Precision Survey and Archaeological Methodology in Deep Water

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ABSTRACT

New technologies allow archaeologists to explore the human past in the depths of the ocean, far beyond the 50 meter depth boundary set by SCUBA diving. Using robots and advanced sensors originally developed for other applications, social scientists now are following the path of marine scientists, adapting deep submergence technologies for their own research. Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) allow archaeologists to survey the sea floor to depths of 6000 m. This brings 98% of the world's ocean floor within reach, and increases dramatically the number of underwater sites available for archaeological study. Several projects in the past five years in the Mediterranean and Black Seas have proven the scientific merit of archaeology in deep water and trained an international cadre of archaeologists in the new technology. Experience shows it is imperative that work in deep water be collaborative. Projects are particularly fruitful when they bring together as a team technologists familiar with the systems, archaeologists trained in the methods of deep water work, and archaeologists specializing in the period, cultures, and geographical regions pertinent to the shipwrecks. A key lesson is that while technology plays a significant part in this work, it must be combined with the research designs, methodology, and insights of archaeologists to form deep water archaeology into a rigorous scientific practice. Toward this goal, underwater vehicles, precision navigation, and remote sensors designed specifically for archaeology will allow archaeologists to make fundamental discoveries about ancient cultures.

Several recent expeditions explored and documented cultural resources in deep water using advanced robotics, remote sensing, and imaging technology. These projects, in which the authors participated, offer compelling reasons to continue examining deep sites.

A series of wrecks off Skerki Bank in the central Mediterranean Sea documented a previously unknown open sea trade route between Carthage and Rome. Countering the argument that ancient mariners hugged the coast, the project's scientists discovered and surveyed five wrecks spanning a period from the second century B.C. to the fourth century A.D. at depths averaging 800 meters [Ballard, *et al*, 2000; McCann 2001;

McCann 1994]. The authors consistently find that deep sites like those at Skerki Bank are easier to interpret than shallow sites. Depth preserves artifacts and their spatial integrity, since waves and storm action have little effect below 100 meters. Also, the sedimentation rate in deep offshore water usually is very low, approximately 2 cm per 1000 years so wrecks are relatively free from sediment.

Excavation often is not necessary to see much of the site. For example, the oldest wrecks yet found in deep water are two eighth century B.C. Phoenician cargo vessels that sank on an open water route between Israel and Egypt. The ships righted themselves as they fell through the water column after foundering and came to rest upright on the seabed. As their hulls decayed, inorganic cargo and fittings settled onto the sea floor, easily viewed by archaeologists via the robotic vehicles' camera systems. The cargoes carried by these blue-water traders may be different from those of coastal craft, providing new information about ancient trade and exchange [Ballard, *et al*, 2002; Ballard, *et al*, 2000].

Additionally, deep water oceanographic phenomena can have significant implications for archaeology that may not be apparent in shallow water. As a prime example, surveys in the Black Sea are exploring the effects of prehistoric flooding on human settlement patterns and also the consequences of an anoxic environment for the complete preservation of ancient shipwrecks [Bascom, 1976]. Intriguing features at 100 m depth hold tantalizing clues about human settlement before the flood. Further offshore, a wreck from the fifth century A.D. located in the Black Sea's deep anoxic water demonstrated that remarkable preservation does occur there [Ballard, 2001; Mindell, *et al*, 1998; Ryan and Pitman, 1998; Heibert, *et al*, 1997].

Perhaps most important from a cultural resource management perspective, deep sites are naturally protected by the environment so they are easier to manage and maintain than those in shallow water or on land. The precise coordinates of sites are submitted to the local authorities for documentation and management but are not published in the open literature. SCUBA divers cannot go beyond 50 m, so sites outside that limit cannot be pillaged by sport divers or treasure hunters. Any access to deep water sites requires oceanographic vessels and expensive equipment that are easy to monitor and detect, both on-site and in port. In addition to the natural protection offered by deep water, the technologies employed to investigate deep water sites are non-intrusive. Information is derived from deep sites by remote sensing, so sampling and excavation are kept to a minimum and often are not required at all. A great deal of information can be recovered from a deep water archaeological site without ever touching an artifact. The combination of natural protection and non-invasive remote sensing investigation means that archaeological exploration can be conducted in deep water without placing a significant burden on the resources of government cultural resource managers.

The physical characteristics of the deep environment preclude humans from working directly in the abyss, so access requires use of technical systems. Underwater robotic systems, either autonomous or remotely operated, are becoming more commonly used for a variety of purposes including archaeology in deep water. Remotely operated vehicles (ROVs) are connected to the surface by a tether. ROVs can carry a number of sensors; usually they are equipped with video cameras linked to the control laboratory on the mother ship. These video systems are the pilot's windows on the world as the vehicle swims over the sea floor. The video feed can also be monitored by any number of

scientists and observers on the support ship, or through satellite communication at sites thousands of kilometers away. Video-equipped ROVs are useful for preliminary site inspection and identification, but simply flying an ROV over a shipwreck site does not constitute archaeology.

Archaeology in deep water must conform to the same professional standards as followed on land and in shallow water. This entails generating accurate site plans before touching a single artifact, with measurement precision at least equal to that registered on traditional sites. If a few selected objects are recovered for dating and provenance studies, their positions must be recorded as accurately as possible.

Some precision acoustic navigation systems deliver this capability for work underwater. The system used successfully on Skerki Bank and Ashkelon is called EXACT. It is in essence a new generation wireless SHARPS, similar to the system used on the Early Helladic site off Dokos, Greece. The EXACT navigation system works by acoustic trilateration. First, accurate measurements of the local speed of sound through the water are collected by the research team. Then two or three battery powered acoustic transponders are placed around the archaeological feature, and one transponder is fitted to the underwater vehicle working on the site. Several times per second the transponders send high frequency signals to one another, and the time lag between send and receive is recorded. With this system, the vehicle's position can be determined within a cubic centimeter. When fed back into the vehicle's control system, these data allow the ROV to be put into "closed loop control". This computer control makes it possible for the vehicle to hover over the site and to run precise, repeatable survey lines. [Kyriakopoulou, 1992; Vossyniotis, 1992; Whitcomb, *et al*, 1998].

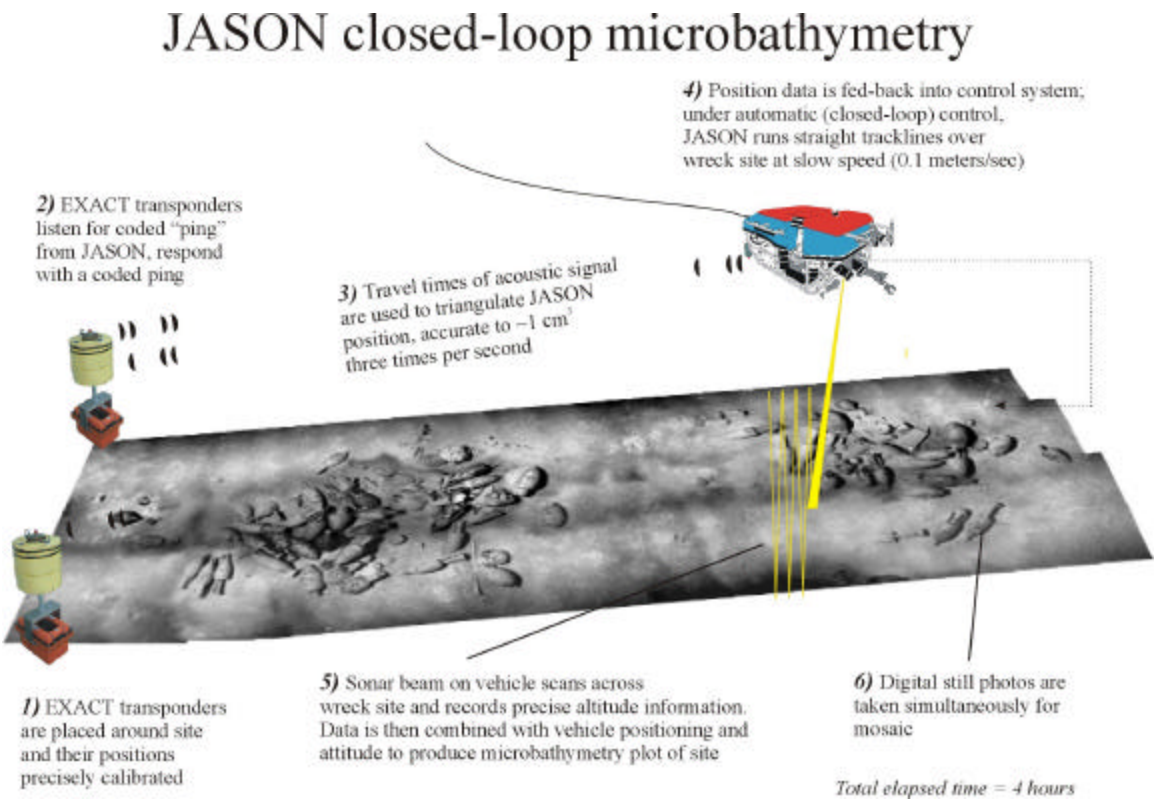

Figure 1 – Precision ROV survey using EXACT acoustic navigation system.
© David Mindell, MIT DeepArch.

An underwater vehicle navigated by a precision system like EXACT can be used to record shipwrecks accurately and precisely. Two broad categories of sensors have been applied to deep water wreck survey: optical and acoustic. Optical systems such as video cameras and electronic still cameras (ESC) offer the benefits of high resolution and real-time site evaluation. If used with an ROV, the data is passed up the cable to the scientists aboard the ship, allowing them to view images immediately. Video data are the easiest to interpret, since everyone is used to viewing motion pictures on television monitors. However, light energy attenuates rapidly in water. The dimensions of any individual image captured by these optical sensors is very small. To see the entire wreck in a single image, a photomosaic must be produced.

Photomosaics built in a computer from ESC images convey a tremendous amount of qualitative information. Since deep water wrecks typically have little or no sediment cover, archaeologists can examine a photomosaic and interpret artifacts in situ. After analyzing a mosaic, archeologists often can tell the age of the wreck, its general dimensions, and the material carried aboard the vessel. Amphora typology and chronology are complete enough for some cultures and periods that archaeologists can surmise the contents of storage jars, possibly the route and ports of call of the ship, perhaps even the vessel's home port. Objects associated with the crew indicate ethnicity, religion, and life aboard ship. All of this information can be gathered from the wreck site mosaic without touching or recovering a single object.

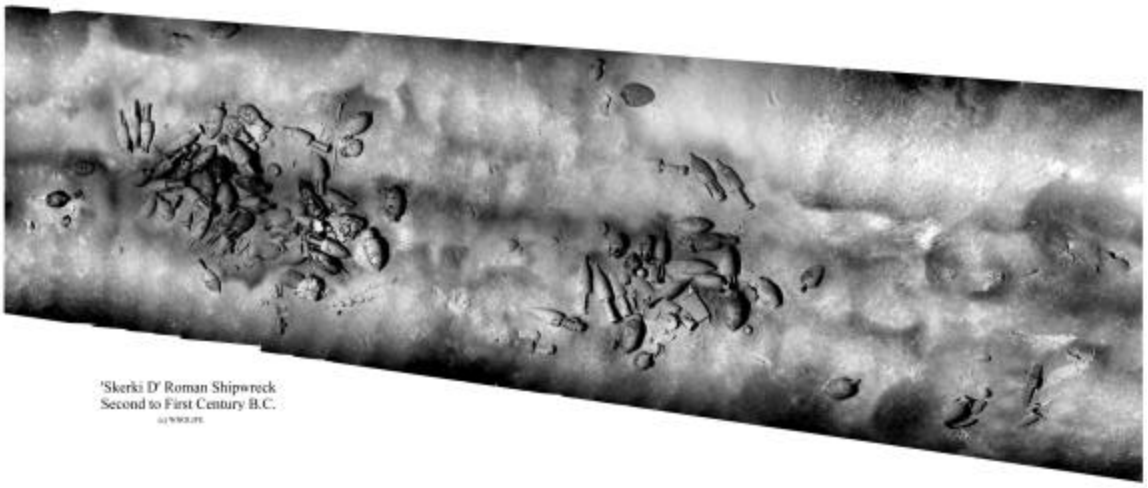

Figure 2 – Completed photomosaic, Skerki D shipwreck. Mosaic composed of 182 individual images, providing overall view of wreck site. Dark stripes are a result of the mosaicking process and uneven lighting in original images.
Image courtesy of Hanumant Singh. ©WHOI, IFE.

Precision navigation is crucial for generating high-quality mosaics. Producing a good photomosaic depends on collecting sufficient overlapping images to cover the site completely; a minimum of 40% overlap is recommended. A proven method is to move the camera slowly along in a straight line, maintaining a constant distance between the

camera lens and the feature. The camera's focal plane should be parallel to the plane of the feature to minimize optical distortion. Depending on the dimensions of the site, a series of adjacent strips of overlapping images may be necessary to cover the entire area. Precisely navigated underwater vehicles are ideal platforms for collecting these images. They can be controlled to maintain a constant heading, altitude, and velocity, greatly simplifying the archaeologist's job when computer mosaicking the captured pictures. This type of survey is time efficient and can be repeated often as work progresses; it takes just a few hours to survey an entire wreck site [Webster, *et al*, 2001; Singh, *et al*, 2001; Ballard, *et al*, 2000].

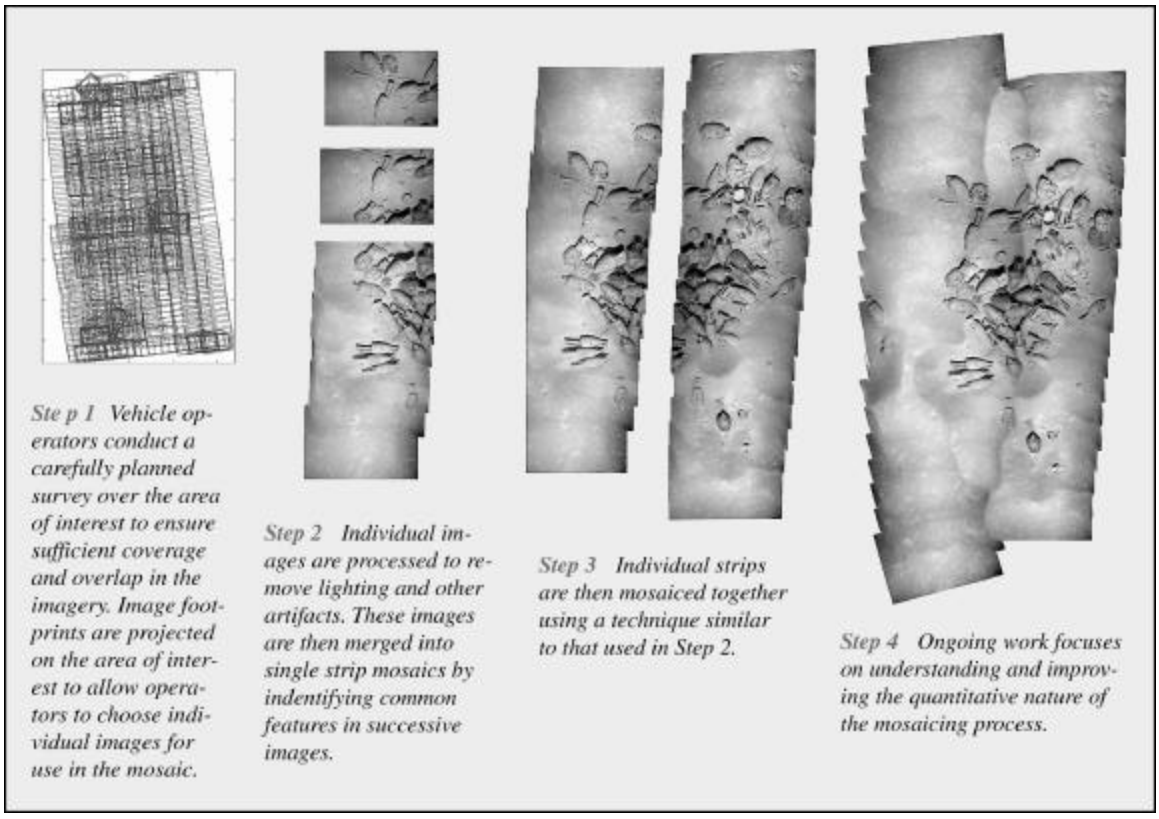

Figure 3 – Mosaic-building process.
Courtesy Hanumant Singh. ©WHOI, IFE.

Photomosaics present an excellent qualitative view of the site, but errors propagate each time the individual images are warped and fit together. Another

shortcoming is that the site's vertical relief is lost in a two-dimensional display. To fully document an archaeological site, photomosaics must be complemented with data from additional sensors. Acoustic sensors such as high-frequency scanning sonar can generate an accurate three-dimensional site plan.

Using a scanning sonar, microbathymetric data is collected from a precisely navigated underwater vehicle to create a high resolution terrain map of the site. The sonar scans the seafloor and archaeological features as the vehicle runs along its computer-controlled survey tracklines. The narrow sonar beam sweeps back and forth, recording distances from the vehicle to the site below it. In addition to navigational information, the pitch, yaw, and roll attitudes of the vehicle are tracked and recorded. This allows engineers to re-navigate the data in order to quantify and correct distortions and errors in the sonar plot. After post-processing, the data are displayed as a three dimensional map accurate to within a couple of centimeters. Efforts are now underway to fuse together photomosaics and microbathymetric plots; the goal is to combine the high qualitative resolution of the photos with the measurement accuracy of the sonar data.

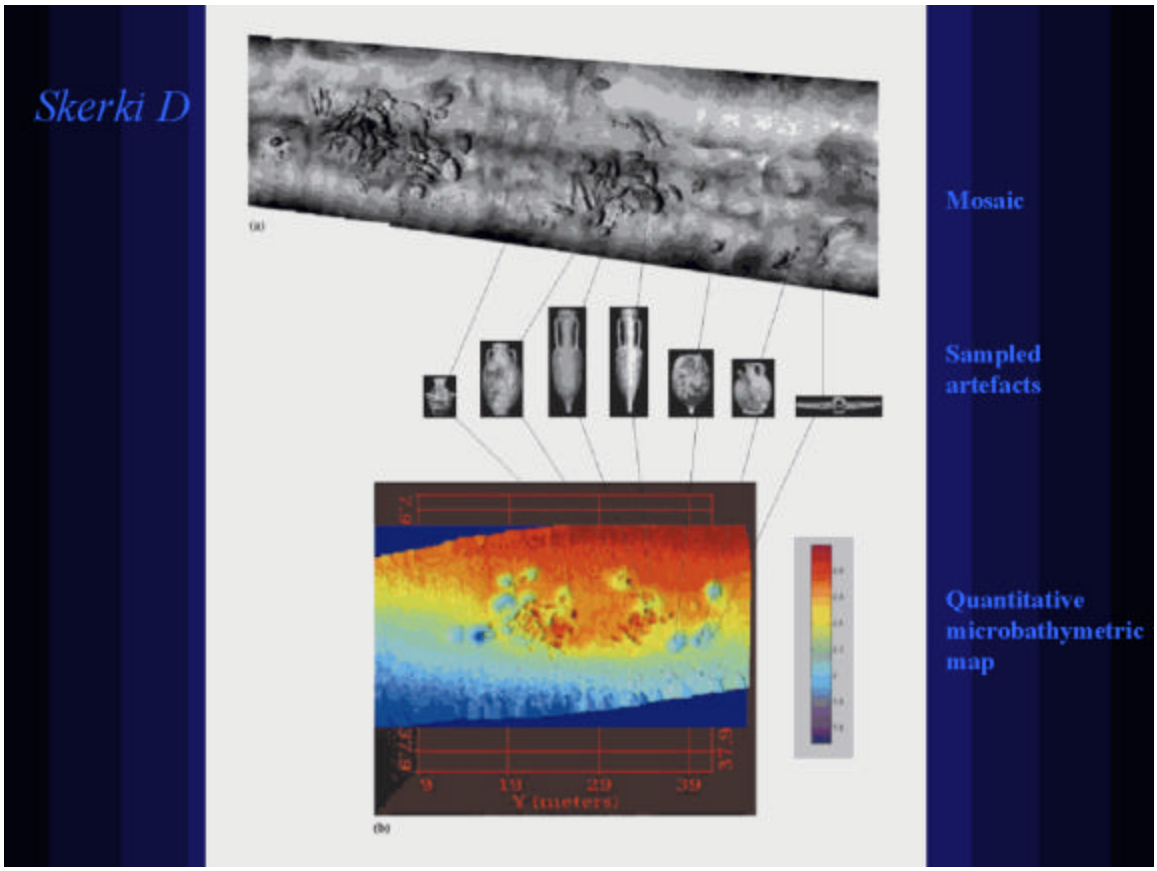

Figure 4 – (a) Site photomosaic, individual artifacts, and corresponding positions on (b) microbathymetric plot. Total vertical relief on this site is approximately 1.5 meters. Microbathymetric plot shows that many of the objects sit in shallow depressions, invisible in the photomosaic.

Acoustic and optical imagery of the site's surface provide a bounty to the archaeologist, but some research questions can only be answered by retrieving information below the visible surface of the wreck. Robotic excavation is one possible method of obtaining this information, but the engineering challenges of that task have not yet been surmounted. Another possibility exists: subbottom remote sensing. The DeepArch research group at MIT is developing a new remote sensing tool to peer beneath the sediments without touching the wreck.

Subbottom profiling sonar systems are used by ocean scientists to map geological layers below the seabed. Those subbottom profilers are designed for tens or hundreds of

meters penetration and therefore transmit low frequency sound energy, typically a wide-beam (20-30 degrees) in the 2 to 20 kHz range. Archaeologists' needs for a subbottom profiling sonar call for a focused high frequency beam capable of resolving objects a few centimeters square buried within 1-2 meters of the surface. To fill this need, we are experimenting with a 150 kHz sonar with a beam focused to 2-3 degrees [Mindell and Bingham, 2001].

Initial characterization experiments with the prototype 150 kHz subbottom profiling sonar demonstrated the instrument's promise. The first deployment was on one of the deep water Phoenician wrecks off Ashkelon, Israel. Data collected from five survey lines across the site indicated buried objects below the amphora pile. In the future we plan to perform precise closely-spaced surveys of submerged sites, the goal of which will be to produce a three-dimensional map of the buried structure. The data could then be viewed as a series of horizontal slices through the site, providing a "virtual excavation" without ever touching a single object. This is a technique familiar to archaeologists: ground penetrating radar data are routinely displayed by time slicing in this manner. Virtual excavation will not answer all the archaeologists' question about a site, but it will allow us to get a sense for the entire site. If archaeologists decide a deep site is so important that it must be investigated through excavation, the subbottom data can be used as a planning tool to pinpoint areas of greatest interest.

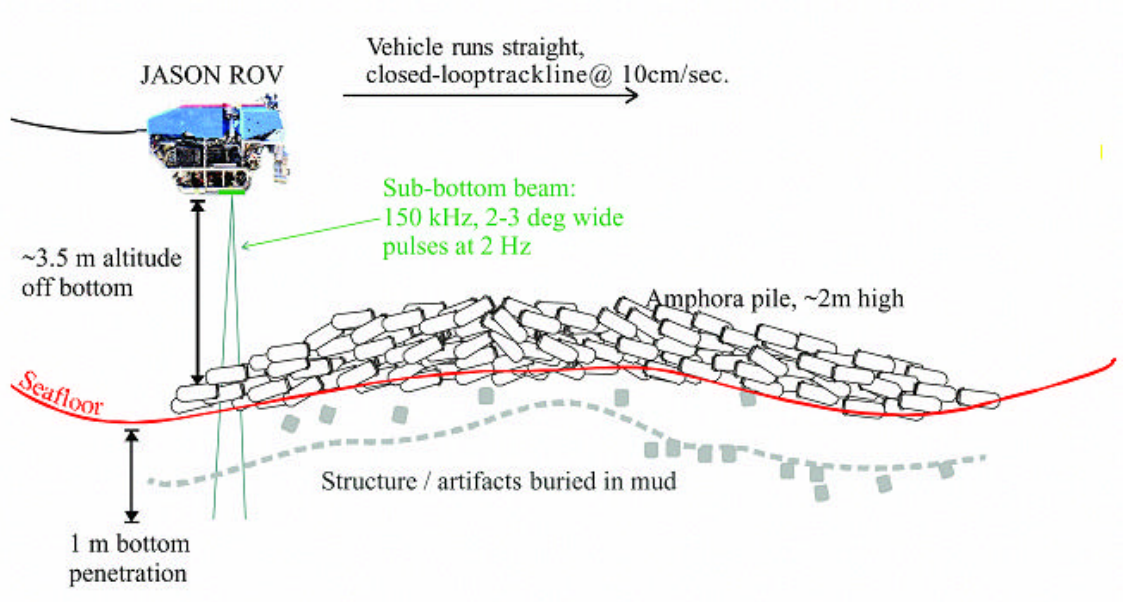

Figure 5 – Illustration of subbottom survey, Ashkelon wreck.

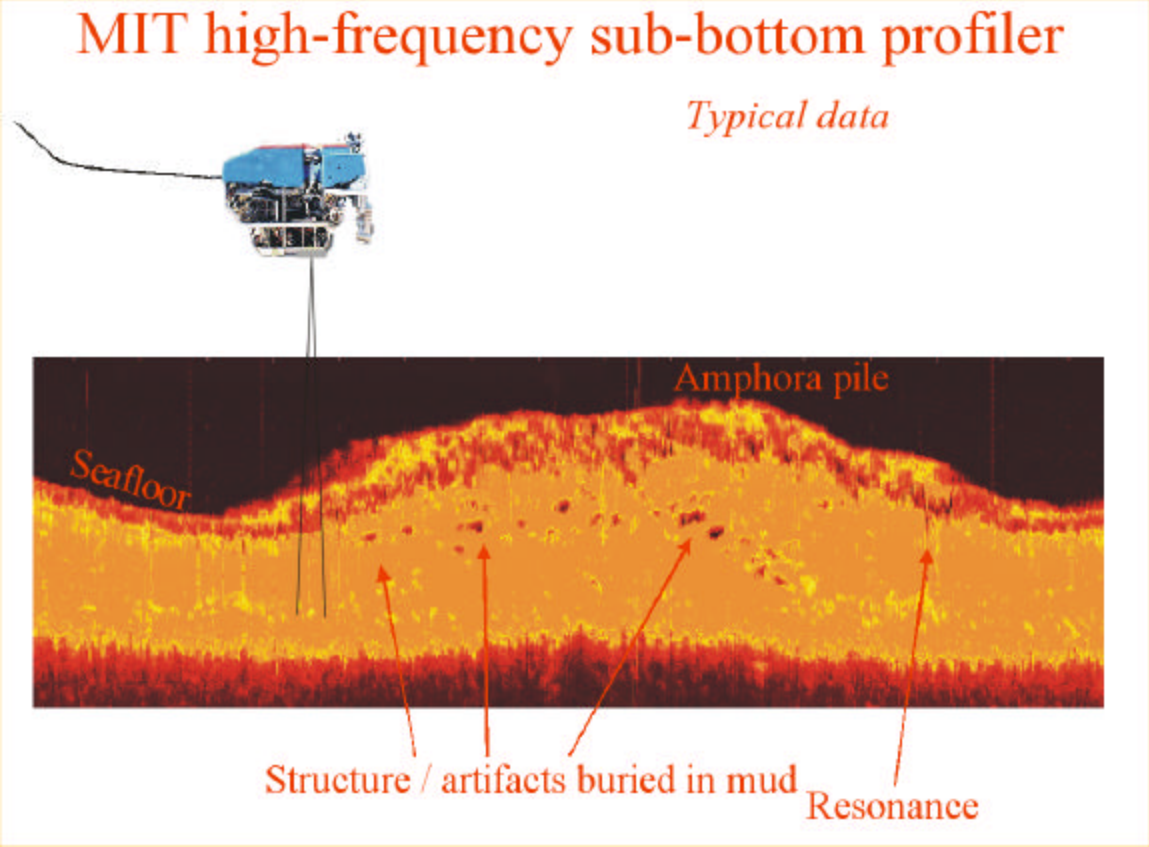

Figure 6 – High-frequency subbottom profiling sonar data from Ashkelon wreck.

The deep waters of the world's oceans and seas hold archaeological resources that we are just beginning to appreciate. Precision navigation makes possible accurate surveys of deeply submerged sites that conform to established professional archaeological standards. Remotely sensed information collected in deep water include photomosaics, microbathymetric plots, and subbottom imaging. Data displayed in these ways are powerful interpretive tools, and they are now available to deep water archaeologists. Underwater technologies including robotic vehicles allow us to discover deep water sites, but investigation becomes archaeology when precision navigation and control of the vehicles is combined with a well-constructed research design, expert interpretation of the data, and relevance to larger historical questions.

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