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Survey techniques in underwater archaeology

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The land archaeologist is, in most instances, helped by the topography of the ground; there are generally good reasons for believing a certain area to be of archaeological interest and the irregularities of the ground will give him leads as to where he should dig. The underwater archaeologist may have no such indications on which to base his search, especially if he is interested in finding a well-preserved ancient wreck. Shallow wrecks can often be found near dangerous rocks but such wrecks are liable to be broken up by succeeding storms with the result that they have little or no interest to the marine archaeologist.

There are three ways in which ancient wrecks may be discovered. Amateur or professional divers find sunken ships in the course of other diving activities. For instance in the eastern Mediterranean hundreds of sponge divers have been active during many years and have covered large underwater areas visually. This has resulted in the accurate positioning of many wrecks. The divers involved have in most instances not precisely pin-pointed the wreck position and although the general area is known they have to be refound. Secondly, the possible existence of wrecks have been suggested by trawler operators either working for fish or sponges. Amphora and in exceptional instances bronzes have been found in their nets. These will give approximate positions and again precise location must be accomplished by other methods. The third approach to finding ancient sunken ships is by searching large areas in the blind hope that something of interest will be found. Unfortunately the sea is very large! Even when using methods having a wide sweep, such as sonar, the time and effort involved make this approach almost impossible except in confined areas where there are reasons to believe that wrecks would have occurred.

Besides the problem of finding wrecks in the open sea, survey methods can be invaluable to the excavator before he starts to excavate a wreck site. Although the presence of a wreck may be obvious from visual observation, its extent under sand or mud may not be obvious; moreover, the presence of ferrous or non-ferrous metals may give an indication of how the ship lies and how it should be excavated. It is worth emphasizing the fact that archaeological excavation underwater is an order of magnitude more time consuming and almost two orders of magnitude more expensive than excavation of a similar area on land; any short-cuts brought about by use of instruments are well worth while.

Search instruments

Side-scan sonar

Sound waves between 1 and 200 kHz will travel through water without undue attenuation. If we tow from a boat a high-power transducer giving a narrow sonar beam at right angles to the direction of travel, these waves will be back-reflected by the sea bottom. If the sea bottom is smooth little preferential reflexion will take place from any one spot. If, however, the topography is not smooth the surfaces presenting a larger incidence angle will reflect more sound back to the transducer. We can use the transducer as both transmitter and receiver. The amplitude of received sound can be used to give a variable record by special contrast recording techniques. Of course rocks as well as wrecks can show up as possible 'targets' on the record, only visual inspection of these targets will provide an answer as to whether they have archaeological significance.

By this technique sweep lanes up to 500 m broad can be searched; this search lane can be doubled by using a twin transducer which emits and receives signals on both sides of the ship's course. To obtain the greatest effect from 'bumps' on the sea bottom it is desirable to get the transducer 'fish' as near the bottom as possible. Considerable research is still required to obtain more accurate fish positioning; for a given fish, speed of tow, cable diameter and length, and added weights will all affect the depth of tow.

At the present time side-scan sonar perhaps provides the most likely method of finding unknown wrecks. Low frequency (below 10 kHz) vertically orientated sonar has also been used recently in more confined locations in the search for particular ships or objects. These low-frequencies have the power of penetration of mud and certain sediments and although most of the transmitted energy will be reflected from the mud surface, a large enough proportion may travel through the mud layer, to be reflected by the underlying rock giving a second echo line on the recorder. If wrecks or other objects are in this mud layer their presence would become visible. This search method will only cover a small area below the transducer and so the search lanes must be close together—perhaps 3 m apart.

Magnetometers

The intensity of the Earth's magnetic field can be modified, as on land, by various features which may have archaeological significance. The proximity of iron objects will, of course, be the most likely cause of a magnetic anomaly. Iron or steel wrecks will provide large changes of field, while such objects as cannon or cannon balls can provide iron masses detectable from considerable distances. Iron fittings are found in ships as far back as classical Greek times but the mass of iron present will not enable such ships to be found more than a few metres from the detector head. Small changes of magnetic field can be measured in the immediate vicinity of fired pottery such as amphorae but the effect is too small for these objects to provide a magnetic field change sufficient for location purposes on anything except a very small search area scale.

A magnetometer for survey purposes must have sufficient sensitivity and speed of operation. There are four types of instrument which might be considered suitable.

(*a*) The *fluxgate magnetometer* was developed during the war for submarine location. This instrument is directional in nature, but its detector elements are automatically alined by somewhat elaborate servo-mechanisms which require maintenance and are not adequate in rough sea conditions. Moreover, the fluxgate is inherently liable to drift problems due to temperature and other causes. An advantage of this type of instrument lies in the fact that it gives a continuous reading rather than intermittent measurements. Fluxgate instruments have been largely superseded by proton devices.

(*b*) *Proton magnetometer*. These instruments are used more than any other type for surveys at sea. Initially developed some 10 years ago, this technique has provided a means of measuring the ambient magnetic field to one part in 100000 with a spatial resolution represented by one reading every second. Stability of the measuring head is not important provided *rotation* about the towing axis does not occur. Accuracies of $\pm 1\gamma$† can be achieved.

† $1\gamma = 10^{-5}\text{Oe} = 10^{-2}/4\pi \text{ A m}^{-1} \approx 7.96\times10^{-4} \text{ A m}^{-1}$.

(*c*) *Proton gradiometer*. If one tows *two* detectors fixed to a rigid bar some 3 m apart and one encounters a magnetic anomaly, one of these detectors will be more affected than the other. Since the measured variable is an output frequency from the detectors, we can combine the signals from both detectors to obtain a beat frequency output. In the normal instrument we must use sophisticated electronics to measure the frequency from one detector accurately, while in the gradiometer all we have to do is to amplify the mixed frequency from both detectors. A beat frequency (rather than the normal 2000 Hz signal) applied to a loudspeaker will indicate the presence of an anomaly. This type of instrument is much cheaper to manufacture. The disadvantages of the system, however, lie in the awkward shape of the towed assembly and the fact that the detectability of a given magnetic object will fall off as the fourth power of distance rather than the third power as is instanced by the single detector absolute proton instrument.

(*d*) *Optically pumped magnetometers*. The rubidium and caesium magnetometers have been developed mainly for observatory work. Their sensitivity is certainly ten times that of the proton magnetometer even in non-observatory conditions; moreover, the principle of operation allows such accuracies to be obtained at a repetition rate of ten times per second. There are, however, two points to be considered; at the present time such instruments are at least five times as expensive as the more simple absolute proton instruments, and optically pumped magnetometers are direction sensitive. Even if the former of these points is of no consequence the latter makes surveying at sea tedious and in bad weather it is impossible to achieve accurate results. In the context of accuracies achievable, it should be pointed out that there would be apparently no particular advantage in exceeding an accuracy of $\pm 1\gamma$ since the changes due to geological causes and wave action would exceed this limit.

Metal detectors

Magnetometers are of course used for the location of ferrous metals, but cannot be used to find non-ferrous objects. On land various 'mine-detector' instruments have been developed functioning with continuous waves and using such detection methods as changes of inductive coupling between two coils or phase changes between transmitter and receiver. These techniques lack sensitivity and in many instances stability.

Detection distances have been greatly improved using the induced eddy-current method developed by Colani. The continuous wave methods have, in general, been found to be unsuitable for underwater application but the Colani technique has been developed for underwater work with some success. In the underwater version of the instrument only one coil need be used for both transmitter and receiver; this is because spurious readings are not produced, as in the land environment, by changes in the magnetic susceptibility of the soil. Also on land other signals generated by sources such as local radio stations, give spurious readings which are absent in the underwater environment due to efficient screening by the sea water.

This technique is especially useful for surveying known wreck sites rather than for searching large areas; it should be realized that the measured signal from a given metal object will fall with the sixth power of distance between object and detector (this should be compared with the third power in the magnetometer instance). This rapid fall-off with distance will mean that even large metal objects cannot be detected more than a few metres away and if a search path is considered using a towed instrument this will be only a few metres wide. When surveying a wreck site before excavation differentiation of ferrous and non-ferrous objects can be made by combining magnetometer and eddy-current detector surveys.

Position fixing at sea

Anybody who has been concerned in a sea-going survey more than 100 m from land will appreciate the difficulties involved when trying to relocate an apparent 'target', e.g. a magnetic anomaly. There are, of course, systems for fixing the position of a *boat* at sea relative to set radio beacons based on fixed buoys or on the shore; the 'Seafix' and 'Loran' systems are such examples. It must be realized in our case that we are interested in the position of the detector rather than the towing boat; since this detector may be at the end of a 100 m cable in conditions of tide and wind, it may have a very variable position with relation to the boat. A method to fix the position of the *detector* is required.

In our laboratory we have developed a sonar fixing system. Very briefly the method is as follows. Two fixed buoys are anchored in known positions. These buoys each have a 10 kHz high-power sonar transmitter with a 360° horizontal beam and a radio receiver tuned to pick up only a set modulation frequency in the 27 MHz band. Attached to the detector is a hydrophone capable of detecting the 10 kHz sonar signal at distances up to 1.6 km between buoy and hydrophone. On the boat a transmitter signals the buoys in turn to transmit a short burst of 10 kHz sonar. Electronic circuitry, also on the boat, measures the time of travel of the sound wave between buoy and hydrophone. Since the speed of sound in sea water is known, the distances of both buoys from the detector can be automatically calculated and displayed digitally. A complete recycle of these readings is repeated every 5 s. When a magnetic anomaly is detected on the magnetometer recorder, its coordinates with respect to the two buoys can be immediately marked on the chart so facilitating relocation of the anomaly for further investigation.

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