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DEEP-SEA RESEARCH
PART I

The discovery of ancient history in the deep sea using advanced deep submergence technology

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Abstract

The Skerki Bank Project was the first interdisciplinary effort to determine the importance of the deep sea to the field of archaeology. Over a nine year period from 1988 to 1997, its various field programs 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 km^2, including five of the Roman era spanning a period of time from 100 B.C. to 400 A.D., documenting the existence of a major trading route in the central Mediterranean Sea between ancient Carthage, Rome, Sicily, and Sardinia. 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 permitted rapid yet careful mapping, both visual and acoustic, of each site with a degree of precision never attained before. Advanced robotics permitted the recovery of selected objects for subsequent analysis without intrusive excavation. This multi-disciplinary effort of archaeologists, oceanographers, and ocean engineers demonstrated that deep water archaeology has great promise and can be done without the exploitation of ancient sites for private gains. The Project also demonstrated

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that in the absence of evolving laws of the sea, a great deal of human history may be at peril.

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1. Background

The Skerki Bank Project represents the first comprehensive attempt to search the deep waters of the world's oceans in an effort to assess their importance for a better understanding of human history. Prior to this effort, investigators interested in this area of research were limited by SCUBA diving technology and forced to work in water depths of less than 100 m, thus reaching less than 5% of the ocean floor (Bass, 1975).

Prior to the Skerki Bank Project, the condition of ancient wooden ships lost in the deep sea was poorly understood. Marine biologists had clearly shown that the deep sea is well oxygenated and wooden objects falling to its floor are quickly found and consumed by wood-boring organisms (Turner, 1973). It was also known that due to its significant distance from the mouths of rivers, the deep sea has a slow sedimentation rate — commonly less than 2 cm per 1000 yr. As a result, ancient wooden ships that founder far from shore and sink to the ocean floor should be exposed to the attack of wood-boring organisms, but the non-organic components of the ship should remain exposed on the surface of the bottom for long periods of time, making their detection relatively easy using recently developed visual and acoustic search systems. One of the purposes of the Skerki Bank Project, therefore, was to conduct the first comprehensive study of ancient wooden ships lost in the deep sea to determine their condition after a long period of submergence.

It was reasoned that an excellent starting point for such a study was the ancient trade routes of the central Mediterranean Sea, where mariners were forced by geography to cross open stretches of the deep sea. One of these is the Straits of Sicily and Skerki Bank just to the north, where numerous trade routes converge that connect North Africa with Sicily, Sardinia, and the Italian mainland. Prior to the actual field program, a study conducted by Harvard University suggested that between 200 B.C. and 400 A.D. thousands of ships had been lost on the high seas along these deep sea trade routes (Pelligrini, 1984).

1.1. The 1988 Expedition

The first field program associated with this research effort was conducted in the summer of 1988 in the Tyrrhenian Sea (Fig. 1) using the Woods Hole Oceanographic Institution's ARGO towed vehicle system (Ballard, 1982, 1993). This vehicle consists of a heavy-duty frame on which is mounted a variety of instruments, including three low-light level, black and white video cameras with running lights, a 35 mm color film

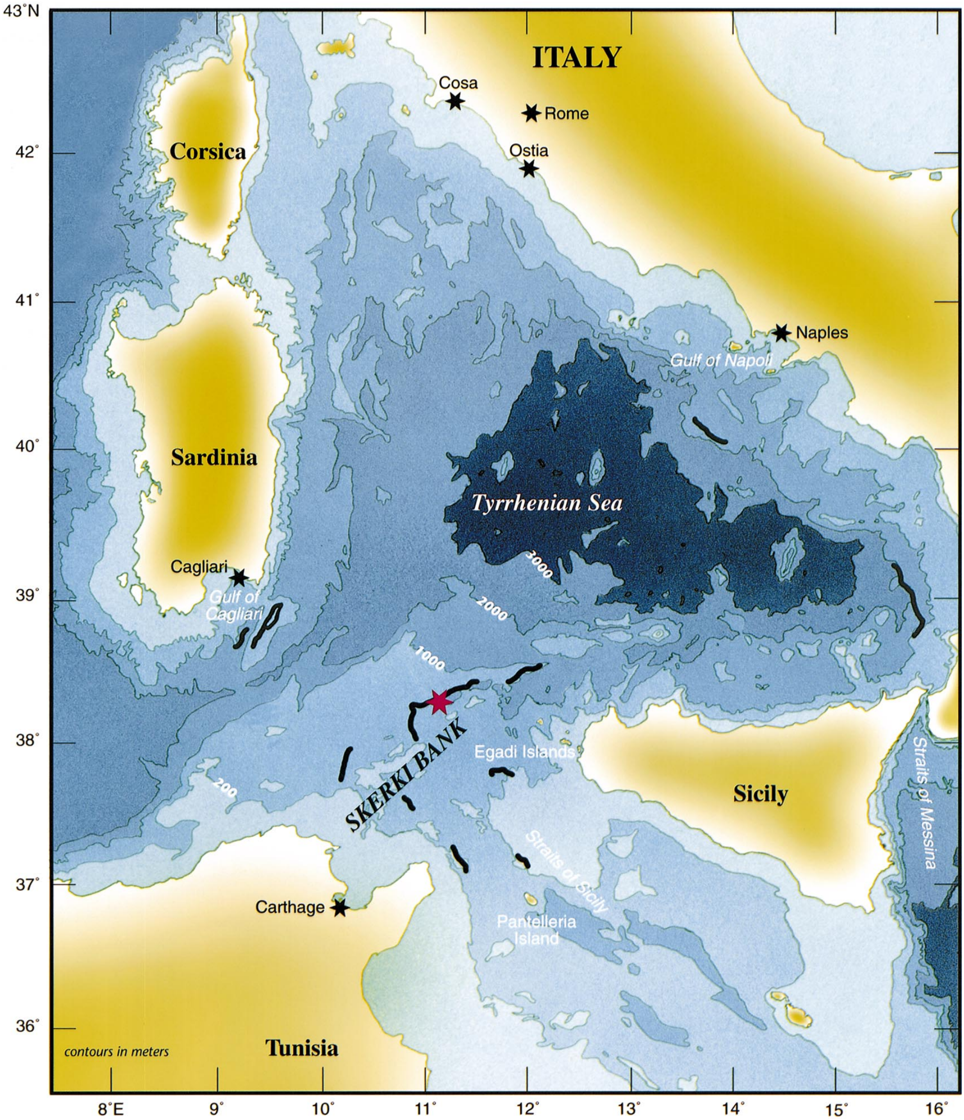

Fig. 1. The Tyrrhenian Sea is situated in the central Mediterranean, bounded by the islands of Sicily, Sardinia, and Corsica, the Italian Peninsula, and the northern coast of Africa. ARGO lowerings conducted in 1988 by the R/V *Starella* are shown as black lines. Depth is in meters. The red star is the location of the Skerki Bank Study Area shown in Fig. 2.

camera and strobes, an echo-sounder, and a 100 kHz side-scan sonar system. The vehicle is flown within visual contact of the bottom at an average altitude of 15 m.

The cruise took place in May, 1988 aboard the R/V *Starella*, a modified stern trawler used for oceanographic research. The search strategy for this effort was to use the ARGO vehicle system to visually investigate the major ancient trade routes connecting the site of ancient Carthage in Tunisia with Sardinia, Sicily, and the more direct route to Ostia, the seaport of ancient Rome (Fig. 1). The northern coast of Sicily, across the Straits of Messina and up the Italian peninsula to Naples were also searched. All of the search lines were conducted in international waters beyond the territorial seas of coastal nations. First, two search lines were conducted south of the Sardinian seaport of Cagliari along the trades routes leading to ancient Carthage and the western tip of Sicily. No ancient artifacts were found on the bottom. Also, several ARGO lowerings were made along the trade route connecting ancient Carthage with western Sicily. All were unsuccessful due to either poor visibility from a recent storm, rugged underwater terrain, or intense fishing activity. Furthermore, long ARGO lowerings were conducted north of the Straits of Messina and off the entrance to the Gulf of Naples but these too were unsuccessful, the latter being the result of intense fishing activities and the threat of entangling ARGO in long gillnets.

The only area where ancient artifacts were seen was on the northern slope of Skerki Bank. Here they were limited to an area of 65 km^2 (Red star in Fig. 1) bound to the east and west by ocean floor that had experienced intense bottom trawling activity characterized by numerous linear grooves caused by otter doors being dragged over the surface of the bottom. Within this area numerous amphoras were either photographed by ARGO's video cameras or detected by its 100 kHz sidescan sonar. A high concentration of amphoras was found within this area, later labeled "Amphora Alley I", located to the left of the central study area and marked in white (Fig. 2). The pattern is long and narrow, suggesting that the amphoras had been thrown overboard by crews attempting to save their ships in a storm.

Initially, a series of east-west search lines was run at a 1-km spacing (Fig. 2) resulting in the location of an ancient ship (later named ISIS) in 818 m of water, (Ballard et al., 1990; McCann and Freed, 1994). The wreck site consists of a series of depressions extending for a distance of 8–9 m on a strike of 010°. Each depression contained one or more artifacts with the southernmost and largest depression containing 30 to 40 artifacts, including large amphoras, commonware pottery, an iron anchor and several grinding stones.

It is difficult to say why this open ocean trade route proved to be the most productive. A variety of factors must be considered. The existence of turbid bottom water within the Straits of Sicily was temporary, a function of a recent storm. Subsequent searches there could prove fruitful. In many of the areas searched, intense bottom fishing activities made search efforts impossible. In some cases, the presence of nets prohibited towing ARGO through the area, while in other places, the bottom had been so intensely scoured that surface artifacts had more than likely been removed years before.

The area discovered north of Skerki Bank that contains the ISIS shipwreck, and "Amphora Alley I", has several factors contributing to the excellent preservation of artifacts. First, the site is far from shore and local sources of river detritus, resulting in low sedimentation rates. The area is relatively flat, limiting the effect of any major mass-wasting processes that could disturb an ancient site. Furthermore, commercial

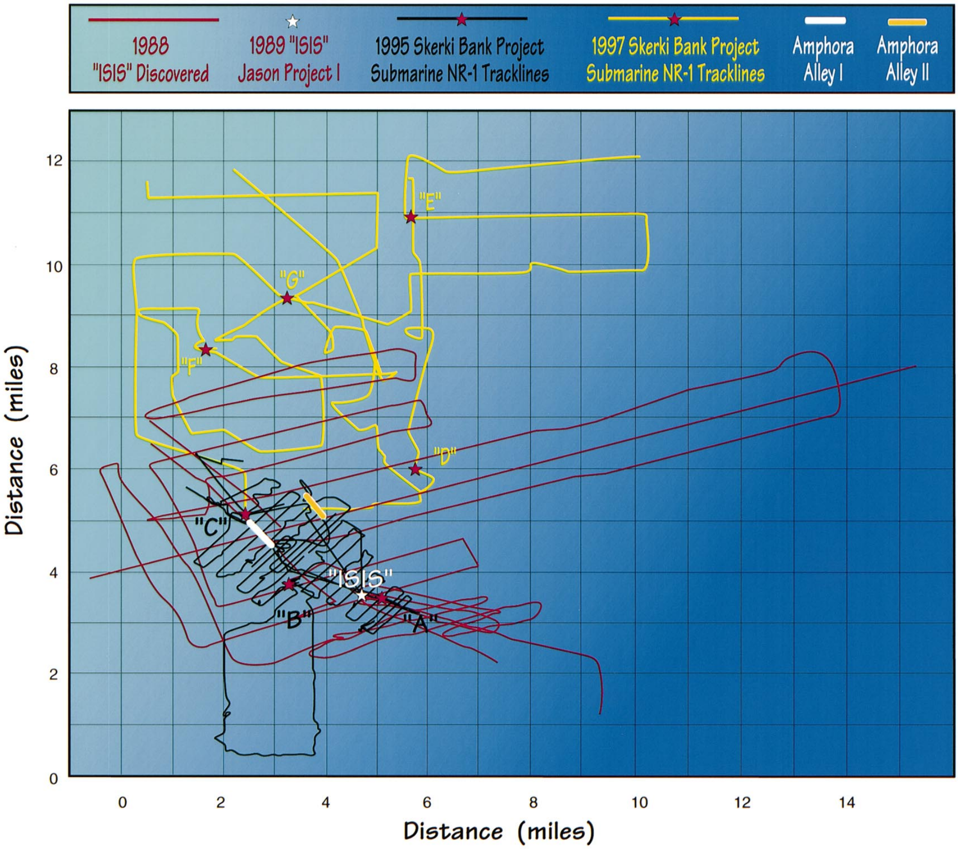

Fig. 2. The latitude and longitude of the Skerki Bank Study Area are not shown in an effort to protect the precise locations of the wreck sites. Instead, the *x* and *y* coordinates are expressed in nautical miles. The red lines represent ARGO lowerings conducted in 1988 combined with Jason tracklines, 1989, and the white star shows the location of the *ISIS* wreck site. The black lines represent the tracklines followed by the *NR*-1 in 1995 along with red stars that depict the locations of wrecks sites A, B, and C. The yellow lines represent the tracklines of the *NR*-1 in 1997 along with the red stars that depict the locations of wreck sites D, E, F, and G. The white and beige lines depict the location of two "Amphora Alleys".

bottom trawlers did not fish in this area. But perhaps the most important factor is that the site appears to be an area of non-deposition and non-erosion, a "relic" surface that has changed little over the last many thousands of years. Another inescapable possibility is that ancient mariners traveled this fast, open, direct, ocean route more frequently than previously suspected, leading to a higher concentration of sunken ships. It is also important to point out that the site is at the intersection of both ancient and modern north-south and east-west trade routes, resulting in the higher probability of finding shipwreck remains and where the counter-currents of the Mediterranean meet.

1.2. 1989 Expedition

In April and May of 1989, a second expedition aboard the R/V *Star Hercules* was conducted at the Skerki Bank research site. The purpose of this expedition was to use the newly developed *JASON* remotely operated vehicle system to map and sample the *ISIS* site and surrounding debris field of ancient amphoras, as well as conduct a series of live broadcasts for the first *JASON* Project (Ballard et al., 1990). A.M. McCann directed the archaeological work for this expedition (McCann and Freed, 1994); M.E. Florian directed the field conservation; and D. Piechota was in charge of the land-based conservation.

The first dive made by the *JASON* system resulted in the documentation of 33 artifacts, mostly single amphoras in the debris area surrounding the *ISIS* wreck site. Each artifact rested in its own depression. The size of the depression or pit was scaled to the size and shape of the amphora. These characteristics suggested that the depression was caused by bottom current activity over a long period of time. The sediments around the object slowly eroded, excavating the pit in which the object now rested. Recent objects thrown from ships, for example, lacked such pit formation.

During the 1989 expedition, a total of 15 dives were made by the *MEDEA/JASON* system during which 65 artifacts were recovered: 17 amphoras from the trade route site north of Skerki Bank ("Amphora Alley I") and 48 artifacts from the *ISIS* site. A comprehensive post-cruise analysis of the data base collected by *JASON* allowed McCann to date the *ISIS* in the last quarter of the 4th century A.D. and the use of the trade route site from the 4th century B.C. to the 12th century A.D. In this area, evidence for four additional Roman wrecks and two Mediaeval ones was also found (McCann and Freed, 1994).

1.3. 1995 NR-1 Expedition

It was six years before the next expedition was conducted by Ballard at the Skerki Bank site to follow-up on the results of the 1988 and 1989 efforts. The purpose of this new expedition was to use the powerful search capabilities of the U.S. Navy's nuclear research submarine *NR*-1 (Ballard, 1985) in an attempt to locate the other ancient shipwrecks thought to exist within the debris field immediately surrounding the *ISIS* wreck site and in the trade route site to the north (McCann and Freed, 1994).

The initial goal of the 1995 search program was to relocate the *ISIS* wreck site and then conduct a new search effort in the surrounding area, building upon previous survey efforts. While searching for the *ISIS* wreck, however, *NR*-1's forward looking sonar discovered a 19th century sailing ship ("*Skerki C*") (Fig. 3) resting in 700 m of water. The wreck site was surveyed in detail using the submarine's side-scan sonar and electronic still camera.

The submarine continued its search for the original *ISIS* wreck site and soon detected another sonar target in the approximate area of the *ISIS* site. This target, however, proved to be yet another shipwreck, which was given the name "*Skerki A*". "*Skerki A*" was characterized by a pile of small ballast stones and a small cluster of artifacts, although no amphoras were seen (Fig. 4). Continuing its search, *NR-1* finally

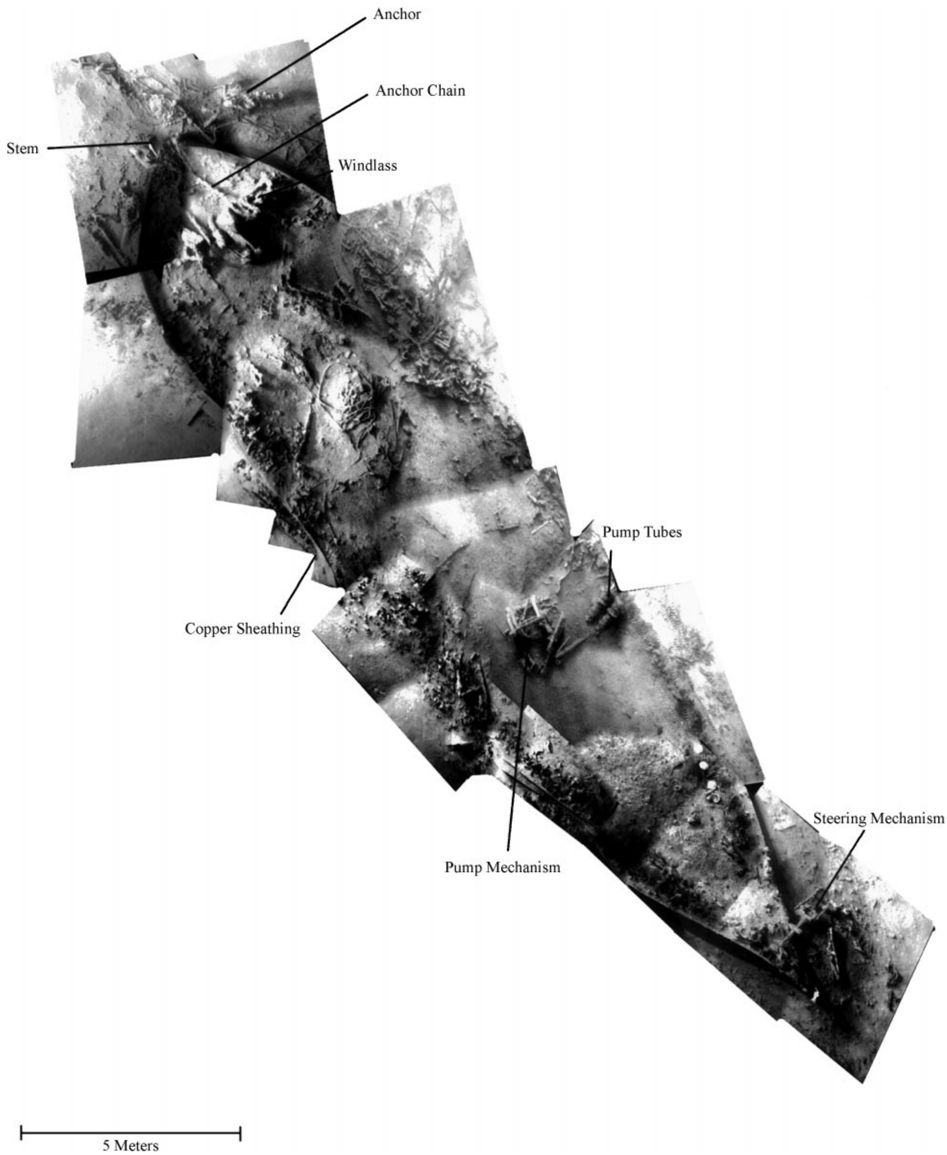

Fig. 3. Skerki C: Photomosaic of Late 19th Century sailing ship found and documented by the *NR*-1 in 1995 using an electronic still camera. Its length is approximately 35 m.

relocated the *ISIS* wreck site. The site was remarkably unchanged since the last visit to the site six years before (Ballard et al., 1990; McCann and Freed, 1994). There was no sign of current activity, erosion, or sedimentation. The imprints of amphoras recovered in 1989 remained visible in the sediment surface.

Fig. 4. Skerki A: Photomosaic of a medieval fishing vessel, A.D. 1000 to 1250.

After discovering *Skerki A* and *Skerki C*, and relocating *ISIS*, the *NR*-1 began a systematic survey of the debris field. Its search lines were spaced approximately 300 m apart (Fig. 2). A new wreck was soon located. Like the ISIS wreck, this new site — called "*Skerki B*" — was characterized by a small cluster of amphoras and numerous smaller artifacts resting inside a large depression approximately 5 m long 3 m wide and 1 to $1\frac{1}{2}$ m deep (Fig. 5). Five m away was a second depression containing two different amphoras in a linear depression three meters long, two meters wide, and 1 to $1\frac{1}{2}$ m deep. Between these two depressions and off axis to the north was an isolated artifact in a small circular depression of similar depth. During the survey, additional artifacts were found near this site that lay along the strike of the ship and appeared to be associated with the site. The first was a large lead anchor lying inside a depression some 20 m along strike to the northeast from the original clusters of artifacts. The other was a single amphora inside a small depression to the southwest, also along the same line. Artifacts and associated depressions stretched for a total distance of 22 m at *Skerki B*. When the 1995 *NR*-1 dive series was completed, a total of 97 km^2 had been searched and four wreck sites had been located.

1.4. 1997 Expedition with both NR-1 and JASON

The most recent phase of the Skerki Bank Project took place in the summer of 1997 (Ballard, 1998). The goal of this expedition was to carefully map and sample the wrecks already located on previous expeditions (i.e. *ISIS*, *Skerki A*, *B*, and *C*) as well as search for additional wreck sites in the adjoining area to date and document further the use of this previously unexplored trading route. McCann served as director of the archaeology/conservation team and D. Yoerger of the engineering team.

Using *NR*-1's effective sonar system the original search area was expanded from 97 to 210 square nautical miles (Fig. 2). The result was the discovery of four additional shipwreck sites ("*Skerki D, E, F*, and *G*"), three of which (*D*, *F*, and *G*) proved to be Roman.

Although eight wreck sites were located, only the five oldest sites (*ISIS*, A, B, D, F and G) were surveyed and sampled in detail. At those sites, the *MEDEA/JASON* vehicle system was deployed and moved into position over the wreck site (Fig. 6). Once *JASON* was in position, an elevator was dropped from the surface, carrying two high-frequency EXACT transponders. *JASON* was used to off load and place them approximately 30 m from the wreck site. With these two transponders, it was possible to track *JASON*'s position three times a second to an accuracy of 2 cm.

With such a precise and rapid up-date rate, it was possible to place the vehicle in "closed-loop" control and conduct a series of survey lines one to two meters apart (Whitcomb et al., 1998). The navigation suite during this survey effort consisted of 300 kHz transponders (the EXACT system), an attitude reference package, a precision depth sensor, and a 1200 kHz bottom track Doppler navigation sonar (Whitcomb et al., 1999). The transponders and Doppler navigator provided complimentary information about the vehicle's horizontal position. The transponders provided a stable reference with high accuracy, but were susceptible to short-term drop-outs. The Doppler navigator provided an excellent dynamic estimate of vehicle motion, but was

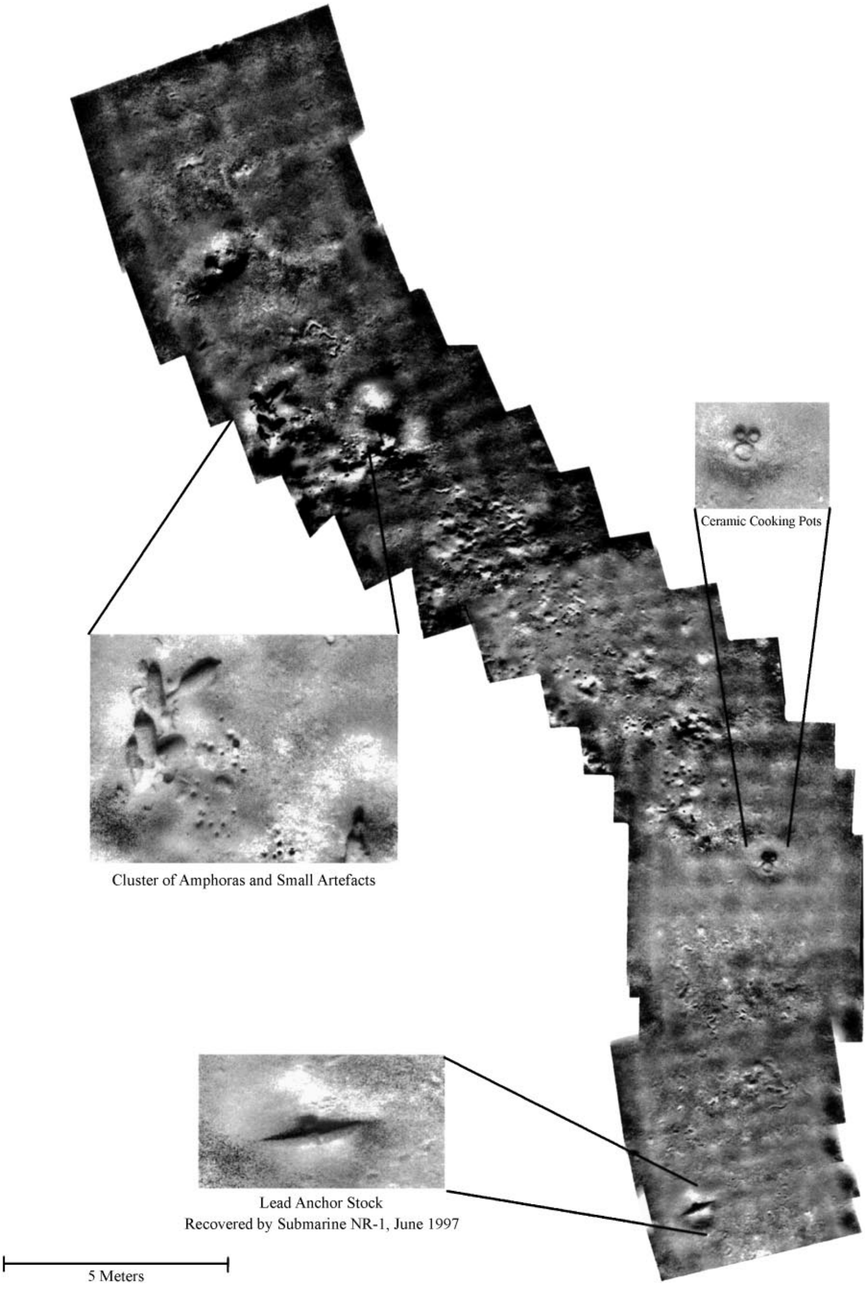

Fig. 5. Skerki B: Photomosaic of late first or early second century A.D. Roman trading ship.

Fig. 6. The *JASON* remotely operated vehicle hovering over the *ISIS* wreck site in 1989. The photograph was taken by its relay vehicle MEDEA, which is connected to *JASON* by a neutrally buoyant tether (seen in photo) and to the surface by a 0.68 in fiber-optic steel cable.

prone to drift due to a variety of errors. By combining the two sensors, a very reliable and accurate position estimate was possible.

Along each survey line, a series of electronic images was collected, while a digital sonar scanned back and forth across the wreck site measuring its micro-topography. Due to the limited scanning rate of the sonar, the speed along track was set at 10 cm/s. High-quality color video and still images were also collected during these survey runs.

Until the precision mapping phase was completed, the vehicle constantly hovered over the site and did not land. Care was taken not to disturb the site with the vehicle's prop wash by insuring the vehicle had a slight positive buoyancy resulting in the wash being directed upward instead of downward. The documentation runs were conducted at very low speeds over the bottom and at a sufficient altitude, 1.5–3 m, to avoid striking any objects. The photographic runs documented not only the exposed artifacts, but also any surface expression such as biological or chemical activity that might help determine the buried outline of the wreck.

Attempts were made to collect a series of sub-bottom profiles across each wreck site using the *NR*-1, but unfortunately, its sub-bottom profiler was not functioning properly. A 130 kHz sub-bottom profiler has been installed on *JASON* and used on its 1999 archaeological program.

Individual still camera images were processed to remove the effects of working in the underwater environment. These images were normalized with respect to reference images for the camera and then histogram equalized to stretch the contrast and thereby bring out the details in the imagery. Photomosaicing techniques were used to circumvent the physical constraints associated with lighting underwater, which make it virtually impossible to frame large objects on the seafloor within a single image. Thus, archaeologists were able to gain a global perspective of the site of interest by looking at a composite of the images collected at a site.

The photomosaicing process involved picking common points in overlapping imagery to compute the relative transformation between the overlapping images. This transformation was used to warp successive images into a composite mosaic while processing the seam between the overlapping imagery to give the mosaic a continuous look.

The mapping process continued until the entire area had been photographed with overlapping imagery and a dense concentration of sonar soundings. The result was the creation of a series of digital mosaic images of the important wreck sites (Figs. 4 and 5, Figs. 7–9) and a fine-scale bathymetric map of the wrecks' upper surface (Fig. 10). This process proved highly efficient and could be completed in less than 12 h for each site. Once completed, the team of archaeologists had a complete photographic record of the site and a database that showed the orientation and size of each exposed object.

The acoustically derived bathymetric map of the same region (Fig. 10) highlights the complementary nature of the imaging sensors. Although the optically derived photomosaics provide a vivid view of the shipwrecks, due to incremental errors in building up the photomosaic, one is unable to make precise measurements over the entire mosaic. The bathymetric maps, on the other hand, though not visually as meaningful for the archaeologist, provide a mechanism for making very precise quantitative measurements across the entire site of interest.

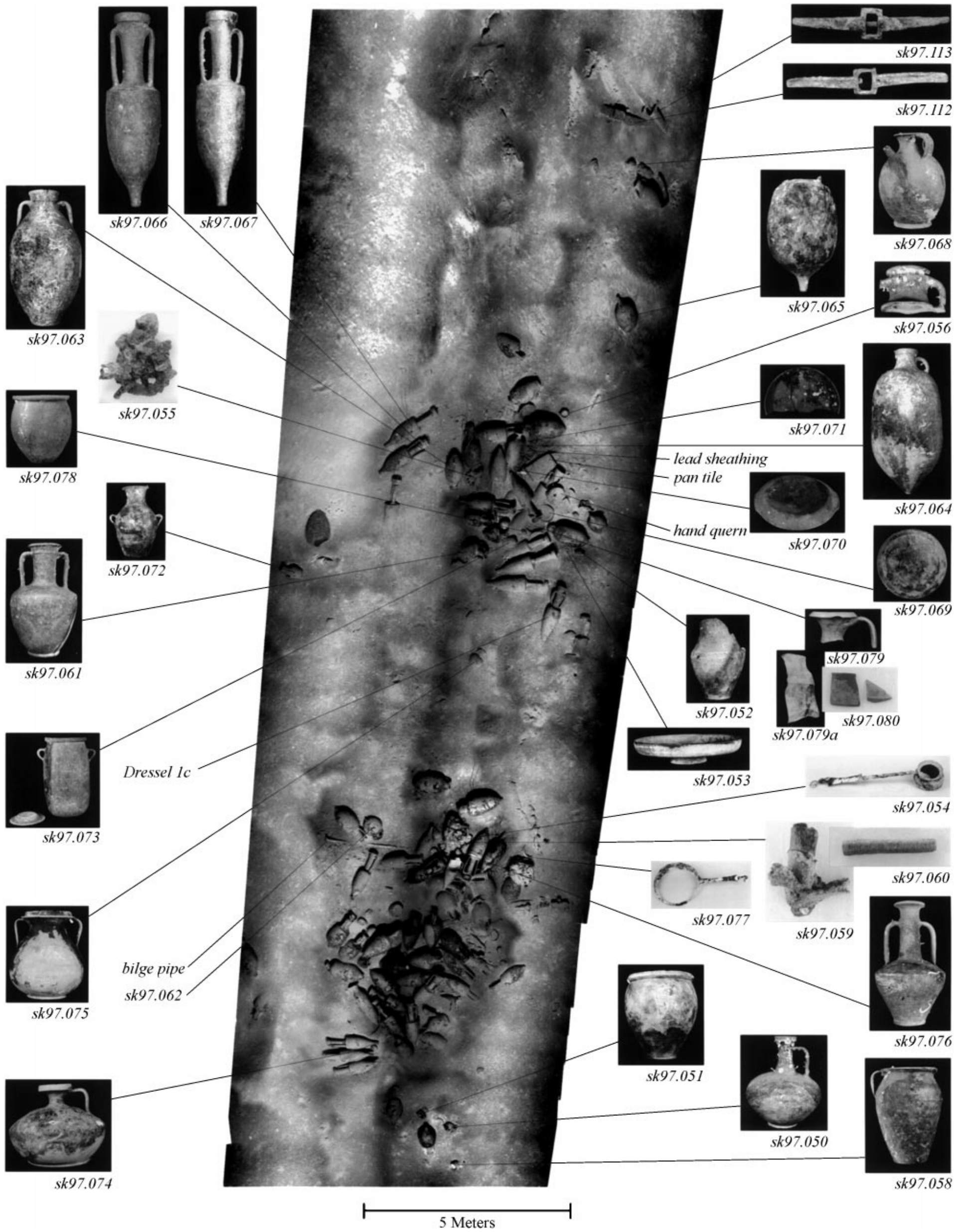

Fig. 7. Skerki D: Photomosaic of 80 - 60 B.C. Roman trading ship showing the location of individual artifacts recovered by *JASON* as well as objects identified but not recovered (i.e. bilge pipe).

After completing this precision survey, specific artifacts were selected by the archaeological/conservation team for recovery, based upon their ability to help determine the age, origin, and significance of each wreck. Commonly, the artifact selected was

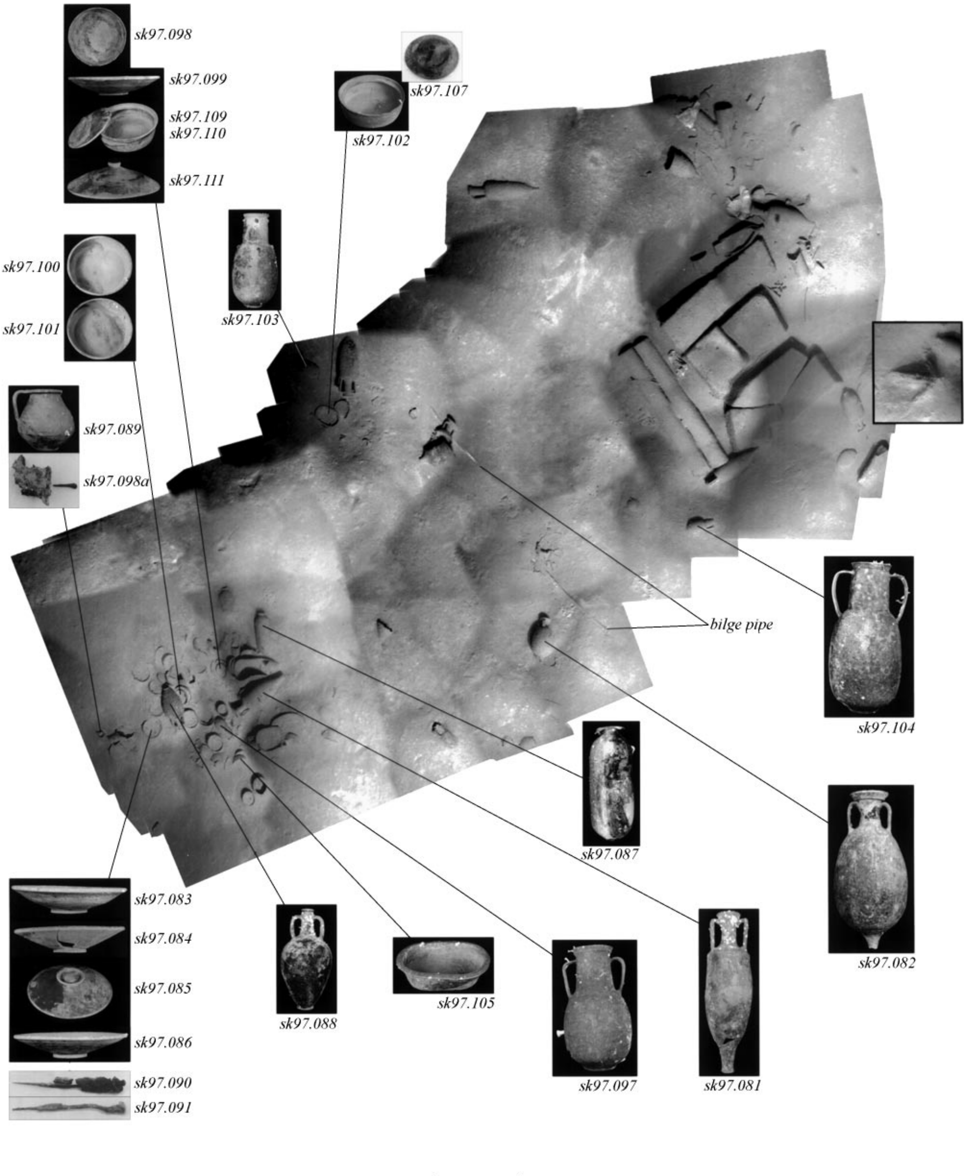

Fig. 8. Skerki F: Photomosaic of Late First Century A.D. Roman trading ship showing the location of individual artifacts recovered by *JASON* as well as objects identified but not recovered (i.e. bilge pipe).

nested within the site amongst other objects. To ensure that they were recovered without damage to themselves or the surrounding objects, *JASON* was moved in incremental steps while in closed-loop control in all three degrees of freedom, centimeters at a time.

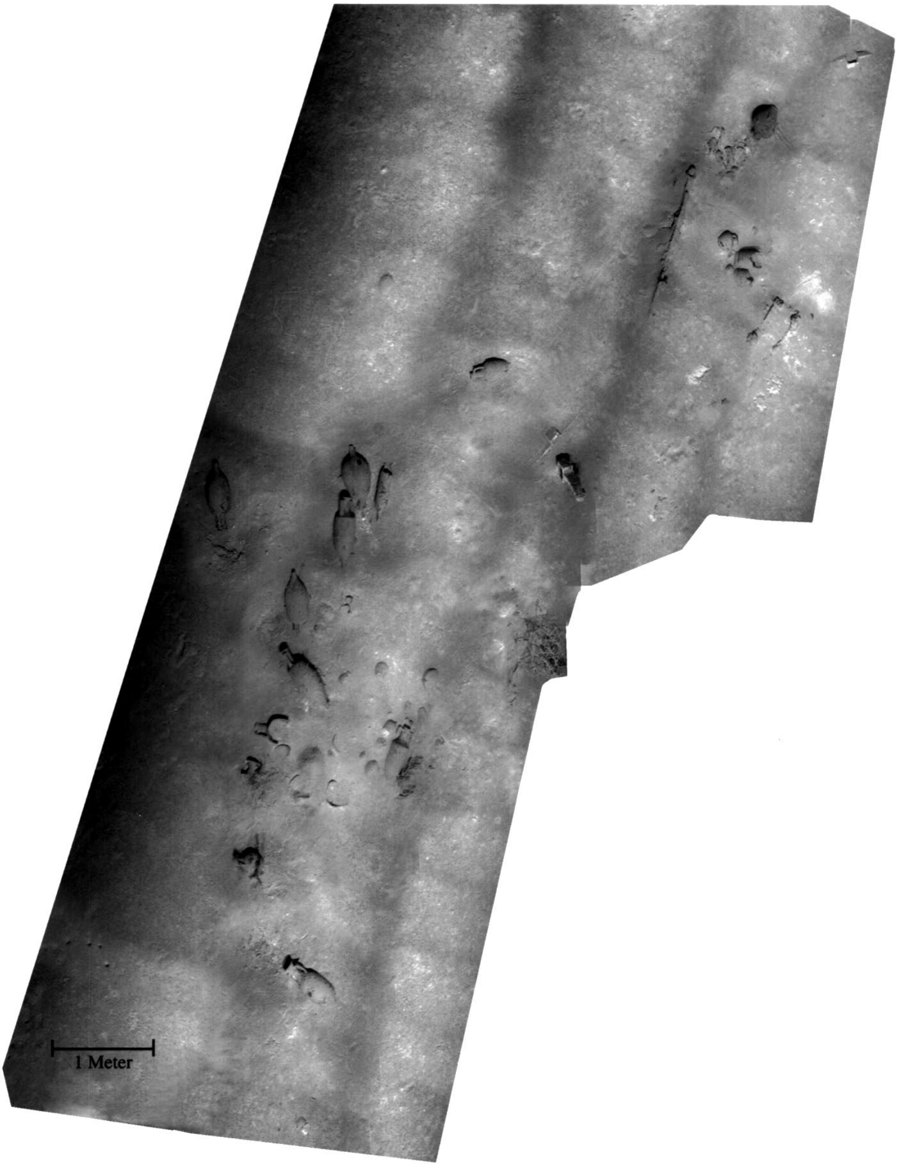

Fig. 9. Skerki G: Photomosaic of Late First Century A.D. Roman trading ship.

Once in position, while hovering (automatically) above the object, the vehicle's mechanical arm was used to gently grasp the object. To avoid damaging fragile materials, the strength of the manipulator's grip could be regulated, applying just enough force to cradle and lift the object. Once properly cradled between the

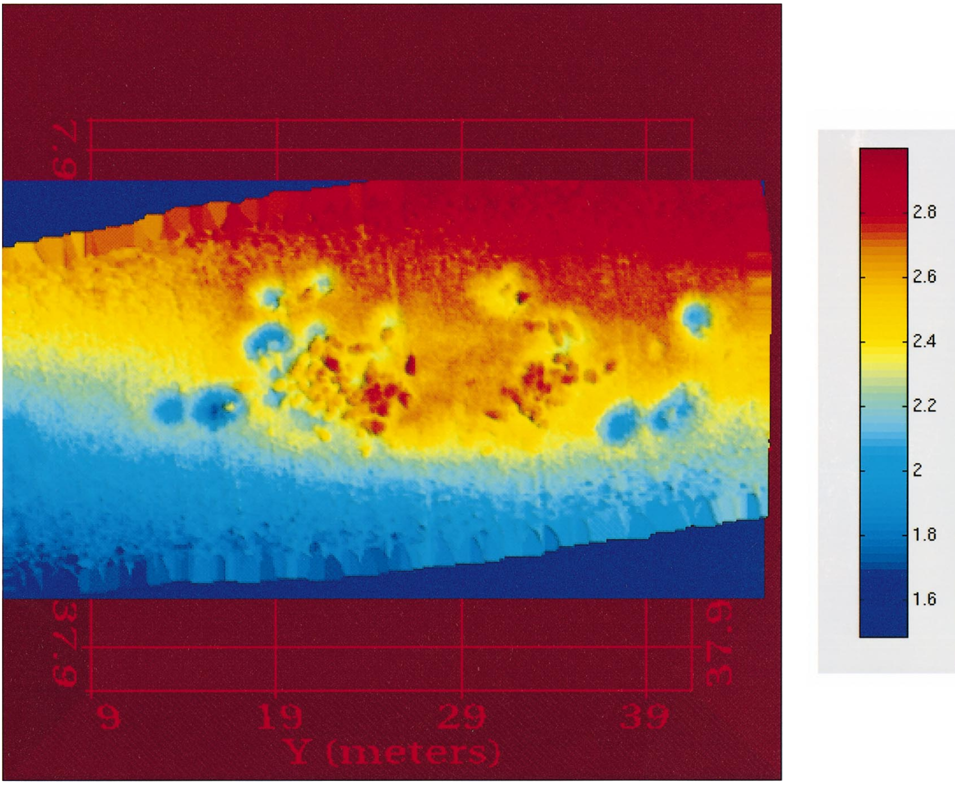

Fig. 10. Microtopography of Skerki D wreck site obtained using digital scanning sonar on *JASON*. Two clusters of objects correspond to amphora clusters shown in Fig. 7. Color scale in m.

net-meshed grippers, the vehicle thrusted upward and away from the site, moving over to the nearby elevator where the object was placed in a numbered compartment.

At the *ISIS* site, as at *Skerki A* and *B*, only a limited number of artifacts were exposed above the mud surface, so the nature of the buried archaeological assemblages was unknown. The initial project design, therefore, incorporated the option of limited excavation in order to assess their degree of coherence and level of preservation for each site. Since the bottom sediment in the area consisted of well indurated deep sea muds, it was predicted that wood would be encountered a short distance into the bottom. For that reason, it was important that any excavation procedure permit the constant monitoring by archaeologists with previous marine excavation experience.

The initial plan was to use the *NR*-1 to remove the major overburden at a site and then use *JASON* to carry out the delicate and final phase of exposing buried objects. For that reason, *NR*-1 was fitted with a 10 hp submersible pump mounted in the science module that could be lowered into place directly in front of the forward viewports. Attached to the pump was a flexible hose with a metal terminus, which could be positioned by *NR*-1's manipulator. A special excavation tool was fabricated that could be held in the manipulator and used to skim successive layers of sediment towards the pump intake.

For several days, a team of archaeologists and engineers excavated a series of test trenches at the margins of the *ISIS* site. It proved possible, though slow, to remove some sediment. However, the pump was not powerful enough to work adequately in the heavy mud of the sea floor. Also, excavation made visibility too poor for safe excavation. Therefore, digging with the pump was abandoned.

Excavation trials were then carried out using *JASON*. A small 1 hp hydraulic motor, driving a rotary pump, was mounted next to the robotic arm. The intake was positioned via a short hose so as to provide suction to the area conveniently reached with the manipulator. A smaller version of the *NR*-1 excavation tool was then fabricated, and tests were also carried out on the ISIS site. For limited excavation, *JASON*'s robotic arm could be used with great precision. Although slow, it was controllable enough to make excavation of certain features feasible. Since using *JASON* to conduct detailed excavations was time consuming and pulled it away from other more important tasks, it was decided to discontinue this activity until more engineering development was possible. Much had been learned about the capabilities of current systems, and work is underway to develop faster and more sophisticated equipment with which to achieve the same degree of control in dismantling archaeological deposits as that required for land or shallow water sites.

1.5. 1997 Skerki Bank archaeological results: preliminary report

1.5.1. Introduction

The archaeological discoveries in the deep sea off Skerki Bank in 1997 have confirmed the existence of an ancient trade route discovered in 1988 and 1989 (McCann and Freed, 1994) between Carthage (modern Tunis) and Ostia (the port of ancient Rome) and documented its use into modern times. Eight individual shipwreck sites ranging in date from the first century B.C. to the 19th century A.D. were studied and mapped in detail, and selected material was recovered from all but the modern wrecks. Five of these wrecks are Roman, the earliest, Wreck D, dating in the first half of the first century B.C. and the latest, named the *ISIS*, dating in the last quarter of the 4th century A.D. (McCann and Freed, 1994). Other amphoras, the terracotta shipping containers of antiquity, scattered over the sea floor or in "Amphora Alleys", further extend the ancient use of this route over the open seas back to about 300 B.C., covering the span of Roman domination of the Mediterranean. A small, medieval fishing vessel dating between A.D. 1000 and 1250 and two 19th century wooden sailing ships complete the present discoveries. The new ability to search with video and still cameras and to document wide areas of the sea floor without excavation is a great break-through for the marine archaeologist.

While our goal was primarily the documentation of the surface remains, the archaeologists, working with the engineers and in consultation with the conservators, selected some key artifacts to be recovered for study and dating of the wrecks and trade route. Deposits of pottery on wrecks at these depths have special value since most pieces are unbroken and undisturbed by wave action or robbing, unlike wrecks found in shallow water.

The 1989 and 1997 Skerki Bank campaigns together recovered and catalogued 180 artifacts: 65 objects in 1989 and 115 in 1997. Of this material, 56 are amphoras. Many more were documented by video, digital, and conventional still cameras. The cargoes from the five ancient Roman shipwrecks found are surprisingly varied, including material from both the eastern and western Mediterranean. Clearly the ancient Mediterranean was an open highway for transport between the east and west, even during war and after the division of the empire. The archaeological evidence from preliminary study of both the photomosaics and the artifacts recovered from two of the best preserved and most informative Roman shipwrecks will be presented here with discussion.

1.5.2. Discussion of Skerki D

The earliest, and probably the largest of the Roman shipwrecks discovered, *Skerki D* (Fig. 7, Table 1), can be dated both by the recovered catalogued finds and by other amphoras left on the sea floor but visible in the photomosaic. The material mainly falls in the first half of the first century B.C. and probably can be narrowed to between 80 and 60 B.C. on the basis of the amphora finds as well as the Campanian black-glazed plate (SK97.053), Morel form 2273 (Morel, 1965). The other datable artifacts include kitchen and common ware, finer pottery, bronze table ware and two lead anchor stocks with one lead anchor strap. They must mark the bow at the north end of the site, which is about 20 m long overall. Only a scatter of intact amphoras can be seen between the anchors and the forward cluster of artifacts (diam. 4 m), 5.0 m to the south. The presence in this area of a hand-rotated stone quern and a large roof tile (to keep the brazier off the wooden structure) suggest the location of the galley (Beltrame and Boetto, 1997). Moving further south, a gap of 3.6 m separates this heap from a second, larger cluster of artifacts (diam. 5 m) at the aft end of the wreck. There are a few scattered amphoras and smaller ceramics around the periphery of the wreck site. The axis of the ship seems clear: the anchors and two artifact clusters are on more or less a straight line, perpendicular to one of the discharge pipes of the bilge pump, visible at the forward end of the aft artifact cluster (Oleson, 1984; Gianfrotta and Pomey, 1981).

The arrangement of surface material raises the question of how ancient ships sank in depths beyond 100 m, well below the depth of ancient shipwrecks carefully examined up to now. Did the hull reach the bottom intact and drive itself into the sediment, leaving exposed only the upper layer of cargo or material used on deck by the crew and deck passengers, or a mixture of both? Why are there two separate heaps of amphoras? Did the hull fracture across the middle as it fell, scattering or crushing the central part of the cargo so that mud covered it more completely? Or were there two separate holds with separate hatches, and empty space around the mast step? Alternatively, the more fragile goods, or the goods loaded first, may simply have been stacked toward the closed ends of the boat, leaving empty space aft of the mast and forward of the bilge pump. Perhaps a cargo had just been unloaded, or the cargo in the central portion of the hull was biodegradable, such as grains, hides or textiles (Tchernia et al.,

Table 1
Wreck D: Summary of catalogued finds

Number	Type	Fabric	Origin	Date
SK97.050	Jug, tall-necked	Ceramic	Italy	I BC
SK97.051	Pot, flat-bottomed	Ceramic	Italy	I BC
SK97.052	Jug, thin ware	Ceramic	Central Italy	I BC
SK97.053	Plate, black-glaze	Ceramic	Central Italy	80–60 BC
SK97.054	Ladle or sieve	Bronze	Central Italy	I BC
SK97.055	Iron wheel, spoked	Iron		
SK97.056	Amphora	Ceramic	Brindisi	Late II–50 BC
SK97.057	Jar, two- handled	Ceramic	Italy	I BC
SK97.058	Pot, two-handled	Ceramic	Italy	I BC
SK97.059	Treenail w/iron nail	Iron,wood		
SK97.060	Nail with plank	Bronze, wood		
SK97.061	Amphora	Ceramic	Gaul	I BC- I AD
SK97.063	Amphora	Ceramic	Gaul	I BC-early-I AD
SK97.064	Amphora, oil	Ceramic	Tripolitania	II-I BC
SK97.065	Amphora	Ceramic	Italy, Adriatic	LateII-75 BC
SK97.066	Amphora, Dressel 1B	Ceramic	Albinia	80–30 BC
SK97.067	Amphora, Dressel 1B	Ceramic	Albinia	80–30 BC
SK97.068	Jug, nipple spout	Ceramic	Italy	I BC
SK97.069	Flat-bottomed pan	Ceramic		
SK97.070	Flat-bottomed pan	Ceramic		
SK97.071	Flat-bottomed pan	Ceramic	Italy?	
SK97.072	Jar, flat-bottomed	Ceramic		
SK97.073	Jar, cylindrical/lid	Ceramic	Central Italy?	I BC
SK97.074	Jug, squat, fineware	Ceramic		
SK97.075	Pot, fineware	Ceramic	Central Italy?	Early I BC
SK97.076	Jug, long-necked	Ceramic	Italy	Early I BC
SK97.077	Saucepan	Bronze	Central Italy	
SK97.078	Pot or cup	Ceramic	Central Italy	
SK97.079	Jug	Ceramic		
SK97.079A	Amphora, Lamboglia 2	Ceramic	Italy, Adriatic	Late II–75 BC
SK97.080	Bowl or cooking pot	Ceramic		
SK97.112	Anchor stock	Lead		II-I BC
SK97.113	Anchor stock	Lead		II-I BC
SK97.114	Anchor strap	Lead		II-I BC

1978; Radic and Jurisic, 1993; Parker, 1992; McGrail, 1989). In any case, the visible cargo is of enormous interest; 35 artifacts were lifted and catalogued from *Skerki D* (Figs. 7, 10 and 11). These include amphoras, common ware and kitchen ware, finer table ware, a Campanian ware plate, bronze table ware, two lead anchor stocks and one lead anchor strap. Our preliminary study of the imagery has identified a surprisingly wide variety of amphora types: at least 10 different forms, originating in Italy, Gaul, North Africa and Greece. Nine amphoras were recovered, representing six different types. By far the most numerous amphora shape on the wreck is that of Dressel Form 1B (Will Type 4b), a popular wine amphora dated from about 80 to 30

Fig. 11. A sample of artifacts after conservation from the Roman merchant ship, Skerki D, 80–60 B.C. Photo: Michael Hamilton.

B.C. and one of the main types manufactured by the Sestius family at the Roman port of Cosa along the coastline of ancient Etruria, modern Tuscany (Will in McCann, 1987). Two were recovered (SK97.066 and SK97.067) and petrological analysis by D.F. Williams at the University of Southampton identifies the clay with an amphora kiln in Albinia, next to the port of Cosa. Since this is by far the dominant shape in the cargo of Wreck D, it is reasonable to suggest that our ship was loaded at Cosa on its way south. There are some interesting parallels with the cargo of the contemporary Fourmique C wreck in Golfe-Juan on the French Riviera, which also loaded cargo at Cosa (Baudoin et al., 1994).

Wreck D, as well as the Sestius amphoras recovered in 1989 from the trade route north of Skerki Bank (McCann and Freed, 1994), provide startling new evidence for the extent of the export trade of the Sestius family and the importance of the port of Cosa in the last centuries of the Republic.

Visible in the photomosaic of *Skerki D* but not recovered were several Dressel 1C (Will Type 5) amphoras used to ship a processed fish sauce called *garum*. This type may occur as early as the late second century B.C. and continues into the second quarter of the first century B.C. (Will in McCann, 1987). Traces of *garum* were found inside a sealed jug (SK97.074) recovered from the wreck. Other amphora shapes recovered as well as other examples still on the sea floor are jars of Lamboglia Form 2 (Will Type 10) (SK97.065,.079A) dated again in the late second and early first centuries B.C. (Will in McCann, 1987). While this popular form is found widely distributed throughout the western Mediterranean, its origin is along the Italian Adriatic coast. E.L.Will associates this shape with olive oil (Will, 1989). Another amphora shape, the "Brindisi type" (SK97.056) is usually associated with olive oil (Peacock and Williams, 1986) and dated before 50 B.C. However, since our example shows evidence of pitch on the interior, it must have contained wine rather than oil.

Also a Tripolitanian oil amphora was recovered (SK97.064), datable to the second or first centuries B.C. (Sciallano and Sibella, 1991) and two small, flat bottomed amphoras from Gaul that may have contained wine or beer (SK97.061, 063). The fabric of the latter is typically "Gaulish", light, fine and cream colored. These Gallic wine jars are usually dated, however, at the end of the first century B.C. in the Augustan period (Laubenheimer, 1989), a date that appears too late for the rest of the material. Wreck D may provide the earliest evidence thus far for the exportation of wine from Gaul.

Another amphora shape visible in the photomosaic but not recovered is a long, narrow, wide mouthed Punic type of amphora (Dressel Form 18) from the west side of the aft cluster of material (Sciallano and Sibella, 1991). It probably contained fruit or pickled fish and is found in both North Africa and Italy. This type also appears on the upper wreck of the Grand Congloué, dated now between 110 and 80 B.C. (Long in McCann, 1987; Parker, 1992). Other amphora forms visible in the aft section but also not recovered are some Greek amphora shapes including several Koan jars with double-rolled handles dated in the earlier first century B.C.

Also included in the cargo of *Skerki D* or used on board were fine unglazed ceramics and some black-glazed pottery found in a wide variety of shapes scattered throughout the amphora heaps. A fine, long-handled bronze ladle (SK97.054) decorated with duck head finials (Overbeck and Mau, 1884; Hayes, 1984), as well as a bronze saucepan (SK97.077) of typical Central Italian type were found in the aft cluster. A curious artifact now under study is a spoked iron wheel, possibly part of the rigging or a loading crane (SK97.055).

Undoubtedly loaded at the Roman port of Cosa on the Tyrrhenian coast of Italy (McCann, 1987), Wreck D expands our knowledge about Roman trade during the late Republic and gives the archaeologist the first glimpse of a major shipwreck in the deep ocean. The artifacts date the shipwreck in the first half of the first century B.C., providing new evidence for the beginning of the French wine trade in the Mediterranean. *Skerki D* is unique in its completeness and the variety of material preserved. It surely deserves further survey and excavation.

1.5.3. Discussion of Skerki F

A second later Roman shipwreck, *Skerki F* (Fig. 8, Table 2) was the heaviest laden of the merchant ships found. Study of the material thus far indicates a date in the later part of the first century A.D. It was loaded with a remarkably varied cargo: high-quality building stone roughed out for columns and blocks, wine, oil and fish sauce amphoras in addition to numerous sets of virtually every shape of cooking and coarse ware needed for a fully equipped Roman kitchen. An iron anchor probably indicates the bow. An isolated amphora and several cooking ware vessels lie near it. The cargo of stone is visible 6 m to the SE: six large, irregular polygons and two column blanks ca. 2.6 m long. For loading purposes, the irregular shapes were carefully arranged to form an efficient rectangular mass ca. 2.6 m side to side and ca. 3.3 m fore and aft. Three other tumbled blocks appear in the mud to the NW. Samples could not be taken of the blocks with the equipment available, but the slightly rounded polygonal shapes and dull color look more like quarry-fractured granite than roughly trimmed marble. The stone probably was loaded before the rest of the cargo (von Hesberg, 1994). If they are granite, the blocks most likely came from the quarries in Aswan, shipped down the Nile to Alexandria on barges to be loaded on sea-going ships there. An empty space now seems to separate the stone from the cargo of pottery to the SE. Two bilge pump discharge pipes can be seen in this area, oriented perpendicular to the restored line of the keel. Organic cargo may have been stored in this section of the hold.

The shipment of Roman kitchen ware was stowed 8 m to the SE, on line with the anchor and stone blocks: basins, saucepans, casseroles, frying pans, bowls, lid-plates, jars, jugs and pitchers. Many of the vessels were still stacked as they were shipped, lids and lid-plates nestled one into another, and casseroles nested one on top of another, according to size (Giacobbi-Lequement, 1987). No remains of packing materials were observed, but the mud between the packed vessels had a more yellow-brown colour than the usual grey clay of the sea floor. Samples were taken of the mud around the pottery, and microscopic examination may reveal remains of packing material, or crates or baskets into which the pottery may have been stacked. While a few amphoras lay around and on top of the stacked kitchen ware shipment, this portion of the cargo is very well defined and probably was packed separately as a unit.

Table 2
Wreck F: Summary of Catalogued Finds

Number	Type	Fabric	Origin	Date
SK97.081	Amphora, Dressel 3,	Ceramic	Tarraconensis	50–100 AD
SK97.082	Amphora, Dressel 9	Ceramic	Baetica	I AD
SK97.083	Lid/plate	Ceramic	N. Africa	I AD
SK97.084	Lid/plate	Ceramic	N. Africa	I AD
SK97.085	Lid/plate	Ceramic	N. Africa	I AD
SK97.086	Lid/plate	Ceramic	N. Africa	I AD
SK97.087	Amphora, Neo-Punic	Ceramic	Tunisia	II BC-IAD
SK97.088	Amphora,	Ceramic	Empoli	End of I-IIAD
SK97.089	Jug	Ceramic	Italy?	I AD
SK97.089A	Nail, with wood	Bronze, wood		
SK97.090	Nail	Bronze		
SK97.091	Nail, in wood	Bronze		
SK97.097	Amphora, flat base	Ceramic	Pompeii?	I AD
SK97.098	Pan, round bottomed	Ceramic	North Africa?	I AD
SK97.099	Lid/plate	Ceramic		
SK97.100	Pan, round bottomed	Ceramic	North Africa?	I AD
SK97.101	Pan, Hayes Form 194	Ceramic	North Africa	50–100 AD
SK97.102	Pan, flat bottomed	Ceramic	Pompeii?	I AD
SK97.103	Amphora, flat base	Ceramic	Pompeii?	I AD
SK97.104	Amphora, flat base	Ceramic	Pompeii?	I AD
SK97.105	Basin	Ceramic	Spain?	I AD
SK97.107	Lid	Ceramic	North Africa?	I AD
SK97.109	Lid	Ceramic	North Africa?	I AD
SK97.110	Pan, Hayes Form 194	Ceramic	North Africa	50–100 AD
SK97.111	Lid	Ceramic	North Africa?	I AD

From *Skerki F* (Fig. 8), 26 artifacts were recovered: seven amphoras, eight lid/plates, six casseroles, two jugs, one large washing basin, and three nails. The amphoras are of five different types. Most interesting are three amphoras of the same form (SK97.097,103,104), but in graduated sizes, suggesting that their contents were for a diverse and varied market. This flat-bottomed shape has been found, it seems, only at Pompeii, where the vessels were filled with a product identified as *lomentum*. *Lomentum* is described by Pliny the Elder as both a blue pigment and a powder made from bean meal used as a cosmetic, detergent and medicine (*Naturalis Historia* 18.117; 33.89, 162). These jars probably date before the destruction of Pompeii in A.D. 79 and are the first evidence for the export of this product.

One of the other amphoras recovered also appears to come from Italy (SK97.088). The form is similar to wine jars from Empoli in Etruria and is dated at the end of the first or second century A.D. (Cambi, 1989). Two of the other amphoras come from Spain; one wine jar from Tarraconensis in southern Spain (SK97.081) (McCann and Freed, 1994) and a Dressel Form 9 *garum* jar from Baetica (SK97.082) (Sciallano and Sibella, 1991; Corsi-Sciallano and Liou, 1985). A neo-Punic amphora from Tripolitania (SK97.087) carried oil or *garum* (Corsi-Sciallano and Liou, 1985). All of these amphora types support a date for *Skerki F* in the late first century A.D. At least some of the shipment of kitchen ware also appears to come from North Africa. Several of the casserole shapes (SK97.101,110) with their brick red fabric are a standard form of red slip ware (Hayes Form 194) found at Carthage and dated in the second half of the first century A.D. (Hayes, 1972).

Where was *Skerki F* loaded and what was its destination? Given the exigencies of weight and balance, it is likely that the stone was loaded first, probably at Alexandria. The ship may then have picked up the large shipment of kitchen ware in Carthage or another coastal city along the North African coast, to head on to southern Italy. Of course, amphoras from Baetica and jars from Pompeii could have been loaded at any of the large entrepôts like Carthage, Tarraconensis, or Puteoli. Again, the visible cargo reinforces the picture of lively trade between the eastern and western Mediterranean in the early Empire.

1.5.4. Conclusions

It has long been known that there was a quick, direct route over the open seas between Africa and Rome. The Roman orator, Cato the Elder, in the first-half of the second century B.C., showed the Senate at Rome a fig that "had been picked at Carthage the day before yesterday" (Pliny, *Naturalis Historia* 15.75; Casson, 1995). What scholars did not know before the Skerki Bank expeditions was that the route passed near the treacherous Skerki Bank reef. It is clear from the archaeological material documented so far that the Skerki Bank route across the open ocean, despite its dangers, was active throughout Rome's long maritime history. Since each shipwreck is a precious "capsule in time", study of the material from the five Roman merchantmen who met their fate off Skerki Bank is providing new information about ancient trade routes, ceramic forms and their chronology, the loading of ships and their cargoes, as well as the ships themselves.

We now have the technology to search the depths for new knowledge about our maritime past. Continued successful collaborative efforts between oceanographers who understand the deep ocean environment, and engineers who have developed precision mapping and robotic technologies, and archaeologists who can identify and interpret the discoveries, as exemplified by the pioneering Skerki Bank Projects, is essential for the future of deep water archaeology.

1.6. Conservation and the deepwater environment

The conservation of archaeological assemblages from deep-water is, in many respects, similar to that of coastal sites. On the 1989 and 1997 Skerki expeditions, safe retrieval and transport remained the focus in the field while desalinization and drying were the critical activities in the land-based laboratory. New problems were, however, presented to the archaeological conservator by the deepwater environment of the artifacts. That environment preserved startlingly good surface detail on unbroken artifacts while at the same time, chemical alterations within those same artifacts created unexpected fragility.

Many artifact classes, including wood, metals, glass and stone, have been retrieved and treated from the Skerki Bank area over the 1989 and 1997 expeditions. The bulk in number and size are low-fired pottery vessels, mostly Roman earthenware and terracotta. Most are self-slipped with a finer portion of the same clay used for the body of the vessel.

All of the pottery shows solubilization to varying degrees. This term refers to pottery that is soft, even powdery, and prone to cracking when dried. This pottery fractures when re-dampened and can even crack when exposed to wide variations in storage room humidity.

The orientation of the finds on the seafloor must be considered when one attempts to understand the deterioration of the Skerki pottery. Three terms are used to describe the discoloration and erosion that occur on different parts of a ceramic vessel from the Skerki region: the biozone, the exposed side and the submerged sides of an artifact. The exposed side of a vessel is in contact with slowly moving, carbonate-saturated seawater. Generations of solitary coral grow and re-dissolve on this surface. The submerged side is embedded in a foraminiferal mud having a higher pH than the seawater. At a few centimeters below the seafloor, this mud is often depleted of carbonates and dominated by silicates. The biozone of a deep-water artifact refers to the boundary between the submerged and exposed sides. Here, most coral growth occurs and can maintain a permanent mass of carbonate crust in the form of a ring circling the artifact. As each pot straddles these environments, it is differentially preserved, and that, in turn, sets up stresses within the clay of the pot.

The primary environmental causes of the Skerki pottery weakness are varied. The exposed side surfaces are thinned by repeated solitary coral growth cycles. Each cycle removes clay at the point of contact with the coral. Typically, all surface details are eventually lost. While the submerged side of the vessel is spared this, the higher alkalinity and salinity of the interstitial water in the surrounding mud causes increased dissolution of silica and other minerals. This allows the submerged surface of the vessel to have fine surface detail. But it also has the softest clay and most crack-prone surface after drying. Carbonate cementation and depletion also plays a role in setting up stresses within the pottery. The biozone, the boundary between the two sides, is usually cemented with carbonates leading to a different shrinkage rate and water saturation content than either the submerged or exposed sides.

The expression of cracking on the dried Skerki vessels is the result of manufacturing weaknesses and environmental alteration. Manufacturing weaknesses were introduced during the mixing of the clay and the throwing and firing of the vessel. The environmental stresses slowly accrued during marine burial. A close examination of all finds from both Skerki excavations showed four types of fractures:

(1) Biozone fracture — occurs along the vessel at the point where it meets the seafloor.
(2) Edge fracture — occurs perpendicular to the rims and edges of a vessel.
(3) Turn fracture — occurs where the shape of the vessel abruptly changes.
(4) Slip crazing and lifting — refers to the fine and sometimes invisible superficial crack pattern on slipped pots.

While there are many factors promoting the breakdown of the Skerki pottery, it is profitably viewed as a function of the pore volume within the clay body. It is a characteristic of low-fired pottery that it has a large pore or void volume. The solid-state sintering that strengthens fired clay at low firing temperatures does not vitrify the clay. This makes the interior of the clay body accessible to seawater. Chemical action and other environmental stresses will, over time, increase that pore volume and lead to a clay fabric that collapses in on itself during drying. This interpretation is confirmed by the 1989 and 1997 artifacts. When cracking occurred it did not express itself until the final stage of drying, when the water-swollen clay particles shrink and embrittle.

An indirect method of measuring the relative pore volume in a clay body is to measure its maximum water retention. Measurements of the Skerki vessels taken at the time of treatment showed that they contained an average of 21% of their dry weight in water. A few of them contained over 30% in water. As a comparison, modern bisque-fired clays absorb only 10–14% of their dry weight in water.

To limit cracking when drying, each Skerki vessel was wrapped in wet fabric to give it an artificial drying surface and placed in incubators at 90–100°F. Elevated humidity was maintained within the incubator during drying to avoid steep moisture gradients within the pottery walls.

While this method is successful in most cases, the Skerki pots with the highest moisture content still experienced some cracking. In the future, improved humidity controllers will be installed in the drying tanks and the rate of drying will be further controlled at the expected fracture zones. Research is being done on two treatment refinements: the formulation of additives for the final desalinating phase that will decrease the surface tension of the water solution and a method of clay reinforcement prior to drying. In the field, data collection will be enhanced to better characterize the immediate environments of deep water artifacts and thus predict their condition. These steps are essential if conservation is to keep pace with the field of deep water archaeology as it retrieves low-fired pottery and other artifacts from earlier archaeological periods.

1.7. Skerki Bank oceanographic findings

In addition to the archaeological aspects of this expedition, much oceanographic insight was gained as it relates to the discovery of ancient archaeological sites in the deep sea and their potential discovery in the future as this new multi-disciplinary field grows and expands into all regions of the world.

It appears, for example, that ancient wooden ships, unlike more recent heavier ships made of steel, founder and sink at a relatively slow speed coming to rest upright on the surface of the bottom. They most likely have a higher probability of sinking intact in deep water since they fill with water instead of breaking up on rock outcrops or coral reefs. Their subsequent burial in the bottom appears to be a function of initial impact, bottom type, sedimentation rates, and eventual benthic processes acting over long periods of time. All of the ancient wreck sites discovered during this project came to rest on well sedimented surfaces, although the combined effects mentioned above did result in varying degrees of burial. None, however, were found on a hardrock substrate, which might have resulted in the exposure of the majority of the ship's non-biodegradable contents and the near complete removal of biodegradable components of the ship. Clearly, such sites will be found in the future — although they will be more difficult to locate using side-scan or sector scanning sonar techniques owing to the acoustic background noise of such terrain.

Although extensive trawling activity was documented several miles to the east of the discovery site and at the same bottom depth, none was observed where the ancient ships were located, implying that the distribution of the exposed artifacts were either a function of the ship's sinking process or subsequent naturally occurring benthic processes unaffected by human activity. No evidence of previous human activity in the area was apparent, ensuring the wrecks were undisturbed and most probably contain all of their non-biodegraded components above the sediment surface and possibly many organic components beneath it.

An examination of the contemporary ship lost in this area (i.e. *Skerki C*) provides some insight into the initial interaction between the bottom and the ships when they first reached the bottom (Fig. 3). As has been documented before, any wood placed in well-oxygenated bottom waters around the world is quickly discovered and attacked by various wood-boring organisms. This process, although quick by geologic standards, does take many years to remove the major wooden components of the exposed portions of ships. During this period of time, bottom currents result in the horizontal movement of sediment along the bottom and the construction of dunal deposits on the down current sides of the ship's exposed surface. If tidal in nature, deposits can form around the entire perimeter of the ship. Sediment also penetrates into ship openings, filling voids already there and those produced later as a result of the bio-degradation of the ship's exposed contents.

The combined result of these processes is the build up of sediments around the initially exposed portions of the ship. As wood removal continues over time, the sediments continue to flood the interior compartments of the ship, filling in around the non-biodegradable artifacts leading to the formation of a small topographic high which assisted in their acoustical identification by the various sonar systems used during the project's various search activities. There are, however, erosional processes operating as well that begin to transport material away from the site as low-energy zones are diminished by the removal of organic material such as the hull standing above the bottom relief. There is also differential erosion around initial objects such as isolated artifacts scattered around the wreck site leading to the creation of small pits.

The ability of individual amphora to resist burial through these erosional and re-depositional processes provides new insight into the behavior of ancient mariners when threatened by bad weather. Two major lines of amphora in the central and northern portions of the survey area (Fig. 2) clearly documented the attempts of ancient mariners to lighten the loads of their ships by throwing their amphora cargos overboard. Whether this technique proved effective in these two instances will have to await further analysis. These "Amphora Alleys", however, formed long linear lines running for distances in excess of 1–2 km, covering a much larger area than one individual shipwreck site. As a result, they were easier to locate. Although these alleys do not directly relate to any of the five ancient Roman shipwrecks discovered in the area, their initial discovery was an indicator that oceanographic conditions in this area favored the long-term exposure of ancient sites which led to a concentrated search effort and the subsequent discovery of the wreck sites.

In addition to the individual shipwreck sites and two "amphora alleys", the study area was characterized by thousands of individual amphoras covering a much larger area. It is clear from their occurrence that the ancient mariners commonly discarded amphoras when they were either broken or empty owing to the large number of isolated amphoras that were recovered intact (McCann and Freed, 1994). If this is true, their ancient trade routes should be characterized, where oceanographic and non-human activity favor, by a high concentration of isolated amphoras.

As the field of deep water archaeology grows and efforts expand to find other ancient trade routes in other areas, the occurrence of these "debris" trails may prove critical in not only delineating where these trade routes are found but also then guide future deep water archaeologists in locating additional shipwreck sites.

In one instance, *Skerki B* (Fig. 5), the unique arrangement of small holes created by burrowing benthic organisms seemed to outline the dimensions of the ship. These organisms seem to be "mining" the wreck site, possibly attracted by the decomposition of the ship's organic components. Whatever the case, the activity of benthic organisms may provide important insight into the nature of the buried remains of a ship.

Although attempts to excavate portions of the wooden hulls did not prove successful, they did provide useful information about the nature of ancient shipwreck sites in the deep sea. The cohesive character of deep sea muds represents a major challenge to future excavation efforts but in the short term may prove beneficial. The process of mud removal is extremely time consuming and should discourage salvagers from excavating sites. Unfortunately, they may then resort to drastic measures such as the use of bucket grabs that would quickly destroy the archaeological value of a site. Once sophisticated excavation techniques are developed and employed by responsible scientists, the results may prove highly rewarding since the deep sea muds provide a protective encasement for the wreck site.

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