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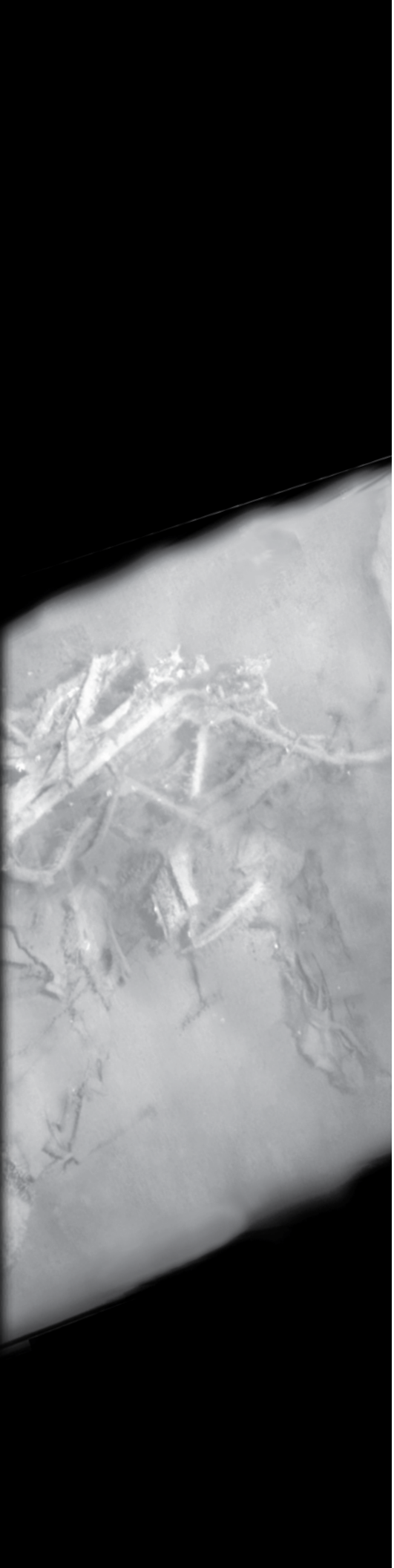
ANALYSIS OF DEEPWATER SHIPWRECKS IN THE GULF OF MEXICO

ARTIFICIAL REEF EFFECT OF SIX WORLD WAR II SHIPWRECKS

BY ROBERT A. CHURCH, DANIEL J. WARREN, AND JACK B. IRION



ABSTRACT. In 2004, researchers from across North America came together to investigate six World War II-era shipwrecks discovered in the Gulf of Mexico. The science team included marine archaeologists, microbiologists, marine vertebrate and invertebrate zoologists, a molecular biologist, an oceanographer, remotely operated vehicle technicians, and professional marine surveyors. The US Department of the Interior, Minerals Management Service, and the National Oceanic and Atmospheric Administration Office of Ocean Exploration and Research sponsored this multidisciplinary project under the auspices of the National Oceanographic Partnership Program. The organizational involvement included six universities, two nonprofit organizations, three commercial companies, and three federal agencies. All six vessels studied were casualties of World War II. Each was found during modern oil and gas surveys in water depths ranging from 87 to 1,964 meters. Today, these wrecks function as artificial reefs. Their well-documented sinking dates offer biologists a unique opportunity to study the "artificial reef effect" of manmade structures in deep water. Historically, these sites represent an underwater battlefield and a vital historical resource documenting a little-studied area of world history. They preserve information vital to scholarly and popular understanding of the impact of World War II in the Gulf of Mexico, on the American home front, and in the wider world.

BACKGROUND

During World War II, German U-boats sank 56 merchant vessels in the Gulf of Mexico. As a result, the Gulf contains one of the greatest concentrations worldwide of Allied shipping lost to German U-boats. Currently, the remains of 18 such vessels and the only known German U-boat sunk in the Gulf, *U-166*, have been identified in federal waters as a result of oil industry surveys required by the US Department of the Interior's Minerals Management Service (MMS). Taken together, these sites represent a unique underwater battlefield and a vital historical resource documenting an understudied but important period in American history. These sites also represent artificial reefs created on known dates that offer biologists a unique opportunity to study the "artificial reef effect" of manmade structures in deep water.

In the summer of 2004, a multidisciplinary team composed of archaeologists, biologists, filmmakers, oceanographers, professional surveyors, and remotely operated vehicle (ROV) operators worked together on the Deep Wrecks Project to document and analyze biological and archaeological aspects of six World War II era shipwrecks in the deep waters of the Gulf of Mexico (Minerals Management Service, 2007; Church et al., 2007). The vessels (*Virginia*, *Halo*, *Gulfpenn*, *Robert E. Lee*, *Alcoa Puritan*, and *U-166*) were lost to wartime activity in 1942. Each of the shipwrecks was discovered during oil and gas surveys and reported to MMS as required by federal regulations. Water depth at the wreck sites ranged from 87 to 1,964 meters. Each shipwreck was investigated to determine site boundaries, National Register of Historic Places eligibility, state of preservation and stability, and the potential for these manmade structures to function as artificial reefs in deep water.

MMS and the National Oceanic and Atmospheric Administration's Office of Ocean Exploration (NOAA OE) sponsored the study under the auspices of the National Oceanographic Partnership Program (NOPP). MMS contracted C & C Technologies Inc. (C & C) to manage the project, provide survey support, and conduct the archaeological analysis. In addition to the three government agencies, researchers from six universities, three private companies, and two nonprofit organizations collaborated to make the project a success; individuals who directly participated in the project are listed in the acknowledgements section of this paper.

A diverse team of researchers, with archaeologists and biologists working side by side, pooled their expertise to meet project goals. Each site was systematically investigated using an acoustically positioned ROV following a pre-established survey grid. The ROV survey was designed to maximize efforts and time for both the archaeological and biological studies. Detailed visual inspections provided needed data to document each wreck's cultural and biological characteristics.

Of the six wrecks designated for this study, three (*Alcoa Puritan*, *Robert E. Lee*, and *U-166*) were positively identified before the project. The remaining vessels (*Gulfpenn, Halo,* and *Virginia*) had only been tentatively identified based on geophysical surveys and limited video documentation. During the project, positive identifications were made for each vessel.

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THE SHIPWRECKS

Virginia

Welding Shipyards Inc. constructed *Virginia* in March 1941. The ship was 501 ft (152.8m) long and 69.8 ft (21.3 m) at the beam (Sawyer and Mitchell, 1974). In May 1942, the tanker transited from Baytown, Texas, toward Baton Rouge, Louisiana, loaded with 180,000 barrels of gasoline. *Virginia* stopped on May 12 near the sea buoy at the Southwest Pass of the Mississippi River (the Southwest Pass is the main deep-draft navigational entrance into the Mississippi River) waiting for a river pilot (Burch, 1942b). Just as the dory carrying the pilot from *Jenny Wilson* to *Virginia* was crossing between the two ships, two of three torpedoes from *U-507* passed under the pilot boat and struck the tanker. In moments, *Virginia* was engulfed in flames as the gasoline-filled tanker exploded. The flames spread over the water, surrounded the tanker, and made it nearly impossible for many of the crew to escape. Those in the pilot boat tried to rescue survivors from the burning tanker, but only 14 of 41 crewmen survived (Burch, 1942a; Michell, 2001, 2004; Peterson 2003).

In 2001, a large shipwreck was discovered in the western portion of the South Pass area of the northern Gulf of Mexico during a geophysical oil and gas survey. Marine archaeologist Rob Floyd tentatively identified the shipwreck as *Virginia*.

The Deep Wrecks Project team examined the site, becoming the first to see the ship in its 62 years on the bottom. They determined that the wreck is oriented with the bow pointing northwest and the stern southeast. Average water depth at the wreck is approximately 87 m. The site has approximately 14.6 m of relief above the seafloor. Most of the superstructure is badly deteriorated, with biofouling making many features difficult to identify. The bridge structure is gone, but the bridge telegraph remains in situ.

Virginia's bow stands approximately 12 m proud of the seafloor. The vessel's stern exhibited approximately 8 m of relief above the ambient seafloor and is badly damaged. The aft deckhouse is a collapsed tangle of bent and broken metal. Several nets are ensnared over this section of the vessel, particularly on the port side, making it difficult to assess.

The fish and invertebrate count at this site was incomplete because of the poor visibility, but many species were documented. Numerous nektonic crustaceans were observed, as well as black wire coral (*Stichopathes* sp.), black thorny coral (*Antipathes furcata*), and colonies of scleractinian corals (*Madracis myriaster* and *Pourtalosmilia conferta*). Vermilion snapper (*Rhomboplites aurorubens*) was the predominant fish specie documented over the wreck, but other species were observed near the site such as red snapper (*Lutjanus campechanus*), scamp (*Mycteroperca phenax*), and spotted soapfish (*Rypticus maculates*).

Halo

Halo was an American tanker built by the Bethlehem Shipbuilding Corporation and launched in 1920. The vessel was

6,986 tons with a length of 436.35 ft (133 m) and beam of 55.77 ft (17 m). The bridge was amidships with a full topgallant forecastle at the bow and engine at the stern (IME, 1919; Hocking, 1969).

On May 19, 1942, the tanker *Halo* weighed anchor at Galveston, Texas, and headed toward New Orleans, Louisiana, carrying 63,000 barrels of crude oil. At approximately 1:00 a.m. on May 20, 1942, the tanker was about 80 km from the Southwest Pass of the Mississippi River when two torpedoes from *U-506* struck the starboard side (Powers, 1942a; Würdemann, 1942).

The tanker sank in less than 15 minutes, going down by the bow with the propeller still turning. The tanker was ablaze as it plunged beneath the water and the oil on the water burned for the next six hours. Of a crew of 42, only 23 managed to escape, most by just grabbing life vests and jumping overboard. The men were adrift for five to seven days in the water, and only three survived the ordeal (Powers, 1942a; Würdemann, 1942).

In 2000, a shipwreck, tentatively identified as *Halo*, was discovered during a pipeline survey for the oil industry (Church, 2000). From July 30 to August 1, 2004, the Deep Wrecks science team deployed an ROV to investigate the site. The vessel's bow is embedded deeper in the seafloor than the stern. The forecastle's upper region stands only 3.0 m above the ambient seafloor as opposed to the stern, which has 7.3 m of relief. Only half of the bow's windlass can be seen protruding from the sediment. The forward mast still stands and the top of the mast is approximately 16.5 m above the ambient seafloor.

The vessel's superstructure and the starboard side of the hull appear relatively intact, but many structural details are obscured by biofouling, and several trawl nets are tangled around the starboard stern. Severe damage to the deck and port side hull is visible between the main superstructure and aft deckhouse. Nets are tangled around the aft starboard quarter. At the stern, the small deckhouse for the steering machinery is present, but damaged. The steering engine is visible through the rear of the structure. Only portions of *Halo*'s deck remains were documented because of safety concerns raised by low visibility and potential entanglement.

Some brown rusticles, which are formed by microbes, were observed on the structure. Examples of the invertebrates documented at the site include sea urchins (*Eucidaris tribuloides* and two *Echinothrix* sp.), mollusks (*Chama* sp., *Siratus beauii*, and Buccinidae), crustaceans (hermit crabs, possibly *Dardanus insignius*), and scleractinian (*Madracis myriaster* and *Pourtalosmilia conferta*) and gorgonian (*Placogorgia rudis*, *Thesea* sp. *cf. T. grandiflora, Thesea* sp. *cf. T. rubra, and Thesea* sp.) corals. Anthiinae basses—yellowfin bass (*Anthias nicholsi*), red barbier (*Hemathias vivanus*), roughtongue bass (*Pronotogrammus martinicensis*), Warsaw grouper (*Epinephelus nigritus*), and yellowedge grouper (*Epinephelus flavolimbatus*)—were the most observed fish species. Examples of other reef-associated fish included vermilion snapper (*Rhomboplites aurorubens*), greater amberjack (*Seriola dumerili*), blacktail moray (*Gymnothorax kolpos*), red porgy (*Pagrus pagrus*), deepwater scorpionfish (*Setarches guenther*), batfishes (*Ogcocephalus* sp.), and a single silvery John Dory (*Zenopsis conchifera*).

> "THE BIOLOGICAL DATA COLLECTED IN THIS STUDY HAVE PROVIDED AN UNPARALLELED AMOUNT OF INFORMATION REGARDING THE ARTIFICIAL REEF EFFECT OF DEEPWATER SHIPWRECKS."

Gulfpenn

The Sun Shipbuilding Company laid the keel of *Agwihavre*, later renamed *Gulfpenn*, on April 2, 1920. Displacing 8,862 gross tons, the ship was launched on June 16, 1921, and had a length of 480.6 ft (146.5 m) and a beam of 65.6 ft (20 m).

On May 13, 1942, *Gulfpenn* crossed paths with *U-506* while transiting from Port Arthur, Texas, to Philadelphia, Pennsylvania. The U-boat's torpedo struck the engine room, destroying that section of the ship, immediately stopping the engines and killing all personnel in the engine room. The tanker sank stern first, taking only five minutes to slip beneath the waves. Of the crew of 38, only 25 survived the attack (Burch, 1942b).

In 1994, the wreck of *Gulfpenn* was discovered during a deepwater survey in Mississippi Canyon, detected at the edge

of the survey swath by side-scan sonar. Marine archaeologist Laura Landry tentatively identified the shipwreck as *Gulfpenn* (Landry, 1994).

Between August 4 and 5 and August 11 and 13, 2004, the science team collected the first spectacular images of *Gulfpenn*. The wreck is oriented with the bow pointing north-northwest. Water depths range from approximately 553 m at the bow to 555 m at the stern. The vessel's bow stands approximately 19 m proud of the seafloor as opposed to the aft deckhouse, which rises only 5.5 m above the ambient seafloor (Figure 1).

The bow and forward section are relatively intact, but the superstructure's upper works show considerable deterioration. The pilothouse is gone and the bridge's deck is disintegrating. The ship's telegraph has fallen over and spans part of the metal framework of the bridge. The superstructure's starboard side is almost entirely covered by coral colonies.

Extensive damage is present aft of the vessel's main superstructure. Although the catwalk and piping from the main structure to the aft deckhouse are intact, the hull amidships has partially collapsed. *Gulfpenn*'s aft portion exhibits the most severe damage. The deck of the aft deckhouse is deteriorating and has partially collapsed inward, exposing the interior. Almost 11 m of the stern is missing and the hull ends abruptly in a contortion of mangled metal plating.

An extensive artifact scatter surrounds the wreck site. The main debris zone extends nearly 161 m northwest from the vessel. The stern's missing section lies within the main debris field 27 m northwest of the bow. Other material within this dense debris field includes vent hoods and pipe, railing, twisted metal, and a lifeboat.

Biologically, *Gulfpenn* had higher species richness than any of the other project sites. This wreck was also the deepest site in this study where both corals and reef fishes were found. Microbial concretions were more abundant at this site than at the two shallower wrecks and coated 30% of the ship's observable surface. Abundant and diverse invertebrates were observed at the site. Many spiny crabs (*Rochinia crassa*) were recorded along with Galatheoid crabs (*Eumunida picta*) and Venus flytrap anemones (*Actinoscyphia* sp.). The deepwater coral *Lophelia pertusa* has

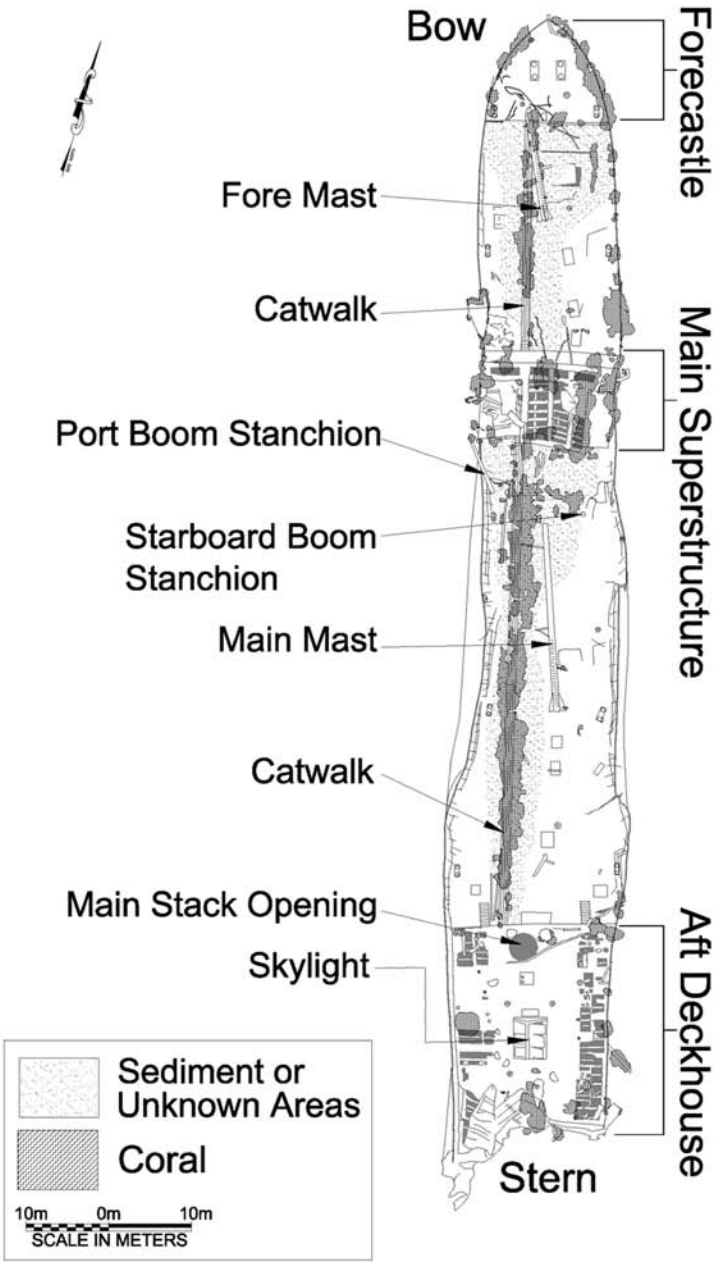

Figure 1. *Gulfpenn* site drawing.

colonized 12–15% of the ship's surface, including a vertical wall of coral 7 m long and 3.5 m high along the starboard side of the ship (Figure 2). The *Gulfpenn* site is currently one of the top three best *Lophelia* sites known in the Gulf of Mexico. The fish community was dominated by slimeheads along with two species of scorpionfishes, blackbelly rosefish (*Helicolenus dactylopterus*), and the Atlantic thornyhead (*Trachyscorpia cristulata*). Conger (*Bathycongrus dubius*), Gulf hake (*Urophycis cirrata*), and Gulf hagfish (*Eptatretus springeri*) were also collected at the site.

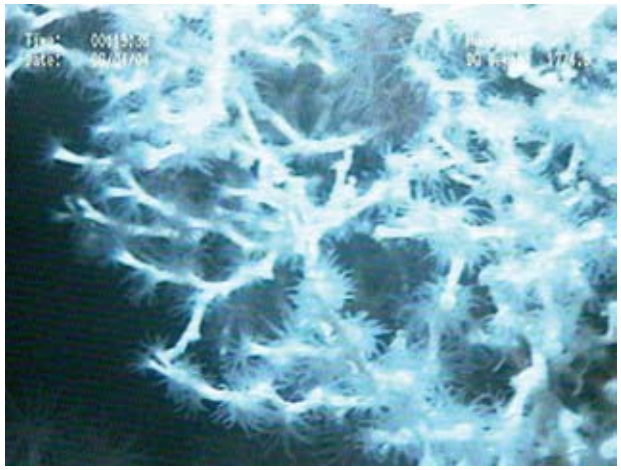

Figure 2. Deepwater coral colony (*Lophelia pertusa*) on *Gulfpenn*.

U-166

U-166 was built at the Seebeck Shipyard in Bremen, Germany, between December 6, 1940, and March 23, 1942. *U-166* was 76.8 m long, had a beam of 6.8 m, and a draft of 4.7 m. It was one of 54 Type IXC U-boats constructed during World War II for long-range, fast attacks (Miller, 2000; Rössler, 2001).

U-166 entered the Gulf of Mexico in mid July 1942 under the command of Oberleutnant zur See Hans-Günther Kühlmann. On July 27, 1942, Kühlmann radioed the Kreigsmarine Command to report 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 *U-166*.

On July 30, 1942, *U-166* had the large passenger freighter *Robert E. Lee* in its sights. It is not known if *U-166* realized *Robert E. Lee* was being escorted by the naval patrol craft *PC-566*. The U-boat attacked and sank the freighter, then found itself under attack from the patrol craft while watching the freighter sink. *PC-566* destroyed the U-boat in minutes with depth charges.

An oil slick appeared after the attack, but the US Naval Command dismissed it as possibly oil from the freighter. They decided *U-166* escaped the attack by the patrol craft after a U-boat was spotted to the west two days later. The mystery surrounding the U-boat's location soon grew into legend during the years following the war. The mystery was finally solved 59 years later when *U-166* was discovered during a pipeline survey.

In January and March 2001, C & C conducted a survey for BP and Shell in the Mississippi Canyon area near *Robert E. Lee*'s reported location. C & C performed the survey using *C-Surveyor I*, its new autonomous underwater vehicle (AUV). In addition to *Robert E. Lee*, a second wreck was imaged. Several years prior to the 2001 surveys, the second wreck location was thought to be another freighter, *Alcoa Puritan*. C & C archaeologists Church and Warren realized the second wreck matched the dimensions of *U-166* and hypothesized that *PC-566* sank the U-boat on July 30, 1942, and that it potentially now had been found.

Between May 31 and June 1, 2001, a research team comprised of representatives from BP, Shell, C & C, and MMS traveled to the Mississippi Canyon area to determine if the German U-boat *U-166* had been located. The first glimpse of the vessel was the unmistakable conning tower of a German U-boat. The 105-mm deck gun, as well as 37-mm and 20-mm antiaircraft guns, were clearly visible. Post-field analysis and research revealed that each feature matched that of *U-166*, an early version of the Type IXC long-rang U-boat design.

In October 2003, C & C, in conjunction with NOAA OE, Droycon Bioconcepts Inc., and the PAST Foundation, returned to *U-166* to conduct a more thorough investigation of the wreck (Warren et al., 2004). Over five days in October 2003, the researchers successfully recorded *U-166*'s remains in one of the deepest archaeological mapping projects undertaken using long baseline positioning. The project's success was a result of the partnership of academic, private, and government entities coming together as a multidisciplinary research team.

Figure 3. Photomosaic of a 70-ft section of *U-166*'s bow.

During the 2003 mapping project, 307 artifacts were documented at the *U-166* site. In addition to the noninvasive archaeological investigations, the microbiological communities (rusticles) growing on *U-166* were described and the team placed long- and short-term experiments at different wreck sections. 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 to help biologists determine the level of bacterial activity at the site. The long-term experiments will assist biologists in determining the wreck site's biocorrosion rate. The experiments left on the wreck were checked during the 2004 site visit.

The 2003 microbiological study determined that microbial activity at the *U-166* site was high, and included white rusticles, which had been seen previously only on the German battleship *Bismarck*. The 2004 archaeological investigations undertaken at *U-166* continued the 2003 fieldwork. The 2004 research team located the southern extent of the site and recorded 23 additional artifacts associated with the wreck. The 2004 team also produced a photomosaic of the bow from video data collected during that survey (Figure 3).

In addition to the microbial analysis, biological findings revealed abundant invertebrates at the site, consisting of red deep-sea crab (*Chaceon quinquedens*), squat lobsters (*Munidopsis* sp.), and Venus flytrap anemones (*Actinoscyphia* sp.). Fish species diversity was low at *U-166* and included cuskeels (Order: Ophidiiformes), Halosaurs (Family: Halosauridae), cutthroat eels (*Synaphobranchus brevidorsalis*), and

grenadiers (Family: Macrouridae). A six-gill shark (*Hexanchus griseus*) also was observed away from the wreck at one of the fish traps.

Robert E. Lee

The passenger freighter *Robert E. Lee*, built in 1924 at Newport News, Virginia, was 373.4 ft (113.8 m) long, 53.8 ft (16.4 m) wide, and had a 17-ft (5.2 m) draft (Talbot-Booth and Sargent, 1942; ACVC, 1945).

In July 1942, the ship was in Port-of-Spain, Trinidad, preparing to transit to New Orleans, Louisiana, with approximately 270 passengers. Six Merchant Marine officers and 131 general crewmen were aboard *Robert E. Lee* when the vessel left port on July 20. *Robert E. Lee* crossed the Caribbean as part of a convoy, but, on the morning of July 29, broke from the group to rendezvous with the US Navy Patrol Craft *566* near Key West, Florida. *PC-566*, commanded by Herbert C. Claudius, was designed for anti-submarine warfare. *PC-566*'s orders were to escort *Robert E. Lee* to Tampa, Florida, where the steamer would take on provisions (Henderson, 1942; USS *PC-566,* 1942; Charlton, 2003).

Around 9:45 p.m. on July 29, *Robert E. Lee* and *PC-566* arrived at Edgemont Key Light near Tampa Bay. When no pilot was available for *Robert E. Lee* to enter the harbor, the ship's captain decided to proceed to New Orleans. The Gulf Sea Frontier Command ordered *PC-566* to continue with *Robert E. Lee* to New Orleans (Henderson, 1942; USS *PC-566,* 1942).

Robert E. Lee and the patrol craft transited the Gulf of Mexico on July 30 without incident until the vessels were 72 km southeast of the Mississippi River. Just after 4:40 p.m., passengers and crew on *Robert E. Lee* noticed an elongated shape about 200 m off the starboard side of the ship. The passengers who noticed the object argued that it was either a shark or a dolphin. The object reportedly turned sharply towards *Robert E. Lee*, and the passengers, to their horror, realized the object was a torpedo. The torpedo struck *Robert E. Lee*'s starboard side aft of the engine room. Lookouts aboard *PC-566*, a half mile ahead of *Robert E. Lee*, observed a periscope off the steamer's starboard side. The freighter settled fast by the stern while *PC-566* moved to attack the U-boat. The passengers and crew frantically abandoned the ship. The more desperate passengers jumped into the water. *Robert E. Lee*'s bow rose out of the water until it reached a precariously steep angle, then the vessel plunged to the bottom of the Gulf (Henderson, 1942; USS *PC-566,* 1942; Winnier, 2003, 2004).

Robert E. Lee sank within ten minutes following the torpedo attack. The disaster resulted in the deaths of ten crewmembers and fifteen passengers. While the freighter was sinking, *PC-566* crossed the submarine's suspected location twice and dropped depth charges. The depth charges were close enough to *Robert E. Lee*'s lifeboats and rafts that the survivors felt shockwaves from the explosions. After attacking the submarine, *PC-566* began rescuing *Robert E. Lee*'s survivors. Naval vessel *SC-519* and the tug *Underwriter* arrived to help with the rescue (Henderson, 1942; USS *PC-566,* 1942; Charlton, 2003).

In 1986, Shell Offshore Inc., hired John E. Chance and Associates to conduct a geophysical survey in the Mississippi Canyon area in the Gulf of Mexico. During the survey, they found two shipwrecks in approximately 1,500 m of water. The only shipwrecks listed by MMS in the vicinity were two World War II casualties, *Robert E. Lee* and *Alcoa Puritan* (Prior et al., 1988). No further investigations of the shipwrecks were undertaken because the sites were not threatened and due to the considerable time and expense involved in conducting deep-tow surveys. *Robert E. Lee* was correctly identified, but the vessel believed in 1986 to be *Alcoa Puritan* was actually *U-166*. The U-boat's true identity was not discovered until additional survey work in 2001 with improved survey technology and stricter MMS archaeological regulations (Church et al., 2003).

During the 2003 *U-166* mapping project (Warren et al., 2004), limited archaeological inspection and microbiological collection was conducted at the *Robert E. Lee* site. Targets near the wreck as well as those away from *Robert E. Lee* were investigated, but the debris field to the north was not examined because of time constraints. Two unidentified targets documented by the 2001 AUV survey approximately 700 m away from the *Robert E. Lee* wreck site were investigated and identified as lifeboats. Their extreme distance from the wreck site suggests these boats were possibly abandoned after the survivors in them were rescued.

The *Robert E. Lee* wreck site was investigated again on August 7, 8, 9, and 12, 2004. *Robert E. Lee*'s wreckage lies 1,481 m below sea level and is oriented with the bow pointing west. Upon initial inspection, the vessel appears to lie evenly on the seafloor, but the ship's bow rises 10.9 m above the ambient seafloor while the stern

stands only 7.6 m above the sediment. Considering the stern is buried deeper than the bow, it is likely that *Robert E. Lee* impacted the seafloor stern-first.

The ROV survey of the hull indicated the vessel is largely intact, but the upper superstructure is severely damaged. A light layer of sediment covers the wreck, likely from the initial impact plume paired with 62 years of sediment deposition. *Robert E. Lee*'s stern is relatively intact. The most prominent structure in this area is a 4-in gun mounted on the top deck of the fantail. The gun and railing on the stern are covered with biological growth (Figure 4).

The survey of the debris field focused on the northern area because of the lack of data from previous investigations. The artifact scatter extends 150 m north of the hull's center. Artifacts within the northern debris field include various items from the ship as well as personal items from the crew and passengers. Shoes, along with other textile remains that appear to have been packed in a suitcase or bag, are located 52.7 m north of the hull. Stacks of dishes are located 8.2 m north of the hull amidships. Bathroom stalls from the vessel's interior were discovered 24.4 m off the starboard bow. Lying 11 m off the vessel's starboard side is a tangled heap of metal, wire, and miscellaneous debris. A signal bell, rudder controls, and an engine-order telegraph indicate this is part of the ship's bridge that fell to the starboard side of the wreck. The remainder of the bridge section was found on an earlier expedition 88 m off the port side of the ship.

During investigations of the southern debris field, two of the ship's engine-order telegraphs were located. One of the telegraphs, documented on earlier expeditions, is standing upright, but the other is lying face down. The upright telegraph's face is visible and the controls are set to "Finished with Engines" (Figure 5). The telegraph lying down is 14 m north of the upright telegraph, but was not documented on previous site visits.

Numerous brown hanging rusticles, ranging up to 2 m long and 250 mm wide, occupied 20% of the wreck's visible areas. A few white rusticles were also documented. Invertebrates observed at the site consisted of red deep-sea crab (*Chaceon quinquedens*), squat lobsters (*Munidopsis* sp.), and abundant Venus flytrap anemones (*Actinoscyphia* sp.) attached to the substrate provided by the shipwreck. Several species of shrimp were observed away from the main hull. Fish species diversity was low at *Robert E. Lee*, consisting mostly of the same species observed at *U-166*.

Figure 4. *Robert E. Lee*'s stern light covered with hydrozoans, a Venus flytrap anemone (*Actinoscyphia* sp.), and squat lobsters (*Munidopsis* sp.).

Figure 5. One of *Robert E. Lee*'s engine-order telegraphs standing upright on the seafloor.

Alcoa Puritan

Alcoa Puritan was a 6,795-ton cargo steamship built in 1941 by the Bethlehem Steel Company in San Francisco. The ship was owned and

operated by the Alcoa Steam Ship Company at the time of its loss. The vessel's length was 417.9 ft (127.4 m) with a 60-ft (18.3-m) beam and a 37.4-ft (11.4-m) depth of hold from the main deck (Marine Engineering and Shipping Review, 1941; Conwell, 1986).

On its last voyage, *Alcoa Puritan* carried 41 officers and crew and seven passengers. At least six passengers were survivors of the tanker *T.C. McCobb,* which had been torpedoed off Brazil (Conwell, 1986; Browning, 1996). In May 1942, *Alcoa Puritan* was en route from Port of Spain, Trinidad, to Mobile, Alabama, with a cargo of 10,000 tons of bauxite. The vessel, under Captain Yngvar Axelstien Krantz's command, plied the Gulf of Mexico's relatively unprotected waters when it crossed paths with the German U-boat *U-507* (Moore, 1983).

U-507's first torpedo just missed *Alcoa Puritan*'s stern. The captain ordered full ahead in an attempt to outrun the U-boat, but *U-507* surfaced and began pursuit. Firing with its deck guns, the U-boat slowly overtook the freighter and managed to cripple *Alcoa Puritan*'s steering. The freighter's crew abandoned ship as the U-boat approached. After the crew was away, *U-507* put a torpedo in *Alcoa Puritan's* port side, sending it down to the depths (Powers, 1942b; Conwell, 1986).

Between March and June 2001, about the same time as *U-166*'s discovery, Shell International Exploration and Production contracted Fugro GeoServices Inc. (FGSI) to conduct a deep-tow survey for a pipeline project. A large shipwreck was discovered on that survey in 1,965 m of water, 23 km southeast of the *Robert E. Lee* and *U-166* sites (Church et al., 2003). Marine archaeologist Laura Landry conducted the archaeological assessment for the survey. Based on survey data and historical information, Landry identified the wreck as *Alcoa Puritan* (USDI MMS, 2002).

Shell International and Production Inc. conducted the first ROV investigation of the wreck site on July 3, 2002. The ship's name "*ALCOA PURITAN*" and homeport "NEW YORK" were observed across the stern. The ROV investigation confirmed the site's identity and provided valuable data for researchers (Church et al., 2003).

> "THESE DATA PROVIDE A BASE OF KNOWLEDGE FOR FUTURE STUDIES AROUND THE WORLD TO BUILD UPON."

The 2004 research team investigated *Alcoa Puritan* on August 9 and 10, 2004. The vessel lies in 1,964 m of water with the bow pointing southeast and stern northwest. The bow stands 4.3 m proud of the ambient seafloor, higher than the stern. A seafloor depression around the stern measures approximately 50 m across and 4 m deep. The stern is approximately 1.2 m lower than the ambient seafloor outside the depression.

ROV reconnaissance of the main structure showed that the hull is mostly intact with moderate superstructure damage. Numerous shell holes are visible along the hull. Moderate damage was observed on the vessel's starboard side, but the most extensive damage is to the port side. A large hull breach caused by a torpedo is visible near the mud line, below the superstructure's aft portion. The tear measures 11.4 m across and extends 2.5 m above the mud line. Physical deterioration is substantial in this area. Part of the aft bridge roof has collapsed, exposing the interior of the bridge; one of the ship's bridge telegraphs, lying on its side, is visible through the opening.

The geophysical survey data did not indicate an extensive debris field surrounding the wreck site. The observed debris was limited and only four scattered artifacts were recorded around the hull. The most notable artifact was one of *U-507*'s 105-mm shell casings, located approximately 112 m east of *Alcoa Puritan*'s bow.

Three transect survey lines run 300 m north of the vessel location revealed a large, 213-m by 213-m debris field containing large sections of wreckage, including a ship's mast and telegraph.

The site had the greatest density of brown rusticles in the study, with 35% of the observable area covered. The rusticle formations are similar to those observed at RMS *Titanic*. Multiple microbial test platforms have been deployed since 1998 at *Titanic* and later analyzed (Cullimore and Johnston, 2000). Based on available data, microbiologists developed a model projecting the *Titanic*'s rate

of deterioration (Ballard, 2004). From these parallel rusticle investigations, an estimate of rusticle growth can be made for *Alcoa Puritan*, where current rusticle development may be similar to that of *Titanic* during the mid-1970s when it had been submerged for a similar length of time (Cullimore et al., 2001; Cullimore and Johnston, 2005).

Vertebrates and invertebrates observed at the site were similar to those observed at *U-166* and *Robert E. Lee*. Red deep-sea crabs (*Chaceon quinquedens*) were the predominant invertebrates collected, but a hermit crab (*Paragiopagurus* sp.) also was collected. Numerous squat lobsters (*Munidopsis* sp.), Elaspodid sea cucumbers, and a bright red carid shrimp (*Notostomus* sp.) were also observed.

> "...OUR KNOWLEDGE OF OUR MARITIME HERITAGE, OUR UNDERSTANDING OF DEEPWATER REEFS, AND HOW THE TWO ARE INTERTWINED WAS SIGNIFICANTLY INCREASED."

SITE DISTRIBUTION

One archaeological goal of the project was to determine site boundaries for each wreck. When a ship sinks, debris falls from the vessel as it passes through the water column. The material disperses outward as it descends and generally continues to trail off from the main hull as it sinks. The greater the water depth, the more time the material has to fall from the ship and the further it will disperse across the seafloor. Therefore, the deeper the water, the wider the debris field or longer the debris trail will be from the main hull. An examination of the debris distribution data from the Deep Wrecks Project (Church et al., 2007) revealed a trend for the site area to increase proportionately as water depth increases. The maximum distance from the core shipwreck remains to the site's periphery forms a uniform curve with respect to water depth that closely follows the mean distribution average between distance and water depth (Figure 6).

Using data from the 2004 study (Church et al., 2007), a formula was developed to estimate a radius slightly larger than the suspected boundary size of a steel-hulled shipwreck site in deepwater. The formula states that 20% of water depth plus vessel length is equal to or slightly greater than the distance from the main hull to the edge of the debris field ($0.20\ wd + vl \geq$ site boundary radius, where wd = water depth and vl = vessel length).

This formula uses 20% of the site water depth plus the estimated vessel length to calculate the boundary radius. However, this formula is based on a small data set consisting of steel-hulled shipwrecks lost under catastrophic wartime conditions, and does not take into account wooden shipwrecks or smaller iron-hulled vessels that foundered at sea. This formula is intended as a working model for future research to build upon. Additional shipwreck information is currently being gathered to refine this model, which will allow government agencies, such as MMS, to determine adequate avoidance criteria at similar wreck sites and will aid researchers in developing survey plans for investigation of such sites.

Although not all deepwater wreck sites fit the model, many deep sites such as RMS *Titanic* do fit. *Titanic* lies in nearly 3,800 m of water in the North Atlantic and has an almost 800-m-long artifact trail leading to the main hull (Ballard, 1987). The most obvious exceptions to the model are wrecks, such as HMS *Ark Royal*, that remained crippled on the surface for a prolonged time (15 to 20 hrs) before sinking. *Ark Royal* sank in 1,066 m of water after being torpedoed. A 750-m artifact trail leads to the main hull (Warren et al., 2004). As a sinking ship drifts with the current at the surface, material may fall to the seafloor. The initial point of the marine tragedy that caused the sinking can be a far distance from the location where the vessel comes to rest on the seafloor, creating a longer debris trail.

CONCLUSIONS

The Deep Wrecks Project was one of the most comprehensive deepwater shipwreck investigations to date. The multidisciplinary approach allowed the research team to maximize expensive ship time and draw on a wide range of expertise for a holistic approach to studying the wreck sites. The biological data collected in this study have provided an unparalleled amount of information regarding the artificial reef

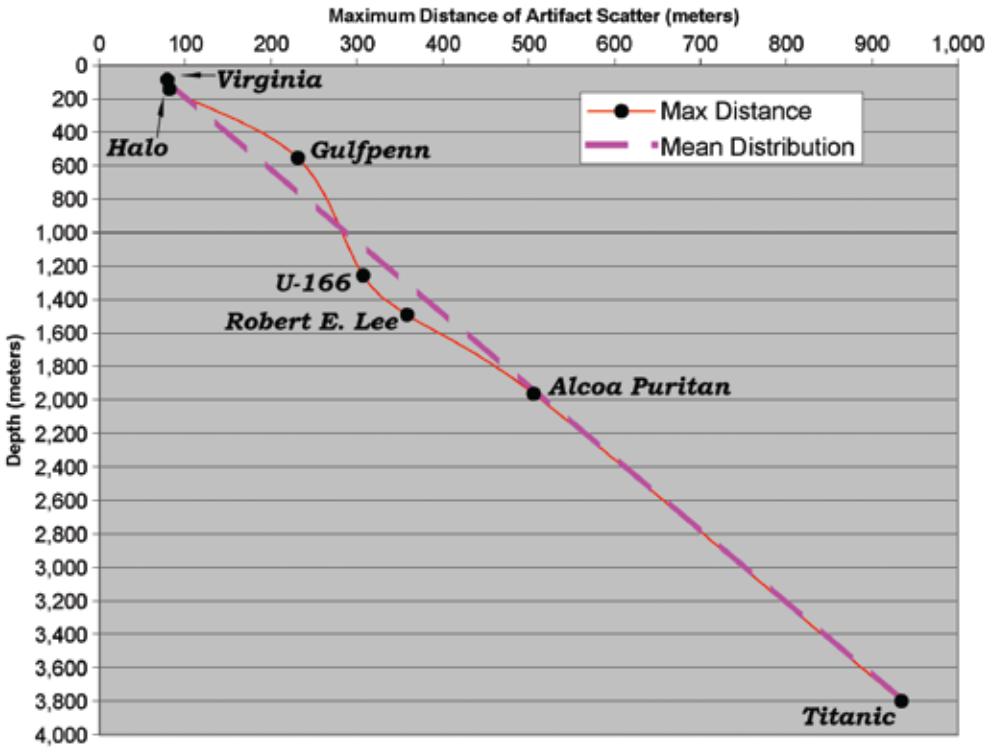

Figure 6. Distribution graph showing the correlation between the distance of shipwreck debris and water depth.

Table of historical and biological site information

Site	Depth	Site Boundary From Center of Wreck	Date In Service	Type	Cargo	Biological Information
Virginia	87 m	79 m	1941 to 1942	Tanker	180,000 barrels gasoline	Fish and invertebrate count incomplete due to poor visibility; vermilion snapper predominant fish species observed; various corals observed
Halo	143 m	82 m	1920 to 1942	Tanker	63,000 barrels crude oil	Few brown rusticles; scleractinian and gorgonian corals observed; diverse invertebrates; reef fishes observed; Anthiinae basses predominant fish species observed
Gulfpenn	554 m	231 m	1921 to 1942	Tanker	90,000 barrels gasoline	Some microbial concretions; abundant *Lophelia pertusa* and high invertebrate diversity; reef fishes observed
U-166	1,256 m	308 m	1942 to 1942	U-boat	Mines & torpedoes	Brown and white rusticles, Venus flytrap anemones, abundant red deep-sea crab, and squat lobsters; other typical deep-water demersal species
Robert E. Lee	1,490 m	359 m	1924 to 1942	Passenger Freighter	Passengers	Abundant brown rusticles, Venus flytrap anemones, red deep-sea crab, and squat lobsters; other typical deep-water demersal species
Alcoa Puritan	1,964 m	506 m	1941 to 1942	Cargo Freighter	10,000 tons bauxite	Greatest density of rusticle formations; predominant invertebrate was red deep-sea crab; other typical deep-water demersal species

effect of deepwater shipwrecks. These data provide a base of knowledge for future studies around the world to build upon. Archaeologically, the study has provided a substantial amount of information on deepwater wreck-site formation processes for steel-hulled vessels. The overwhelming success of this project not only was due to the assembled expertise of the science team but also was the direct result of the cooperation of the team members with each other. Through this excellent partnership, our knowledge of our maritime heritage, our understanding of deepwater reefs, and how the two are intertwined was significantly increased.

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