

processes are enhanced and in which many heterotrophic organisms obtain a living. They are a food source for a variety of free-living organisms some of which have already been shown to adopt complex behaviour in order to locate them.

See also

Floc Layers. Nepheloid Layers. Particle Aggregation Dynamics. Remotely Operated Vehicles (ROVs). Trapped Particulate Flux. Temporal Variability of Particle Flux.

Further Reading

- Allredge A (1998) The carbon, nitrogen and mass content of marine snow as a function of aggregate size. *Deep-Sea Research* (Part 1) 45 (4–5): 529–541.
- Allredge AL and Gotschalk C (1988) In situ settling behaviour of marine snow. *Limnology and Oceanography* 33: 339–351.
- Allredge AL, Granata TC, Gotschalk CC and Dickey TD (1990) The physical strength of marine snow and its implications for particle disaggregation in the ocean. *Limnology and Oceanography* 35: 1415–1428.
- Dilling L and Allredge AL (2000) Fragmentation of marine snow by swimming macrozooplankton: a new process impacting carbon cycling in the sea. *Deep-Sea Research* (Part 1) 47(7): 1227–1245.
- Dilling L, Wilson J, Steinberg D and Allredge A (1998) Feeding by the euphausiid *Euphausia pacifica* and the copepod *Calanus pacificus* on marine snow. *Marine Ecology Progress Series* 170: 189–201.
- Gotschalk CC and Allredge AL (1989) Enhanced primary production and nutrient regeneration within aggregated marine diatoms. *Marine Biology* 103: 119–129.
- Kiorboe T (1997) Small-scale turbulence, marine snow formation, and planktivorous feeding. *Scientia Marina (Barcelona)* 61, suppl. 1: 141–158.
- Lampitt RS, Hillier WR and Challenor PG (1993) Seasonal and diel variation in the open ocean concentration of marine snow aggregates. *Nature* 362: 737–739.
- Lampitt RS, Wishner KF, Turley CM and Angel MV (1993) Marine snow studies in the northeast Atlantic: distribution, composition and role as a food source for migrating plankton. *Marine Biology* 116: 689–702.
- Lohmann H (1908) On the relationship between pelagic deposits and marine plankton. *Int. Rev. Ges. Hydrobiol. Hydrogr.* 1(3): 309–323 (in German).
- Simon M, Allredge AL and Azam F (1990) Bacterial carbon dynamics on marine snow. *Marine Ecology Progress Series* 65(3): 205–211.
- Suzuki N and Kato K (1953) Studies on suspended materials. marine snow in the sea. Part 1, sources of marine snow. *Bulletin of the Faculty of Fisheries of Hokkaido University* 4: 132–135.

MARITIME ARCHAEOLOGY

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Introduction

For thousands of years, ancient mariners have traversed the waters of our planet. During this long period of time, many of their ships have been lost along the way, carrying their precious cargo and the history it represents to the bottom of the sea. Although it is difficult to know with any degree of precision, some estimate that there are hundreds of thousands of undiscovered sunken ships littering the floor of the world's oceans.

For hundreds of years, attempts have been made to recover their contents. In *Architettura Militare* by Francesco de Marchi (1490–1574), for example, a device best described as a diving bell was used in a series of attempts to raise a fleet of 'pleasure galleys'

from the floor of Lake Nemi, Italy in 1531. In *Treatise on Artillery* by Diego Ufano in the mid-1600s, a diver wearing a crude hood and air-hose of cowhide was shown lifting a cannon from the ocean floor. Clearly, these early attempts at recovering lost cargo were done for economic, not archaeological, reasons and were very crude and destructive.

The field of maritime archaeology, on the other hand, is a relatively young discipline, emerging as a recognizable study in the later 1800s. Not to be confused with nautical archaeology which deals solely with the study of maritime technology, maritime archaeology is much broader in scope, concerning itself with all aspects of marine-related culture including social, religious, political, and economic elements of ancient societies.

Early History

Sunken ships offer an excellent opportunity to learn about those ancient civilizations. Archaeological sites on land can commonly span hundreds to even

thousands of years with successive structures being built upon the ruins of older ones. Correlating a find in one area to a similar stratigraphic find in another can introduce errors that potentially represent long periods of time. A shipwreck, on the other hand, represents a 'time capsule', the result of a momentary event where the totality of the artifact assemblage comes from one distinct point in time.

It is important to point out that maritime archaeology's first major field efforts were not conducted underwater but, in fact, were the excavation of boats that are now located in land-locked sites. In 1867, the owners of a farm began to cart away the soil from a large mound some 86 m in length only to discover the timbers of a large Viking ship, the Tune ship, complete with the charred bones of a man and a horse revealing it to be a burial chamber. In 1880, the Gokstad burial ship was discovered in a flat plain on the west side of the Oslo fiord. It was buried in blue clay which resulted in a high state of preservation. Contained within the grave was a Viking king, his weapons, twelve horses, six dogs and various artifacts.

Since the late 1890s, the excavation of boats and harbor installations in terrestrial settings continues to this day, following more or less traditional land excavation protocol. One of the most famous discoveries took place in 1954 near the Great Pyramid of Egypt. While building a new road around the Pyramid, a series of large limestone blocks were encountered beneath which was found an open pit containing the oldest intact ship ever discovered. Dating to 2600 BC, the ship measures 43 m in length, weighs 40 tons, and stands 7.6 m from the keel line.

Although ships found in terrestrial settings provide valuable insight into the culture of their period, many have a more religious significance than one reflecting the economics of the period. Burial ships were commonly modified for this unique purpose and were not engaged in maritime activity at the time of their burial.

Prior to the advent of SCUBA diving technology invented by Captain Jacques-Yves Cousteau and Emile Gagnan in 1942, archaeology conducted underwater by trained archaeologists was extremely rare. In fact, owing to the dangerous aspects of pre-SCUBA diving techniques which included the use of 'hard hats' employed by commercial sponge divers, archaeologists relied upon these commercial divers instead of doing the underwater work themselves.

Even after SCUBA technology became available to the archaeological community it was the commercial or recreational divers by their numbers who tended to discover an ancient shipwreck site. As

a result, it was not uncommon for a site to be stripped of its small, unique and easily recovered artifacts before the 'authorities' were notified of a wreck's location. Even after learning of these sites, many of the early efforts in underwater archaeology were conducted by divers lacking archaeological training.

The first was the famous *Antikythera* wreck off Greece which contained a cargo of bronze and marble sculptures. The site was initially raided in 1900 by sponge divers wearing copper helmets, lead weights, and steel-soled shoes with air supplied to them from the surface by a hand-cranked compressor.

Fortunately, the location of the wreck was soon discovered by the Greek government which with the help of their navy, mounted a follow-up expedition under supervision from the surface by Professor George Byzantinos, their Director of Antiquities, which resulted in the recovery of more of its valuable cargo. The wreck turned out to be a first century Roman ship carrying its Greek treasures back to Rome including the famous bronze statue *Youth*, thought to be done by the last great classical Greek sculptor, Lysippos.

A few years later, another Roman argosy was discovered off Mahdia, Tunisia which was also initially plundered for its Greek statuary. Again, the local government and their Department of Antiquities took control of the salvage operation which continued from 1907 to 1913 enriching the world with its bronze artwork.

Unfortunately, not all of these early shipwreck discoveries were reported to the local government. Their fate was far less fortunate than those just mentioned including a first century BC wreck lost off Albenga, Italy which was torn apart by the Italian salvage ship *Artiglio II* using bucket grabs to penetrate its interior holds.

One of the first ancient shipwrecks to be excavated under some semblance of archaeological control was carried out by Captain Cousteau in 1951 along with Professor Fernand Benoit, Director of Antiquities for Provence off Grand Congloue near Marseilles, France. It, too, was initially discovered by a salvage diver. Although no site plan was ever published after three seasons of diving, the ship was thought to be Roman from 230 BC, 31 m long, at a depth of 35 m, and carrying 10 000 amphora and 15 000 pieces of Campanian pottery bowls, pots, and 40 types of dishes with an estimated 20 tons of lead aboard.

At the same time, a colleague of Cousteau, Commander Philippe Taillez of the French Navy organized a similar excavation of a first century BC wreck

on the Titan reef off the French coast but in the absence of an archaeologist failed to actually document the site. Without the presence of trained archaeologists working underwater, there was little hope that acceptable techniques would be developed that met archaeological standards.

In 1958, Peter Throckmorton who was the Assistant Curator of the San Francisco Maritime Museum, went to Turkey hoping to locate an ancient shipwreck site. Like many before him, he learned from local sponge divers the location of a wreck off Cape Gelidonya on the southern coast of Turkey from which a series of broken objects had been recovered. During the following year, Throckmorton's team made a number of dives on the site and recovered a series of bronze tools and ingots revealing the ship to be a late Bronze Age wreck from around 1200 BC but no major effort was mounted.

Throckmorton and veteran diver Frederick Dumas, however, returned in 1960 along with a young archaeologist eager to make his first open-ocean dives, George Bass. With Bass in charge of the archaeological aspects of the diving program, they began to establish for the first time true archaeological mapping and sampling protocol. Although primitive by today's standard, they established a traditional grid system using anchored lines followed by the use of an airlift system to carefully remove the overburden covering the wreck. Working in 28 m of water, the ship proved to be 11 m in length, covered with a coralline concretion some 20 cm thick. Its more than one ton of cargo consisted of four-handled ingots of copper and 'bun' ingots of bronze as well as a large quantity of broken and unfinished tools, including both commercial and personal goods. These assemblages of artifacts suggested the captain was a Syrian scrap-metal dealer who was also a tinker making his way from Cyprus along the coast of Turkey to the Aegean Sea.

Maritime archaeology truly came of age with the excavation of the Yassi Adav wreck from 1961 to 1964 off the south coast of Turkey. Running offshore near the small barren island of Yassi Adav is a reef which is as shallow as 2 m that has claimed countless ships over the years. Its surface is strewn with Ottoman cannon balls from various wrecks of that period. Several of the ships that have run aground on its unforgiving coral outcrops slide off its rampart coming to rest on a sandy bottom. One such ship, lying in 31 m of water was the focus of an intense effort carried out by the University Museum of Pennsylvania under the direction of George Bass.

Prior to this effort, no ancient ship had ever been recovered in its entirety; this became the objective of

this project. With the help of fifteen specialists and thousands of hours underwater, the team carefully mapped the site. The techniques developed during this excavation effort became the new emerging standards for this young field of research and continue to be followed today by research teams around the world.

Bass' team first cleared the upper surface of cargo of its encrustation of weed. Its 900 amphora were then mapped, cataloged, and removed. One hundred were taken to the surface for subsequent conservation and preservation whereas the remaining 800 were stored on the bottom at an off-site location. Simple triangulation was first used to initially delineate the wreck site followed by the establishment of a complex series of wire grids. Each object was given a plastic tag and artists hovered over the grid system making numerous sketches of the site before any object was recovered.

Copper and gold coins recovered from the site revealed the ship to be of Byzantine age sinking during the reign of Emperor Heraclius from AD. 610 to 641. Following the recovery of the ship's contents, the now-exposed hull provided marine archaeologists with their first opportunity to develop techniques needed to document and recover the ship's timbers.

This effort was extremely time consuming but the resulting insight proved worth the effort, providing the archaeological community with a transitional method of ship construction between the classical 'shell' technique to the later evolved 'skeleton' technique. Its length to width ratio of 3.6 to 1 further supported earlier suggestions that ships of this period would have to be built with more streamlined hulls to outrun and outmaneuver hostile or piratical adversaries.

The Growth of Maritime Archaeology

Following the excavation of the Yassi Adav wreck, members of Bass' team then conducted the extensive excavation of a fourth century BC wreck near Kyrenia in Cyprus directed by Michael Katzev. This effort mirrored the Yassi Adav project and resulted in the raising and conservation of the ship's preserved hull structure.

Since these early pioneering efforts, numerous maritime archaeology programs have emerged around the world. Off Western Europe and in the Mediterranean maritime archaeology remains a strong focus of activities. Bass and his Institute for Nautical Archaeology (Texas A&M University in College Station, Texas) continue to carry out a growing number of underwater research projects

off the southern coast of Turkey centered at their research facility in Bodrum.

His excavation of the late Bronze Age Ulu Burun wreck off the southern Turkish coast led to the recovery of thousands of artifacts that provided valuable insight in a period of time marked by the reign of Egypt's Tutankhamun and the fall of Troy. His Byzantine 'Glass Wreck' found north of the island of Rhodes and dating from the twelfth to thirteenth century AD, continues to generate important information about this particular period of maritime trade.

In addition to the well-known work with the *Wasa*, Swedish archaeologists have conducted excellent work in the worm-free waters of the Baltic. In Holland, Dutch archaeologists have drained large sections of shallow water areas which contain a rich history of maritime trade dating from the twelfth to nineteenth centuries.

Another major program directed by Margaret Rule took place in England with the recovery and preservation of the *Mary Rose*, a large warship lost in July 1545 during the reign of King Henry VIII. From this project, a great deal was learned about the long-term preservation of wooden timbers which is being incorporated in other similar conservation programs.

Research efforts in America span the length of its human habitation. Recent archaeological research suggests that humans arrived in North America more than 12 000 years ago when a southern route was first thought to have opened in the glacial icesheet covering the continent. Some scientists now suggest that early humans may have circumvented this barrier by way of water or overland surfaces now submerged on the continental shelf. New research programs are now being designed to work on the continental shelf looking for early evidence of Paleoindian settlements.

For years Indian canoes, rafts, dugouts, and reed boats have been discovered in freshwater lakes, and sinkholes in the limestone terrains of North and Central America have attracted researchers for many years in search of human sacrifices and other religious artifacts associated with native American cultures.

Ships associated with early explorers, including Columbus, French explorer Rene La Salle, the British, and countless Spanish explorers, have been the focus of research efforts in the Gulf of Mexico, the Northwest Passage, and the Caribbean while shipwrecks from the Revolutionary War and War of 1812 have been discovered in the Great Lakes and Lake Champlain. Warships associated with the American Civil War have received renewed interest

including the *Monitor* lost off Cape Hatteras, the submarine *Huntley* and numerous other recent finds in the coastal waters of the US east coast.

Within the last two decades, deep water search systems developed by the oceanographic community have been used to successfully locate the remains of the RMS *Titanic*, the German Battleship *Bismarck*, fourteen warships lost during the Battle of Guadalcanal, and the US aircraft carrier *Yorktown* lost during the Battle of Midway.

Ships associated with World War II have been carefully documented including the *Arizona* in Pearl Harbor and numerous ships sunk during nuclear bomb testing in the atolls of the Pacific. Maritime archaeology is not limited to European or American investigators. A large number of underwater sites too numerous to mention have been investigated off the coasts of Africa, the Philippines, the Persian Gulf, South America, China, Japan, and elsewhere around the world as this young field begins to experience an explosive growth.

Marine Methodologies

As was previously noted, early underwater archaeological sites were not discovered by professional archaeologists; they were found, instead, by commercial or recreational divers. It wasn't until the mid-1960s that archaeologists, notably George Bass, began to devise their own search strategies. Being divers, their early attempts tended to favor visual techniques from towing divers behind their boats, to towed camera systems, and finally small manned submersibles (Figure 1).

It was not until the introduction of side-scan sonars that major new wreck sites were found. Operating at a frequency of 100 kHz, such sonar systems are able to search a swath-width of ocean floor 400 m wide, moving through the water at a typical speed of 3–5 knots (5.5–9 km h⁻¹). Today, numerous companies build side-scan sonars each offering a variety of options ranging from higher frequencies (i.e. 500 kHz) to improved signal processing, recording, and display.

Various magnetic sensors have been used effectively over the years in locating sunken shipwreck sites having a ferrous signature. This is particularly true for warships with large cannons aboard. Magnetic sensors have also proved effective in locating buried objects in extremely shallow water, on beaches, and beneath coastal dunes.

Over the years, a variety of changes have taken place with regard to the actual documentation of a wreck site. Beginning in the early 1960s, various stereophotogrammetry techniques were used. More



Figure 1 Archaeological mapping techniques pioneered by Dr George Bass of Texas A&M University for shallow water archaeology. These techniques were heavily dependent on the use of divers and were limited to less than 50m water depths.

recently the SHARPS (sonic high accuracy ranging and positioning system) acoustic positioning system has proved extremely rapid and cost effective in accurately mapping submerged sites. This tracking technique coupled with electronic imaging sensors, has produced spectacular photomosaics.

More recently, remotely operated vehicles have begun to enter this field of research. In 1990, the JASON vehicle from the Woods Hole Oceanographic Institution was used to map the *Hamilton* and *Scourge*, two ships lost during the War of 1812 in Lake Ontario. Using a SHARPS tracking system, the vehicle was placed in closed-loop control and made a series of closely spaced survey lines across and along the starboard and port sides of the ships. Mounted on the remotely operated vehicle (ROV) was a pencil-beam sonar and electronic still camera which resulted in volumetric models of the ships as well as electronic mosaics.

Deep-Water Archaeology

The shallow waters of the world's oceans where the vast majority of maritime archaeology has been done represent less than 5% of its total surface area.

For years, archaeologists have argued that the remaining 95% is unimportant since the ancient mariner stayed close to land and it was there that their ships sank.

This premise was challenged in 1988 when an ancient deep-water trade route was first discovered between the Roman seaport of Ostia and ancient Carthage. The discovery site was situated more than 100 nautical miles (185 km) off Carthage in approximately 1000 m of water. Over a nine-year period from 1988 to 1997, a series of expeditions resulted in the discovery of the largest concentration of ancient ships ever found in the deep sea. In all, eight ships were located in an area of 210 km², including five of the Roman era spanning a period of time from 100 BC to AD 400. The project involved the use of highly sophisticated deep submergence technologies including towed acoustic and visual search vehicles, a nuclear research submarine, and an advanced remotely operated vehicle. Precision navigation and control, similar to that first used in Lake Ontario in 1990, permitted rapid yet careful visual and acoustic mapping of each site with a degree of precision never attained before utilizing advanced robotics, the archaeological team recovered selected

objects from each site for subsequent analysis ashore without intrusive excavation.

Deep-water wreck sites offer numerous advantages over shallow water sites. Ships lost in shallow water commonly strike an underwater obstacle such as rocks or reefs severely damaging themselves in the process. Each winter more storms continue to damage the site as encrustation begins to form. Commonly, the site is located by nonarchaeologists who frequently retrieve artifacts before reporting the wreck's location.

Ships that sink in deep water, however, tend to be swamped. As a result, they sink intact, falling at a slow speed toward the bottom where they come to rest standing upright in the soft bottom ooze. When they are located, they have not been looted. Sedimentation rates in the deep sea are extremely slow, commonly averaging 1 cm per 1000 years. That coupled with cold bottom temperatures, total darkness, and high pressures result in conditions favoring preservation. Although wood-boring organisms remove exposed wooden surfaces, deep sea muds encase the lower portions of the wreck in an oxygen free environment. When

deep-sea excavation techniques are developed in the near future, these wrecks may provide highly preserved organic material normally lost in shallow-water sites.

The Roman shipwrecks located off Carthage were found within a much larger area of isolated artifacts spanning a longer period of time. The isolated artifacts appear to have been discarded from passing ships overhead. Given the slow sedimentation rates in the deep sea, it might be possible to easily delineate ancient trade routes by looking for these debris trails, thus learning a great deal about ancient maritime trading practices.

Since this new field of deep-water archaeology has grown out of the oceanographic community, it brings with it a strong expertise in deep submergence technology. The newly developed ROVs possess the latest in advanced imaging, robotics, and control technologies. Using this technology, archaeologists are able to map underwater sites far faster than their shallow water counterparts (Figure 2).

Most recently, a second deep-water archaeological expedition resulted in the discovery of two Phoenician ships lost some 2700 years ago. Located in

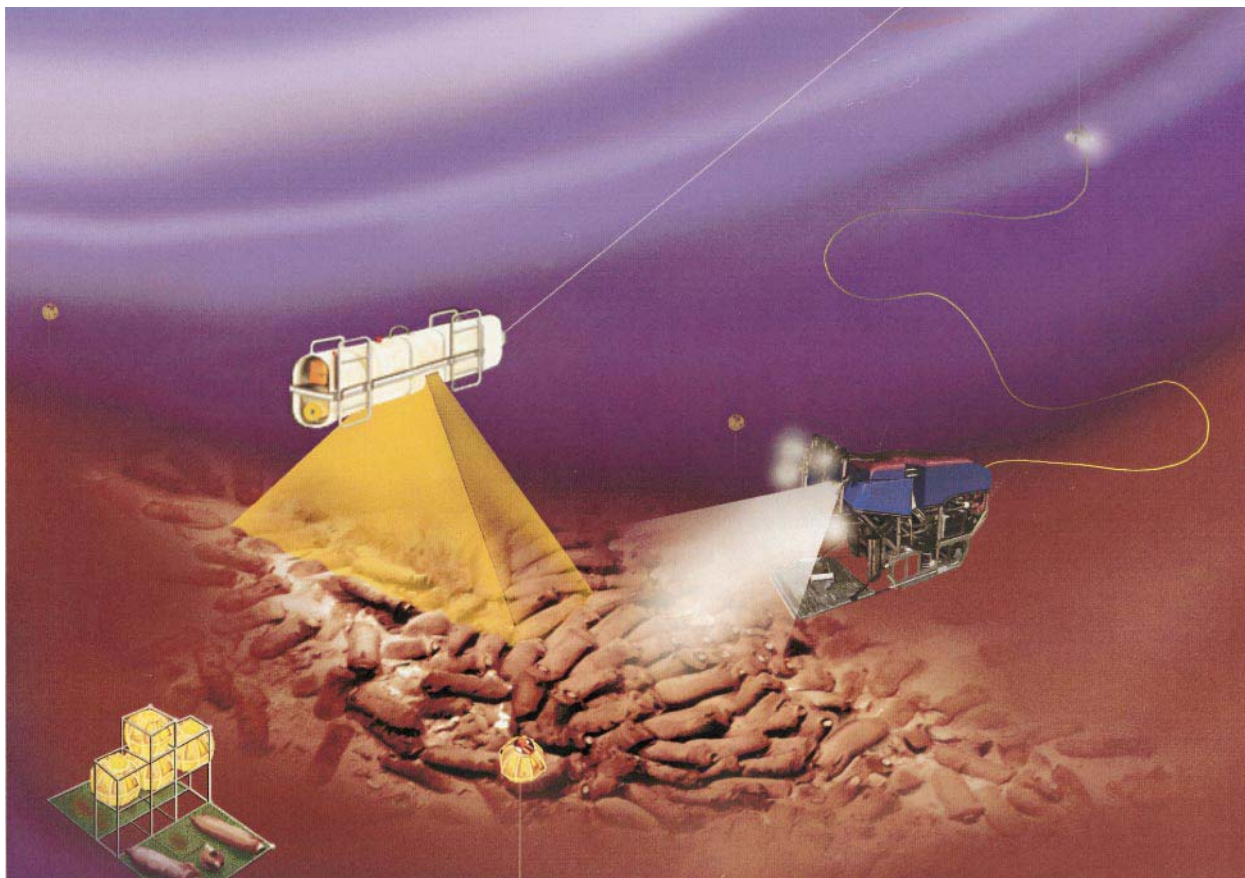


Figure 2 Archaeological techniques pioneered at the Woods Hole Oceanographic Institution and the Institute for Exploration rely exclusively on remotely operated vehicle systems with operating depths down to 6000 m.

450 m of water about 30 nautical miles (55 km) off the coast of Egypt, these two ships are lying upright. Due to local bottom currents, both ships are completely exposed resting in two-meter deep elongated depressions.

Ethics

As pointed out earlier, the salvaging of cargo from lost ships goes back much farther in time than marine archaeological research. As a result, this long history of maritime salvage, rooted in international law, has led to a quasipublic acceptance of salvage operations, making it difficult for the archaeological community to garner moral and legal public support to protect and preserve truly important underwater archaeological sites. 'Finders keepers' remains rooted in the public's mind as a logical policy governing lost ships. Further blurring the boundary between these two extremes in the early years, was the fact that marine archaeologists relied upon the very community that was removing artifacts from underwater sites to tell them where they were located.

This uneasy marriage between the diving community and the archaeological community has, in many ways, stifled the growth and acceptance of the field. Its lack of development of systematization which arises from its immaturity and lack of a large database has further hindered its acceptance into mainstream archaeology.

Today's marine salvagers commonly employ individuals with archaeological experience to participate in their operations. In some cases, this results in important documentation of the site as was the case with the salvage of the *Central America*. In other cases, however, they are being used to create a false impression that archaeological standards are being followed when they are not.

American salvagers have, in large part, concentrated their attention on lost ships of the Spanish Main beginning with search efforts off the coast of Florida where a large number of silver- and gold-bearing ships were lost in hurricanes between 1715 and 1733. A famous shipwreck in this area, the *Atocha*, was exploited by salvager Mel Fisher.

On the Silver Bank off the Dominican Republic in the Caribbean the richly laden *Nuestra Señora de la Pura y Limpia Concepcion* sank in October 1641. Salvage efforts seeking to retrieve its valuable cargo began almost immediately including one by the

British in 1687. Lost from memory, the *Concepcion* was relocated in 1978 by American treasure hunters who continue their recovery efforts to this day.

Fortunately, more and more countries are beginning to enact laws to protect offshore cultural sites, but with the emergence of deep-water archaeology which is conducted on the high seas, the majority of the world's oceans and the human history contained within them are not protected.

One logical step is to add human history to the present Law of the Sea Convention that governs the exploitation of natural resources. Although this would not protect all future underwater sites, it would serve as an important first step.

See also

Remotely Operated Vehicles (ROVs). Sonar Systems.

Further Reading

- Babits LE and Tilburg HV (1998) *Maritime Archaeology*. New York: Plenum Press.
- Ballard RD (1993) The MEDEA/JASON remotely operated vehicle system. *Deep-Sea Research* 40(8) 1673-1687.
- Ballard RD, McCann AM, Yoerger D, Whitcomb L, Mindell D, Oleson J, Singh H, Foley B, Adams J, Piechota D and Giangrande C (2000) The discovery of ancient history in the deep sea using advanced deep submergence technology. *Deep Sea Research Part I* 47: 1591-1620.
- Bass GF (1972) *A History of Seafaring Based on Underwater Archaeology*. New York: Walker.
- Bass GF (1975) *Archaeology Beneath the Sea*. New York: Walker.
- Bass GF (1988) *Ships and Shipwrecks of the Americas*. New York: Thames and Hudson.
- Cockrell WA (1981) Some moral, ethical, and legal considerations in archaeology. In: Cockrell WA (ed.) *Realms of Gold*. Proceedings of the Tenth Conference on Underwater Archaeology, Fathom Eight San Marino, California. pp. 215-220.
- Dean M and Ferrari B (1992) *Archaeology Underwater: The NAS Guide to Principles and Practice*. London: Nautical Archaeology Society.
- Greene J (1990) *Maritime Archaeology*. London: Academic Press.
- Muckelroy K (1978) *Maritime Archaeology*. New York: Cambridge University Press.
- NESCO (1972) *Underwater Archaeology - A Nascent Discipline*. Paris: UNESCO.