TECHNOLOGY

Archaeological Survey

When we think of underwater archaeology, we often think first of technology - the remarkable modern tools which allow us to probe the ocean floor, calculate coordinates and discover artefacts that, without technology, might remain among the secrets of the seas.

But most underwater archaeology begins just as any archaeological excavation for which the precise location of the site or artefact is not known: in a library, or amid other historical archives. This research must sometimes proceed for years before the surface of the water is broken!

In most cases, however, the best that archival research can do is to narrow down an area, a hypothetical "zone of exploration", which can vary from a few square nautical miles to a vast area of ocean, depending on the historical context and on how much specific information is known.

The next step is the geophysical survey, which takes place within the zone of exploration. The survey is conducted using different sensors to measure the physical characteristics of the site. The purpose of this is to reveal anomalies, which may correspond to archaeological remains.

A boat equipped with measuring instruments and computer systems, systematically scours the entire search area along parallel lines spaced 30-80m apart depending on the average depth of the site and the nature of the remains to be discovered.

Nuclear magnetic resonance magnetometers (NMRs) and a side scan sonar, operated by electrical winches, are towed behind the boat: barely sub-surface in shallow water or submerged by hydrodynamic depressors in deeper water. An acoustic positioning system continuously transmits the position of the towed sensors. The boat is also equipped with high-resolution echo sounders.

In on-land archaeology, these measurements would be calibrated and compared against a constant measure of longitude, latitude, and elevation - since like all sciences archaeology requires measurable and duplicable results. At sea, we have an intensified use satellite-based Differential Global Positioning System, or DGPS, to provide this constant positioning.

All the recorded parameters are subjected to an initial analysis during the course of the survey. Daily processing of the data leads to the generation of bathymetric maps (showing a relief of the ocean bed) and magnetometric maps (showing magnetic fields) of the area under survey, completed by a sonar image of the seabed (using acoustic photography).

The analysis of the data generated allows the geophysicists to determine the most promising positions for further exploration.

When an anomaly has been measured, experienced divers or remotely operated vehicles (ROVs) make an initial inspection in order to identify its origin. Even in clear water the remains are usually rarely visible. The process of uncovering detected material, which is often buried or covered with thick deposits, generally requires soundings to be taken.

Technical Features

Catamaran

A catamaran is a sailing ship made with two parallel adjoined hulls. Very stable thanks to its width - and non-magnetic when made of fibreglas - a catamaran, with its very small draught, is the perfect ship for magnetometric surveys even in shallow water areas.

Research Vessel

For the missions in Egypt, the “Princess Duda” serves as the base for the team and the equipment. During the mission, the boat is securely anchored on six concrete moorings, just above the main excavation site. During the missions usually 30 people live and work on board. The boat is equipped with a compressor for filling the diving tanks, a crane to hoist discoveries on board and a spacious deck where the archaeological material is housed and initial conservation can be done. For pinpoint excavations or soundings, the team uses several motorised fishing boats.

Anomalies

The techniques of geophysical analysis consist of revealing the discontinuities of the parameters measured, such as the ambient magnetic field and the acoustic response of various terrains. These discontinuities or contrasts are called ‘anomalies’.

In archaeological terms the range of interesting anomalies is very limited. The sensors also pick up numerous naturally occurring geological features, which show up as anomalies. The discovery of remains depends on correctly differentiating between these two kinds of anomalies.

The success of this relies on both technology, and on the judgement of trained professionals. It comes down to the sensitivity of the sensors, and the expertise with which they are implemented; on the computer processing of the measurements, and on the analysis of the results.

NMR Magnetometer

Nuclear Magnetic Resonance (NMR) Magnetometers are the principal sensors in our surveying system. These highly sensitive sensors were developed by the French Atomic Energy Commission (CEA). Based on simultaneous proton and electron magnetic resonance (the Abragam-Overhauser effect), the NMR magnetometers measure the absolute value of the earth’s magnetic field more than one thousand times per second - with an accuracy of one fifty-millionth of its value.

MRM-2000 Frequency Meter

A specialized frequency meter delivers the absolute value of the magnetic field with an accuracy of one thousandth of a Gamma, which means an accuracy of a frequency measurement to the seventh decimal place (10^{-7} Hz).

A highly integrated version of this frequency meter, named MRM-2000 has been developed by Franck Goddio's engineering team in collaboration with the French Atomic Energy Commission.

Geomagnetism

The earth's magnetic field superimposes very complex temporal and spatial phenomena - the earth's crust geology, dynamo effect, sun-earth interaction, ionospheric and telluric currents, etc. - involving magnetic and electric properties. The earth's magnetic field can be schematically considered as bipolar and of a value between 20000 nanoTesla (nT) on the equator and 60000 nT at the poles, in addition to which there exists a field of global anomalies (of about 10000 nT), a field of geological local anomalies and temporary phenomena of some tens of nT every day.

Application to Archaeology

The magnetic anomalies created by archaeological remains are superimposed on the anomalies of natural origin. The ability to differentiate between these anomalies is based on the extreme sensitivity of our magnetometers and, where necessary, on the measurement of the local magnetic gradient between two sensors towed simultaneously. This gradient meter reduces the temporal variations of the earth's magnetic field and enables us to dismiss a great many of the geological anomalies. This method, implemented using NMR magnetometers, permits the detection of objects with very weak magnetism, even when they are buried deep under layers of sediment.

Sidescan Sonar

This seismic sensor provides an image of the acoustic contrasts on the seabed, on a band of 50 metres on each side of the boat. It reveals rocks and other objects lying on the seabed and can give an indication of their size by measuring the shadow, which they project. Magnetometers can simultaneously determine whether these targets are magnetic or not. By juxtaposing geographically positioned bands, the sonar information can be used to create a mosaic of the surveyed area.

Echo Sounder

A precise bathymetric or relief map of the area is obtained using echo sounders. These acoustic sensors deliver continuous accurate depth measurements along the surveying profiles.

Acoustic Positioning System

The system, called "short base acoustic positioning", is based on the regular transmission of an acoustic signal from a transmitter - called a "pinger," and mounted on the mobile unit to be positioned - to an immersed boat-fixed receiver. Several pingers sending on request from the transceiver can be used at the same time. The positioning of each mobile unit is then calculated in terms of range and bearing seen from the receiver. Taking into account the geographical position of the boat recorded by the DGPS, and the known fixed position of the transceiver on the boat, the geographic position of all pinger-equipped sensors can be determined in real time.

Differential Global Positioning System (DGPS)

The GPS (Global Positioning System) is an absolute geographical positioning system, providing for the entire surface of the earth the position in latitude, longitude, and altitude of the mobile receiver, through information sent by a constellation of satellites. To get within an accuracy of less than one metre, which is necessary in archaeological research, a GPS ground station is installed to send real time corrections by radio to the mobile receiver. The positions given by the mobile receiver after correction are then called differential positions.

Franck Goddio's team has also developed an original underwater DGPS to collect the position of the archaeological remains during excavation.

Computing Systems

The survey vessel is equipped with computer systems for data acquisition and navigation, collecting, recording, and graphically displaying the data from the geophysical sensors (magnetometers, echo sounders, sidescan sonar, etc.) and the sensors recording positioning and altitude (GPS, acoustic positioning, pressure sensors, heading, winch control parameters, etc.). An on-board geophysical data processing station is then used, running specialised software, to create maps from the survey results for analysis.

Deep Rovers

The remotely operated vehicles (ROVs) invented by Graham Hawkes are equipped with cameras and able to perform surveys in up to 1,000 metres depths. One can follow the reconnaissance of the robot in real time in front of screens like a video game.

The deep rovers *Jules* and *Jim* are submersibles especially designed for searching at great depths for Franck Goddio's *Royal Captain* project. Capable of descending to a depth of 1,000 metres and carrying two passengers, they are fitted with a camera and powerful searchlights. The submersibles are equipped with multifunctional articulated robotic arms with a pincer on one side and a suction cup on the other which makes it possible to pick up objects delicately. The plastic bubble in which the passengers travel is 20 centimetres (8 inches) thick to be able to withstand pressure and to allow a panoramic view. Each dive can last up to 8 hours.

EMS-SRS3000 Deep-Sea Photo System

The EMS-SRS3000 Deep-Sea Photo System was developed and constructed especially for the *Royal Captain* project and according to its needs. On the very same dive it had to be able to produce vertically orientated mosaic photo series with photogrammetrical precision, close-ups of artefacts *in situ* as well as wide-angle landscapes of the excavation scenery and submersible action. Due to the site lying in the depth zone of total darkness the camera system had to be equipped with powerful electronic flash units and be capable of working within parameters that could change at any time. The result was a high-performance photo studio, which was manually controlled by the photographer from inside the cabin of the deep rover submersible via a laptop computer and a special power and laser control panel.

Water Dredge

The water dredge is an underwater suction device to remove sediment covering the objects. This instrument is indispensable to underwater excavations. The light plastic dredge is supplied with water under pressure by a diesel-run motor pump situated at the surface. A fine mesh screen at the mouth of the dredge serves to collect any small artefacts, which the diver may have missed.

The Grid Reference System

Traditionally, in archaeology the site is divided into squares with the aid of ropes and cables. This system enables us to provide each object with a set of coordinates determining its position.

In underwater archaeology, usually a mobile grid system, firmly anchored to the ocean bed, is used. The grid can be sledded along the fixed reference lines, the baselines. The base mesh of a grid usually measures 1m x 1m. The preferred method is, however, the electronic one. Nowadays, underwater positioning systems such as DGPS can achieve a degree of precision within centimetres. The grid will be limited in the future to help the diver determine his own position, particularly in poor visibility, which can at worst be within centimetres.

<u>Labelling</u>
Every diver is supplied with nylon nets or plastic bags, to which a label with the excavation code is attached. Every item recovered is placed in its individual net and the position of the object in terms of latitude, longitude and altitude, its azimuth (compass orientation), and the angle of the object from the vertical, as well as the diver's identifying mark is added.

<u>The Excavation Plan</u>
The actual grid is reproduced on paper, e.g. every object is drawn in exactly the same position that it was found in. Objects retrieved have a label from which their position, orientation and elevation is noted. For objects that cannot be brought to the surface, or naval structures, the method of triangulation is used: three posts, or base points, are precisely measured by GPS. From there a tape measure is extended towards the point to be measured, and the distance noted. The three measurements should then on paper intersect and thus pinpoint the location of the object in question.

The excavation plan is built up day by day, until a complete picture of the archaeological site emerges. Only then can the site be interpreted.

<u>Moulding</u>
The moulding technique allows to make imprints of artefacts discovered, and thus provides scientific experts with immediate access to the archaeological material for study purposes.

In order to take a surface impression of an object, underwater or on land, the stamping method is applied. This technique is usually used for huge stone blocks on which inscriptions have been engraved. A special flexible silicone has been developed to make underwater impressions of the engraved objects. After cleaning the object, the silicone is attached to it to coat the imprints. The layer is then covered with a sheet of lead, which is gently hammered in order to insure that the silicone moulds into the smallest crevices. Once the silicone has transformed into a flexible membrane, usually after 16 to 24 hours, the inscriptions appear in reverse on the silicone and can be studied in detail on land.

<u>Elevator</u>
The support vessel of each excavation is equipped with a hoist to raise artefacts to the surface. At first the artefacts are carefully places in nets, each individually labelled, then in plastic baskets. Heavier objects (like statues or steles) are lifted by means of a special balloon or crane. For the *Royal Captain* project a special elevator was designed, which had to be anchored at a depths of 350 metres. The large support buoy of the elevator consisted of sixty spherical buoys, each of them capable of resisting a pressure of 100 atmospheres. A metal platform was laid on the seabed to support the two-ton lead counterweight needed to operate the elevator. The lead weight – in four pieces of half-ton pins – was attached to a balloon to make it

weightless and placed in position by a submersible. The elevator was operated by a submersible and raised objects – like the ship's bell – to the surface with greatest care.

Conservation and Restoration

Once an object reaches the surface, it is immediately cleaned in seawater, the date of discovery in entered on the label, and it is placed into a desalination tank. The tank is filled with 50% seawater and 50% fresh water, in order to avoid deterioration due to violent osmosis. After a couple of days it is placed in fresh water, which is continuously renewed. The salinity of the bath is constantly measured in order to determine when the object can be dried without damage. On land, a more complex desalination process is executed, using distilled water. Organic materials are kept in a damp environment on board, and are treated on land.

After the desalination process, the object is described, measured and inventoried. A second label bearing a pre-printed inventory number is attached to the net. All information is then entered into a database with the corresponding photos.

In general, pottery remains are the first objects that can be dated and studied, as they tell a lot about consumption habits and trading channels of a particular period. Pottery is cleaned using micro-burins and scalpels to remove deposits and shells. Once the underwater sediments have been cleared, the object is carefully studied in reference to shape, texture and decoration in order to determine its date and provenance. Every piece, or sherd is described, measured, numbered, photographed, and drawn, and the data entered into the database. Following desalination, pottery is restored. Fragments are glued together, if necessary, gaps are filled and a tint is applied. Fragile objects are consolidated with a resin.

Organic material requires swift and delicate treatment as soon as it has been recovered. After desalination, the material is dried out slowly and excess water is gradually replaced by a resin, so that the volume of the material is maintained.

Metals like bronze, silver, iron and lead corrode as soon as they are exposed to air. Gold, on the other hand, remains completely unaltered. In addition to desalination, metals are bathed in a regulated and precise system of chemical or electrochemical treatments. Restoration takes place chemically and ultrasonically. The revived objects are then chemically stabilised and covered with a varnish or a wax.

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