameter and approximately 5–8 ft. deep. Dredge spoil. |
| HL-0541 | 6/11/2000 | PA/ FI | Miscellaneous modern materials (paint chip; woven fragment, plant fiber, 15 × 1.8 × 0.1 cm) | Starboard berm between OI trench and submarine, 0–3 ft. deep. Dredge spoil. |
| HL-0542 | 6/11/2000 | OT | Unidentified object, calcareous mineral, possibly fossilized wood | Forward suction pile hole, 20 ft. diameter and approximately 5–8 ft. deep. Dredge spoil. |
| HL-0543 | 6/11/2000 | ME | Miscellaneous modern materials (thin wire; lead/zinc “plug” with the word CANADA molded on side) | Forward suction pile hole, 20 ft. diameter and approximately 5–8 ft. deep. Dredge spoil. |
| HL-0544 | 6/11/2000 | CO | Coal – 1 pieces; 0.345 kg | Forward suction pile hole, 20 ft. diameter and approximately 5–8 ft. deep. Dredge spoil. |
| HL-0545 | 6/12/2000 | OT | Dental putty molds (2) of thin, flat concretion sticking out of side of hull | Port side, just forward of diving plane. |
| HL-0546 | 6/13/2000 | ME | Custom-made steel wrench used to remove torpedo spar bolt during excavation | Located within torpedo spar trench approximately 1 m from end of bow. |
| HL-0547 | 6/12/2000 | SL | Boiler slag – 52 pieces; 0.195 kg | Starboard side of hull; cleaning silt, some excavation to concretions, exposing rod along hull. |
| HL-0548 | 6/12/2000 | CO | Coal – 18 pieces; 0.065 kg | Starboard side of hull; cleaning silt, some excavation to concretions, exposing rod along hull. |
| HL-0549 | 6/12/2000 | WO | Wood fragments – ca. 16 pieces | Starboard side of hull; cleaning silt, some excavation to concretions, exposing rod along hull. |
| HL-0550 | 6/12/2000 | CC | Iron concretions – 10 pieces, from hull surface tests | Starboard side of hull; cleaning silt, some excavation to concretions. |
| HL-0551 | 6/12/2000 | SL | Boiler slag – 28 pieces; 0.155 kg | Stern suction pile hole, cleanup plus additional excavation approximately 1 ft. below floor of hole. |
| HL-0552 | 6/12/2000 | CO | Coal – 8 pieces; 0.06 kg | Stern suction pile hole, cleanup plus additional excavation approximately 1 ft. below floor of hole. |
| HL-0553 | 6/12/2000 | WO | Wood fragments, primarily intrusive | Stern suction pile hole, cleanup plus additional excavation approximately 1 ft. below floor of hole. |
| HL-0554 | 6/14/2000 | CC | Metal concretion, thin, curved. Possible fragment of can body. | Port side of hull near aft end of diving plane, discovered lying loose in sediment. |
| HL-0555 | 6/20/2000 | CC | Iron concretion containing stern cutwater* | Starboard side of hull, forward of aft hatch, 100 cm below deck level. |
| HL-0556 | 6/13/2000 | ME | Iron torpedo spar (concreted)* | Attached to bottom tip of bow casting; removed from submarine for recovery. |
| HL-0557 | 6/19/2000 | CC | Concretion – 34 pieces, removed from hull in order to take gas sample | Port side of hull, forward of third deadlight. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|------|---|--|
| HL-0558 | 6/15/2000 | SL | Boiler slag – 21 pieces; 0.145 kg. Intrusive, washed in from surrounding area. | Starboard trench; recovered from spoil during maintenance dredging. |
| HL-0559 | 6/15/2000 | CO | Coal – 5 pieces; 0.13 kg. Intrusive, washed in from surrounding area. | Starboard trench; recovered from spoil during maintenance dredging. |
| HL-0560 | 6/15/2000 | CC | Metal concretion, one flat surface, 3.8 × 2.3 × 2.5 cm | Starboard trench; maintenance dredging of infilled mud. Dredge spoil. |
| HL-0561 | 6/16/2000 | WO | Wood fragments – 6 pieces, one with extensive teredo damage | Starboard trench; recovered during maintenance dredging. Dredge spoil. |
| HL-0562 | 6/16/2000 | SL | Boiler slag – 1 large piece, 14.5 × 11.5 × 8.5 cm; 0.625 kg | Bow, port side, just aft of suction pile hole. |
| HL-0563 | 6/16/2000 | SL | Boiler slag – 9 pieces, medium-small; 0.305 kg. Likely intrusive, washed in from surrounding area. | Port perimeter trench; maintenance dredging of infilled mud. Dredge spoil. |
| HL-0564 | 6/15/2000 | SL | Boiler slag – 217 pieces; 1.27 kg | Starboard side of hull, aft end, near hatch, around concretion HL-0555. |
| HL-0565 | 6/15/2000 | CO | Coal – 198 pieces; 0.34 kg | Starboard side of hull, aft end, near hatch, around concretion HL-0555. |
| HL-0566 | 6/15/2000 | WO | Wood fragments – 23 small fragments | Starboard side of hull, aft end, near hatch, around concretion HL-0555. |
| HL-0567 | 6/15/2000 | OR | Nut husk fragment, species unidentified | Starboard side of hull, aft end, near hatch, around concretion HL-0555. |
| HL-0568 | 6/16/2000 | BO | Bone, possible vertebra fragment from marine organism | Starboard side of hull, aft end, near hatch, around concretion HL-0555. |
| HL-0569 | 6/19/2000 | CC | Concretion – 2 pieces, 2 cm and 2.5 cm | Starboard side of hull, aft end, around concretions below hatch. |
| HL-0570 | 7/26/2000 | WO | Wood fragments – 9 pieces, largest 7.5 cm long | Hole excavated for bow end truss legs. |
| HL-0571 | 7/26/2000 | BO | Bone, possible rib, broken at one end | Hole excavated for bow end truss legs. |
| HL-0572 | 7/26/2000 | CO | Coal – 3 pieces; 0.06 kg | Hole excavated for bow end truss legs. |
| HL-0573 | 7/26/2000 | SL | Boiler slag – 6 pieces; 0.085 kg | Hole excavated for bow end truss legs. |
| HL-0574 | 7/26/2000 | CO | Coal – 3 pieces; 0.015 kg | Hole excavated for bow end truss legs. |
| HL-0575 | 7/26/2000 | CC | Metal concretion, amorphous, 3.8 × 3.2 × 2.2 cm | Bow area, hole excavated for truss legs, between pile & bow, 3 ft. × 10 ft. |
| HL-0576 | 7/26/2000 | CO | Coal – 3 pieces; 0.02 kg | Deepening of hole for truss legs at stern end. |
| HL-0577 | 7/26/2000 | SL | Boiler slag – 1 piece; 0.001 kg | Deepening of hole for truss legs at stern end. |
| HL-0578 | 7/27/2000 | CO | Coal – 68 pieces; 0.24 kg. Intrusive. | Recovered after sandbag removal, after excavation hiatus. |
| HL-0579 | 7/27/2000 | SL | Boiler slag – 24 pieces; 0.075 kg. Intrusive. | Recovered after sandbag removal, after excavation hiatus. |
| HL-0580 | 7/27/2000 | WO | Wood fragments – 9 pieces. Intrusive. | Recovered after sandbag removal, after excavation hiatus. |
| HL-0581 | 7/27/2000 | FI | Rope fragment comprised of three strands of fibrous plant material (likely hemp or sisal). The fragment measures ca. 21.5 cm in overall length and is 1 cm in diameter. Each strand measures ca. 6 mm in diameter.* | The forward end of the rope was located 60 cm below the tip of the bow and 43 cm aft of the bow's upper surface. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|-----------|--|---|
| HL-0582 | 7/27/2000 | ME | Conglomerate containing a wrought-iron shackle or bracket associated with spar torpedo assembly and 2 additional artifacts (HL-3288 and HL-3289).* | Located 35 cm to starboard, 5 cm forward, and 57 cm below the forwardmost end of the submarine's bow. |
| HL-0583 | 7/27/2000 | WO | Wood, cylindrical piece, unworked, with areas of bark intact, 13.2 × 3.5 cm | Located 15 cm forward, 45 cm to starboard, and 85 cm beneath the forwardmost end of the submarine's bow (atop spar yoke). |
| HL-0584 | 7/27/2000 | SL | Boiler slag – 2 pieces; 0.145 kg | Located immediately to starboard of the forwardmost end of the submarine's bow, in close proximity to concretion HL-0582. |
| HL-0585 | 7/27/2000 | FI | U-shaped rope fragment comprised of three strands of fibrous plant material (likely hemp or sisal). The fragment measures ca. 27 cm in overall length (if straightened) and is 1 cm in diameter. Each strand comprising the main rope body measures approx. 6 mm in diameter.* | Located 60 cm beneath the forwardmost end of the submarine's bow, and to starboard of the bow, below breach in the hull. |
| HL-0586 | 7/27/2000 | CC | Iron concretion, likely partial base and wall of can. Very thin (ca. 0.25 mm) layer of metal survives. May also include HL-0590, HL-0591, HL-0592, HL-0593, & HL-0595. | Starboard bow, below breach in hull. |
| HL-0587 | 7/27/2000 | WO | Wooden barrel cant* | Starboard bow, below breach in hull. |
| HL-0588 | 7/27/2000 | CO | Coal – 1 large piece; 2.05 kg | Starboard bow. |
| HL-0589 | 7/27/2000 | CO/ SL | Coal with slag adhesions – 1 piece; 0.305 kg | Starboard bow, below breach in hull. |
| HL-0590 | 7/27/2000 | CC | Iron concretion; thin, curved plate; possible can or container wall. May be part of HL-0586. | Starboard bow, below breach in hull. |
| HL-0591 | 7/27/2000 | CC | Iron concretion; flat surface with remains of rim and possible small rivet head. May be part of HL-0586. | Starboard bow, below breach in hull. |
| HL-0592 | 7/27/2000 | CC | Iron concretion; thin plate, curved in center with flatter edges; possible can fragment. May be part of HL-0586. | Starboard bow, below breach in hull. |
| HL-0593 | 7/27/2000 | CC | Iron concretion; thin, curved plate, with remains of rim and base. May be part of HL-0586. | Starboard bow, below breach in hull. |
| HL-0594 | 7/27/2000 | WO | Wooden plank with chamfered end, curved or warped along 82 cm length. Parallel saw marks on both surfaces.* | Starboard bow, 92 cm below top of hull, 77 cm aft of bow. |
| HL-0595 | 7/27/2000 | CC | Iron concretion; thin, curved plate; bent at one end as if crushed. May be part of HL-0586. | Starboard bow, immediately adjacent to the breach in the hull. |
| HL-0596 | 7/27/2000 | CO | Coal – 199 pieces: 0.865 kg | Starboard bow, near breach in hull. |
| HL-0597 | 7/27/2000 | SL | Boiler slag – 70 pieces; 0.415 kg | Starboard bow near breach, at and below level of rope. |
| HL-0598 | 7/27/2000 | WO | Wood fragments – 10 small pieces | Starboard bow near breach, at and below level of rope. |
| HL-0599 | 7/27/2000 | CC | Iron concretion – 4 pieces; two preserving folded rim | Starboard bow near breach, at and below level of rope. |
| HL-0600 | 7/27/2000 | SL | Boiler slag – 4 pieces; 0.02 kg | Starboard bow near breach in hull. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|-----------|---|---|
| HL-0601 | 7/27/2000 | CO | Coal – 4 pieces; 0.2 kg | Starboard bow. |
| HL-0602 | 7/27/2000 | WO | Wood – 3 pieces of bark; longest piece 32 cm | Starboard bow near breach in hull, beneath the breach. |
| HL-0603 | 7/27/2000 | CO | Coal – 28 pieces; 0.17 kg | Recovered during dredging along port side of bow. |
| HL-0604 | 7/27/2000 | SL | Boiler Slag – 6 pieces; 0.06 kg | Recovered during dredging along port side of bow. |
| HL-0605 | 7/28/2000 | CO | Coal – 6 pieces; 0.285 kg | Starboard and port bow, aft of and beneath Slings 0 and 1. |
| HL-0606 | 7/28/2000 | SL | Boiler slag – 3 pieces; 0.035 kg | Aft of and below first two slings, starboard and port bow. |
| HL-0607 | 7/28/2000 | CO | Coal – 188 pieces; 0.66 kg | Starboard bow, dredging for Slings 2 and 3. |
| HL-0608 | 7/28/2000 | SL | Boiler slag – 53 pieces; 0.155 kg | Starboard bow, dredging for Slings 2 and 3. |
| HL-0609 | 7/28/2000 | WO | Wood fragments – 16 small pieces; largest 4.3 × 2.0 cm | Starboard bow, dredging for Slings 2 and 3. |
| HL-0610 | 7/28/2000 | CO | Coal – 6 pieces; 0.105 pieces | Dredging below shell layer in bow for Slings 3 and 6. |
| HL-0611 | 7/28/2000 | WO | Wood fragments – 2 rounded, worn pieces; largest 3.9 × 4.5 × 2.9 cm | Preparing for Slings 3 and 4, dredging starboard and port side, and underneath hull. |
| HL-0612 | 7/28/2000 | SL | Boiler slag – 1 piece; 0.05 kg | Preparing for Slings 3 and 4, dredging starboard and port side, and underneath hull. |
| HL-0613 | 7/27/2000 | CC | Concretion – 3 pieces; one with folded or lapped seam. | Starboard bow, near hole, around level of rope HL-0581 & below. |
| HL-0614 | 7/29/2000 | ME | Iron snorkel tube, Fragment A, 67 cm long* | Starboard bow, below cutwater, clearing for Slings 4 and 5. |
| HL-0615 | 7/29/2000 | ME | Iron snorkel tube, Fragment B, 85 cm long* | Starboard bow, below cutwater and forward hatch. |
| HL-0616 | 7/29/2000 | ME | Iron snorkel tube, 142 cm long* | Starboard side of hull, below forward hatch and snorkel box. |
| HL-0617 | 7/29/2000 | CC/ ME | Iron concretion, gently curving flat plate with loosely connected lead strip. Likely soldered can fragment. | Starboard bow aft of Sling 5, excavating around snorkel tubes HL-0615 and HL-0616. |
| HL-0618 | 7/29/2000 | SL | Boiler slag – 31 pieces; 0.53 kg | Starboard bow, aft of Sling 5, excavating around snorkel tubes HL-0614 and HL-0616. |
| HL-0619 | 7/29/2000 | CO | Coal – 36 pieces; 0.43 kg | Starboard bow, aft of Sling 5, excavating around snorkel tubes HL-0614 and HL-0616. |
| HL-0620 | 7/29/2000 | CO | Coal – 41 pieces; 0.24 kg | Port side of hull beneath diving plane, excavating in preparation for installation of Slings 6 and 7. |
| HL-0621 | 7/29/2000 | SL | Boiler slag – 29 pieces; 0.08 kg | Port side of hull beneath diving plane, excavating in preparation for installation of Slings 6 and 7. |
| HL-0622 | 7/29/2000 | CC | Iron concretion – thin, flat, curved plate, thickly concreted; 13.4 × 11.9 × 5.0 cm | Starboard bow, attached to hull, forward of diving plane. |
| HL-0623 | 8/4/2000 | BO | Bone – 1 specimen, animal, partial long bone | Dredging under forward section of keel. |
| HL-0624 | 7/29/2000 | CO | Coal – 7 pieces; 0.01 kg | Dredging under forward section of keel. |
| HL-0625 | 7/29/2000 | ME | Lead, possible nail, broken; circular head with rectangular shaft; 2 cm long | Dredging along forward section of keel. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|-----------|---|--|
| HL-0626 | 7/29/2000 | SL | Boiler slag – 9 pieces; 0.03 kg | Dredging along forward section of keel. |
| HL-0627 | 7/30/2000 | CC/ ME | Iron concretion – thin, flat, curved plate; strip of lead solder preserved along edge | Dredging beneath hull for Slings 6 and 7. Likely fell in from higher strata. |
| HL-0628 | 7/30/2000 | CO | Coal – 2 pieces; 0.13 kg | Excavating beneath hull for Slings 6 and 7, after jetting through marl. Probably fell in from above. |
| HL-0629 | 7/30/2000 | SL | Boiler slag – 1 piece; 0.25 kg | Excavating beneath hull for Slings 6 and 7, after jetting through marl. Probably fell in from above. |
| HL-0630 | 7/30/2000 | CO | Coal – 1 piece; 0.03 kg | Dredging starboard side of hull in preparation for Slings 8 and 9. |
| HL-0631 | 7/30/2000 | CO | Coal – 7 pieces; 0.07 kg | Beneath hull, in area between Slings 8 and 9. |
| HL-0632 | 7/30/2000 | SL | Boiler slag – 1 piece; 0.035 kg | Beneath hull, in area between Slings 8 and 9. |
| HL-0633 | 7/31/2000 | CO | Coal – 45 pieces; 0.195 | Below and aft of port diving plane, excavating in preparation for Slings 11 and 12. |
| HL-0634 | 7/31/2000 | WO | Wood fragments – 19 pieces, 2 of which are cylindrical | Below and aft of port diving plane, excavating along port side of hull in preparation for Slings 11 and 12. |
| HL-0635 | 7/31/2000 | SL | Boiler slag – 19 pieces; 0.05 kg | Below and aft of port diving plane, excavating along port side of hull between Slings 11 and 13 in preparation for Slings 11 and 12. |
| HL-0636 | 7/31/2000 | WO/ CC | Wood piece, natural, knee-like, 35 × 10.7 × 9 cm, with patch of iron concretion, 14.2 × 4.6 cm, adhered to side | Excavating in preparation for Slings 11 and 12, beneath sub, 3.5 ft. aft of port diving plane. |
| HL-0637 | 8/1/2000 | CC | Concretion – small sample (4.8 × 1.6 × 1.1 cm) of large encrustation on hull surface. No metal visible. | Starboard side of hull, beneath second deadlight aft, approx. 40 cm above keel. |
| HL-0638 | 8/1/2000 | OT | Dental putty mold of hull surface | Starboard, between and beneath first and second deadlights aft. |
| HL-0639 | 7/31/2000 | CC | Concretion – amorphous lump, no void or metal | Port side of hull, beneath diving plane, clearing for Slings 11 and 12. |
| HL-0640 | 8/1/2000 | SL | Boiler slag – 38 pieces; 0.125 kg | Dredging port side of hull in preparation for Slings 15 thru 19. |
| HL-0641 | 8/1/2000 | WO | Wood fragments – 6 small pieces, longest 6.9 cm | Dredging port side of hull in preparation for Slings 15 thru 19. |
| HL-0642 | 8/1/2000 | CC | Iron concretions – 22 pieces, from hull surface tests | Dredging port side of hull in preparation for Slings 15 thru 19. |
| HL-0643 | 8/1/2000 | CO | Coal – 94 pieces; 0.32 kg | Dredging port side of hull in preparation for Slings 15 thru 19. |
| HL-0644 | 8/1/2000 | CC/ ME | Iron concretions – 4 flat, curved pieces, one with lead strip, one preserving a rim or seam. Likely from a can. | Excavating port side of hull, close to centerline; beneath the hull; and in area between Slings 18 and 19. |
| HL-0645 | 8/1/2000 | CO | Coal – 10 pieces; 0.96 kg | Excavating starboard side of hull, close to centerline; beneath the hull; and in area between Slings 18 and 19. |
| HL-0646 | 8/1/2000 | CC | Iron concretions – 5 small, flat pieces. Likely from a can. | Port side of hull, dredging for Slings 15 thru 19 (midships to forward hatch). |
| HL-0647 | 8/1/2000 | CC | Iron concretion – 1 amorphous piece, no diagnostic features | Port side of hull, dredging for Slings 15 thru 19 (midships to forward hatch). |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|----------|-----------|---|---|
| HL-0648 | 8/1/2000 | SL | Boiler slag – 1 piece; 0.001 kg | Starboard side of hull, dredging for Slings 18 thru 20. |
| HL-0649 | 8/1/2000 | CC | Iron concretion – one related to HL-0637, one natural | Starboard side of hull, dredging for Slings 18 thru 20. |
| HL-0650 | 8/1/2000 | CO | Coal – 14 pieces; 0.21 kg | Port side of hull, dredging for Slings 18 thru 20. |
| HL-0651 | 8/1/2000 | SL | Boiler slag – 6 pieces; 0.065 kg | Port side of hull, dredging for Slings 18 thru 20. |
| HL-0652 | 8/1/2000 | CC | Iron concretions – 2 small pieces from hull surface tests | Port side of hull, dredging for Slings 18 thru 20. |
| HL-0653 | 8/1/2000 | CC/ ME | Iron cylinder, fragile, heavily concreted, with lead strip adjoining two pieces. Partial soldered can. | Concreted to underside of keel in midships area. |
| HL-0654 | 8/1/2000 | CC/ ME | Iron object, roughly cylindrical; lead strip visible within concretion. Partial soldered can. | Concreted to port side of keel, directly on side/bottom junction. |
| HL-0655 | 8/1/2000 | CC | Iron concretions – 3 curved, flat pieces. Likely can fragments. | Port side of hull, amidships near distinct joint in keel. |
| HL-0656 | 8/2/2000 | ME | Iron concretions – one thin, flat, with slaggy surface; one small, amorphous piece | Dredging beneath port and starboard sides of hull for installation of Slings 21 thru 23. |
| HL-0657 | 8/2/2000 | CO | Coal – 3 pieces; 0.02 kg | Dredging beneath and alongside port and starboard sides of hull for installation of Slings 21 thru 23. |
| HL-0658 | 8/2/2000 | SL | Boiler slag – 3 pieces; 0.035 kg | Dredging beneath and alongside port and starboard sides of hull for installation of Slings 21 thru 23. |
| HL-0659 | 8/2/2000 | WO | Wood fragments – 6 small pieces, longest 10.7 × 4.6 × 2.9 cm | Dredging beneath and alongside port and starboard sides of hull for installation of Slings 21 thru 23. |
| HL-0660 | 8/2/2000 | ME | Iron strap 1.77 cm long, possibly part of propeller shroud attachment* | Dredging along starboard side from aft hatch to hole in starboard side of stern. Originally attached to hull. |
| HL-0661 | 8/3/2000 | CM | Completely intact American-produced Bristol-style glazed bottle* | Port side of hull, 45 cm below and 40 cm abaft aft hatch, 10 cm below bottom of sub. |
| HL-0662 | 8/2/2000 | GL | Two basal shards from a cylindrical olive green glass bottle dating from c. 1821 until the early 20 th century.* | Dredging along port side of hull for installation of Slings 23 thru 26. |
| HL-0663 | 8/2/2000 | BO | Bone – 1 specimen, animal vertebra | Dredging along port side of hull for installation of Slings 23 thru 26. |
| HL-0664 | 8/2/2000 | CO | Coal – 24 pieces; 0.2 kg | Dredging along port side of hull for installation of Slings 23 thru 26. |
| HL-0665 | 8/2/2000 | SL | Boiler slag – 11 pieces; 0.07 kg | Dredging along port side of hull for installation of Slings 23 thru 26. |
| HL-0666 | 8/2/2000 | CC | Concretion, amorphous, roughly cylindrical, 3.4 × 1.8 cm | Dredging along port side of hull for installation of Slings 23 thru 26. |
| HL-0667 | 8/2/2000 | CO | Coal – 2 pieces; 0.035 kg | Dredging beneath starboard side of hull in preparation for installation of Slings 24 and 25. |
| HL-0668 | 8/2/2000 | BO | Bone – 1 specimen, animal scapula, cut by sharp tool | Dredging starboard side of hull between Slings 23 and 26. |
| HL-0669 | 8/2/2000 | WO | Wood fragment, dense, almost coal-like | Dredging starboard side of hull between Slings 23 and 26. |
| HL-0670 | 8/2/2000 | CO | Coal – 27 pieces; 0.16 kg | Dredging starboard side of hull between Slings 23 and 26. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|----------|------|---|--|
| HL-0671 | 8/2/2000 | SL | Boiler slag – 16 pieces; 0.21 kg | Dredging starboard side of hull between Slings 23 and 26. |
| HL-0672 | 8/2/2000 | WO | Wood fragments – 2 small pieces | Dredging starboard side of hull between Slings 23 and 26. |
| HL-0673 | 8/2/2000 | CC | Iron concretions – 3 small pieces, one possibly from can | Dredging starboard side of hull between Slings 23 and 26. |
| HL-0674 | 8/3/2000 | WO | Wood fragments – 17 fragments, one oblong with a square notch | Dredging abaft aft hatch to port side of rudder. |
| HL-0675 | 8/3/2000 | GL | Olive green glass fragment, likely from a cylindrical bottle; may be associated with artifact HL-0662.* | Dredging abaft aft hatch to port side of rudder. |
| HL-0676 | 8/3/2000 | CO | Coal – 46 pieces; 0.14 kg | Dredging abaft aft hatch to port side of rudder. |
| HL-0677 | 8/3/2000 | SL | Boiler slag – 9 pieces; 0.04 kg | Dredging abaft aft hatch to port side of rudder. |
| HL-0678 | 8/3/2000 | CC | Iron concretions – 15 pieces; most flat, curved plate; one with lead strip, 2 with seams. Likely can fragments. | Dredging along the starboard side of the stern abaft Sling 25. |
| HL-0679 | 8/3/2000 | SL | Boiler slag – 43 pieces; 0.135 kg | Dredging along the starboard side of the stern abaft Sling 25. |
| HL-0680 | 8/3/2000 | CO | Coal – 31 pieces; 0.9 kg | Dredging along the starboard side of the stern abaft Sling 25. |
| HL-0681 | 8/3/2000 | ME | Lead (or lead-alloy) ring, triangular cross section. Likely solder from hole-and-cap can. | Dredging along the starboard side of the stern abaft Sling 25. |
| HL-0682 | 8/3/2000 | ME | Lead (or lead-alloy) curved strip, with fragments of iron concretion attached. Likely solder from can. | Dredging along the starboard side of the stern abaft Sling 25. |
| HL-0683 | 8/3/2000 | CC | Iron concretion containing mold of flat metal strap* | Excavating around and below rudder, 3 cm of concretion beneath rudder. |
| HL-0684 | 8/4/2000 | CC | Concretion containing remains of iron rivet, likely lost from hull during formation of stern hole.* | Starboard side of hull, in the shell layer forward of propeller and propeller shroud. |
| HL-0685 | 8/4/2000 | CC | Iron concretion containing mold of iron spike* | Starboard side of hull in shell layer. 10 cm forward of propeller and propeller shroud. |
| HL-0686 | 8/4/2000 | ME | Submarine's iron rudder. Approx. measurements: 51 cm wide × 78 cm long. Heavily shell encrustation.* | Directly beneath stern end of submarine, at slings 28 and 29. Rudder positioned diagonally across keel line. |
| HL-0687 | 8/3/2000 | SL | Boiler slag – 25 pieces; 0.135 kg | Dredging starboard side of stern in preparation for Slings 28 and 29. |
| HL-0688 | 8/3/2000 | CO | Coal – 82 pieces; 0.195 kg | Dredging starboard side of stern in preparation for Slings 28 and 29. |
| HL-0689 | 8/3/2000 | WO | Wood fragments – 16 small pieces | Dredging starboard side of stern in preparation for Slings 28 and 29. |
| HL-0690 | 8/3/2000 | SL | Boiler slag – 1 piece, associated with Rivet #3 on the northern side of CT4; 0.01 kg | Dredging starboard side of stern in preparation for Slings 28 and 29. |
| HL-0691 | 8/3/2000 | CO | Coal – 16 pieces; 0.07 kg | Dredging on and around the upper surface of rudder; resting on clay. |
| HL-0692 | 8/3/2000 | WO | Wood – 1 small piece, flat with rounded edges | Dredging starboard side of stern in preparation for Slings 28 and 29. |
| HL-0693 | 8/3/2000 | BO | Bone – 1 piece from edge of turtle carapace | Dredging on and around the upper surface of rudder; resting on clay. |
| HL-0694 | 8/3/2000 | SL | Boiler slag – 3 pieces; 0.005 kg | Dredging on and around the upper surface of rudder; resting on clay. |

| Artifact # [†] | Date | Mat. | Description | Provenience |
|-------------------------|-----------|-----------|---|--|
| HL-0695 | 8/4/2000 | CO | Coal – 31 pieces; 0.17 kg | Starboard side of stern, just forward of propeller. |
| HL-0696 | 8/4/2000 | SL | Boiler slag – 21 pieces; 0.155 kg | Starboard side of stern, just forward of propeller. |
| HL-0697 | 8/4/2000 | CC | Concretions – 1 small, flat, possibly can; 1 slag-like | Starboard side of stern, just forward of propeller. |
| HL-0698 | 8/4/2000 | WO | Wood fragments – 4 small pieces | Starboard side of stern, just forward of propeller. |
| HL-0699 | 8/4/2000 | CO | Coal – 105 pieces; 0.62 kg | Starboard side of stern, just forward of propeller. |
| HL-0700 | 8/4/2000 | CC | Iron concretion, cylindrical; a nearly complete can | Starboard side of extreme stern edge. |
| HL-0701 | 8/4/2000 | SL | Boiler slag – 39 pieces; 0.205 kg | Dredging starboard side of stern to area abaft propeller. |
| HL-0702 | 8/4/2000 | CC | Iron concretion – 1 small, flat piece; likely from a can | Dredging starboard side of stern to area abaft propeller. |
| HL-0703 | 8/4/2000 | CO | Coal – 52 pieces; 0.14 kg | Dredging beneath aft edge of stern. |
| HL-0704 | 8/4/2000 | SL | Boiler slag – 8 pieces; 0.075 kg | Dredging beneath aft edge of stern. |
| HL-0705 | 8/3/2000 | CC | Concretion containing remains of iron rivet, likely lost from hull during formation of stern hole.* | Dredging starboard stern area abaft Sling 25. |
| HL-0706 | 8/6/2000 | CO | Coal – 1 piece, 14.4 × 5.7 × 3.8 cm; 0.29 kg | Lying loose on upper surface of port diving plane. |
| HL-0708 | 8/8/2000 | ME | <i>H. L. Hunley</i> submarine | In Charleston Harbor, South Carolina, approx. 4 miles offshore in 40 ft. of water. |
| HL-2917 | | ME | Grapple anchor with 5 tines | |
| HL-2918 | | ME | Iron ring originally attached to grapple anchor (HL-2917) | |
| HL-3288 | 5/11/2004 | CC/ ME | Iron food can, heavily concreted, metal layer thin and fragile. Removed from conglomerate HL-0582.* | Recovered from within ferrous concretion (HL-0582) containing iron shackle. |
| HL-3289 | 5/11/2004 | ME | Wooden handle(?), possibly for a tool such as an awl or file.* | Recovered from within ferrous concretion (HL-0582) containing iron shackle. |

[†] Numbers were assigned from the same pool to both artifacts and environmental samples in order of recovery. Any gaps in numbering sequence in this catalog represent samples taken for analysis, which have been omitted for brevity.

* See full entry in Chapter 15.

APPENDIX H

**Cumulative Frequency Diagrams
of
Sediment Cores Taken at the *H. L.*
Hunley Site**

Transect 1

T1-1 Bottom of Core HL 0270

| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
|-----|----|------|------|------|------|------|-----|------|------|------|-------|-------|-------|-------|
| | | | 0.05 | 0.12 | 0.24 | 0.31 | 0.4 | 0.51 | 0.82 | 3.38 | 18.28 | 25.19 | 27.89 | 28.44 |

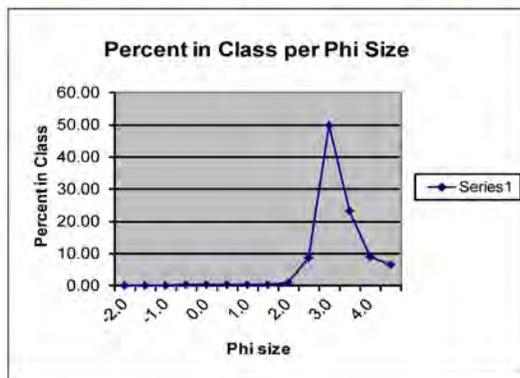
vessel weight 0.00
 wet weight 30.00
 dry weight 30.00

Dry Wt. Before wet sie 30.00
 Dry Wt. After sieving 28.57

| Size (φ) | Class midpoint (mm) | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|---------------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.05 | 0.05 | 0.05 | 0.17 | 0.17 | 99.83 | -0.2092 | 3.0344 | -12.9192 | 55.0048 |
| -0.5 | -0.75 | 1.4142 | 0.12 | 0.12 | 0.07 | 0.23 | 0.40 | 99.60 | -0.1758 | 3.3089 | -12.4337 | 46.7210 |
| 0.0 | -0.25 | 1.0000 | 0.24 | 0.24 | 0.12 | 0.40 | 0.80 | 99.20 | -0.1004 | 4.2633 | -13.8882 | 45.2424 |
| 0.5 | 0.25 | 0.7071 | 0.31 | 0.31 | 0.07 | 0.23 | 1.04 | 98.96 | 0.0586 | 1.7821 | -4.9143 | 13.5518 |
| 1.0 | 0.75 | 0.5000 | 0.4 | 0.40 | 0.09 | 0.30 | 1.34 | 98.66 | 0.2260 | 1.5357 | -3.4670 | 7.8272 |
| 1.5 | 1.25 | 0.3536 | 0.51 | 0.51 | 0.11 | 0.37 | 1.71 | 98.29 | 0.4603 | 1.1376 | -1.9995 | 3.5144 |
| 2.0 | 1.75 | 0.2500 | 0.82 | 0.82 | 0.31 | 1.04 | 2.75 | 97.25 | 1.8162 | 1.6414 | -2.0643 | 2.5961 |
| 2.5 | 2.25 | 0.1768 | 3.38 | 3.38 | 2.56 | 8.57 | 11.32 | 88.68 | 19.2836 | 4.9193 | -3.7269 | 2.8236 |
| 3.0 | 2.75 | 0.1250 | 18.28 | 18.28 | 14.90 | 49.88 | 61.20 | 38.80 | 137.1778 | 3.3105 | -0.8528 | 0.2197 |
| 3.5 | 3.25 | 0.0884 | 25.19 | 25.19 | 6.91 | 23.13 | 84.33 | 15.67 | 75.1841 | 1.3591 | 0.3294 | 0.0798 |
| 4.0 | 3.75 | 0.0625 | 27.89 | 27.89 | 2.70 | 9.04 | 93.37 | 6.63 | 33.8969 | 4.9818 | 3.6984 | 2.7456 |
| 6.0 | 5.00 | 0.0156 | 28.44 | 29.87 | 1.98 | 6.63 | 100.00 | 0.00 | 33.1436 | 26.3133 | 52.4263 | 104.4532 |

| | | | |
|-------------|------|-----------|------|
| % gravel | 0.2 | mean(phi) | 3.01 |
| % sand | 93.2 | mean(mm) | 0.12 |
| % silt-clay | 6.6 | sorting | 0.76 |
| % water | 0.0 | skewness | 0.00 |
| | | kurtosis | 8.59 |

salt weight 0.00 (This worksheet assumes salt water and 3.5% concentration)
 wt. Loss of wt siev 1.43
 dry sed weight 30.00
 wt of water lost 0.00
 dry sed 30.00



T1-3 0-10 cm HL 0271

| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
|-----|----|------|------|------|------|-----|------|------|------|------|-------|-------|-------|-------|
| | | | 1.35 | 1.73 | 2.05 | 2.3 | 2.55 | 2.83 | 3.41 | 6.96 | 20.59 | 24.45 | 25.46 | 25.54 |

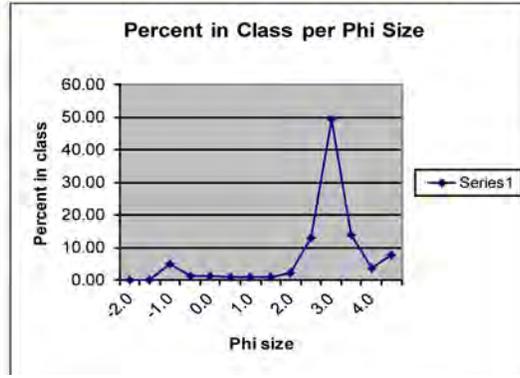
vessel weight 0.00
 wet weight 30.00
 dry weight 27.84

Dry Wt. Before wet sie 27.84
 Dry Wt. After sieving 25.69

| Size (φ) | Class midpoint (mm) | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|---------------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 1.35 | 1.35 | 1.35 | 4.89 | 4.89 | 95.11 | -6.1109 | 72.9272 | -281.6664 | 1087.8790 |
| -0.5 | -0.75 | 1.4142 | 1.73 | 1.73 | 0.38 | 1.38 | 6.26 | 93.74 | -1.0321 | 15.5568 | -52.3065 | 175.8701 |
| 0.0 | -0.25 | 1.0000 | 2.05 | 2.05 | 0.32 | 1.16 | 7.42 | 92.58 | -0.2897 | 9.4939 | -27.1743 | 77.7809 |
| 0.5 | 0.25 | 0.7071 | 2.3 | 2.30 | 0.25 | 0.91 | 8.33 | 91.67 | 0.2263 | 5.0521 | -11.9346 | 28.1930 |
| 1.0 | 0.75 | 0.5000 | 2.55 | 2.55 | 0.25 | 0.91 | 9.23 | 90.77 | 0.6790 | 3.1398 | -5.8472 | 10.8893 |
| 1.5 | 1.25 | 0.3536 | 2.83 | 2.83 | 0.28 | 1.01 | 10.25 | 89.75 | 1.2675 | 1.8818 | -2.5635 | 3.4923 |
| 2.0 | 1.75 | 0.2500 | 3.41 | 3.41 | 0.58 | 2.10 | 12.35 | 87.65 | 3.6756 | 1.5617 | -1.3467 | 1.1612 |
| 2.5 | 2.25 | 0.1768 | 6.96 | 6.96 | 3.55 | 12.86 | 25.20 | 74.80 | 28.9251 | 1.6874 | -0.6113 | 0.2215 |
| 3.0 | 2.75 | 0.1250 | 20.59 | 20.59 | 13.63 | 49.36 | 74.56 | 25.44 | 135.7353 | 0.9359 | 0.1289 | 0.0177 |
| 3.5 | 3.25 | 0.0884 | 24.45 | 24.45 | 3.86 | 13.98 | 88.54 | 11.46 | 45.4292 | 5.6845 | 3.6250 | 2.3117 |
| 4.0 | 3.75 | 0.0625 | 25.46 | 25.46 | 1.01 | 3.66 | 92.20 | 7.80 | 13.7157 | 4.7342 | 5.3861 | 6.1278 |
| 6.0 | 5.00 | 0.0156 | 25.54 | 27.61 | 2.15 | 7.80 | 100.00 | 0.00 | 39.0086 | 44.4786 | 106.2018 | 253.5784 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 4.9 | mean(phi) | 2.61 |
| % sand | 87.3 | mean(mm) | 0.16 |
| % silt-clay | 7.8 | sorting | 1.29 |
| % water | 7.5 | skewness | -1.24 |
| | | kurtosis | 5.90 |

salt weight 0.08 (This worksheet assumes salt water and 3.5% concentration)
 wt. Loss of wt siev 2.07
 dry sed weight 27.76
 wt of water lost 2.16
 dry sed 27.84



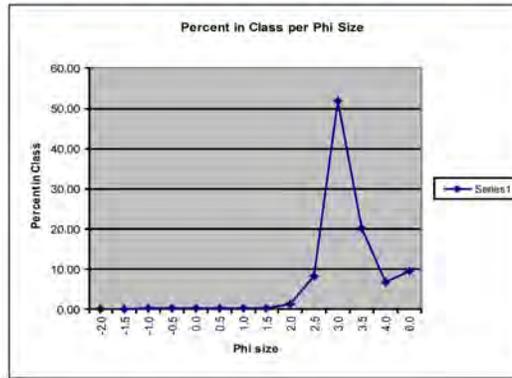
| T1-3 10-20 cm | | HL 0272 | | | | | | | | | | | |
|---------------|----|---------|------|------|-----|------|------|------|------|-------|-------|-------|-------|
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan |
| | | 1.35 | 1.73 | 2.05 | 2.3 | 2.55 | 2.83 | 3.41 | 6.96 | 20.59 | 24.45 | 25.46 | 25.54 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 28.36 |
| wet weight | 30.00 | Dry Wt. After sieving | 25.85 |
| dry weight | 28.36 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.1 | 0.10 | 0.10 | 0.35 | 0.35 | 99.65 | -0.4417 | -6.4674 | -27.6698 | 118.3814 |
| -0.5 | -0.75 | 1.4142 | 0.19 | 0.19 | 0.09 | 0.32 | 0.67 | 99.33 | -0.2385 | -4.5397 | -17.1525 | 64.8082 |
| 0.0 | -0.25 | 1.0000 | 0.26 | 0.26 | 0.07 | 0.25 | 0.92 | 99.08 | -0.0618 | 2.6582 | -8.7145 | 28.5693 |
| 0.5 | 0.25 | 0.7071 | 0.34 | 0.34 | 0.08 | 0.28 | 1.20 | 98.80 | 0.0707 | 2.1819 | -6.0622 | 16.8430 |
| 1.0 | 0.75 | 0.5000 | 0.41 | 0.41 | 0.07 | 0.25 | 1.45 | 98.55 | 0.1855 | 1.2839 | -2.9251 | 6.6644 |
| 1.5 | 1.25 | 0.3536 | 0.54 | 0.54 | 0.13 | 0.46 | 1.91 | 98.09 | 0.5742 | 1.4526 | -2.5833 | 4.5941 |
| 2.0 | 1.75 | 0.2500 | 0.89 | 0.89 | 0.35 | 1.24 | 3.14 | 96.86 | 2.1641 | 2.0209 | -2.5835 | 3.3026 |
| 2.5 | 2.25 | 0.1768 | 3.26 | 3.26 | 2.37 | 8.37 | 11.52 | 88.48 | 18.8410 | 5.0732 | -3.9488 | 3.0736 |
| 3.0 | 2.75 | 0.1250 | 17.95 | 17.95 | 14.69 | 51.90 | 63.42 | 36.58 | 142.7342 | 4.0217 | -1.1195 | 0.3116 |
| 3.5 | 3.25 | 0.0884 | 23.69 | 23.69 | 5.74 | 20.28 | 83.70 | 15.30 | 65.9127 | 0.9963 | 0.2208 | 0.0489 |
| 4.0 | 3.75 | 0.0625 | 25.59 | 25.59 | 1.90 | 6.71 | 90.42 | 8.58 | 25.1744 | 3.4960 | 2.5228 | 1.8206 |
| 6.0 | 5.00 | 0.0156 | 25.86 | 28.30 | 2.71 | 9.58 | 100.00 | 0.00 | 47.9214 | 37.2575 | 73.4584 | 144.8334 |

| | | | |
|-------------|------|-----------|------|
| % gravel | 0.4 | mean(phi) | 3.03 |
| % sand | 90.1 | mean(mm) | 0.12 |
| % silt-clay | 9.6 | sorting | 0.85 |
| % water | 5.7 | skewness | 0.06 |
| | | kurtosis | 7.70 |

| | | | |
|---------------------|-------|--|--|
| salt weight | 0.06 | (This worksheet assumes salt water and 3.5% concentration) | |
| wt. Loss of wt siev | 2.44 | | |
| dry sed weight | 28.30 | | |
| wt of water lost | 1.64 | | |
| dry sed | 28.36 | | |



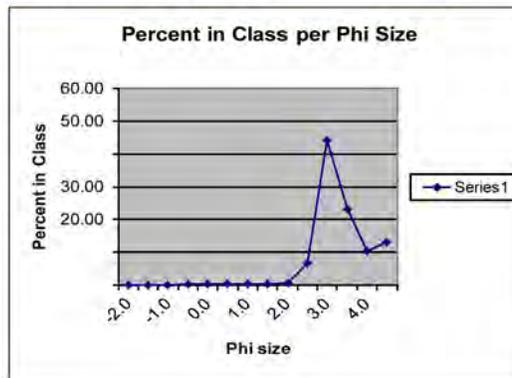
| T1-3 Top 5 cm | | HL 0273 | | | | | | | | | | | |
|---------------|----|---------|------|------|------|------|------|------|------|-------|-------|-------|-------|
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan |
| | | 0.03 | 0.11 | 0.2 | 0.29 | 0.37 | 0.44 | 0.65 | 2.49 | 14.69 | 21.09 | 23.95 | 24.43 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 27.62 |
| wet weight | 30.00 | Dry Wt. After sieving | 24.39 |
| dry weight | 27.62 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.03 | 0.03 | 0.03 | 0.11 | 0.11 | 99.89 | -0.1360 | 2.1375 | -9.4746 | 41.9970 |
| -0.5 | -0.75 | 1.4142 | 0.11 | 0.11 | 0.08 | 0.29 | 0.40 | 99.60 | -0.2176 | 4.4865 | -17.6438 | 69.3862 |
| 0.0 | -0.25 | 1.0000 | 0.2 | 0.20 | 0.09 | 0.33 | 0.73 | 99.27 | -0.0816 | 3.8455 | -13.2000 | 45.3106 |
| 0.5 | 0.25 | 0.7071 | 0.29 | 0.29 | 0.09 | 0.33 | 1.05 | 98.95 | 0.0816 | 2.8068 | -8.2312 | 24.1390 |
| 1.0 | 0.75 | 0.5000 | 0.37 | 0.37 | 0.08 | 0.29 | 1.34 | 98.66 | 0.2176 | 1.7167 | -4.1761 | 10.1588 |
| 1.5 | 1.25 | 0.3536 | 0.44 | 0.44 | 0.07 | 0.25 | 1.60 | 98.40 | 0.3173 | 0.9481 | -1.8323 | 3.5411 |
| 2.0 | 1.75 | 0.2500 | 0.65 | 0.65 | 0.21 | 0.76 | 2.36 | 97.64 | 1.3326 | 1.5629 | -2.2391 | 3.2077 |
| 2.5 | 2.25 | 0.1768 | 2.49 | 2.49 | 1.84 | 6.67 | 9.03 | 90.97 | 15.0127 | 5.8034 | -5.4123 | 5.0476 |
| 3.0 | 2.75 | 0.1250 | 14.69 | 14.69 | 12.20 | 44.24 | 53.27 | 46.73 | 121.6607 | 8.2798 | -3.5820 | 1.5496 |
| 3.5 | 3.25 | 0.0884 | 21.09 | 21.09 | 6.40 | 23.21 | 76.48 | 23.52 | 75.4260 | 0.1054 | 0.0071 | 0.0005 |
| 4.0 | 3.75 | 0.0625 | 23.95 | 23.95 | 2.86 | 10.37 | 86.85 | 13.15 | 38.8915 | 3.3387 | 1.8943 | 1.0748 |
| 6.0 | 5.00 | 0.0156 | 24.43 | 27.58 | 3.63 | 13.15 | 100.00 | 0.00 | 65.7566 | 43.4374 | 78.9425 | 143.4689 |

| | | | |
|-------------|------|-----------|------|
| % gravel | 0.1 | mean(phi) | 3.18 |
| % sand | 86.7 | mean(mm) | 0.11 |
| % silt-clay | 13.2 | sorting | 0.89 |
| % water | 8.2 | skewness | 0.22 |
| | | kurtosis | 5.67 |

| | | | |
|---------------------|-------|--|--|
| salt weight | 0.08 | (This worksheet assumes salt water and 3.5% concentration) | |
| wt. Loss of wt siev | 3.15 | | |
| dry sed weight | 27.54 | | |
| wt of water lost | 2.38 | | |
| dry sed | 27.62 | | |



T1-5 Base to 10 cm

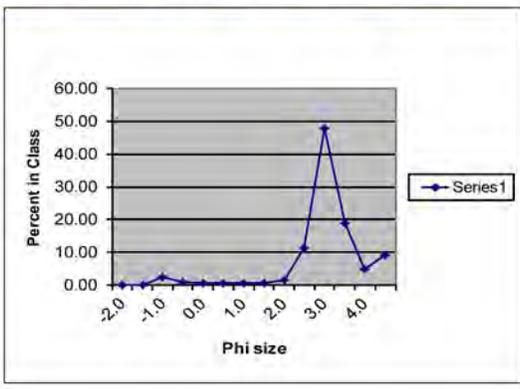
| | | | | | | | | | | | | | | |
|-----|----|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|
| PHI | -2 | -1.5 | -1 | -0.6 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan |
| | | | 0.69 | 0.92 | 1.12 | 1.32 | 1.46 | 1.67 | 2.13 | 5.18 | 18.3 | 23.46 | 24.82 | 24.93 |

vessel weight 0.00
 wet weight 30.00
 dry weight 27.46
 Dry Wt. Before wet sie 27.46
 Dry Wt. After sieving 24.96

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | F _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 100.00 | 0.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 100.00 | 0.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.69 | 0.69 | 0.69 | 2.52 | 2.52 | 97.48 | -3.1546 | 42.1459 | -172.2330 | 703.8458 |
| -0.5 | -0.75 | 1.4142 | 0.92 | 0.92 | 0.23 | 0.84 | 3.36 | 96.64 | -0.6309 | 10.8212 | -38.8112 | 139.1999 |
| 0.0 | -0.25 | 1.0000 | 1.12 | 1.12 | 0.20 | 0.73 | 4.10 | 95.90 | -0.1829 | 6.9690 | -21.5105 | 66.3942 |
| 0.5 | 0.25 | 0.7071 | 1.32 | 1.32 | 0.20 | 0.73 | 4.83 | 95.17 | 0.1829 | 4.8941 | -12.6589 | 32.7435 |
| 1.0 | 0.75 | 0.5000 | 1.46 | 1.46 | 0.14 | 0.51 | 5.34 | 94.66 | 0.3840 | 2.2294 | -4.6518 | 9.7065 |
| 1.5 | 1.25 | 0.3536 | 1.67 | 1.67 | 0.21 | 0.77 | 6.11 | 93.89 | 0.9601 | 1.9334 | -3.0676 | 4.8670 |
| 2.0 | 1.75 | 0.2500 | 2.13 | 2.13 | 0.46 | 1.68 | 7.79 | 92.21 | 2.9443 | 1.9864 | -2.1584 | 2.3453 |
| 2.5 | 2.25 | 0.1768 | 5.18 | 5.18 | 3.05 | 11.16 | 18.95 | 81.05 | 25.0996 | 3.8384 | -2.2516 | 1.3208 |
| 3.0 | 2.75 | 0.1250 | 18.3 | 18.30 | 13.12 | 47.99 | 66.93 | 33.07 | 131.9625 | 0.3598 | -0.0312 | 0.0027 |
| 3.5 | 3.25 | 0.0884 | 23.46 | 23.46 | 5.16 | 18.87 | 85.80 | 14.20 | 61.3362 | 3.2255 | 1.3334 | 0.5513 |
| 4.0 | 3.75 | 0.0625 | 24.82 | 24.82 | 1.36 | 4.97 | 90.78 | 9.22 | 18.6532 | 4.1501 | 3.7907 | 3.4625 |
| 6.0 | 5.00 | 0.0156 | 24.93 | 27.34 | 2.52 | 9.22 | 100.00 | 0.00 | 46.1046 | 43.1570 | 83.3654 | 201.9897 |

% gravel 2.5
 % sand 88.3
 % silt-clay 9.2
 % water 8.8
 mean(phi) 2.84
 mean(mm) 0.14
 sorting 1.12
 skewness -1.13
 kurtosis 7.38

salt weight 0.09 (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 2.41 concentration)
 dry sed weight 27.37
 wt of water lost 2.54
 dry sed. 27.46



T1-5 10-20 cm

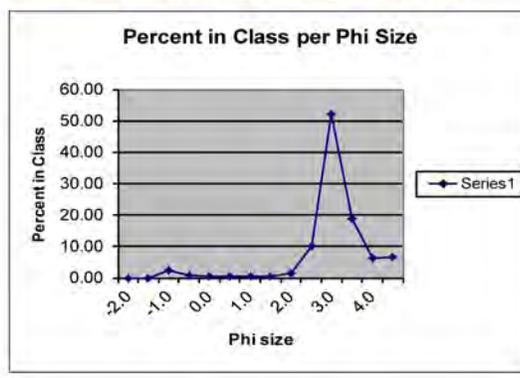
| | | | | | | | | | | | | | | |
|-----|----|------|------|------|------|------|------|------|------|-----|-------|-------|-------|-------|
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan |
| | | | 0.68 | 0.88 | 1.05 | 1.18 | 1.28 | 1.41 | 1.79 | 4.7 | 19.64 | 25.03 | 26.84 | 26.91 |

vessel weight 0.00
 wet weight 30.00
 dry weight 28.76
 Dry Wt. Before wet sie 28.76
 Dry Wt. After sieving 26.91

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | F _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 100.00 | 0.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 100.00 | 0.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.68 | 0.68 | 0.68 | 2.37 | 2.37 | 97.63 | -2.9600 | 39.3812 | -160.5998 | 654.9395 |
| -0.5 | -0.75 | 1.4142 | 0.88 | 0.88 | 0.20 | 0.70 | 3.06 | 96.94 | -0.5223 | 8.9166 | -31.9043 | 114.1563 |
| 0.0 | -0.25 | 1.0000 | 1.05 | 1.05 | 0.17 | 0.59 | 3.66 | 96.34 | -0.1480 | 5.6089 | -17.2647 | 53.1421 |
| 0.5 | 0.25 | 0.7071 | 1.18 | 1.18 | 0.13 | 0.45 | 4.11 | 95.89 | 0.1132 | 3.0089 | -7.7572 | 19.9986 |
| 1.0 | 0.75 | 0.5000 | 1.28 | 1.28 | 0.10 | 0.35 | 4.46 | 95.54 | 0.2612 | 1.5038 | -3.1251 | 6.4941 |
| 1.5 | 1.25 | 0.3536 | 1.41 | 1.41 | 0.13 | 0.45 | 4.91 | 95.09 | 0.5659 | 1.1274 | -1.7791 | 2.8076 |
| 2.0 | 1.75 | 0.2500 | 1.79 | 1.79 | 0.38 | 1.32 | 6.23 | 93.77 | 2.3157 | 1.5380 | -1.6581 | 1.7876 |
| 2.5 | 2.25 | 0.1768 | 4.7 | 4.70 | 2.91 | 10.13 | 16.37 | 83.63 | 22.8004 | 3.3864 | -1.9577 | 1.1317 |
| 3.0 | 2.75 | 0.1250 | 19.64 | 19.64 | 14.94 | 52.03 | 68.39 | 31.61 | 143.0706 | 0.3172 | -0.0248 | 0.0019 |
| 3.5 | 3.25 | 0.0884 | 25.03 | 25.03 | 5.39 | 18.77 | 87.16 | 12.84 | 61.0013 | 3.3412 | 1.4097 | 0.5948 |
| 4.0 | 3.75 | 0.0625 | 26.84 | 26.84 | 1.81 | 6.30 | 93.47 | 6.53 | 23.6362 | 5.3571 | 4.9388 | 4.5531 |
| 6.0 | 5.00 | 0.0156 | 26.91 | 28.72 | 1.88 | 6.53 | 100.00 | 0.00 | 32.6745 | 30.8265 | 66.9525 | 145.4151 |

% gravel 2.4
 % sand 91.1
 % silt-clay 6.5
 % water 4.3
 mean(phi) 2.83
 mean(mm) 0.14
 sorting 1.02
 skewness -1.43
 kurtosis 9.24

salt weight 0.04 (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 1.81 concentration)
 dry sed weight 28.72
 wt of water lost 1.24
 dry sed. 28.76

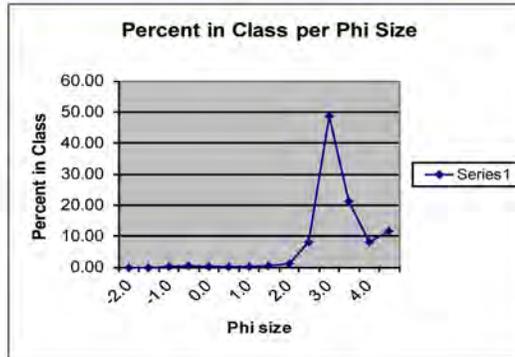


| T1-5 20-30 cm | | HL 0274 | | | | | | | | | | | | | |
|---------------|--|---------|------|-----|------|------|------|------|------|-----|------|------|-------|-------|-------|
| PHI | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | | 0.5 | 0.68 | 0.83 | 0.98 | 1.11 | 1.28 | 1.7 | 4.34 | 17.2 | 21.95 | 23.7 | 23.88 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 27.93 |
| wet weight | 32.27 | Dry Wt. After sieving | 24.76 |
| dry weight | 27.93 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.05 | 0.05 | 0.05 | 0.18 | 0.18 | 99.82 | -0.2260 | 3.4203 | -14.9095 | 64.9925 |
| -0.5 | -0.75 | 1.4142 | 0.14 | 0.14 | 0.09 | 0.32 | 0.50 | 99.50 | -0.2430 | 4.8252 | -18.6211 | 71.8611 |
| 0.0 | -0.25 | 1.0000 | 0.19 | 0.19 | 0.05 | 0.18 | 0.68 | 99.32 | -0.0450 | 2.0310 | -6.8225 | 22.9177 |
| 0.5 | 0.25 | 0.7071 | 0.25 | 0.25 | 0.06 | 0.22 | 0.90 | 99.10 | 0.0540 | 1.7657 | -5.0483 | 14.4338 |
| 1.0 | 0.75 | 0.5000 | 0.32 | 0.32 | 0.07 | 0.25 | 1.15 | 98.85 | 0.1890 | 1.4025 | -3.3086 | 7.8054 |
| 1.5 | 1.25 | 0.3536 | 0.41 | 0.41 | 0.09 | 0.32 | 1.48 | 98.52 | 0.4050 | 1.1198 | -2.0819 | 3.8705 |
| 2.0 | 1.75 | 0.2500 | 0.68 | 0.68 | 0.27 | 0.97 | 2.45 | 97.55 | 1.7010 | 1.7955 | -2.4403 | 3.3166 |
| 2.5 | 2.25 | 0.1768 | 2.93 | 2.93 | 2.25 | 8.10 | 10.55 | 89.45 | 18.2248 | 5.9785 | -5.1362 | 4.4126 |
| 3.0 | 2.75 | 0.1250 | 16.41 | 16.41 | 13.48 | 48.53 | 59.08 | 40.92 | 133.4505 | 6.2585 | -2.2476 | 0.8072 |
| 3.5 | 3.25 | 0.0884 | 22.32 | 22.32 | 5.91 | 21.28 | 80.35 | 19.65 | 69.1462 | 0.4223 | 0.0595 | 0.0084 |
| 4.0 | 3.75 | 0.0625 | 24.54 | 24.54 | 2.22 | 7.99 | 88.34 | 11.66 | 29.9697 | 3.2825 | 2.1037 | 1.3482 |
| 6.0 | 5.00 | 0.0156 | 24.76 | 27.78 | 3.24 | 11.66 | 100.00 | 0.00 | 58.2851 | 41.6788 | 78.8094 | 149.0191 |

| | | | |
|------------------|-------|---|------|
| % gravel | 0.2 | mean(phi) | 3.11 |
| % sand | 88.2 | mean(mm) | 0.12 |
| % silt-clay | 11.7 | sorting | 0.86 |
| % water | 13.9 | skewness | 0.32 |
| | | kurtosis | 6.30 |
| salt weight | 0.15 | wt. Loss of wt siev (This worksheet assumes salt water and 3.5% 3.02 concentration) | |
| dry sed weight | 27.78 | | |
| wt of water lost | 4.34 | | |
| dry sed | 27.93 | | |

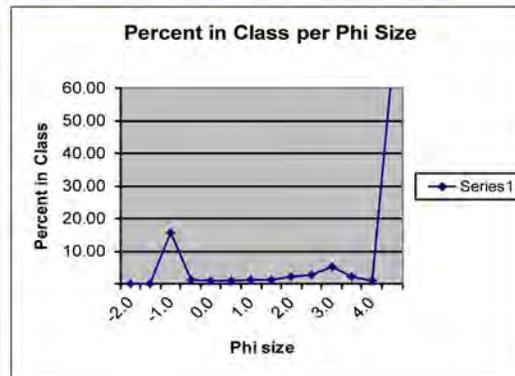


| T1-10 Base to 10 cm | | HL 0277 | | | | | | | | | | | | | |
|---------------------|--|---------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|
| PHI | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | | 0.91 | 1.98 | 3.06 | 4.33 | 5.43 | 6.48 | 7.38 | 8.29 | 9.62 | 10.4 | 10.64 | 10.67 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 16.94 |
| wet weight | 31.97 | Dry Wt. After sieving | 5.81 |
| dry weight | 16.94 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|---------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 2.6 | 2.60 | 2.60 | 15.84 | 15.84 | 84.16 | -19.800 | 344.413 | -1605.974 | 7488.551 |
| -0.5 | -0.75 | 1.4142 | 2.79 | 2.79 | 0.19 | 1.16 | 17.00 | 83.00 | -0.868 | 20.060 | -83.510 | 347.648 |
| 0.0 | -0.25 | 1.0000 | 2.96 | 2.96 | 0.17 | 1.04 | 18.03 | 81.97 | -0.259 | 13.896 | -50.901 | 186.446 |
| 0.5 | 0.25 | 0.7071 | 3.14 | 3.14 | 0.18 | 1.10 | 19.13 | 80.87 | 0.274 | 10.971 | -34.700 | 109.754 |
| 1.0 | 0.75 | 0.5000 | 3.37 | 3.37 | 0.23 | 1.40 | 20.53 | 79.47 | 1.051 | 9.937 | -26.460 | 70.462 |
| 1.5 | 1.25 | 0.3536 | 3.6 | 3.60 | 0.23 | 1.40 | 21.93 | 78.07 | 1.752 | 6.555 | -14.179 | 30.668 |
| 2.0 | 1.75 | 0.2500 | 3.94 | 3.94 | 0.34 | 2.07 | 24.00 | 76.00 | 3.625 | 5.728 | -9.526 | 15.840 |
| 2.5 | 2.25 | 0.1768 | 4.38 | 4.38 | 0.44 | 2.68 | 26.68 | 73.32 | 6.031 | 3.625 | -4.216 | 4.903 |
| 3.0 | 2.75 | 0.1250 | 5.26 | 5.26 | 0.88 | 5.36 | 32.05 | 67.95 | 14.744 | 2.356 | -1.562 | 1.036 |
| 3.5 | 3.25 | 0.0884 | 5.61 | 5.61 | 0.35 | 2.13 | 34.18 | 65.82 | 6.930 | 0.057 | -0.009 | 0.002 |
| 4.0 | 3.75 | 0.0625 | 5.78 | 5.78 | 0.17 | 1.04 | 35.21 | 64.79 | 3.884 | 0.118 | 0.040 | 0.013 |
| 6.0 | 5.00 | 0.0156 | 5.81 | 16.41 | 10.63 | 64.79 | 100.00 | 0.00 | 323.930 | 163.181 | 258.979 | 411.017 |

| | | | |
|------------------|-------|--|-------|
| % gravel | 15.8 | mean(phi) | 3.41 |
| % sand | 19.4 | mean(mm) | 0.09 |
| % silt-clay | 64.8 | sorting | 2.41 |
| % water | 48.7 | skewness | -1.12 |
| | | kurtosis | 2.57 |
| salt weight | 0.53 | wt. Loss of wt siev (This worksheet assumes salt water and 3.5% 10.60 concentration) | |
| dry sed weight | 16.41 | | |
| wt of water lost | 15.03 | | |
| dry sed | 16.94 | | |



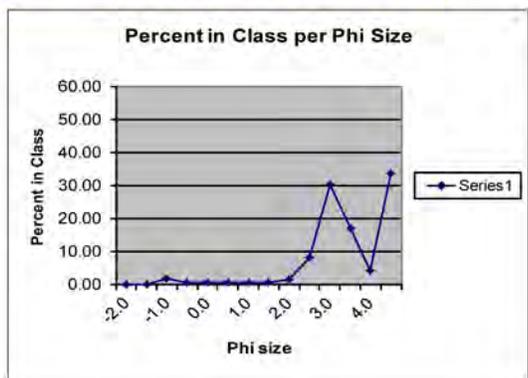
| | | | | | | | | | | | | | | | | | | | | |
|-----------------------|----|---------|-----|------|------|-----|------|------|------|------|-------|-------|-------|-------|--|--|--|--|--|--|
| T1-10 10-20 cm | | HL 0278 | | | | | | | | | | | | | | | | | | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan | | | | | | |
| | | | 0.5 | 1 | 1.53 | 2.2 | 2.95 | 3.76 | 5.04 | 8.17 | 15.14 | 17.41 | 18.14 | 18.24 | | | | | | |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 23.67 |
| wet weight | 32.82 | Dry Wt. After sieving | 15.58 |
| dry weight | 23.67 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.41 | 0.41 | 0.41 | 1.76 | 1.76 | 98.24 | -2.1949 | 38.4193 | -179.7102 | 840.6133 |
| -0.5 | -0.75 | 1.4142 | 0.54 | 0.54 | 0.13 | 0.56 | 2.31 | 97.69 | -0.4176 | 9.7166 | -40.5923 | 169.5786 |
| 0.0 | -0.25 | 1.0000 | 0.71 | 0.71 | 0.17 | 0.73 | 3.04 | 96.96 | -0.1820 | 9.8468 | -36.2128 | 133.1765 |
| 0.5 | 0.25 | 0.7071 | 0.83 | 0.83 | 0.12 | 0.51 | 3.55 | 96.45 | 0.1285 | 5.1892 | -16.4892 | 52.3961 |
| 1.0 | 0.75 | 0.5000 | 0.98 | 0.98 | 0.15 | 0.64 | 4.20 | 95.80 | 0.4818 | 4.6058 | -12.3324 | 33.0214 |
| 1.5 | 1.25 | 0.3536 | 1.16 | 1.16 | 0.18 | 0.77 | 4.97 | 95.03 | 0.9636 | 3.6555 | -7.9603 | 17.3344 |
| 2.0 | 1.75 | 0.2500 | 1.55 | 1.55 | 0.39 | 1.67 | 6.64 | 93.36 | 2.9229 | 4.7007 | -7.8859 | 13.2295 |
| 2.5 | 2.25 | 0.1768 | 3.47 | 3.47 | 1.92 | 8.22 | 14.86 | 85.14 | 18.5013 | 11.4030 | -13.4282 | 15.8132 |
| 3.0 | 2.75 | 0.1250 | 10.57 | 10.57 | 7.10 | 30.41 | 45.27 | 54.73 | 83.6197 | 13.9615 | -9.4604 | 6.4104 |
| 3.5 | 3.25 | 0.0884 | 14.51 | 14.51 | 3.94 | 16.67 | 62.14 | 37.86 | 54.8400 | 0.5323 | -0.0945 | 0.0168 |
| 4.0 | 3.75 | 0.0625 | 15.48 | 15.48 | 0.97 | 4.15 | 66.30 | 33.70 | 15.5783 | 0.4318 | 0.1392 | 0.0449 |
| 5.0 | 5.00 | 0.0156 | 15.58 | 23.35 | 7.87 | 33.70 | 100.00 | 0.00 | 168.5189 | 83.3300 | 131.0275 | 206.0269 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 1.8 | mean(phi) | 3.43 |
| % sand | 64.5 | mean(mm) | 0.09 |
| % silt-clay | 33.7 | sorting | 1.36 |
| % water | 28.9 | skewness | -0.76 |
| | | kurtosis | 4.31 |

| | | | |
|---------------------|-------|--|--|
| salt weight | 0.32 | (This worksheet assumes salt water and 3.5% concentration) | |
| wt. Loss of wt siev | 7.77 | | |
| dry sed weight | 23.35 | | |
| wt of water lost | 9.15 | | |
| dry sed | 23.67 | | |



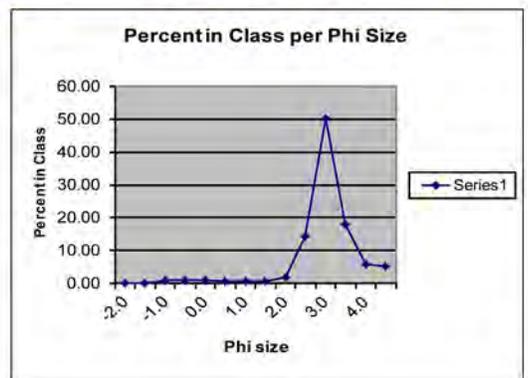
| | | | | | | | | | | | | | | | | | | | | |
|-----------------------|----|---------|------|------|------|------|------|------|------|-----|-------|-------|-------|-------|--|--|--|--|--|--|
| T1-10 20-30 cm | | HL 0279 | | | | | | | | | | | | | | | | | | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan | | | | | | |
| | | | 0.27 | 0.52 | 0.76 | 0.93 | 1.06 | 1.22 | 1.72 | 5.3 | 17.89 | 22.37 | 23.81 | 23.96 | | | | | | |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 25.31 |
| wet weight | 30.00 | Dry Wt. After sieving | 23.99 |
| dry weight | 25.31 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.27 | 0.27 | 0.27 | 1.08 | 1.08 | 98.92 | -1.3438 | 17.4505 | -70.3081 | 283.2706 |
| -0.5 | -0.75 | 1.4142 | 0.52 | 0.52 | 0.25 | 1.00 | 2.07 | 97.93 | -0.7465 | 12.3963 | -43.7466 | 154.3814 |
| 0.0 | -0.25 | 1.0000 | 0.76 | 0.76 | 0.24 | 0.96 | 3.03 | 96.97 | -0.2389 | 8.7672 | -26.5557 | 80.4370 |
| 0.5 | 0.25 | 0.7071 | 0.93 | 0.93 | 0.17 | 0.68 | 3.70 | 96.30 | 0.1692 | 4.3291 | -10.9482 | 27.6880 |
| 1.0 | 0.75 | 0.5000 | 1.06 | 1.06 | 0.13 | 0.52 | 4.22 | 95.78 | 0.3882 | 2.1309 | -4.3235 | 8.7724 |
| 1.5 | 1.25 | 0.3536 | 1.22 | 1.22 | 0.16 | 0.64 | 4.86 | 95.14 | 0.7963 | 1.4893 | -2.2771 | 3.4817 |
| 2.0 | 1.75 | 0.2500 | 1.72 | 1.72 | 0.50 | 1.99 | 6.85 | 93.15 | 3.4839 | 2.1079 | -2.1690 | 2.2319 |
| 2.5 | 2.25 | 0.1768 | 5.3 | 5.30 | 3.58 | 14.25 | 21.10 | 78.90 | 32.0714 | 3.9887 | -2.1100 | 1.1162 |
| 3.0 | 2.75 | 0.1250 | 17.89 | 17.89 | 12.59 | 50.13 | 71.23 | 28.77 | 137.8512 | 0.0421 | -0.0012 | 0.0000 |
| 3.5 | 3.25 | 0.0884 | 22.37 | 22.37 | 4.48 | 17.84 | 89.07 | 10.93 | 57.9714 | 3.9572 | 1.8639 | 0.8779 |
| 4.0 | 3.75 | 0.0625 | 23.81 | 23.81 | 1.44 | 5.73 | 94.80 | 5.20 | 21.5004 | 5.4058 | 5.2491 | 5.0969 |
| 5.0 | 5.00 | 0.0156 | 23.96 | 25.12 | 1.31 | 5.20 | 100.00 | 0.00 | 25.9965 | 25.6475 | 56.9634 | 126.5161 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 1.1 | mean(phi) | 2.78 |
| % sand | 93.7 | mean(mm) | 0.15 |
| % silt-clay | 5.2 | sorting | 0.94 |
| % water | 18.2 | skewness | -1.20 |
| | | kurtosis | 9.02 |

| | | | |
|---------------------|-------|--|--|
| salt weight | 0.16 | (This worksheet assumes salt water and 3.5% concentration) | |
| wt. Loss of wt siev | 1.16 | | |
| dry sed weight | 25.15 | | |
| wt of water lost | 4.69 | | |
| dry sed | 25.31 | | |



| | | | | | | | | | | | | | | |
|-----------------------|----|------|------|------|------|-----|------|------|------|------|-------|-------|---------|-------|
| T1-10 30-35 cm | | | | | | | | | | | | | HL 0280 | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | 1.35 | 1.73 | 2.05 | 2.3 | 2.55 | 2.83 | 3.41 | 6.96 | 20.59 | 24.45 | 25.46 | 25.54 |

vessel weight 0.00
 wet weight 30.00
 dry weight 28.15

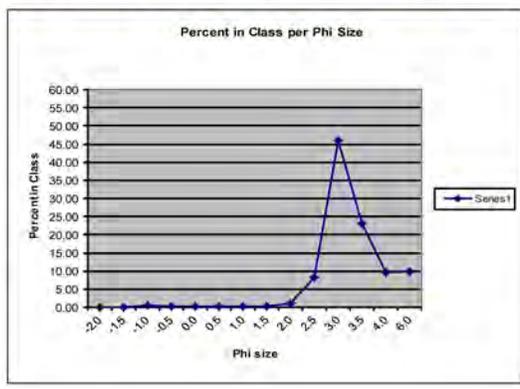
Dry Wt. Before wet sie 28.15
 Dry Wt. After sieving 25.82

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.16 | 0.16 | 0.16 | 0.57 | 0.57 | 99.43 | -0.7121 | 10.6270 | -45.8979 | 198.2331 |
| -0.5 | -0.75 | 1.4142 | 0.25 | 0.25 | 0.09 | 0.32 | 0.89 | 99.11 | -0.2403 | 4.6737 | -17.8490 | 68.1655 |
| 0.0 | -0.25 | 1.0000 | 0.37 | 0.37 | 0.12 | 0.43 | 1.32 | 98.68 | -0.1068 | 4.7067 | -15.6216 | 51.8483 |
| 0.5 | 0.25 | 0.7071 | 0.44 | 0.44 | 0.07 | 0.25 | 1.57 | 98.43 | 0.0623 | 1.9807 | -5.5835 | 15.7399 |
| 1.0 | 0.75 | 0.5000 | 0.51 | 0.51 | 0.07 | 0.25 | 1.82 | 98.18 | 0.1869 | 1.3404 | -3.1083 | 7.2082 |
| 1.5 | 1.25 | 0.3536 | 0.59 | 0.59 | 0.08 | 0.28 | 2.10 | 97.90 | 0.3561 | 0.9425 | -1.7144 | 3.1185 |
| 2.0 | 1.75 | 0.2500 | 0.88 | 0.88 | 0.29 | 1.03 | 3.13 | 96.87 | 1.8070 | 1.7964 | -2.3695 | 3.1254 |
| 2.5 | 2.25 | 0.1768 | 3.23 | 3.23 | 2.35 | 8.37 | 11.50 | 88.50 | 18.8266 | 5.6126 | -4.5967 | 3.7647 |
| 3.0 | 2.75 | 0.1250 | 16.12 | 16.12 | 12.89 | 45.90 | 57.40 | 42.60 | 126.2139 | 4.6705 | -1.4899 | 0.4753 |
| 3.5 | 3.25 | 0.0884 | 22.59 | 22.59 | 6.47 | 23.04 | 80.43 | 19.57 | 74.8703 | 0.7547 | 0.1366 | 0.0247 |
| 4.0 | 3.75 | 0.0625 | 25.33 | 25.33 | 2.74 | 9.76 | 90.19 | 9.81 | 36.5850 | 4.5244 | 3.0811 | 2.0982 |
| 6.0 | 5.00 | 0.0156 | 25.82 | 28.09 | 2.76 | 9.81 | 100.00 | 0.00 | 49.0515 | 36.5801 | 70.6361 | 136.3960 |

% gravel 0.6
 % sand 89.6
 % silt-clay 9.8
 % water 6.4

mean(phi) 3.07
 mean(mm) 0.12
 sorting 0.88
 skewness -0.35
 kurtosis 8.01

salt weight 0.06 (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 2.27 concentration)
 dry sed weight 28.09
 wt of water lost 1.85
 dry sed 28.15



| | | | | | | | | | | | | | | |
|----------------------------|----|------|------|------|------|-----|------|------|-------|-------|-------|-------|---------|-------|
| T1-20 Base to 10 cm | | | | | | | | | | | | | HL 0282 | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | 0.28 | 0.49 | 0.76 | 1.3 | 3.29 | 8.07 | 15.09 | 19.23 | 20.58 | 21.43 | 21.82 | 21.87 |

vessel weight 0.00
 wet weight 32.77
 dry weight 30.65

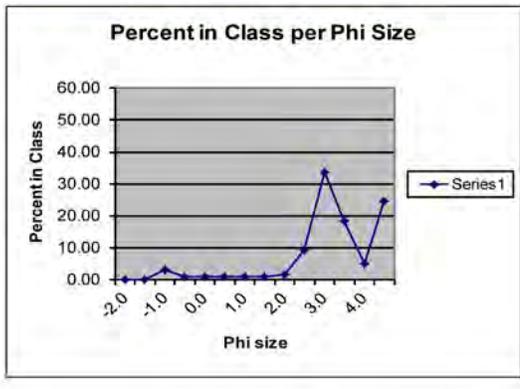
Dry Wt. Before wet sie 30.65
 Dry Wt. After sieving 23.21

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.91 | 0.91 | 0.91 | 2.98 | 2.98 | 97.02 | -3.7203 | 57.4014 | -252.0879 | 1107.0861 |
| -0.5 | -0.75 | 1.4142 | 1.2 | 1.20 | 0.29 | 0.95 | 3.92 | 96.08 | -0.7113 | 14.3645 | -55.9020 | 217.5520 |
| 0.0 | -0.25 | 1.0000 | 1.52 | 1.52 | 0.32 | 1.05 | 4.97 | 95.03 | -0.2616 | 12.0392 | -40.8331 | 138.4922 |
| 0.5 | 0.25 | 0.7071 | 1.8 | 1.80 | 0.28 | 0.92 | 5.89 | 94.11 | 0.2289 | 7.6573 | -22.1424 | 64.0286 |
| 1.0 | 0.75 | 0.5000 | 2.05 | 2.05 | 0.25 | 0.82 | 6.70 | 93.30 | 0.6132 | 4.6770 | -11.1857 | 26.7526 |
| 1.5 | 1.25 | 0.3536 | 2.35 | 2.35 | 0.30 | 0.98 | 7.69 | 92.31 | 1.2265 | 3.5110 | -6.6417 | 12.5638 |
| 2.0 | 1.75 | 0.2500 | 2.86 | 2.86 | 0.51 | 1.67 | 9.35 | 90.65 | 2.9190 | 3.2305 | -4.4957 | 6.2565 |
| 2.5 | 2.25 | 0.1768 | 5.7 | 5.70 | 2.84 | 9.29 | 18.64 | 81.36 | 20.8989 | 7.3849 | -6.5849 | 5.8715 |
| 3.0 | 2.75 | 0.1250 | 15.97 | 15.97 | 10.27 | 33.59 | 52.23 | 47.77 | 92.3688 | 5.1526 | -2.0181 | 0.7904 |
| 3.5 | 3.25 | 0.0884 | 21.58 | 21.58 | 5.61 | 18.35 | 70.58 | 29.42 | 59.6305 | 0.2153 | 0.0233 | 0.0025 |
| 4.0 | 3.75 | 0.0625 | 23.08 | 23.08 | 1.50 | 4.91 | 75.48 | 24.52 | 18.3969 | 1.8155 | 1.1044 | 0.6719 |
| 6.0 | 5.00 | 0.0156 | 23.21 | 30.58 | 7.50 | 24.52 | 100.00 | 0.00 | 122.5773 | 84.6617 | 157.3296 | 292.3706 |

% gravel 3.0
 % sand 72.5
 % silt-clay 24.5
 % water 6.7

mean(phi) 3.14
 mean(mm) 0.11
 sorting 1.42
 skewness -0.85
 kurtosis 4.58

salt weight 0.07 (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 7.37 concentration)
 dry sed weight 30.58
 wt of water lost 2.12
 dry sed 30.65



APPENDIX H

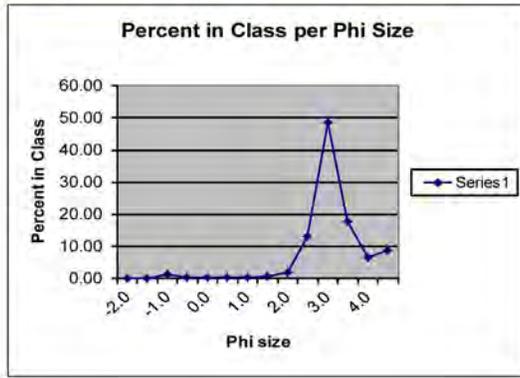
| | | | | | | | | | | | | | | | | | | | |
|-----------------------|--|---------|----|------|------|------|------|-----|------|------|------|------|-------|-------|-------|-------|--|--|--|
| T1-20 10-20 cm | | HL 0281 | | | | | | | | | | | | | | | | | |
| PHI | | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan | | | |
| | | | | | 1.35 | 1.73 | 2.05 | 2.3 | 2.55 | 2.83 | 3.41 | 6.96 | 20.59 | 24.45 | 25.46 | 25.54 | | | |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 25.56 |
| wet weight | 30.00 | Dry Wt. After sieving | 23.44 |
| dry weight | 25.56 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.32 | 0.32 | 0.32 | 1.26 | 1.26 | 98.74 | -1.5745 | 21.9360 | -91.5415 | 382.0128 |
| -0.5 | -0.75 | 1.4142 | 0.39 | 0.39 | 0.07 | 0.28 | 1.54 | 98.46 | -0.2067 | 3.7175 | -13.6549 | 50.1560 |
| 0.0 | -0.25 | 1.0000 | 0.48 | 0.48 | 0.09 | 0.35 | 1.89 | 98.11 | -0.0886 | 3.5670 | -11.3184 | 35.9147 |
| 0.5 | 0.25 | 0.7071 | 0.56 | 0.56 | 0.08 | 0.31 | 2.20 | 97.80 | 0.0787 | 2.2502 | -6.0149 | 16.0785 |
| 1.0 | 0.75 | 0.5000 | 0.64 | 0.64 | 0.08 | 0.31 | 2.52 | 97.48 | 0.2362 | 1.4871 | -3.2316 | 7.0227 |
| 1.5 | 1.25 | 0.3536 | 0.78 | 0.78 | 0.14 | 0.55 | 3.07 | 96.93 | 0.6889 | 1.5426 | -2.5810 | 4.3183 |
| 2.0 | 1.75 | 0.2500 | 1.26 | 1.26 | 0.48 | 1.89 | 4.96 | 95.04 | 3.3065 | 2.6002 | -3.0503 | 3.5784 |
| 2.5 | 2.25 | 0.1768 | 4.62 | 4.62 | 3.36 | 13.23 | 18.19 | 81.81 | 29.7584 | 5.9924 | -4.0336 | 2.7150 |
| 3.0 | 2.75 | 0.1250 | 16.99 | 16.99 | 12.37 | 48.69 | 66.88 | 33.12 | 133.9029 | 1.4592 | -0.2526 | 0.0437 |
| 3.5 | 3.25 | 0.0884 | 21.51 | 21.51 | 4.52 | 17.79 | 84.67 | 15.33 | 57.8242 | 1.9012 | 0.6215 | 0.2032 |
| 4.0 | 3.75 | 0.0625 | 23.19 | 23.19 | 1.68 | 6.61 | 91.28 | 8.72 | 24.7987 | 4.5216 | 3.7388 | 3.0916 |
| 6.0 | 5.00 | 0.0156 | 23.44 | 25.40 | 2.21 | 8.72 | 100.00 | 0.00 | 43.5866 | 37.6018 | 78.0948 | 162.1941 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 1.3 | mean(phi) | 2.92 |
| % sand | 90.0 | mean(mm) | 0.13 |
| % silt-clay | 8.7 | sorting | 0.94 |
| % water | 15.3 | skewness | -0.64 |
| | | kurtosis | 8.51 |

| | | |
|---------------------|-------|---|
| salt weight | 0.16 | (This worksheet assumes salt water and 3.5% wt. Loss of wt siev |
| wt. Loss of wt siev | 1.96 | concentration) |
| dry sed weight | 25.40 | |
| wt of water lost | 4.44 | |
| dry sed | 25.56 | |



Transect 2

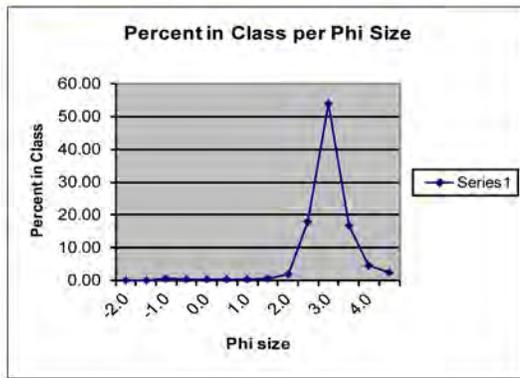
| T2-1 Base to 10 cm | | | | HL 0285 | | | | | | | | | | | | |
|--------------------|--|--|--|---------|------|------|------|-----|------|------|------|------|-------|-------|-------|-------|
| PHI | | | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan |
| | | | | | 1.35 | 1.73 | 2.05 | 2.3 | 2.55 | 2.83 | 3.41 | 6.96 | 20.59 | 24.45 | 25.46 | 25.54 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 26.25 |
| wet weight | 30.00 | Dry Wt. After sieving | 25.54 |
| dry weight | 26.25 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.2 | 0.20 | 0.20 | 0.77 | 0.77 | 99.23 | -0.9572 | 12.2687 | -49.1086 | 196.5701 |
| -0.5 | -0.75 | 1.4142 | 0.29 | 0.29 | 0.09 | 0.34 | 1.11 | 98.89 | -0.2584 | 4.2278 | -14.8069 | 51.8721 |
| 0.0 | -0.25 | 1.0000 | 0.36 | 0.36 | 0.07 | 0.27 | 1.38 | 98.62 | -0.0670 | 2.4165 | -7.2562 | 21.7887 |
| 0.5 | 0.25 | 0.7071 | 0.46 | 0.46 | 0.10 | 0.38 | 1.76 | 98.24 | 0.0957 | 2.3982 | -6.0022 | 15.0220 |
| 1.0 | 0.75 | 0.5000 | 0.54 | 0.54 | 0.08 | 0.31 | 2.07 | 97.93 | 0.2297 | 1.2286 | -2.4605 | 4.9278 |
| 1.5 | 1.25 | 0.3538 | 0.68 | 0.68 | 0.14 | 0.54 | 2.60 | 97.40 | 0.6700 | 1.2105 | -1.8191 | 2.7336 |
| 2.0 | 1.75 | 0.2500 | 1.18 | 1.18 | 0.50 | 1.91 | 4.52 | 95.48 | 3.3501 | 1.9249 | -1.9303 | 1.9356 |
| 2.5 | 2.25 | 0.1768 | 5.86 | 5.86 | 4.68 | 17.92 | 22.44 | 77.56 | 40.3159 | 4.5292 | -2.2771 | 1.1449 |
| 3.0 | 2.75 | 0.1250 | 19.94 | 19.94 | 14.08 | 53.91 | 76.34 | 23.66 | 148.2460 | 0.0004 | 0.0000 | 0.0000 |
| 3.5 | 3.25 | 0.0884 | 24.28 | 24.28 | 4.34 | 16.62 | 92.96 | 7.04 | 54.0034 | 4.1083 | 2.0428 | 1.0158 |
| 4.0 | 3.75 | 0.0625 | 25.44 | 25.44 | 1.16 | 4.44 | 97.40 | 2.60 | 16.6547 | 4.4167 | 4.4045 | 4.3924 |
| 6.0 | 5.00 | 0.0156 | 25.54 | 26.12 | 0.68 | 2.60 | 100.00 | 0.00 | 12.9935 | 13.1237 | 29.4920 | 66.2754 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 0.8 | mean(phi) | 2.75 |
| % sand | 96.6 | mean(mm) | 0.15 |
| % silt-clay | 2.6 | sorting | 0.72 |
| % water | 12.9 | skewness | -1.33 |
| | | kurtosis | 13.67 |

| | | | |
|------------------|-------|---|--|
| salt weight | 0.13 | (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 0.58 concentration) | |
| dry sed weight | 26.12 | | |
| wt of water lost | 3.75 | | |
| dry sed | 26.25 | | |



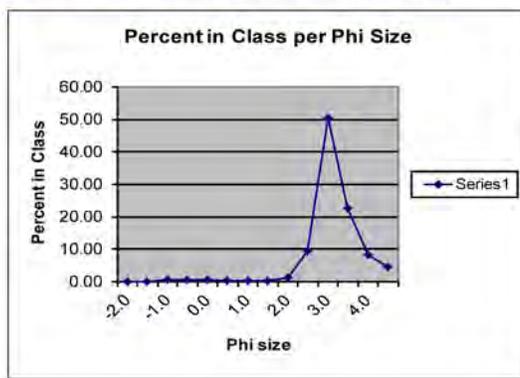
| T2-1 10-20 cm | | | | HL 0284 | | | | | | | | | | | | |
|---------------|--|--|--|---------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|
| PHI | | | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan |
| | | | | | 0.18 | 0.34 | 0.51 | 0.61 | 0.71 | 0.81 | 1.09 | 3.53 | 16.49 | 22.33 | 24.49 | 24.68 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 25.87 |
| wet weight | 30.00 | Dry Wt. After sieving | 24.76 |
| dry weight | 25.87 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.18 | 0.18 | 0.18 | 0.70 | 0.70 | 99.30 | -0.8773 | 12.0752 | -50.0850 | 207.7414 |
| -0.5 | -0.75 | 1.4142 | 0.34 | 0.34 | 0.16 | 0.62 | 1.33 | 98.67 | -0.4679 | 8.3017 | -30.2826 | 110.4643 |
| 0.0 | -0.25 | 1.0000 | 0.51 | 0.51 | 0.17 | 0.66 | 1.99 | 98.01 | -0.1657 | 6.5682 | -20.6752 | 65.0809 |
| 0.5 | 0.25 | 0.7071 | 0.61 | 0.61 | 0.10 | 0.39 | 2.38 | 97.62 | 0.0975 | 2.7337 | -7.2382 | 19.1652 |
| 1.0 | 0.75 | 0.5000 | 0.71 | 0.71 | 0.10 | 0.39 | 2.77 | 97.23 | 0.2924 | 1.7987 | -3.8633 | 8.2975 |
| 1.5 | 1.25 | 0.3538 | 0.81 | 0.81 | 0.10 | 0.39 | 3.16 | 96.84 | 0.4874 | 1.0587 | -1.7446 | 2.8746 |
| 2.0 | 1.75 | 0.2500 | 1.09 | 1.09 | 0.28 | 1.09 | 4.25 | 95.75 | 1.9107 | 1.4383 | -1.6509 | 1.8949 |
| 2.5 | 2.25 | 0.1768 | 3.53 | 3.53 | 2.44 | 9.51 | 13.76 | 86.24 | 21.4073 | 3.9923 | -2.5861 | 1.6752 |
| 3.0 | 2.75 | 0.1250 | 16.49 | 16.49 | 12.96 | 50.54 | 64.30 | 35.70 | 138.9720 | 1.1036 | -0.1631 | 0.0241 |
| 3.5 | 3.25 | 0.0884 | 22.33 | 22.33 | 5.84 | 22.77 | 87.07 | 12.93 | 74.0092 | 2.8252 | 0.9951 | 0.3505 |
| 4.0 | 3.75 | 0.0625 | 24.49 | 24.49 | 2.16 | 8.42 | 95.49 | 4.51 | 31.5846 | 6.1172 | 5.2132 | 4.4428 |
| 6.0 | 5.00 | 0.0156 | 24.68 | 25.65 | 1.16 | 4.51 | 100.00 | 0.00 | 22.5274 | 19.9113 | 41.8580 | 87.9949 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 0.7 | mean(phi) | 2.90 |
| % sand | 94.8 | mean(mm) | 0.13 |
| % silt-clay | 4.5 | sorting | 0.82 |
| % water | 14.2 | skewness | -1.25 |
| | | kurtosis | 11.05 |

| | | | |
|------------------|-------|---|--|
| salt weight | 0.14 | (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 0.97 concentration) | |
| dry sed weight | 25.73 | | |
| wt of water lost | 4.13 | | |
| dry sed | 25.87 | | |



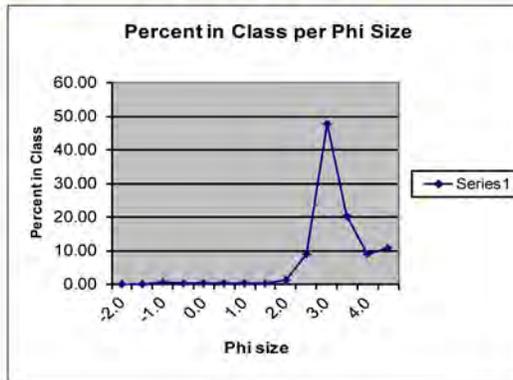
| | | | | | | | | | | | | | | |
|----------------------|----|---------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|
| T2-1 20-25 cm | | HL 0283 | | | | | | | | | | | | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | 0.16 | 0.21 | 0.27 | 0.35 | 0.43 | 0.54 | 0.87 | 3.09 | 15.08 | 20.16 | 22.42 | 22.62 |

vessel weight 0.00 Dry Wt. Before wet sie 25.27
 wet weight 30.00 Dry Wt. After sieving 22.62
 dry weight 25.27

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.16 | 0.16 | 0.16 | 0.64 | 0.64 | 99.36 | -0.7967 | 11.8606 | -51.1654 | 220.7218 |
| -0.5 | -0.75 | 1.4142 | 0.21 | 0.21 | 0.05 | 0.20 | 0.84 | 99.16 | -0.1494 | 2.8970 | -11.0490 | 42.1397 |
| 0.0 | -0.25 | 1.0000 | 0.27 | 0.27 | 0.06 | 0.24 | 1.08 | 98.92 | -0.0598 | 2.6247 | -8.6979 | 28.8239 |
| 0.5 | 0.25 | 0.7071 | 0.35 | 0.35 | 0.08 | 0.32 | 1.39 | 98.61 | 0.0797 | 2.5232 | -7.1000 | 19.9787 |
| 1.0 | 0.75 | 0.5000 | 0.43 | 0.43 | 0.08 | 0.32 | 1.71 | 98.29 | 0.2390 | 1.7062 | -3.9479 | 9.1360 |
| 1.5 | 1.25 | 0.3536 | 0.54 | 0.54 | 0.11 | 0.44 | 2.15 | 97.85 | 0.5477 | 1.4417 | -2.6150 | 4.7433 |
| 2.0 | 1.75 | 0.2500 | 0.87 | 0.87 | 0.33 | 1.31 | 3.47 | 96.53 | 2.3004 | 2.2692 | -2.9815 | 3.9174 |
| 2.5 | 2.25 | 0.1768 | 3.09 | 3.09 | 2.22 | 8.84 | 12.31 | 87.69 | 19.8969 | 5.8578 | -4.7676 | 3.8803 |
| 3.0 | 2.75 | 0.1250 | 15.08 | 15.08 | 11.99 | 47.76 | 80.07 | 39.93 | 131.3413 | 4.7057 | -1.4771 | 0.4636 |
| 3.5 | 3.25 | 0.0884 | 20.16 | 20.16 | 5.08 | 20.24 | 80.30 | 19.70 | 65.7652 | 0.7009 | 0.1304 | 0.0243 |
| 4.0 | 3.75 | 0.0625 | 22.42 | 22.42 | 2.26 | 9.00 | 89.31 | 10.69 | 33.7590 | 4.2379 | 2.9076 | 1.9950 |
| 5.0 | 5.00 | 0.0156 | 22.62 | 25.10 | 2.68 | 10.69 | 100.00 | 0.00 | 53.4656 | 40.0834 | 77.6060 | 150.2538 |

% gravel 0.6 mean(phi) 3.06
 % sand 88.7 mean(mm) 0.12
 % silt-clay 10.7 sorting 0.90
 % water 16.3 kurtosis -0.18
 skewness 7.43

salt weight 0.17 (This worksheet assumes salt water and 3.5% concentration)
 wt. Loss of wt siev 2.48
 dry sed weight 25.10
 wt of water lost 4.73
 dry sed 25.27



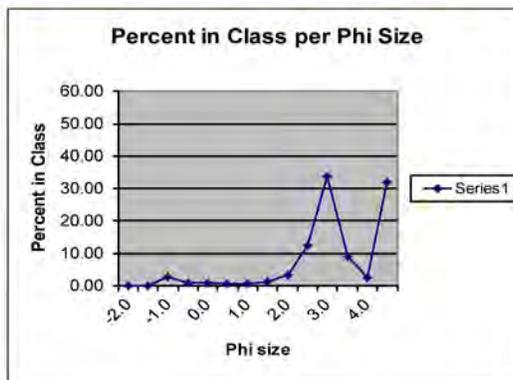
| | | | | | | | | | | | | | | |
|---------------------------|----|---------|------|------|------|------|-----|------|------|------|-------|-------|-------|-------|
| T2-3 Base to 10 cm | | HL 0326 | | | | | | | | | | | | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | 0.65 | 1.32 | 1.89 | 2.68 | 3.5 | 4.17 | 5.39 | 8.65 | 16.76 | 19.09 | 19.78 | 19.87 |

vessel weight 0.00 Dry Wt. Before wet sie 22.09
 wet weight 30.92 Dry Wt. After sieving 14.92
 dry weight 22.09

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.61 | 0.61 | 0.61 | 2.80 | 2.80 | 97.20 | -3.5008 | 55.7866 | -248.9820 | 1111.2359 |
| -0.5 | -0.75 | 1.4142 | 0.84 | 0.84 | 0.23 | 1.06 | 3.86 | 96.14 | -0.7920 | 16.5954 | -65.7297 | 260.4946 |
| 0.0 | -0.25 | 1.0000 | 1.02 | 1.02 | 0.18 | 0.83 | 4.68 | 95.32 | -0.2066 | 9.9113 | -34.3240 | 118.8679 |
| 0.5 | 0.25 | 0.7071 | 1.19 | 1.19 | 0.17 | 0.78 | 5.46 | 94.54 | 0.1951 | 6.8528 | -20.3057 | 60.1683 |
| 1.0 | 0.75 | 0.5000 | 1.35 | 1.35 | 0.16 | 0.73 | 6.20 | 93.80 | 0.5509 | 4.4567 | -10.9774 | 27.0366 |
| 1.5 | 1.25 | 0.3536 | 1.62 | 1.62 | 0.27 | 1.24 | 7.44 | 92.56 | 1.5495 | 4.7773 | -9.3783 | 18.4108 |
| 2.0 | 1.75 | 0.2500 | 2.35 | 2.35 | 0.73 | 3.35 | 10.79 | 89.21 | 5.8652 | 7.1747 | -10.4974 | 15.3590 |
| 2.5 | 2.25 | 0.1768 | 5.03 | 5.03 | 2.68 | 12.30 | 23.09 | 76.91 | 27.6847 | 11.4134 | -10.9925 | 10.5870 |
| 3.0 | 2.75 | 0.1250 | 12.37 | 12.37 | 7.34 | 33.70 | 56.79 | 43.21 | 92.6727 | 7.2277 | -3.3473 | 1.5502 |
| 3.5 | 3.25 | 0.0884 | 14.31 | 14.31 | 1.94 | 8.91 | 65.70 | 34.30 | 28.9473 | 0.0121 | 0.0004 | 0.0000 |
| 4.0 | 3.75 | 0.0625 | 14.86 | 14.86 | 0.55 | 2.53 | 88.22 | 31.78 | 9.4693 | 0.7279 | 0.3908 | 0.2098 |
| 5.0 | 5.00 | 0.0156 | 14.92 | 21.78 | 6.92 | 31.78 | 100.00 | 0.00 | 158.8762 | 101.4567 | 181.2913 | 323.9462 |

% gravel 2.8 mean(phi) 3.21
 % sand 65.4 mean(mm) 0.11
 % silt-clay 31.8 sorting 1.50
 % water 29.6 kurtosis -0.68
 skewness 3.80

salt weight 0.31 (This worksheet assumes salt water and 3.5% concentration)
 wt. Loss of wt siev 6.86
 dry sed weight 21.78
 wt of water lost 8.83
 dry sed 22.09



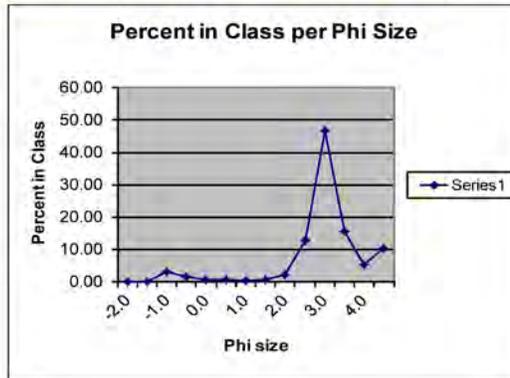
| T2-3 10-20 cm | | HL 0327 | | | | | | | | | | | | | |
|---------------|--|---------|------|------|------|------|------|------|------|------|-----|-------|-------|-------|-------|
| PHI | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | | 0.36 | 0.86 | 1.25 | 1.61 | 1.92 | 2.24 | 2.88 | 6.1 | 17.66 | 21.63 | 22.87 | 23.03 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 26.68 |
| wet weight | 32.75 | Dry Wt. After sieving | 23.99 |
| dry weight | 26.68 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.85 | 0.85 | 0.85 | 3.21 | 3.21 | 96.79 | -4.0143 | 52.3438 | -211.3220 | 853.1483 |
| -0.5 | -0.75 | 1.4142 | 1.24 | 1.24 | 0.39 | 1.47 | 4.68 | 95.32 | -1.1051 | 18.4361 | -65.2121 | 230.6680 |
| 0.0 | -0.25 | 1.0000 | 1.43 | 1.43 | 0.19 | 0.72 | 5.40 | 94.60 | -0.1795 | 6.6219 | -20.1121 | 61.0845 |
| 0.5 | 0.25 | 0.7071 | 1.62 | 1.62 | 0.19 | 0.72 | 6.12 | 93.88 | 0.1795 | 4.6211 | -11.7247 | 29.7479 |
| 1.0 | 0.75 | 0.5000 | 1.73 | 1.73 | 0.11 | 0.42 | 6.54 | 93.46 | 0.3117 | 1.7248 | -3.5138 | 7.1583 |
| 1.5 | 1.25 | 0.3536 | 1.88 | 1.88 | 0.15 | 0.57 | 7.10 | 92.90 | 0.7084 | 1.3392 | -2.0586 | 3.1644 |
| 2.0 | 1.75 | 0.2500 | 2.49 | 2.49 | 0.61 | 2.30 | 9.41 | 90.59 | 4.0332 | 2.4793 | -2.5716 | 2.6672 |
| 2.5 | 2.25 | 0.1788 | 5.85 | 5.85 | 3.36 | 12.69 | 22.10 | 77.90 | 28.5633 | 3.6635 | -1.9680 | 1.0572 |
| 3.0 | 2.75 | 0.1250 | 18.24 | 18.24 | 12.39 | 46.81 | 68.91 | 31.09 | 128.7331 | 0.0648 | -0.0024 | 0.0001 |
| 3.5 | 3.25 | 0.0884 | 22.38 | 22.38 | 4.14 | 15.64 | 84.56 | 15.44 | 50.8358 | 3.3503 | 1.5505 | 0.7176 |
| 4.0 | 3.75 | 0.0625 | 23.77 | 23.77 | 1.39 | 5.25 | 89.81 | 10.19 | 19.6939 | 4.8683 | 4.6872 | 4.5129 |
| 6.0 | 5.00 | 0.0156 | 23.96 | 26.47 | 2.70 | 10.19 | 100.00 | 0.00 | 50.9596 | 49.9047 | 110.4294 | 244.3585 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 3.2 | mean(phi) | 2.79 |
| % sand | 86.6 | mean(mm) | 0.14 |
| % silt-clay | 10.2 | sorting | 1.22 |
| % water | 19.2 | skewness | -1.10 |
| | | kurtosis | 6.44 |

| | | | |
|---------------------|-------|--|--|
| salt weight | 0.21 | (This worksheet assumes salt water and 3.5% concentration) | |
| wt. Loss of wt siev | 2.51 | | |
| dry sed weight | 26.47 | | |
| wt of water lost | 6.07 | | |
| dry sed | 26.68 | | |



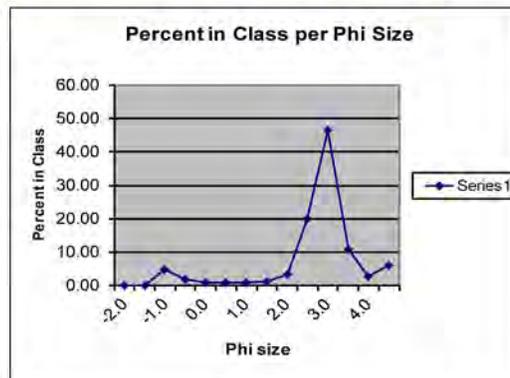
| T2-5 Base to 10 cm | | HL 0331 | | | | | | | | | | | | | |
|--------------------|--|---------|------|------|------|------|------|------|------|------|-----|-------|-------|-------|------|
| PHI | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | | 1.33 | 1.82 | 2.11 | 2.37 | 2.65 | 2.99 | 3.89 | 9.3 | 22.01 | 24.99 | 25.73 | 25.8 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 27.50 |
| wet weight | 30.00 | Dry Wt. After sieving | 25.86 |
| dry weight | 27.50 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 1.33 | 1.33 | 1.33 | 4.86 | 4.86 | 95.14 | -6.0781 | 67.6982 | -252.6028 | 942.5392 |
| -0.5 | -0.75 | 1.4142 | 1.82 | 1.82 | 0.49 | 1.79 | 6.65 | 93.35 | -1.3436 | 18.7049 | -60.4414 | 195.3048 |
| 0.0 | -0.25 | 1.0000 | 2.11 | 2.11 | 0.29 | 1.06 | 7.71 | 92.29 | -0.2651 | 7.9094 | -21.6030 | 59.0044 |
| 0.5 | 0.25 | 0.7071 | 2.37 | 2.37 | 0.26 | 0.95 | 8.66 | 91.34 | 0.2376 | 4.7326 | -10.5598 | 23.5622 |
| 1.0 | 0.75 | 0.5000 | 2.65 | 2.65 | 0.28 | 1.02 | 9.69 | 90.31 | 0.7678 | 3.0684 | -5.3123 | 9.1973 |
| 1.5 | 1.25 | 0.3536 | 2.99 | 2.99 | 0.34 | 1.24 | 10.93 | 89.07 | 1.5538 | 1.8846 | -2.3205 | 2.8573 |
| 2.0 | 1.75 | 0.2500 | 3.89 | 3.89 | 0.90 | 3.29 | 14.22 | 85.78 | 5.7582 | 1.7597 | -1.2869 | 0.9411 |
| 2.5 | 2.25 | 0.1768 | 9.3 | 9.30 | 5.41 | 19.78 | 34.00 | 66.00 | 44.5023 | 1.0582 | -0.2448 | 0.0566 |
| 3.0 | 2.75 | 0.1250 | 22.01 | 22.01 | 12.71 | 46.47 | 80.47 | 19.53 | 127.7854 | 3.3547 | 0.9014 | 0.2422 |
| 3.5 | 3.25 | 0.0884 | 24.99 | 24.99 | 2.98 | 10.89 | 91.36 | 8.64 | 35.4081 | 6.4376 | 4.9485 | 3.8039 |
| 4.0 | 3.75 | 0.0625 | 25.73 | 25.73 | 0.74 | 2.71 | 94.07 | 5.93 | 10.1453 | 4.3546 | 5.5246 | 7.0080 |
| 6.0 | 5.00 | 0.0156 | 25.8 | 27.35 | 1.62 | 5.93 | 100.00 | 0.00 | 29.6591 | 37.6303 | 94.7791 | 238.7192 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 4.9 | mean(phi) | 2.48 |
| % sand | 89.2 | mean(mm) | 0.18 |
| % silt-clay | 5.9 | sorting | 1.26 |
| % water | 8.6 | skewness | -1.24 |
| | | kurtosis | 5.90 |

| | | | |
|---------------------|-------|--|--|
| salt weight | 0.09 | (This worksheet assumes salt water and 3.5% concentration) | |
| wt. Loss of wt siev | 1.55 | | |
| dry sed weight | 27.41 | | |
| wt of water lost | 2.50 | | |
| dry sed | 27.50 | | |



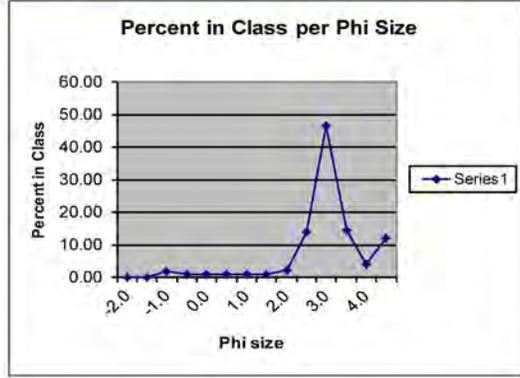
| | | | | | | | | | | | | | | | | | | | | |
|----------------------|--|---------|------|------|------|-----|------|------|------|------|------|-------|-------|-------|-------|--|--|--|--|--|
| T2-5 10-20 cm | | HL 0330 | | | | | | | | | | | | | | | | | | |
| PHI | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan | | | | | |
| | | | | 0.93 | 1.57 | 2.2 | 2.87 | 3.49 | 4.23 | 5.54 | 9.73 | 19.46 | 22.38 | 23.15 | 23.24 | | | | | |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 29.96 |
| wet weight | 33.96 | Dry Wt. After sieving | 26.37 |
| dry weight | 29.96 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.58 | 0.58 | 0.58 | 1.95 | 1.95 | 98.05 | -2.4313 | 32.7439 | -134.3495 | 551.2406 |
| -0.5 | -0.75 | 1.4142 | 0.88 | 0.88 | 0.30 | 1.01 | 2.95 | 97.05 | -0.7545 | 13.0502 | -47.0564 | 169.5460 |
| 0.0 | -0.25 | 1.0000 | 1.19 | 1.19 | 0.31 | 1.04 | 3.99 | 96.01 | -0.2599 | 10.0098 | -31.0609 | 96.3831 |
| 0.5 | 0.25 | 0.7071 | 1.43 | 1.43 | 0.24 | 0.80 | 4.80 | 95.20 | 0.2012 | 5.4534 | -14.1953 | 36.9508 |
| 1.0 | 0.75 | 0.5000 | 1.67 | 1.67 | 0.24 | 0.80 | 5.60 | 94.40 | 0.6036 | 3.5596 | -7.4859 | 15.7431 |
| 1.5 | 1.25 | 0.3536 | 1.93 | 1.93 | 0.26 | 0.87 | 6.47 | 93.53 | 1.0899 | 2.2405 | -3.5917 | 5.7575 |
| 2.0 | 1.75 | 0.2500 | 2.56 | 2.56 | 0.63 | 2.11 | 8.58 | 91.42 | 3.6972 | 2.5705 | -2.8353 | 3.1274 |
| 2.5 | 2.25 | 0.1768 | 6.7 | 6.70 | 4.14 | 13.88 | 22.47 | 77.53 | 31.2374 | 5.0487 | -3.0445 | 1.8360 |
| 3.0 | 2.75 | 0.1250 | 20.61 | 20.61 | 13.91 | 46.65 | 69.11 | 30.89 | 128.2780 | 0.4952 | -0.0510 | 0.0053 |
| 3.5 | 3.25 | 0.0884 | 24.97 | 24.97 | 4.36 | 14.62 | 83.74 | 16.26 | 47.5184 | 2.3040 | 0.9146 | 0.3631 |
| 4.0 | 3.75 | 0.0625 | 26.21 | 26.21 | 1.24 | 4.16 | 87.89 | 12.11 | 15.5936 | 3.3455 | 3.0008 | 2.6916 |
| 5.0 | 5.00 | 0.0156 | 26.37 | 29.82 | 3.61 | 12.11 | 100.00 | 0.00 | 60.5298 | 55.8020 | 119.8049 | 257.2169 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 1.9 | mean(phi) | 2.85 |
| % sand | 85.9 | mean(mm) | 0.14 |
| % silt-clay | 12.1 | sorting | 1.17 |
| % water | 12.2 | skewness | -0.75 |
| | | kurtosis | 6.11 |

| | | | |
|---------------------|-------|--|--|
| salt weight | 0.14 | (This worksheet assumes salt water and 3.5% concentration) | |
| wt. Loss of wt siev | 3.45 | | |
| dry sed weight | 29.82 | | |
| wt of water lost | 4.00 | | |
| dry sed | 29.96 | | |



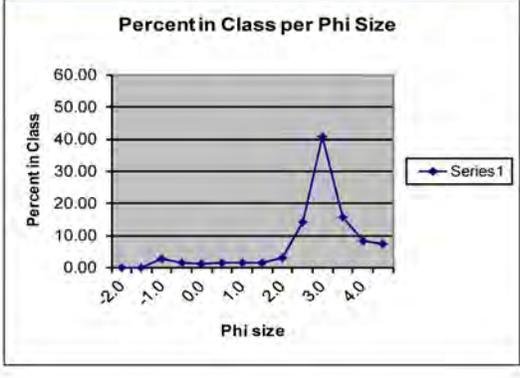
| | | | | | | | | | | | | | | | | | | | | |
|----------------------|--|---------|------|------|------|------|------|-------|------|------|------|-------|-------|-------|-------|--|--|--|--|--|
| T2-5 20-28 cm | | HL 0329 | | | | | | | | | | | | | | | | | | |
| PHI | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan | | | | | |
| | | | | 0.67 | 1.04 | 1.34 | 1.75 | 2.165 | 2.55 | 3.29 | 6.76 | 16.83 | 20.72 | 22.78 | 22.46 | | | | | |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 24.88 |
| wet weight | 30.00 | Dry Wt. After sieving | 22.55 |
| dry weight | 24.88 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.67 | 0.67 | 0.67 | 2.72 | 2.72 | 97.28 | -3.4030 | 42.1031 | -165.5755 | 651.1460 |
| -0.5 | -0.75 | 1.4142 | 1.04 | 1.04 | 0.37 | 1.50 | 4.23 | 95.77 | -1.1276 | 17.7145 | -60.8071 | 208.7279 |
| 0.0 | -0.25 | 1.0000 | 1.34 | 1.34 | 0.30 | 1.22 | 5.44 | 94.56 | -0.3047 | 10.4835 | -30.7443 | 90.1614 |
| 0.5 | 0.25 | 0.7071 | 1.75 | 1.75 | 0.41 | 1.67 | 7.11 | 92.89 | 0.4165 | 9.8584 | -23.9818 | 58.3388 |
| 1.0 | 0.75 | 0.5000 | 2.165 | 2.17 | 0.42 | 1.69 | 8.80 | 91.20 | 1.2647 | 6.2982 | -12.1721 | 23.5240 |
| 1.5 | 1.25 | 0.3536 | 2.55 | 2.55 | 0.39 | 1.56 | 10.36 | 89.64 | 1.9554 | 3.2107 | -4.5997 | 6.5897 |
| 2.0 | 1.75 | 0.2500 | 3.29 | 3.29 | 0.74 | 3.01 | 13.37 | 86.63 | 5.2619 | 2.6153 | -2.4391 | 2.2747 |
| 2.5 | 2.25 | 0.1768 | 6.76 | 6.76 | 3.47 | 14.10 | 27.47 | 72.53 | 31.7239 | 2.6389 | -1.1416 | 0.4939 |
| 3.0 | 2.75 | 0.1250 | 16.83 | 16.83 | 10.07 | 40.92 | 68.38 | 31.62 | 112.5217 | 0.1857 | 0.0125 | 0.0008 |
| 3.5 | 3.25 | 0.0884 | 20.72 | 20.72 | 3.89 | 15.81 | 84.19 | 15.81 | 51.3697 | 5.0882 | 2.8869 | 1.6380 |
| 4.0 | 3.75 | 0.0625 | 22.78 | 22.78 | 2.08 | 8.37 | 92.56 | 7.44 | 31.3887 | 9.5362 | 10.1788 | 10.8646 |
| 5.0 | 5.00 | 0.0156 | 22.46 | 24.61 | 1.83 | 7.44 | 100.00 | 0.00 | 37.1951 | 39.9492 | 92.5774 | 214.5368 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 2.7 | mean(phi) | 2.68 |
| % sand | 89.8 | mean(mm) | 0.16 |
| % silt-clay | 7.4 | sorting | 1.22 |
| % water | 17.7 | skewness | -1.07 |
| | | kurtosis | 5.66 |

| | | | |
|---------------------|-------|--|--|
| salt weight | 0.18 | (This worksheet assumes salt water and 3.5% concentration) | |
| wt. Loss of wt siev | 2.15 | | |
| dry sed weight | 24.70 | | |
| wt of water lost | 5.12 | | |
| dry sed | 24.88 | | |



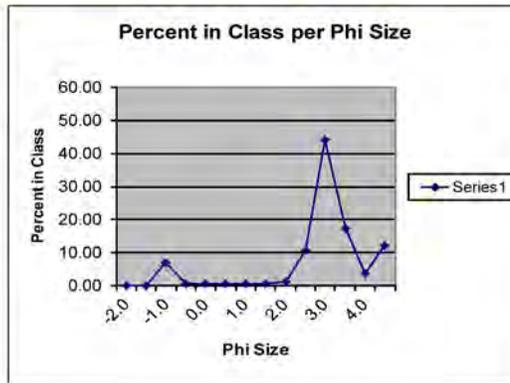
| T2-10 Base to 10 cm | | HL 0336 | | | | | | | | | | | | | |
|---------------------|--|---------|------|------|-------|------|------|------|------|------|------|-------|------|-------|-------|
| PHI | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | | 0.88 | 1.387 | 1.75 | 2.07 | 2.39 | 2.73 | 3.87 | 8.42 | 20.91 | 24.1 | 24.97 | 25.08 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 27.88 |
| wet weight | 31.07 | Dry Wt. After sieving | 24.43 |
| dry weight | 27.86 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 1.99 | 1.99 | 1.99 | 7.17 | 7.17 | 92.83 | -8.9647 | 112.8278 | -447.5184 | 1775.0294 |
| -0.5 | -0.75 | 1.4142 | 2.16 | 2.16 | 0.17 | 0.61 | 7.78 | 92.22 | -0.4595 | 7.3617 | -25.5183 | 88.4563 |
| 0.0 | -0.25 | 1.0000 | 2.34 | 2.34 | 0.18 | 0.65 | 8.43 | 91.57 | -0.1622 | 5.7082 | -16.9328 | 50.2291 |
| 0.5 | 0.25 | 0.7071 | 2.52 | 2.52 | 0.18 | 0.65 | 9.08 | 90.92 | 0.1622 | 3.9461 | -9.7326 | 24.0043 |
| 1.0 | 0.75 | 0.5000 | 2.68 | 2.68 | 0.16 | 0.58 | 9.66 | 90.34 | 0.4325 | 2.2296 | -4.3843 | 8.6212 |
| 1.5 | 1.25 | 0.3536 | 2.86 | 2.86 | 0.18 | 0.65 | 10.31 | 89.69 | 0.8109 | 1.3949 | -2.0454 | 2.9994 |
| 2.0 | 1.75 | 0.2500 | 3.23 | 3.23 | 0.37 | 1.33 | 11.64 | 88.36 | 2.3335 | 1.2453 | -1.2034 | 1.1630 |
| 2.5 | 2.25 | 0.1788 | 6.23 | 6.23 | 3.00 | 10.81 | 22.45 | 77.55 | 24.3264 | 2.3517 | -1.0968 | 0.5115 |
| 3.0 | 2.75 | 0.1250 | 18.53 | 18.53 | 12.30 | 44.33 | 66.78 | 33.22 | 121.9022 | 0.0501 | 0.0017 | 0.0001 |
| 3.5 | 3.25 | 0.0884 | 23.34 | 23.34 | 4.81 | 17.33 | 84.12 | 15.88 | 56.3381 | 4.9360 | 2.6339 | 1.4055 |
| 4.0 | 3.75 | 0.0625 | 24.34 | 24.34 | 1.00 | 3.60 | 87.72 | 12.28 | 13.5147 | 3.8503 | 3.9797 | 4.1135 |
| 6.0 | 5.00 | 0.0156 | 24.43 | 27.75 | 3.41 | 12.28 | 100.00 | 0.00 | 61.4043 | 64.0435 | 146.2509 | 333.9810 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 7.2 | mean(phi) | 2.72 |
| % sand | 80.5 | mean(mm) | 0.15 |
| % silt-clay | 12.3 | sorting | 1.45 |
| % water | 10.7 | skewness | -1.17 |
| | | kurtosis | 5.20 |

| | | | |
|------------------|-------|---|--|
| salt weight | 0.11 | (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 3.32 concentration) | |
| dry sed weight | 27.75 | | |
| wt of water lost | 3.21 | | |
| dry sed | 27.86 | | |



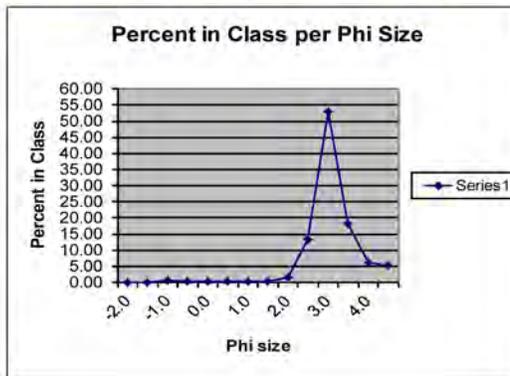
| T2-10 10-20 cm | | HL 0335 | | | | | | | | | | | | | |
|----------------|--|---------|------|------|------|------|-----|------|------|------|------|-------|-------|-------|-------|
| PHI | | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | | 1.35 | 1.73 | 2.05 | 2.3 | 2.55 | 2.83 | 3.41 | 6.96 | 20.59 | 24.45 | 25.46 | 25.54 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 25.34 |
| wet weight | 30.00 | Dry Wt. After sieving | 23.93 |
| dry weight | 25.34 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.15 | 0.15 | 0.15 | 0.60 | 0.60 | 99.40 | -0.7453 | 9.8285 | -39.9036 | 162.0087 |
| -0.5 | -0.75 | 1.4142 | 0.23 | 0.23 | 0.08 | 0.32 | 0.91 | 99.09 | -0.2385 | 4.0303 | -14.3477 | 51.0779 |
| 0.0 | -0.25 | 1.0000 | 0.31 | 0.31 | 0.08 | 0.32 | 1.23 | 98.77 | -0.0795 | 2.9777 | -9.1117 | 27.8817 |
| 0.5 | 0.25 | 0.7071 | 0.39 | 0.39 | 0.08 | 0.32 | 1.55 | 98.45 | 0.0795 | 2.0841 | -5.3352 | 13.6582 |
| 1.0 | 0.75 | 0.5000 | 0.47 | 0.47 | 0.08 | 0.32 | 1.87 | 98.13 | 0.2385 | 1.3495 | -2.7799 | 5.7267 |
| 1.5 | 1.25 | 0.3536 | 0.58 | 0.58 | 0.11 | 0.44 | 2.31 | 97.69 | 0.5466 | 1.0641 | -1.8600 | 2.5896 |
| 2.0 | 1.75 | 0.2500 | 0.96 | 0.96 | 0.38 | 1.51 | 3.82 | 96.18 | 2.6434 | 1.6972 | -1.7991 | 1.9070 |
| 2.5 | 2.25 | 0.1788 | 4.34 | 4.34 | 3.38 | 13.44 | 17.25 | 82.75 | 30.2303 | 4.2134 | -2.3595 | 1.3213 |
| 3.0 | 2.75 | 0.1250 | 17.66 | 17.66 | 13.32 | 52.95 | 70.20 | 29.80 | 145.6062 | 0.1906 | -0.0114 | 0.0007 |
| 3.5 | 3.25 | 0.0884 | 22.27 | 22.27 | 4.61 | 18.32 | 88.52 | 11.48 | 59.5562 | 3.5477 | 1.5610 | 0.6868 |
| 4.0 | 3.75 | 0.0625 | 23.81 | 23.81 | 1.54 | 6.12 | 94.65 | 5.35 | 22.9559 | 5.4090 | 5.0845 | 4.7794 |
| 6.0 | 5.00 | 0.0156 | 23.91 | 25.16 | 1.35 | 5.35 | 100.00 | 0.00 | 26.7700 | 25.6783 | 56.2355 | 123.1557 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 0.9 | mean(phi) | 2.81 |
| % sand | 92.6 | mean(mm) | 0.14 |
| % silt-clay | 6.5 | sorting | 0.90 |
| % water | 16.4 | skewness | -0.79 |
| | | kurtosis | 9.09 |

| | | | |
|------------------|-------|---|--|
| salt weight | 0.16 | (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 1.25 concentration) | |
| dry sed weight | 25.18 | | |
| wt of water lost | 4.66 | | |
| dry sed | 25.34 | | |



| | | | | | | | | | | | | | | | | | | | | |
|-----------------------|----|---------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|--|--|--|--|--|--|
| T2-10 20-30 cm | | HL 0334 | | | | | | | | | | | | | | | | | | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan | | | | | | |
| | | | 0.06 | 0.16 | 0.24 | 0.34 | 0.42 | 0.54 | 1.01 | 4.92 | 17.37 | 21.98 | 23.42 | 23.53 | | | | | | |

vessel weight 0.00
 wet weight 30.00
 dry weight 25.57

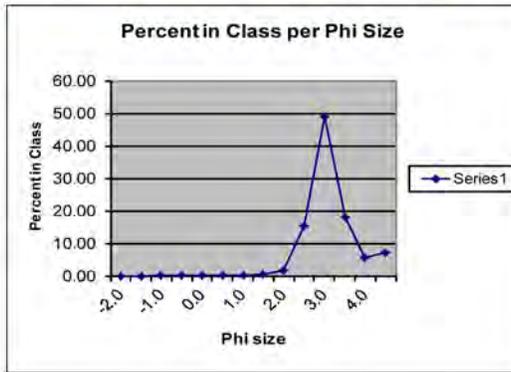
Dry Wt. Before wet sie 25.57
 Dry Wt. After sieving 23.65

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.06 | 0.06 | 0.06 | 0.24 | 0.24 | 99.76 | -0.297 | 4.110 | -17.111 | 71.231 |
| -0.5 | -0.75 | 1.4142 | 0.16 | 0.16 | 0.10 | 0.40 | 0.63 | 99.37 | -0.297 | 5.304 | -19.427 | 71.159 |
| 0.0 | -0.25 | 1.0000 | 0.24 | 0.24 | 0.08 | 0.32 | 0.95 | 99.05 | -0.079 | 3.164 | -10.006 | 31.649 |
| 0.5 | 0.25 | 0.7071 | 0.34 | 0.34 | 0.10 | 0.40 | 1.34 | 98.66 | 0.099 | 2.803 | -7.464 | 19.878 |
| 1.0 | 0.75 | 0.5000 | 0.42 | 0.42 | 0.08 | 0.32 | 1.66 | 98.34 | 0.237 | 1.479 | -3.200 | 6.921 |
| 1.5 | 1.25 | 0.3536 | 0.54 | 0.54 | 0.12 | 0.47 | 2.13 | 97.87 | 0.593 | 1.312 | -2.181 | 3.627 |
| 2.0 | 1.75 | 0.2500 | 1.01 | 1.01 | 0.47 | 1.86 | 3.99 | 96.01 | 3.252 | 2.512 | -2.922 | 3.397 |
| 2.5 | 2.25 | 0.1768 | 4.92 | 4.92 | 3.91 | 15.46 | 19.45 | 80.55 | 34.780 | 6.791 | -4.501 | 2.984 |
| 3.0 | 2.75 | 0.1250 | 17.37 | 17.37 | 12.45 | 49.22 | 68.67 | 31.33 | 135.353 | 1.305 | -0.212 | 0.035 |
| 3.5 | 3.25 | 0.0884 | 21.98 | 21.98 | 4.61 | 18.22 | 86.89 | 13.11 | 59.231 | 2.072 | 0.699 | 0.236 |
| 4.0 | 3.75 | 0.0625 | 23.42 | 23.42 | 1.44 | 5.69 | 92.59 | 7.41 | 21.348 | 3.990 | 3.340 | 2.796 |
| 6.0 | 5.00 | 0.0156 | 23.53 | 25.29 | 1.87 | 7.41 | 100.00 | 0.00 | 37.062 | 32.290 | 67.396 | 140.667 |

% gravel 0.2
 % sand 92.4
 % silt-clay 7.4
 % water 15.3

mean(phi) 2.91
 mean(mm) 0.13
 sorting 0.82
 skewness 0.08
 kurtosis 7.87

salt weight 0.16 (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 1.76 concentration)
 dry sed weight 25.41
 wt of water lost 4.43
 dry sed 25.57



| | | | | | | | | | | | | | | | | | | | | |
|-----------------------|----|---------|------|------|------|------|------|-----|------|------|-------|-------|-------|-------|--|--|--|--|--|--|
| T2-10 30-40 cm | | HL 0333 | | | | | | | | | | | | | | | | | | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan | | | | | | |
| | | | 0.18 | 0.32 | 0.44 | 0.52 | 0.59 | 0.7 | 1.05 | 4.02 | 17.84 | 22.53 | 23.91 | 24.02 | | | | | | |

vessel weight 0.00
 wet weight 30.00
 dry weight 24.90

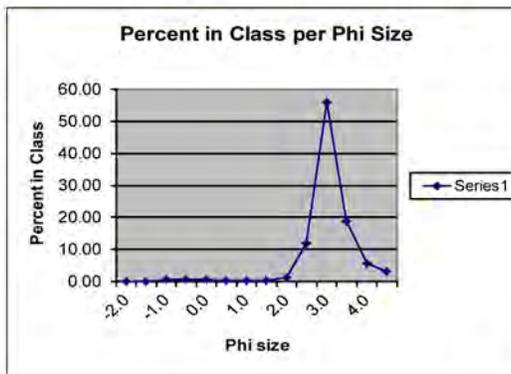
Dry Wt. Before wet sie 24.90
 Dry Wt. After sieving 24.05

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.18 | 0.18 | 0.18 | 0.73 | 0.73 | 99.27 | -0.9112 | 12.0385 | -48.9212 | 198.8020 |
| -0.5 | -0.75 | 1.4142 | 0.32 | 0.32 | 0.14 | 0.57 | 1.30 | 98.70 | -0.4252 | 7.2009 | -25.6621 | 91.4525 |
| 0.0 | -0.25 | 1.0000 | 0.44 | 0.44 | 0.12 | 0.49 | 1.78 | 98.22 | -0.1215 | 4.5618 | -13.9760 | 42.8184 |
| 0.5 | 0.25 | 0.7071 | 0.52 | 0.52 | 0.08 | 0.32 | 2.11 | 97.89 | 0.0810 | 2.1295 | -5.4595 | 13.9967 |
| 1.0 | 0.75 | 0.5000 | 0.59 | 0.59 | 0.07 | 0.28 | 2.39 | 97.61 | 0.2126 | 1.2074 | -2.4917 | 5.1423 |
| 1.5 | 1.25 | 0.3536 | 0.7 | 0.70 | 0.11 | 0.45 | 2.83 | 97.17 | 0.5569 | 1.0893 | -1.7034 | 2.6637 |
| 2.0 | 1.75 | 0.2500 | 1.05 | 1.05 | 0.35 | 1.42 | 4.25 | 95.75 | 2.4806 | 1.6039 | -1.7061 | 1.8148 |
| 2.5 | 2.25 | 0.1768 | 4.02 | 4.02 | 2.97 | 12.03 | 16.28 | 83.72 | 27.0640 | 3.8224 | -2.1548 | 1.2147 |
| 3.0 | 2.75 | 0.1250 | 17.84 | 17.84 | 13.82 | 55.97 | 72.25 | 27.75 | 153.9194 | 0.2273 | -0.0145 | 0.0009 |
| 3.5 | 3.25 | 0.0884 | 22.53 | 22.53 | 4.69 | 18.99 | 91.25 | 8.75 | 61.7318 | 3.6154 | 1.5773 | 0.6881 |
| 4.0 | 3.75 | 0.0625 | 23.91 | 23.91 | 1.38 | 5.59 | 96.83 | 3.17 | 20.9586 | 4.8994 | 4.5872 | 4.2949 |
| 6.0 | 5.00 | 0.0156 | 24.02 | 24.69 | 0.78 | 3.17 | 100.00 | 0.00 | 15.8253 | 15.1284 | 33.0749 | 72.3109 |

% gravel 0.7
 % sand 96.1
 % silt-clay 3.2
 % water 17.6

mean(phi) 2.81
 mean(mm) 0.14
 sorting 0.76
 skewness -1.44
 kurtosis 13.15

salt weight 0.18 (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 0.67 concentration)
 dry sed weight 24.72
 wt of water lost 5.10
 dry sed 24.90



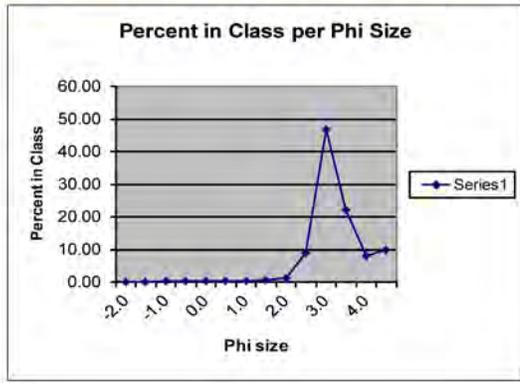
| | | | | | | | | | | | | | | |
|-----------------------|----|------|------|------|------|------|------|------|------|------|-------|-------|---------|-------|
| T2-10 40-50 cm | | | | | | | | | | | | | HL 0332 | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | 0.08 | 0.18 | 0.27 | 0.37 | 0.48 | 0.61 | 0.94 | 3.12 | 14.41 | 19.77 | 21.68 | 21.93 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 24.34 |
| wet weight | 30.00 | Dry Wt. After sieving | 22.04 |
| dry weight | 24.34 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.08 | 0.08 | 0.08 | 0.33 | 0.33 | 99.67 | -0.4161 | 6.1132 | -26.1970 | 112.2625 |
| -0.5 | -0.75 | 1.4142 | 0.18 | 0.18 | 0.10 | 0.42 | 0.75 | 99.25 | -0.3121 | 5.9623 | -22.5694 | 85.4323 |
| 0.0 | -0.25 | 1.0000 | 0.27 | 0.27 | 0.09 | 0.37 | 1.12 | 98.88 | -0.0936 | 4.0421 | -13.2797 | 43.6280 |
| 0.5 | 0.25 | 0.7071 | 0.37 | 0.37 | 0.10 | 0.42 | 1.54 | 98.46 | 0.1040 | 3.2282 | -8.9916 | 25.0445 |
| 1.0 | 0.75 | 0.5000 | 0.48 | 0.48 | 0.11 | 0.46 | 2.00 | 98.00 | 0.3433 | 2.3906 | -5.4632 | 12.4851 |
| 1.5 | 1.25 | 0.3536 | 0.61 | 0.61 | 0.13 | 0.54 | 2.54 | 97.46 | 0.6762 | 1.7242 | -3.0782 | 5.4957 |
| 2.0 | 1.75 | 0.2500 | 0.94 | 0.94 | 0.33 | 1.37 | 3.91 | 96.09 | 2.4031 | 2.2685 | -2.9158 | 3.7477 |
| 2.5 | 2.25 | 0.1768 | 3.12 | 3.12 | 2.18 | 9.07 | 12.98 | 87.02 | 20.4104 | 5.5945 | -4.3935 | 3.4503 |
| 3.0 | 2.75 | 0.1250 | 14.41 | 14.41 | 11.29 | 46.98 | 59.96 | 40.04 | 129.1929 | 3.8245 | -1.0912 | 0.3113 |
| 3.5 | 3.25 | 0.0884 | 19.77 | 19.77 | 5.36 | 22.30 | 82.27 | 17.73 | 72.4870 | 1.0279 | 0.2207 | 0.0474 |
| 4.0 | 3.75 | 0.0625 | 21.68 | 21.68 | 1.91 | 7.95 | 90.21 | 9.79 | 29.8041 | 4.0595 | 2.9012 | 2.0734 |
| 6.0 | 5.00 | 0.0156 | 21.93 | 24.03 | 2.35 | 9.79 | 100.00 | 0.00 | 48.9329 | 37.7759 | 74.2175 | 145.8137 |

| | | | |
|-------------|------|-----------|--------|
| % gravel | 0.3 | mean(phi) | 3.035 |
| % sand | 89.9 | mean(mm) | 0.122 |
| % silt-clay | 9.8 | sorting | 0.883 |
| % water | 19.5 | skewness | -0.154 |
| | | kurtosis | 7.227 |

| | | | |
|------------------|-------|---|--|
| salt weight | 0.20 | (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 2.10 concentration) | |
| dry sed weight | 24.14 | | |
| wt of water lost | 5.66 | | |
| dry sed | 24.34 | | |



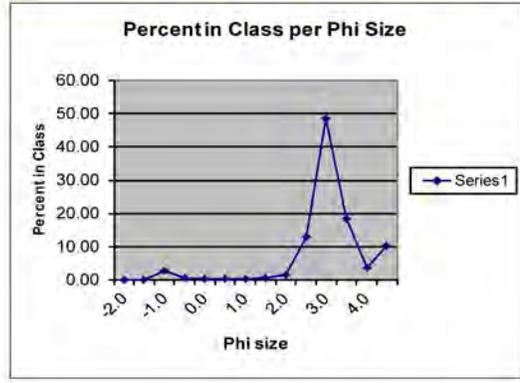
| | | | | | | | | | | | | | | |
|----------------------------|----|------|------|------|------|------|------|------|------|------|-------|-------|---------|-------|
| T2-20 Base to 10 cm | | | | | | | | | | | | | HL 0341 | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | 0.51 | 0.8 | 1.06 | 1.29 | 1.51 | 1.77 | 2.33 | 5.98 | 19.25 | 23.63 | 24.67 | 24.78 |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 28.28 |
| wet weight | 31.89 | Dry Wt. After sieving | 25.30 |
| dry weight | 28.28 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.76 | 0.76 | 0.76 | 2.70 | 2.70 | 97.30 | -3.3743 | 45.6994 | -188.0294 | 773.6445 |
| -0.5 | -0.75 | 1.4142 | 0.93 | 0.93 | 0.17 | 0.60 | 3.30 | 96.70 | -0.4529 | 7.8887 | -28.5137 | 103.0625 |
| 0.0 | -0.25 | 1.0000 | 1.06 | 1.06 | 0.13 | 0.46 | 3.77 | 96.23 | -0.1154 | 4.4790 | -13.9498 | 43.4465 |
| 0.5 | 0.25 | 0.7071 | 1.16 | 1.16 | 0.10 | 0.36 | 4.12 | 95.88 | 0.0888 | 2.4279 | -6.3478 | 16.5963 |
| 1.0 | 0.75 | 0.5000 | 1.27 | 1.27 | 0.11 | 0.39 | 4.51 | 95.49 | 0.2930 | 1.7469 | -3.6938 | 7.8105 |
| 1.5 | 1.25 | 0.3536 | 1.42 | 1.42 | 0.15 | 0.53 | 5.04 | 94.96 | 0.6660 | 1.3888 | -2.2421 | 3.6199 |
| 2.0 | 1.75 | 0.2500 | 1.81 | 1.81 | 0.39 | 1.39 | 6.43 | 93.57 | 2.4242 | 1.7206 | -1.9176 | 2.1371 |
| 2.5 | 2.25 | 0.1768 | 5.45 | 5.45 | 3.64 | 12.93 | 19.36 | 80.64 | 29.0904 | 4.8819 | -2.9999 | 1.8434 |
| 3.0 | 2.75 | 0.1250 | 19.08 | 19.08 | 13.63 | 48.41 | 67.77 | 32.23 | 133.1355 | 0.6346 | -0.0726 | 0.0083 |
| 3.5 | 3.25 | 0.0884 | 24.23 | 24.23 | 5.15 | 18.29 | 86.06 | 13.94 | 59.4506 | 2.7186 | 1.0481 | 0.4040 |
| 4.0 | 3.75 | 0.0625 | 25.23 | 25.23 | 1.00 | 3.55 | 89.62 | 10.38 | 13.3198 | 2.7852 | 2.4663 | 2.1840 |
| 6.0 | 5.00 | 0.0156 | 25.3 | 28.15 | 2.92 | 10.38 | 100.00 | 0.00 | 51.9231 | 47.3582 | 101.1341 | 215.9733 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 2.7 | mean(phi) | 2.86 |
| % sand | 86.9 | mean(mm) | 0.14 |
| % silt-clay | 10.4 | sorting | 1.11 |
| % water | 11.7 | skewness | -1.04 |
| | | kurtosis | 7.65 |

| | | | |
|------------------|-------|---|--|
| salt weight | 0.13 | (This worksheet assumes salt water and 3.5% wt. Loss of wt siev 2.85 concentration) | |
| dry sed weight | 28.15 | | |
| wt of water lost | 3.61 | | |
| dry sed | 28.28 | | |



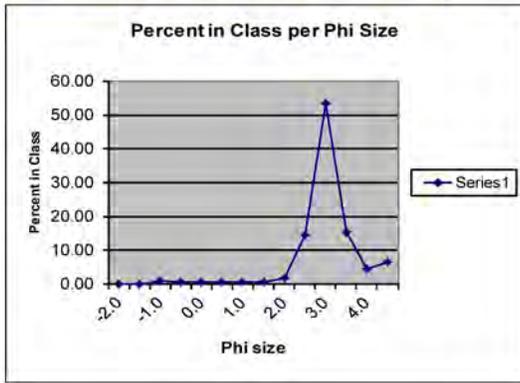
| T2-20 10-20 cm | | HL 0340 | | | | | | | | | | | | |
|----------------|----|---------|------|------|------|-----|------|------|------|-----|-------|-------|-------|-------|
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | 0.23 | 0.39 | 0.56 | 0.7 | 0.83 | 0.98 | 1.43 | 5.1 | 18.47 | 22.35 | 23.45 | 23.53 |

| | | | |
|---------------|-------|-------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet siev | 25.25 |
| wet weight | 30.00 | Dry Wt. After sieving | 23.54 |
| dry weight | 25.25 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.23 | 0.23 | 0.23 | 0.92 | 0.92 | 99.08 | -1.1466 | 15.1438 | -61.5315 | 250.0118 |
| -0.5 | -0.75 | 1.4142 | 0.39 | 0.39 | 0.16 | 0.64 | 1.56 | 98.44 | -0.4786 | 8.1016 | -28.8671 | 102.8579 |
| 0.0 | -0.25 | 1.0000 | 0.56 | 0.56 | 0.17 | 0.68 | 2.23 | 97.77 | -0.1695 | 6.3616 | -19.4865 | 59.6902 |
| 0.5 | 0.25 | 0.7071 | 0.7 | 0.70 | 0.14 | 0.56 | 2.79 | 97.21 | 0.1396 | 3.6682 | -9.4022 | 24.0994 |
| 1.0 | 0.75 | 0.5000 | 0.83 | 0.83 | 0.13 | 0.52 | 3.31 | 96.69 | 0.3889 | 2.2069 | -4.5532 | 9.3940 |
| 1.5 | 1.25 | 0.3536 | 0.98 | 0.98 | 0.15 | 0.60 | 3.91 | 96.09 | 0.7478 | 1.4618 | -2.2849 | 3.5717 |
| 2.0 | 1.75 | 0.2500 | 1.43 | 1.43 | 0.45 | 1.79 | 5.70 | 94.30 | 3.1407 | 2.0285 | -2.1566 | 2.2928 |
| 2.5 | 2.25 | 0.1768 | 5.1 | 5.10 | 3.67 | 14.64 | 20.34 | 79.66 | 32.9328 | 4.6419 | -2.6141 | 1.4721 |
| 3.0 | 2.75 | 0.1250 | 18.47 | 18.47 | 13.37 | 53.32 | 73.66 | 26.34 | 146.6374 | 0.2127 | -0.0134 | 0.0008 |
| 3.5 | 3.25 | 0.0884 | 22.35 | 22.35 | 3.88 | 15.47 | 89.14 | 10.86 | 50.2916 | 2.9531 | 1.2900 | 0.5636 |
| 4.0 | 3.75 | 0.0625 | 23.45 | 23.45 | 1.10 | 4.39 | 93.52 | 6.48 | 16.4515 | 3.8505 | 3.6073 | 3.3795 |
| 6.0 | 5.00 | 0.0156 | 23.53 | 25.07 | 1.62 | 6.48 | 100.00 | 0.00 | 32.3795 | 30.9697 | 67.7261 | 148.1088 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 0.9 | mean(phi) | 2.81 |
| % sand | 92.6 | mean(mm) | 0.14 |
| % silt-clay | 6.5 | sorting | 0.90 |
| % water | 16.4 | skewness | -0.79 |
| | | kurtosis | 9.09 |

| | | | |
|---------------------|-------|---|--|
| salt weight | 0.17 | (This worksheet assumes salt water and 3.5% 1.54 concentration) | |
| wt. Loss of wt siev | 1.54 | | |
| dry sed weight | 25.08 | | |
| wt of water lost | 4.75 | | |
| dry sed | 25.25 | | |



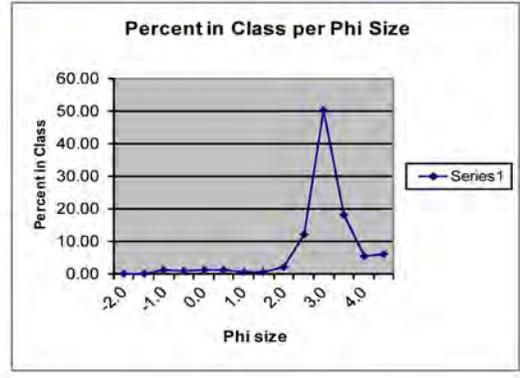
| T2-20 20-30 cm | | HL 0339 | | | | | | | | | | | | |
|----------------|----|---------|------|------|------|-----|------|------|------|------|-------|-------|-------|-------|
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 pan | |
| | | | 1.35 | 1.73 | 2.05 | 2.3 | 2.55 | 2.83 | 3.41 | 6.96 | 20.59 | 24.45 | 25.46 | 25.54 |

| | | | |
|---------------|-------|-------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet siev | 25.78 |
| wet weight | 30.00 | Dry Wt. After sieving | 24.09 |
| dry weight | 25.78 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | f'm | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.28 | 0.28 | 0.28 | 1.09 | 1.09 | 98.91 | -1.3655 | 17.7501 | -71.5511 | 288.4239 |
| -0.5 | -0.75 | 1.4142 | 0.55 | 0.55 | 0.27 | 1.05 | 2.15 | 97.85 | -0.7900 | 13.1334 | -46.3743 | 163.7488 |
| 0.0 | -0.25 | 1.0000 | 0.84 | 0.84 | 0.29 | 1.13 | 3.28 | 96.72 | -0.2828 | 10.3941 | -31.5049 | 95.4920 |
| 0.5 | 0.25 | 0.7071 | 1.12 | 1.12 | 0.28 | 1.09 | 4.37 | 95.63 | 0.2731 | 6.9978 | -17.7116 | 44.8285 |
| 1.0 | 0.75 | 0.5000 | 1.3 | 1.30 | 0.18 | 0.70 | 5.07 | 94.93 | 0.5267 | 2.8968 | -5.8834 | 11.9493 |
| 1.5 | 1.25 | 0.3536 | 1.48 | 1.48 | 0.18 | 0.70 | 5.77 | 94.23 | 0.8778 | 1.6461 | -2.5202 | 3.8584 |
| 2.0 | 1.75 | 0.2500 | 2 | 2.00 | 0.52 | 2.03 | 7.80 | 92.20 | 3.5502 | 2.1565 | -2.2234 | 2.2924 |
| 2.5 | 2.25 | 0.1768 | 5.14 | 5.14 | 3.14 | 12.25 | 20.05 | 79.95 | 27.5629 | 3.4544 | -1.8343 | 0.9741 |
| 3.0 | 2.75 | 0.1250 | 18.05 | 18.05 | 12.91 | 50.37 | 70.42 | 29.58 | 138.5069 | 0.0485 | -0.0015 | 0.0000 |
| 3.5 | 3.25 | 0.0884 | 22.72 | 22.72 | 4.67 | 18.22 | 88.64 | 11.36 | 59.2124 | 4.0071 | 1.8793 | 0.8813 |
| 4.0 | 3.75 | 0.0625 | 24.11 | 24.11 | 1.39 | 5.42 | 94.06 | 5.94 | 20.3357 | 5.0916 | 4.9337 | 4.7806 |
| 6.0 | 5.00 | 0.0156 | 24.09 | 25.63 | 1.52 | 5.94 | 100.00 | 0.00 | 29.6950 | 29.2428 | 64.8891 | 143.9874 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 1.1 | mean(phi) | 2.78 |
| % sand | 93.0 | mean(mm) | 0.15 |
| % silt-clay | 5.9 | sorting | 0.98 |
| % water | 14.6 | skewness | -1.13 |
| | | kurtosis | 8.12 |

| | | | |
|---------------------|-------|---|--|
| salt weight | 0.15 | (This worksheet assumes salt water and 3.5% 1.54 concentration) | |
| wt. Loss of wt siev | 1.54 | | |
| dry sed weight | 25.63 | | |
| wt of water lost | 4.22 | | |
| dry sed | 25.78 | | |



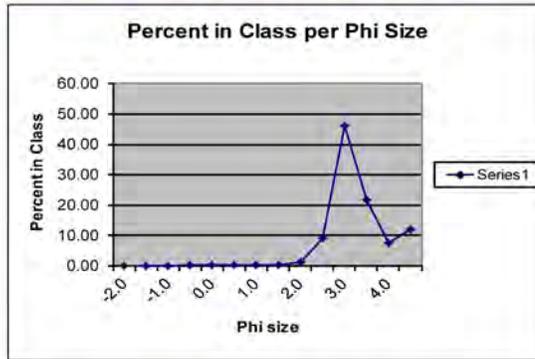
| | | | | | | | | | | | | | | | | | | |
|-----------------------|----|---------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|--|--|--|--|
| T2-20 30-40 cm | | HL 0338 | | | | | | | | | | | | | | | | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan | | | | |
| | | | 0.04 | 0.15 | 0.22 | 0.27 | 0.35 | 0.44 | 0.75 | 3.18 | 15.32 | 21.06 | 23.01 | 23.43 | | | | |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 26.33 |
| wet weight | 30.00 | Dry Wt. After sieving | 23.43 |
| dry weight | 26.33 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | F _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.04 | 0.04 | 0.04 | 0.15 | 0.15 | 99.85 | -0.1908 | 2.8954 | -12.6093 | 54.9132 |
| -0.5 | -0.75 | 1.4142 | 0.15 | 0.15 | 0.11 | 0.42 | 0.57 | 99.43 | -0.3149 | 6.2389 | -24.0509 | 92.7158 |
| 0.0 | -0.25 | 1.0000 | 0.22 | 0.22 | 0.07 | 0.27 | 0.84 | 99.16 | -0.0668 | 3.0071 | -10.0888 | 33.8478 |
| 0.5 | 0.25 | 0.7071 | 0.27 | 0.27 | 0.05 | 0.19 | 1.03 | 98.97 | 0.0477 | 1.5554 | -4.4407 | 12.6781 |
| 1.0 | 0.75 | 0.5000 | 0.35 | 0.35 | 0.08 | 0.31 | 1.34 | 98.66 | 0.2290 | 1.6933 | -3.9877 | 9.3910 |
| 1.5 | 1.25 | 0.3536 | 0.44 | 0.44 | 0.09 | 0.34 | 1.68 | 98.32 | 0.4294 | 1.1819 | -2.1925 | 4.0670 |
| 2.0 | 1.75 | 0.2500 | 0.75 | 0.75 | 0.31 | 1.18 | 2.86 | 97.14 | 2.0705 | 2.1722 | -2.9433 | 3.9881 |
| 2.5 | 2.25 | 0.1768 | 3.18 | 3.18 | 2.43 | 9.27 | 12.14 | 87.86 | 20.8671 | 6.7794 | -5.7962 | 4.9556 |
| 3.0 | 2.75 | 0.1250 | 15.32 | 15.32 | 12.14 | 46.33 | 58.47 | 41.53 | 127.4161 | 5.8384 | -2.0725 | 0.7357 |
| 3.5 | 3.25 | 0.0884 | 21.06 | 21.06 | 5.74 | 21.91 | 80.38 | 19.62 | 71.1981 | 0.4807 | 0.0668 | 0.0097 |
| 4.0 | 3.75 | 0.0625 | 23.01 | 23.01 | 1.95 | 7.44 | 87.62 | 12.15 | 27.9087 | 3.0964 | 1.9972 | 1.2883 |
| 6.0 | 5.00 | 0.0156 | 23.43 | 26.20 | 3.19 | 12.18 | 100.00 | 0.00 | 60.9038 | 43.7424 | 82.8929 | 157.0837 |

| | | | |
|-------------|------|-----------|------|
| % gravel | 0.2 | mean(phi) | 3.10 |
| % sand | 87.7 | mean(mm) | 0.12 |
| % silt-clay | 12.2 | sorting | 0.89 |
| % water | 12.7 | skewness | 0.24 |
| | | kurtosis | 6.07 |

| | | |
|---------------------|-------|--|
| salt weight | 0.13 | (This worksheet assumes salt water and 3.5% concentration) |
| wt. Loss of wt siev | 2.77 | |
| dry sed weight | 26.20 | |
| wt of water lost | 3.67 | |
| dry sed | 26.33 | |



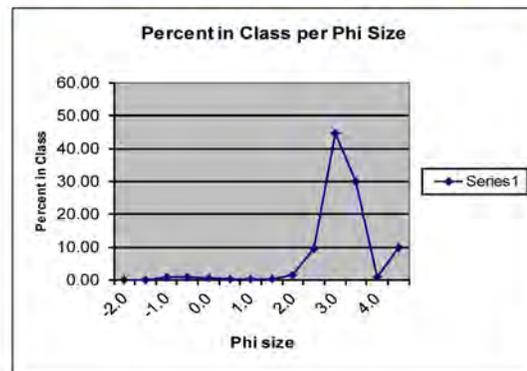
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|-----------------------|----|---------|------|------|-----|------|------|------|------|------|-------|-------|-------|-------|--|--|--|--|
| T2-20 40-45 cm | | HL 0337 | | | | | | | | | | | | | | | | |
| PHI | -2 | -1.5 | -1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | pan | | | | |
| | | | 0.25 | 0.46 | 0.6 | 0.69 | 0.76 | 0.87 | 1.24 | 3.62 | 14.84 | 22.37 | 22.57 | 22.84 | | | | |

| | | | |
|---------------|-------|------------------------|-------|
| vessel weight | 0.00 | Dry Wt. Before wet sie | 25.25 |
| wet weight | 30.00 | Dry Wt. After sieving | 22.84 |
| dry weight | 25.25 | | |

| Size (φ) | Class midpoint | Size (mm) | Cumulative Weight + Vessel | Cumulative Weight | Weight in Class | % in class | % larger | % smaller | F _m | f(m-mean) ² | f(m-mean) ³ | f(m-mean) ⁴ |
|----------|----------------|-----------|----------------------------|-------------------|-----------------|------------|----------|-----------|----------------|------------------------|------------------------|------------------------|
| -2.0 | -2.25 | 4.0000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.5 | -1.75 | 2.8284 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0 | 0 | 0 | 0 |
| -1.0 | -1.25 | 2.0000 | 0.25 | 0.25 | 0.25 | 1.00 | 1.00 | 99.00 | -1.2458 | 17.7012 | -74.5985 | 314.3818 |
| -0.5 | -0.75 | 1.4142 | 0.46 | 0.46 | 0.21 | 0.84 | 1.83 | 98.17 | -0.6279 | 11.5501 | -42.9007 | 159.3470 |
| 0.0 | -0.25 | 1.0000 | 0.6 | 0.60 | 0.14 | 0.56 | 2.39 | 97.61 | -0.1395 | 5.7665 | -18.5354 | 59.5788 |
| 0.5 | 0.25 | 0.7071 | 0.69 | 0.69 | 0.09 | 0.36 | 2.75 | 97.25 | 0.0897 | 2.6435 | -7.1752 | 19.4757 |
| 1.0 | 0.75 | 0.5000 | 0.76 | 0.76 | 0.07 | 0.28 | 3.03 | 96.97 | 0.2093 | 1.3683 | -3.0299 | 6.7091 |
| 1.5 | 1.25 | 0.3536 | 0.87 | 0.87 | 0.11 | 0.44 | 3.47 | 96.53 | 0.5482 | 1.2888 | -2.2094 | 3.7876 |
| 2.0 | 1.75 | 0.2500 | 1.24 | 1.24 | 0.37 | 1.48 | 4.94 | 95.06 | 2.5814 | 2.1751 | -2.6412 | 3.2073 |
| 2.5 | 2.25 | 0.1768 | 3.62 | 3.62 | 2.38 | 9.49 | 14.43 | 85.57 | 21.3485 | 4.8414 | -3.4583 | 2.4703 |
| 3.0 | 2.75 | 0.1250 | 14.84 | 14.84 | 11.22 | 44.73 | 59.16 | 40.84 | 123.0079 | 2.0546 | -0.4403 | 0.0944 |
| 3.5 | 3.25 | 0.0884 | 22.37 | 22.37 | 7.53 | 30.02 | 89.18 | 10.82 | 97.5632 | 2.4500 | 0.6999 | 0.2000 |
| 4.0 | 3.75 | 0.0625 | 22.57 | 22.57 | 0.20 | 0.80 | 89.98 | 10.02 | 2.9900 | 0.4922 | 0.3867 | 0.3038 |
| 6.0 | 5.00 | 0.0156 | 22.84 | 25.08 | 2.51 | 10.02 | 100.00 | 0.00 | 50.1071 | 41.5287 | 84.5393 | 172.0949 |

| | | | |
|-------------|------|-----------|-------|
| % gravel | 1.0 | mean(phi) | 2.96 |
| % sand | 89.0 | mean(mm) | 0.13 |
| % silt-clay | 10.0 | sorting | 0.97 |
| % water | 16.4 | skewness | -0.76 |
| | | kurtosis | 8.42 |

| | | |
|---------------------|-------|--|
| salt weight | 0.17 | (This worksheet assumes salt water and 3.5% concentration) |
| wt. Loss of wt siev | 2.24 | |
| dry sed weight | 25.08 | |
| wt of water lost | 4.75 | |
| dry sed | 25.25 | |

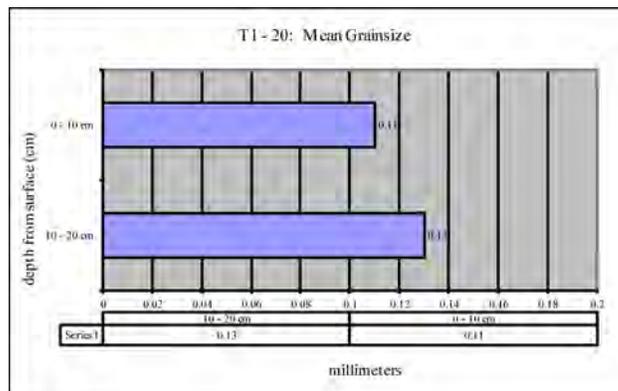
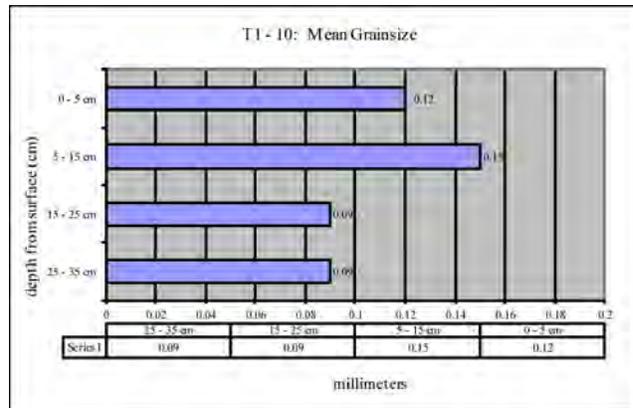
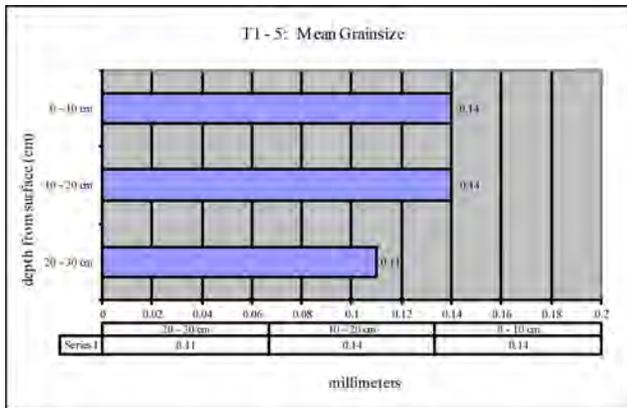
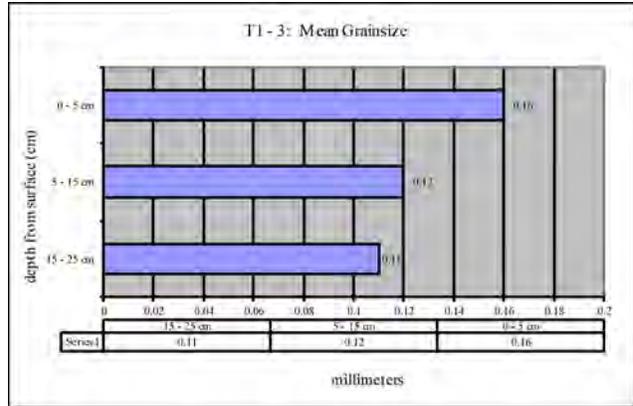
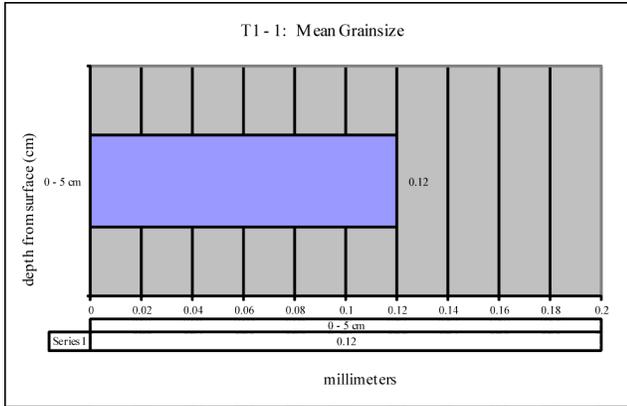


APPENDIX I

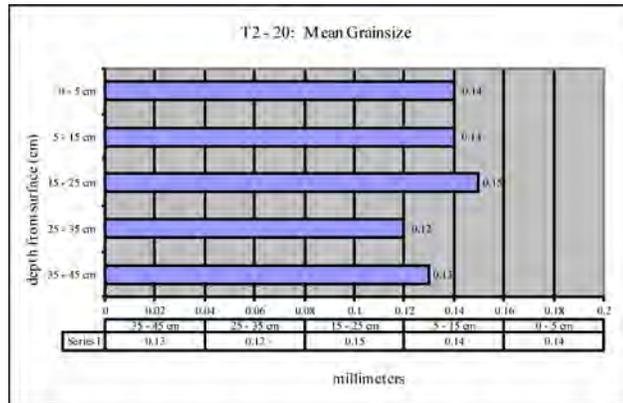
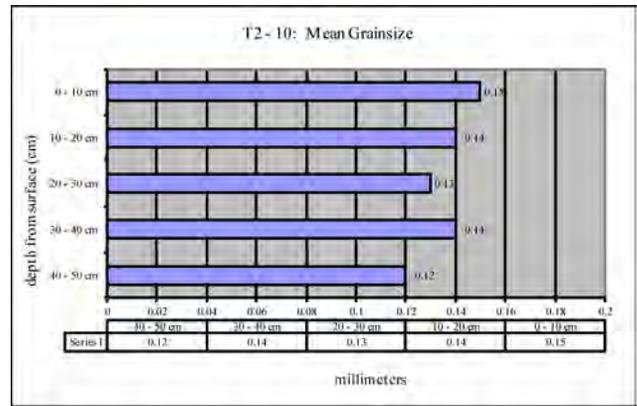
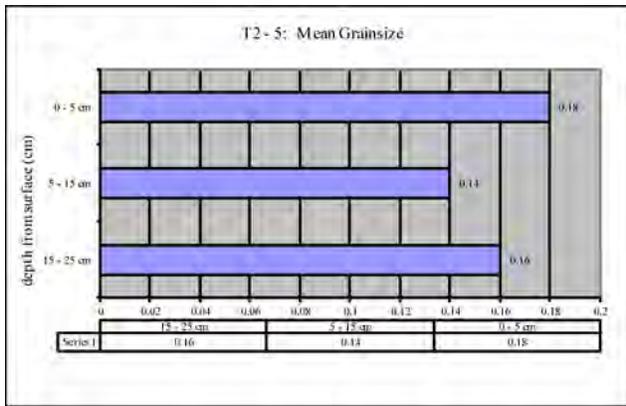
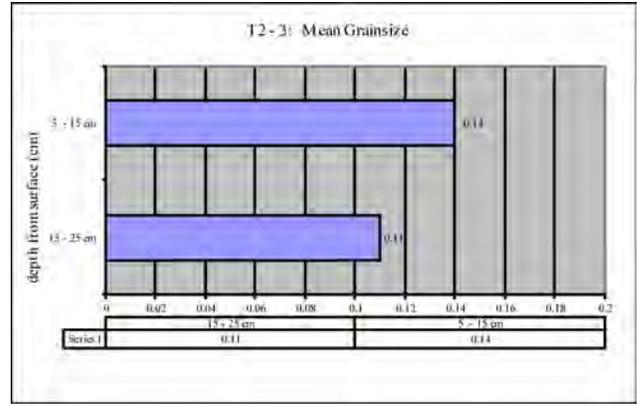
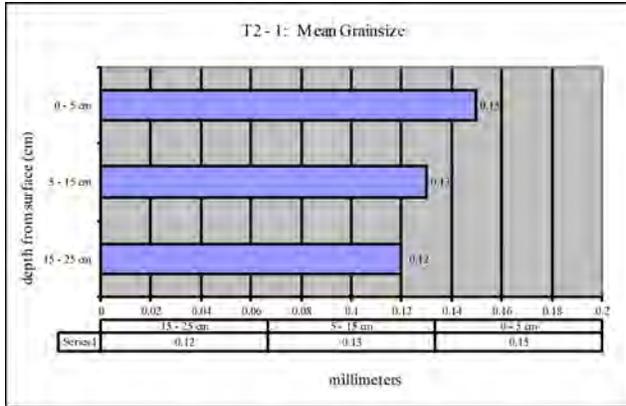
**Trends for Mean Grain Size,
Standard Deviation, and
Skewness
of Sediment Samples Taken
at the *H. L. Hunley* Site**

Mean Grain Size Plots (mm)

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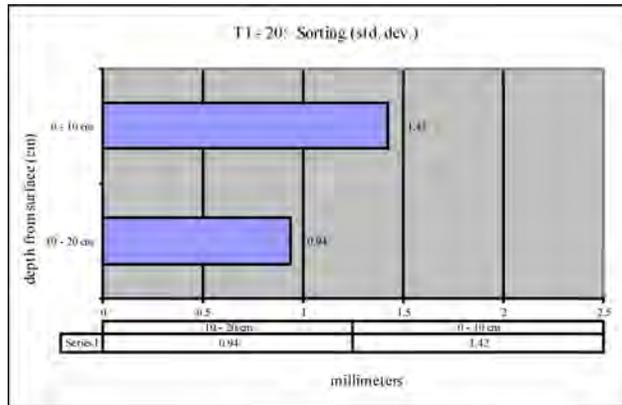
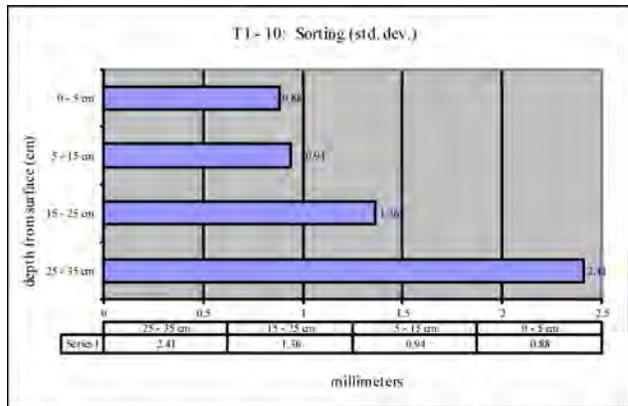
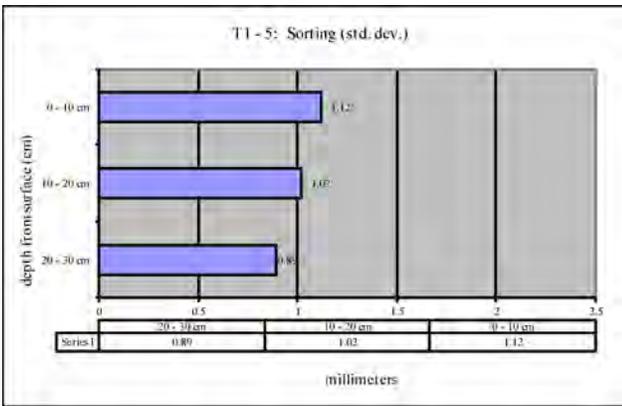
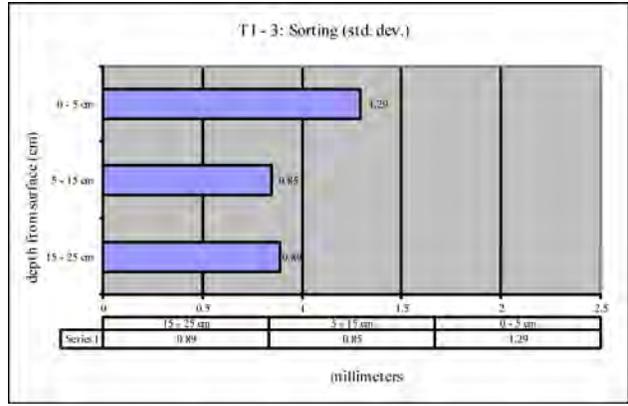
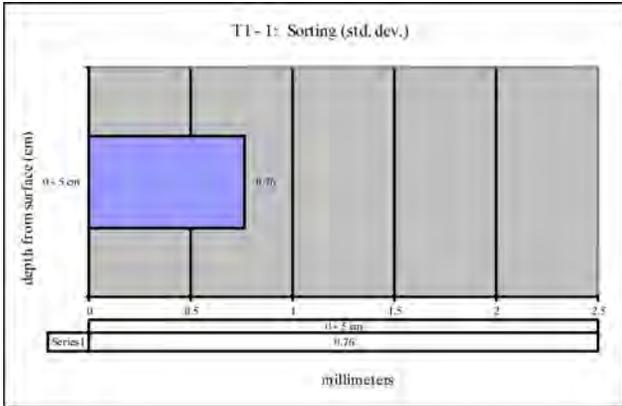


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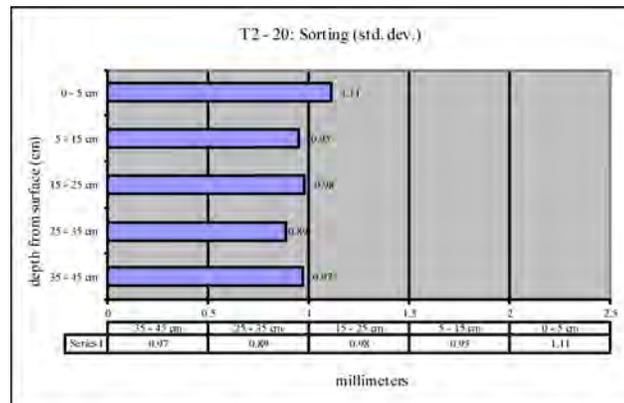
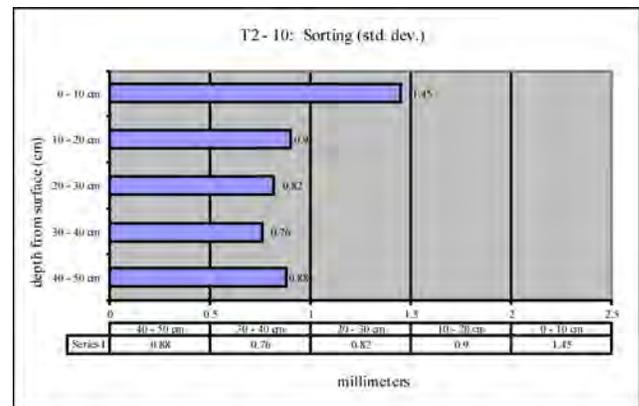
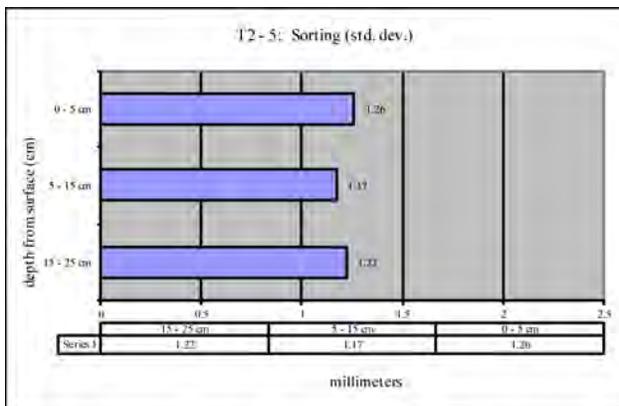
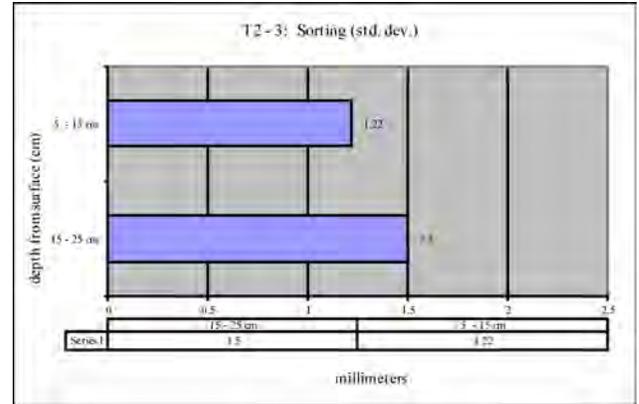
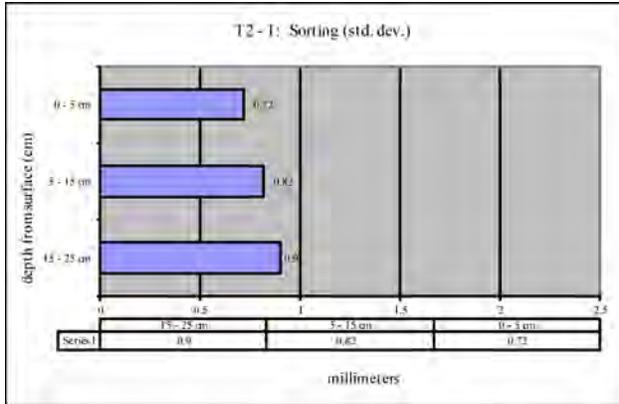


Standard Deviation (Sorting) Plots

TRANSECT 1

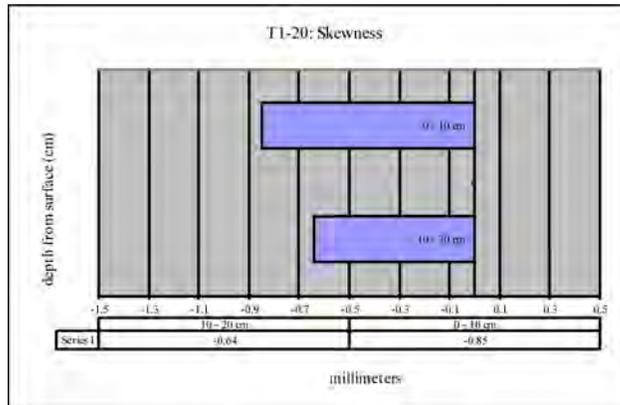
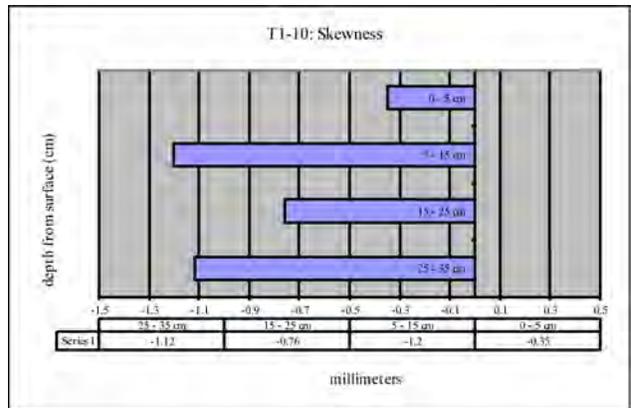
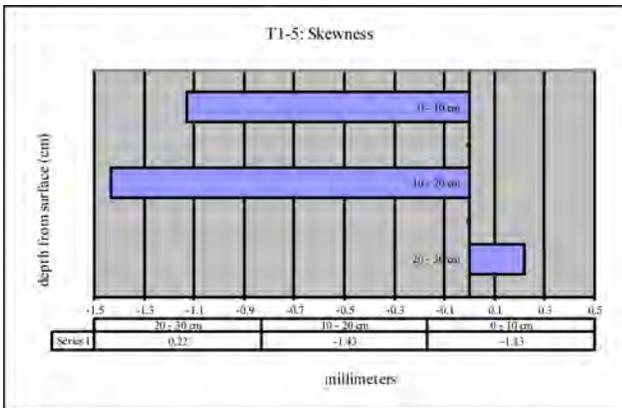
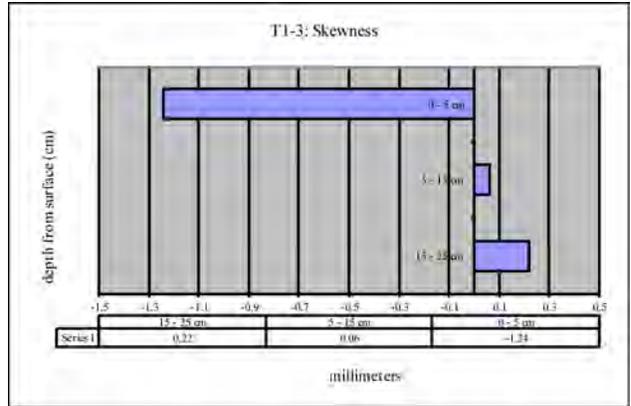
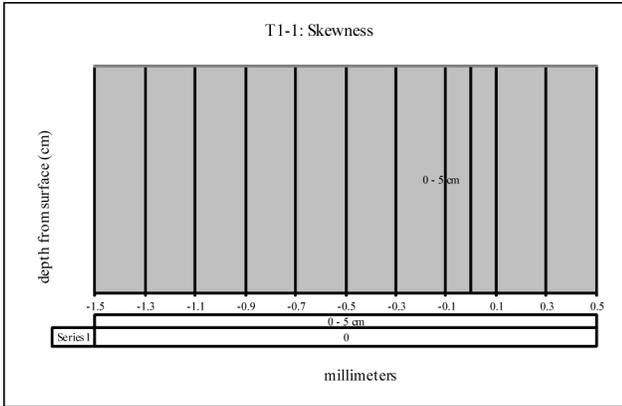


TRANSECT 2

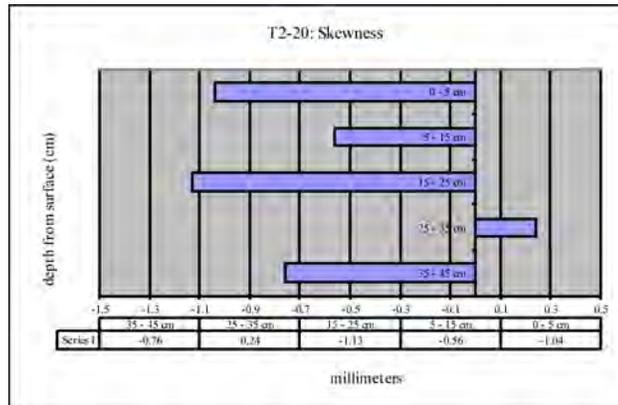
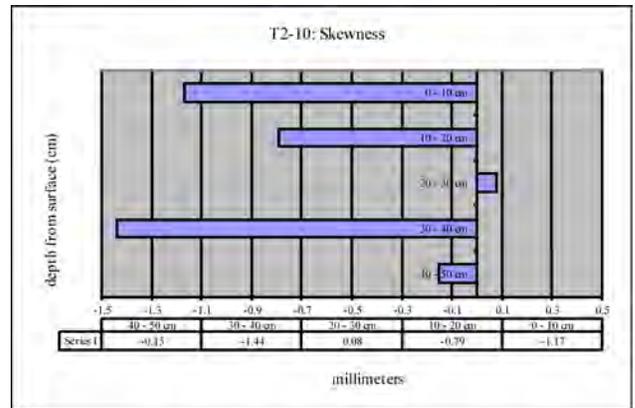
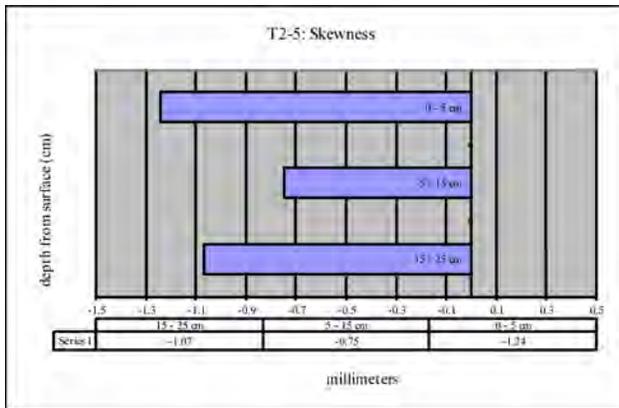
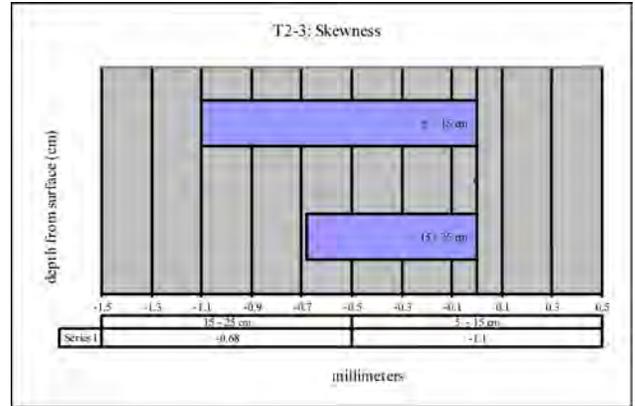
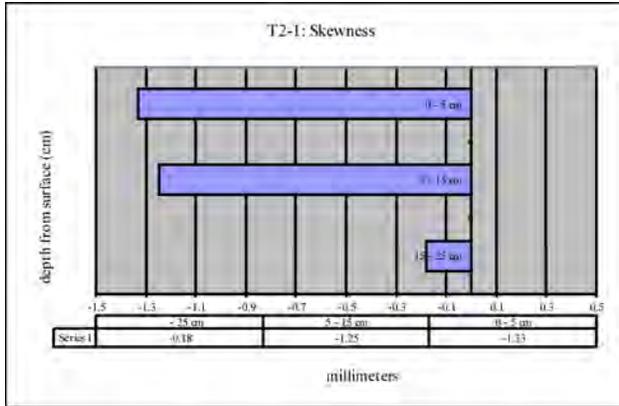


Skewness Plots

TRANSECT 1



TRANSECT 2



APPENDIX J

Benthic Infaunal Samples Identified from Cores Taken at the *H. L. Hunley* Site

Transect 1

| Phylum/Class/ Sub-classification | T1-0M-A | T1-0M-B | T1-1M-A | T1-1M-B | T1-3M-A | T1-3M-B | T1-5M-A | T1-5M-B | T1-10M-A | T1-10M-B | T1-20M-A | T1-20M-B |
|-------------------------------------|---------|---------|---------|---------|---------|---------|---------|---------|----------|----------|----------|----------|
| ANNELIDA | | | | | | | | | | | | |
| POLYCHAETES | | | | | | | | | | | | |
| <i>Amphicteis gunneri</i> | 8 | | 1 | | 8 | 2 | | | 5 | 6 | 1 | |
| <i>Magelon sp.</i> | 1 | | 1 | 4 | | 2 | | 3 | 2 | 4 | 3 | 3 |
| <i>Mediomastus sp.</i> | 20 | 6 | 6 | 9 | 8 | 12 | | 1 | | 1 | | |
| <i>Mediomastus ambiseta</i> | 1 | 1 | 2 | | | | | | | | | |
| <i>Leitoscoloplos fragilis</i> | 1 | 1 | | 1 | | | | | | | | |
| <i>Aglaophamus verrilli</i> | | 1 | 1 | 1 | | 1 | | 1 | | | 1 | 1 |
| <i>Aricidae suecica</i> | | | | | | | | | | 2 | | 1 |
| <i>Sigambra tentaculata</i> | | | | | | | 1 | | | | | |
| <i>Ophelina cylindricaudata</i> | | | | | | | | | | | 1 | |
| <i>Glycera sp.</i> | | | | 1 | | | | | | | | |
| <i>Spionidae</i> | | | | | | 1 | | | | 1 | | |
| <i>Spiophanes bombyx</i> | 1 | 3 | 2 | | 1 | 3 | 12 | 21 | 8 | 7 | 46 | 4 |
| <i>Paraprionospio pinnata</i> | | | | 1 | | | | | | | | |
| <i>Cirratulidae</i> | | 1 | 1 | | | | | | | 1 | | |
| ENCHINODERMA | | | | | | | | | | | | |
| OPHIUROIDEA | | | | | | | | | 1 | | | |
| PLATYHELMINTHES | | | | 1 | | | | | | | | |
| NEMERTEA | | | | 1 | | | | | | | | |
| ARTHROPODA | | | | | | | | | | | | |
| MALACOSTRACA | | | | | | | | | | | | |
| AMPHIPODA | | | | | | | | | | | | |
| <i>Synchelidium americanum</i> | | 2 | | | | | | | | | | 1 |
| <i>Listriella barnardi</i> | 1 | 1 | | | | | | | | | | |
| <i>Rhepoxynius hudsoni</i> | | | | | | | | 2 | | 3 | | |
| <i>Gammaropsis</i> | | | | | | | | | | | 9 | |
| <i>Corophium</i> | | | | | | | | | 1 | | | |
| <i>Corophium simile</i> | | | | | | | | | | | 1 | |
| <i>Batea catharinensis</i> | | | | | | | | | | 2 | 3 | |
| ISOPODA | | | | | | | | | | | | |
| <i>Edotea triloba</i> | | 1 | | | | | | | 1 | 4 | | 1 |
| CUMACEA | | | 2 | | | | | | | 2 | | |
| <i>Oxyurostylis smithi</i> | 6 | 2 | 3 | 1 | 4 | | 2 | 7 | 7 | | 7 | |
| <i>Leucon americanus</i> | 1 | 1 | | 5 | 4 | | | | | | | |
| MOLLUSCA | | | | | | | | | | | | |
| BIVALVIA | | | | | | | | | | | | |
| <i>Abra aequalis</i> | 2 | | 1 | | | | | | | | 2 | |
| <i>Macoma tenta</i> | | | | | | | 1 | | 2 | 1 | 2 | |
| <i>Solenidae</i> | | | | | | | | 2 | 1 | 1 | | 2 |
| GASTROPODA | | | | | | | | | | | | |
| <i>Polinices lacteus</i> | | | | | | | | | 1 | | | |
| <i>Callianassa bifformis</i> | | | | | | | | | | | | 1 |
| | 42 | 20 | 20 | 25 | 25 | 21 | 16 | 37 | 29 | 35 | 76 | 14 |

Transect 2

| Phylum/Class/ Sub-classification | T2-0M-A | T2-0M-B | T2-1M-A | T2-1M-B | T2-3M-A | T2-3M-B | T2-5M-A | T2-5M-B | T2-10M-A | T2-10M-B | T2-20M-A | T2-20M-B |
|-------------------------------------|---------|---------|---------|---------|---------|---------|---------|---------|----------|----------|----------|----------|
| ANNELIDA | | | | | | | | | | | | |
| POLYCHAETES | | | | | | | | | | | | |
| <i>Amphiteis gunneri</i> | | 1 | 1 | | 2 | | | 4 | 1 | 1 | 1 | |
| <i>Magelon sp.</i> | 4 | 1 | 6 | 2 | 3 | 1 | 3 | 3 | 2 | 2 | 3 | 5 |
| <i>Mediomastus sp.</i> | 2 | 1 | 1 | | | 1 | 2 | | 2 | 1 | 1 | 2 |
| <i>Aglaophamus verrilli</i> | | | | | | | | | 1 | | | 2 |
| <i>Sigambra tentaculata</i> | | | | | | | | | | | 1 | |
| <i>Arabella mutenas</i> | | 1 | | | | 1 | | | | | | |
| <i>Phyllodoce arenae</i> | | | | | | | | | | 1 | | |
| <i>Clymenella torquata</i> | | | | | | 1 | | | | | | |
| <i>Spiochaetopterus costarum</i> | | | | | | 1 | | | | | | |
| <i>Glycera sp.</i> | | | | | | 1 | 1 | | | | 1 | |
| <i>Spionidae</i> | | | | | | | | | | | 1 | |
| <i>Spiophanes bombyx</i> | 48 | 6 | 54 | 49 | 5 | 57 | 28 | | 11 | 7 | 17 | 32 |
| <i>Cirratulidae</i> | | | 1 | 1 | | | 1 | | | 2 | 1 | 2 |
| <i>Tharyx acutus</i> | | | 1 | | | | | | | | | |
| PLATYHELMINTHES | | | 1 | 4 | | | 1 | | | | | |
| NEMERTEAN | | | | | | | | | | | 1 | |
| ARTHROPODA | | | | | | | | | | | | |
| MALACOSTRACA | | | | | | | | | | | | |
| AMPHIPODA | | | | | | | | | | | | |
| <i>Synchelidium americanum</i> | 2 | | | | | 2 | | | | | | |
| <i>Listriella barnardi</i> | | | | | | | 1 | | | | | |
| <i>Gammaridea</i> | | | | | | | | 1 | | | | |
| <i>Rhepoxynius hudsoni</i> | | | 1 | | | | | | 1 | | | |
| CUMACEA | | | | | | | | | | | | |
| <i>Oxyurostylis smithi</i> | 3 | 1 | | | | 3 | | 1 | 3 | 1 | 2 | 2 |
| <i>Leucon americanus</i> | | | | | | | | 1 | | | | |
| ISOPODA | | | | | | | | | | | | |
| <i>Edotea triloba</i> | 1 | | | | | | | | | | | |
| MOLLUSCA | | | | | | | | | | | | |
| BIVALVIA | | | | | | | | | | | | |
| <i>Solenidae</i> | | 2 | 1 | 1 | | | | | | | 2 | 1 |
| GASTROPODA | | | | | | | | | | | | |
| <i>Terebra dislocata</i> | | | | 1 | | | | | | | | |
| | 60 | 13 | 67 | 58 | 10 | 68 | 37 | 10 | 21 | 15 | 31 | 46 |

APPENDIX K

Profiling of Iron-Reducing Microbial Populations Associated with the *H. L. Hunley* by Denaturing Gel Electrophoresis Analysis of Polymerase Chain Reaction-Amplified Genes Coding for 16S rDNA

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Department of Biology
Grice Marine Laboratory
College of Charleston, S.C.
Charleston, South Carolina 29412
Monday, August 13th, 2001

ABSTRACT

Anaerobic goethite media enriched with sediments associated with the sunken confederate submersible, the *H. L. Hunley*, was examined by denaturing gradient gel electrophoresis (DGGE) of PCR-amplified 16S rDNA fragments. DGGE analysis shows that microbial community structure is dissimilar between interior and exterior sediments. This distinction suggests that the environment within the *Hunley* is significantly different than the surrounding benthos. Analysis also implies a substantial impact of the *Hunley* on inhabitant microorganisms. This study presents the first molecular analysis of microbial communities associated with shipwrecks.

INTRODUCTION

During the American Civil War, the Confederacy was under an economic blockade by the Union Naval Fleet. Consequently, there was pressure to produce submersibles to attack Federal ironclads that guarded southern ports. The *H. L. Hunley* was the first successful submarine of such innovations by sinking the USS *Housatonic* on February 17, 1864. However, on its return to port it disappeared without a trace. Almost 131 years later, the *Hunley* was discovered approximately 4 miles off the coast of Sullivan's Island, Charleston County, South Carolina. The vessel was successfully excavated and transported to the Warren Lasch Conservation Center on August 8th, 2000.

Representing a significant breakthrough in technology and an important piece of United States history, the conservation of the *Hunley* is of particular concern. More interestingly, the knowledge of the environment within and surrounding the sub that has existed for the duration of its burial may be better understood through microbiological techniques. The most critical component influencing the relationship between the *Hunley* and marine microorganisms is the sub's wrought-iron hull. In addition to normal corrosion rates in seawater, iron is also susceptible to the biochemical effects of microbial communities. Through the formation of biofilms, microorganisms are able to augment metal chemistry into microenvironments where corrosion is more thermodynamically favorable (Videla 1996).

Iron-reducing bacteria (FeRB) possess the ability to couple the dissimilatory reduction of Fe (III) to the oxidation of organic compounds, yielding energy for microbial growth (Lovely 1993). Under anaerobic conditions, FeRB have been shown to utilize Fe³⁺ as the sole electron acceptor during oxidative phosphorylation (Lovely and Phillips 1988). This metabolic characteristic directly affects the integrity of the iron hull by causing the dissolution of the protective iron oxide layer, thus creating pits and other forms of localized attack on the substrate. Other microorganisms, such

as sulfate-reducing bacteria (SRB), can indirectly affect the iron hull by producing the highly corrosive agent hydrogen sulfide (Edyvean 1991, Lee et al. 1995). In a similar mechanism to FeRB, SRB couple the dissimilatory reduction of sulfate to the oxidation of organic compounds (Postage 1979). Both FeRB and SRB have the ability to form comensal biofilms and synergistically promote the corrosion of iron surfaces.

The *Hunley* may have an impact on resident marine microorganisms. Through its burial by anoxic sediment and iron constitution, unique environments may exist to promote the proliferation of specific microorganisms that can out-compete other microorganisms. Through molecular techniques microbial communities from sediment associated with the *Hunley* may be analyzed to predict environments that have existed during its burial. The relationship between shipwrecks and microorganisms has never been studied in terms of microbial community structure. Previous studies involving microorganisms and shipwrecks solely include a bacterial growth assay on the Porcupine-class frigate *Pandora* (Guthrie et al. 1994).

The aim of this project is to investigate iron-reducing microbial community structure representative of sediments associated with the *H. L. Hunley*. Samples of sediment will be obtained from two opposable transects leading away from the bow and stern, as well as from within the ship. Sediments and concretions will be sub-sampled introduced into anaerobic goethite enrichment media to select for iron reducing microorganisms. Goethite (α -FeOOH) is an amorphous iron oxyhydroxide used to mimic naturally occurring iron oxides in marine sediment as well as the oxide layer on the *Hunley* hull. After incubation of goethite enrichments, DNA will be extracted using a modified bead beating protocol. Extracted DNA will be amplified by polymerase chain reaction (PCR) specific for the highly variable 323-bp V9 region on the 16S ribosomal DNA of prokaryotes. Successful PCR fractions will be subject to denaturing gradient gel electrophoresis (DGGE) to determine microbial community structure. DGGE, first introduced by Fischer and Lerman (1983), denatures double stranded DNA fragments based on guanine-cytosine content. An increasing gradient of denaturant immobilizes the melted DNA fragment at a specific location on the gel which is representative of its genetic sequence. While DGGE was first used to detect point mutations, it is now increasingly being used in studies involving microbial community structure (Muyzer et al. 1993, Ferris et al. 1996, Teske et al. 1996, Rolleke et al. 1996, MacNaughton et al. 1999).

MATERIALS AND METHODS

Sample Acquisition. Divers from the National Park Service obtained core sediment samples from

two opposable transects leading away from the bow and stern of the *H. L. Hunley* prior to its excavation. Transects displayed intervals of 1, 3, 5, 10 and 20 m distances at which sediment samples were taken with aluminum core barrels (3 in. in diameter and 1.3 m in length). The core barrels were capped, brought to the surface, flushed with nitrogen, anaerobically sealed, and placed on ice for transport the Ft. Johnson campus. Samples were placed in 4°C and sub-sampled for storage in -80°C for microbial community analysis.

Enrichment of FeRB. To select for FeRB, goethite media (Schwertmann and Cornell 1991) was made through the combination of hydrolyzed Fe (NO₃)₃•9H₂O and 5M KOH. In a 2L-polyethylene flask 180 mL of 5M KOH is added and stirred quickly into 100 mL of 1M Fe(NO₃)₃. Without delay, the chimera is diluted to 2L with distilled water, stupider and placed in 70°C for 60 hrs. After incubation, the flask is centrifuged and the precipitate is washed and dried. Under anaerobic conditions, sediment sub-samples were introduced into the goethite enrichments and incubated for 8 months.

DNA Extraction. A 1.5 mL aliquot was transferred from the goethite enrichments and transferred to a 'bead beating vial' containing 2.0 g of silica/zirconia beads. From the moment of transfer, the samples were placed on ice through the entire DNA extraction process. The remaining volume of the vial is filled with 250 µl of 10% SDS solution (J. T. Baker, Phillipsburg, NJ) and an equal amount of TE Buffer (10mM Tris-HCl, pH7.5; 1mM EDTA, pH 8.0). Vials were then placed on bead mills and processed for two 2.5 minute cycles at 2,500 rpm. After milling, the vials are centrifuged for 5 minutes at 14,000 rpm at 4°C. The supernatant was removed from the vials after centrifugation and placed into a sterile 1.5 mL microcentrifuge tube. As a rinse, 250 µl of TE buffer is added to the bead vial and a 30 second milling cycle follows at 2500 rpm. The super-

natant from this process is combined with the supernatant from the previous step and treated with 100 µl of 5M NaCl and 80 µl of CTAB (10% in 0.7 M NaCl, J. T. Baker, Phillipburg, NJ). Following this addition, the samples are placed in a hot water bath for 10 minutes at 65°C. After incubation, an equal amount of Tris-buffered phenol was added to the microcentrifuge tube. The tubes were centrifuged for 10 minutes at 14,000 rpm at 4°C. The resulting supernatant was transferred to a sterile 1.5 mL microcentrifuge tube. The phenol wash procedure is repeated on this transferred supernatant. A 0.6 volume of ice cold isopropanol was added to the suspension and the samples were stored overnight at -20°C. The following day, samples were allowed to thaw then centrifuged for 10 minutes at 4°C. The isopropanol was then poured off of the pelleted DNA. The remaining pellets were rinsed with 500 µl of 70% ethanol and stored at -20°C for 30 minutes. After incubation, the samples were centrifuged for 10 minutes at 4°C. The supernatant formed in the previous step was removed and the remaining ethanol droplets surrounding the pellet were evaporated in a fume hood for one hour. Next, the DNA pellet was resuspended in 50 µl of TE buffer. Extractions were confirmed with a 1% agarose gel infused with ethidium bromide which was run in 1xTAE buffer (20 mM Tris acetate [pH 7.4], 10 mM sodium acetate, 1 mM Na₂EDTA). The resultant DNA extraction-gel complex was analyzed and photographed using an ultraviolet transilluminater.

DNA Amplification. Successful DNA extracts were amplified using PCR with a set of universal eubacterial primers that target the V9 323-bp region of the 16S rDNA (Ferris et al. 1996). The conserved sequences targeted by these primers are shown in Figure 1. A GeneMATE Thermal Cycler (ISC BioExpress, Kaysville, UT) was used to control the ambient temperature changes involved in the amplification reactions. The method of Muyzer et al. (1993) was used for the PCR reactions.

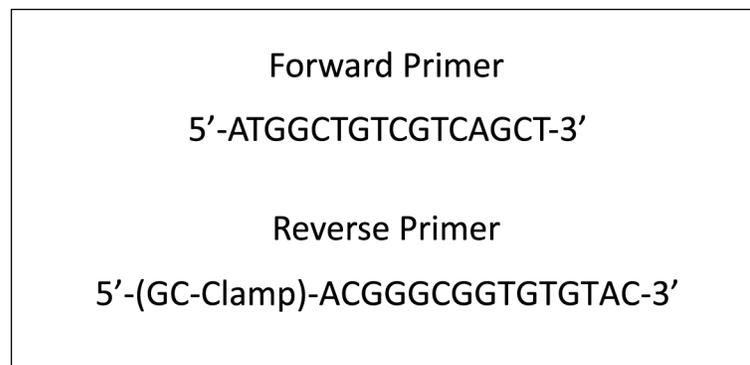


Figure 1. The forward primer and reverse primer, E. coli positions 1055 to 1070 and 1392 to 1406 respectively, used in the PCR amplifications. The reverse primer includes a 40bp GC clamp to improve DNA stabilization and sequence differentiation.

Template DNA strands were initially denatured for 5 minutes at 94°C. Next, 10 annealing cycles of 30 sec intervals, decreasing 1°C from 53°C to 43°C, each followed by a 2 min primer extension. Next, 20 annealing cycles took place at 43°C, followed by final primer extension at 72°C for a duration of 6 mins. To determine PCR effectiveness, products were confirmed under ultraviolet light with a 1% agarose gel stained with ethidium bromide in 1xTAE buffer.

DGGE Analysis. Successful PCR products were analyzed following the methodology of Muyzer et al. (1993) of denaturing gradient gel electrophoresis. A D-code Universal Mutation Detection system (Bio-Rad Laboratories, Richmond, VA) was used to run the amplified 16S rDNA fragments through an 8% (wt:vol) polyacrylamide gel in 0.5xTAE (20mM Tris acetate [pH 7.4], 10 mM sodium acetate, 1mM Na₂-EDTA) buffer at 60°C for 18 hours. The gels were processed with 40% (vol:vol) formamide deionized with AG501-X8 mixed bed resin (Bio-Rad Laboratories, Richmond, VA) and a denaturing gradient (7M urea) which would subject the PCR product to an initial 40% denaturant that increases linearly with propagation to a final 60% denaturant. Completed gels were stained with SYBR Green I (Molecular Probes, Eugene, OR) for one hour in preparation for analysis. Visualization of the prepared gels involved a model 595 laser Flourimager with ImageQuant software (Molecular Dynamics, Sunnyvale, CA).

RESULTS

The reduction of goethite enrichments was observed after 8 months incubation by the volumetric decrease of the Fe (III) matrix to the more compact Fe (II) structure. The observed transforma-



Figure 2. The reduction of goethite enrichments after 8 months incubation. A) Un-enoculated goethite media. Iron (III) oxyhydroxide. B) Goethite media enoculated with Hunley sediment. Reduced Iron (II).

tion is shown in Figure 2 compared to the control enrichment.

Nucleic acids were successfully extracted and amplified from goethite enrichments from interior and exterior sediments of all distances except for 3m. Denaturing gradient gel electrophoresis analysis of these amplified 16S rDNA fragments is shown in Figure 3, displaying the inherit banding pattern and its respective location.

DISCUSSION

DGGE analysis of PCR-amplified extracts indicates a distinct difference in microbial community structure between interior sediments and exterior sediments. In terms of exterior sediments, no substantial difference in banding patterns can be observed among different distances, depths, or transects. Note that the decrease in band

number in samples from 1 m and 20 m distances may be due to weak amplification of DNA fragments rather than a representation of fewer microorganisms. The ubiquitous community structure observed from exterior sediments may emulate the benthic environment characteristic of estuarine sediments of this area.

The observed distinction between interior and exterior sediments may reflect the difference between the *Hunley's* interior environment and the environment surrounding the submersible. Considering the limited

amount of oxygen within the sub upon sinking, the anoxic sediments that aided in its burial, decomposition of Confederate soldiers, restricted ocean current flow and oxygenation by benthic organisms, the interior environment of the *Hunley* may have been anaerobic for a number of years. With the *Hunley* now excavated, there is now no

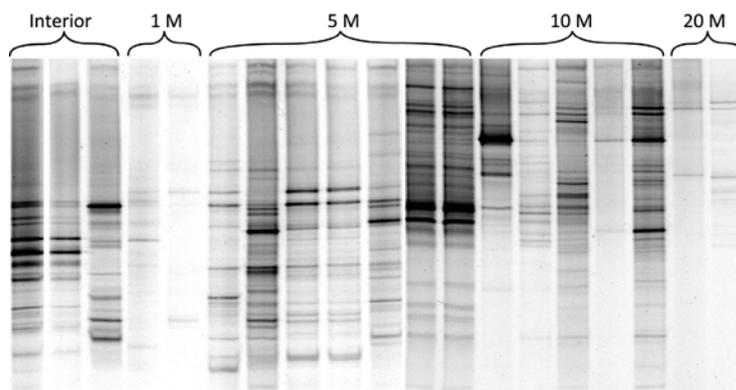


Figure 3. DGGE Analysis of PCR-amplified 16S rDNA fragments extracted from goethite media enriched with interior sediments and exterior sediments of 1m, 5m, 10m, and 20m distances from H. L. Hunley.

way to determine interior environmental conditions except through inferences through microbial community structure. This study provides the first multiparameter proxy data regarding the past environmental conditions within the *H. L. Hunley*. Continuing studies to identify specific microorganisms within these communities will further our understanding of the relationship between the submersible and its associated microorganisms.

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APPENDIX L

Analytical Characterization of Coal Artifacts Recovered from *H. L. Hunley* and USS *Housatonic*

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**Analytical Characterization of Coal Artifacts
Recovered from USS Housatonic and HL Hunley**

By
Rod Hatt
Coal Combustion, Inc.
Versailles, KY

Executive Summary

Twelve samples of coal were examined and six were deemed suitable for analytical analyses. This report covers the analytical laboratory results for six samples of coal, three recovered from the USS Housatonic, two recovered from just outside the HL Hunley and one found within the HL Hunley itself. The test results indicate that the coals recovered the HL Hunley consist of several different types of coal and that the coal found within the USS Housatonic is anthracite.

Sample Descriptions

| CCI No. | WLCC No. | Description | Date Collected |
|------------------------|---------------|----------------------------|-------------------|
| <u>Housatonic Coal</u> | | | |
| 6001 | HunHou 99-004 | Trench 1 BN | 6/16/99 |
| 6002 | HunHou 99-006 | Trench 1 DW | 6/16/99 |
| 6003 | HunHou 99-019 | Trench 1 3pieces | 6/21/99 |
| 6004 | HunHou 99-051 | Trench 2 DC 2 pieces | 6/24/99 |
| <u>Hunley Coal</u> | | | |
| 6005 | Hunley HL #84 | Sub sample Several Pieces | 1/26/01 2/6/01 |
| 6006 | Hunley HL 398 | Port cutback BZ | 5/20/00 |
| 6007 | Hunley HL 588 | Starboard bow HP | 7/27/00 |
| 6008 | Hunley HL 603 | Starboard + port of bow WH | 7/27/00 |
| 6009 | Hunley HL 620 | Portside blw dive plnR | 7/29/00 |
| 6010 | Hunley HL 645 | Starboard cntrln S | 8/1/00 |
| 6011 | Hunley HL 670 | Starboard 23-26 R | 8/2-3/00 |
| 6012 | Hunley HL 699 | Strbrd stern to aft RN | 8/4/00 |



Samples 6004 and 6008 - 6012 were deemed unusable for traditional chemical analyses due to apparent oxidation and/or the sample consisting of a mixture of anthracite, bituminous, and partially bunt coal material. These samples may be characterized using petrology due to smaller sample size requirements.

Results

| | MMMF Volatile | MAF Btu/lb | C/H | (C+H)/O | Fuel Ratio | Rank |
|---------------------|---------------|------------|-----|---------|------------|--------------------|
| USS Housatonic Coal | | | | | | |
| 6001 | 4.2 | 14,949 | 49 | 30 | 23 | Anthracite |
| 6002 | 4.4 | 15,039 | 42 | 182 | 22 | Anthracite |
| 6003 | 5.2 | 14,691 | 47 | 35 | 18 | Anthracite |
| HL Hunley Coal | | | | | | |
| 6005 | 23.2 | 15,698 | 17 | 44 | 3 | Med. Volatile Bit. |
| 6006 | 19.4 | 15,564 | 20 | 38 | 4 | Low Volatile Bit. |
| 6007 | 4.0 | 15,115 | 50 | 202 | 24 | Anthracite |

Interpretation

The USS Housatonic coal samples 6001,6002,6003 all classify as having the ASTM rank of anthracite.

Potential seam names with similar characteristics include:

- Buck Mountain
- Primrose
- Parlor
- Wharton
- Mammoth
- Lykens Valley (No 2 Lykens)

The anthracite coal sample (6007) found off of the starboard bow of the HL Hunley has similar physical and chemical properties as the USS Housatonic coal.

The remaining two HL Hunley coal samples are substantially different than the anthracite coal samples. 6005 classifies as ASTM medium volatile bituminous coal and 6006 as ASTM low volatile bituminous coal. These coals are primarily mined on the eastern slope of the Appalachian Mountains from Pennsylvania to Alabama. Contemporary coals that compare favorably include coals Virginia, West Virginia and Pennsylvania.



Summary

The coals found in and near the HL Hunley are mixture several types of coal, whereas the coal from the USS Housatonic all appears quite similar.

Additional work is being performed at the University of Kentucky and will be available shortly.

Additional resources covering the analyses of historical coal are being investigated.

* *Images submitted with this report were not reproduced due to the low resolution of archived files.*

APPENDIX M

South Atlantic Blockading Squadron Ships Stationed off Charleston, South Carolina

**24 December 1861–
1 July 1865**

24 December 1861 – 16 December 1862

| Class | Vessel | 24 Dec. 1861 | 18 Mar. 1862 | 23 Apr. 1862 | 14 May 1862 | 30 May 1862 | 3 June 1862† | 25 June 1862† | 23 July 1862 | 26 Sept. 1862 | 12 Oct. 1862 | 27 Oct. 1862 | 16 Nov. 1862 | 1 Dec. 1862 | 16 Dec. 1862 |
|-------------------------------|-----------------------|--------------|--------------|--------------|-------------|-------------|----------------|----------------|--------------|---------------|--------------|--------------|--------------|-------------|--------------|
| 1 | <i>Powhatan</i> | | | | | | | | | X | X | X | X | X | X |
| 2 | <i>Bienville</i> | | | X | X | X | | | X | X | X | X | X | X | |
| 2 | <i>Canandaigua</i> | | | | | | | | | X | X | X | | X | X |
| 2 | <i>Housatonic</i> | | | | | | | | | X | | X | X | | X |
| 2 | <i>Pawnee</i> | | | | | | | | S | | | | | | |
| 2 | <i>Quaker City</i> | | | | | | | | | | | X | X | X | X |
| 3 | <i>Alabama</i> | | | X | | X | | X | X | | | | | | |
| 3 | <i>Augusta</i> | | | X | X | X | X | | X | | | | | | |
| 3 | <i>Conemaugh</i> | | | | | | | | | S | S | | | | |
| 3 | <i>Flag</i> | | | | | | | X | | | X | X | X | | X |
| 3 | <i>Flambeau</i> | | X | S | X | X | X | X | | X | X | X | X | X | X |
| 3 | <i>Florida</i> | X | X | | | | | | | | | | | | |
| 3 | <i>James Adger</i> | | X | X | X | X | X | | X | | | | | | |
| 3 | <i>Keystone State</i> | | | | X | X | X | X | | | | X | X | X | X |
| 3 | <i>Memphis</i> | | | | | | | | | | | X | X | X | X |
| 3 | <i>Mercedita</i> | | | | | | | | | X | X | X | X | X | |
| 3 | <i>Mohican</i> | X | | | | | | | | | | | | | |
| 3 | <i>Pocahontas</i> | S | | X | X | X | X | X | | | | | | | |
| 3 | <i>South Carolina</i> | | | | | | | | | X | X | X | X | X | |
| 4 | <i>Crusader</i> | | | | | | | | X | | | | | | |
| 4 | <i>Ellen</i> | | | | | S | S [†] | S [†] | S | S | | | | | |
| 4 | <i>Gemsbok</i> | | | | | | | | | B | | | | | |
| 4 | <i>Henry Andrew</i> | | | | | | | | S | | | | | | |
| 4 | <i>Huron</i> | | | X | | X | | | | | | | | X | X |
| 4 | <i>Isaac Smith</i> | | | | | | | | | | | S | S | S | S |
| 4 | <i>Madgie</i> | | | | X | | | | | | | | | | |
| 4 | <i>Marblehead</i> | | | | | | | | | X | | | X | X | X |
| 4 | <i>Norwich</i> | | | | | X | X | | | | | | | X | |
| 4 | <i>Ottawa</i> | | | | S | S | S [†] | S [†] | S | | | | | S | S |
| 4 | <i>Pembina</i> | | | | | S | S [†] | S [†] | S | | | | X | | |
| 4 | <i>Potomska</i> | | | | | | | | | | | | | | |
| 4 | <i>Seneca</i> | | | | | | | X | | | | X | X | S | S |
| 4 | <i>Stettin</i> | | | | | | | | | | | | | X | X |
| 4 | <i>Sumpter</i> | | X | | | X | X | X | X | | | | | | |
| 4 | <i>Unadilla</i> | | | | X | S | S [†] | S [†] | | | | | | | |
| Sail | <i>America</i> | | | | | | | | X | X | X | | | | |
| Sail | <i>Fernandina</i> | | | | | | | | X | | | | | | |
| Sail | <i>G. W. Blunt</i> | | | | | X | X | X | | X | X | X | X | X | X |
| Sail | <i>Onward</i> | | X | B | X | | | X | X | | | | | | |
| Sail | <i>Para (MS)</i> | | | | | | | | | | | | X | X | X |
| Sail | <i>Restless</i> | | | X | B | X | B | B | B | | B | B | B | B | B |
| Sail | <i>Roebuck</i> | X | | X | X | X | X | X | | | | | | | |
| Sail | <i>Shepherd Knapp</i> | | | | | X | X | X | X | | | | | | |
| Sail | <i>Vandalia</i> | | | | | | | | X | | | | | | |
| Total Ships on Station | | 4 | 5 | 10 | 12 | 18 | 15 | 16 | 17 | 13 | 11 | 15 | 17 | 19 | 17 |

(Source: ORN 1.12:427, 635, 773, 814–15; ORN 1.13:59, 72, 138, 206, 348–49, 387, 419–20, 451–52, 465–66, 480–81)

B On Station off Bull's Bay
S On Station off Stono InletX On Station off Charleston
MS Mortar Schooner

† Reports do not include ships off Stono; Stono ships from prior report presumed to have been still on station

1863

| Class | Vessel | Jan. 15, 1863 | Feb. 1, 1863 | Feb. 15, 1863 | Mar. 1, 1863 | Mar. 15, 1863 | Apr. 15, 1863 | May 1, 1863 | May 15, 1863 | June 1, 1863 | June 15, 1863 | July 1, 1863 | July 15, 1863 | July 24, 1864* | Oct. 23, 1863** | Nov. 15, 1863** | Dec. 1, 1863 | Dec. 15, 1863 |
|-------|--------------------------|---------------|--------------|---------------|--------------|---------------|---------------|-------------|--------------|--------------|---------------|--------------|---------------|----------------|-----------------|-----------------|--------------|---------------|
| 1 | <i>New Ironsides (I)</i> | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 1 | <i>Powhatan</i> | X | X | X | X | X | X | | X | X | X | X | X | | | | | |
| 1 | <i>Wabash</i> | | | | | | | | | | | | X | X | X | X | X | X |
| 2 | <i>Canandaigua</i> | | | X | X | X | | X | X | X | | X | X | X | X | | X | X |
| 2 | <i>Housatonic</i> | X | X | X | | X | X | | X | X | X | | X | X | X | X | X | X |
| 2 | <i>Lehigh (I)</i> | | | | | | | | | | | | | | X | X | | |
| 2 | <i>Pawnee</i> | | | | S | S | S | S | S | S | S | S | S | | S | S | S | S |
| 2 | <i>Quaker City</i> | X | X | X | X | | | | | | | | | | | | | |
| 3 | <i>Augusta</i> | | X | X | X | X | X | X | X | X | | X | | | | | | |
| 3 | <i>Catskill (I)</i> | | | | | | | | | | | | X | | X | | | |
| 3 | <i>Conemaugh</i> | | | | | | | | | | | | X | | | | | |
| 3 | <i>Flag</i> | X | X | X | | X | X | X | | X | X | X | X | X | | | | |
| 3 | <i>Flambeau</i> | X | | | | | | | | | | | | | | | | |
| 3 | <i>James Adger</i> | | X | X | X | | | | | X | X | | | | | | | |
| 3 | <i>Keystone State</i> | X | | | | | | | | | | | | | | | | |
| 3 | <i>Lodona</i> | | | | | | | | | X | X | X | X | X | | | | |
| 3 | <i>Mary Sanford</i> | | | | | | | | | | | | | | | X | X | X |
| 3 | <i>Memphis</i> | X | X | X | | X | | | | | | X | B | | | | | |
| 3 | <i>Mercedita</i> | X | | | | | | | | | | | | | | | | |
| 3 | <i>Montauk (I)</i> | | | | | | | | | | | | X | X | | X | X | X |
| 3 | <i>Nahant (I)</i> | | | | | | | | | | | | X | | X | X | X | X |
| 3 | <i>Nantucket (I)</i> | | | | | | | | | | | S | X | | | | | |
| 3 | <i>Passaic (I)</i> | | | | | | | | | | | | | | | X | X | X |
| 3 | <i>Patapsco (I)</i> | | | | | | | | | | | | | X | | | | |
| 3 | <i>Paul Jones</i> | | | | | | X | X | X | | | | X | | X | | | |
| 3 | <i>Sebago</i> | | | | | | | | | X | X | | | | | | | |
| 3 | <i>Sonoma</i> | | | | | | | | | | | | | | X | | X | X |
| 3 | <i>South Carolina</i> | | | | | | X | X | X | B | B | B | | | | | | X |
| 3 | <i>Weehawken (I)</i> | | | | | | | | | | | | X | X | X | | X | X |
| 4 | <i>Cdre. McDonough</i> | S | | | S | S | S | S | S | | S | S | X | | | X | X | X |
| 4 | <i>Chippewa</i> | | | | | | | | | | X | X | X | | | | | |
| 4 | <i>Dai Ching</i> | | | | | | | | | | | | | X | | | | |
| 4 | <i>E. B. Hale</i> | | | | | | | | | S | | | | | | | | |
| 4 | <i>Huron</i> | X | X | X | X | X | X | X | X | | | X | S | S | | | | |
| 4 | <i>Isaac Smith</i> | S | | | | | | | | | | | | | | | | |
| 4 | <i>Madgie</i> | | | | | | | | | | | X | | | | | | |
| 4 | <i>Marblehead</i> | | | | | | | | X | X | X | | S | S | S | S | S | S |
| 4 | <i>Nipsic</i> | | | | | | | | | | | | | | | X | X | X |
| 4 | <i>Norwich</i> | | | | | | | | | | | | | | X | | | |
| 4 | <i>Ottawa</i> | X | X | | | | | | | X | | X | X | X | | | | |
| 4 | <i>Philadelphia</i> | | | | | | | | | | | | | | X | X | X | X |
| 4 | <i>Seneca</i> | | | | | | | | | | | | X | X | | | | |
| 4 | <i>Stettin</i> | X | X | | X | X | X | | X | X | | | | | | | | |
| 4 | <i>Unadilla</i> | X | X | | S | X | X | X | X | X | | | | | | | | |

APPENDIX M

| Class | Vessel | Jan. 15, 1863 | Feb. 1, 1863 | Feb. 15, 1863 | Mar. 1, 1863 | Mar. 15, 1863 | Apr. 15, 1863 | May 1, 1863 | May 15, 1863 | June 1, 1863 | June 15, 1863 | July 1, 1863 | July 15, 1863 | July 24, 1864* | Oct. 23, 1863** | Nov. 15, 1863** | Dec. 1, 1863 | Dec. 15, 1863 |
|-------------------------------|----------------------------|---------------|--------------|---------------|--------------|---------------|---------------|-------------|--------------|--------------|---------------|--------------|---------------|----------------|-----------------|-----------------|--------------|---------------|
| 4 | <i>Wamsutta</i> | | | | | | | X | X | | | | | | | | | |
| 4 | <i>Wissahickon</i> | | | | | X | | | | | | X | X | | | | | |
| 4 | <i>Clover (T)</i> | | | | | | | | | | | | | | | | | X |
| 4 | <i>Columbine (T)</i> | | | | | | | | | | | | | X | | | | |
| 4 | <i>Daffodil (T)</i> | | | | | | | | | | | X | | | | | X | X |
| 4 | <i>Dandelion (T)</i> | | | | | | | | X | X | X | X | X | | | X | X | X |
| 4 | <i>Geranium (T)</i> | | | | | | | | | | | | | | | | | X |
| 4 | <i>Home (T)</i> | | | | | | | | | | | | | | | X | X | X |
| 4 | <i>Iris (T)</i> | | | | | | | | | | | | | | | X | X | X |
| 4 | <i>Jonquil (T)</i> | | | | | | | | | | | | | | | X | X | |
| 4 | <i>Oleander (T)</i> | | | | | | | | | | | | | X | X | X | X | |
| 4 | <i>O. M. Petit (T)</i> | | | | | | | | | | | X | | | | | | |
| Sail | <i>America</i> | X | X | X | X | X | X | X | | | | | | | | | | |
| Sail | <i>C. P. Williams (MS)</i> | | | | | | S | S | S | S | S | S | | | S | S | S | S |
| Sail | <i>Dan Smith</i> | | | | | | | | | | | | | | X | | | |
| Sail | <i>Ethan Allen</i> | | | | | | | | | | | | | | | | | X |
| Sail | <i>G. W. Blunt</i> | X | X | X | X | X | X | X | | | X | X | X | X | B | B | B | B |
| Sail | <i>Hope</i> | | | | | | | | | | | | | | X | X | X | X |
| Sail | <i>Norfolk Packet</i> | | | | | | | | | X | X | X | X | X | | | | |
| Sail | <i>Para (MS)</i> | X | | | | | | X | | | | | | | | | | |
| Sail | <i>Racer (MS)</i> | | | | | | | | | | | | | | X | X | X | X |
| Sail | <i>Restless</i> | B | | | | | | | | | | | | | | | | |
| Sail | <i>Supply</i> | | | | | | | | | | | | | | | X | X | X |
| Sail | <i>T. A. Ward</i> | | | | | | | | | | | | | | | X | X | X |
| Total Ships on Station | | 18 | 14 | 12 | 13 | 15 | 15 | 14 | 17 | 19 | 16 | 20 | 28 | 16 | 21 | 24 | 27 | 30 |

(Sources: ORN 1.13:511–12, 625, 663–64, 709, 755–56; ORN 1.14:135–36, 167, 195, 224–25, 305–6, 343–44, 390; ORN 1.15:69, 113, 144, 176)

X On Station off Charleston
 B On Station off Bull's Bay
 S On Station off Stono Inlet

MS Mortar Schooner
 T Tug

* This report does not include ships already in Stono, only those on the way; there is no reference to Bull's Bay

** Also listed was the storeship Hannibal, not on the Navy roster; it is not clear whether this was a steam powered or sailing vessel.

1864

| Class | Vessel | Jan. 1, 1864 | Jan. 15, 1864 | Feb. 1, 1864 | Feb. 15, 1864 | Mar. 1, 1864 | Mar. 15, 1864 | Apr. 1, 1864 | Apr. 15, 1864 | May 15, 1864 | June 1, 1864 | June 15, 1864 | July 1, 1864 | July 16, 1864 | Aug. 1, 1864 | Aug. 16, 1864 | Sept. 1, 1864 | Sept. 15, 1864 | Oct. 1, 1864 | Oct. 15, 1864 | Oct. 22, 1864 | Nov. 1, 1864 | Nov. 15, 1864 | Dec. 12, 1864 |
|-------|--------------------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|--------------|---------------|--------------|---------------|--------------|---------------|---------------|----------------|----------------|----------------|----------------|----------------|---------------|----------------|
| 1 | <i>New Ironsides (I)</i> | X | X | X | X | X | X | X | X | X | X | | | | | | | | | | | | | |
| 1 | <i>Wabash</i> | X | | X | X | X | X | X | X | | | | | | | | X | X | | | | | | |
| 2 | <i>Canandaigua</i> | X | X | X | X | X | X | X | X | X | X | X | | | X | | | | | X | | | | |
| 2 | <i>Housatonic</i> | X | X | X | X | X | | | | | | | | | | | | | | | | | | |
| 2 | <i>Lehigh (I)</i> | | X | X | X | X | X | X | X | X | X | X | S | X | X | X | X | X | X | X | | | | X |
| 2 | <i>Pawnee</i> | S | S | | | | | | | | | | S | X | X | X | | X | X | | | X | X | |
| 3 | <i>Augusta</i> | | | | X | | | | | | | | | | | | | | | | | | | |
| 3 | <i>Catskill (I)</i> | X | X | X | | X | | | | X | X | X | X | X | X | X | X | X | X | | X | X | X | X ^R |
| 3 | <i>Cimarron</i> | S | S | S | S | S | X | X | | | | | | | | | | | | | | | | |
| 3 | <i>Flag</i> | | | | X | X | | X | X | X | X | X | X | X | | | | | | | | | | |
| 3 | <i>Flambeau</i> | | | | | | | | | | | | | | | | | | X | X | X | X | X | X |
| 3 | <i>James Adger</i> | | | | | | | | | | | | | | | | | X | B | | X | X | X | X |
| 3 | <i>Mary Sanford</i> | X | | X | X | X | X | | | X | X | X | | X | X | X | | | | | | | X | X |
| 3 | <i>Memphis</i> | | | | | | | | | | | | | | | | | | | | | | | X |
| 3 | <i>Mingoe</i> | | | | | | | | | | | | | | | | | X | X | X | X | X | | |
| 3 | <i>Montauk (I)</i> | X | | | X | X | X | X | | | | | S | X | X | X | S | X | X ^R | X ^R | X ^R | X ^R | X | X |
| 3 | <i>Nahant (I)</i> | X | X | X | X | X | | | | X | | | X | X | X | X | | | | | | X | X | X |
| 3 | <i>Nantucket (I)</i> | | | | | | X | X | X | X | X | X | X | X | X | | | | X | X | X | | | |
| 3 | <i>Passaic (I)</i> | X | X | X | | | | | X | X | X | X | | | | | | | | | | | | |
| 3 | <i>Patapsco (I)</i> | | | | | | | | | | | | | | | | | | | X | X | X | X | X |
| 3 | <i>Paul Jones</i> | | | | | | | | | S | S | | | | | | | | | | | | | |
| 3 | <i>Pocahantas</i> | | | | | | | | | | | | | | | | | | X | | | | | |
| 3 | <i>Pontiac</i> | | | | | | | | | | | | | | | X | X | X | | | | | X | |
| 3 | <i>Sangamon (I)</i> | | | | | | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | X ^R |
| 3 | <i>Sonoma</i> | | | S | S | S | S | S | S | S | S | S | | | | | | | | | X | X | X | |
| 3 | <i>South Carolina</i> | X | X | X | | | | | | | | | | | | | | | | | | | | |
| 3 | <i>Weehawken (I)</i> | X | X | X | X | X | | | | | | | | | | | | | | | | | | |
| 4 | <i>Acacia</i> | | X | | | X | X | X | X | | X | X | X | X | | | X | X | X | X | X | X | X | X |
| 4 | <i>Cdre. McDonough</i> | X | X | X | X | X | X | | | | | S | S | S | S | S | S | S | S | S | S | S | S | S |
| 4 | <i>Dai Ching</i> | | | | | | | | | | | | | | | | | | | | | | X | |
| 4 | <i>Nipsic</i> | X | X | X | X | X | X | X | X | X | | | | | | | X | X | X | | | | | |
| 4 | <i>Ottawa</i> | | | | | | | | | | | | | | | | X | | | | | | | |
| 4 | <i>Philadelphia</i> | X | X | X | | | | | X | X | X | X | S | | | | | B | | | | | | |
| 4 | <i>Potomska</i> | | | | | | | | | | | | | | | | | X | | X | | X | X | X |
| 4 | <i>Seneca</i> | | | | | | S | S | S | | | | | | | | | | | | | | | |
| 4 | <i>Wamsutta</i> | | | | | | | | | X | X | | | X | X | X | X | X | X | X | X | X | X | X |
| 4 | <i>Winona</i> | | | | | | X | X | X | X | X | | X | X | X | X | X | X | | | | | | X |
| 4 | <i>Amaranthus (T)</i> | | | | | | | | | | | | | | | X | X | X | X | | X | X | X | X |
| 4 | <i>Azalea (T)</i> | | | | | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | X |
| 4 | <i>Camelia (T)</i> | | | X | | X | X | X | | | | X | | | X | X | X | X | | | | | | |
| 4 | <i>Catalpa (T)</i> | | | | | | | | | | | | | | X | X | | | X | X | X | X | X | X |
| 4 | <i>Clover (T)</i> | X | X | | | X | X | X | X | X | X | | | | | | X | X | X | X | X | X | X | X |

APPENDIX M

| Class | Vessel | Jan. 1, 1864 | Jan. 15, 1864 | Feb. 1, 1864 | Feb. 15, 1864 | Mar. 1, 1864 | Mar. 15, 1864 | Apr. 1, 1864 | Apr. 15, 1864 | May 15, 1864 | June 1, 1864 | June 15, 1864 | July 1, 1864 | July 16, 1864 | Aug. 1, 1864 | Aug. 16, 1864 | Sept. 1, 1864 | Sept. 15, 1864 | Oct. 1, 1864 | Oct. 15, 1864 | Oct. 22, 1864 | Nov. 1, 1864 | Nov. 15, 1864 | Dec. 12, 1864 | | |
|-------------------------------|----------------------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|--------------|---------------|--------------|---------------|--------------|---------------|---------------|----------------|--------------|---------------|---------------|--------------|---------------|---------------|---|---|
| 4 | <i>Daffodil (T)</i> | X | X | X | X | X | X | X | | | X | X | S | X | X | X | X | | | | | | | X | | |
| 4 | <i>Dandelion (T)</i> | X | | | | | | | X | X | X | X | X | X | X | X | | | X | X | X | X | X | | | |
| 4 | <i>Geranium (T)</i> | X | X | X | X | X | X | X | | X | | | S | | | | | | X | X | X | X | X | | | |
| 4 | <i>Gladiolus (T)</i> | | | | | | | | | | | | X | X | X | X | X | X | | X | X | X | X | | X | |
| 4 | <i>Home (T)</i> | X | X | | | X | X | X | X | X | X | | | X | X | | X | X | X | X | X | X | X | X | X | |
| 4 | <i>Hydrangea (T)</i> | | | | | | | | | | | | | | | | | | | | X | X | X | X | | |
| 4 | <i>Iris (T)</i> | X | X | X | X | X | X | | X | X | X | X | X | X | | | | | | | | | X | X | X | |
| 4 | <i>Jonquil (T)</i> | | X | X | X | X | X | | | | | | X | | | | | | | | | | | | | |
| 4 | <i>Laburnum (T)</i> | | | | | | | | | | | | | | X | X | X | X | | X | X | X | X | X | X | |
| 4 | <i>Oleander (T)</i> | | | | | | | | | | | | S | | | | | | | | | | | | | |
| 4 | <i>Sweet Brier (T)</i> | | | | | | X | X | X | X | X | X | X | | | X | X | | | | | | X | S | | |
| Sail | <i>C. P. Williams (MS)</i> | S | S | S | S | | | | | | | | | | | | | | | | | | S | S | | |
| Sail | <i>Dan Smith</i> | | | | | | | | | | | | | | | | S | S | S | S | S | S | S | S | S | |
| Sail | <i>Ethan Allen</i> | X | X | | | | | | | | | | | | | | | | | | | | | | | |
| Sail | <i>G. W. Blunt</i> | B | B | B | B | X | X | X | X | X | X | X | X | X | X | | | | | | | | | | | |
| Sail | <i>George Mangham</i> | | | | | | B | | | | | | | | | | | | | B | B | B | B | B | B | |
| Sail | <i>Hope</i> | X | X | X | X | B | X | B | B | B | B | B | B | B | B | B | B | B | | | | | | | | |
| Sail | <i>John Adams</i> | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Sail | <i>Orvetta (MS)</i> | | | | | | | | | | | | | | | | | | | | | | | X | X | |
| Sail | <i>Perry</i> | X | | | | | | | | | | | | | | | | | | | | | | | | |
| Sail | <i>Racer (MS)</i> | X | S | S | X | S | S | S | S | S | S | S | S | S | S | S | | | | | | | | | | |
| Sail | <i>Sarah Bruen</i> | | | | | | | | | | | | | | | | X | X | | X | X | X | X | X | X | |
| Sail | <i>Supply</i> | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | | | | | | | | | | |
| Sail | <i>T. A. Ward</i> | X | X | X | | | | | | | | | | | | | | | | | | | | | X | |
| Total Ships on Station | | 31 | 29 | 28 | 25 | 28 | 29 | 27 | 26 | 26 | 27 | 22 | 27 | 24 | 25 | 24 | 26 | 26 | 23 | 24 | 26 | 31 | 31 | 29 | | |

(Sources: ORN 1.15:217, 242, 258, 324, 347, 365, 390, 400, 433, 465, 524, 550, 570, 588, 628, 656, 676; ORN 1.16:3, 17, 27, 39, 54, 125)

- B On Station off Bull's Bay
- S On Station off Stono Inlet
- X On Station off Charleston
- I Ironclad
- MS Mortar Schooner
- T Tug
- R Repairing

1 January – 1 July 1865

| Class | Vessel | Jan. 1, 1865 | Jan. 15, 1865 | Feb. 1, 1865 | Feb. 15, 1865 | Mar. 1, 1865 | Mar. 15, 1865 | Apr. 1, 1865 | Apr. 15, 1865 | May 1, 1865 | May 15, 1865†† | June 1, 1865†† | June 15, 1865†† | July 1, 1865 |
|-------|----------------------------|----------------|---------------|--------------|---------------|--------------|----------------|--------------|----------------|-------------|----------------|----------------|-----------------|--------------|
| 2 | <i>Canandaigua</i> | | | X | | | | | | | | | | |
| 2 | <i>Juniata</i> | | | | X | X | | | | | | | | |
| 2 | <i>Lehigh (I)</i> | X | X | X | S | S | | | | | | | | |
| 2 | <i>Pawnee</i> | | X | | | | | X | X | X | X | X | X | |
| 2 | <i>Shenandoah</i> | | | X | B | X | | | | | | | | |
| 3 | <i>Cambridge</i> | | | | X | X | | | | | | | | |
| 3 | <i>Canonicus (I)</i> | | | X | X | | | | | | | | | |
| 3 | <i>Catskill (I)</i> | X ^R | X | X | X | X | X ^R | X | X | X | X | X | X | X |
| 3 | <i>Chenango</i> | | | | | X | | | | | | | | |
| 3 | <i>Cimarron</i> | | | | | | X | X | | X | X | X | | |
| 3 | <i>Conemaugh</i> | | | | | | | | | | | | X | |
| 3 | <i>Flambeau</i> | X | X | X | X | | | | | | | | | |
| 3 | <i>James Adger</i> | X | X | X | | | | | | | | | | |
| 3 | <i>Mary Sanford</i> | X | X | X | | | | | | | | X | | |
| 3 | <i>Memphis</i> | X | | | | | | | | | | | | |
| 3 | <i>Mohican</i> | | | X | | | | | | | | | | |
| 3 | <i>Monadnock</i> | | | X | X | | | | | | | | | |
| 3 | <i>Montauk (I)</i> | X | X | | | | | | | | | | | |
| 3 | <i>Nahant (I)</i> | X | X | X | X | S | S ^R | S | | | | | | |
| 3 | <i>Nantucket (I)</i> | X | X | X | X | X | R | X | | | | | | |
| 3 | <i>Passaic (I)</i> | X | X | X | | | | | X | X | X | X | | |
| 3 | <i>Patapsco (I)</i> | X | X | | | | | | | | | | | |
| 3 | <i>Sangamon (I)</i> | | | X | X | | | | | | | | | |
| 3 | <i>Sonoma</i> | | | | B | X | X | X | X | | | | | |
| 3 | <i>South Carolina</i> | X | X | X | X | X | | | | | | | | |
| 3 | <i>State of Georgia</i> | | | | B | X | | X | | | | | | |
| 4 | <i>Acacia</i> | | X | X | X | | | | X ^R | | | | | |
| 4 | <i>Calypso</i> | | | | | | | | | | | | | X |
| 4 | <i>Commodore McDonough</i> | S | S | S | S | S | S | S | S | S | S | S | | |
| 4 | <i>Donegal</i> | | | | | | | | X | | X | | X | |
| 4 | <i>Ellen</i> | | | | | | | | | | | | X | |
| 4 | <i>Fahkee</i> | | | | | | | | | X | | | | |
| 4 | <i>Gemsbok</i> | | | X | | | | | | | | | | |
| 4 | <i>Harvest Moon</i> | | | | S | | | | | | | | | |
| 4 | <i>Mahopac (I)</i> | | | | X | X | | | | | | | | |
| 4 | <i>Nipsic</i> | X | X | | | | X ^R | | | | | | | |
| 4 | <i>Ottawa</i> | | | | B | | | | | | | | | |

APPENDIX M

| | | | | | | | | | | | | | | |
|-------------------------------|----------------------------|-----------|-----------|-----------|-----------|-----------|-----------|----------------|-----------|----------------|----------------|-----------|-----------|-----------|
| 4 | <i>Philadelphia</i> | | | S | S | | X | X | X | X | X | X | X | X |
| 4 | <i>Potomska</i> | X | | X | X | X | X | | | | | X | | |
| 4 | <i>Tuscarora</i> | | | | | | | X | X | X | | | | |
| 4 | <i>Wamsutta</i> | X | X | X | X | X | | | X | | | | | |
| 4 | <i>Wando</i> | | | X | X | X | | X | X | | | | | |
| 4 | <i>Winona</i> | | | | | X | | | | | | | | |
| 4 | <i>Wissahickon</i> | S | S | S | S | S | S | S | S | | | | X | |
| 4 | <i>Amaranthus</i> | | X | X | X | X | | X | | | X | X | | |
| 4 | <i>Azalea (T)</i> | X | X | X | X | X | | | | | | | | |
| 4 | <i>Camelia (T)</i> | | | X | X | X | X | X ^R | X | X | X | | | |
| 4 | <i>Catalpa (T)</i> | X | X | | X | | | | | | | | X | X |
| 4 | <i>Clover (T)</i> | | | X | | X | X | X | X | X ^R | X | X | X | X |
| 4 | <i>Daffodil (T)</i> | | | | | | | X | | | | | X | |
| 4 | <i>Dandelion (T)</i> | | | | | | | | X | X | X | X | | |
| 4 | <i>Geranium (T)</i> | X | X | X | B | X | | | X | X | X | | X | |
| 4 | <i>Gladiolus (T)</i> | X | X | X | X | X | X | | X | | | X | | |
| 4 | <i>Home (T)</i> | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 4 | <i>Hydrangea (T)</i> | X | X | X | X | | X | | | | | X | | |
| 4 | <i>Iris (T)</i> | | | | S | | X | X ^R | X | | X ^R | X | X | |
| 4 | <i>Jonquil (T)</i> | X | X | X | X | X | X | X | X | X ^R | X | X | X | X |
| 4 | <i>Laburnum (T)</i> | X | X | X | X | X | X | | X | X | X | X | | |
| 4 | <i>Larkspur (T)</i> | | | | X | X | | | | | | | | |
| 4 | <i>Oleander (T)</i> | X | X | | | | | | | | | | | |
| 4 | <i>Sweet Brier (T)</i> | X | X | | | | | | | | | X | | |
| Sail | <i>C. P. Williams (MS)</i> | S | S | S | S | S | S | S | X | X | | X | | |
| Sail | <i>Dan Smith</i> | S | S | S | S | S | | | X | X | X | X | | |
| Sail | <i>G. W. Blunt</i> | | | | | | | X | X | X | X | X | X | X |
| Sail | <i>George Mangham</i> | B | | | | | | | | | | | | |
| Sail | <i>Hope</i> | | | | | | | X | X | X ^R | X | X | X | X |
| Sail | <i>John Adams</i> | X | X | X | X | X | X | | X | X | X | X | X | X |
| Sail | <i>James S. Chambers</i> | X | B | B | B | B | B | | | | | | | |
| Sail | <i>Orvetta (MS)</i> | X | X | X | X | X | X | X | X | X | X | | | |
| Sail | <i>Sarah Bruen</i> | X | X | X | X | X | X | X | X | X | X | X | | |
| Sail | <i>Sea Foam</i> | X | | | | | | | | | | | | |
| Sail | <i>Sophonra (MS)</i> | | | | | | | | | | | X | | |
| Sail | <i>Supply</i> | | | | | | | | | | | X | | |
| Sail | <i>T. A. Ward</i> | X | X | | X | X | X | X | X | X | X | X | | |
| Total Ships on Station | | 36 | 35 | 39 | 43 | 35 | 24 | 25 | 29 | 23 | 23 | 27 | 17 | 10 |

(Sources: ORN 1.16:154, 169–70, 210–12, 244–46, 281–82, 292–93, 303–4, 317–18, 326–28, 331–33, 340–42)

B On Station off Bull's Bay
 S On Station off Stono Inlet
 X On Station off Charleston

I Ironclad
 MS Mortar Schooner
 T Tug
 R Repairing

†† Also listed were the lightship *Lady Davis* and tug *Transport*, not on the official Navy roster, as well as captured ships *Mab* and, on 15 May only, *Columbia*.

APPENDIX N

**Oral Account of *H. L. Hunley* by William G. Mazyck,
Taken Down and Summarized by Robert Lunz
(1957)**

Bears Bluff Laboratories
WADMALAW ISLAND, S. C.

*H-5-2 Confederate
Navy*

ESTABLISHED IN 1946
BY
H. JERMAIN SLOCUM

December 2, 1957

SUPPORTED BY
THE STATE OF SOUTH CAROLINA
THROUGH
THE WILDLIFE RESOURCES DEPARTMENT

Dr. Harold J. Easterby
S. C. Archives Department
War Memorial Building
Columbia, S. C.

Dear Harold:

Two or 3 weeks ago one of the shrimp trawlermen located what he thinks is the Confederate submarine in about 18 feet of water somewhere off Sullivans Island. He was able to go down and feel around sufficiently to be pretty positive that the hull was made of very heavy iron plate riveted together. He removed a stay of wrought iron. This he turned over to Milby at the Museum.

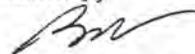
So far as I know, nothing further has been done about the submarine.

In going through some of my 1935 notes, I ran into a couple of sheets of notes I had made one day talking to old Mr. Mazyck. I have sent a copy on to the shrimp trawlerman. There is something wrong with my calculations somewhere. Note at the bottom of the page the mathematics involved. Mr. Mazyck said he was a "small boy", but it looks to me like he was at least 16 years old.

Anyhow, I thought you might be interested in having the notes. If they are worthless, don't hesitate to file them in the waste basket.

Trust everything goes well with you. Best regards to your staff and your family at home.

Sincerely,



G. Robert Lutz
Director

GRL/je

H-5-2 Conf. Navy

In conversation with Mr. W. G. Mazyck, June 19, 1936 the following points were brought out concerning the appearance and structure of the submarine used in Charleston Harbor during the War Between the States.

It is advisable to note, in the beginning, that Mr. Mazyck now ninety years old, is probably the only living person who has seen the submarine in question. He states that his brother somewhat older than himself, was at the time working in the yards of the North Eastern Railroad. Mr. Wm. Mazyck, released from school, closed for the duration of the War, occupied his time watching his brother at work in the railroad yards.

One afternoon he says that he noticed an object loaded on two flat cars and covered over with canvas. This had just come into the yard. He went to investigate but was ordered off by workmen near by. The next day however, he was able to witness the unloading of Hunley's Submarine.

Either at the Railroad Yard or along some wharf, Mr. Mazyck, acting the role of helpful small boy*, was able to get a good impression of the ship. He was even allowed to look down the hatches into the ship.

Mr. Mazyck does not remember the exact dimensions of the boat but he believes that she was between 35 and 50 feet long. It was made out of heavy "boiler iron". This type of construction accounts for the shape. He says that the sides were parallel but the bow and stern were tapered at an angle to a point. The deck was apparently parallel to the bottom. From Mr. Mazyck's description, the depth of the boat could not have been much over 5 feet.

On the forward end was fastened a long steel spar 15 to 20 feet long. This was stayed to the boat by iron stays. On the end of this spar, the torpedo was carried by means of a hook. On the deck of the boat, just forward of the forward hatch was a reel carrying a steel cable. The distal end of the cable was attached to the trigger of the torpedo. The proximal

*"Small boy" Mazyck, born: 1935 minus 90 = 1845/ 1861 minus 1845 = 16 yrs. old

p.2 (Hunley's submarine)

H. S. 2 Conf. Navy.

end, in some manner ran through the deck so that the torpedo could be operated from the inside.

Along the sides of the boat were two lateral fins. These about 6 feet long and perhaps 6 inches wide. They were arranged on hinges and could be operated from the inside. These fins were used to control the up and down movements of the submarine. In addition to the fins, a tank was placed forward. This tank was flooded in order to sink the ship. In order to come to the surface, the tank was pumped out by means of what Mr. Mazyck calls "an ordinary cistern hand pump".

There were two hatches - one aft and one forward. These were raised on a coaming about 6 inches in height. They were elliptical in shape and covered by "hinged smoke-stack covers", which were fastened from the inside. These hatches were made watertight by an "indian rubber ring". In the forward hatch coamings were two ports for vision.

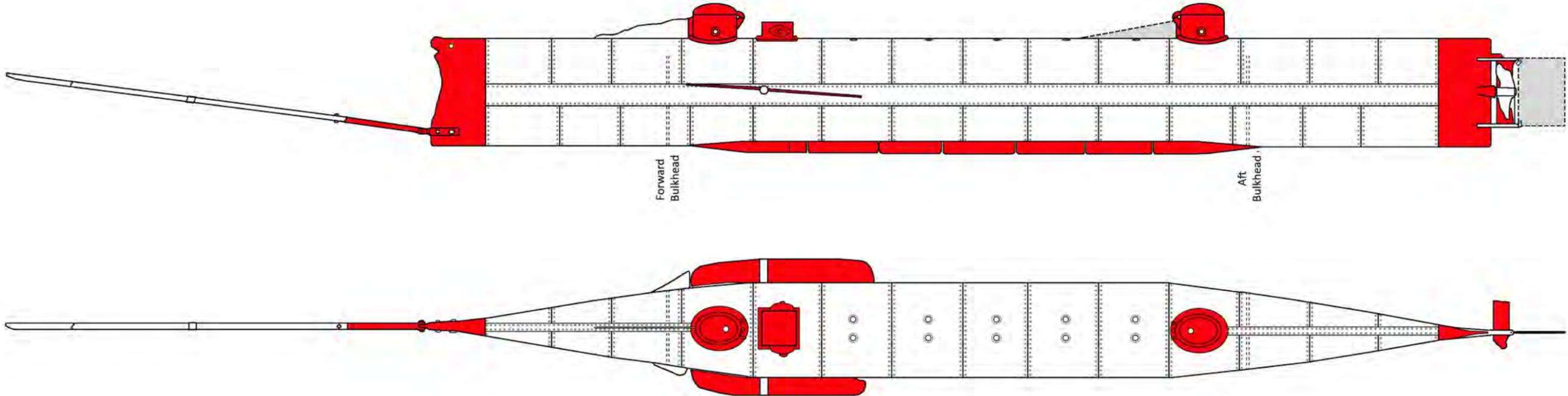
On the deck were two pipes about 2 inches in diameter and 10 to 12 feet in length. These pipes (one on each side) were hinged to the deck. They also communicated with the inside of the boat. There was a control valve inside which could be closed to keep out water. When the submarine was on the surface these pipes lay along the deck. When the boat was submerged the pipes stood up. This gave a circulation of air into the boat. If the boat went down more than 10 or 12 feet the valves had to be closed and the crew depended entirely on the air bottled up in the boat.

The motive power for this submarine was either a three or four blade propeller. The propeller was surrounded by a cylindrical pipe. Mr. Mazyck surmises that this cylinder kept the splash of the propeller from being seen by the enemy. Inside the boat was a crank shaft fitted with handles. Eight men turned this crank.

Mr. Mazyck actually saw this submarine make a test dive. He saw the submarine maneuvering around in upper Charleston Harbor or really in the Cooper River, approach the Confederate training ship "Indian Chief" and dive under to come up on the other side. At the time the "Indian Chief" was anchored opposite the North Eastern Railroad Wharf.

The activities of this submarine during the War is a matter of history and need not be set down here. Mr. Mazyck spoke briefly on these activities and commended the crews who were lost in the boat.

H. L. Hunley Plate Plan



-  Cast Iron Components
-  Components found detached from hull

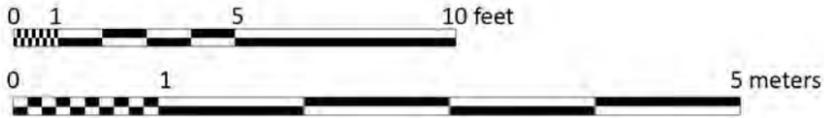


Plate plan by Michael Scafuri, Warren Lasch Conservation Center, Courtesy of Friends of the Hunley