ROV INVESTIGATIONS OF THE DKM *U-166* SHIPWRECK SITE TO DOCUMENT THE ARCHAEOLOGICAL AND BIOLOGICAL ASPECTS OF THE WRECK SITE

FINAL PERFORMANCE REPORT

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Author's Note

The DKM *U-166* and the S.S. *Robert E. Lee* are recognized war graves and irreplaceable pieces of the world's maritime heritage. Therefore, all coordinates and block numbers have been excluded from this report in an effort to protect the integrity of the wreck sites.

ABSTRACT

In October 2003, investigations were undertaken by C & C Technologies Inc., in conjunction with the NOAA Office of Ocean Exploration, Droycon Bioconcepts, Inc. and the PAST Foundation, to document the wreck site of the DKM *U-166* in 5,000 feet of water in the Mississippi Canyon Area of the Gulf of Mexico. At the time, the project was the deepest archaeological investigation ever conducted in the Gulf of Mexico. This project marked one of the first instances that positioning technology that is routinely used in the offshore oil and gas industry was utilized on a deepwater archaeological investigation of a shipwreck. During the five-days between October 5 and October 10, 2003, scientists utilized a Sonsub Innovator Class remotely operated vehicle, deployed from the NOAA Research Vessel *Ronald H. Brown*, to produce a detailed archaeological map of the wreck of DKM *U-166*, place microbiological experiments, and obtains samples of the microbiological communities present at the site. During the investigation, a 945 x 600 feet area encompassing 718,760 square feet or 16.5 acres of seafloor was surveyed and three hundred and seven individual or groups of artifacts were mapped and documented using digital video and still imagery. Through careful examination of the data collected from the site, we have a better understanding of the site size and artifact distribution, the microorganisms that now thrive on the wreck, and the events that destroyed the DKM *U-166*. This report describes the fieldwork that was undertaken and discusses the results of the analysis of both the archaeological and microbiological findings.

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Sheet 1 ROV TRACKLINES MAP 1" = 40'

Sheet 2 ARTIFACT DISTRIBUTION MAP 1" = 40'

EXECUTIVE SUMMARY

- Between October 5 and 10, 2003 a team of Marine Archaeologists, Microbiologists, and Surveyors conducted a deepwater archaeological investigation on the wreck of the German U-boat DKM *U-166* in the Mississippi Canyon Area of the Gulf of Mexico.
- During the project, 307 individual artifacts or groups of artifacts were documented using high-resolution digital video and still imagery in conjunction with a highly accurate positioning system.
- The project determined that the DKM *U-166* wreck site is approximately 900 x 900 feet in size and is oriented north to south.
- The vessel is broken into two sections: The bow section near the western extent of the site and the stern section near the eastern extent of the site.
- The bow section exhibits significant structural damage where it separated from the stern section, including a large indentation in the deck that is interpreted as the result of a depth charge explosion.
- The stern section is intact except for the missing portion of the bow but is buried up to deck level in the bottom sediments.
- There is an extensive debris field present at the wreck site.
- The debris is concentrated near the bow and appears to be associated with that portion of the vessel.
- The artifact scatter extends to the south away from the hull remains.
- The artifact distribution at the site suggests the hull pieces broke apart relatively close to the seafloor (<1000 feet) to the south of their current position.
- A study of the Microbiological aspects was also undertaken as part of this project.
- Experiments were placed on the wreck site to determine the bacterial activity at the site and the rate of biocorrosion.
- Samples of bacterial communities (rusticles) were gathered from the DKM *U-166* wreck and the wreck of the S.S. *Robert E. Lee*
- Considerable differences were observed in 2003 between the rusticles found on the S.S. *Robert E. Lee* and DKM *U-166*. These differences related to the dominant metal content. Iron was dominant in the rusticles of DKM *U-166* and aluminum was dominant in rusticles from the S.S. *Robert E. Lee*, which was possibly used for the bulk shipping of bauxite.
- The rusticles found on both the S.S. *Robert E. Lee* and DKM *U-166* showed strontium levels that were at least one order of magnitude higher than the strontium levels from rusticles that had grown on the HMHS *Britannic*.
- Microbiologically the site was rich in both bacterial and fungal activity. The etching technique revealed very aggressive proteolytic activity.

1.0 INTRODUCTION

In 2003, the National Oceanic and Atmospheric Administration Office of Ocean Exploration (NOAA OE) awarded a grant to C & C Technologies, Inc. (C & C) of Lafayette, Louisiana, to conduct investigations on the Deustche Kreigsmarine (DKM) *Unterseeboot 166* (*U-166*) wreck site in the Gulf of Mexico. C & C partnered with Droycon Bioconcepts, Inc., and the PAST Foundation on the project. The purpose of the investigation was to archaeologically document the remains of the DKM *U-166* in an effort to better understand the wreck site and the events that led to the vessel's destruction. In addition to the archaeology, the microbiological communities (rusticles) would be examined for comparison to similar organisms located on other deepwater shipwrecks such as RMS *Titanic* and DKM *Bismarck*. Between October 5 and October 10, 2003, the project objectives were accomplished using a Sonsub, Inc. remotely operated vehicle working from the NOAA Research Vessel *Ronald H. Brown*. Highly accurate undersea positioning technology was provided by C & C's Marine Construction Division in conjunction with Sonardyne, Inc. The project completed or partially completed all of the project objectives within the allotted five days. The resounding success of this project is an example of what can be accomplished through partnerships of academic, private, and government entities. The following report provides a detailed discussion of the project including objectives, methods, and findings as required by the NOAA OE award contract.

2.0 OBJECTIVES

The DKM *U-166*'s historical significance and its unique state of preservation provided the basis for further study following its discovery in 2001. The 2003 field investigations of the DKM *U-166* wreck site were carried out to fulfill the following objectives:

Archaeological:

1) Determine the extent of the DKM *U-166* wreck site
2) Collect high-definition video of the wreck sections and artifact field
3) Photo-document the visible wreck sections, artifacts, and relevant biological communities
4) Acoustically position visible wreck sections and artifacts

Microbiological:

5) Deploy long-term and short-term microbiological experiments
6) Collect biological samples (rusticles) from the wreck site

3.0 HISTORICAL BACKGROUND

U-boat War in the Gulf of Mexico

In America during the early months of 1942 the war seemed far away, but in reality an ominous threat, Hitler's U-boats, lurked in the waters off the Eastern and Gulf Coasts. Following America's entry into World War II after Japan's attack on Pearl Harbor, Hitler extended U-boat attacks to the shores of America just as Germany had done during World War I. This time, however, the U-boats were not limited to operations on America's East Coast. U-boat captains would also strike deeply into America's backyard, the Gulf of Mexico.

Over roughly a year's time, beginning in May 1942, twenty-four German U-boats entered the Gulf of Mexico. Seventeen of these U-boats sank fifty-six merchant ships and damaged several others (Wiggins, 1995:passim). The DKM *U-166*, under the command of Hans-Günther Kühlmann was one such boat. The DKM *U-166* entered the Gulf of Mexico in early July 1942 and proceeded on a mission to lay mines off the mouth of the Mississippi River. On July 27, 1942 Kühlmann radioed German Naval Command reporting completion of mine laying activities and that he was proceeding to hunt shipping (War Diary, 1942: 36,53,92;). It would be the final message from DKM *U-166*.

On July 30, 1942 the passenger freighter S.S. *Robert E. Lee* was bound for New Orleans under escort from a newly commissioned patrol craft, *PC-566*. Approximately 45 miles from the Mississippi River's Southwest Pass, a torpedo fired from the DKM *U-166* struck the S.S. *Robert E. Lee's* starboard side. As the freighter began to sink, *PC-566* rushed to attack the submarine. After gaining sonar contact the patrol dropped ten depth charges across the U-boat's path as it attempted to dive to a safer depth. An oil slick and the patrol craft's inability to regain sonar contact with DKM *U-166* led *PC-566*'s crew to believe the U-boat had fled or been sunk. A Navy review board later ruled it unlikely that *PC-566* sank the U-boat.

Two days later, on August 1, 1942, two U.S. Coast Guardsmen, Pilot Henry White and Radio Operator George Boggs, were patrolling in a J4F amphibious aircraft roughly 100 miles south of Houma, Louisiana when they spotted a U-boat on the surface. As the U-boat crash-dived towards the safety of deep water, White and Boggs attacked with their only weapon, a single depth charge. White and Boggs reported the depth charge exploded near the submarine and an oil slick appeared on the surface. When they returned to base they were informed the incident was classified. A year later, White and Boggs were told they had destroyed the DKM *U-166* and were decorated for their action.

For the next 59, years history recorded that the DKM *U-166* was sank off Louisiana's coast 100 miles south of Houma. Despite numerous oil and gas surveys in the region and expeditions to the area by groups seeking DKM *U-166*, it was not found until 1986 and was not correctly identified until 2001. Its location, 140 miles east of the location where White and Boggs attacked a U-boat, proves that *PC-566* did destroy the U-boat that sank

the S.S. *Robert E. Lee* and that it was the *U-166*. Historical records regarding the actions of U-boats operating in the Gulf of Mexico indicate that the U-boat White and Boggs attacked was most likely the *U-171*. Although White and Boggs did not sink the *U-171*, they did drive it away from the coast and temporarily keep it from sinking allied vessels. Unfortunately, the commanding officer of *PC-566*, H. G. Claudius, died in 1981 before learning that his attack on the U-boat that day in July 1942 had succeeded. Most of the surviving members of *PC-566* have been informed of the discovery and history has been corrected.

4.0 PREVIOUS INVESTIGATIONS

Shell Deep-Tow

In 1986, Shell Offshore, Inc. had interests in the deep waters of the Mississippi Canyon Area in the Gulf of Mexico. To explore this region they contracted John E. Chance and Associates to conduct a survey using a 4075 EDO deep-tow system. While performing the survey, they detected two shipwrecks. The only shipwrecks the U.S. Department of the Interior, Minerals Management Services (MMS) listed in the vicinity were two World War II casualties, the *Robert E. Lee* and the *Alcoa Puritan*. At the time, no archaeological assessments were required in deepwater lease blocks and it would not be until 1994 that archaeologists would review the data and prepare an assessment. Given the information current at the time it was realistic to assume the *Robert E. Lee* and the *Alcoa Puritan* had been found. No further investigations of the shipwrecks were conducted because of the expense and more importantly the time involved in conducting deepwater surveys with a towed array.

2001 BP/Shell AUV Survey

In January 2001, C & C Technologies, Inc. (C & C) conducted another survey for BP and Shell International in the Mississippi Canyon Area near the reported location of the S.S. *Robert E. Lee*. This survey was conducted using C & C's new HUGIN 3000 Autonomous Underwater Vehicle (AUV), a completely untethered survey platform. During this survey, a large wreck was detected near the edge of the survey swath. C & C Marine Archaeologists Robert Church and Daniel Warren verified with the Minerals Management Service (MMS) that this was the S.S. *Robert E. Lee*. Because the S.S. *Alcoa Puritan* was known to be in close proximity to the wreck of the S.S. *Robert E. Lee*, BP and Shell agreed that additional survey investigation with the HUGIN 3000 AUV be carried out to precisely position any wreckage in relation to the proposed pipeline route.

In March 2001, the additional survey work was completed. When the data was reviewed by C & C's Marine Archaeologists, they noted the wreck of the S.S. *Robert E. Lee* and a new area of wreck debris, less than a mile to the east, where the 1986 survey had placed the wreck of the S.S. *Alcoa Puritan*. During the analysis, it became apparent to Church and Warren that the wreckage thought to be the S.S. *Alcoa Puritan* was not consistent with that

size and type of freighter. The wreckage was consistent, however, with the dimensions of a Type IXC German U-boat (252 feet in length and 22 feet wide), the same class as the DKM *U-166*.

Church and Warren developed a new hypothesis to explain why the DKM *U-166* was 140 miles east of where history had recorded it lost. This hypothesis proposed the DKM *U-166* was destroyed on July 30, 1942 by Patrol Craft *566*'s depth charge attack, and Coast Guard aviators White and Boggs bombed a different submarine that escaped. To lend credence to this hypothesis, the reconstructed logs of the DKM *U-171*, the only other U-boat in the area at the time, were examined. These logs stated that around early August 1942 while off the Louisiana Coast the DKM *U-171* was bombed by a "flying boat" (a good description of an amphibious aircraft) but sustained no damage. The attack's exact date could not be determined since the original logbooks were lost when the DKM *U-171* was destroyed by a mine in the Bay of Biscay when returning from its patrol in the Gulf of Mexico.

The hypothesis that the second area of wreckage could be the DKM *U-166* led BP and Shell to sponsor further site-specific investigations of the S.S. *Robert E. Lee* and suspected DKM *U-166* sites using the HUGIN 3000 AUV. The results of this data (Figure 1) provided additional support to the DKM *U-166* hypothesis and stressed the need for a final verification of the wreck's identity through visual inspection with a Remotely Operated Vehicle (ROV).

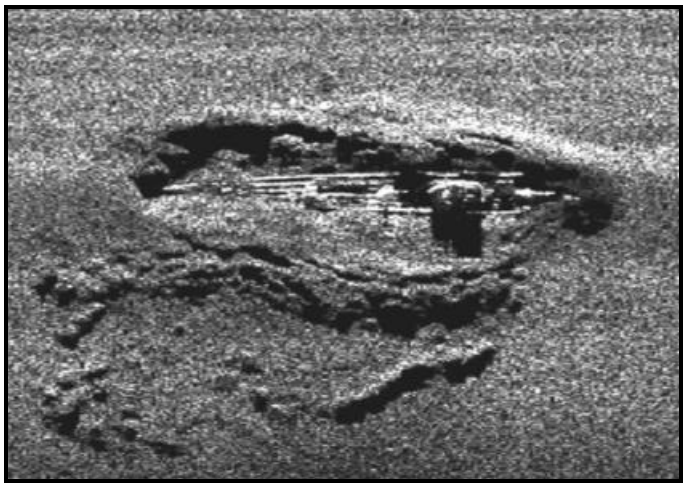

Figure 1. High-resolution Side Scan of DKM *U-166* remains, 2001.

On May 31 and June 1, 2001 a research team comprised of representatives from BP, Shell, C & C, and the MMS traveled to the Mississippi Canyon Area to determine if the German *U-boat*, DKM *U-166* had actually been located. The research team utilized the *Gary Chouest*, an anchor-handling vessel on contract to Shell and equipped with an Oceaneering Millennium VI ROV.

The first glimpse of the vessel was the unmistakable conning tower of a German U-boat. The 105-mm deck gun, 37-mm, and 20-mm antiaircraft guns were clearly visible. Although there was some initial confusion concerning the conning tower "wintergarten" configuration, that was soon resolved with additional research. Each feature documented matched that of the U-*166*.

The investigation of the bow section provided a revealing look at a possible cause of the U-boat's destruction. A large indentation was visible in the top of the deck, which appears to be the result of a depth charge explosion. Just aft of this damaged area the bow had torn away from the rest of the vessel and the serrated metal flares outward as if caused by an internal explosion. Possibly a depth charge exploded very near the deck, rupturing the pressure hull, which then caused an internal explosion. It was speculated that salt water rushing into the battery room or a torpedo in that location of the U-boat could have caused such an explosion.

The ROV vessel was then moved a mile to the west to collect detailed video images of the final resting place of the *Robert E. Lee*. The *Robert E. Lee* has subsided into the seafloor and the torpedo damage was hidden below the mudline. Many points of interest were recorded including the deck gun on the stern, two lifeboats lying off to the port side of the ship, and the brass signal bell on the bow, but the most spectacular find from the *Robert E. Lee* was the ship's telegraph, which was used to communicate from the bridge to the engine room. The telegraph was found lying over 200 feet off the port side of the *Robert E. Lee*. It was all alone standing upright on the seafloor. Because it was made of brass, it was in pristine condition and most the words on the face were clearly legible. The engine room indicator arrow was in the "STOP" position and the handle was back in the "FINISHED WITH ENGINES" position, a command that was never executed.

The expedition was successful in identifying the long sought after U-boat and its last victim. Unfortunately, only cursory examinations of the wreck sites were carried out due to the limited availability and capabilities of the ROV. Time constraints with the ROV allowed only 24 hours (approximately 8 hours of dive time) to investigate both shipwreck sites with less than 4 hours being spent to document the DKM *U-166* site.

Significance of the DKM *U-166*

Hitler's U-boat war along America's East Coast and in the Gulf of Mexico succeeded in sinking numerous merchant ships during the initial forays. This success, however, was not without cost. Many of the U-boats that conducted attacks along America's coast were sunk, among them the DKM *U-166*. These vessels resting in U.S. waters are recognized war graves and are considered historically significant shipwrecks. Of the U-boats lost in American waters, however, the DKM *U-166* stands out. The DKM *U-166* is significant among the other U-boats because it was the only one lost in the Gulf of Mexico, and because of its unique state of preservation.

Many U-boats lost along America's coasts were sunk in the relatively shallow waters along the Eastern Continental Shelf. Over the past 60 years, these U-boats have been repeatedly subjected to the elements, and more recently souvenir hunting sport divers. The result of these depredations, by nature and man, has been the partial destruction of many of these wrecks. This is not the case with the DKM *U-166*. Resting in approximately 5,000 feet of water the wreck has not been subjected to the strong currents, wave action, or storms associated with shallow waters. Its extreme depth has also protected it from being preyed upon by souvenir scavenging divers. As a consequence of its location, the DKM *U-166* represents a pristine example of a Type IXC U-boat, not withstanding the fact that the wreck is in two sections 500 feet apart.

The DKM *U-166*'s location in deepwater water has led to rusticle formation. The rusticles are actually microbial communities that live off of the iron on wrecks. These microbial communities have been documented on other deepwater shipwrecks including RMS *Titanic* and DKM *Bismarck*. Several groups of these rusticles are visible on the 2001 video of DKM *U-166*, mainly on the damaged part of the bow section. There is a lack of knowledge of the manner in which rusticles can afflict maritime steel structures leading to premature failures. These effects are a combination of embrittlement, corrosion, and losses in tensile strength. Studying the nature of the rusticle growths could have long-term implications for the sustainability of maritime steel structures.

5.0 SITE OVERVIEW

The wreck of the DKM *U-166* is located in the Mississippi Canyon Area in the Gulf of Mexico. Water depth at the wreck site is approximately 5,000 feet. Sediments at the wreck site consist of greenish-gray silt and clay. Overall the seafloor around the wreck site is relatively flat, except for an area of low relief sediment mounds near the stern section of the wreck.

Three distinct areas of wreck remains were noted during the 2001 investigations of the DKM *U-166* wreck site - the stern wreckage, the bow wreckage, and a debris field. The site is oriented roughly north to south (Figure 2). The stern remains are located near the eastern limits of the site and consist of an approximately 200-foot section of hull wreckage including all the deck guns and the conning tower. The bow remains are located near the western extent of the site approximately 500 feet west of the stern section. It consists of an approximately 50-foot section of hull extending from the prow aft to just past the forward torpedo hatch. Debris is scattered throughout the wreck site, but the main scatter appears to in between the bow and stern section. The debris consists of various materials dislodged or ripped from the U-boat as it plunged to the seafloor.

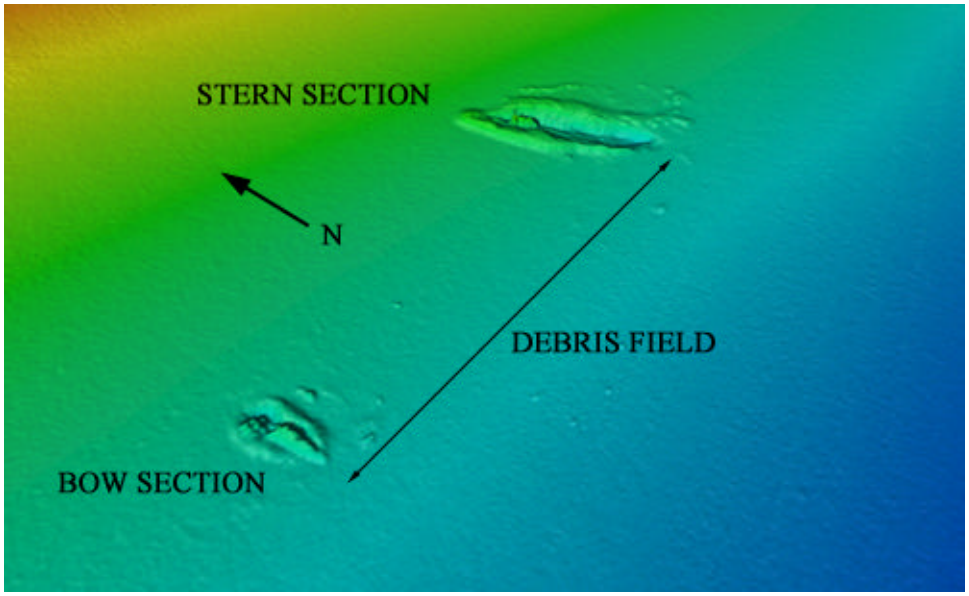

Figure 2. Multibeam site plan of DKM *U-166* wreck site, 2003.

6.0 CURRENT RESEARCH

Equipment and Methods

The challenges of conducting an archaeological investigation on the DKM *U-166* wreck site were different than those faced in shallow water environments. Many of the difficulties associated with this site were the result of the distance from any major port and the significant water depth at the site. These challenges were not insurmountable and were resolved through planning, technology, and ingenuity.

The DKM *U-166*'s location nearly 50 miles off the southeastern Louisiana coast and over eight hours away from the nearest port required that the support vessel remain on station for the entire project. The vessel used for this project would have to be capable of extended self-sustaining operations away from port facilities. The NOAA Office of Ocean Exploration provided such a vessel, the Research Vessel *Ronald H. Brown*. The *Ronald H. Brown* is a 274-foot NOAA research ship capable of working independently offshore for long periods of time. It has extensive laboratory facilities, a heavy-duty crane system, and ample deck space for the ROV. Additionally, the vessel is equipped with a dynamic positioning system that allows the ship to remain on station without the use of an anchor spread (Figure 3).

Figure 3. The NOAA Research Vessel *Ronald H. Brown.*

The extreme water depth of the DKM *U-166* site, 5,000 feet, required the use of mechanical undersea vehicles to investigate the wreck remains. Because of the need to conduct 24-hour operations, remotely operated vehicles (ROV) were chosen over manned submersibles for this project. ROVs can operate for extended periods without having to return to the surface to recharge batteries, as manned submersibles would have had to do. The ROV used was an Innovator Class provided by Sonsub, Inc.

Sonsub's Innovator Class ROV (Figure 4) is rated at 200 horsepower and is capable of operating at depths up to 3,000 meters. It is equipped with 5 and 7-function manipulator arms, scanning sonar, high intensity lighting, and a fiber-optic uplink. It uses a top hat Tether Management System (TMS) with a positively buoyant tether. The use of a TMS with a positive tether is essential to prevent the possibility of the wreck being damaged by the tether dragging on the seafloor. Additionally, for the DKM *U-166* investigations, the Innovator ROV was outfitted with a 3-chip digital video camera, digital still camera, and an acoustic positioning beacon both on the ROV and the TMS.

The Innovator ROV would survey the area of the wreck site following a pre-designated survey grid. The survey grid was designed to provide multiple areas of overlapping coverage to insure no areas were missed during the investigation. The grid consisted of sixty-three lines oriented north-to-south and spaced 15-feet apart. During the survey the ROV flew between 6 and 15 feet above the seafloor to minimize the chance of missing wreck remains (Sheet 1).

Figure 4. The Sonsub Innovator ROV used for the DKM *U-166* project.

Real-world positioning of the wreck remains was an essential element of the investigations on the DKM *U-166*. Accurate coordinates were required to produce a realistic site plan and distinguish artifact patterns. In order to provide accurate positioning, a global positioning system was employed on the project. For this project C & C's proprietary C-Nav global positioning system was used.

C-Nav is a globally corrected global positioning system. It utilizes Real Time Gypsy (RTG) technology developed by NASA's Jet-Propulsion Laboratory. Since it uses RTG technology, C-Nav is not susceptible to the spatial decorrelation errors that plague other systems. By using C-Nav, the position of the *Ronald H. Brown* would be known within 4 inches (horizontally) of its actual position.

The real-world position of the ROV while working on the site was determined by using a Sonardyne Fusion Long Baseline (LBL) or range-range acoustic measurement system (Figure 5). This system utilizes transponders placed at known locations on the seafloor to calculate the position of the transceivers mounted on the ship and the ROV. The signals from the transponders and ROV are sent to the support vessel where they are calculated using positioning software, in this case Sonardyne's Pharos Navigation Software. During the DKM *U-166* fieldwork, five medium frequency COMPATT transponder beacons were deployed in a 2,296-foot diameter array around the site. Once these beacons were calibrated, the Sonardyne Pharos software calculated the position of the ROV in real-world coordinates. Using the Sonardyne Fusion LBL system in conjunction with C-Nav and the Pharos Navigation software, positions taken on the wreck were accurate to within 1-foot in 5,000 feet of water.

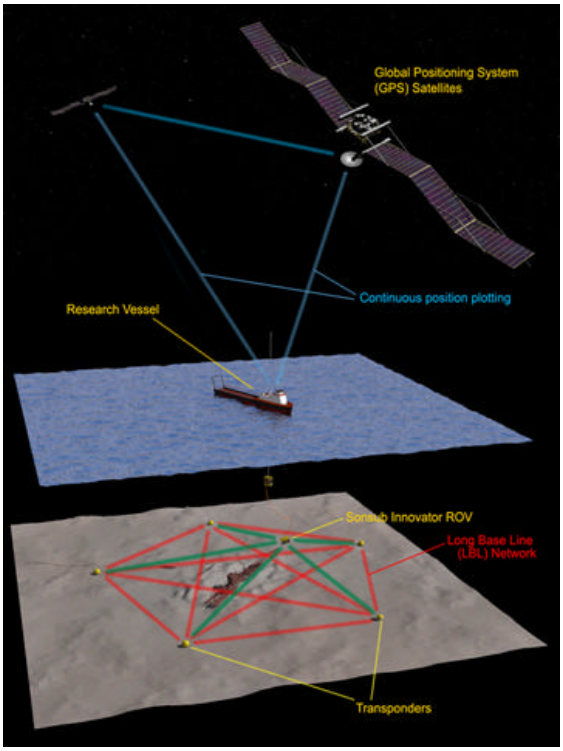

Figure 5. How long baseline positioning works. (Drawing courtesy of Andy Hall)

Mapping of the wreck remains on the DKM *U-166* was carried out using the Innovator ROV. Before dive operations began, the digital still camera was mounted in a vertical position on the ROV. The location of the camera was made the navigation center-point, meaning that any position fixes taken on the ROV would indicate the position of this point. As the ROV traveled along its pre-designated survey grid, members of the research team would watch the seafloor for wreck remains. When artifact material was located, the ROV would hover with the object centered in the viewfinder of the digital still camera. A fix would be taken and the object documented using the digital imagery systems. This documentation included recording images of the object with size reference scale. Initially, parallel lasers were planned to provide scale in the images. However, a malfunction in the system required the use of an alternate method. A metal straight edge, two feet in length and marked in increments of 6 inches was used for scale in the photos (Figure 6). Using this procedure, 307 artifacts or groups of artifacts were documented on the DKM *U-166* wreck site. This documentation created in excess of 50 hours of high-resolution digital video and approximately 1800 digital still images. No artifact materials were recovered from the site due to its status as an international war grave.

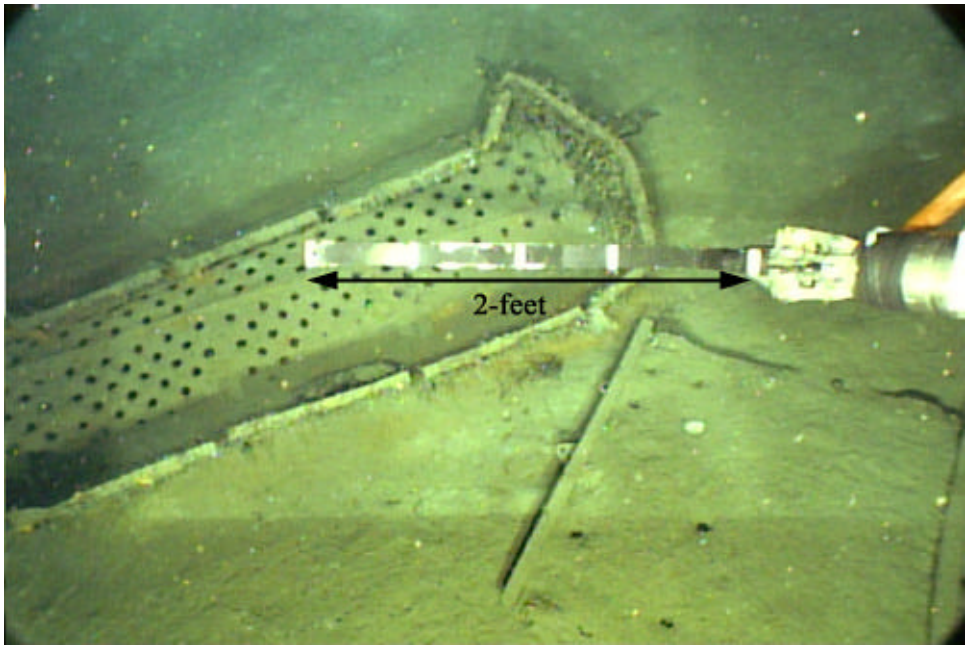

Figure 6. Reference scale being used to measure Artifact Group No. 113.

In addition to the archaeological investigations, documentation of the microbiological communities (rusticles) growing on the DKM *U-166* was also conducted. The assessment of the rusticles at the DKM *U-166* was done through the placement of long and short-term experiments and sampling of rusticle growths from different sections of the wreck. Short-term experiments, called BARTS and etch tests, were placed on the wreck site at various locations and left in place for approximately 48 hours. These experiments are designed to help determine the types and the level of bacterial activity present at a wreck site. The long-term experiments consist of test platforms containing samples of a variety of materials such as wood, iron, and aluminum. These experiments are used to determine the rate of biocorrosion on a wreck site. They were left in place on the wreck and will be checked periodically on subsequent visits to the wreck (Figure 7).

The collection of rusticle samples was necessary to further identify the types of bacteria present on the wreck. The collection of all rusticle samples taken during this project was done under the supervision of MMS and NOAA OE representatives to insure that there was no adverse impact to the wreck. The rusticles were collected in a 12-inch piece of clear PVC closed on one in with a handle attached. This device was fabricated by one of the members of the Sonsub ROV crew and was called the "Lucas Stein" after its developer. Once the sample had been acquired in the "Lucas Stein" it was placed in a sample bucket to be brought back to the surface where it was given to microbiologist Lori Johnston of Droycon Bioconcepts, Inc. (Figure 8).

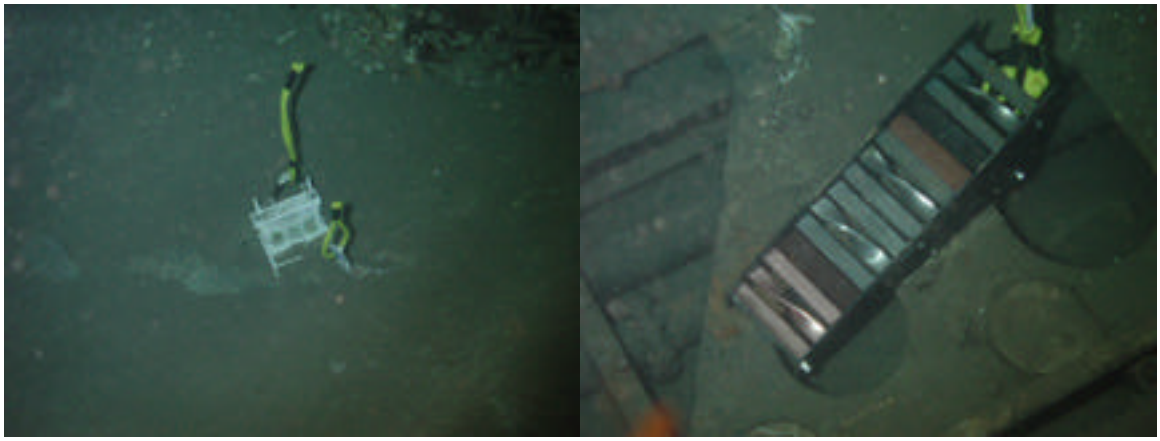

Figure 7. Microbiological experiments, BARTS and etch tests (l) and test platforms (r).

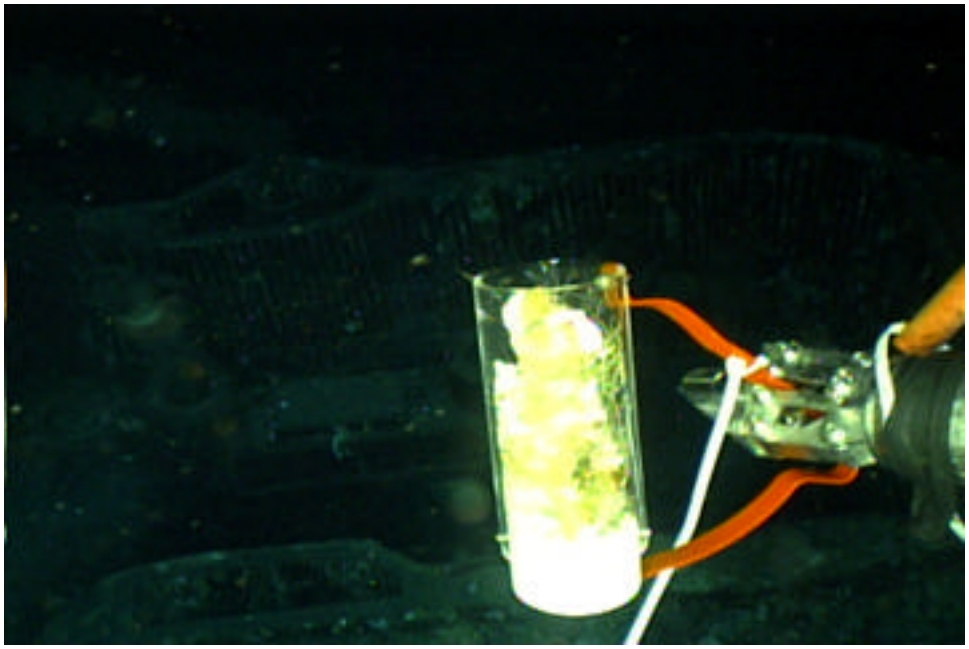

Figure 8. The "Lucas Stein" with rusticles from the DKM *U-166.*

Following the completion of the fieldwork, the materials related to the archaeological investigation were brought back to the C & C offices in Lafayette, Louisiana. At C & C the digital data was copied and distributed to the groups involved in the project. The archaeological analysis consisted of analyzing the digital imagery to in an effort to classify the wreck remains. The wreckage was classified into five basic categories: Unidentified Wreckage, Crew-Personal Items/Equipment, Outer Hull/Deck Wreckage, Interior Hull Wreckage, and Intrusive Non-site Related Materials. Using these designations, a site map was developed using the coordinates acquired during the wreck investigation (Sheet 2). The microbiological experiments were taken to Droycon Bioconcepts, Inc. office in Regina Canada for further analysis.

Summary of Operations

Between October 5 and 10, 2003, investigations were undertaken from the NOAA ship R/V *Ronald H. Brown* to document the wreck site of the DKM *U-166* using a remotely operated vehicle (ROV). This project represented the deepest archaeological investigation conducted to date in the Gulf of Mexico. It also marked one of the first times that positioning technology that is standard in the offshore oil and gas industry was utilized for a deepwater archaeological investigation.

Field investigations began on October 5, 2003. After transiting from Gulfport, Mississippi to the wreck site location, the *Ronald H. Brown* took position over the wreck to begin operations. The first task was the deployment of the acoustic beacons (COMPATTS), which made up the long baseline positioning system. Over a period of roughly 18 hours, five COMPATTS were deployed in a 2,296-foot diameter array around the wreck site. Once placed on the seafloor, the beacons were calibrated to ensure positioning was within acceptable accuracy levels. After the beacons had been calibrated, documentation of the wreck commenced. The first phase of the documentation was to produce a photo mosaic of the hull remains. Work on the photo mosaic was started at the bow section. The ROV followed a series of predetermined lines over the bow section while digital still images were taken approximately every 10 feet along the hull and digital video imagery was collected. Once the bow section had been documented the short and long term microbiological experiments were placed on the bow. The photo mosaic process was then repeated on the stern section and the microbiological experiments placed on that section of the wreck site.

Once the photo documentation of the hull remains was complete, a survey of the entire wreck site commenced. The ROV traversed a pre-designated grid of 63 north-south survey lines spaced 15 feet apart while collecting continuous digital video imagery. The ROV's altitude during the survey ranged from between 6 to 15 feet above the seafloor. Survey of the debris field continued until the late afternoon of October 9, 2003 at which time the originally planned 63 survey lines were completed. ROV operations on the DKM *U-166* site were then temporarily halted to allow an additional survey of the DKM *U-166* site with the HUGIN 3000 AUV. During the next roughly 9.5 hours while the HUGIN 3000 conducted a survey of the DKM *U-166*, the R/V *Ronald H. Brown* transited approximately a mile to the west to allow an investigation of the S.S. *Robert E. Lee* to be carried out using the ROV. The investigation of the S.S *Robert E. Lee* identified several sonar targets that had not been investigated in 2001, collected digital video imagery and still images of the wreck remains, and collected samples of rusticle colonies from the wreck for study.

Early on the morning of 10 October, following the completion of the HUGIN 3000 AUV survey, the R/V *Ronald Brown* returned to station over the DKM *U-166* wreck site and the ROV resumed the documentation of the debris field. The debris field was determined to extend beyond the southern extent of the original survey area and it was decided that additional lines would be surveyed as time permitted to attempt to locate the southern edge of the debris scatter. Prior to running the additional lines, rusticle samples from the DKM

U-166 were taken from the conning tower under the guidance of NOAA OE and Mineral Management Service representatives and the short-term microbiological experiments were also recovered. The additional survey to locate the southern boundary of the debris field began early on the morning of October 10 and continued until approximately noon before deteriorating weather conditions and time constraints forced the termination of field operations. Five additional east-west lines approximately 540 feet in length spaced 30 feet apart were surveyed to the south of the original survey area, but the southern extent of the debris scatter was not located.

Following the termination of the wreck site investigations, the ROV and the beacons were recovered and brought on board the R/V *Ronald H. Brown*. Once the ROV and other equipment had been secured, the R/V *Ronald H. Brown* began transiting to the Port of Pensacola, Florida where it arrived on the morning of 11 October 2003.

Analysis of Objectives

The goal of the 2003 Field Investigations on the DKM *U-166* wreck site was to achieve the six objectives listed in section 2.0. With the exception of one, the objectives were fully completed. The following is a detailed discussion of the success of each objective.

1) Determine the extent of the DKM *U-166* wreck site

Of the six objectives, determining the DKM *U-166* wreck site boundaries was the only objective that was only partially completed. The determination of the site limits is important to understanding the site distribution and formation. It will also assist in developing a nomination to the National Register of Historic Places, or as a National Battlefield Site. A standard archaeological survey grid consisting of 63 parallel survey lines covering an area of approximately 945 x 600 feet was developed using information from the 2001 AUV and ROV investigations. Based on the available data, the debris field was considered to be light to moderate and was not expected to extend beyond the coverage area.

During the 2003 field investigations, the ROV completed the survey of the entire 945 x 600 feet survey area. This survey determined the northern, eastern and western extents of the wreck site, but indicated the southern edge extended beyond the planned survey area. Additional lines were surveyed in an effort to find the southern end of the debris field. Five additional east-west lines were surveyed out to approximately 93 feet south of the southern edge of the original survey area before weather and time constraints forced an end to the seafloor investigations. Each line was approximately 540 feet in length spaced 30 feet apart. The data from the additional lines indicated that the debris field continues further to the south but is of light density. Additional survey work is planned for the 2004 field season to locate the southern boundary of the wreck site.

There are several reasons that this objective was only partially completed. First, the density of the debris field was much heavier than expected. The 2001 data used to plan the 2003 survey indicated a light to moderate density of material (artifacts) in the debris field, when it was actually a heavy density. This required more time than originally estimated to document the numerous artifacts within the debris field, leaving less time for additional survey.

Second, equipment malfunctions increased the time necessary to document each artifact or groups of artifacts. Initially a dual parallel laser measuring system was to be utilized to measure artifacts. Prior to the commencement of this cruise the single unit on the R/V *Ronald H. Brown* failed and could not be replaced. This required that an alternative method of measurement be developed and used. This system used a two-foot metal straight edge scale marked in 6-inch increments. This scale rule was extended using the ROV's manipulator arm to measure an artifact. Measuring each artifact located using this system also increased the time necessary to document artifacts in the debris field thereby leaving less time for additional survey.

Finally, the HUGIN 3000 AUV survey and deteriorating weather conditions also contributed to the only partial completion of this objective. The HUGIN 3000 AUV was scheduled to conduct a high-resolution remote sensing survey of the DKM *U-166* site in conjunction with the ROV investigations. It was estimated that approximately 8 hours would be needed for the AUV to complete the survey for both the S.S. *Robert E. Lee* and the DKM *U-166* sites; however, the AUV was on location at the DKM *U-166* site for approximately 9.5 hours. During this time, the ROV was utilized to investigate the S.S. *Robert E. Lee* site and several previously unidentified targets to the south of the S.S. *Robert L. Lee*. After the AUV completed its survey, ROV operations resumed on the DKM *U-166* site, but poor weather conditions moved in faster than expected forcing a halt to survey operations several hours earlier than planned due to safety concerns.

Despite the fact that the southern extent of wreck site was not located, the survey itself can be considered a success. Approximately 718,760 square feet or 16.5 acres of seafloor were surveyed at a water depth of 5,000 feet. This represents the deepest and most detailed survey of a shipwreck site conducted in the Gulf of Mexico.

2) Collect High Definition Video of the Wreck Sections and Debris Field

The objective to collect high definition video imagery of the DKM *U-166* wreck site was successful. The collection of this video is important to further study of the site. Because of the inaccessibility of the site, detailed video documentation is necessary to allow future study of the site by other interested scientists. To provide the highest definition imagery possible a three chip digital video camera was used. During the project approximately 58 hours or 200 gigabytes of digital video imagery was collected on mini-digital videotape and on DVD. This imagery details the hull remains of the DKM *U-166* and the S.S. *Robert E. Lee*, the artifact remains located in the debris field, biological aspects of the wreck site, and bottom topography at the site.

3) Photo-document the visible wreck sections, artifacts, and relevant biological communities

The objective to photo-document the archaeological and biological aspects was successful. Still digital photographs were taken of the main hull remains, 307 individual or groups of artifacts, and biological communities. Approximately 1800 still digital images were collected during the project. These images have been analyzed and are currently being cataloged and placed into a database.

4) Acoustically position visible wreck sections and artifacts

The objective to provide real-world locations for the hull remains and artifacts located at the wreck site was successful. Accurate positioning of wreck site debris is important to the study of the site formation process and to the study of artifact distribution and patterning at the site. To achieve this object a Sonardyne Fusion Long Baseline (LBL) or range-range acoustic measurement system was used. This system uses transponders placed at known locations on the seafloor to calculate the position of the transceivers mounted on the ship and/or ROV. During the 2003 DKM *U-166* field investigations five medium frequency COMPATT transponder beacons were deployed in a 2,296-foot diameter array around the site. Once these beacons had been calibrated the overall positioning accuracy was within 1 foot in 5,000 feet of water.

The LBL positioning system was used to provide position information on the ROV as it surveyed the site (Sheet 1). It also provided one of the highest accuracies for artifact positioning achieved on an archaeological site survey at this depth. Using the LBL positioning system 307 individual artifacts or groups of artifacts were located and real world coordinates obtained for them (Sheet 2). The digital images and coordinates of each artifact are currently being correlated and placed into an artifact database.

5) Deploy long-term and short-term microbiological experiments

The objective to deploy long and short-term microbiological experiments on the wreck of the DKM *U-166* was successful. Two IPSCO long-term test platforms were deployed, one on the bow and one on the stern wreckage. These platforms provide data on the structural degradation of the wreck over time. Additionally short-term Biological Activity Reaction Tests (BARTS) and Etch tests were placed at various locations on the bow and stern hull structures. These tests provide information on the types of bacterial communities on the wreck and the level of bacterial activity at the site. At the conclusion of the 2003 field investigations, the BARTS and Etch tests were recovered from the seafloor for analysis. The IPSCO test platforms were left in place. They will be monitored during subsequent visits to the wreck site.

6) Collect biological samples (rusticles) from the wreck site

The objective to collect rusticle samples from the DKM *U-166* wreck site was successful. Samples of rusticles from the DKM *U-166* were obtained from the area of the conning tower. The rusticles on the DKM *U-166* were noted to be white in coloration. This type of rusticle has only been previously observed on the wreck of the German Battleship DKM *Bismarck*. In addition to the rusticles obtained from the DKM *U-166*, rusticle samples were also gathered from the site of the S.S. *Robert E. Lee*. All rusticle samples were brought to the surface where preliminary analysis was carried out. Following the field investigations the rusticles were transported to Droycon Bioconcepts, Inc. in Regina, Saskatchewan, Canada where further analysis was carried out.

Discussion of Findings -Archaeology

During the field investigations of the DKM *U-166*, a better understanding of the site was gained. This investigation confirmed the 2001 findings that the U-boat broke into two sections and that the sections are approximately 500 feet apart. Between the two sections is a debris field. The 2003 expedition determined that the debris field was much denser than originally estimated based on the 2001 ROV survey. The wreck remains are oriented north to south with the bow and sterns sections demarcating the relative western and eastern edges of the site, respectively. Although the southern extent of the wreck site was not located during this investigation, the diminished artifact density suggests that it likely does not extend farther. Based on this information it is estimated that the site covers an area of approximately 900 x 900 feet.

The bow section of the DKM *U-166* lies near the western extent of the site. It is an approximately 50-foot long section of the forward hull that is partially imbedded in the seafloor and resting on its starboard side at a relatively acute angle. It is uncertain how much of the forward hull is buried, although there appears to have been a substantial amount of sediment displacement from the impact into the seafloor. This portion of the U-boat appears to have been torn away from the stern section near the forward torpedo loading hatch area. The prow of the vessel is facing south with the damaged area to the north. The bow remains appear to be covered with a thin layer of corrosion product and silt. A substantial growth of rusticles was noted near the damaged portions of the bow.

The prow is exposed but is only a few inches above the seafloor. The hawse hole can still be seen on the tip of the prow. Moving aft from the prow, the deck appears to be relatively intact. A portion of the metal jump wire is still attached to its bow hook. The drain holes for the hull are still visible. All of the wooden decking has disintegrated and the hatch covers are gone (many were seen in the debris field) revealing the U-boats interior bulwarks. Just forward of where the forward torpedo hatch would have been there is a large indentation in the deck (Figure 9) that corresponds to a crack on the port side of the hull extending from the silt line to nearly deck level. Just behind this indentation there is an area of severe damage where metal is twisted and mangled (Figure 9). The metal is pushed and bent outward rather than crushed as would be suspected in an implosion scenario.

Still visible in the wreckage are the remains of the forward torpedo winch that would have been used to load torpedoes through the forward torpedo hatch.

Figure 9. Images of the DKM *U-166* showing possible depth charge indentation (l) and damaged area near what would have been the forward torpedo loading hatch (r).

Approximately 500 feet east of the bow section is the stern section of the DKM *U-166*. The stern sections lies behind a small berm of sediment located directly to its west. To the east of the stern is an area of low relief sediment mounds. This portion of the wreck is oriented north-to-south with the damaged foredeck toward the north. Other than the missing bow section, this portion of the hull is almost entirely intact including the conning tower. It is buried almost entirely in the seafloor up to the deck level. As with the bow section, all the wood decking is gone revealing the open spaces of the outer hull. Conduits and piping are visible through these open areas. Most of the hatch and deck covers are also missing off this section of the wreck. The outside of the conning tower is heavily saturated with rusticle growth except for a small section on the starboard side just forward of the conning tower hatch.

Moving down the stern wreckage from forward to aft, most of the remaining forward deck is buried under sediment, the 105-mm deck gun is the first visible deck feature (Figure 10). It is intact and setting upright on the deck. The gun muzzle is facing forward and the bore plug is still in place.

Figure 10. Overhead view of the 105-mm forward deck gun.

Continuing aft, the conning tower is encountered next extending up from the deck. The conning tower is intact and extremely well preserved. The splashguard on the forward section of the conning tower remains intact and two running lights on either side of the conning tower are still visible. Moving over the top of the conning tower (Figure 11), the direction finding antenna is visible on the starboard side stowed in a recessed slot. Looking over the edge of the conning tower, the conning tower hatch, bridge controls and lookout stands are visible. Just aft conning tower hatch is the UZO surface attack mounting. The UZO was used to set up torpedo attacks when the U-boat was surfaced. Just aft of the UZO mount and the conning tower hatch is the periscope console. Only two periscopes were used on the Type IX U-boats. Both periscopes are fully retracted as would be expected since the sub was diving. Immediately behind the periscope console is a compass mount. On either side of the conning tower to the rear of the deck are the engine exhaust vents. Near the vent on the port side, the short-wave radio antenna is partially extended and bent. Aft of the conning tower bridge area is the wintergarten with the 20-mm machinegun still in its mount. The gun's barrel is pointed upwards and to port, with the shoulder supports resting on the wintergarten deck (Figure 12).

On the port side of the conning tower the ladder from the conning tower to the deck is still attached. On the starboard the exterior door of the conning tower is ajar revealing the two interior hatches into the pressure hull of the conning tower (Figure 12). No visible symbols or markings, such as insignias or unit symbols, were noted on either side of the conning tower.

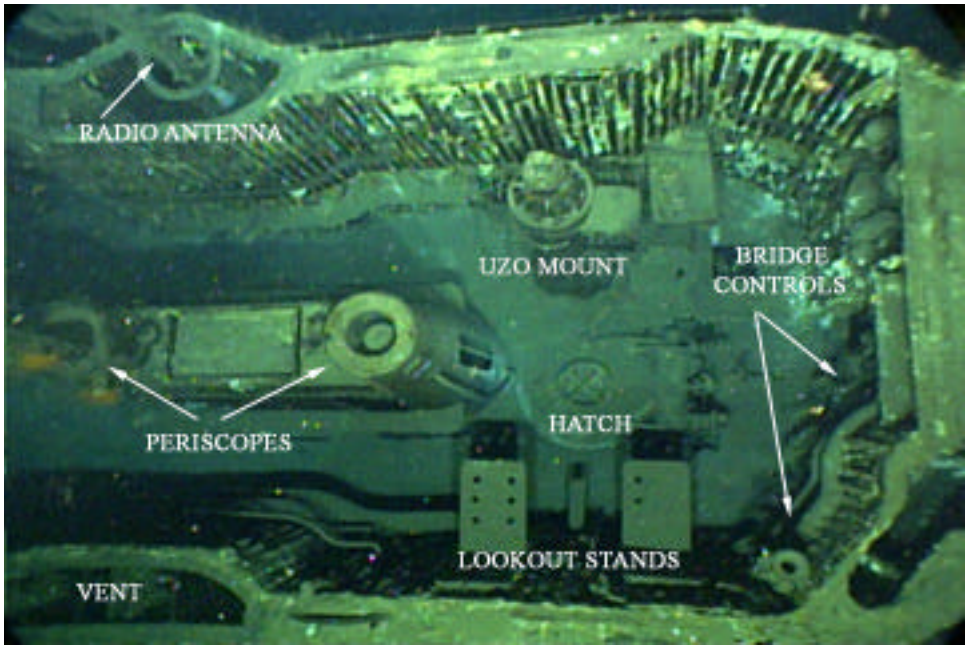

Figure 11. Overhead view of the DKM *U-166*'s conning tower bridge

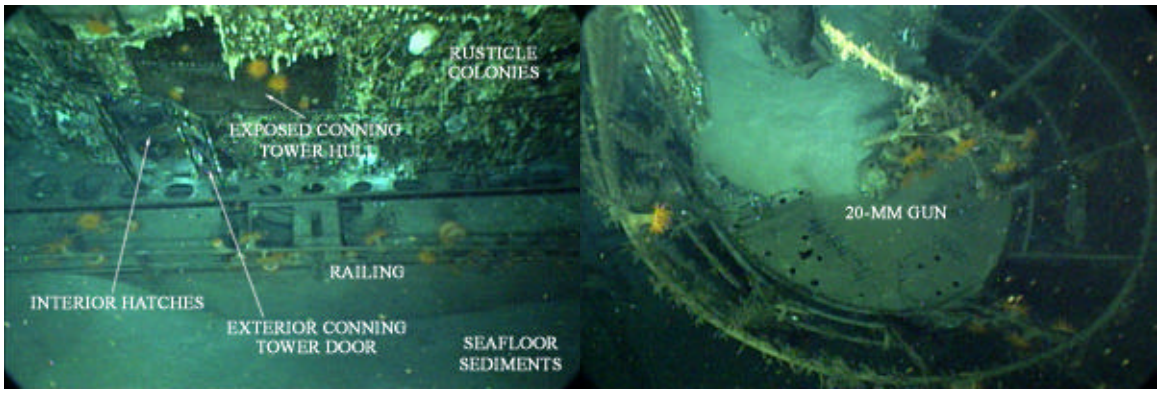

Figure 12. Starboard side of conning tower (l) and 20-mm deck gun on Wintergarten (r).

Moving toward the stern from the conning tower, several segments of railing are visible and appear intact. The segment of the aft jump wire is lying along the starboard deck, the insulators and wire near the conning tower. Towards the middle of the after deck stands the 37-mm antiaircraft gun (Figure 13). Used primarily for defense against airborne attack, the barrel is parallel to the deck and pointing towards the conning tower. As with the 105-mm gun, the bore plug for the 37-mm is also in place. Moving aft from the 37-mm gun, the after torpedo loading hatch comes into view. The deck cover over the hatch is missing, as is the hatch cover itself. The remnants of the hinges look as if the hatch was ripped away (Figure 14). Continuing from the aft torpedo loading hatch toward the stern, silt has covered a portion of the after hull but the stern running light is visible as is the end of the stern deck.

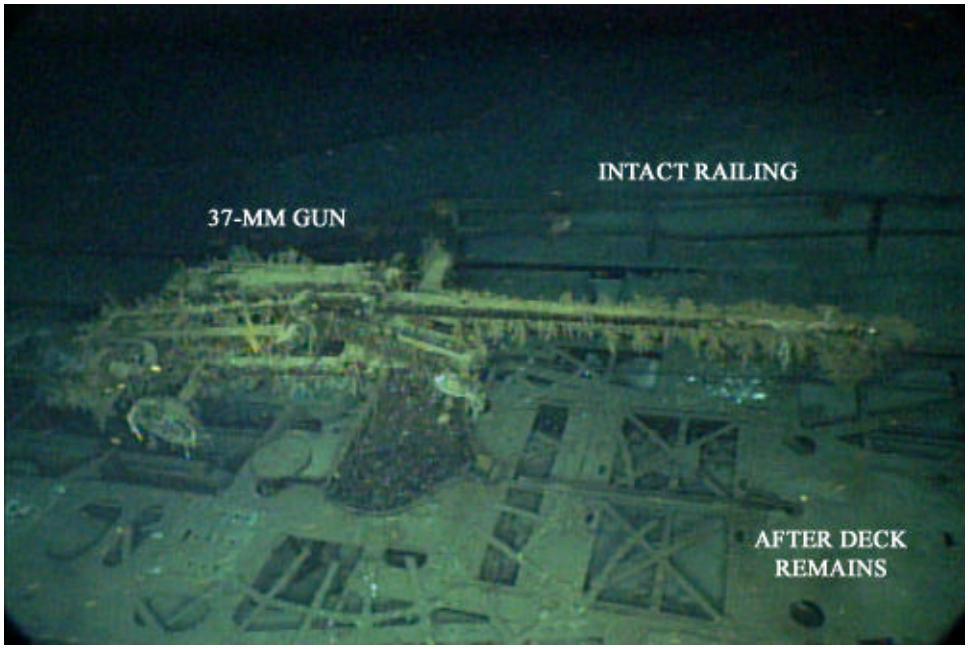

Figure 13. The after deck of DKM *U-166* showing the 37-mm gun and intact deck railing.

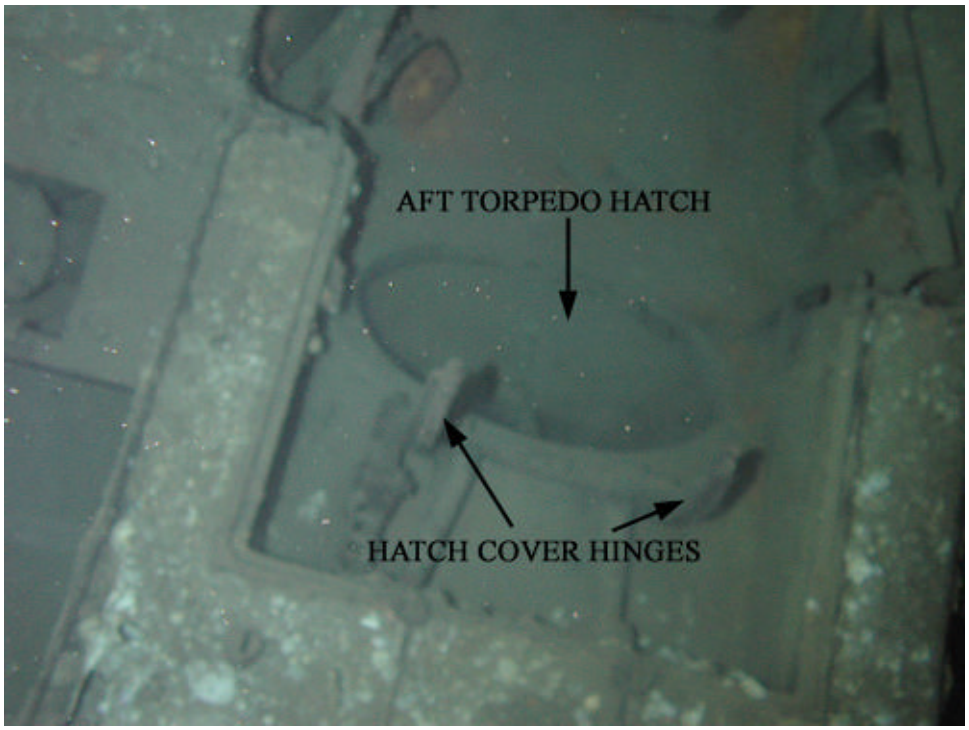

Figure 14. View showing aft torpedo hatch on stern wreckage.

Between the bow and the stern section is a dense debris field. Near the stern section, however, artifact remains are few and scattered. Proceeding west from the stern section, the debris density steadily increases, becoming heaviest near the bow section where the

heavy scatter extends to the south (Sheet 2). West and north of the bow, the artifact scatter abruptly stops with the exception of one or two scattered objects as the extent of the site is reached in these areas.

The wreck remains in the debris field are comprised of a variety of objects. Hull fragments, personal materials, electrical equipment, survival gear, and hatch covers are strewn randomly throughout the area. In addition to the materials associated with the DKM *U-166*, intrusive materials such as aluminum soda cans and cardboard boxes that have drifted down to the site from ships passing or working overhead were also noted in the debris field.

The materials in the debris field include many non-descript metal fragments that cannot be identified or associated with a particular part of the ship. Other pieces are barely visible because of silt build up and could not be seen clearly, and therefore could not be identified. No attempts were made to remove the silt from the remains in order to keep the site disturbance to a minimum.

The identifiable hull components consist of sections of the outer hull, bracing, and bulkhead fragments (Figure 15). These components range in size from small fragments to large pieces. Many of the materials have jagged edges and are mangled as if they were violently ripped from the hull. Numerous pieces of piping, similar to the conduits visible running under the stern deck structure, were also observed within the debris field.

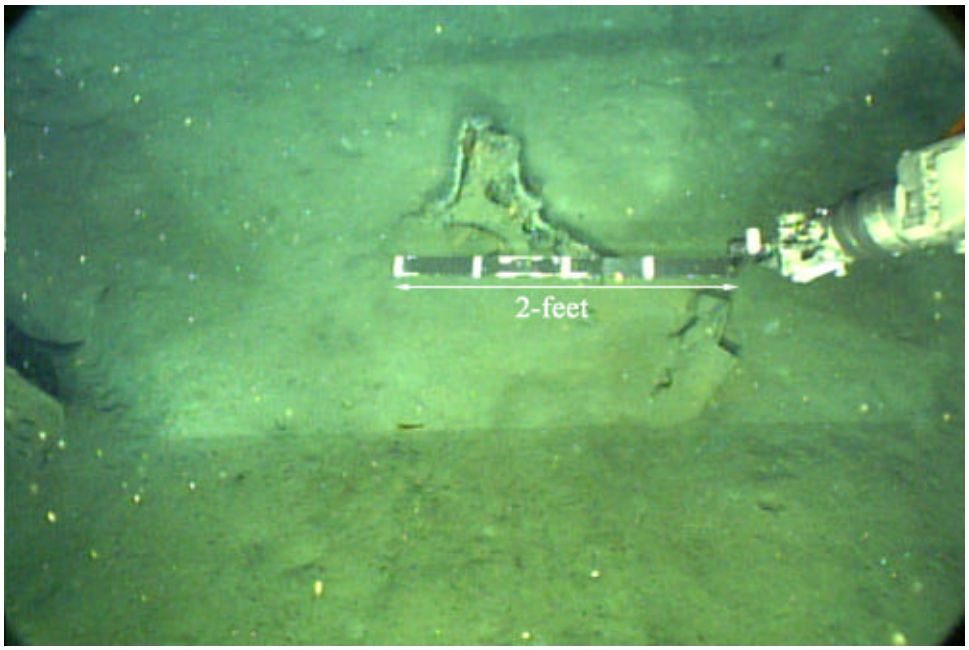

Figure 15. An approximately 2-foot long section of bulkhead from the DKM *U-166* found in the debris field (Artifact No. 60).

Several artifacts within the debris field appear to be equipment from inside the pressure hull. These include hatch covers, electrical boxes, switches, and electrical cable. Several

pressurized cylinders were not within the debris field (Figure 16). The use of these cylinders is uncertain, but they were all deeply imbedded in the seafloor, one up to the valve neck.

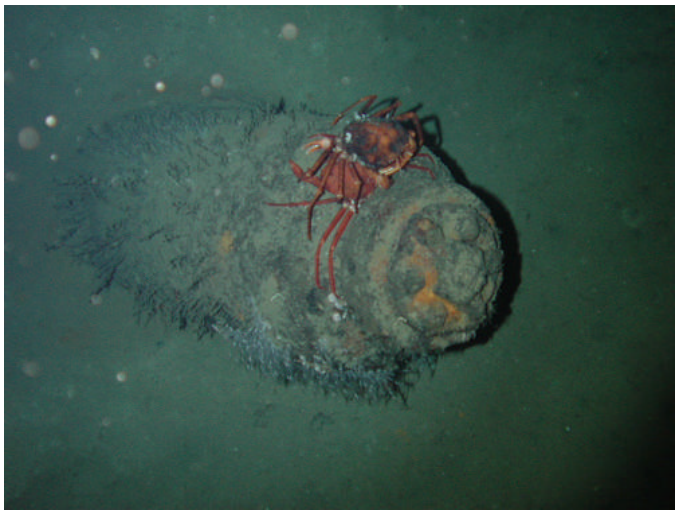

Figure 16. Pressurized cylinder from DKM *U-166* debris field (Artifact No. 47).

Personal equipment or personal items of the DKM *U-166*'s crew were also observed scattered within the debris field. These materials are probably from the forward portion of the pressure hull where the crew was quartered and where the hull was most likely breached. Among the items observed were shoes, leather heavy weather gear, a dinner tray, and several Dräger Lung rescue devices (Figure 17). The Dräger Lungs were intended for shallower water escapes from the U-boat, but the crew of the DKM *U-166* never had that chance.

Figure 17. A Dräger Lung from the DKM *U-166* debris field (Artifact No. 127).

Discussion of Findings - Microbiological (Rusticle) Analysis

The following analysis of the microbiological aspects of the DKM *U-166* wreck site was provided by Dr. Roy Cullimore and Lori Johnston of Droycon Bioconcepts, Inc. Regina, Saskatchewan, Canada.

Introduction

The following is a report relating specifically to the nature of the rusticles and microbiological activity in deep ocean environments explored by DBI over the term period from 1996 to 2003. Experiments conducted at various sites are listed in Table 1.

Table 1. Location and Times for Deep Ocean Microbiological Studies to 2003

Site	Year	Rusticle investigation	Etching determination	BART activity
RMS Titanic	1996	Full	Partial	Full
RMS Titanic	1998	Full	Full	Full
RMS Titanic	2001	Full	Partial	Full
RMS Titanic	2003	Partial*	Partial	None
DKM Bismarck	2002	Full	Partial	Partial
MAR vents	2002	Partial	None	Partial
HMHS Britannic	2003	Full	Full	Full
DKM U 166	2003	Full	Full	Full
SS Robert E. Lee	2003	Full	None	None

Note: Full means that the investigation was completed and data generated; Partial means that some investigations were pursued but not in a comprehensive manner (the * indicates no samples were recovered and the study was limited to observation only); None means no studies were undertaken.

Rusticle investigations were conducted to include observations of on-site growths, recovery of rusticles for archival and microbiological purposes as well as photomicrographic examination of the structures and chemical analysis. Etching consists essentially, of using the enzymatic degradation of unexposed but developed (black) color slide film as the indicator of the form of proteolytic (protein degrading) microbial activity. BART activity was undertaken both on-site using deployable platforms on which different groups of bacteria could grow and also on-ship determination of the level of bacterial activity in collected samples of water from the site of study.

On the basis of these various investigations, this report summarizes the observed differences and similarities in the various microbiological parameters investigated. These will be reported for the rusticles first followed by the proteolytic (etching) function secondly and the BART activities thirdly.

Rusticle Studies

Rusticles resemble very porous fragile living concrete (bioconcretions). These structures appear to have been created by the joint activities of a number of microbial consortia that function cooperatively. These consortia are clustered at different locations within the rusticles and include: iron related bacteria (IRB), sulfate reducing bacteria (SRB), heterotrophic aerobic bacteria (HAB), slime forming bacteria (SLYM), denitrifying bacteria (DN) as well as a variety of fungi and mycelial bacteria. Five specific bacterial consortia are routinely recognized together with at least 28 different microbial species that can be identified.

Rusticle Studies, Chemistry

Samples were subjected to ICP analysis from selected recovered rusticle fragments from the S.S. *Robert E. Lee* (Table 2), DKM *U-166* (Table 3) and HMHS *Britannic* (Table four). Each of these three tables gives, in tabular form, the percentage of non-combustible elements gravimetrically followed by the atomic formula based upon the percentage of atoms within the samples examined. While S.S. *Robert E. Lee* had a combustible fraction of 75%, both the HMHS *Britannic* and DKM *U-166* samples had less than 5% of combustible material in the dried weight of the sampled rusticle material. This suggests that the rusticle sample from the S.S. *Robert E. Lee* had a much higher combustible organic fraction.

Table 2. Percentile Gravimetric Composition of Sample from S.S. *Robert E. Lee*

88.320%	Aluminum
4.101%	Sodium
2.366%	Silicon
2.007%	Calcium
1.404%	Magnesium
0.670%	Potassium
0.631%	Phosphorus
0.351%	Iron
0.115%	Strontium
0.020%	Titanium
0.014%	Manganese
0.003%	Barium

Atomic Composition:

$Al_{88} > Na_5 > > Si_3 > Mg_{1.5} > Ca_{1.3} > P_{0.5} > K_{0.5} > Fe_{0.2} > Sr_{0.04} > Ti_{0.01} > Mn_{0.007} > Ba_{0.0006}$

In color and texture, the rusticle samples from the S.S. *Robert E Lee* resembled those from other deep ocean sites. However, they had the highest amount of combustible materials present in the sample, possibly organic in origin. This sample was dominated in the analysis by aluminum (88%) along with sodium (4%), silicon and calcium at 2%. Iron,

which was the dominant element in the other rusticles, was at only 0.35% even though the color of this sample was similar to the others (medium brown ferric oxide). Another difference related to strontium that was detected at 0.11% gravimetrically in the non-combustible material.

Table 3. Percentile Gravimetric Composition of Sample from DKM *U-166*

79.70%	Iron
13.14%	Calcium
2.34%	Magnesium
1.78%	Silicon
1.69%	Sodium
0.35%	Manganese
0.33%	Aluminum
0.22%	Potassium
0.21%	Strontium
0.13%	Barium
0.09%	Phosphorus
0.02%	Titanium

Atomic Composition:

$Fe_{70} > Ca_{16} > Mg_5 > Si_4 > Na_4 > Al_{0.6} > Mn_{0.3} > K_{0.3} > P_{0.1} > Sr_{0.1} > Ba_{0.05} > Ti_{0.02}$

The rusticle sample from DKM *U-166* showed a very different dominant element composition with iron (80%) and calcium (13%) dominating even though the sample site is close to that of S.S. *Robert E Lee* (dominated by aluminum, calcium, silicon and sodium. Strontium was detected in higher concentration (0.21%) compared to *Robert E Lee* (0.11%).

Table 4. Percentile Gravimetric Composition of Sample from HMHS *Britannic*

92.220%	Iron
2.626%	Sodium
2.159%	Silicon
1.049%	Magnesium
0.619%	Calcium
0.444%	Potassium
0.408%	Phosphorus
0.360%	Aluminum
0.074%	Manganese
0.024%	Titanium
0.012%	Strontium
0.006%	Barium

Atomic Composition:

$Fe_{84} > Na_6 > Si_5 > Mg_2 > Ca_{0.8} > Al_{0.7} > P_{0.7} > K_{0.6} > Mn_{0.07} > Ti_{0.03} > Sr_{0.007} > Ba_{0.002}$

For the HMHS *Britannic* sample, the rusticle was dominated by iron (92%) with sodium and silicon at greater than 2% while calcium was at 0.6% (considerably less than on the other samples. Strontium was detected at 0.012%, an order of magnitude less than the levels observed for the S.S. *Robert E. Lee* (0.11%) and DKM *U-166* (0.21%). One element commonly closely associated with biological activity is phosphorus since it essential in energy transfer and storage within the cell. In these samples, the determined phosphorus levels were: S.S. *Robert E. Lee* (0.63%), DKM *U-166* (0.09%) and HMHS *Britannic* (0.41%). This would indicate a possible stress would exist in the rusticles growing on DKM *U-166*.

The order of magnitude difference in the concentration of strontium between the rusticle analyses from S.S. *Robert E. Lee* (0.11%), and DKM *U-166* (0.21%) with HMHS *Britannic* (0.012%) is of concern. Given that both S.S. *Robert E. Lee* and DKM *U-166* were both sunk within a militarily very active zone in the Gulf of Mexico at the height of World War II it could be surmised that these higher concentration could be related to this. The United States of America imported significant quantities of strontium during the war but not prior to the build up for that war (Figure 18).

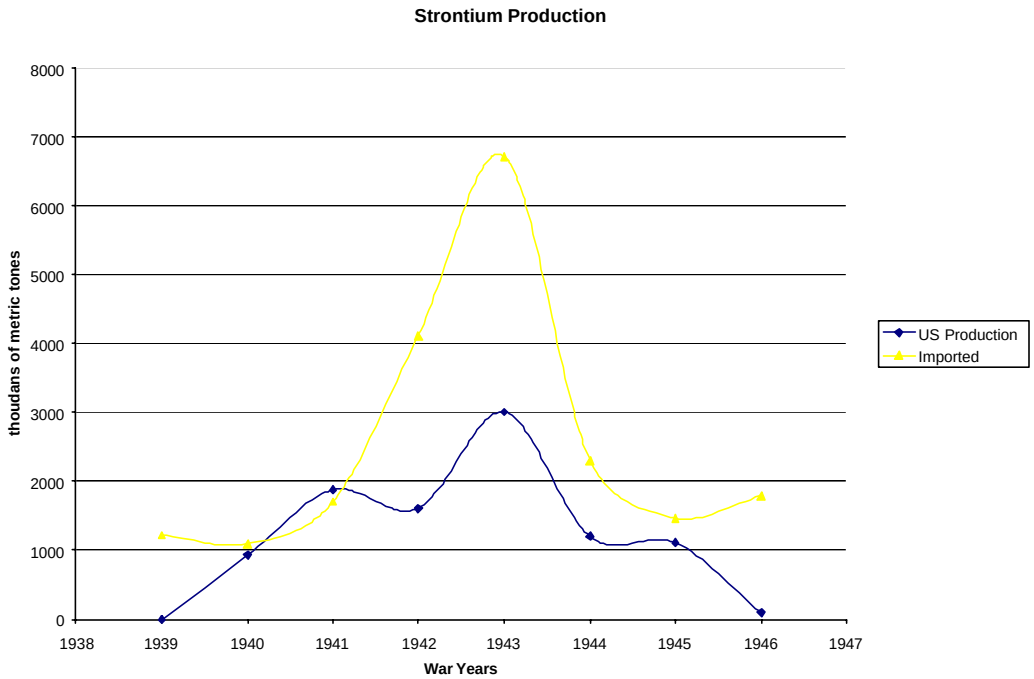

Figure 18. Strontium Use in USA during World War II period

Figure 18 gives the US production and importation of strontium during the War years. Note that virtually no strontium was imported for two decades prior to 1939 and it

stopped after the war, to pick up again in the early fifties. This suggests the possible use of strontium (possibly to improve the effectiveness of explosives). Possible sources of the strontium in the rusticles from S.S. *Robert E. Lee*, and DKM *U-166* could be:

1. Natural strontium in the gulf sediments and organic floc
2. Strontium from explosives or flares carried on the ships
3. From the coatings of monitor screens
4. Strontium 90 from nuclear testing

One of the observations of the (lack of density) of rusticle growths on the S.S. *Robert E. Lee*, and DKM *U-166* compared to the HMHS *Britannic* and other ships visited could be that the higher level of strontium bio-accumulated in these rusticles could have become inhibitory to some of the microbial consortia necessary for the rampant growth of rusticles.

From direct chemical analysis it is possible to categorize these rusticles as different ores (Table 5). This supports the hypothesis first proposed by Molisch in the 1890s and supported by Ellis (1919) that pig iron, bauxite and dolomites could have been biologically generated.

Table 5. Mineralogical Categorization of the Rusticles

Rusticle sample source	Mineralogical type	Dominant elements
S.S. Robert E. Lee	Bauxite	Aluminum
DKM U-166	Pig Iron (SG)	Iron, calcium
HMHS Britannic	Pig Iron (high silica)	Iron, silica

The high aluminum content of the rusticle from the S.S. *Robert E. Lee* may also be a reflection of the cargo being carried by the liner freighter at that time. Had the ship been carrying a load of bauxite when sunk, then the ore would have stayed primarily in the holds. However this bauxite may have been subjected to microbiological leaching (either oxidatively or reductively) with the releases of colloidal forms of aluminum that was then accumulated by the rusticles along with very significant amounts of sodium, silicon, and calcium.

These observations are based upon single source observations and would need to be confirmed by further analysis of related samples.

Rusticle Studies, Structure

Only limited rusticles were obtained from the S.S. *Robert E. Lee* but they showed high porosity, typical colors (in spite of the high aluminum and low iron content), similar textural and structural qualities to those observed from other vessels. Like rusticles from the RMS *Titanic*, there were central water conduits indicating the relatively free movement of water through the rusticles (Figure 19). One difference between the rusticles from the DKM *U-166* and the S.S. *Robert E. Lee* when compared to rusticles from other sites was

the form of crystalline structures within the rusticles. In other rusticles studied from other sites, the general observation had been that these structures are whorled to some extent, generally showed a lack of repeatable structures and did not appear to follow a geometric pattern. Frequently, however, the specimens from both ships under study did follow a geometric pattern (Figures 20 and 21) that was also frequently set up in a planar manner.

Figure 19. Central Water Conduit in Rusticle from the S.S. *Robert E. Lee*

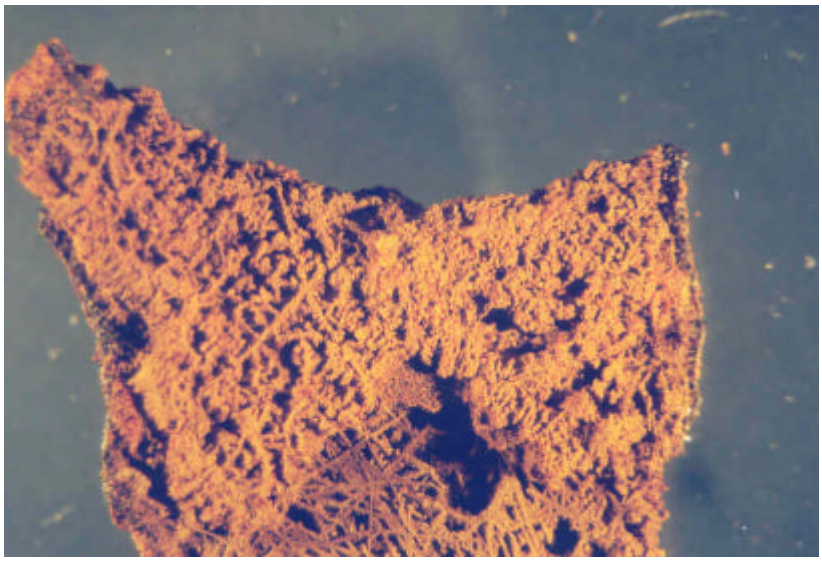

Figure 20. View across a Fractured Rusticle from the DKM *U-166* (No magnifaction, midpoint with approximately 16 mm)

In keeping with the characteristics of rusticles from other sites, these rusticles appeared to have a high porosity consistent with large surface area: volume ratios. Rusticles from the RMS *Titanic* were found to have ratios as high as one third of that of granulated activated charcoal, which would imply considerable ability for the sorption.

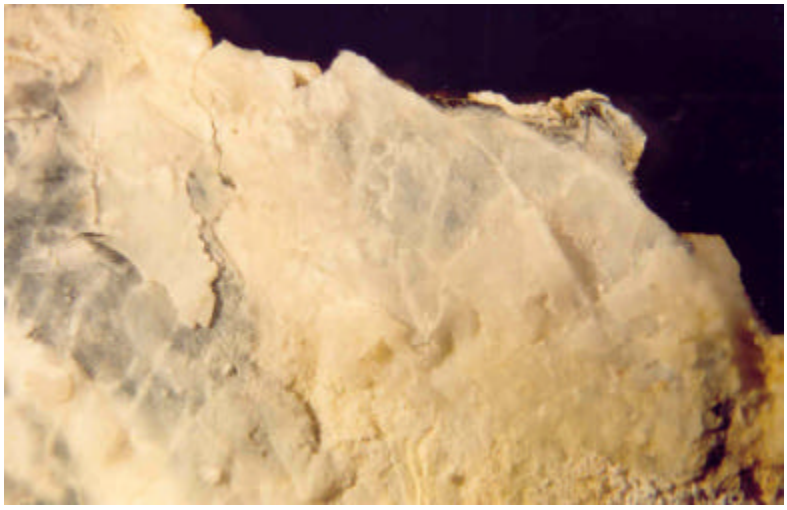

Figure 21. Crystallized Structure within a Rusticle taken from DKM *U-166* (No magnification, width of image is approximately 8 mm)

A common feature of all of the rusticles so far investigated has been the presence of thread-like structures associable with fungal mycelium. These structures are commonly observed forming extensions out from the rusticle coats and also within the larger water conduits. These fungal "mats" were also observed in rusticles from the DKM *U-166* and S.S. *Robert E. Lee*. However resin-like structures of the type seen commonly on the HMHS *Britannic* (Figure 22) were not observed dominating the rusticles from the DKM *U-166* and S.S. *Robert E. Lee.*

Rusticle Studies, Density of Visible Growths

Rusticles were observed on every sunken wreck discussed in this report, however, the density of the growth varied from site to site on each specific wreck but also from wreck to wreck. Local variations within a single site can cause differences in the appearance and density of the observed rusticle growth primarily restricted to the outer hull and superstructures that are visible. These variations can be the result of water currents, the state of the metal (e.g., entire, torn, twisted or burnt), local ambient light levels, inherent electrical potentials, nutrient loadings and the potential for predation by other organisms. It should be noted that the high iron content of typical rusticles severely restricts the predation potential and it has been noted that rusticles are capable of collectively generating effective antibiotics to restrict competition (Cullimore, Johnston, Pellegrino & Newman, 2004, U.S. Patent Pending). The density of rusticles growths is summarized in a semi-quantitive manner in Table 6.

Figure 22. Resin-Like Columns on fractured Rusticle Surfaces, HMHS *Britannic* (No magnification, width of image is approximately 5 mm)

Table 6. Relative Density of Rusticle Growths on Selected Sunken Ships

Ship	Density	Hanging	Attached	Coating
RMS Titanic	***	***	**	**
DKM Bismarck	***	**	***	*
HMHS Britannic	***	*	*	***
DKM U 166	*	*	**	*
SS Robert E. Lee	*	*	**	*

Notes: Density refers to the amount of rusticle activity visible on the ship (***, >60%; **. 40 – 60%; * 5 – 40%). Hanging rusticles are those rusticles that freely hanging from a steel "perch" (***, >20% of available "perch" has hanging rusticles; **, 5 – 20%; and * noted to be present). Coating refers to the rusticles growing over the surface of the steel regardless of angle usually getting a thickness of 2 to 10mm (***, greater than 80% visible surfaces covered; **, 20 – 50% surfaces coated; and *, < 20% to observable). HMHS *Britannic* was the only ship in the ambient light zone. DKM *U-166* observations are for the stern section including the conning tower only.

From Table 6, it can be seen that there were lower levels of rusticle growth on both the DKM *U-166* and S.S. *Robert E. Lee* when compared to the other ships. One factor that may be considered as contributing to the lack of rusticle growth at these sites might be the relatively high (tenfold higher) concentrations of strontium observed in rusticles from these two sites compared to HMHS *Britannic.* Strontium is well known to be a major ingredient in explosives and flares (possible origin) and also biologically toxic. This latter factor might be one explanation for relatively sparse growth of rusticles on these two ships. A second factor could be the influence of bauxite (thought to be carried by S.S. *Robert E. Lee* at the time of sinking). It is possible for the aluminum in the bauxite to become biologically mobilized and to have accumulated into the rusticles on that ship (80%). If this were to have been the case then clearly this aluminum had not moved significantly to the neighboring ship, DKM *U-166*, where the aluminum content was only 0.33%.

Microbiological Studies

Microbiological evaluations were undertaken in four ways: (1) short-term placement of BART test laboratories on-site; (2) short-term placement of detectors for proteolysis using the etching of unexposed color slide film; (3) long-term placement of metal clad platforms to assess rusticle growth rates; and (4) at-site determination of bacterial activity levels in samples taken from the site. These are discussed separately below.

Microbiological Studies, BART test laboratories on-site

To undertake these studies, BART test laboratory platforms were placed on a suitable deck on the sunken ship in a manner that it could be recovered and a qualitative assessment of bacteria activity made. A summary of the outcome of these studies is given in Table 7.

Table 7. Microbiological Activity at Deep Ocean sites using On-site BART test laboratories

Site	Year	Iron Related Bacteria (IRB)	Sulfate Reducing Bacteria (SRB)	Heterotrophic Aerobic Bacteria (HAB)
RMS Titanic	1996	*	*	**
RMS Titanic	1998	*	*	**
RMS Titanic	2001	**	**	***
DKM Bismarck	2002	*	**	**
Mid-Atlantic Ridge	2002	**	***	***
HMHS Britannic	2003	**	**	****
DKM U 166	2003	*	*	**

Note: asterisks indicate the level of activity of the specified bacterial group, * - present but low level of activity; ** - moderate level of activity; *** - high level of activity; **** - exceptionally high level of activity.

Of the three bacterial groups routinely examined it was the HAB that was found to be the most active (aggressive) but the IRB and SRB were detected at all sites. All three of these bacterial groups also are commonly found functioning with rusticles. The fundamental observation is that all three bacterial groups are able to function and grow under the environmental conditions present at the sites. These include: high hydrostatic pressures, low temperatures, and highly saline conditions. In directly exposing pure bacterial cultures (five species) to those conditions in the Aquanaut experiment (not reported here in depth), it was found that all exposed species survived with no losses in cell numbers exceeding one order of magnitude.

Microbiological Studies, Proteolysis using Etching

In 1996, a method for detecting on-site microbial activity was developed specifically for the detection of the potential for proteins to be degraded. This was achieved at that time by deploying etch coupons. Information gathered from this experiment includes the extent of the protein degradation (by the speed with which the surrogate film degrades) and the types

of microorganisms causing the degradation (by the patterns and form of the etching viewed after the film has been dried). Relative rates of proteolysis are given in Table 8 and a photograph of an etching from the DKM *U-166* is shown in Figure 23.

Table 8. Rates of Etching on Various Sunken Ships

Site	Year	Time to start of etching (d)	Time to total etching estimated (d)	Dominant forms of microorganisms recognized
RMS Titanic	1996	3	14	B
RMS Titanic	1998	3	12	B
DKM Bismarck	2002	2	12	B, F
HMHS Britannic*	2003	0.25	1.5	B
DKM U 166	2003	1	4	B, F

*HMHS *Britannic* showed very fast rates of protein degradation which meant that once the etch coupons were recovered by the SCUBA divers in 2003, the film coupons were largely already etched. B refers to bacterial types of etching involving tunneling, fracture plates, radical dissolution of the film's pigments but very little formation of threads. F refers to fungal growth that tends to be seen by more even degradation of the colored pigments and the observation of a web-like mass of threads (fungal mycelium),

Microbiological Studies, Long-term placement of metal clad platforms

To-date, eight IPSCO-style metal biodeterioration platforms have been set down at four sites (Table nine). In this work the prime objective was to determine the manner in which rusticles colonize the various coupons on a ladder-styled platform. A second objective related to the rate at which the coupons were compromised as a result of the biodeterioration processes. Due to the deep ocean locations of these platforms, observations of the rusticle growths are infrequent (Table 10).

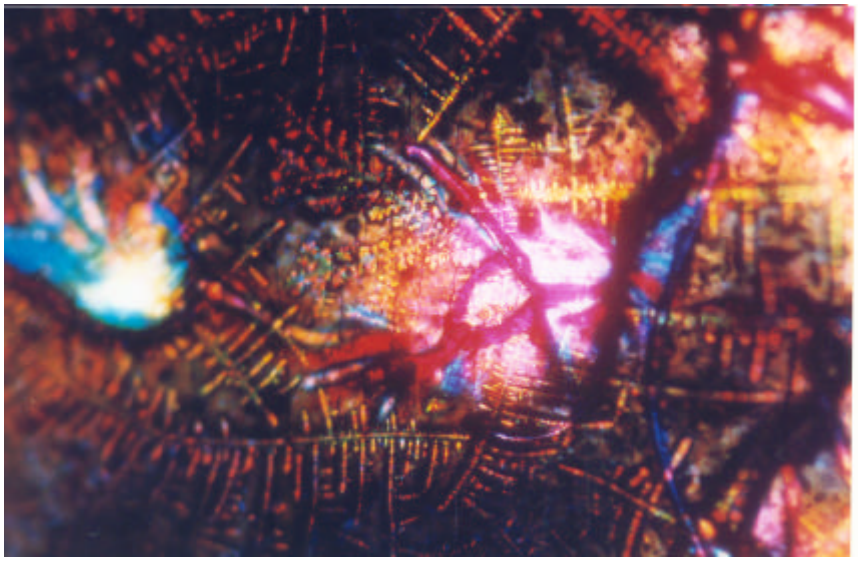

Figure 23. Photomicrograph of Etching taken from DKM *U-166*

Table 9. Location and composition of IPSCO-style platforms

Platform	Deployed	Ship	Steels**	Aluminum	Wood	Copper
A	1998	*RMS Titanic*	15			
B	1998	*RMS Titanic*	15			
C	1998	*RMS Titanic*	15			
D	1998*	*RMS Titanic*	15			
E	2002	*DKM Bismarck*	15			
F	2003	*HMHS Britannic*	6	3	3	3
G	2003	*DKM U-166*	6	3	3	3
H	2003	*DKM U-166*	6	3	3	3

Notes: * platform D was moved in 2001 from the portside stem to 100 m north-west, it was returned to the portside stem in 2003; ** two or three grades of steel were employed and subjected to embarrassment through twisting, burning, and pressure applications. In 2003, the platforms were modified to include stainless steel, aluminum, hardwood and copper coupons as well.

Table 10. Evaluation of deployed platforms for rusticle activity

Platform	Ship	Visited*	Retrieval **
A	*RMS Titanic*	2001, 2003,	(2004) 2112
B	*RMS Titanic*	2001, 2003,	(2004) 2112
C	*RMS Titanic*	2001, 2003, 2004	2112
D	*RMS Titanic*	2001, 2003, 2004	(2001)*** 2112
E	*DKM Bismarck*	2002, 2006	N/D
F	*HMHS Britannic*	2003, 2005	2009
G	*DKM U-166*	2003, 2004, 2005	2113
H	*DKM U-166*	2003, 2004, 2005	2113

Notes: * Visited refers to the platforms being minimally videoed and manipulated; the years indicate the past observations and in the future are planned to be visited; and dates in

brackets indicate that the platform has been / will be retrieved. ** shows the planned recovery dates for the platforms. *** Platform retrieved to the surface by mistake and immediately returned to the site. N/D indicates that no date for retrieval has been planned.

Platforms A to D are the only platforms that have been visited since deployment and full interpretation of the video images has still to be undertaken using various sites where the information is currently stored. Of these four platforms, inspection in 2003 revealed that three (B, C and D) had fallen over onto the side (B) and onto the face (C and D) where the coupons came into close contact (approximately 20 mm) of the ocean floor. A had remained upright but had a mooring rope draped over it which extended to an iron hook some 10 m from the platform. General evaluations of the forms of rusticle growths are summarized as:

- Rusticles grew over all steel coupons and showed interconnection across the 14 mm gaps between each coupon.
- Rusticles also grew as descending attached whorled concretions over the supporting ABS walls of the platform directly down to the ocean floor.
- No difference could be discerned between the growth, form and function of the rusticles based upon the different steels employed and the form of compromise.
- Rusticle growths extended out from the coupon by an average of 6 mm with finger-like processes extending out a further 5 to 25 mm.
- There was evidence of a life cycle in which the rusticle grow in size, matured and then broke away through a sheering close to the steel coupon. In 2003 there were three sites on the platforms where rusticles appear to have sheered away exposing the underpinning oxidized metal surfaces.
- While no debris on the ocean floor could be directly determined to be from the rusticles growing on the platforms, the first evaluation of these platforms suggests that a life cycle exists that takes two to five years to complete. Evidence from rusticle growths on the RMS *Titanic* further supports the probability that there is a growth – mature – decay cycle during which the rusticles expand in size – become denser – and collapse.

It is planned to develop critical components in the evaluation of the significance of the rusticles. These are:

1. A standard rusticle mapping technique (biological evaluation of sunken ships, BESS) that can be applied universally to all ships being examined for growth densities and forms. This graphing technique would include lateral lineal application for hanging rusticles and two-dimensional intensity plotting for both whorled and plated concretions.
2. A standard scaling system to quantify to amount of attached growth directly on each coupon and indirectly around the coupons can be quantified to generate volumetric information.
3. Using the projected rusticle volumes computed from video imagery and a projected life cycle based upon observations of the forms and sites of rusticle growths then a

mass balance equation would be generated for the movement of iron from the ship into the rusticles and out into the ocean environment.

4. A significant body of information already exists on the porosity, surface area and the chemistry of rusticles that would allow the rates of movement of iron out of the coupons to be projected.
5. Redesigning the steel test platforms to assure that growth on each steel coupon is not compromised by growths on neighboring coupons.

Such information would be valuable for the management of non-recoverable sunken platforms through optimizing the biodeterioration and thus allowing the iron to recycle more efficiently through the placement of catalytic conditions that would accelerate the recycling processes. This would then allow a more rapid and managed collapses of the platforms that have passed their active life cycle but are too deep to consider economic recovery.

7.0 CONCLUSIONS

During the 2003 investigations of the DKM *U-166* wreck, 307 individual or groups of artifacts were documented at the site. Over 50 hours of high-resolution digital video, roughly 1800 digital images were acquired of the debris at the wreck site, and the microbiological aspects of the site were sampled. Analysis of the data has provided a better understanding of the wreck site and the site formation processes that have and are continuing to shape the site.

The 2003 investigations confirmed the 2001 findings that the DKM *U-166* broke into just two main sections - an approximately 200-foot section that extends from the stern to just past the forward gun and an approximately 50-foot section of the bow, which has separated from the rest of the hull and rests roughly 500 feet to the west. No other significant sections of hull remains were noted during the 2003 survey. Between the two sections of hull remains and extending to the south is a debris field containing materials from both the interior and exterior of the U-boat. The 2003 investigations determined that the debris field was much denser that originally estimated based on the 2001 fieldwork.

Based on the artifact distribution patterns at the site, the northern and westernmost boundaries of the site are just past the remains of the bow section. The eastern boundary of appears to be just east of the stern and conning tower. The debris field extends south from the bow remains beyond the limits of the 2003 survey. The density of wreck material decreased near the southern limit of this survey. This suggests that the site does not extend much farther to the south. Additional survey work conducted in August 2004 will provide additional information of the southern site limits once analysis of that data is complete. From the available data, it is estimated that the site probably covers a roughly 900 x 900-foot area.

The heaviest concentration of artifact material in the debris field is located in the western area of the site near the bow debris (Sheet 2). The density of the material and the artifact distribution suggests the DKM *U-166* may have broken up relatively close to the seafloor and that the vessel did not implode. The evidence also indicates that the hull broke up somewhere to the south of the current site and the separate portions impacted the seafloor with most of the artifacts observed on the seafloor being strewn from the bow section as it plunged to the bottom. The 2003 data supports the hypothesis that a depth charge from *PC-566* ruptured the pressure hull causing the U-boat to fill with water, as the vessel approached the seafloor, an internal explosion of unknown origin possibly occurred causing the bow section to be torn away from the rest of the vessel.

The microbiological study, carried out as part of the 2003 investigations, gathered the rusticles from both the DKM *U-166* and the S.S. *Robert E. Lee* wreck sites. This analysis determined that the microbacterial activity on the DKM *U-166* site was high, and that the rusticle formations from the DKM *U-166* and the S.S. *Robert E. Lee* were significantly different. High levels of strontium in the DKM *U-166* and S.S. *Robert E. Lee* rusticles have raised more questions regarding the site. Additional studies conducted in August of 2004 may help answer these questions once that data is reviewed. The data gathered during the 2003 investigations provided comparative data to that retrieved from other wrecks around the world. Utilizing these multiple data sets will give us a better understanding of rusticles and their significance.

The 2003 investigation of the DKM *U-166* wreck site was a resounding success. Never before has a deepwater wreck in the Gulf of Mexico been mapped with the precision achieved on this project. The success of this project cannot, however, be given to technology alone. The success of this project was the direct result of the groundbreaking partnership between private industry, government agencies, and academic institutions. The further development of the partnerships implemented during this project will insure success of future projects to document our maritime heritage remains in deepwater environments.

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PLAN VIEW

LINE SWEEP_A >>> ROV navigation trackline and number

Contours shown from an AUV Site Specific Survey performed in 2001.

Contour interval = 20 feet

Zero datum = Mean Sea Level

Multibeam Processing Sequence

Bin size = 3 meters (9.84 feet)

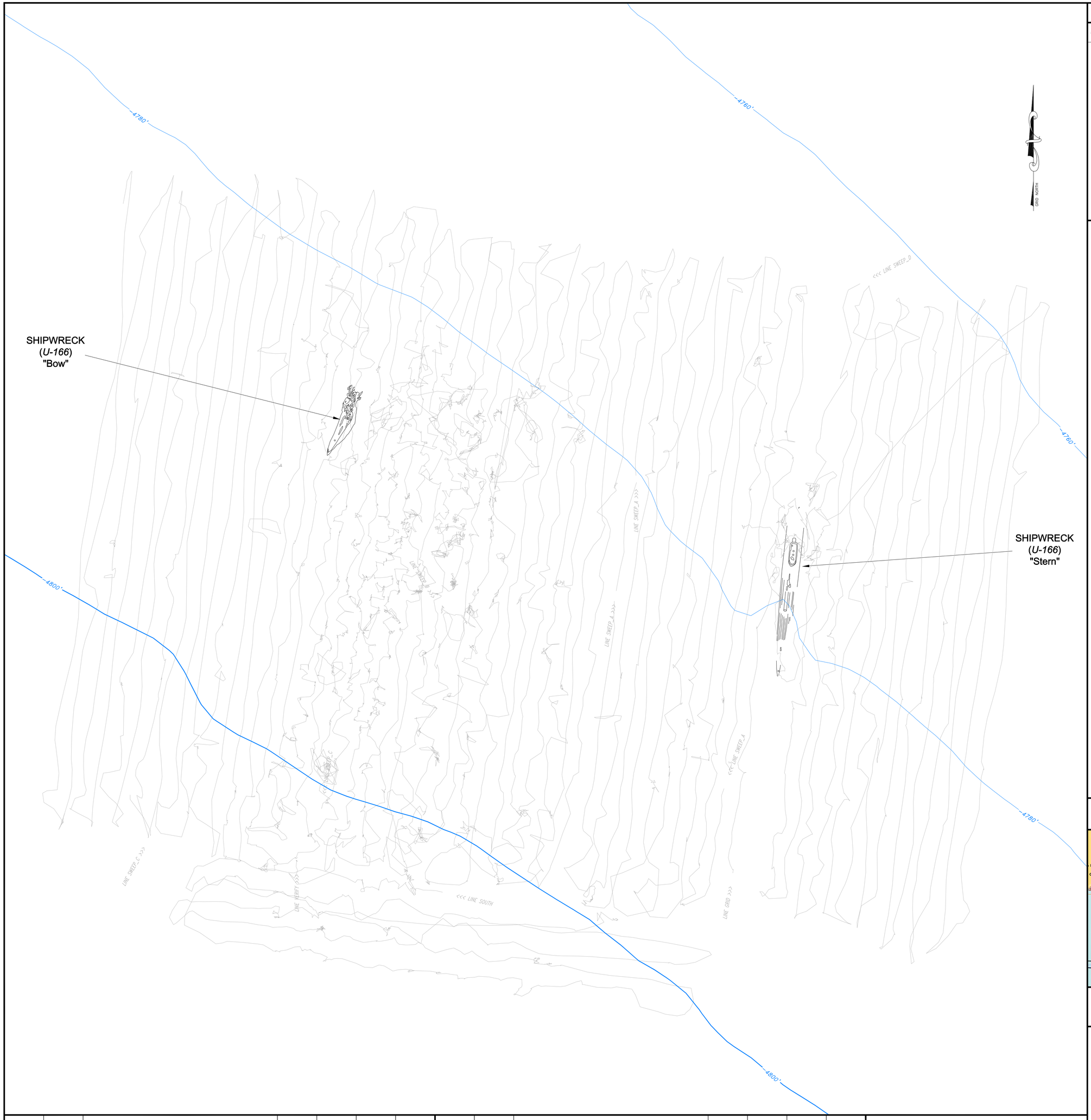
Median filter applied

Produced gridded-binned dataset using weighted-neighbor algorithm

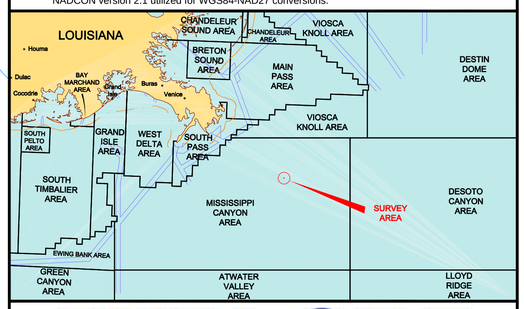
Search radius = 9 meters (29.53 feet)

Water column velocity corrections applied

Tide corrections applied using Goddard Ocean Tide Model GOT99.2



NOTE: Investigations were carried out on October 5-10, 2003 aboard the NOAA R/V *Ronald H. Brown*.
Equipment utilized: Sonsub *Innovator* ROV, C-Nav DGPS, Sonardyne Fusion Long Base Line System, and Sonardyne Pharos Navigation Software.
NADCON version 2.1 utilized for WGS84-NAD27 conversions.



EXPLORE

U-166 INVESTIGATION

ROV TRACKLINES MAP

MISSISSIPPI CANYON AREA

40' 0' 40' 80'

SCALE IN U.S. SURVEY FEET

ISSUE	DATE	DESCRIPTION	INTERP	DRAWN	CHECKED	APPROVED
1	10/01/2004	ORIGINAL ISSUE	D. WARREN	D. PIERROTTIE		

ISSUE	DATE	DESCRIPTION	INTERP	DRAWN	CHECKED	APPROVED

GEODETIC DATUM: NAD27
ELLIPSOID: CLARKE 1866
GRID UNITS: U.S. SURVEY FEET
PROJECTION: UNIVERSAL TRANSVERSE MERCATOR
ZONE: 16N
CENTRAL MERIDIAN: 87° 00' W
FALSE EASTING: 1,640,416.67 ft. at C.M.
FALSE NORTHING: 0.00 ft. at 00° 00' N

PREPARED BY:
C&C Technologies
SURVEY SERVICES
730 E. KALISTE SALOOM ROAD, LAFAYETTE, LA (337) 261-0660

JOB NO. 3795 **DATE:** Oct. 1, 2004

FILENAME: J:\3795\3795A.DWG

SHEET 1 of 2

35.5"x 31"
DATE: 10/01/2004 TIME: 11:01 FILENAME: J:\3795\3795A.DWG

PLAN VIEW

ART#160	Unidentified wreckage and reference number
ART#246	Crew - Personal items/equipment and reference number
ART#148	Outer hull/deck wreckage and reference number
ART#248	Interior pressure hull wreckage and reference number
ART#163	Intrusive non-site related materials and reference number

Contours shown from an AUV Site Specific Survey performed in 2001.

Contour interval = 20 feet

Zero datum = Mean Sea Level

Multibeam Processing Sequence

Bin size = 3 meters (9.84 feet)

Median filter applied

Produced gridded-binned dataset using weighted-neighbor algorithm

Search radius = 9 meters (29.53 feet)

Water column velocity corrections applied

Tide corrections applied using Goddard Ocean Tide Model GOT99.2

SHIPWRECK
(*U-166*)
"Bow"

SHIPWRECK
(*U-166*)
"Stern"

-4780'
-4760'
-4800'

GRID NORTH

NOTE: Investigations were carried out on October 5-10, 2003 aboard the NOAA R/V *Ronald H. Brown.*
Equipment utilized: Sonsub *Innovator* ROV, C-Nav DGPS, Sonardyne Fusion Long Base Line System, and Sonardyne Pharos Navigation Software.
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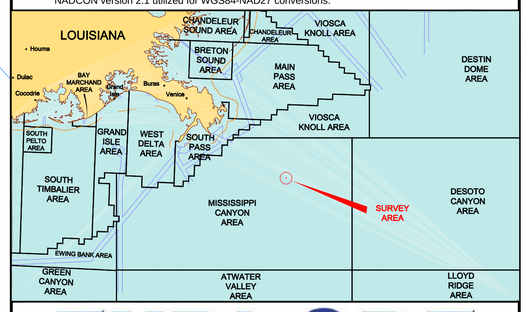

EXPLORE

U-166 INVESTIGATION

ARTIFACT DISTRIBUTION MAP

MISSISSIPPI CANYON AREA

40' 0' 40' 80'
SCALE IN U.S. SURVEY FEET

ISSUE	DATE	DESCRIPTION	INTERP	DRAWN	CHECKED	APPROVED
1	10/01/2004	ORIGINAL ISSUE	D. WARREN	D. PIERROTTIE		

ISSUE	DATE	DESCRIPTION	INTERP	DRAWN	CHECKED	APPROVED

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JOB NO. 3795 **DATE:** Oct. 1, 2004

FILENAME: J:\3795\3795A.DWG

SHEET 2 of 2

35.5"x 31"
DATE: 10/01/2004 TIME: 11:01 FILENAME: J:\3795\3795A.DWG