

USS ARIZONA MEMORIAL

Submerged Cultural Resources Study:
USS Arizona and Pearl Harbor National Historic
Landmark



Submerged Cultural Resources Study

USS ARIZONA MEMORIAL
and
PEARL HARBOR NATIONAL HISTORIC LANDMARK



DANIEL J. LENIHAN, EDITOR
SUBMERGED CULTURAL RESOURCES UNIT
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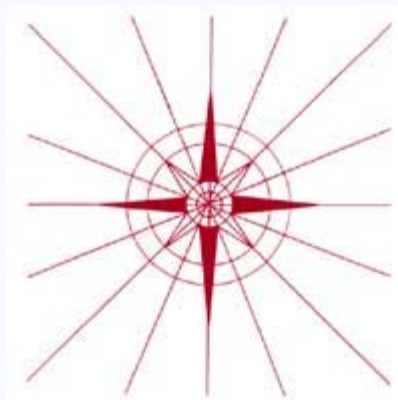
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SUBMERGED CULTURAL RESOURCES STUDY **USS ARIZONA MEMORIAL** **and** **PEARL HARBOR NATIONAL HISTORIC LANDMARK**



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through a donation from the
Arizona Memorial Museum Association.

Submerged Cultural Resources Unit
Southwest Cultural Resources Center
Southwest Region
Santa Fe, New Mexico

**Professional Papers No. 23
1989**

*The on-line edition of this study is dedicated to
the memory of my father
Doyne E. Payne, Sr.
a Pearl Harbor survivor aboard the USS
Argonne...*

*...and to those fathers and husbands
who never made it home to their loved ones.*

RD Payne, Volunteer

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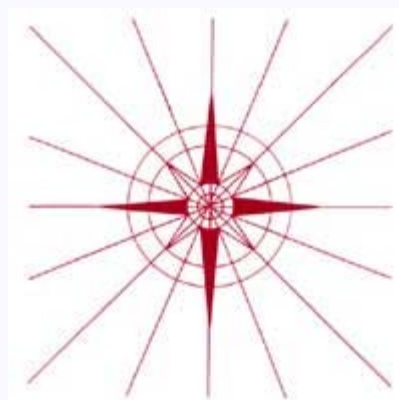
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RD Payne, Volunteer

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Foreword

At a time when more and more flashy, high-tech discoveries and salvage of long-lost undersea wrecks occur, this submerged cultural resource study of the Arizona Memorial is a refreshing change. The combined experience of the National Park Service's Submerged Cultural Resources Unit and the Navy's Mobile Diving and Salvage Unit One is remarkable, they are as expert at their business as can be found. What stands out, though, is that these talented divers sought and brought back for us all not artifacts, not souvenirs, not booty - simply knowledge. After the years of meticulous studies, foot-by-foot inspection and recording -- the USS ARIZONA and its sister ships all still rest secure, exactly as they were before this energetic endeavor began. You, too, can rest assured that these historic undersea relics will remain unimpaired. This is a classic study of how under sea explorations ought to be done so as to leave their historic subjects intact. In this publication, you have a thoughtful summary of the knowledge they gleaned.

Bryan Harry
Pacific Area Director
National Park Service

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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Acknowledgements

The work conducted on the USS ARIZONA and associated sites in Pearl Harbor was a complex undertaking. It involved cooperation among three major players: the U.S. Navy, the Arizona Memorial Museum Association and the National Park Service. Numerous individuals from each of these entities gave much of their time and energy to see the project through to its completion. Although this list is certainly not comprehensive, I would like to recognize some of these people for their efforts.

I won't dwell on individuals who have participated in authorship of this volume (including Gary Cummins and Bill Dickinson, Superintendents of the Memorial during the project), because their contributions will become apparent on reading the report. Several other employees of the memorial who continually gave much support to the project include Mark Senning, Farley Watanabe, Yvonne Menard, John Martini, Gary Warshefsky, Ric Smith, Andy Johnson, Lisa DuPratt, Mark Hertig, Mary Martinez, Lisa Collins, Dick Hilgendorf, Lina Fuamatu, Jamie Parish, Mark Tenaka-Sanders and the late Fred Kukonu. Daniel Martinez conducted important background research for the project each year besides writing the historical research chapter. Ray Emory, Pearl Harbor survivor, researched potential sites for Japanese submarines and aircraft. In addition, all members of the memorial staff made our frequent visits to Pearl Harbor a pleasure, and they put up with the disruptions we caused in their daily routines with warmth and good humor.

Jerry Livingston, besides his role as chief illustrator, was responsible for formatting the document in a desktop publication system and preparation of much of the camera-ready copy. Larry Murphy, besides being a co-author, was an important participant on the field level bringing his extensive background in underwater archeology and his photographic skills to the project. Larry Nordby, Chief of the Branch of Cultural Research in the NPS Southwest Regional Office, made a major contribution in his 1984 field renderings of the USS ARIZONA, port and starboard elevations, which the volume illustrator has incorporated into the final five perspectives. This, in addition to work he accomplished for us in 1986, made Larry a key figure in the ARIZONA project. Dave McLean, NPS Diving Officer from Lake Mead National Recreation Area, provided excellent daily coordination with Navy dive teams and was a valuable team member during all the field sessions. Jim Delgado, NPS Maritime Historian, obtained National Historic Landmark designation for both ARIZONA and UTAH, offered many helpful changes and additions to the historical record chapter and contributed a chapter to this report. Scott Henderson from the Naval Ocean Systems Center (NOSC), in addition to authoring a chapter, volunteered for followup dives to his original research along with Jeff Grouvhog, also from NOSC. Jim Miculka, interpretive ranger from War in the Pacific National Historical Park, participated in the project and brought several volunteers-in-parks from Guam, including Joe Taitano and Suzanne Hendricks. Scott Lopez from Hawaii Volcanoes

National Park participated frequently in the diving operations.

From the Arizona Memorial Museum Association, Gary Beito was very supportive of the survey work from its earliest stages. The clerks of the association bookstore were friendly to us despite our intrusive presence for weeks at a time over several years. The food and drinks donated by Concessionnaire Carol Lim are also appreciated. Pacific Area Director Bryan Harry, senior park service official in the study area, kept a quiet, watchful eye on the project as it unfolded but was ready to lend his support whenever necessary. This project also required smooth coordination between two NPS regional offices. Regional Directors of Western and Southwest Region (home office of SCRUC) during the period the work took place were Howard Chapman and Stan Albright (Western) and Bob Kerr and John Cook (Southwest). Roger Kelly, regional archeologist for Western Region played an active role each year in ensuring that this interregional coordination and cooperation held together. Chief archeologist of the National Park Service, Doug Scovill, has programmatic authority over the Submerged Cultural Resources Unit and strongly supported the Pearl Harbor operation. Cal Cummings, senior service archeologist in Denver, paid an on-site visit in 1986 and offered comparisons to work he was involved with on the USS MONITOR.

As will become apparent to the reader, the U.S. Navy was a close partner in this operation from the inception. We enjoyed active participation by U.S. Navy divers from Mobile Diving and Salvage Unit One (MDSU) and Explosive Ordnance Disposal (EOD) Mobile Unit One and Training and Evaluation Unit One in all phases of the research.

None of the activity would have taken place, however, without the sanction of Admirals Jeremiah, Anderson and Rorie, and Rear Admirals Boyle, Chadwick and Reimann. Commander Peck of MDSU supported the operation in the first few years. His successor, Commander David McCampbell, became intensely involved in the project and pulled out the stops in giving support to our operations; eventually, going beyond Pearl Harbor to various projects in Micronesia. In so doing, Commander McCampbell greatly advanced the concept of Project SeaMark, the name eventually assigned to the U.S. Navy/NPS cooperation on submerged resources work. That concept was first articulated by Commander James "Otto" Orzech as an active-duty training function for his reserve unit from Long Beach, California. Otto and his unit were primarily responsible for Navy support in the mapping of the USS UTAH, and Otto also was a major player in advancing the SeaMark concept to the Western Pacific. Commodore Rob Wells and Commodore David Wallace released fleet assets to assist NPS operations in Pearl Harbor and other joint ventures in the Pacific. Commander Steve Epperson provided services of his highly professional BOD divers for side scan and ordnance clearance activities on several occasions. Sub base support came from Captain Marshall. Lt. Michael Morrissey became an advocate for the SeaMark proposal with the Naval Surface Reserve Force in New Orleans and was largely responsible for securing funding for the work in 1986 at Pearl Harbor and later in Palau. Rob Hommon, archeologist with the Naval Facilities Engineering Command, provided coordination regarding matters of legal compliance with environmental legislation. Brian O'Connor, diver from MDSU One participated both in his Navy capacity and at other times as a volunteer diver and researcher.

The University of Hawaii, and Dr. Alex Malahof in particular, are thanked for contributing the use of a research submersible to the 1988 survey effort.

This manuscript was reviewed in draft form by Larry Nordby, Doug Scott, archeologist with the NPS Midwest Archeological Center, Don Boyer with the Bureau of Land Management in Santa Fe, Neil Mangum, NPS Historian in Santa Fe, Chief Historian of the National Park Service, Ed Bearss and his staff including Kevin Foster, Jim Charleton

and Jim Delgado. Joy Murphy did a technical edit of the contents. Fran Day, SCRU secretary, was responsible for typing the manuscript and mastering the interplay of several word processing systems.

In addition, we thank the following individuals and agencies for their help on the history section of this report.

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Chapter I: Introduction

On Dec. 7, 1941 the United States of America became directly involved in the greatest of human conflicts: World War II. Even before bombs fell on Pearl Harbor that Sunday morning, it was clear to many Americans that they would soon be at war with Japan. What was unexpected was the seemingly apocalyptic nature of the sneak attack. It was an event that emblazoned itself in the minds of millions of Americans, a passionate, inflamed response alive even today, spanning generations. The single most powerful image associated with the Pearl Harbor attack was the twisted, smoking metal and mast of the USS ARIZONA.

In 1983 the Submerged Cultural Resources Unit (SCRU) was tasked with mapping and photo-documenting the remains of the USS ARIZONA in its final resting place in Pearl Harbor. Superintendent Gary Cummins was responsible for managing a major national shrine, one that he couldn't see and for which there existed no management precedents. During the war Navy salvage teams had cut away most of the ship's superstructure. Eventually a memorial was built over the sunken ship's hull that is the grave of approximately 1,000 U.S. servicemen. Cummins wanted to know what sort of integrity the hull retained. Was it in imminent danger of falling apart? Where was the oil coming from that leaked so conspicuously from the ship? Did armament or live ordnance still exist in the wreckage? He asked those and a host of other questions that boiled down to "What's there?" It was perfectly clear what had been there before Dec. 7 1941, but notions regarding its present condition were riddled with contradiction and mystery.



Figure 1.1. Gary Cummins, Superintendent of ARIZONA National Memorial inspects embrasures of No. 1 turret. It was not known that the 14-inch guns were still in place on the ship until the underwater survey.
(NPS photo by Larry Murphy)

SCRU conducted a 10-day site assessment with assistance from park staff, the Arizona Memorial Association, and the U.S. Navy's Mobile Diving and Salvage Unit (MDSU) One in Pearl Harbor. Information gleaned from the 1983 assessment was used to plan comprehensive mapping operations that took place in 1984. This preliminary operation also dramatically illustrated how little was known of the ship's remains. The entire No. 1 turret with its 14-inch guns intact (which were believed to have been salvaged) was discovered by the first divers, as was a profusion of live 5-inch shells directly under the memorial structure. The latter were immediately removed by a Navy Explosive Ordnance Disposal (EOD) team.

The three weeks of intensive diving in 1984 produced sufficient data to complete a planimetric view of the ship, as well as drawings of the port and starboard elevations of the hulk. Drawings were finalized in winter 1984 and released in 1985 by SCRU in a five-part format that included two additional artist's perspectives from the port and starboard quarters. Jerry Livingston was responsible for the final rendering, which subsequently received the John Wesley Powell prize for Historic Display.



Figure 1.2. The USS ARIZONA from the air. Note that 14-inch guns of No. 1 turret are not visible.

(Photo courtesy of Hawaiian Service, Inc.)

In September 1985 Bill Dickinson became superintendent of the Arizona Memorial and resolved to continue research diving on the ship. He felt that the 1985 drawings had satisfactorily answered the question of "what's there?" but he was anxious to proceed with the next step in a logical research progression in order to determine "what's happening to what's there?" Before leaving his post, Cummins had suggested a corrosion study. Dickinson broadened that concept to include a full inventory of the biota and the relevant chemical environment around the hull that might influence long-term preservation. Both managers had come to realize during their tenure that the USS ARIZONA was essentially a large, multicompositional metal structure resting in a biochemical soup, and many more questions needed answering before they could confidently exercise proper stewardship over the site. It soon became clear that the first challenge in the process of obtaining good answers was to ask good questions, the parameters of which stretched across managerial and scientific disciplines.

Dickinson and the memorial staff spent much of winter 1985 and spring 1986 coordinating with SCRUI, the University of Hawaii and the Naval Ocean Systems Center (NOSC) on the research design for a field operation scheduled for June of that year. As in prior years, Dan Lenihan would be overall director of research operations, but primary responsibility for the biofouling aspects of the study lay with Scott Henderson from NOSC.

The 1986 endeavor would be especially complicated because of several developments. Robert Sumrall, a ship modeler from Annapolis, was contracted to construct a model of the USS ARIZONA on the harbor bottom from the 1985 drawings produced by SCRUI. To do so, Sumrall needed more information from the planimetric or "bird's eye" view, one of the five perspectives produced by the earlier work. To provide additional detail, it was decided to resurvey that "bird's eye" view of the site and add objects lying on the deck that might have been overlooked previously.

Another event that altered the course of the 1986 research was an encounter between Lenihan and a U.S. Navy Reserves officer at the fall 1985 meeting of the American Academy of Underwater Sciences. There Commander James "Otto" Orzech expressed great interest in the project because it seemed to be a realistic training exercise for his

detachment of reserve Navy divers from Long Beach, California. He agreed to assist with the task of mapping the USS UTAH, which was lying on its side on the other side of Ford Island from the ARIZONA. Orzech's unit would participate as part of the unit's active-duty training at no cost to the National Park Service, if the Service could provide under water and topside supervision of the research.



Figure 1.3. NPS and Navy divers deploy from the tour boat. Operations were so visible to visitors that park staff discussed the survey in their interpretive talks.
(NPS photo by Larry Murphy)

By now all the principal players realized that the most meaningful context to present the results of the ARIZONA study would be the Pearl Harbor attack. Describing that context would involve research in other parts of Pearl Harbor, but it was unclear where the funding would come from for operations outside the park boundary. The UTAH was the only other ship that remained from the attack. Japanese planes and submarines were believed to be on the harbor bottom. Documenting all those would be logical steps in completing the Pearl Harbor story from an underwater perspective. With support from the active-duty Navy at Pearl and the Long Beach Reserves unit, and the continued backing of the Arizona Memorial Museum Association, they now became realizable objectives.

A final element that raised the complexity and intensity of the 1986 field operations was the British Broadcasting Corporation (BBC), who felt that the research was important and merited inclusion in a major public television series, titled "Discoveries Underwater." Consequently, when the three-week session began in June, logistics involved coordinating Navy, National Park Service and BBC dive teams. Lenihan assigned SCRU Archeologist Larry Murphy oversight responsibilities for the UTAH site and Larry Nordby the task of revising the planimetric view of the ARIZONA. NPS divers from the memorial staff who were veterans of the three previous project phases were assigned to work with Scott Henderson. To the surprise of many, the project progressed smoothly and effectively, and all major objectives were achieved. It was decided early in the project, however, to postpone any search for Japanese aircraft lost in the attack because it would overextend the SCRU staff, which was by then supervising the research activities of 60 divers at two separate sites under a complex research design.



Figure 1.4. An already complex operation in 1986 was further complicated by the addition of a BBC camera team that filmed the operation for a public broadcasting system special.
(NPS photo)

In 1987 the USS UTAH documentation was completed. In a comparatively low-key operation, a small contingent of Navy divers from the Long Beach unit assisted Lenihan and Jerry Livingston in obtaining final details on the target ship. During that time Bill Dickinson also used the dive team -- supervised from the surface by a structural engineer -- to conduct an underwater survey of the mooring chains for the memorial's floating dock. The results of that survey will be reported separately.

The research project had expanded to be a full submerged cultural resources study of World War II remains in Pearl Harbor. The final phase occurred over a three-week period in 1988. Daniel Martinez, a staff historian at the memorial, in 1986 developed a predictive model for airplane crash sites, based on cross-sitings from different vessels during the attack. The model isolated high-probability areas by matching sitings of splashdowns and high-velocity crashes with an assessment of post-war dredging reports. Active-duty MDSU One divers from Pearl Harbor were assigned to survey the predicted crash sites. In addition, a side-scan sonar team from EOD One in Pearl Harbor was assigned to the project. Under the leadership of Lieutenant Hank Chace, EOD was to survey the inner harbor for planes. EOD was also assigned to search the 1,000+-foot-deep defensive perimeter outside the harbor mouth for a Japanese mini-sub reportedly sunk by the destroyer USS WARD more than an hour before the aerial attack began. The submarine base at Pearl Harbor provided major boat and logistic support, and Mesotech Corporation donated a sophisticated sonar unit to help in the inner harbor. Background research for that survey was provided by Ray Emory, a USS Arizona Memorial volunteer and Pearl Harbor survivor, with assistance from Daniel Martinez and others on the memorial staff, and Brian O'Connor, a U.S. Navy diver. The survey in the inner harbor was grueling but effective, and yielded primarily negative data returns. In the eleventh hour of the offshore operation, however, a sonar contact was made with what may well be the midget submarine sunk by the USS WARD. At the time of this report the identity of the contact has yet to be confirmed, although an attempt was made to locate it with a submersible provided by the University of Hawaii.

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Chapter II: Historical Record

The purpose of this chapter is to provide a historical context for World War II remains in Pearl Harbor. As discussed in Chapter I, the research project reported here primarily documented the archeological materials remaining from the December 7 attack. In order to understand the significance of these materials as cultural resources, it is important to place them in their contemporary historical context.

As is the format for historical/archeological studies, the discussion will focus primarily on remains that are known or suspected to be still present in the archeological record. The degree of emphasis placed on discussion of individual ships, events or places has been strongly influenced by what sites the archeologists chose to concentrate their energies on during the survey.

In addition to the remains directly attributable to the attack, a discussion of the West Loch disaster that occurred in 1944 is also included. This event is thought to be a major contributor of additional World War II remains to the universe of potential sites that might be encountered in the harbor.

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Chapter III: Archeological Record

USS ARIZONA

Methodology

The approach used to document the USS ARIZONA and its immediate environment was low-tech and labor-intensive. No one had ever attempted a detailed mapping of a 608-foot battleship in water of 6-foot visibility. There were no guidelines to follow and no black-box technology that could significantly help. Photogrammetry was precluded because of the visibility constraints, shallow water and high site relief. High-resolution sonar mapping techniques are still in the early stages of development.

The most valuable assets at the disposal of the research director were a highly experienced team of NPS survey archeologists and illustrators, and other diving personnel from the park and US Navy. The methodology centered around string, clothespins, measuring tapes and a lot of mapping savvy -- ironically, much of that derived from mapping Pueblo Indian sites in the desert. About half a mile of No. 18 nylon string was laid over the ship to establish straight lines in a world of twisted metal. Lines were marked every 10 feet with numbered plastic clips, forming a kind of "cat's cradle" over the site. The cradle with its measurable lines was first plotted on paper and then, laboriously, the shipwreck measurements followed. Simple trilateration techniques related known points on the marked lines to target features on the wreck.



Figure 3.1. U.S. Navy divers add marked clips every 10 feet to survey line on USS ARIZONA after it was installed by NPS underwater archeologists.
(NPS photo by Larry Murphy)

Each evening all the data acquired during the day were copied onto a master set of drawings. Each morning mylar overlays were made of small sections of the drawing and affixed to divers' slates, who returned to the bottom for additional detail. Divers had a list of required measurements, and they would simply fill in the blanks on each dive. On some dives more than 60 measurements were taken by a two-person team. Thousands of separate measurements were taken during the four weeks spent in the field. An ordinary plastic protractor was used to record changes in angles of the straight lines.

Responsibility for the planimetric view was given to Jerry Livingston and the elevations (profiles) to Larry Nordby. Farley Watanabe and Mark Senning were assigned to the starboard elevation, while Larry concentrated his own in-water time on the port elevation.

To confirm accuracy of critical points along the gunnel and other features of the badly deformed deck, a local survey crew shot targets with an infrared theodolite, or electronic distance-measuring (EDM) instrument. Divers held the reflective mirrors of the EDM motionless on top of a PVC pole, as the bottom was held in place on the feature to be mapped. This proved to be useful in areas where the pole could be stabilized, but was awkward at other points.



Figure 3.2. Numbered clothespins in upper right hand corner marks a survey point. Diver is sketching feature for inclusion in site map.
(NPS photo by Larry Murphy)

A particularly vexing problem developed over the first few days, when the string baseline calculations on the planimetric view repeatedly indicated the gunnels to be several feet wider apart in the bow than was described in the construction plans. This beam measurement was not a detail that should have been altered on ship modifications. We hoped that the infrared theodolite would correct the disparity. To our surprise, the theodolite confirmed the data gleaned from the strings, indicating the ship had expanded at the explosion point, much like an overpressurized tin can. This buckling had not been evident to the divers underwater, whose visual references were compromised by the visibility.

The hull curvature presented other problems for the elevation views. A diver even one body length away could not see the ship, so it was necessary to hand-measure over curves as if they were on a two-dimensional plane. For our purposes, the ship was divided into 10 sections of 60 feet long by the vertical strings from the cradle, creating 20 individual "frames" to be drawn in two dimensions. This approach had one problem: When the whole vessel was pieced together, the scaled drawing was longer than the actual ship. Consequently, the illustrators had to correct each frame to compensate for the two-dimensional depiction of the ship's curved hull. This correcting process was more pronounced on some frames than others, depending on the curvature of each specific section of hull. This was a point in the project where it was highly advantageous to have mappers experienced in rendering cliff dwellings on Southwestern archeological sites. The irregular, three-dimensional features nestled in curving alcove walls of sandstone cliffs provide similar problems for illustrators.



Figure 3.3. After being drawn, each feature is measured back to two points on the baseline. This allows accurate mapping through a simple geometric procedure called trilateration.
(NPS photo by Larry Murphy)

By the time the assessment project began in 1983, low-cost and self-contained color video systems had become commercially available. One of these units was purchased and put to great use in these field operations. The video was capable of recording at least as much as a diver could see in the limited visibility, and was much easier to use in the harbor environment than standard photographic systems. Still photography does not provide instant feed back to the photographer, whereas the color video had a monitor built into the housing that permitted the operator to see exactly what was coming back in "real time." Tricky photographic problems associated with using artificial light in silty water were also reduced by the supplemental use of video.

Perhaps the greatest advantage of video became apparent in the office in Santa Fe months after the field work was completed. Livingston was able to fill in much detail between known map points on specific features by consulting the video tapes. Besides the assistance this provided in the mapping process, tapes resulting from the survey activities proved to be exceptional tools for education, both at the visitors center and on loan to the electronic media. During the active phase of the project, all Honolulu TV channels carried several minutes of the video returns every night for weeks running, and some segments were broadcast on national television.

In addition to rendering architectural drawings of the hull, the team conducted perimeter searches of the battleship to establish the site's extent, inventory the recognizable artifacts where they lay in the wreckage, and mark their positions on the site's base map. The depth of silt around the perimeter of the site was determined by probing with a PVC rod marked in 1-foot increments. All artifacts were left in place, with the exception of items that presented an unacceptable hazard to the memorial that straddles the ARIZONA and through which 5,000 visitors pass each day. Hazardous material included unexploded shells from the 5-inch guns, sacks of congealed gun powder, and corroded high-pressure air or acetylene bottles that were probably used during the salvage activity. The Navy's Explosive Ordnance Disposal (EOD No. 1) team was stationed nearby, and on several occasions they responded to our request to remove such items while the surveyors gingerly exited the water.

Additional studies of the wreck's natural environment were carried out with much greater intensity in 1986, and the methodology is reported in detail in Chapter IV. Those studies included a detailed analysis of the biomass and corrosive properties of the ship, in addition to silt measurements. The technology included manual probes, sampling containers, oxygen probes and a bathythermometer, which measures galvanic potential of the metal underneath the biofouling crust.

Perimeter surveys to determine the extent of the wreckage field were accomplished using two modes: side-scan technology and divers. Side-scan sonar passes were run in 1983 and again in 1988 using a Klein 100 KHz. A Mesotech side-scan unit used in sector-scan and polar-scan modes was added in 1988. To augment sonar results, dive teams were deployed to conduct 180-degree sweeps that covered the bottom at least 100 feet from the hull remains. The only items divers found were features already noted by the sonar. These features have been incorporated into the site map.

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Chapter IV: Biofouling And Corrosion Study

Introduction

Until the joint National Park Service (NPS) and Navy mapping survey in 1983, no major assessment of the USS ARIZONA had occurred since salvage activities after the ship's sinking in 1941. The five-year project contained many facets in its search for information relevant to long-term management of submerged components of the Pearl Harbor National Historic Landmark, especially the USS ARIZONA and the USS UTAH. The July 1986 study examined, among others, one particular aspect of the ship: the role of biofouling in the overall corrosion process. This chapter discusses the methodology and presents the results of that biofouling and corrosion study. Although some comparative data was taken from the USS UTAH, this research focused almost exclusively on the USS ARIZONA.

Our objectives were to: 1) develop a baseline inventory of biological communities and sedimentation extant on structural remains of the ship, and 2) obtain quantifiable measurements of the present state of deterioration of the ship's metal structural elements at various locations (ref. 1). The data gathered would then be used to assess the causes and rates of deterioration of the ship components, and would subsequently provide a scientific basis for making informed decisions regarding the ARIZONA's management and preservation. These objectives do not imply a commitment by federal managers to undertake stabilization of deterioration or in-place preservation (ref. 1).

Several working hypotheses pertaining to the ship's biofouling and corrosion status were formulated prior to the survey to define specific data requirements.

Hypotheses related to vertical ship surfaces were:

1. A layer of hard fouling growth creates anoxic (low oxygen) conditions at the metal surface and reduces the corrosion rate to far below what would occur on a nonfouled surface.
2. The fouling growth (dead and alive) is stable and dense, and forms a relatively homogenous layer over nearly all vertical areas.
3. Thickness and density of fouling growth is negatively correlated with corrosion rate of the underlying surface.

4. Interior hull and wall surfaces are expected to have lesser areal coverage and thickness of fouling growth, and thus may be subjected to higher corrosion rates than exterior surfaces.

5. Hull components buried in silt exhibit a very low corrosion rate.

Hypotheses related to horizontal (wood and steel) ship surfaces were:

1. A layer of sediment creates anoxic conditions on horizontal surfaces and reduces corrosion and decomposition rates far below those that would occur on uncovered surfaces.

2. The sediment layer is stable and covers nearly all horizontal areas.

3. Corrosion and deterioration of horizontal surfaces are correlated with sediment thickness and porosity.

Two other hypotheses were formulated concerning possible long-term effects on biofouling communities:

1. Nutrient, pollutant and plankton levels will slowly decline in Pearl Harbor as a result of ongoing pollution abatement.

2. Biofouling communities will decrease because of their dependence on the above factors.

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Chapter V: USS Arizona: The Management Experience

This chapter was written by two managers, Gary Cummins and Bill Dickinson, who served consecutively as superintendents of the USS Arizona Memorial from 1980 through 1988.

Introduction

The USS ARIZONA, USS UTAH and Pearl Harbor surveys, a five-year project to inventory those cultural resources, contributed to our knowledge of the historical significance of submerged cultural resources within Pearl Harbor National Historic Landmark. As a result of these surveys, managers at the USS Arizona Memorial have become aware of the unique and complex issues surrounding submerged-resource protection, and have learned how acute the need is for decisions affecting future preservation policy.

As site managers responsible for an internationally significant submerged cultural resource, we have wrestled with management decisions that had precious few guidelines and precedents. If other National Park Service managers are wrestling with similar issues and making different decisions, NPS will be perpetuating inconsistencies in management practices.

Should we be doing anything to preserve shipwrecks in place? What about shipwrecks that are also grave sites? Should we let the natural processes continue unimpaired? Should we be looking for means to slow or stop deterioration? Should we be retrieving significant artifacts? Should we, for example, remove the 14-inch guns from the USS ARIZONA so they can be displayed and people can see them before they are lost to corrosion? Should we document wrecks with known dead? Should we merely monitor the deterioration process, noting changes in conditions that occur over time but allowing deterioration to continue? Should we be diving on such submerged grave sites? Should we penetrate them? Some people argue that we are disturbing the final resting place of those who perished by diving on these wrecks. If we don't dive them, how do we learn enough to make responsible management decisions regarding health, safety and appropriate visitor use?

As we continue to study submerged cultural resources, we will gain more experience -- and answers. Equally important, we will better understand what future questions to ask.

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Chapter VI: SIGNIFICANCE: Memorials, Myths And Symbols

Yesterday, December 7, 1941 -- a date which will live in infamy -- the United States of America was suddenly and deliberately attacked by naval and air forces of the Empire of Japan . . . The attack yesterday on the Hawaiian Islands has caused severe damage to American naval and military forces. Very many American lives have been lost . . . Always we will remember the character of the onslaught against us. No matter how long it may take us to overcome this premeditated invasion, the American people in their righteous might will win through to absolute victory . . .

(Franklin Delano Roosevelt December 8, 1941)

The underwater survey of the Pearl Harbor National Historic Landmark mapped and photodocumented the USS ARIZONA and the USS UTAH. The survey team also searched for a Japanese midget submarine sunk by the USS WARD in the defensive zone, Japanese aircraft, and parts from American vessels damaged or sunk on December 7, 1941. The scientific recordation of these war remains, while fulfilling a management need, also allowed archeologists to compare the physical aftermath of one of the most dramatic events in 20th-century American history to the historical record. The fabric of history could be viewed against the back drop of contemporary perceptions and now-fading memories of the "day of infamy."

While the archeological evaluation of the Pearl Harbor attack fascinates many Americans, it is the event itself that so ingrained itself in the nation's consciousness. Pearl Harbor, particularly the USS ARIZONA, has become a national shrine. Pearl Harbor and every trace of the American forces that defended it are now imbued with an almost religious significance. As such, the ARIZONA and the UTAH, along with pieces of other battleships are relics of considerable cultural value, while artifacts associated with the attacker have their own special emotional impact for citizens of both nations. The conclusion of the Japanese attack of December 7, 1941 left behind a range of traces, artifacts and relics that form the most significant site associated with the Second World War in the United States. Pearl Harbor is one of the most emotion-laden and important war sites in the world for two generations of Americans and Japanese.

The late Gordon W. Prange, assessing the impact of Pearl Harbor, notes, "Not all the tragedy . . . could be measured in terms of lost men, ships and aircraft, nor all its glory in terms of courage, unity and the seizing of a new day. With the events of December 7, 1941, something happened to the American spirit. The flames of Pearl Harbor burned away a certain national innocence" (Prange 1986:604-605). Prange believed that Pearl Harbor's primary value lay in warning future generations about being caught unprepared and by surprise. For many visitors to the USS Arizona Memorial, the memorial is a

"silent protest against smugness and unpreparedness" (Prange 1986:598).

Although cultural values are diverse and often intensely personal, certain sites carry obvious transcendent values. Decades of increasing tensions between the United States and Japan erupted in the attack on the United States Pacific Fleet at Pearl Harbor. The attack, a tactical coup for the Japanese, followed their longstanding tradition of surprise attack. To many Americans, the surprise and shock of suddenly being plunged into a world war after two decades of isolationism was a brutal awakening. It was attended by horror at American unpreparedness, the near destruction of the battleships of the Pacific Fleet, and the death of thousands of servicemen and civilians. Almost any American not an infant on December 7, 1941 remembers with clarity where they were and what they were doing when the news of the attack was flashed to an unsuspecting nation. Shock turned to indignation, then rage, and finally a steely determination to wage total war. The slogan was "Remember Pearl Harbor!"

The United States Naval Base, Pearl Harbor, was designated a National Historic Landmark in 1965 because of its role in American expansion into the Pacific. Although still an active naval base, the harbor is prominent because the United States recognizes the importance of those historic events. The attack of December 7, 1941 was one aspect of the base's history and significance. In 1978 further study of the Pearl Harbor National Historic Landmark indicated that specific aspects of the attack deserved additional attention and designation, and a number of nearby sites including Wheeler, Kaneohe and Hickam Field were designated National Historic Landmarks on the basis of their roles on December 7, 1941. These designations were part of a larger study of sites associated with the War in the Pacific specially requested by Congress and prepared by Historian Erwin Thompson. As part of that study, a number of vessels that served in the War in the Pacific were separately evaluated by National Park Service historian Harry A. Butowsky. Butowsky's "warship" study identified more than 25 vessels, including aircraft carriers, battleships, destroyers and submarines. On January 22, 1984, 21 of those vessels were designated as National Historic Landmarks, including the submarine USS BOWFIN, on display at Pearl Harbor (Butowsky 1985).

No vessel present at Pearl Harbor on December 7, 1941 became a National Historic Landmark until recently. Of 97 U.S. vessels present at Pearl Harbor, and of the 31 Japanese vessels deployed in the "Hawaii Operation," only two American and two Japanese vessels are known to survive. The United States Coast Guard cutter TANEY is now a museum ship in Baltimore, Maryland; the only surviving U.S. Naval vessel left afloat is the former yard tug HOGA (YT-146), now the fireboat CITY OF OAKLAND, in Oakland, California; and two Japanese midget submarines lost during the attack. HA. 19, a midget submarine that washed ashore at Bellows Point on December 8, 1941, was exhibited in Key West, Florida, after the war. Another midget, discovered sunk in 1960, was raised and returned to Japan. It is a memorial on display at the Japanese Naval Academy at Eta Jima.

Of the other vessels present that day, all were removed except two: the USS ARIZONA and the USS UTAH. Some of these vessels exist as shipwrecks elsewhere. Of these, only the wreck of the USS PENNSYLVANIA -- the ARIZONA'S sister-ship and the flagship of the Pacific Fleet, which was slightly damaged in drydock at Pearl Harbor -- lies in deep waters off Kwajalein, where it was sunk after postwar weapons tests. TANEY was designated a National Historic Landmark on January 27, 1988. HOGA and HA. 19 were assessed in late 1988 and designated NHLs on June 30, 1989. Another Japanese midget submarine may have been located in 1988 during the NPS/Navy submerged cultural resources survey.

The sunken hulks of the USS ARIZONA and the USS UTAH were merely mentioned in the initial National Historic Landmark documentation of Pearl Harbor. The 1978 NHL reassessment determined that the two vessels, as well as their memorials, were contributing elements to the NHL. The two hulks were not assessed or documented under the criteria of the National Historic Landmarks program until 1988, following five years of archaeological documentation. Substantially intact, the USS ARIZONA and the USS UTAH were nominated on July 9, 1988 as properties of exceptional national significance worthy of individual designation as National Historical Landmarks. On October 24, 1988, the National Park System Advisory Board, meeting in New Orleans, reviewed the studies and formally recommended them to the Secretary of the Interior for NHL designation. Both the USS ARIZONA and the USS UTAH were designated National Historic Landmarks by Secretary of the Interior Manuel P. Lujan on May 5, 1989.

The Secretary's designation recognized the ARIZONA's exceptional national importance, both as a historical property and as a national shrine. The battle-scarred remains of the submerged battleship are the focal point of a memorial erected by the people of the United States to honor all American servicemen killed on December 7, 1941. The ARIZONA's burning superstructure and listing foremast, photographed in the aftermath of the attack epitomized to the nation the words "Remember Pearl Harbor," and is one of the best-known images of the Second World War in the Pacific. One war poster graphically presented the image of the shattered, burning ARIZONA, exhorting viewers to "Avenge December 7" while a seaman shook an angry fist (Figure 6.1).



Figure 6.1. This war poster illustrates the role of Pearl Harbor as a national symbol used in accelerating the war effort.
(NPS photo)

The USS ARIZONA and the Arizona Memorial have become a major shrine and point of remembrance not only for the lost battleship but also for the entire attack. The explosion that destroyed the ARIZONA shook the harbor, blew debris and parts of bodies for thousands of feet. It was the central event of the attack and remains central in the reminiscences of most survivors. Indelibly impressed into the national memory, the ARIZONA is visited by millions who quietly file through, toss flower wreaths and leis into the water, look at the rusting hulk through the oil-stained water, and read the names of the dead carved on the marble plaque attached to the memorial's walls. Perhaps more important than the modern memorial that straddles ARIZONA is the battleship itself, which is the ultimate shrine. Resting in the silt of Pearl Harbor, the USS ARIZONA is a naval memorial and a war grave. It was the scene of tragedy, triumph and heroism. The wrecked ARIZONA is also a crystallized moment in time, its death wounds visible and

still bleeding oil, the intact hull holding most of the crew.

The wreck now serves as a "temporal touchstone," drawing visitors who reflect on the tragedy of the Pearl Harbor attack: the loss of many of the ARIZONA's crew and more than a thousand other Americans on December 7, 1941, and the heroism of those who died defending their country. Among the honors awarded to Pearl Harbor survivors and victims were sixteen Medals of Honor, 48 Navy Crosses, 7 Distinguished Service Crosses, one Army Distinguished Service Medal, 1 Navy Distinguished Service Medal, 3 Legions of Merit, and hundreds of commendations (Ross and Ross 1988).

The other victim of the attack still left at Pearl Harbor, the USS UTAH, was also designated a National Historic Landmark. Less known than the ARIZONA, the UTAH has been called the "forgotten victim" of Pearl Harbor. The UTAH was not an intended target of the Japanese, and the mythology is incorrect that says the former battleship turned target ship was sunk after a mistaken identification as an aircraft carrier. The UTAH did not explode dramatically. Torpedoed, it capsized, killing 64 of its crew. Chief Watertender Peter Tomich stayed at his post and helped save other men's lives by laying down his own, posthumously winning the Medal of Honor. After unsuccessful attempts at salvage, the outdated target ship was left as a tomb for 58 members of its crew behind Ford Island. Neglected, the UTAH was recognized with its own memorial in 1971. Although its sinking did not capture the public imagination like the ARIZONA, the target ship was by far the more historically significant at the time of sinking.

The UTAH's career as both a battleship and target ship spanned three decades and included nationally significant service with international implications. The UTAH was the primary U.S. warship involved in the American landings at Vera Cruz, Mexico in 1914 and participated in the First World War. Its alteration from battleship to target ship because of conditions of the Washington Naval Treaty of 1922 was part of a program that had considerable impact on the U.S. Navy, as well as many other nations' navies. Ironically, Japanese anger over what they perceived to be unfair treaty ratios contributed to the war that followed. As a target ship, the UTAH trained naval gunnery and bombing crews. Its use as a platform for antiaircraft weapons was of particular importance: Many of the gunners who shot down Japanese aircraft in the opening stages of the war were trained aboard the UTAH. The intact battleship's hull, still armed with 1941 state-of-the-art antiaircraft weapons, is a unique, well-preserved entity with considerable architectural integrity. Grouped with the National Historic Landmark battleship USS TEXAS (1913) at San Jacinto, Texas and the ARIZONA, the UTAH (1909) is one of only three surviving pre WWII American super-dreadnoughts. The three battleships recall an earlier arms race when power was measured in battleship tonnage and the diameter of shells in a ship's main battery of guns.

The significance of the ARIZONA, also a World War I participant, clearly focuses on the events of December 7, 1941 and its aftermath. "ARIZONA is best remembered for the nature of her loss, perhaps the worst single naval disaster in our history, and certainly the best known symbol of the attack on Pearl Harbor" (Friedman et al. 1978:39). Thus it is fitting that it be the focal point of memorialization and remembrance. The ship is the basis of a special type of memorial that focuses on ultimate victory against initial bad odds, on death not in vain, of sacrifice and honor. A malleable symbol, a national shrine and a historic property, the USS ARIZONA's significance is not that of a historic vessel, as is the UTAH. The significance of the ARIZONA more closely relates to its status as a naval memorial, a war grave and a national symbol.

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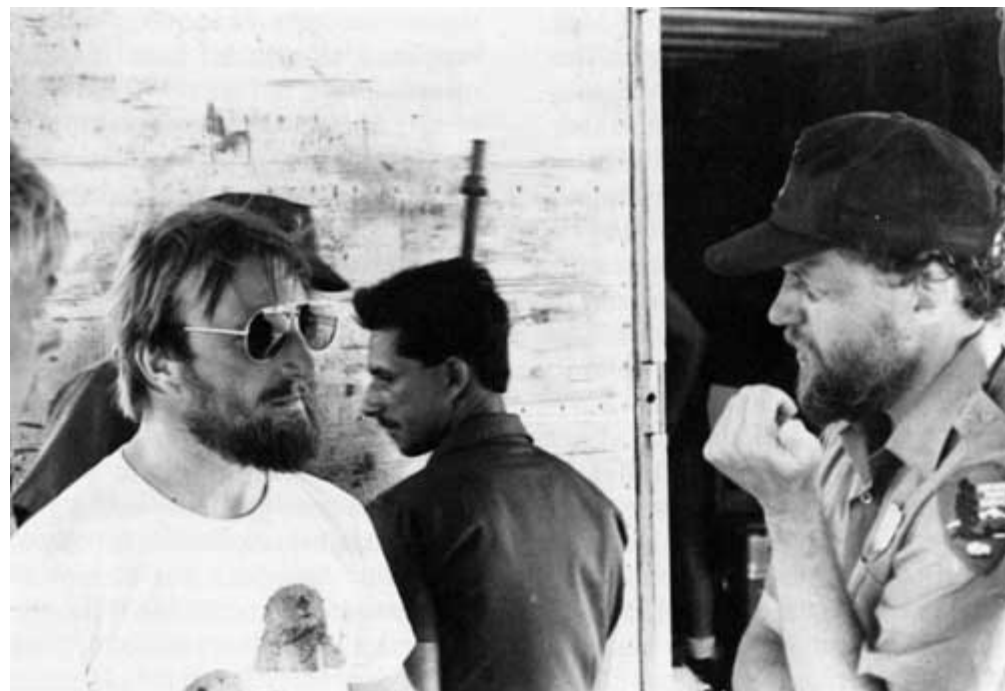
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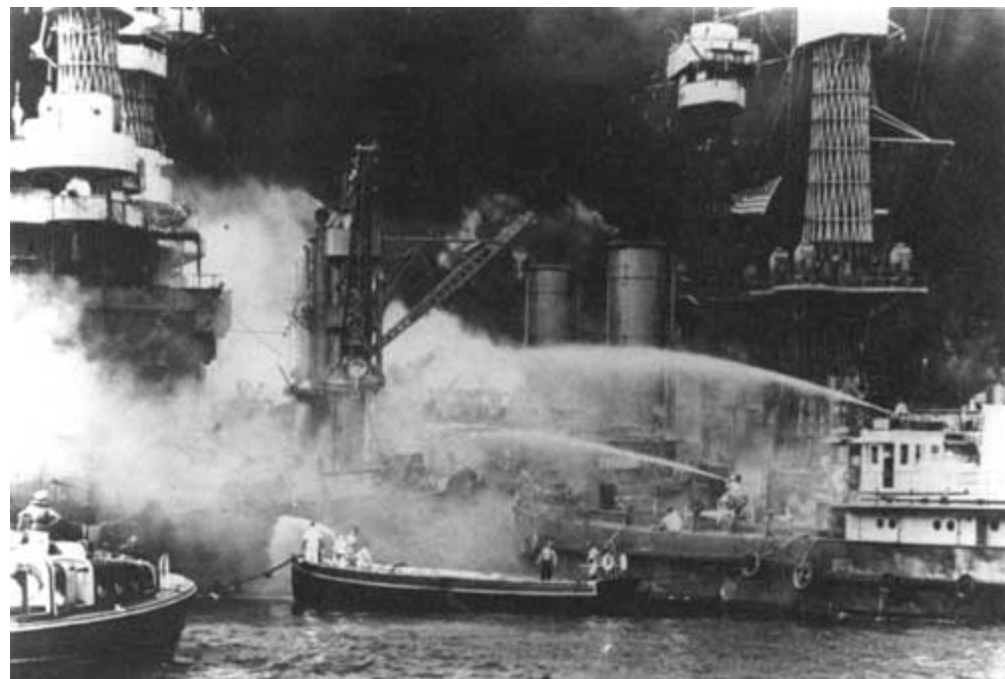




























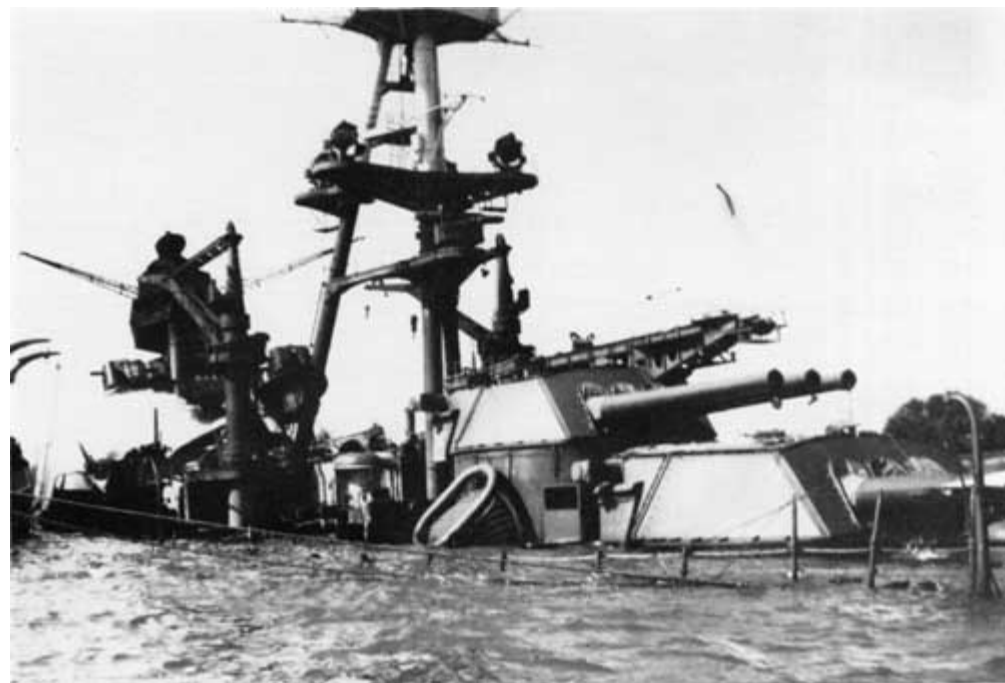






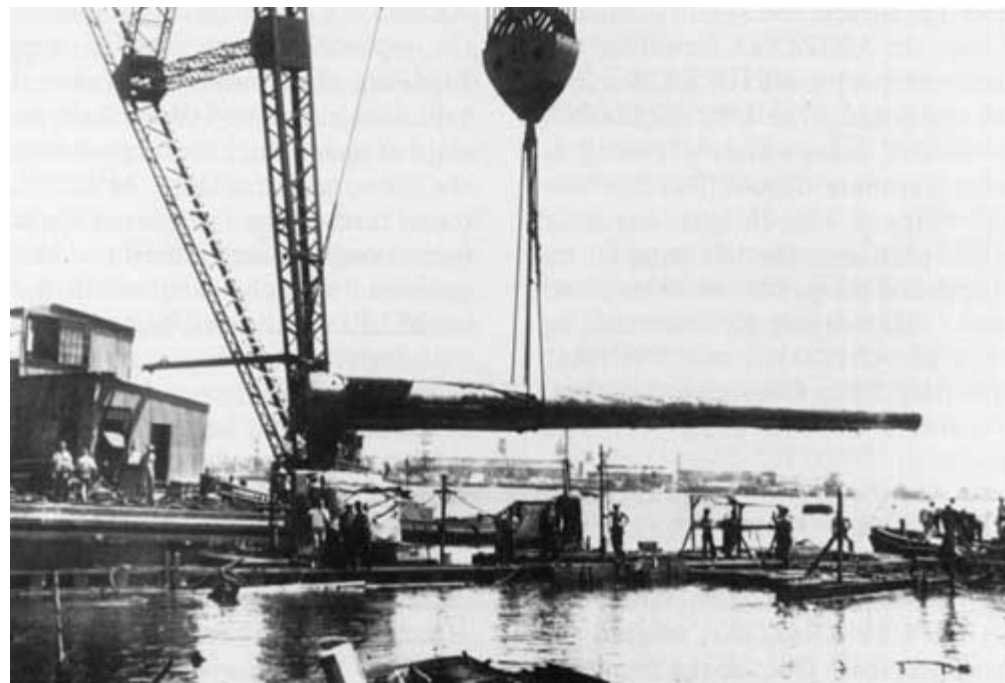


USS ARIZONA (BB-39)









CONFIDENTIAL

NAVY YARD PEARL HARBOR, T.H.

NOT TO BE RELEASED FOR PUBLICATION

4-3-42

REAR VIEW OF UPPER SECTION OF ROTATING PORTION OF TUN
LIFTED FROM TOWING CRANE

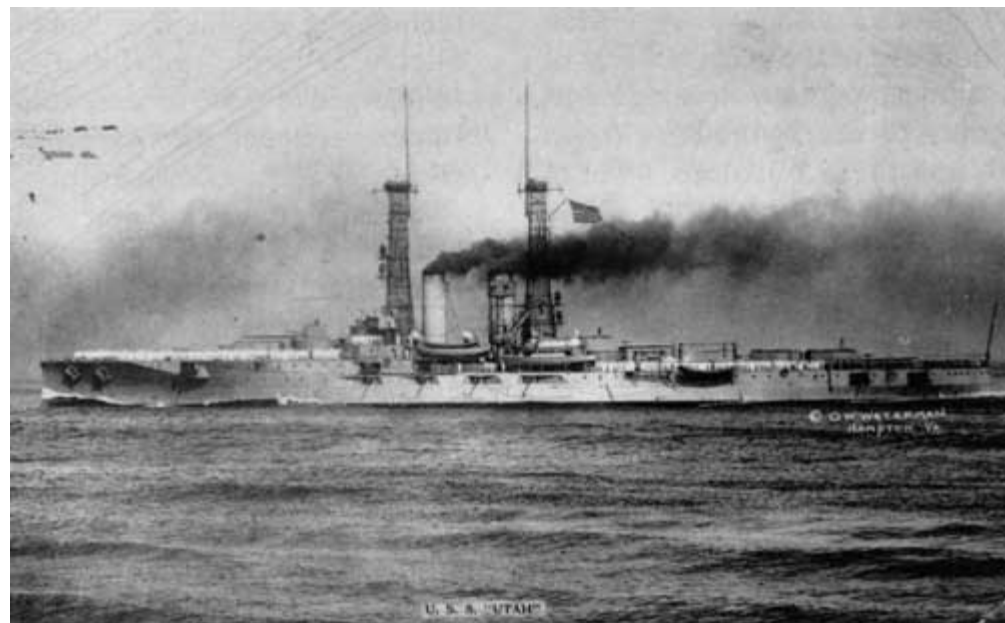
USS ARIZONA (BB-39) - SALVAGE

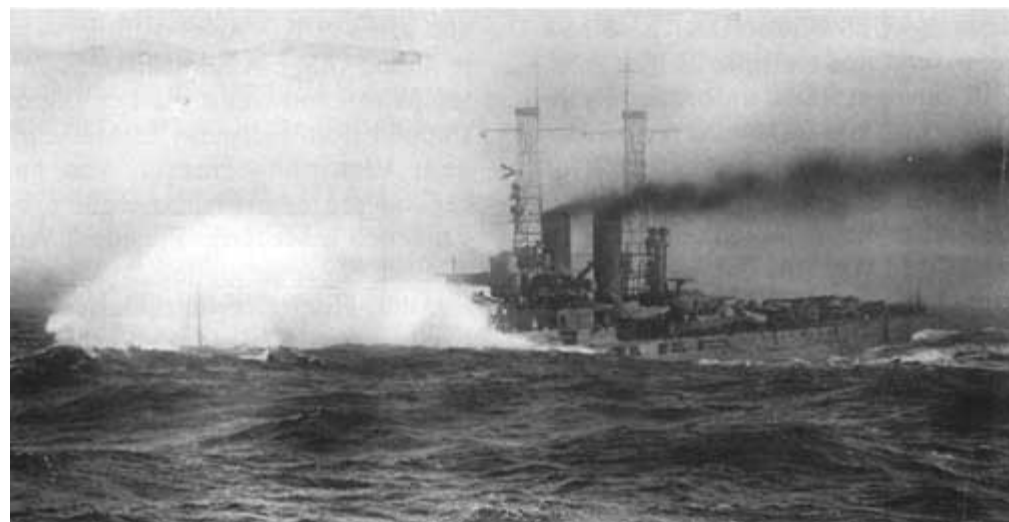










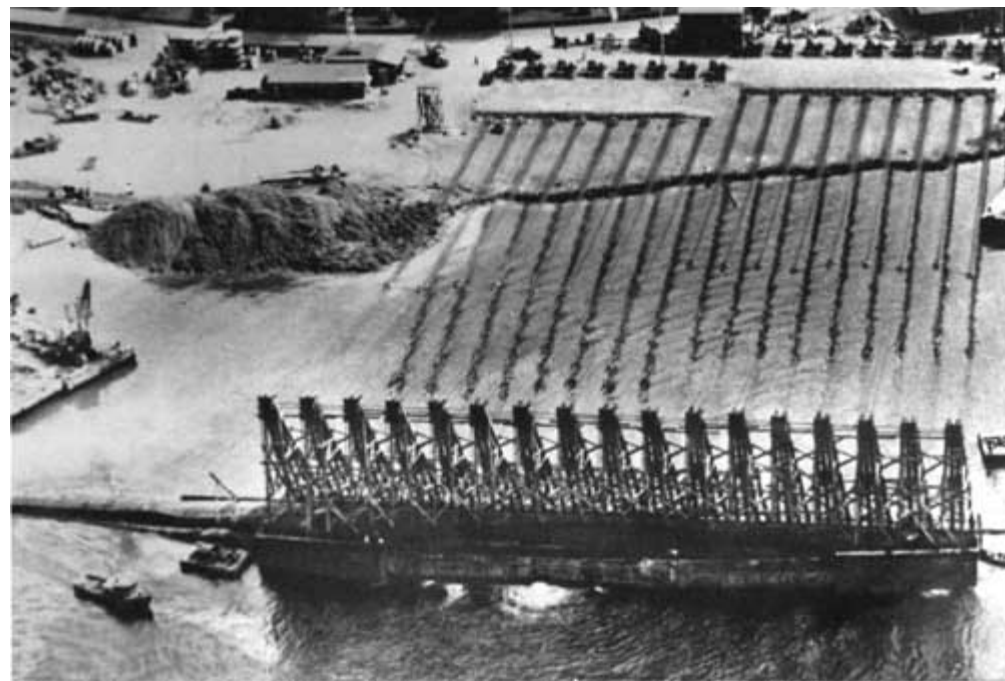


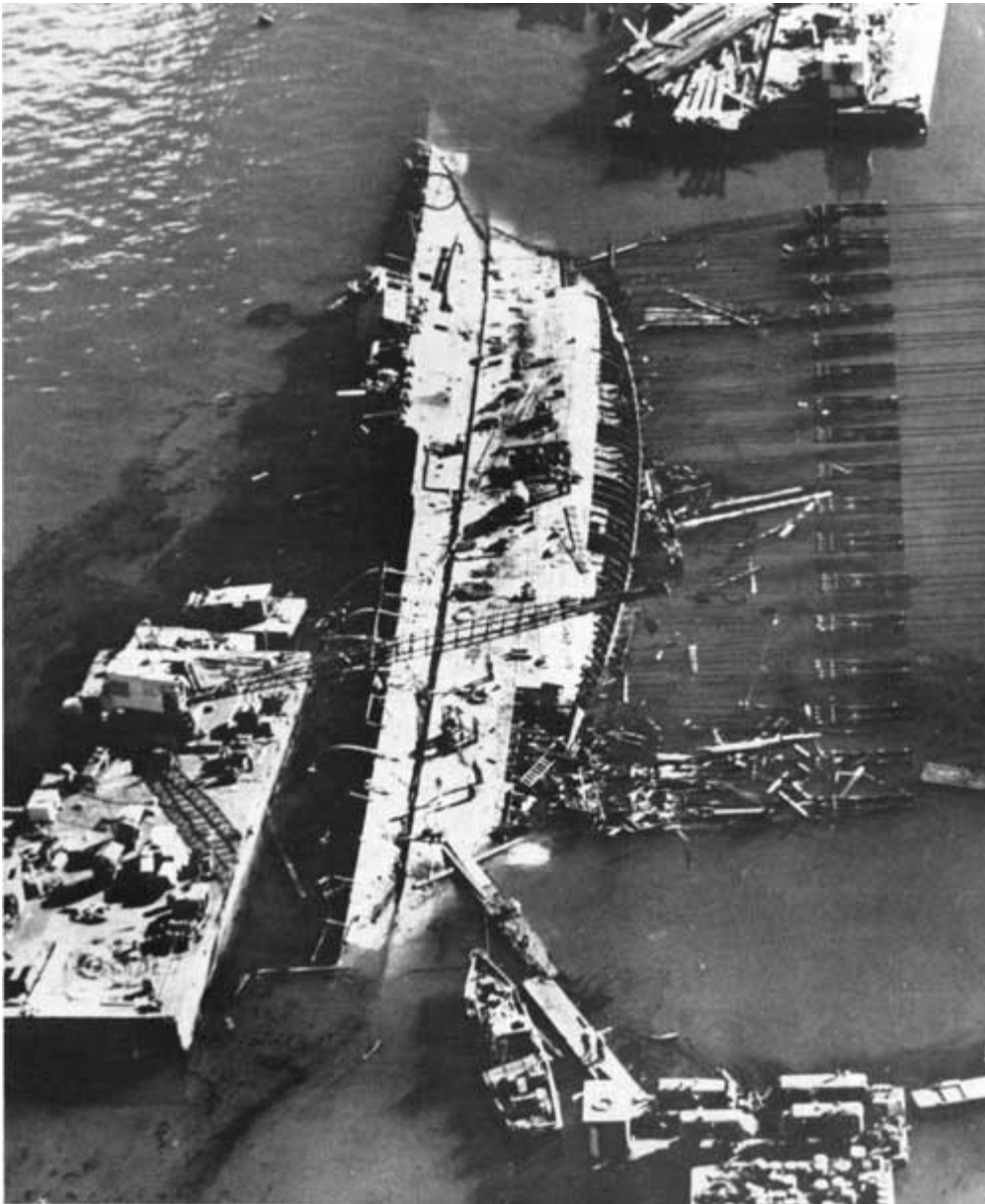


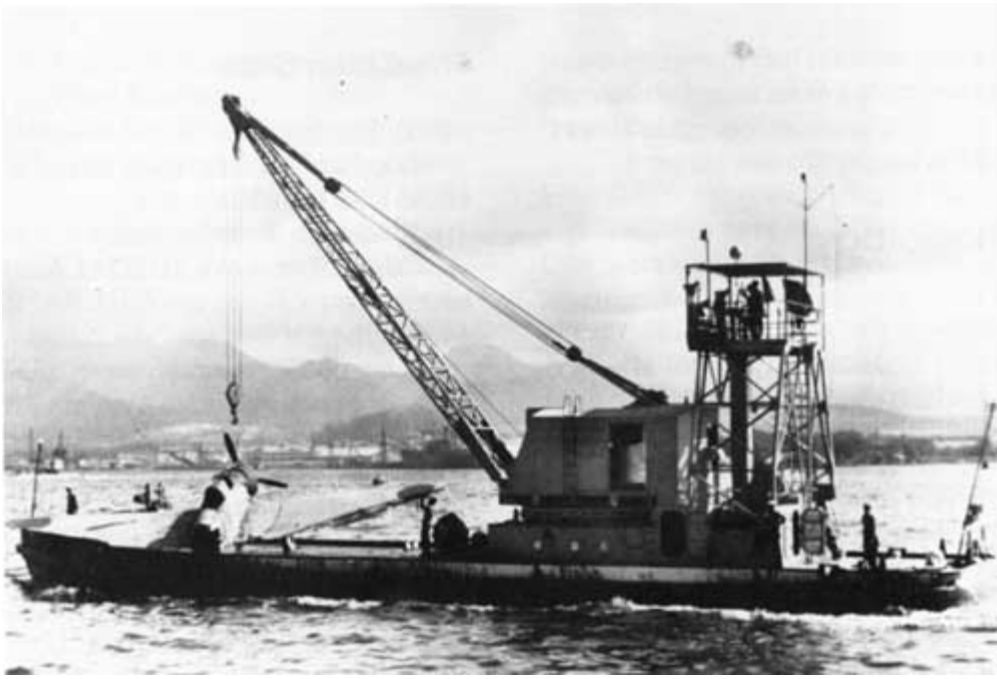








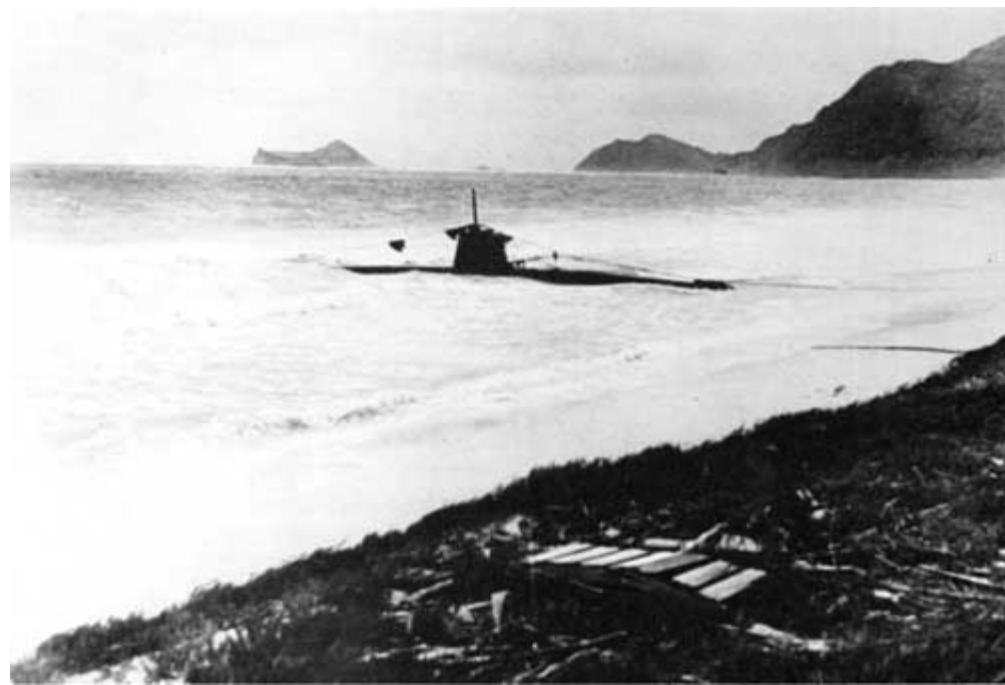


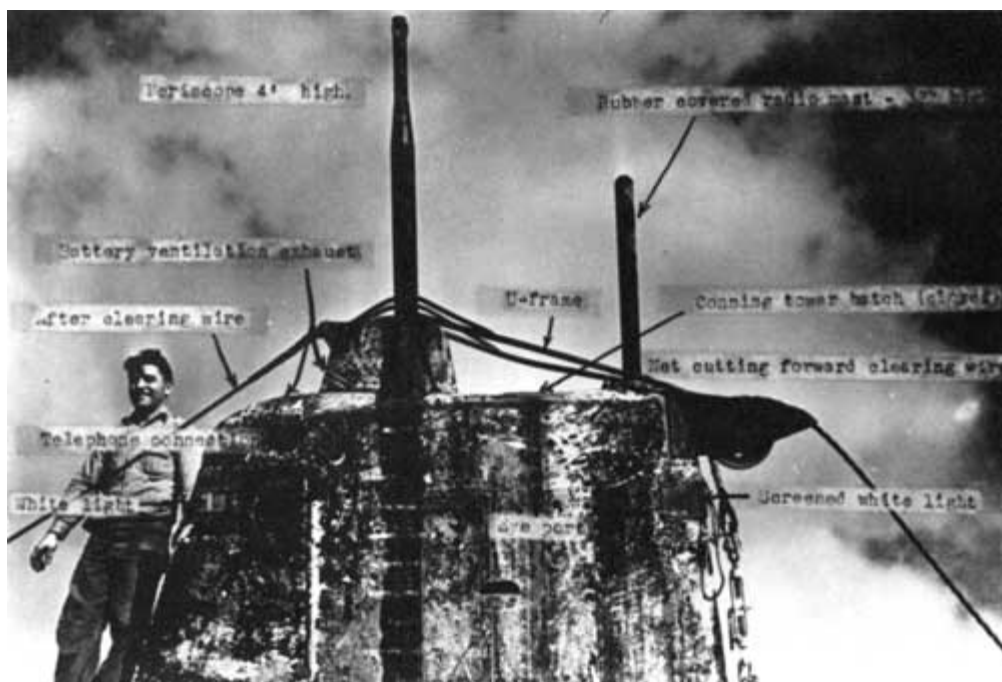




















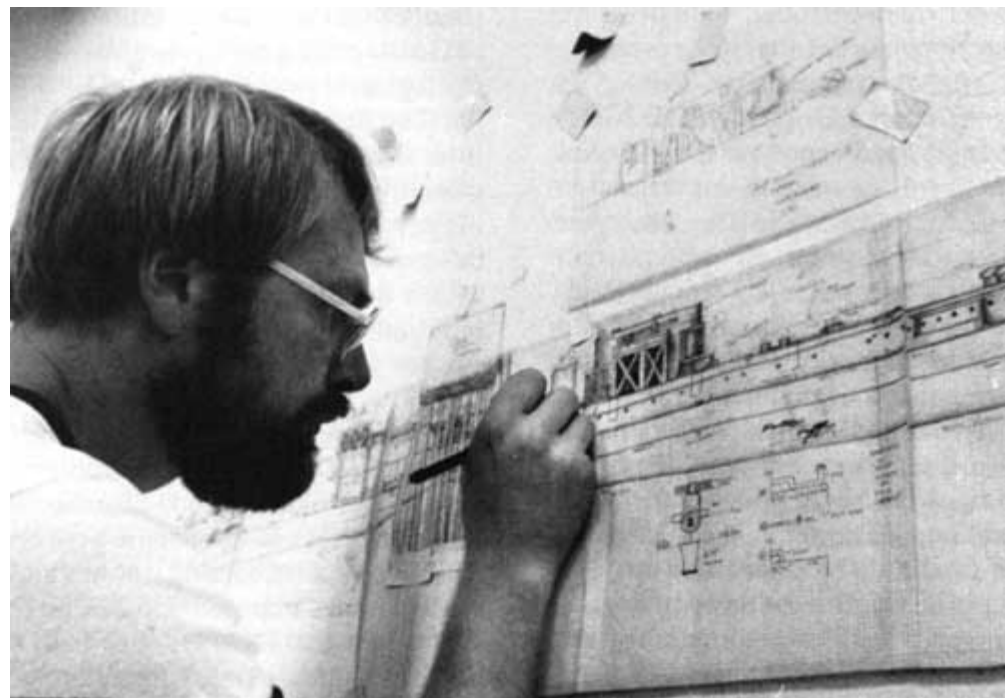


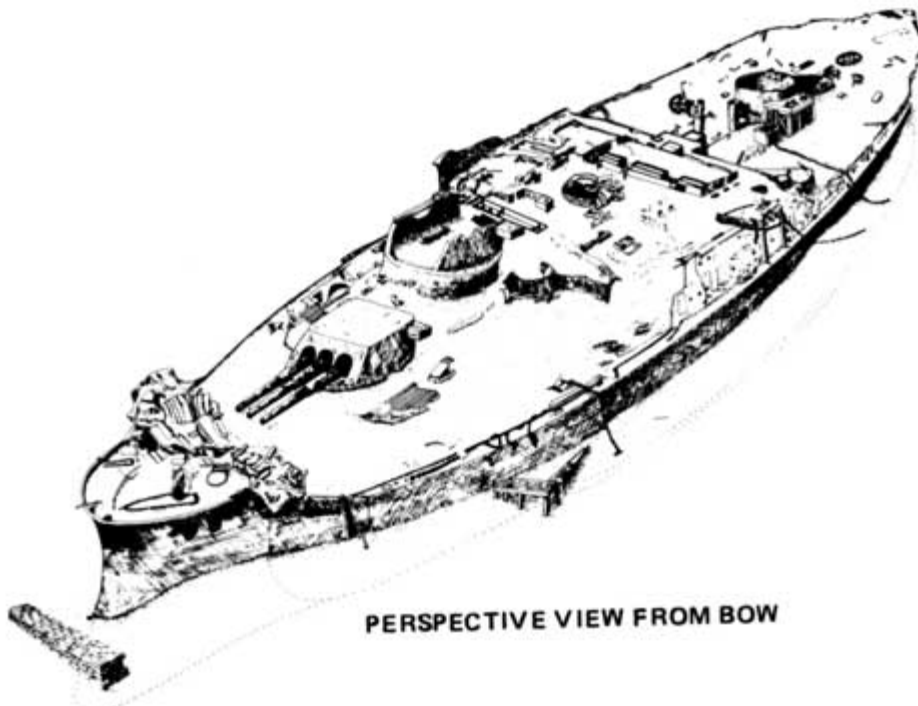




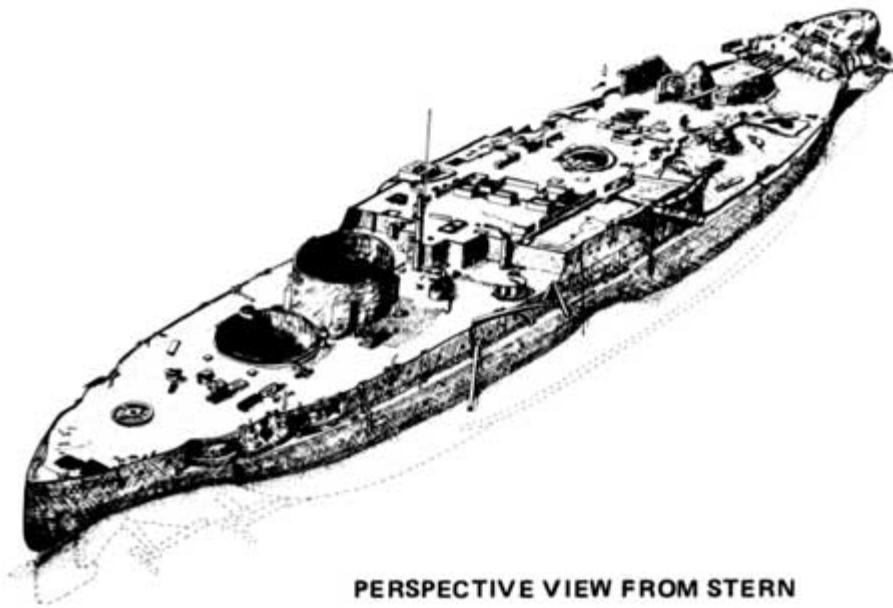








PERSPECTIVE VIEW FROM BOW



PERSPECTIVE VIEW FROM STERN

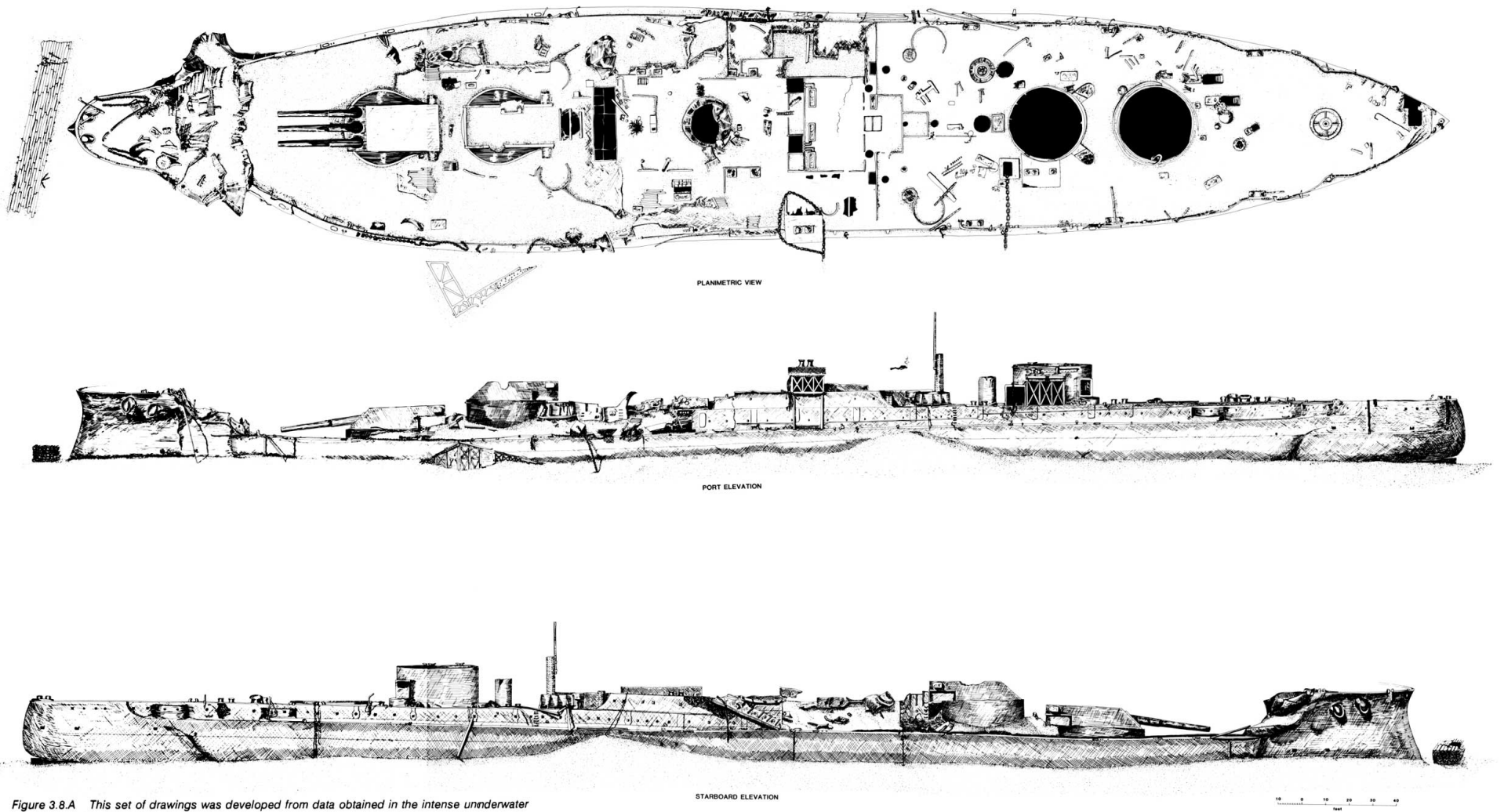


Figure 3.8.A This set of drawings was developed from data obtained in the intense underwater mapping sessions that took place in 1984.

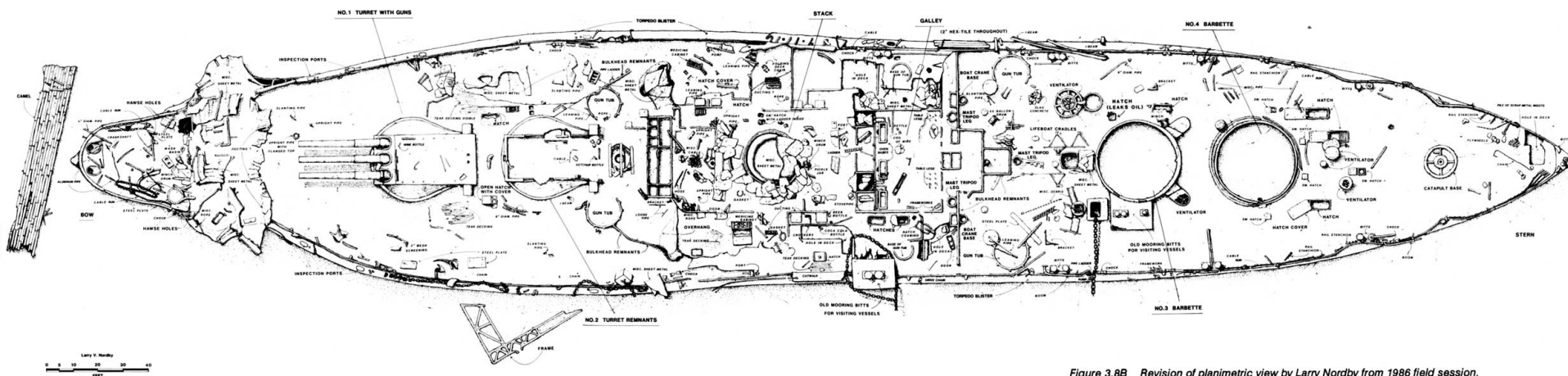
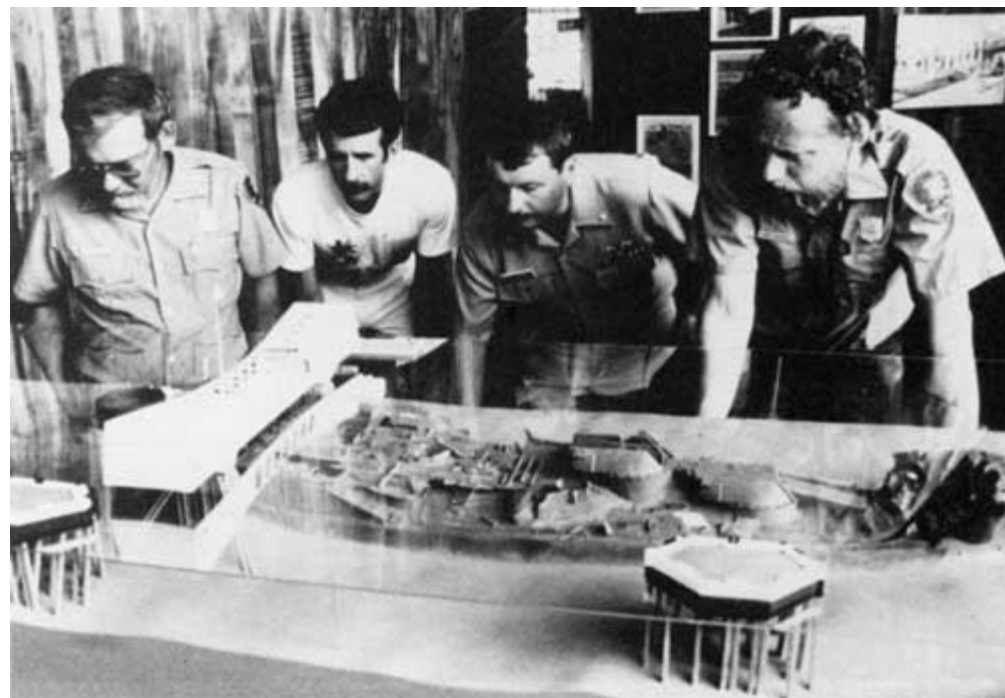
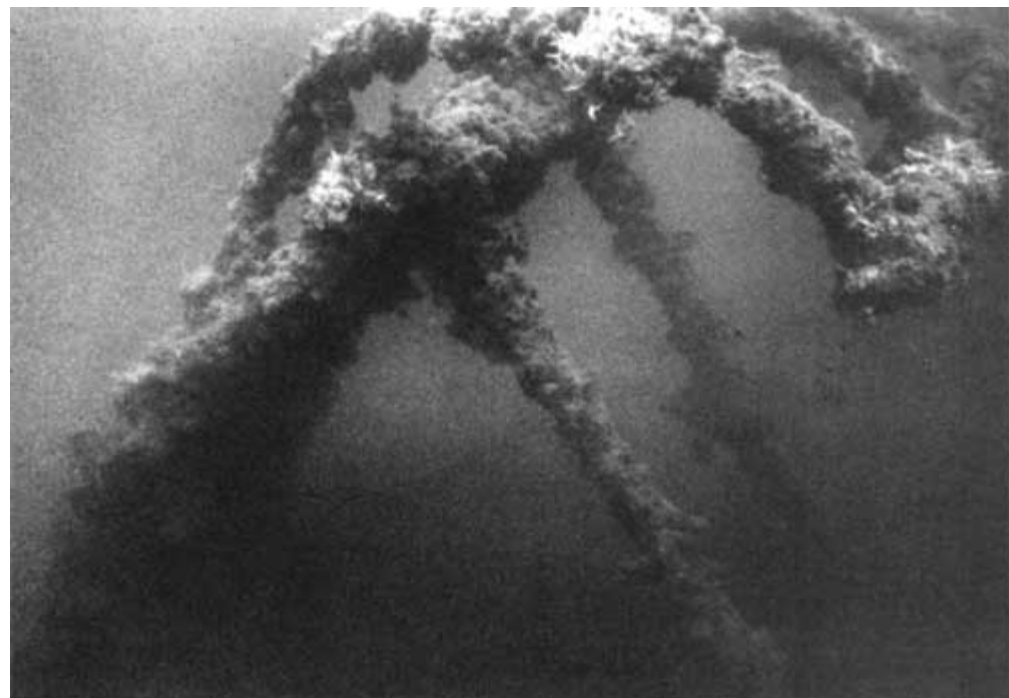


Figure 3.8B Revision of planimetric view by Larry Nordby from 1986 field session.

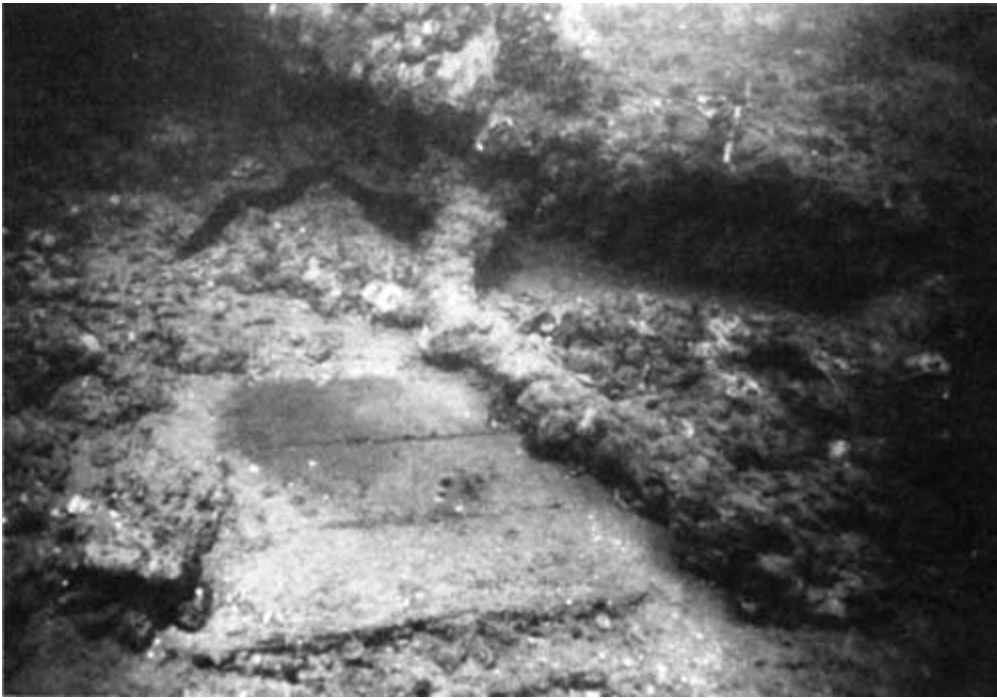


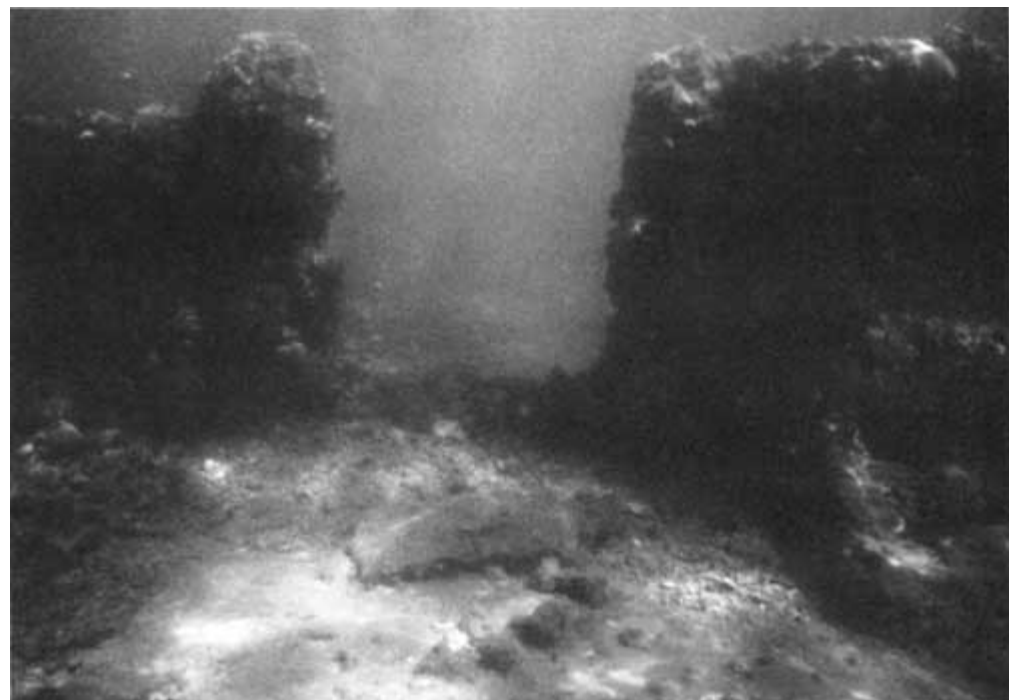






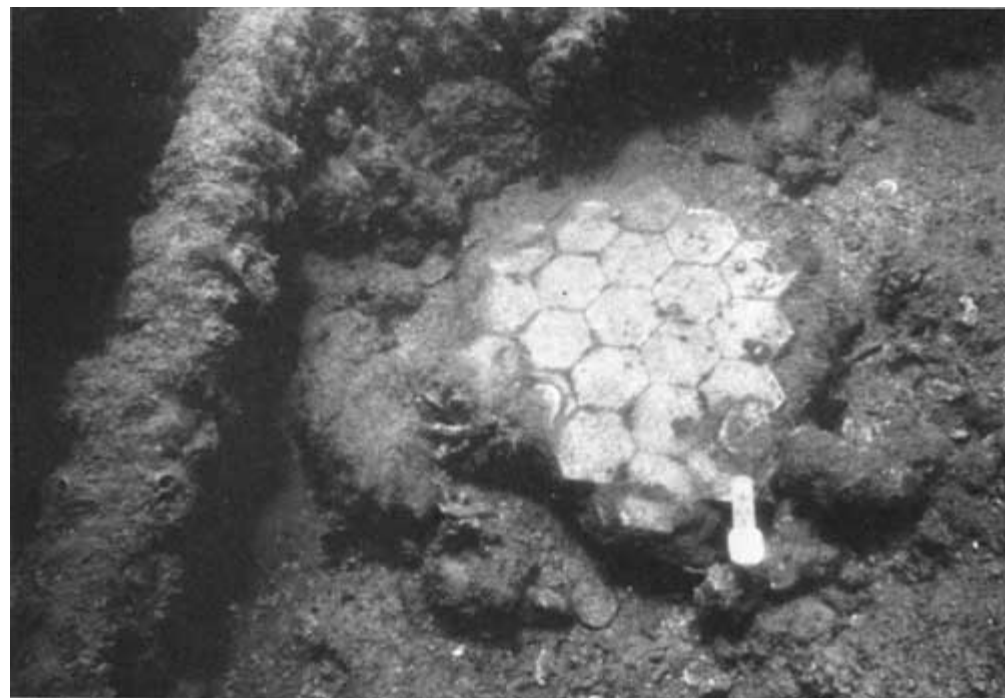


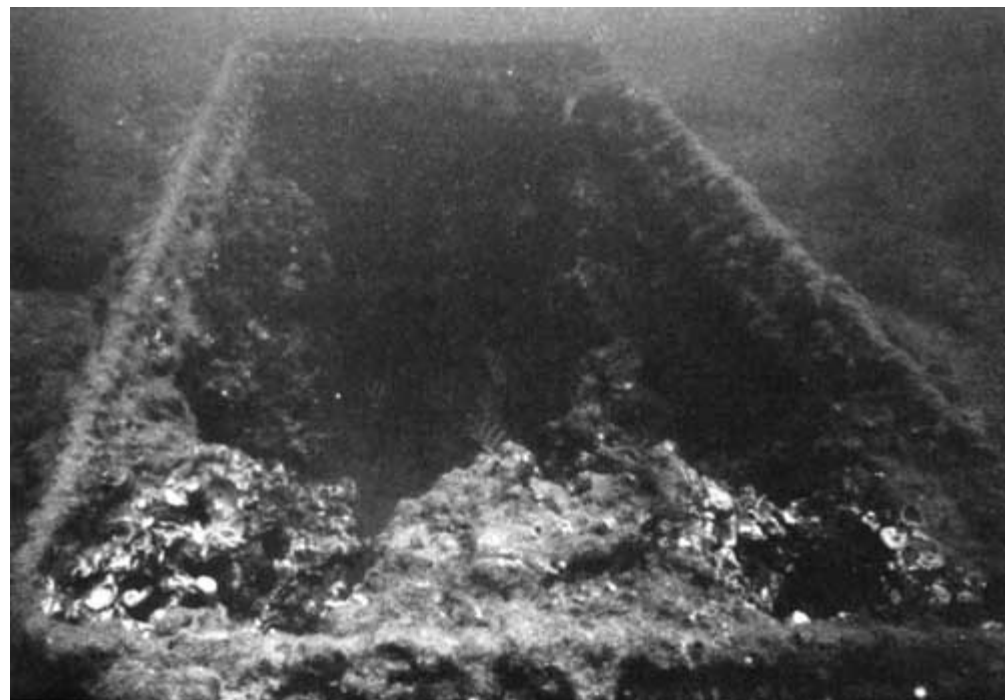


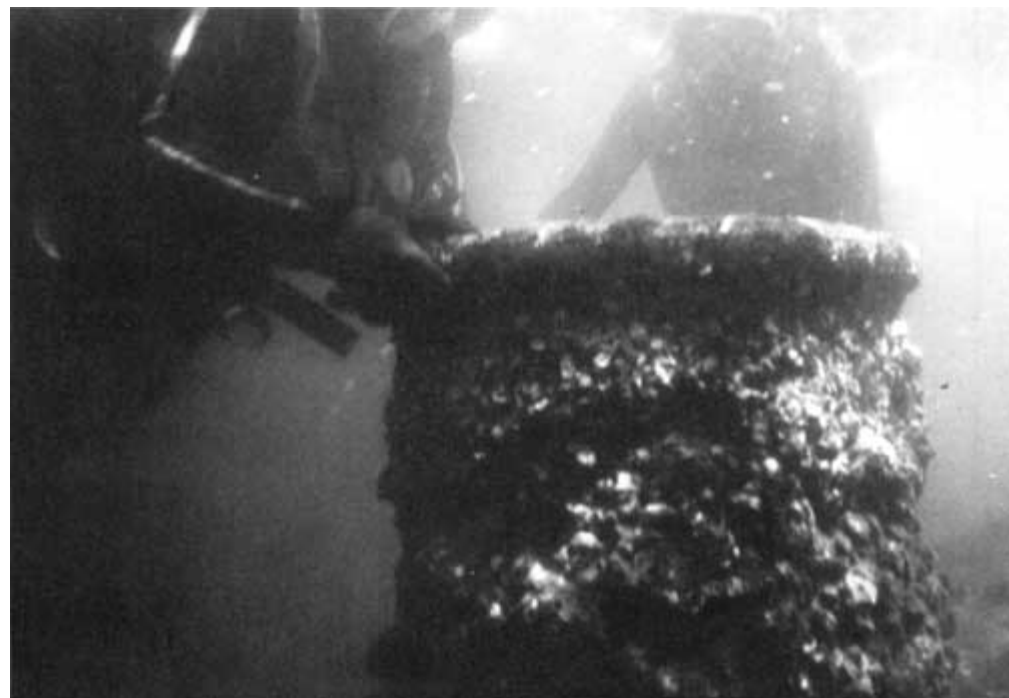








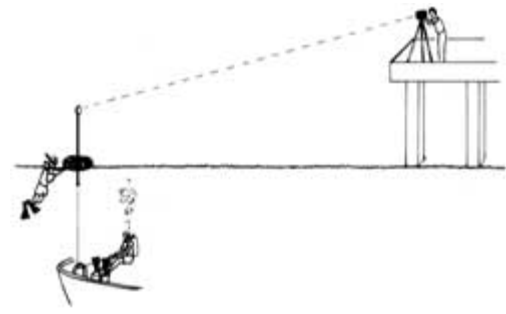












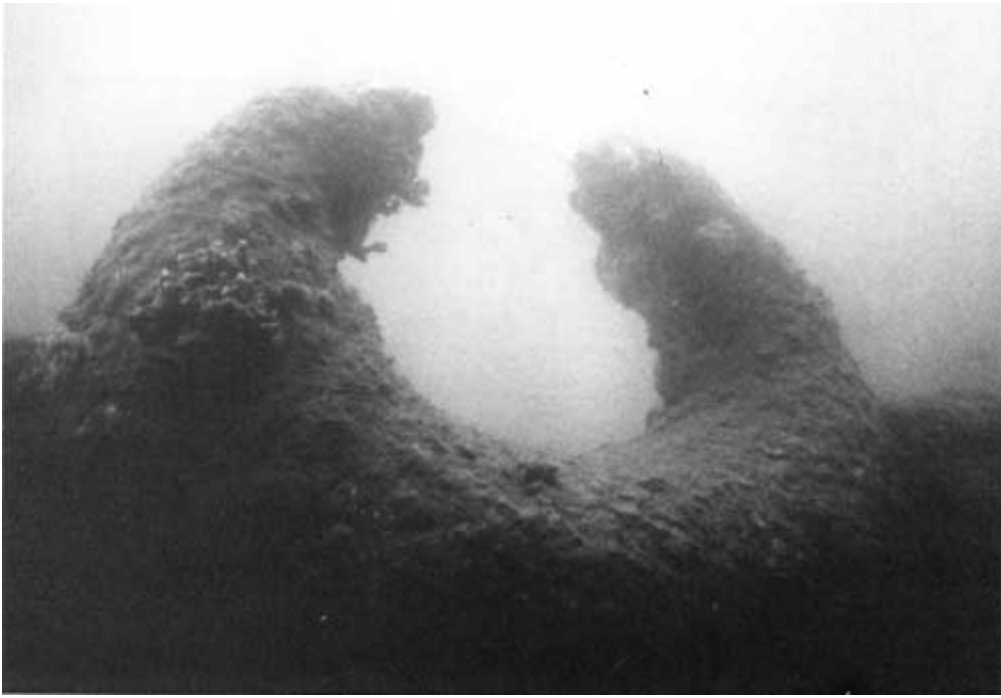




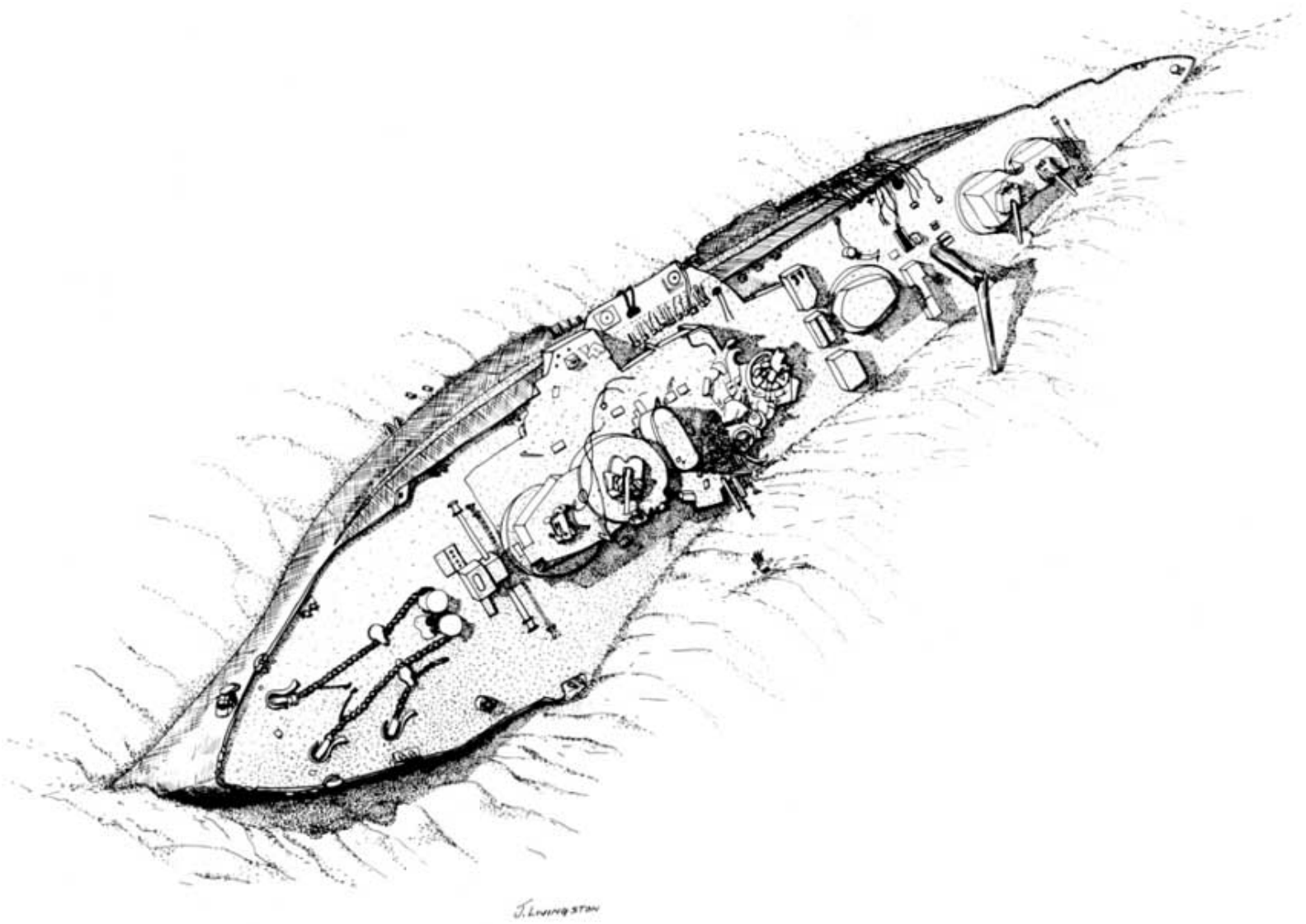




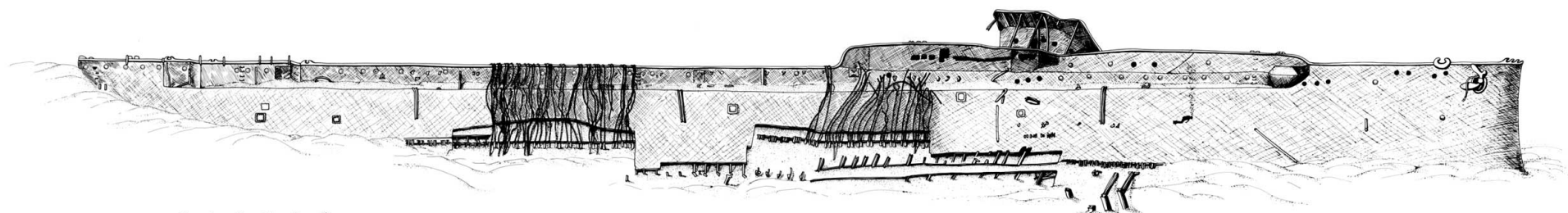
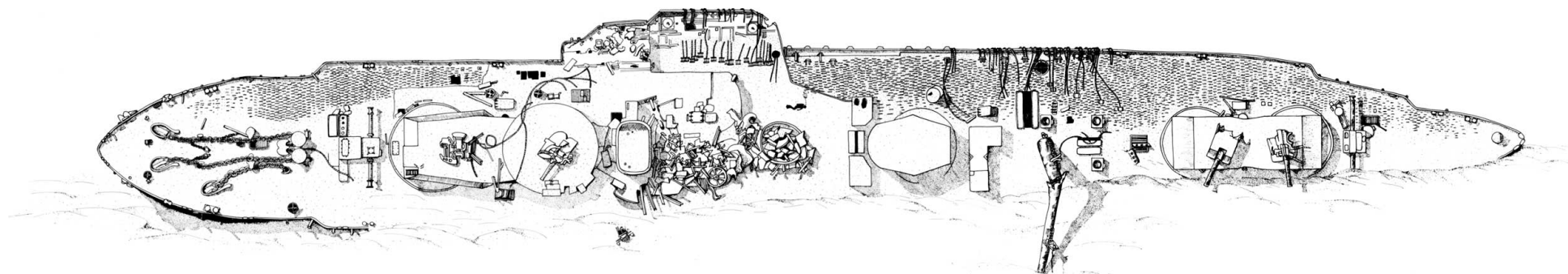








J. LIVINGSTON



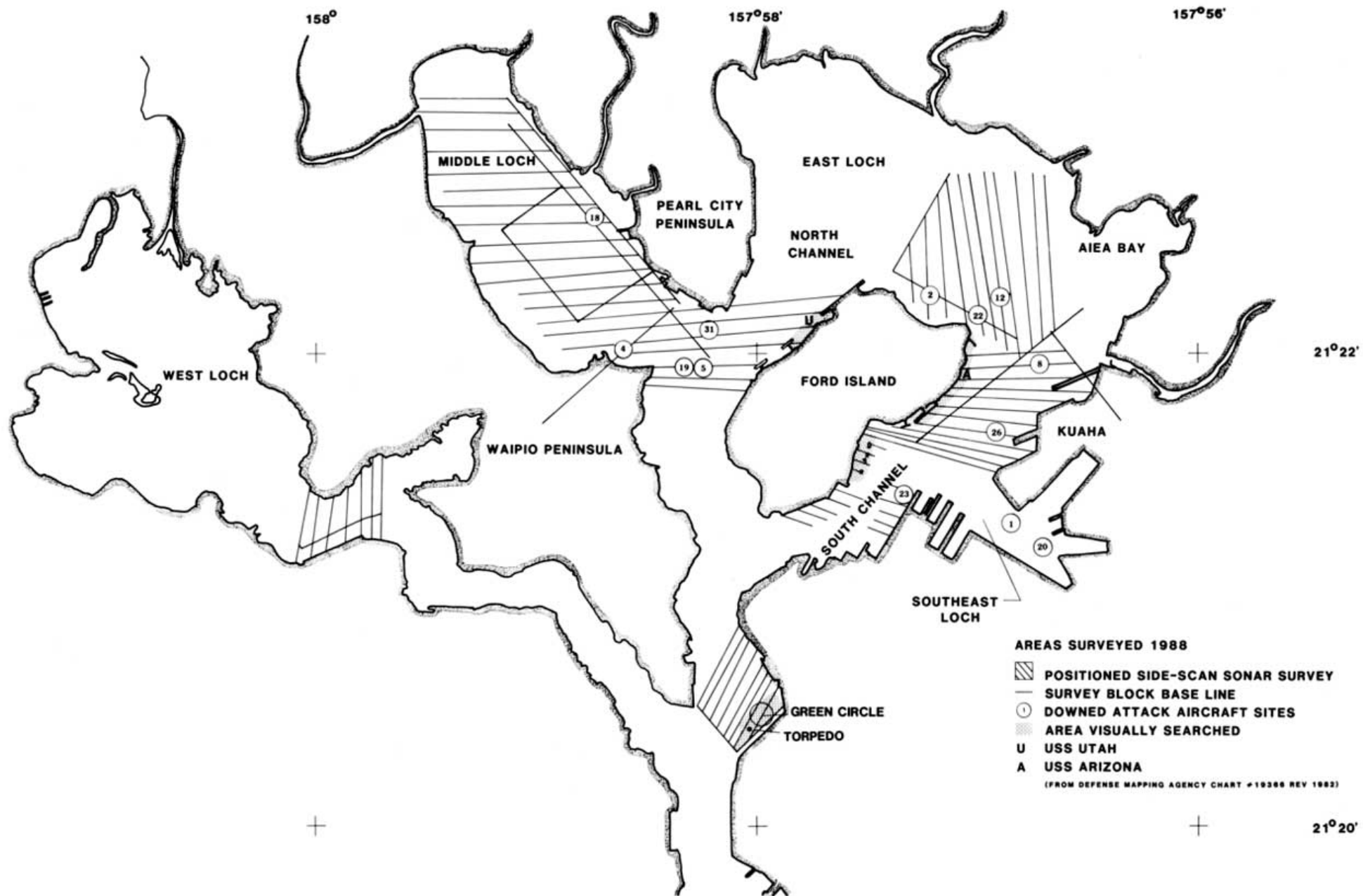
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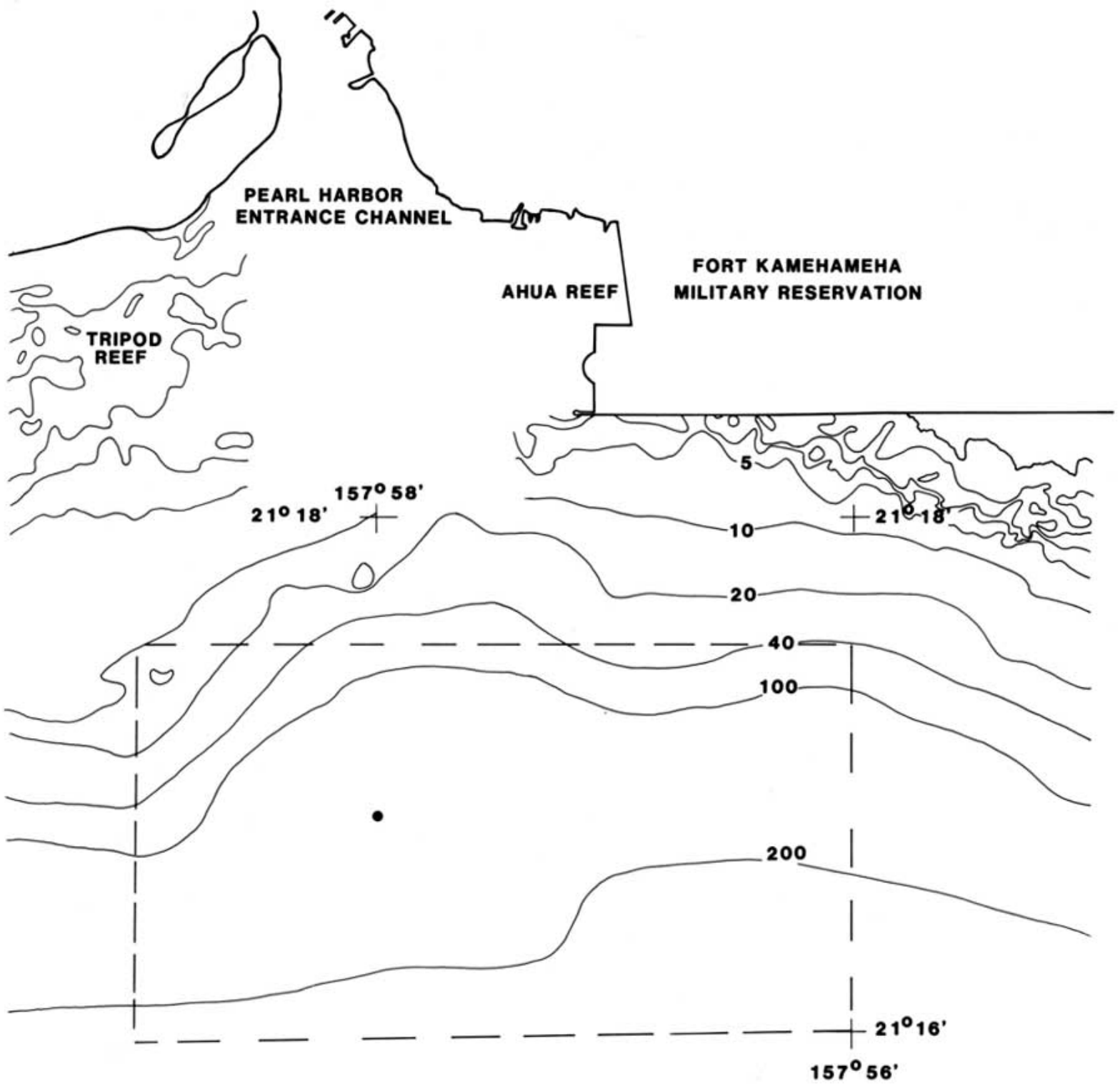
JERRY L. LIVINGSTON

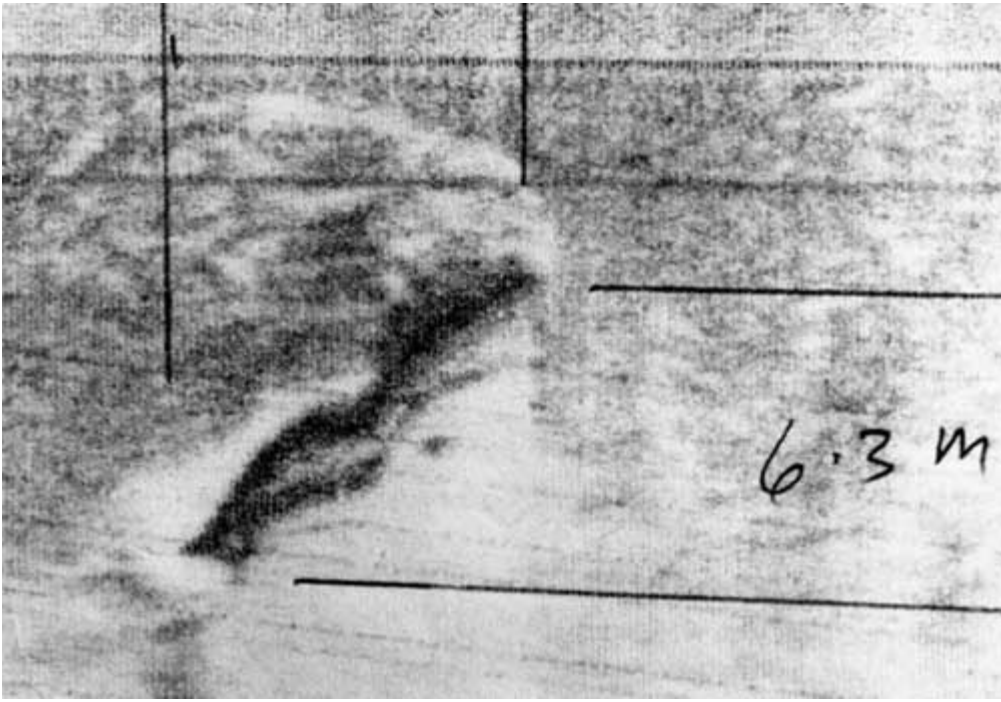
Figure 3.33. Two-part drawings of remains of USS UTAH. Drawn by Jerry Livingston from underwater operations conducted by SCRUI and US Navy Reserve MDSU One (Det 319).

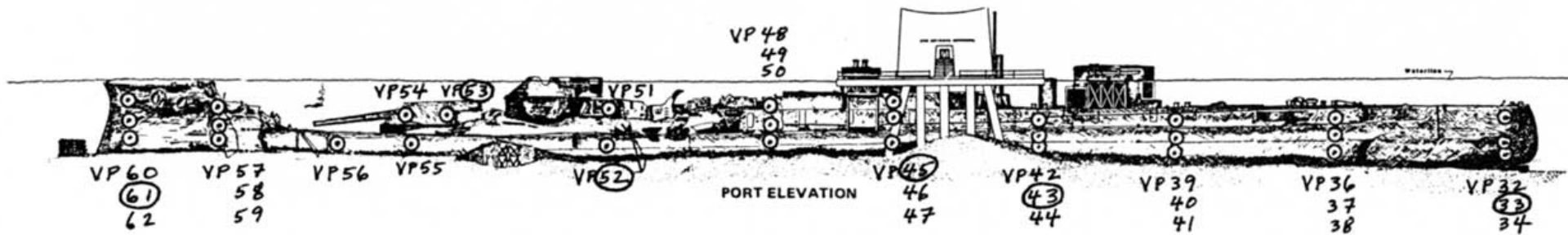
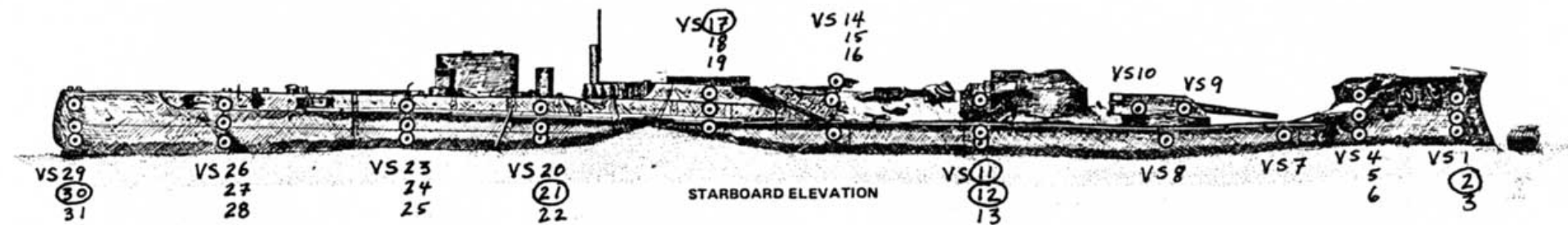


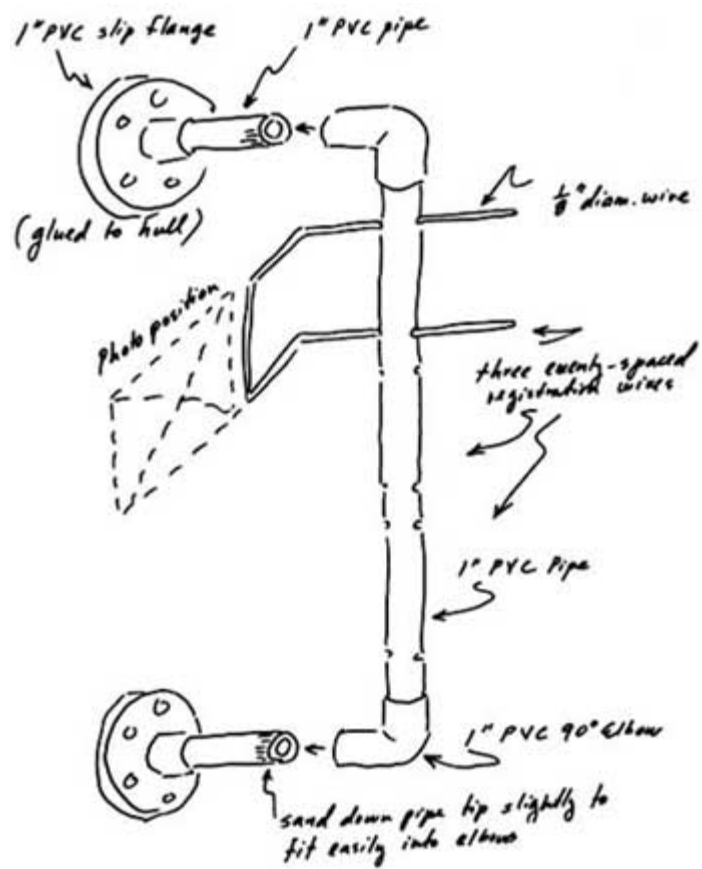


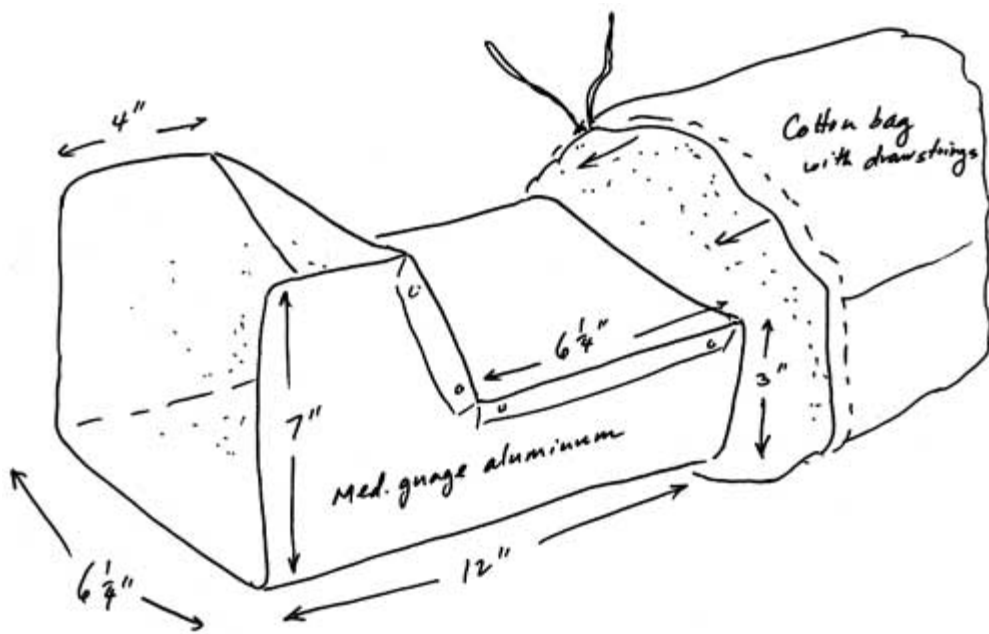




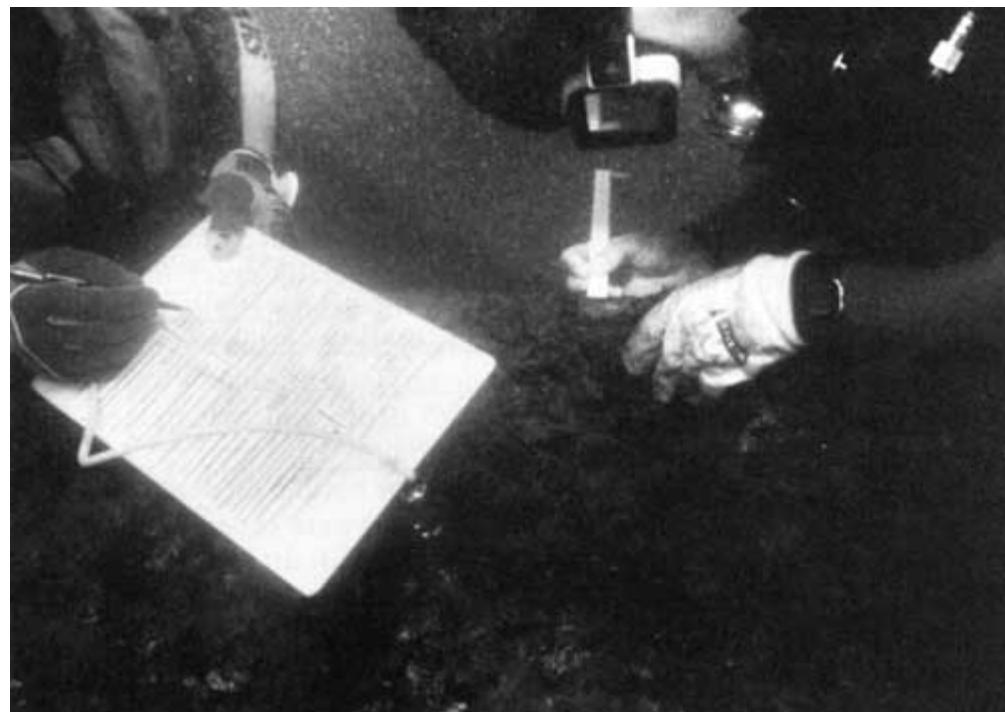


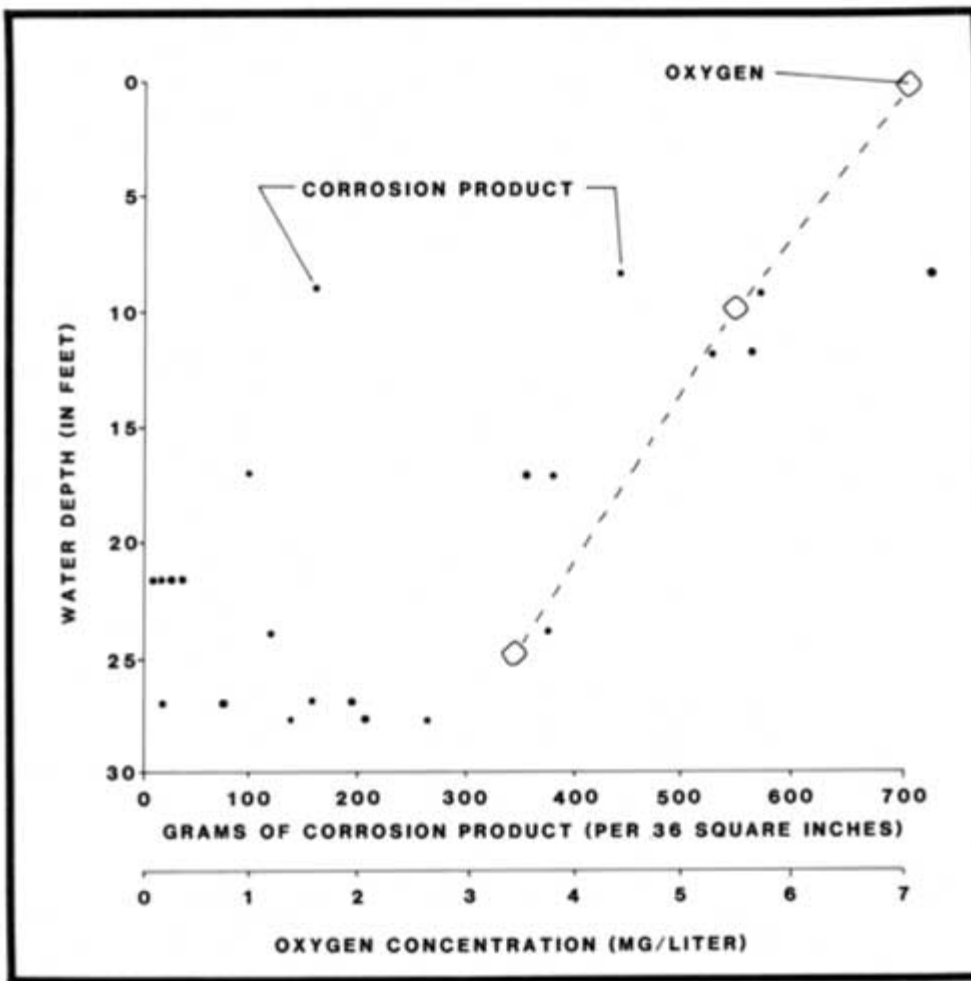


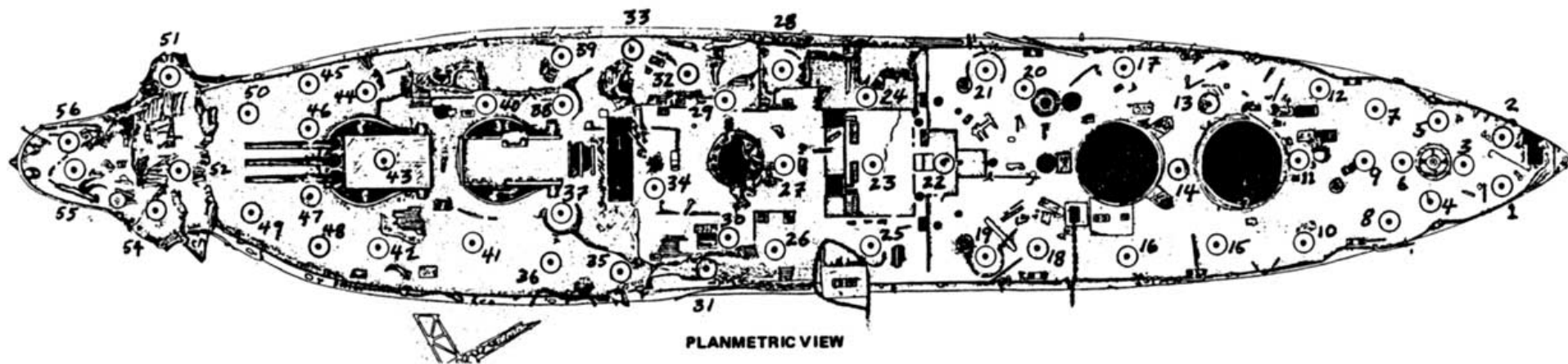












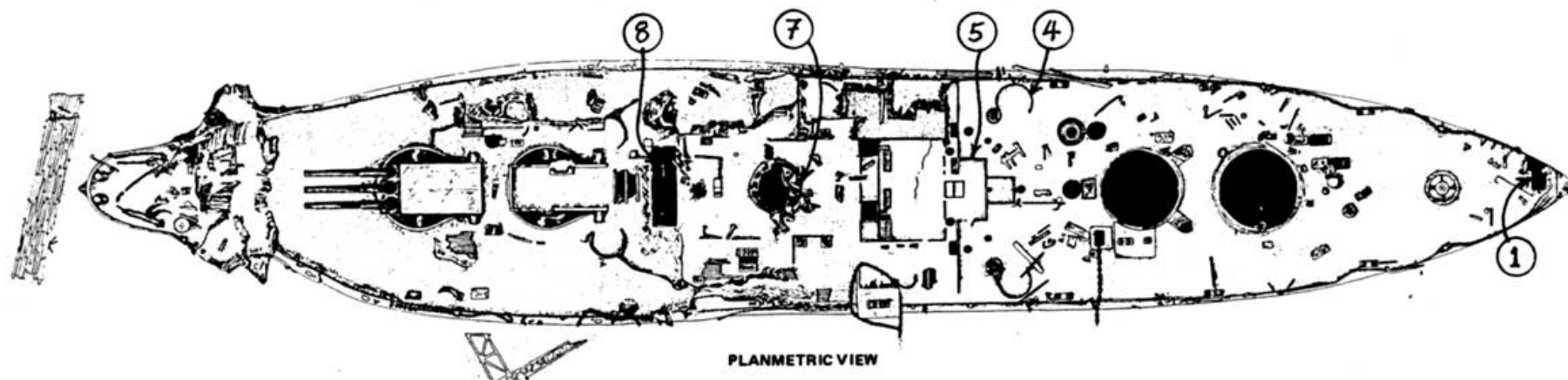
PLANMETRIC VIEW







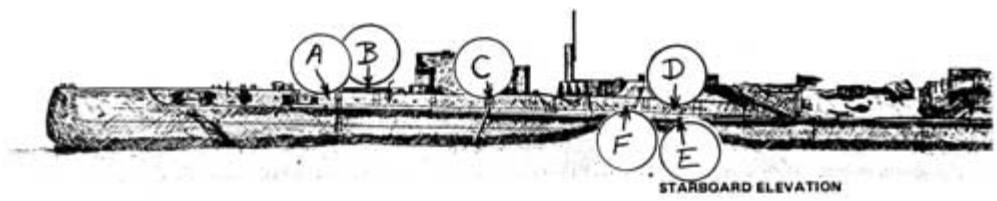
STARBOARD ELEVATION



PLANMETRIC VIEW



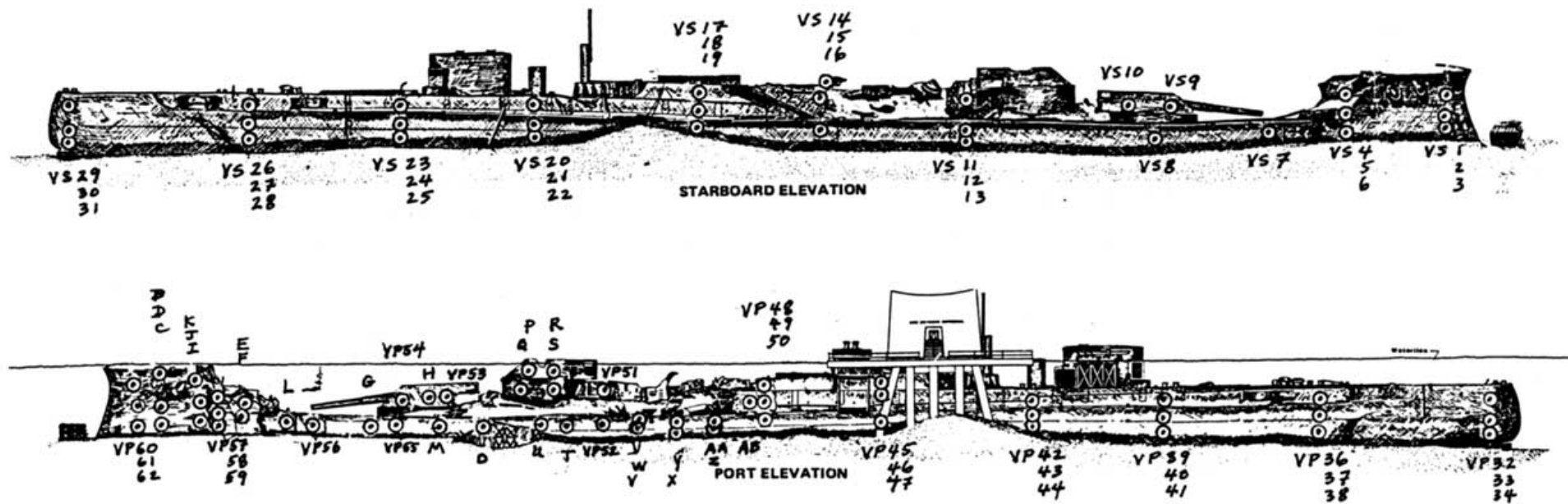
PORT ELEVATION



STARBOARD ELEVATION

















USS ARIZONA MEMORIAL

Submerged Cultural Resources Study:
USS Arizona and Pearl Harbor National Historic
Landmark



Chapter IV: Biofouling And Corrosion Study (continued)

Biofouling of Vertical Surfaces

Results

Approximately 25 common taxa of fouling organisms and 25 common species of fish were observed near the ship (Table 4.1). The checklist of organisms includes only macroorganisms that were readily identifiable and that collectively comprised more than 90 percent of the living biomass on or near the ship. The limits of time and survey resources excluded the inventory and identification of organisms that were rare, microscopic or cryptic in nature. Such organisms probably contribute little over all biomass or stability to the fouling communities and are only minimally relevant to the ship's corrosion.

Table 4-1. Phyletic checklist of common organisms observed on USS ARIZONA.

Plant Kingdom

CYANOPHYTA (Blue-green Algae) -- film and filamentous blue-green algae
CHLOROPHYTA (Green Algae) -- filamentous green algae
CHYSOPHYTA (Golden-brown Algae) -- primarily diatoms in diatom/detritus mats
RHODOPHYTA (Red Algae) -- filamentous red algae

Animal Kingdom

PROIFERA (Sponges)
Several "encrusting" species in the following colors: tan, grey, black, white, orange, pink, green, yellow and blue.
Several "erect" species including a pink form, light- blue rounded form, and a black "finger" sponge.

CNIDARIA (Coelenterates)
Hydrozoa
Hydroida
Pennairiidae
 Pennaria tiarella (Feather hydroid)
Anthozoa
Telestidae
 Telesto riisei (Orange soft coral)
Actinaria
Aiptasiidae
 Aiptasia pulchella

ANNELIDA (Segmented worms)
Polychaeta
Sedentaria
Sabellidae
 Branchiomma cingulata (Colonial feather-duster worm)
 Sabellastarte sanctijosephi (Feather-duster worm)
Serpulidae
 Hydroides spp, (Tube worms)
 Salmacina dysteri (Sagebrush tube worm)

- ARTHROPODA (Arthropods)
 - Crustacea
 - Cirripedia
 - Balanidae
 - Balanus spp. (Barnacles)
 - Decapoda/Natantia
 - Alpheidae
 - Aipheid spp. (Snapping shrimps)
 - Stomatopoda
 - Squillidae
 - Squilla sp. (Mantis shrimp)
 - MOLLUSCA (Molluska)
 - Mesogastropoda
 - Vermetidae
 - Vermetus alii (Vermetid worm)
 - Bivalvia
 - Pteroida
 - Isognomidae
 - Isognomon spp. (Flat oysters)
 - Ostreidae
 - Ostrea spp. (Native oysters)
 - Anomiidae
 - Anomia nobilis (Saddle oyster)
 - Myoida
 - Pholadidae
 - Martesia striata (Wood-burrowing bivalve)
 - Teredinidae
 - Teredinid spp. (shipworms)
- ECTOPROCTA (Moss Animals)
 - Gymnolaemata
 - Ascophora
 - Schizoporellidae
 - Schizoporella errata (Encrusting bryozoan)
- CHORDATA (Chordates)
 - Urochordata
 - Ascidacea
 - Didemnid spp. (Colonial tunicates)
 - Unidentified colonial tunicates, several species
 - Unidentified solitary tunicates (Sea squirts), several species
 - Vertebrata
 - Osteichthyes (Bony Fishes)
 - Aguilliformes
 - Muraenidae
 - Gymnothorax sp. (Moray eel)
 - Perciformes
 - Kuliidae
 - Kuhlia sandvicensis (Silver bass)
 - Priacanthidae
 - Priacanthus cruentatus (Glass eye)
 - Apogonidae
 - Apogon spp. (Cardinal fish)
 - Carangidae
 - Caranx melampygus (Jack, Papio)
 - Mullidae
 - Upeneus arge (Goat fish)
 - Mulloidichthys samoensis (Goat fish, Kumu)
 - Chaetodontidae
 - Chaetodon auriga (Gold butterfly fish)
 - Chaetodon lunula (Raccoon butterfly fish)
 - Chaetodon ephippium (Butterfly fish)
 - Pomacentridae
 - Abudefduf sordidus (Sordid damsel fish)
 - Abudefduf abdominalis (Sergeant Major, Mamo)
 - Mugilidae
 - Mugil cephalus (Mullet)
 - Labridae
 - Cheilio inermis (Mongoose fish)

- Scaridae
 - Scaridae spp. (Parrot fish)
- Gobiidae
 - Psilogobius mainlandi (Burrow goby)
 - Bathygobius fuscus (Goby)
- Eleotridae
 - Asterropteryx samipunctatus (Burrow eleotrid)
- Acanthuridae
 - Acanthurus dussumieri (Surgeon fish, Palani)
 - Acanthurus xanthopterus (Surgeon fish, Pualu)
 - Acanthurus mata (Surgeon fish, Pualu)
 - Zebrasoma veliferum (Sailfin tang)
 - Naso brevirostris (Unicorn fish)
 - Naso unicornis (Unicorn fish, Kasla)
- Tetraodontidae
 - Arothron hispidus (Balloon fish)

Ten taxa of fauna and five taxa of flora comprised the bulk of fouling observed on vertical hull and superstructure stations (Table 4.2). A combination of dead and live fouling covered an estimated 99+ percent of all surface area around all vertical stations. Zonation of organisms was evident, with maximum diversity and abundance of animals occurring in areas of higher water motion, such as in shallower depths and near the ship's bow and stern. In particular, the abundance of biofouling -- such as sponges (especially erect forms), foliaceous form of Schizoporella errata (bryozoan), large feather-duster worms, and Salmaoia dysteri (sagebrush tube worm) -- decreased with depth and the greater coverage of diatom/detritus mat. Vertical surfaces near the bottom (at depths of about 28 feet or more) were generally covered by a high percent of diatom/detritus mat and Branchiomma cingulata (colonial feather-duster worms).

Table 4-2 Composition and thickness of fouling at vertical hull and superstructure stations.

Key: % = % areal coverage
 * = photo station
 #/m² = no. of individuals per square meter

abun = abundant (% areal coverage given if greater than 20%)
pres = present in low abundance
com = common
b/g = blue/green; grn = green

Station	Water Depth (ft.)	Sponges		Schizoporella	Branchiomma	Annelids lg. Sabellida	Salmacina	Mollusks		Tunicates		Diatoms/detritus	Algae	Fouling Thickness (in.)
		encrust.	erect					Vermetids	Oysters	Solitary	Colonial			
VS 1	12	65%	10%	5%	com	5/m ²	1%	com		15/m ²		10%		.75-2.5
2*	22	65%	10%	5%	com	5/m ²	1%	com		10/m ²		20%		1.0-3.0
3	28	55%	10%	3%	com	5/m ²	1%	com	pres	10/m ²		25%		.75-2.5
4	12	45%	5%	5%	pres	4/m ²		com	pres	10/m ²		10%		1.0-2.5
5	25	45%	5%	5%	pres	4/m ²		com	pres	10/m ²		15%		1.0-2.5
6	30	10%		1%	com				pres	20/m ²		10%	red 80%	.75-3.0
7	30	10%		1%	com				pres	20/m ²	1%	35%		.75-3.0
8	32	10%		1%	com				pres	40/m ²		35%		.75-3.0
9	21	10%			abun(50%)				pres	12/m ²		90%		.75-2.0
10	20	10%	2%		abun(50%)			pres	pres	12/m ²		90%		.75-2.5
11*	13	20%	7%	1%	pres	2/m ²		pres	pres	15/m ²		20%	b/g 7% red 10%	.75-2.0
12*	27	25%	5%	2%	com	1/m ²		com		10/m ²		15%	b/g 7%	1.0-3.0
13	31	20%			abun(50%)					5/m ²		90%		1.3-3.0
14	7	20%	5%	1%	pres	10/m ²		com				20%		.63-2.0
15	16	20%	20%		pres	10/m ²		pres	pres	5/m ²		20%		1.3-3.0
16	28	25%			abun(40%)	3/m ²						75%		1.0-3.0

17*	8	15%	5%	15%	pres	10/m ²				5/m ²		20%	b/g 7%	.75-3.0
18	17	15%	10%	1%	pres	10/m ²		pres	pres	20/m ²		30%	b/g 5%	.5-2.0
19	23	40%			pres					10/m ²		90%	red 40%	1.0-3.0
20	14	60%	15%	1%	pres	30/m ²		pres	pres	10/m ²		40%		1.0-3.0
21*	22	30%	10%	2%	pres	1/m ²		pres	pres	5/m ²		50%	red 10%	1.0-3.0
22	28	10%	5%		abun(30%)				pres			90%		.75-3.0
23	15	75%		2%	pres	10/m ²		com		12/m ²		20%		1.5-3.0
24	23	70%		2%	com	1/m ²		pres	pres			20%		.75-3.0
25	28	10%	5%		abun(80%)				pres			90%		.75-3.0
26	17	40%	5%	1%	pres	15/m ²				10/m ²		20%		.75-3.0
27	24	25%	10%	4%	pres	5/m ²						25%	red 20%	.75-3.0
28	29	10%			abun(40%)			pres				90%		.75-3.0
29	17	30%	20%	5%	pres	1/m ²		abun	pres	5/m ²		20%		2.0-4.0
30*	27	40%	5%	10%	pres	1/m ²		pres	pres	10/m ²		15%	red 60% grn 2%	.75-3.0
31	32	30%			abun(40%)	3/m ²				100/m ²		50%	red 20%	
32	17	75%	10%	2%	com	10/m ²	1%	com		10/m ²		15%		.50-2.0
33*	28	25%	20%	2%	com	1/m ²		com		30/m ²	2%	15%	grn 15%	.50-2.5
34	32	5%	5%	1%	abun(75%)	4/m ²		com		10/m ²		10%	red 40%	.75-2.0
36	17	15%	15%	5%	pres	5/m ²	1%	abun		12/m ²		20%	red 50%	.75-3.0
37	24	70%	10%	10%	com	15/m ²		pres		12/m ²		40%		.75.-2.5
38	32	20%	30%	5%	abun(50%)	3/m ²		pres		20/m ²		50%		1.0-2.5
39	17	50%		10%	com	10/m ²		com		12/m ²		25%		.75-3.0
40	26	20%	5%	1%	pres	12/m ²		pres		15/m ²		60%	red 25%	.75-3.0
41	31	20%		1%	abun(60%)			pres		50/m ²		90%	red 20%	.75-3.0
42	18	50%			pres	3/m ²		pres	pres	10/m ²		40%		1.0-3.0
43*	24	50%	5%	2%	pres					5/m ²		40%	red 10% grn 3%	1.0-3.0
44	29	10%			abun(60%)					20/m ²		90%		.75-2.5
45*	9	40%	10%		pres	8/m ²		com		50/m ²		30%	red 15% b/g 5%	.75-3.0
46	14	30%	10%	1%	pres	5/m ²		pres		20/m ²		50%		.75-3.0
47	27	5%			abun(50%)			pres		5/m ²		80%		.75-2.5
48	10	50%	5%	5%	pres	10/m ²		abun		10/m ²		15%	red 20%	.75-3.5
49	18	50%	5%		abun(20%)			pres	pres	30/m ²		80%		1.0-3.0
50	27	1%			abun(20%)			pres	pres	30/m ²		80%		.75-3.0
51	12	20%	5%	10%	pres	10/m ²		com				5%	red 20%	1.5-3.5
52*	20	5%	2%	1%	abun(40%)			pres		30/m ²		50%		1.0-2.5
53*	17	5%	2%	1%	abun(80%)	5/m ²	1%			15/m ²		90%	b/g 1%	.75-3.0
54	17	5%	2%	2%	abun(80%)		1%			15/m ²		90%		.75-3.0
55	28	10%	3%		abun(80%)			pres		20/m ²		40%		.75-2.5
56	27	5%			abun(75%)			pres		5/m ²		70%		1.0-3.0
57	11	50%	15%	2%	pres	5/m ²	1%	com		100/m ²		10%		.75-3.0
58	18	75%	12%	1%	pres	25/m ²		com	pres	100/m ²		20%		.75-3.0
59	24	25%	10%	1%	abun(50%)			com	pres	100/m ²		25%		1.0-3.0
60	10	50%	10%	15%	pres	5/m ²	1%	pres	pres	100/m ²	1%	10%		.75-3.0
61*	17	70%	10%	5%	com	5/m ²	1%	pres	pres	100/m ²		30%		.75-3.0
										2				

62	27	10%	5%	1%	abun(80%)		1%			5/m		90%	red 30%	.75-3.0
----	----	-----	----	----	-----------	--	----	--	--	-----	--	-----	---------	---------

Although vermetid mollusks and oysters were not observed at some vertical stations, it is likely they were present at the majority of those stations but not readily visible because of coverage by encrusting biofouling. Hard fouling at all stations was found to consist of entwined masses of oyster and vermetid shells. Hard fouling extended beneath the bottom silt on hull surfaces, and was exposed by digging holes about 3 feet into the silt at representative locations; that hard fouling layer had apparently grown on the lower hull areas-before they were covered with silt by sedimentation or hull settling.

No correlation was found to exist between water depth and thickness of hard fouling, indicating that, over the long term, growth of oysters and vermetids had been relatively unaffected by depth and water motion. Hard fouling averaged about 3/4-inch thickness on vertical stations, where that layer serves as a primary barrier in protecting underlying steel/oxides from corrosive effects of overlying water and, at present, appears to be stable and well-bonded to the hull.

Dry weights of fouling growth scraped from 36-inch-square areas at the photo biostations ranged from 45 to 197 grams (Table 4.3). No correlation exists between fouling dry weight (or hard fouling thickness) and the amount of dry-weight corrosion product underlying that fouling. However, a plot of grams of corrosion product per scraping area versus water depth (Figure 2) indicates that formation of corrosion products has been maximal at shallower depths and has occurred at lower rates at depths of 20 to 30 feet. This correlation is consistent with the fact that oxygen, which accelerates corrosion by serving as a cathodic depolarizer, also declines with depth in Pearl Harbor waters.

Table 4.3. Water depths (in feet), hard fouling thickness (in inches) and dry weights (in grams per 36 inches square) of scraped corrosion product and fouling growth for photo biostations on USS ARIZONA.

STATION	WATER DEPTH	HARD FOULING	DRY WEIGHT	
		THICKNESS	CORROSION	FOULING
2a	22	1	14	99
2b			35	79
11a	13	3/4	565	76
11b			530	64
12a	27	1	76	92
12b			21	64
17a	8	3/4	440	87
17b			718	123
21a	22	1	6	109
21b			25	95
30a	27	3/4	198	81
30b			165	77
33a	28	1/2	206	89
33b			270	98
43a	24	1	376	92
43b			118	146
45a	9	3/4	161	45
45b			568	197
52	28	1	138	129
(a & b averaged)				
53	17	3/4	99	79
(a & b averaged)				
61a	17	3/4	354	90
61b			374	97

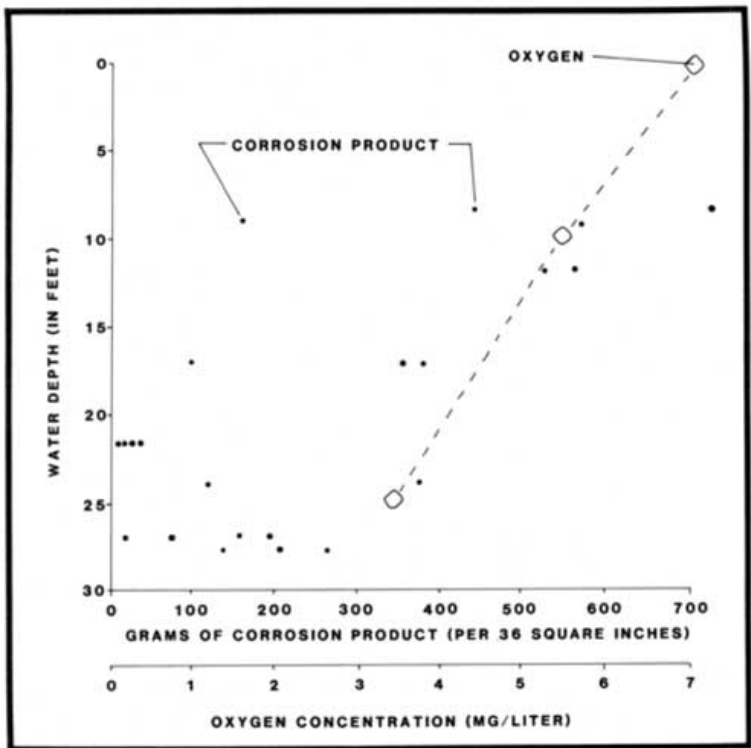


Figure 4.6. Plot of water depth versus grams of corrosion product removed from 36-inch square areas of steel surface at vertical photostations on the USS ARIZONA. For comparative purposes, typical oxygen concentrations that occur at surface and two midwater depths (R.S. Henderson, unpublished Pearl Harbor survey data, 1978-1986) are provided.

No traces of coral growth were found on or mixed in any of the hard fouling examined on the hull or superstructure surfaces. Lack of any coral growth on the USS ARIZONA hull, which had been submerged for nearly 45 years at time of study, agrees with observations that live hard corals have apparently not existed in Pearl Harbor in historic times.

Data regarding the presence/absence of biofouling and the rate of coverage was obtained by examination of the biostation photographs combined (averaged) with in situ visual data, presented here in Table 4.2. The photo slides are in the possession of NPS (Arizona Memorial) for comparison with photos of the same biostation areas that may be obtained in future monitoring studies.

Biofouling now present on the USS ARIZONA consists largely of filter-feeding organisms that depend primarily on plankton and suspended detritus for food. The high concentrations of those food items found in Pearl Harbor are in turn dependent on abundant supplies of dissolved nutrients (primarily nitrogen and phosphorus compounds) derived from freshwater influx (streams and springs) and domestic sewage. As nearly all sewage discharge has been terminated in recent years, it is expected that plankton populations will decline drastically in abundance as residual nutrients are slowly discharged from the harbor.

Because it is not known how long "excess" nutrients will be recycled or stored in the harbor, it is difficult to assess potential time frames and degrees of effects that sewage diversion will have on Pearl Harbor fouling communities. Additionally, data relating to the biological condition of Pearl Harbor prior to accumulation of sewage (nutrient) pollutants is very sparse and of no predictive value.

It should be noted that even if it were known with certainty that fouling communities would be reduced significantly by declines in pollution, that there are probably no practical ameliorative measures that could halt those declines. A recommended strategy is to establish a long-term program to monitor fouling growth on the hull. Annual inventory of density and composition of fouling at the photo biostations (which are marked by attachment studs) would probably be sufficient to define changes in the biofouling layer that would be of possible consequence to corrosion potential of the hull.

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Chapter IV: Biofouling And Corrosion Study (continued)

Sedimentation and Condition of Horizontal Surfaces

Results

Descriptions of sediment, biota and underlying surfaces observed at the horizontal stations are presented in Table 4.4. Four distinct zones of differing sediment types were delineated:

Table 4.4. Horizontal stations, USS ARIZONA, descriptions of sediment, biota and underlying surfaces.

Station 1
Sediment 1-2" deep. Sandy rubble held together in spongy mat by Branchiomma and sponges. Branchiomma very abundant and sponges in about 20% planar coverage. Sediment about 10% silt, 50% sand, 20% rubble and 20% Branchiomma tubes and burrowing sponges. About 3 sabellids (large feather duster worms) per sq. m.

Smooth teak under sediment.

Station 2
Sediment 3/4-1" deep. Sediment same as station 1.

Teak with burrow holes and some coverage of hard fouling.

Station 3
Sediment 2 1/2" deep. Sediment same as station 1.

Smooth teak under sediment.

Station 4
Sediment 4" deep. Sediment same as station 1.

Smooth teak under sediment.

Station 5

Sediment 2 1/2" deep. Sediment same as station 1.

Smooth teak under sediment.

Station 6

Sediment 3" deep. Sediment same as station 1.

Smooth teak under sediment.

Station 7

Sediment 3/4-1 1/2" deep. Sediment same as station 1.

Teak with some burrows under sediment.

Station 8

Sediment 4-5" deep. Sediment same as station 1.

Smooth teak under sediment.

Station 9

Sediment 4 1/2" deep. Sediment same as station 1.

Smooth teak under sediment.

Station 10

Sediment 4 1/2" deep. Sediment same as station 1.

Smooth teak under sediment.

Station 11

Sediment 4-12" deep. Sediment same as station 1.

Surface below sediment is irregular, corroded metal and hard fouling.

Station 12

Sediment 1 1/2-2 1/2" deep. Sediment same as station 1.

Smooth teak under sediment.

Station 13

Sediment 6" deep. Sediment same as station 1.

Smooth teak under sediment.

Station 14

Sediment 10-13" deep. Overlying sediments same as station 1, but at 3" depth sediment grades into coarse rubble (largely oyster shells and vermetid worm tubes) admixed with silt and sand.

Surface under sediment felt like wood, but could not see surface because of turbidity in hole.

Station 15

Sediment 5" deep. Sediment same as station 14.

Smooth teak under sediment.

Station 16

Sediment depth exceeded 18" probe length. Sediment same as station 14.

Surface beneath sediment in nearby area felt like wood from probe contact.

Station 17

Sediment 4" deep. Sediment same as station 14, but burrowing sponges more abundant.

Smooth teak under sediment.

Station 18

Sediment 5-7" deep. Sediment 60% silt/mud, 20% rubble. 10% sand and 10% sponges. Snapping shrimp burrows present.

Surface below sediment not observed.

Station 19

Sediment 9-10" deep. Sediment 75% rubble with sand and wilt admixed. Abundance of sponges in sediment.

About 10% of sediment surface covered with erect "finger" and "ball" sponges.

Branchiomm uncommon here.

Surface below sediment not observed.

Station 20

Sediment 7-8" deep. Sediment 40% Branchiomm, 20% sponges, 15% rubble, 10% and, and 15% silt/mud.

Teak under sediment. Condition not noted.

Station 21

Sediment 9" deep. 50% rubble, 20% sponges, 10% Branchiomm tubes, 10% sand, and 10% silt/mud.

Surface under sediment not observed.

Station 22

Sediment 3-6" deep. Sediment same as station 21.

Surface under sediment is corroded metal.

Station 23

Sediment 5" deep. Sediment 60% rubble (40% oyster shells, 20% vermetid tubes, some coins and porcelain fragments), 15% mud/silt, 15% sand, 5% sponges and 5% Branchiomm.

Surface under sediment is porcelain tile in good condition.

Station 24

Sediment 5-10" deep. Sediment 50% rubble, 25% silt/mud, and 25% sand. snapping shrimp and commensal goby fish present.

Surface under sediment not observed.

Station 25

Sediment 4-6" deep. Sediment 80% rubble with some very large (4-8" diameter) on surface. Some 50 caliber bullets seen on sediment surface. About 5 sabellids per meter square. Branchiommma rare. Some solitary tunicates on sediment surface.

Surface under sediment is corroded metal that is exfoliating in 2-4" flakes that are about 1/8" thick.

Station 26

Sediment 1-4" deep. Sediment 75% rubble, 10% mud and sand, 10% sponges, and 5% Branchiommma.

Unidentified hard surface under sediment is overlain by at least 1" of black, "crusty" tar-like substance.

Station 27

Sediment 3-4" deep. Sediment similar to station 23. Some surface and burrowing sponges (about 1-2% of sediment surface).

Surface under sediment is heavily corroded metal that is reddish brown and black in color and is overlain by the same tar-like substance described above.

Station 28

Sediment 2-3" deep. Sediment 70% rubble, 10% mud/silt, 5% sand, and 15% sponges.

Surface under sediment similar to station 27.

Station 29

Sediment 10" deep. Sediment 90% rubble with some sand and very little silt/mud in upper layers. Fines concentrated deeper in sediment. Five sabellids per square meter.

Surface under sediment is corroded metal.

Station 30

Sediment 4-7" deep. Sediment 70% rubble, 10% sand, 10% sponges, and 10% silt/mud.

Surface under sediment is grey steel overlain by tar-like substance.

Station 31

Sediment 1-9" deep. Sediment similar to station 30.

Surface under sediment is grey steel overlain by tar-like substance.

Station 32

Sediment 3-9" deep. Sediment similar to station 30.

Surface under sediment is grey steel

Station 33

Sediment 8-16" deep. Sediment 50% rubble, 20% sponges, 20% Branchiommma, and 10%

silt/mud/sand.

Surface under sediment not observed.

Station 34

Sediment 5-11" deep. Sediment 70% rubble, 10% sponges, 10% Branchiomma, and 10% sand/silt/mud.

Surface under sediment not observed.

Station 35

Sediment 3-20" deep. Sediment 50% rubble, 30% Branchiomma, 10% sponges, and 10% sand/silt/mud.

Surface under sediment is grey steel.

Station 36

Sediment 11-18" deep. Sediment similar to station 35.

Surface under sediment not observed.

Station 37

Sediment 21-24" deep. Sediment 50% rubble, 20% sponges, 10% Branchiomma, and 10% sand/mud.

Surface under sediment not observed.

Station 38

Sediment 9-15" deep. Sediment 60% rubble, 15% sand, 10% silt, and 15% sponges. No Branchiomma were noted there.

Surface under sediment not observed.

Station 39

Sediment 17-37" deep. Sediment 95% mud/silt and 5% sand.

Surface under sediment not observed.

Station 40

Sediment 12-17" deep. Sediment 50% Branchiomma, 25% mud/sand, 15% sponges, and 10% rubble.

Surface under sediment not observed.

Station 41

Sediment 24" to over 36" deep. Sediment 60% rubble, 10% Branchiomma, 20% sponges, 10% sand/silt/mud.

Surface under sediment not observed.

Station 42

Sediment 7-11" deep. Sediment 80% silt/mud, 15% rubble, and 5% sand.

Surface under sediment not observed.

Station 43

Sediment 1-2" deep. Sediment 70% Branchiomma, 10% sponges, 10% sand, and 10% mud/silt.

Surface under sediment is steel (armor plate) covered with a thin blackish finish.

Station 44

Sediment more than 36" deep. Sediment 90% silt/mud and 10% sand.

Surface under sediment not observed.

Station 45

Sediment more than 36" deep. Sediment 90% silt/mud, 5% rubble, and 5% sand.

Surface under sediment not observed.

Station 46

Sediment more than 36" deep. Sediment same as station 45.

Surface under sediment not observed.

Station 47

Sediment more than 36" deep. Sediment same as station 45.

Surface under sediment not observed.

Station 48

Sediment 39" deep. Sediment same as station 45.

Surface under sediment not observed.

Station 49

Sediment 24" deep. Sediment same as station 45.

Surface under sediment not observed.

Station 50

Sediment 20" deep. Sediment same as station 45.

Surface under sediment not observed.

Station 51

Sediment 8-14" deep. Sediment 40% Branchiomma, 20% mud/sand, 30% rubble, and 10% sponges.

Surface under sediment not observed.

Station 52

Sediment 12-17" deep. Sediment 40% Branchiomma, 20% mud/sand, 25% rubble, 15% sponges.

Surface under sediment not observed.

Station 53 - No station

Station 54

Sediment 1" deep. Sediment 95% rubble and 5% silt/mud.

Corroded metal under sediment. Bathycorrometer reading = 0.572.

Station 55

Sediment 4" deep. Sediment same as station 54.

Wood (teak?) under sediment.

Station 56

Sediment 8" deep. Sediment same as station 54.

Corroded metal under sediment.



Figure 4.7A. Area is cleared on deck for installation of horizontal surface monitoring stations.
(NPS photo by Larry Murphy)

Zone 1

Aft area, about 40 percent of ship length (Stations 1 through 22). This area lies in an average depth of 8 to 10 feet. Sediment is generally 1 to 6 inches deep and is characteristically about 50 percent sand, 20 percent rubble, and 10 percent mud/silt. The sediment is held together in a spongy mat by pervading growth of colonial feather-duster worms ([Branchiommma cingulata](#)) and sponges. Large feather-duster worms ([Sabellastarte sanctijosephi](#)) inhabit the sediment in densities of about 1 to 5 per square meter. Encrusting and erect sponges are common on the sediment surface in area coverage of 1 to 10 percent.

Most substrate underlying Zone 1 sediment is teak wood. Teak is smooth and relatively dense under the thickest sediment layer. Finger-sized burrows, largely created by burrowing mollusks (primarily [Martesia striata](#) and possible [Teredinid](#) species), are

evident in teak that is exposed or covered by thinner sediment cap. The color of teak in some areas is normal, whereas in other areas it has been blackened, possibly stained by exposure to sulfide compounds formed in anoxic environments under thicker sediment,

Gelatinous veneers of fish eggs (clear to purplish in color) are commonly found laid on teak and smooth metal areas that are exposed in Zone 1. Egg nests are often situated in areas that appear to have been naturally exposed by water motion, but more than 50 percent of the nest depressions have apparently been created or enhanced by fanning actions of egg-laying fish. These egg nests are likely built by the Maomao (Sergeant Major fish, *Abudefduf abdominalis*) that schools abundantly on the wreck. An estimated 100+ nests of 1-to-3-foot diameter were present in Zone 1 at the time of the survey.

Teak surfaces exposed in fish-egg nests exhibit considerably more mollusk-burrow damage than surfaces covered by sediment. Therefore, nesting activity should be considered as a potential chronic, deleterious process that should be monitored in future studies. Such monitoring should examine the density and seasonality of nesting activity and should compare the decomposition state of wood areas in and near nests to the control sites continuously covered by moderate sediment thickness.

Metal surfaces were encountered under sediment at only two stations in Zone 1, and that material was largely irregular texture corrosion products.



Figure 4.7B. Horizontal surface monitoring station marker in place.
(NPS photo by Larry Murphy)

Zone 2

Midships, about 25 percent of ship length (Stations 23 through 38). Depths in this area range from about 4 to 10 feet. Sediments are characterized by high rubble content (50 to 90 percent) with lesser quantities of sand and mud/silt. Coins were very common in the sediment immediately beneath the visitor viewing area of the Arizona Memorial.

Colonial tube worms and burrowing sponges are present, although in much lesser abundance than in the finer sediments of Zone 1. Erect and encrusting sponges are present at some stations. Alpheid snapping shrimps and commensal gobies are common in burrow

complexes in the sediment.

The higher content of coarse material in these sediments is probably due to the presence of superstructure that provides abundant vertical substrate conducive to growth of vermetid worms and oysters. Those organisms provide shell material that comprises the bulk of the rubble. Also, the surge tends to wash finer sediments out of this shallow zone or works them into concentrated horizons in lower sediment layers.

The occurrence and thickness of mud/silt horizons under the rubble varied considerably from station to station, and where present often made viewing of the underlying ship fabric difficult or impractical because of persistent turbidity. Surfaces encountered under sediment were usually irregular corroded metal of red dish-brown or blackish coloration.

In several areas a black "tarry" hydrocarbon layer 3/4 to 2 inches thick existed over grey metal. The tarry layer is probably made up of heavier fractions of fuel oil that has settled into the lower sediment horizons over the 45-year interval since the ship's sinking. That layer appears to provide some corrosion protection to the deck steel, because most oxides observed under the layer were darker (black and grey) forms resembling "stable" oxides (magnetite and hematite). Deck surface under sediment at Station 23 was found to be porcelain tile in good condition. That area is reported to have been the ship's galley.

Zone 3

Area surrounding gun turrets No. 1 and 2, and about 25 percent of ship length (stations 39 through 50). Depths in this area are about 20 to 25 feet. Sediments are predominantly (75 to 95 percent) mud and silts with some admixed rubble and sand. These fine sediments are generally 2 to 3+ feet in thickness and contain abundant burrows of alpheid snapping shrimp and portunid crabs. Colonial feather-duster worms and sponges occur on the sediment surface in some areas but are generally rare.

Water motion in this zone is gentle and turbidity is high, indicative of an area of high sedimentation. Some of the turbidity and influx of suspended fine sediment to this area is probably caused by propeller wash from shuttle boats going to and from the Arizona Memorial dock.

Fabric underneath a 1- to 2-inch layer of "Branchiomma mat" on the top of gun No. 1 was found to be shiny steel armor plate covered by a thin black oxide coat. Surfaces under sediments at all other stations in this zone were not examined because of the extreme thickness of sediment and the turbid conditions.

Zone 4

Bow deck, 12 percent of ship length (Stations 51 through 56). Depths range from 4 to 10 feet. Sediments in this zone are similar to those found in Zones 1 and 2 (as described above) and ranged from 1 to 17 inches in thickness. Fabric under one station was found to be wood (probably teak), and corroded metal was observed under sediment at the other two stations where examination holes were dug. Water motion conditions are similar to Zone 2.

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Chapter IV: Biofouling And Corrosion Study (continued)

Corrosion and Steel Fabric Thickness Study

Results

Data from observations of the edge sections are presented in Table 4.5.

Table 4.5. Thickness (in millimeters) of hard fouling, black and grey oxide layers, and shiny steel of hull and superstructure edge sections on USS ARIZONA. Station locations are provided in Figure 4.8.

<u>STATION</u>	<u>FOULING LAYER</u>	<u>BLACK LAYER</u>	<u>GREY LAYER</u>	<u>STEEL LAYER</u>
1	35	15	12	13
2	20	8	0	2
3	15	5	1	2
4	20	12	1	10
5	20	1	0.5	1
6	35	10	7	5
7	20	6	3	5
8	15	7	2	0
9	30	5	3	3-1mm steel layers alternating 2/2-3mm grey layers
10	30	6	5	5
11	25	12	3	10
12	30	5	3	15

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Chapter IV: Biofouling And Corrosion Study (continued)

Water Quality and Biofouling in Interior Spaces

Results

Fouling growth observed on interior surfaces through portholes and other openings was composed largely of vermetid worms and oysters occurring in patchy distribution. Although large clumps of fouling were often common within a radius of a few feet inside hull and superstructure openings, fouling coverage was generally less than 50 percent on interior walls and ceilings. Fine sediment covered most wall areas not covered by fouling, and silt/mud layers estimated at several inches to several feet in thickness covered all upward-facing horizontal surfaces. Ceiling areas contained patchy fouling. Unfouled surfaces were often black and flossy in appearance, probably being coated by hydrocarbon (fuel and oil) residues.

It was not possible to visually determine the corrosion state of interior surfaces because of coverage of fouling, sediment and hydrocarbons. However, exfoliating corrosion layers were not observed on any surfaces in the spaces deeper than about 8 feet, suggesting that high rates of corrosion were not occurring in those areas.



Figure 4.10. Water is drawn from interior spaces of the USS ARIZONA to surface through a PVC pipe and vinyl tube. Pipe is marked to establish exact distance of penetration.
(NPS photo by Larry Murphy)

As expected, oxygen levels measured 15 to 16 feet inside interior spaces were substantially lower than ambient values (Table 4.6). At distances of 8 to 9 feet inside openings, oxygen levels were only moderately lower than ambient, indicating that water volumes within about 10 feet of hull openings are relatively well flushed. Oxygen concentrations were at or less than 1 mg/l at 15-foot distance from opening in 3 out of 6 stations, thus it would be reasonable to assume that most other enclosed volumes in the hull that are distant from openings would also exhibit sub-1 mg/l oxygen concentrations.

Temperature and pH values measured in interior spaces were only slightly below ambient values. Those differences were not large enough to alter the corrosion or biofouling status of interior metal surfaces.

At the three midships stations (D, E and F), viscous black hydrocarbon residue was encountered while pumping at maximum probe insertions. Water samples collected at those times had a distinct volatile hydrocarbon fuel odor. Hydrocarbons were pumped in pulses when the intake end of the probe pipe was allowed to drop down and thus sample water closer to or at the bottom level of spaces. These heavy-fraction hydrocarbons are thus trapped in low stagnant areas of the ship and will likely persist in those areas for a long time.



Figure 4.11. On the surface, water drawn from inside the wreck was analyzed for oxygen, temperature and pH levels.
(NPS photo by Larry Murphy)

Low oxygen and near-normal seawater pH values documented in the spaces sampled would be expected to reduce corrosion rates substantially below those that would exist in high-oxygen harbor water (ref. 2). The presence of viscous hydrocarbon compounds as coatings on steel surfaces would further reduce availability of oxygen. Furthermore, oxygen consumption by microbes digesting hydrocarbon products would be another process that may help maintain an oxygen-depleted environment in the ship's stagnant areas. Collectively, these anticorrosion factors would probably more than compensate for the scarcity of protective biofouling cover expected on interior substrates.

Table 4.6. Oxygen, pH and temperature measurements made inside hull openings shown in Figure 4.9. Units. O2 = mg/liter (ppm), pH = pH units, temperature = degrees centigrade.

LOCATION A -- Porthole about 3 feet below starboard gunnel. About even with aft end of No. 4 gun foundation. Depth = about 10 feet.

<u>Water Source</u>	<u>O2</u>	<u>pH</u>	<u>temp</u>
Ambient (Outside porthole)	5.2	8.1	27.0
9 feet inside porthole	4.2	8.05	26.5
15.5 feet inside porthole	3.8	8.0	26.5

LOCATION B -- 25-foot depth inside No. 4 gun foundation "well."

<u>Water Source</u>	<u>O2</u>	<u>pH</u>	<u>temp</u>
25 foot depth	3.25	8.05	26.5

LOCATION C -- Porthole about 3 feet below starboard gunnel. About even with forward end of No. 3 gun foundation. Depth = about 10 feet.

<u>Water Source</u>	<u>O2</u>	<u>pH</u>	<u>temp</u>
Ambient (Outside porthole)	5.1	8.1	26.8
16 feet inside porthole	1.0	8.05	26.5
8 feet inside porthole	4.0	8.1	26.5
Ambient (Outside porthole)	5.3	8.1	27.0

LOCATION D -- Porthole about 3 feet above starboard gunnel. About 5 feet aft of bio/photo station No.- VS18. Depth = about 10 feet.

<u>Water Source</u>	<u>O2</u>	<u>pH</u>	<u>temp</u>
Ambient (Outside porthole)	5.3	8.1	26.8
8 feet inside porthole	3.7	8.1	26.5
15 feet inside porthole	0.6	8.05	26.0
Ambient (Outside porthole)	5.2	8.1	26.7

LOCATION E -- Open inspection hatch on main deck near starboard gunnel. Below location D. Depth = about 13 feet. Opening extends downward on vertical axis.

<u>Water Source</u>	<u>O2</u>	<u>pH</u>	<u>temp</u>
Ambient (Outside hatch)	5.2	8.15	26.6
14 feet down hatch	0.5	8.3	25.4
Ambient (Outside hatch)	5.2	8.15	26.6

LOCATION F -- Fourth porthole aft of location D on starboard side.- Immediately below Arizona Memorial structure. Depth = about 10 feet.

<u>Water Source</u>	<u>O2</u>	<u>pH</u>	<u>temp</u>
Ambient (Outside porthole)	5.0	8.15	26.7
12 feet inside porthole	2.9	8.05	26.5
Ambient (outside porthole)	5.2	8.15	26.7

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USS ARIZONA MEMORIAL

Submerged Cultural Resources Study:
USS Arizona and Pearl Harbor National Historic
Landmark



Chapter IV: Biofouling And Corrosion Study (continued)

Bathycorrometer Measurements

A description of the methods used to obtain bathycorrometer measurements and a listing of the resultant measurements are provided in Table 4.7 of this report. A copy of the data has been given to metallurgical engineers at Pearl Harbor Naval Shipyard for analysis.

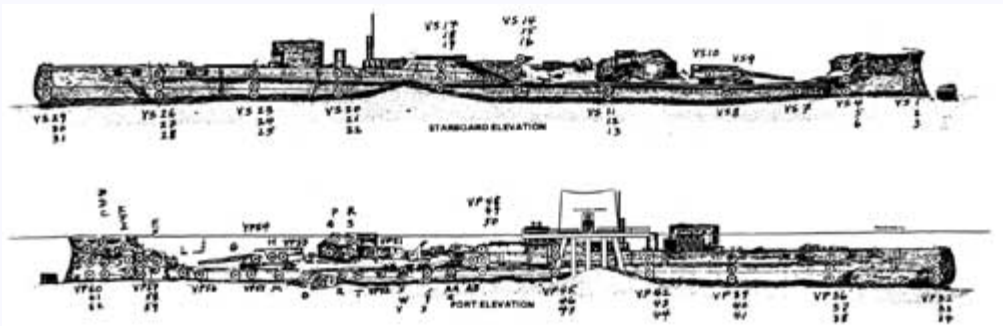


Figure 4.12. Location of bathycorrometer measurements made on the USS ARIZONA.
(click on image for a larger size)

Table 4-7 Bathycorrometer measurements - USS ARIZONA

Method used for bathycorrometer measurements: Prior to dive ops, instrument was turned on and suspended in seawater for about 30 minutes for equilibration. Soft and hard fouling growth was scraped away from metal surfaces (about a 2-inch diameter area) and black and grey oxide coatings over shiny metal were penetrated. Preliminary measurements had shown that readings made on black and grey oxides (presumably composed primarily of magnetite and hematite, respectively) were not consistently the same as readings made on shiny steel - thus all subsequent readings were made only on clean steel.

Measurements on the USS ARIZONA were made on: 1. vertical exterior hull surfaces, 2. superstructure surfaces, 3. a few hull surfaces beneath silt line, and 4. at and just below water surface at a few superstructure sites. Additionally, a few measurements were obtained from gunnel and superstructure locations on the USS UTAH in the course of one dive.

Control/drift check measurements were usually made on a gunnel site on the USS ARIZONA that was located about midship on port side. Drift was generally in the range of 0.002 volt over the course of a 1 to 2 hour dive.

Other notes: Fouling thickness measurements (in centimeters) include is total thickness of live and dead fouling. Dead fouling on most vertical surfaces averaged 1 to 2 cm thickness. Most of that material consisted of oyster and vermetid mollusk worm tubes that adhered tightly to the underlying oxide surfaces. Exfoliated = irregular oxide/steel plates delaminating from hull. Some exfoliated areas may actually be areas where a double hull exists with gaps of 1 to 5cm between plates. Areas of active corrosion, exfoliation and "delamination" were actually rare on the hull and superstructure surfaces deeper than 5 feet below surface.



Figure 4.13. Scott Henderson and another diver record bathycorrometer readings.
(NPS photo by Larry Murphy)

VERTICAL STATIONS DATA

Note: Readings were made in closer area spacing on the forward port side of the USS ARIZONA. When it became evident that there was very little variation in readings, measurements were made only at tagged biological observations (numerical designation) stations.

STA	FOULING (cm)	BLACK LAYER (mm)	VOLTS	NOTES
Contr	2 - 5	3 - 5	.587	16 Jul 85
60	2 - 8	5 - 10	.579	
61	2 - 6	5 - 10	.583	
A	5 - 15	10 - 15	.585	
B	1.5 - 5	10	.580	
C	1 - 8	10 - 15	.581	
D	1 - 7	15	.582	
57	1 - 4	15	.583	

58	1 - 6	15 - 30	.583	
59	1 - 8	15 - 20	.584	
E	1 - 3	5	.587	
F	2 - 13	15 - 25	.586	.592-17 Jul reading same site
56	2 - 10		.591	
G	1 - 5	10 - 20	.594	exfoliated - hvy yellow
55	1 - 3	10 - 15	.601	
54	1 - 4	5 - 10	.578	
53	1 - 4	<5	.575	
H			.576	
Contr			.587	stop 16 Jul 86
Contr	3 - 8	25 - 30	.589	start 17 Jul 86
I	1 - 5	1 - 10	.579	
J	1 - 5	1 - 15	.584	exfoliating
K	5 - 15	10 - 20	.583	
L	2 - 6	1 - 10	.593	
M	5 - 10	2 - 10	.592	
O	1 - 3	5 - 15	.592	exfoliating
P	1 - 4	15 - 25	.569	
Q	1 - 2	5 - 10	.574	
R	1 - 2	15 - 20	.562	
S	1 - 4	20 - 30	.571	
T	3 - 5	20 - 30	.597	exfoliating
U	2 - 5	20 - 3	.596	exfoliating
52	1 - 7	25 - 40	.592	
51			.584	exfoliating
Contr			.589	
Contr	2 - 5	10 - 25	.588	
V	2 - 6	25 - 35	.587	
W	2 - 6	<5	.591	
X	2 - 6	15 - 25	.592	
Y	1 - 4	5 - 15	.591	gas
Z	2 - 4	10 - 15	.590	
AA	2 - 4	<5	.591	gas
AB	2 - 5	10 - 15	.589	
50	5 - 7	10 - 30	.591	
49	1 - 2	15	.592	exfoliating
48	1 - 4	10	.587	
47	1 - 4	10	.591	
46	2 - 6	10	.596	
45	2 - 6	5	.590	
44	2 - 6	5 - 10	.592	
43	2 - 6	5 - 10	.591	
42	2 - 6	5 - 15	.588	exfoliating

41	2 - 6	10 - 15	.591	
40	1 - 3		.594	
39	2 - 5	15 - 20	.585	exfoliating
38	1 - 4	10	.587	exfoliating
37	1-3	5 - 15	.583	
36	5 - 10	5 - 15	.580	
35	5 - 10	5 - 10	.571	
34	2 - 8	10 - 20	.573	
33	2 - 8	5 - 10	.578	
32	2 - 4	<5	.586	exfoliating
31	2 - 3	<5	.574	
30	2 - 4	10 - 15	.581	
29			.591	
Contr			.588	stop 17 Jul 86
Contr	1 - 3	5 - 10	.593	start 18 Jul 86
28	1 - 3	5 - 10	.586	
27	1	<5	.593	
26	1 - 4	10	.600	exposed scar
25	1 - 3	<5	.595	
24	1 - 5	5 - 15	.595	
23	1 - 5	5 - 10	.597	
22	1 - 3	5 - 10	.596	
21	1 - 5	5 - 10	.598	
22	1 - 3	5 - 10	.596	
21	1 - 5	5 - 10	.598	
20	1 - 6	<5	.602	exfoliated w/ 1cm gap
19	1 - 5	5 - 15	.595	
18	1 - 4	10	.597	
17	3	5 - 10	.593	exfoliating
16	1 - 3	<5	.592	
15	1 - 3	<5	.592	exfoliating
14	1 - 3	<5	.588	
13	1 - 4	5 - 10	.596	
12	3	5	.605	
11	3 - 6	5 - 10	.592	exfoliated w/ 1cm gap
10	1 - 3	<5	.575	
9	3 - 6	5	.581	
8	2 - 6	5 - 10	.587	
7	10	<5	.588	
6	2 - 5	5 - 10	.579	
5	2 - 5	5 - 10	.583	exfoliated
4	2 - 4	<5	.588	exfoliated
3	1 - 3	<5	.586	.290 on grey layer
2	2 - 4	<5	.588	

1	.587	exfoliated
50	.594	
49	.598	
48	.590	.587 previously

SUPERSTRUCTURE STATIONS DATA

<u>STA</u>	<u>FOULING (cm)</u>	<u>BLACK LAYER (mm)</u>	<u>VOLTS</u>	<u>NOTES</u>
Contr			.590	21 Jul 86
1	1	<2	.568	#2 gun ear
2	1 - 3	5 - 10	.568	#2 gun turret
3	2 - 6	10 (black/grey)	.579	interior #2 gun turret
4	2 - 7	10	.578	interior #2 gun turret
5	1 - 4	10	.569	#2 gun turret
6	1 - 4	<2	.567	#2 gun ear
7	1 - 2	2	.586	interior wall
8	1 - 6	5 - 10	.586	interior wall
9	2 - 4	<2	.561	interior wall stack base
9	1 - 4	2/3 (black/grey)	.563	exterior wall stack base
10	1 - 5	10 - 20	.580	ext wall stbd gun tub
11	1 - 3	3 - 5	.574	stbd #3 gun foundation
12	1 - 4	<5	.579	exterior wall #4 gun found
12	1 - 2	<5	.576	exterior wall #4 gun found
13	1 - 2	<5	.583	aft ext wall stbd stairwell
14	1	<3	.580	aft ext wall port stairwell
15	0.5	<1	.585	center launch crane base
16	-	-	.641	stern anchor scraping
17	0.1	10 - 20	.583	ext wall stern vent
18	1	4/4 (black/grey)	.580	ext wall forw stern vent
19	1 - 2	<4	.576	ext port #4 gun foundation
19	1 - 4	10	.576	int port #4 gun foundation
20	1 - 2	5 - 8	.574	port #3 gun foundation
			.616	aft dock chain (recent?)
21	1 - 3	?	.581	vent forward of #2 gun foun
22	1 - 6	3/10 (black/grey)	.585	port ext wall gun tub
Contr			.589	21 Jul 86

SUBSILT HULL DATA

Note: Holes were dug into silt adjacent to hull at four locations on both port and starboard sides. Holes were about 2.5 feet deep and hull at all subsilt locations was found to be covered with layer of dead, hard fouling. Depth of bathycorrometer reading (below silt surface) is given in notes column.

<u>STA</u>	<u>FOULING (cm)</u>	<u>BLACK LAYER (mm)</u>	<u>VOLTS</u>
Contr			.599
			22 Jul 86

62	1 - 4	<5	.595	Below sta VP1 - d = 1.5 ft
52	1 - 3	<5	.602	Below sta VP4 - d = 2 ft
44	1 - 3	<5	.599	Below sta VP7 - d = 2 ft
33	1 - 3	<5	.583	Below sta VP10 - d = 2 ft
Contr			.593	22 Jul 86
Contr			.592	23 Jul 86
3	1 - 2	5 - 10	.590	Below sta VS1 - d = 1.5 ft
VS6	1 - 2	<5	.599	Below sta VS6 - d = 1.5 ft
Contr			.592	23 Jul 86
Contr			.592	23 Jul 86
7	1 - 2	<5	.602	Below sta VS7 - d = 2 ft
VS10	1 - 3	<5	.585	Below sta VS10 - d = 2 ft
VS3	1 - 3	<5	.593	Below sta VS3 - d = 2 ft
Contr			.592	23 Jul 86

NEAR-SURFACE TRANSECT DATA

These measurements were performed on superstructure pieces that penetrated the water surface. B = water line, C = 1.5 foot below water line, D = 3 feet below water line.

STA	FOULING (cm)	BLACK LAYER (mm)	VOLTS
1B	1 - 3	<5	.574
1C	1 - 3	<5	.578
1D	1 - 3	<5	.578
2B	1 - 4	<5	.578
2C	1 - 3	5 - 10	.582
2D	1 - 3	5 - 10	.582
3B	1 - 6	<5	.576
3C	1 - 5	20 - 25	.580
3D	1 - 4	15 - 20	.579
4B	1 - 5	<5	.572
4C	1 - 5	5 - 10	.576
4D	1 - 5	5 - 10	.574
5B	1 - 4	5 - 10	.580
5C	1 - 5	10 - 15	.581
5D	1 - 6	5 - 10	.579
VS48			.607
VS49			.616
VS11			.629
6B	1 - 6	10 - 15	.585
6C	2 - 10	5 - 15	.586
6D	1 - 4	5 - 10	.586
7B	1 - 5	5 - 10	.582
7C	1 - 3	3 - 6	.582
7D	1 - 4	5 - 10	.584

8B	1 - 6	5 - 15	.585
8C	1 - 4	5 - 10	.584
8D	1 - 4	5 - 10	.584

MISCELLANEOUS BATHYCORROMETER READINGS FROM USS UTAH

25 July 1986 - R. Scott Henderson

VOLTS	NOTES
.965	On galvanized dive ladder in water.
.598	On gunnel at bow.
.597	On anchor chain hole in hull - port gunnel.
.599	On vertical closed cylinder about 3 feet in diameter with cross-section like a keyhole. 1/2" black layer over steel 1/2" fouling.
.591	Pipe-like structure with "crowsnest" on top - lying on deck, 5 feet north of BP20.
.588	On jumbled steel beams and plate - corrosion/fouling as per previous station.
.588	On block-like structure at CP60 that measures about 3' x 3' x 5' - very thin fouling over what appears to be bronze or brass.
.582	Large superstructure surface - @E5 clip - black layer with some white laminations inside.
.578	Objects on wood deck that look like "nuts" measuring about 8" x 8" x 3" high made of brass or bronze.
.585	Round stack near clip P3.
.596	Large diameter salvage cable about 15' NE of FS20.
.588	Steel nearly exposed on hull by fish nest about 15' SW of FS20.
.590	Gunnel at 6.
.593	Bollard top at clip V7.
.290	Reading in normal salinity seawater at about 5' depth.
.280	Reading in lower salinity seawater near surface. No contact with solid substrates on these two readings.

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