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Geophysical Survey of Marine Archaeological Sites off East Coast of India

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Introduction

Classification of archaeological features depend upon whether the site is prehistoric, historic or recent. Prehistoric sites may have architectural feature ranging from house floors to stone walls, subsided mounds, filled ditches and storages. Historic sites can have structural features such as foundations, filled cellars, wells and some of them may have discarded artifacts. In many of these sites we may find the concentration of bricks, stones or ferrous metals. Recent sites not only contain cultural remains and artifacts but also the ports, harbours and shipwrecks, comprising of trade goods such as lead ingots, gun parts, anchors, axe-blades or metal pots. Thus the archaeological requirements for geophysical surveying are shaped by the attributes of archaeological features. Since archaeology deals with objects ranging from a few centimetres to a few metres in size and depths normally not greater than a few metres, the size and depth of the features are much smaller when compared to the usual targets in the geophysical exploration.

Application of geophysical methods to survey archaeological sites have been in operation since 1940 and have been more intensified since the development of Proton Precession Magnetometer in early 1950s and the Side Scan Sonar in early 1960s. The role of geophysical techniques in archaeology are discussed in detail by Aitken (1974), Weymouth and Higgins (1985). In recent times, application of geophysical methods to archaeology has increased considerably with environmental and political pressures mandating assessments before land development. There has also been a relatively sudden growth in the number of geophysicists and archaeologists working together. Thus the application of geophysical exploration methods in archaeological investigations has opened a new field called Archaeogeophysics, which is also called as archaeological prospecting.

National Institute of Oceanography at Visakhapatnam has undertaken geophysical surveys comprising of Side Scan Sonar and Proton Precession Magnetometer supplemented by Echosounding and Shallow Seismic Profiling for the archaeological investigations in the off-shore regions from Tranquebar to Poompuhar on Tamil Nadu coast. Basic principles of geophy-

social equipments and the preliminary findings obtained from the surveys carried out off Tamil Nadu coast along with some of the geophysical findings that may bear archaeological importance/significance on the continental shelf of Visakhapatnam are presented in this paper.

Geophysical Surveys

Several types of search operations are employed in the marine archaeological investigations to detect the underwater objects. Selection of a particular technique or a method depends upon the effectiveness, practicality, cost and time. Direct detection techniques include the engagement of divers, crew, ports on surface, vessels etc. A grappling hook is sometimes used to locate the object by direct physical contact. Side Scan Sonar and underwater television monitors are used to provide a view plan of the underwater objects that are exposed over the ocean floor. Sub-bottom Seismic Profilers, electromagnetic detectors and magnetometers are commonly employed to detect the objects that are submerged under the sand, silt and clay. In the surveys along the east coast of India, Side Scan Sonar and Proton Precession Magnetometer are mainly used to search for the underwater objects. These are supplemented by Seismic Profiler, continuous Echosounding and the diving operations.

Magnetometer

Detection of submerged objects by magnetic measurements is one of the best known, quick and cost-effective archaeogeophysical applications (Briener, 1975). The magnetic surveys could only be effective when the objects of search would and could involve ferro-magnetic materials. The common objects that come under this category include pipelines, steel-hulled ships, engines, anchors, guns, mines, iron cannons, submarines, sunken aircrafts, ancient ships etc. Objects made of brass, bronze, aluminium, copper, gold, silver, wood, plastic etc., are not ferro-magnetic and cannot be detected by magnetometer. However, some ballast stores, most potteries and kiln-dried clay material are slightly ferro-magnetic and may be detected even if encrusted with coral or covered by silt and sand.

Two types of Proton Precession Magnetometers are commonly employed for the magnetic search operations at sea. One of them is called Absolute Magnetometer which measures the absolute value of the total intensity of earth's magnetic field. This instrument is widely used because it is more versatile and has a wider range of applications. Magnetic Gradiometer is the other type of magnetometer and it measures the gradient or difference of the earth's total magnetic field between two points. In this, two sensors, separated by a fixed distance are used. The gradiometers have the advantage that they cancel out the long term changes in the absolute field during the day.

Estimation of shape and amplitude of the expected magnetic anomaly is of great importance in all magnetic search operations because it is useful in planning the search grid, sensor-

tow requirements and in determining the feasibility of conducting the search. It is possible to estimate the maximum amplitude of the anomaly for a given weight of steel or iron if the distance between the object and the sensor is known and whether it is a finite sized or a pipeline. The estimate thus made will be very approximate due to several ambiguities involved in the several possibilities of physical dimensions and magnetization of the object and other operational problems. For an isolated object such as a ship or an anchor, whose dimensions are shorter than its distance to the magnetometer, sensor would behave as a magnetic dipole. The magnetic anomaly for such an object varies inversely as cube of the distance between the sensor and the object and directly with the weight of the object and can be represented by the formula:

$$T = M/R^3 \text{ for latitudes upto } 60^\circ$$

where T is the anomaly in gauss (1 gauss = 10^5 nT), M is the dipole moment in cgs units and R is the distance in cm between the object and the sensor. Normally the magnetic moment varies between 10^5 and 10^6 cg units for objects made of steel or iron. Thus the maximum anomaly for 0.1 ton of iron or steel at a distance of 1000 cm would be between 1 and 10 nT. As a thumb rule it can be remembered as 1 ton of iron produces an anomaly of 1 nT at 100 ft distance. Since there is a large variation in amplitude of the anomaly for a relatively small change in distance to the object, it is of utmost importance in the magnetic search operations that the magnetometer sensor passes as close to the object as possible to provide more assurance of detection.

In all our magnetic search operations Barringer Proton Precession Magnetometer constituting of a portable sensor, lightweight tow cable and the shipboard console unit was used. The sensor contains only a copper wire coil immersed in kerosene in a streamlined, watertight casing. The Proton Precession Magnetometer operates on the principle of precession of protons in a hydrocarbon fluid for the measurement of total intensity. The kerosene inside the sensor unit is momentarily magnetized by applying the direct current to the coil. This current is then removed and the protons precess like a spinning top about the direction of the earth's magnetic field at a frequency proportional to the total magnetic field intensity and independent of the direction of the sensor. The frequency of this signal is transmitted through the tow cable to the console unit where it is measured accurately by electronic circuits with resolution of 1 nT or even 0.1 nT. The repetition rate of a Proton Magnetometer is selectable from one reading every 6 seconds to a high rate of 3 times per second. Higher repetition rate is essential in order to adequately portray an anomaly signature of short duration. The data can be recorded on an analog strip chart recorder at two full scale sensitivities and also digitally displayed which can also be recorded for further computer processing.

Side Scan Sonar

The first side looking sonar was designed by Tucker and Stubbs (1961) at the National Institute of Oceanography in England. Since then it has undergone rapid development and

improvement (Tucker, 1966). Detailed description of the technical and operational aspects of the instrument and the interpretation of records are given by Belderson *et al.* (1974), McKinney *et al.* (1974), Werner and Newton (1975) and Flemming (1976).

The Side Scan Sonar system basically consists of a fish, a steel wire reinforced cable and a dual channel recorder. The fish is made up of a streamlined and hydrodynamically balanced body of about 1 m length. It contains two sets of transducers through which the acoustic signals are transmitted and the echoes are received from both sides. The fish can be towed by means of the steel wire reinforced cable off the stern of the survey vessel, off either side or even off the bow, depending upon the objective of the survey, the water depth, sea floor topography and swell conditions. For deep water surveys, the fish is towed astern because it will be far below the surface and well away from the propeller turbulence. In shallow water surveys the fish is normally towed off port or starboard where it will also be away from the propeller noise.

The dual channel recorder contains most of the electronic as well as the graphic mechanism. The sonar pulses of 0.1 min duration and 500 kHz frequency sent out from the transducers inside the fish and also the returning signals received by it are fed into the recorder. These are amplified and fed in the form of variable currents to the helix electrodes which sweep out from the centre of the recording drum. The current passing through the recording paper produce marks of varied intensity which are proportional to the strength of the incoming signal. The image thus produced is called the sonograph. The instrument is calibrated such that by doubling the range, the pulse rate is reduced by one half. In order to avoid gaps on the recording paper, the feed rate of the paper is also reduced by one half. The stronger the returning signal, the darker will be the image on the paper. The strength of the returning signal is a function of material properties, size of the object and the topography. Large objects are not only good reflectors but also produce an acoustic shadow zone behind the image. The width of the shadow and the position of the object relative to the fish are utilized to calculate the height (ht.) of such objects as per the formula:

$$\text{ht.} = \frac{L_s \times H_f}{L_s + R_s}$$

where L_s is the acoustic shadow length, H_f is the height of the fish above the seabed and R_s is the range distance at which it is recorded.

When reproducing sonograph mosaics in map form, various distorting factors have to be observed. The distortion parallel to the line of travel occurs due to variable ship speeds resulting in a compression of all sonographs in that direction. This effect was best demonstrated in the form of distortion ellipses by Newton *et al.* (1973). The height of the fish above the seabed causes lateral distortion, perpendicular to the line of travel. Finally, due to the obliquity of the sonar beam, equal true distance intervals will not follow a linear scale on the sonograph. The

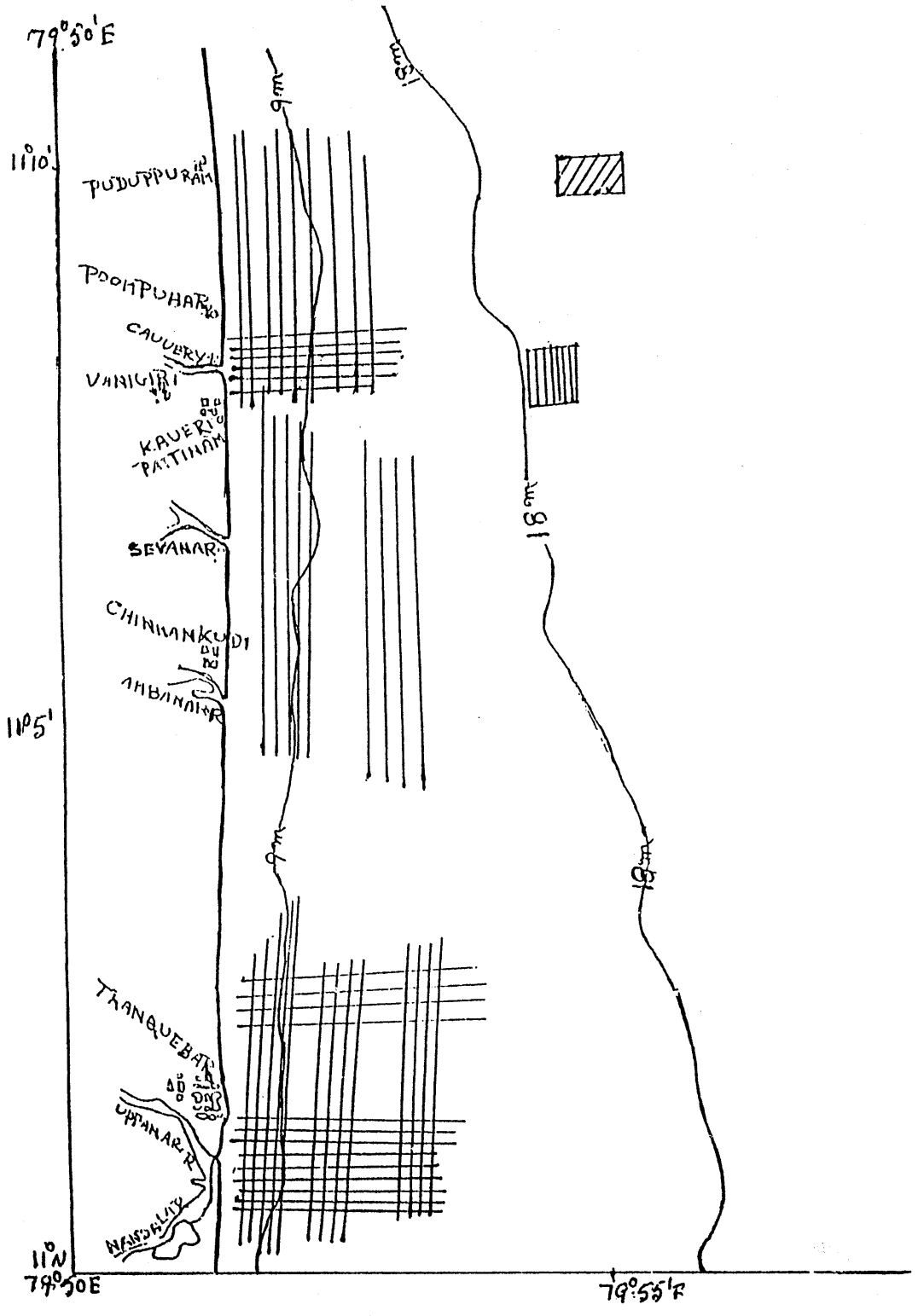
short range intervals are compressed and the far range intervals are slightly stretched. However, this effect has been taken care of in latest types of Side Scan Sonar.

There are three main sources of acoustic interferences which produce characteristic pattern on the sonograph. Operation of seismic equipments simultaneously with the Side Scan Sonar causes a continuous interference pattern overlying the sonographs. This can be reduced considerably by running both the instruments well apart. The second type of interference is caused by dense particle suspension in the water column. Whenever, suspension becomes dense enough the sonar beam is partially dispersed and partially reflected before it reaches the seabed resulting in white gaps through all ranges whereas the area within depth profile is blackened. Similar effects in the form of scattered dark patches with sharp outlines are produced by shoals of fish. The third type of interference is caused by ultrasonic waves generated by passing ships.

Side Scan Sonar and magnetic surveys supplemented by Echosounding were carried out for the archaeological investigations off Tamil Nadu coast, between Tranquebar and Poompuhar (fig. 1). The surveys are done on a 50 ft long, wooden hull fishing trawler along the coast, covering the areas between 5 and 12 m 18 to 20 m, and 22 to 24 m water depth. There were no navigational aids except the magnetic compass and the locations were noted by visual observations with reference to the objects available on the coastline. Therefore, all the positions mentioned here are very approximate. Geophysical surveys are also carried out over the continental shelf of Visakhapatnam. Magnetic anomalies recorded over the inner shelf suggest the possible existence of underwater objects of archaeological significance. The magnetometer sensor was towed about 30 m astern of the boat while the side scan sonar fish was towed about 15 m behind the boat on starboard or port side. The Side Scan Sonar and magnetic surveys could not be conducted simultaneously because of interference of Side Scan Sonar pulses with the magnetometer. Continuous Echosounding was done throughout the surveys with the help of Simrad Shallow Echosounder.

Results

Detailed Side Scan Sonar and continuous Echosounding surveys were carried out in March, 1990 between Tranquebar and Vanigiri (Kaveripattinam) on Tamil Nadu coast. Surveys were carried out both parallel and perpendicular to the coast between 5 and 12 m water depth. The echograms obtained in this area did not record any major undulation of the ocean bottom or any outcrops except some submerged river valleys. However, Side Scan Sonar recorded images of several objects of different sizes and shapes. Near Tranquebar, most of the objects are recorded between 5 and 7 m water depth. Off Masalamani temple, near Tranquebar fort, disjointed structures (fig. 2) that resemble the fragments of linear structure, running parallel to the coast were recorded at about 7 m water depth (Rao & Rao, 1991). These objects each of 25 to 30 m length extend for more than half a kilometre along the coast. Off Tranquebar fort, isolated



objects of varying sizes and some of them circular in shape (fig. 3) are present between 9 and 11 m water depth. Off Chinnankudi, which is located about 5 km north of Tranquebar, several small objects are recorded (fig. 4) between 9 and 11 m water depth. At the first look they appear as scattered objects. But a close examination of the records suggests that they are arranged mostly in a semicircular pattern covering an area of more than a kilometre. Between Chinnankudi and Vanigiri, several large scale isolated objects (fig. 5) are recorded at about 10 m water depth. They are also arranged either linearly or in a semicircular pattern. In the absence of any rock outcrops on the coastline and the echograms being devoid of any topographic features, the images recorded in the sonographs may possibly correspond to some man-made structures that subsequently got destroyed and submerged. No detailed diving operations were made in this area. A few experimental divers made in this area were also not successful because of very poor visibility due to extremely turbid water.

Detailed Side Scan Sonar, magnetic and topographic surveys were undertaken off Poompuhar in March, 1991. All these surveys were carried out parallel to the coast between Vanigiri and Puduppuram which are 1 km to the south and about 3 km to the north of Poompuhar respectively. These surveys covered the area from 5 to 12 m water depth between Vanigiri and Puduppuram, 18 to 19 m off Vanigiri and 22 to 24 m about 4 km north-east of Poompuhar. Between 6 and 12 m water depth the sonograph recorded several images of the objects of different sizes particularly from 5 to 7 m water depth between the circuit house and lighthouse of Poompuhar (fig. 6). They appear to have been aligned in lines parallel to the coast. Echograms did not record any topographic features over these objects except the extension of river valley into the sea. Magnetometer also did not record any anomalies. Divers reported that the ocean floor is covered with black clay and silt and the visibility is extremely poor to locate any object. After repeated divers, they could find the scattered stones in the areas where the images are recorded. The stone pieces recovered from these areas are greyish black in colour and vary in sizes from 1×1.5 ft to 2×2.5 ft while some of them look exactly like slabs, the other objects vary in the shapes from rectilinear to hexagonal to octagonal. Geological analysis of these rocks revealed that they are the sandstones and are typical of Cuddalore sandstones, that are extensively used for construction purposes on land. From these preliminary observations, it is provisionally concluded that the images recorded in the sonographs correspond to the scattered sandstone pieces which may be the debris of the collapsed structures in these areas. The foundations of these structures could have been covered under the sediments. Detailed investigations could not be carried out due to very poor visibility and also because the sea started becoming rough towards the end of March. More detailed geophysical surveys including high resolution sub-bottom profiling and the intensive airlift operations have to be undertaken to confirm those mentioned above.

Local people believe that a submerged temple exists at 22 m water depth, about 4 km

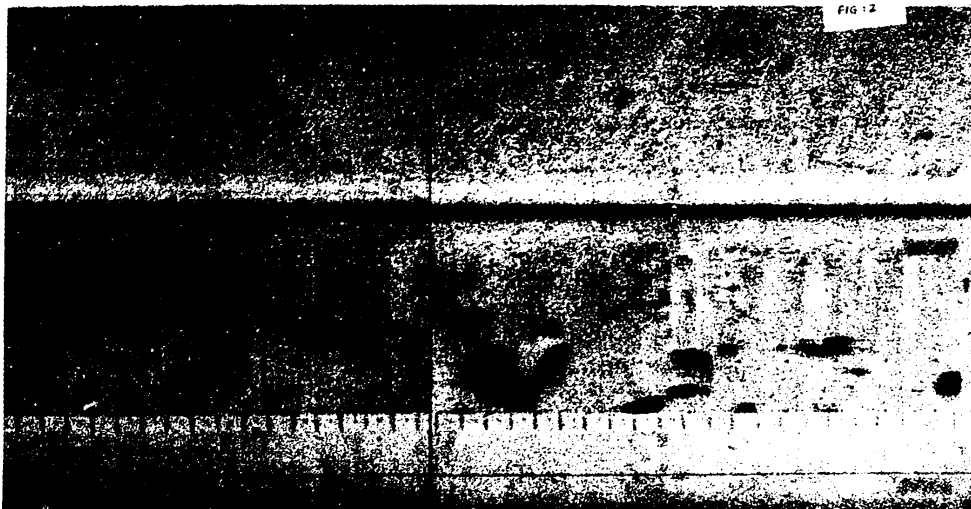


Fig 2 Disjoined structure at 7 m water depth off Masalamani Temple near Tranquebar.

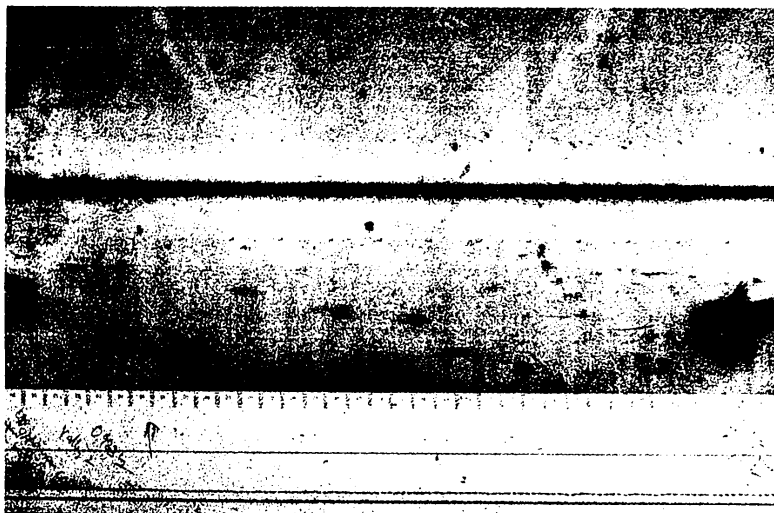


Fig. 3 Isolated objects of different sizes between 9 and 11 m water depth off Tranquebar.

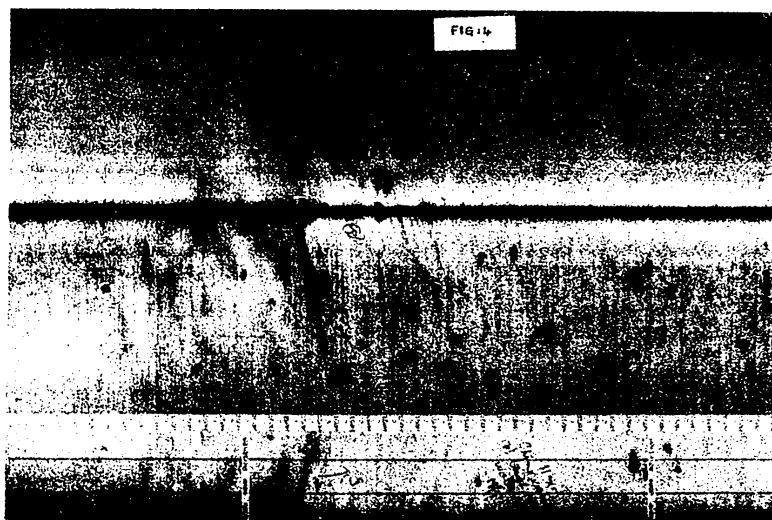


Fig. 4 Small objects arranged in semi-circular pattern between 9 and 11 m water depth off Chinnankudi.

north-east of Poompuhar. As per their statements, about 60 years back one local fisherman had recovered an idol from that site and it is now being worshipped in a village on the coast. Based on this information, detailed Side Scan Sonar, bathymetric and magnetic surveys were carried out between 21.5 and 22.5 m water depth in that area to locate the suspected submerged temple. Echosounder recorded two topographic peaks at 22 m water depth. One peak is more than 2 m above the ocean floor while the other is about 1.5 m high. Side Scan Sonar recorded an image of elliptical shape with its longer axis, more than 30 m long and the minor axis about 20 m long. The sizes mentioned are approximate because the distortion factors are not taken into consideration. Sonographs recorded on some sides of this object are shown in figure 7. About 40 m north of this site two other small objects were recorded both in echogram and sonograph. The topographic relief of these objects varies from 1 to 2 m. A close observation of the sonographs suggests that these two small objects are so aligned that one of these objects is located exactly in line with the eastern edge of the main object while the other object coincides with the western edge of the main object. No magnetic anomalies are recorded in this area. Diving operations in this area could cover only small portion of the site and other areas of the site could not be covered for want of time. By comparing the statements of the divers with the sonographs, it appears that the divers have gone only to the south and south-west portion of the site. The diving operations revealed that the elevated portions are arranged in a semicircular pattern covering an area of about 20 m in width. The elevated ones are steep, rising vertically above the ocean floor and do not have sloping surfaces. These may possibly represent the man-made walls now broken in between. However, this could not be confirmed since they are thickly covered by barnacles, corals and other sea plants. Laterite and sandstone pieces that are commonly employed for construction purposes were recovered from this site. In the centre of the site, divers reported wide and thick sand, pond on the eastern side and a hard surface covered with thin sand on the western side. Similar types of materials were reported and recovered from the two small objects located 40 m north of the main site. The preliminary investigations give fairly good evidence to conclude that the object recorded in this site may possibly be the man-made structure and perhaps the temple, as believed by the local people. Detailed surveys and intensive airlift operations should be carried out to confirm these findings. About 1 km south-east of this main site another object was recorded at about 24 m water depth. The shape of this image is surprisingly same as the shape of the object located at 22 m depth but smaller in size. No diving operations could be undertaken in this area since the sea had become rough and all our operations had to be discontinued. It is believed that the image recorded at 24 m depth could also be a man-made structure. From the general global sea-level variations it is rather difficult to explain for the existence of man-made structures now submerged at 22 and 24 m depth. If the future diving operations in this area could confirm the presence of man-made structure, suitable explanations, possibly based on the local tectonics may have to be found out to justify their



Fig. 5 Big size isolated objects at 10 m water depth between Chinnankudi and Vanigiri (Kaveripattinam).

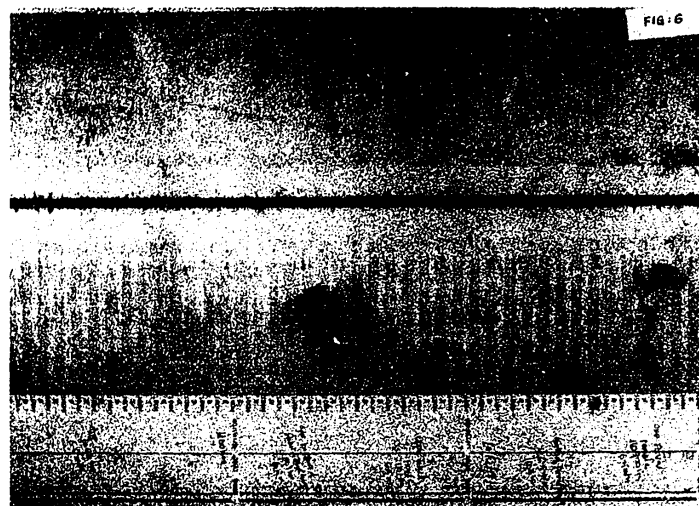


Fig. 6 Objects of different sizes from 5 to 7 m water depth between circuit house and light house at Poempuhar.

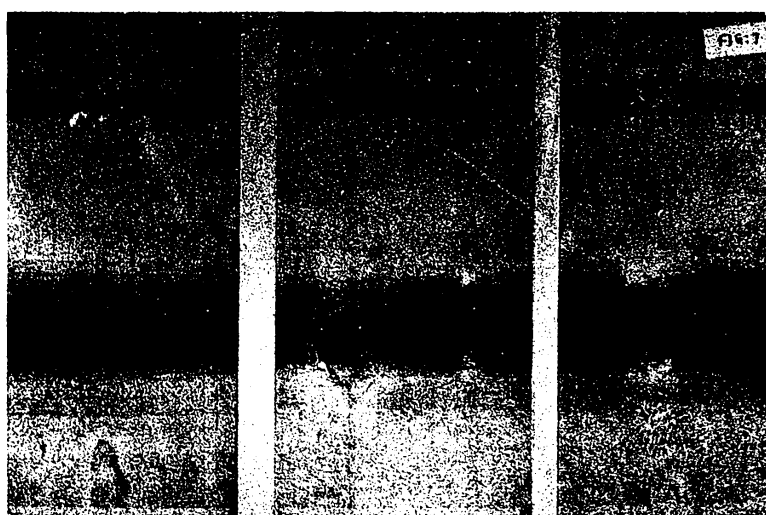


Fig. 7 Suspected man made structure at about 22 m water depth off Poempuhar.

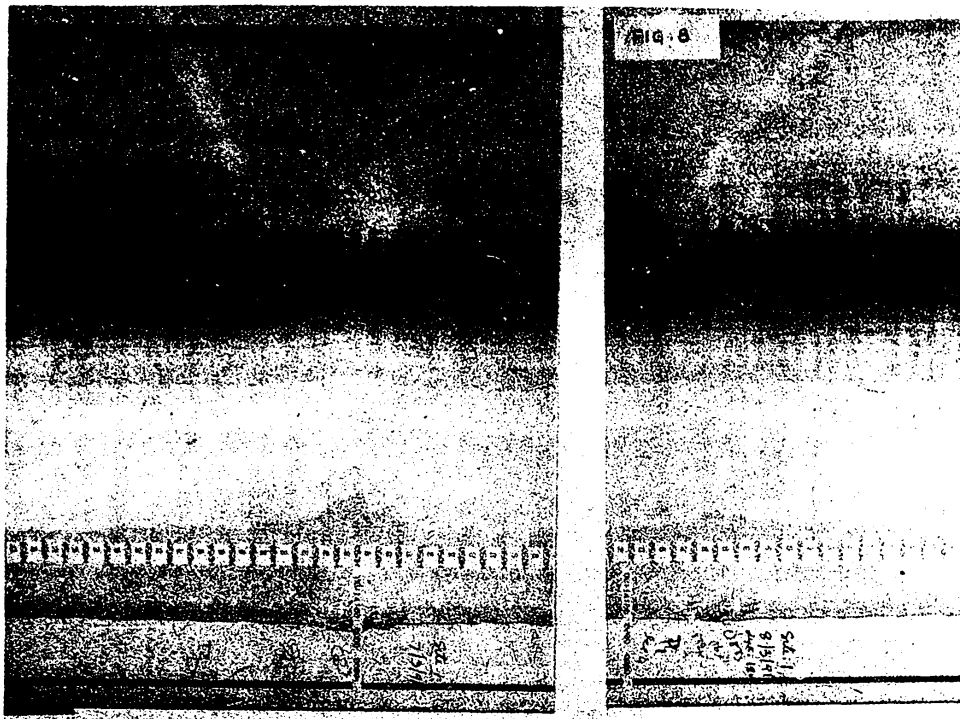


Fig. 8 Ship wreck at about 19 m water depth off Vanigiri (Kaveripattinam).

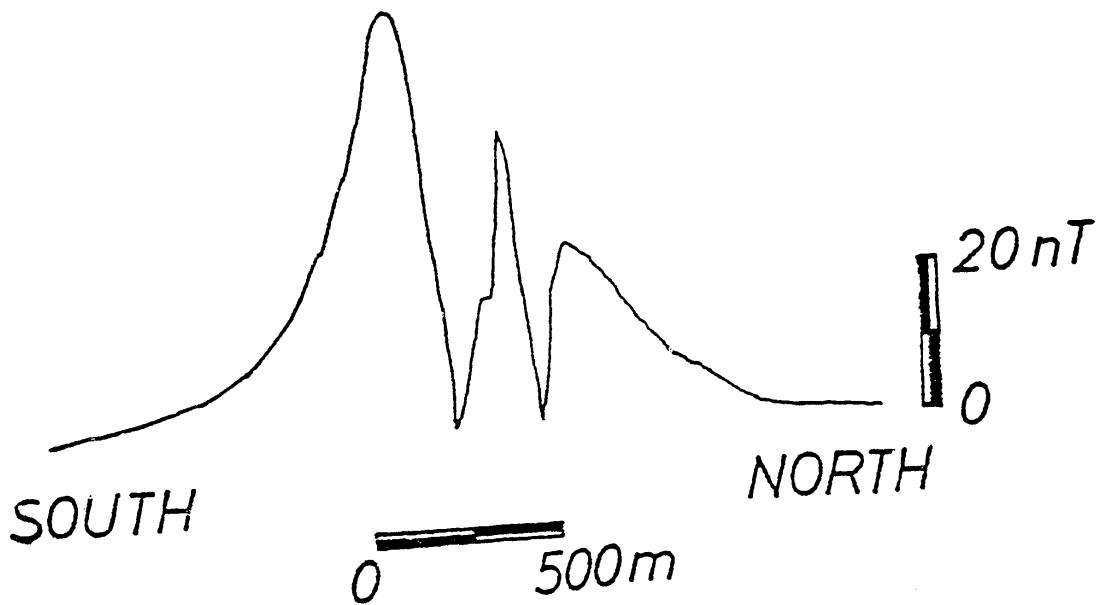


Fig. 9 Magnetic anomalies over the shipwreck off Vanigiri (Kaveripattinam).

existence at these depths. Confirmation of these structures will also pave the way to conduct more detailed archaeological investigations in this area to locate the structures of the submerged Poompuhar city as reported in the Tamil Sangam literature.

Side Scan Sonar, magnetic and bathymetric surveys are also carried out both parallel and perpendicular to the coast between 18 and 19 m water depth off Vanigiri (Kaverippattinam). Echograms have recorded the topographic relief of more than one metre. Side Scan Sonar recorded two images (fig. 8) adjacent to each other, separated by about 10 to 15 m. One of them is fairly big while the other is very small in size. Magnetometer recorded sharp magnetic anomalies (fig. 9). The peak to peak amplitude of the anomaly varies from 40 to 50 nT. Diving operations in this area confirmed the presence of a shipwreck which is partially submerged and partially exposed over the ocean floor. Lead ingots with the inscriptions "W. Blacket, 1791" were also recovered from this area.

Thus the geophysical surveys have proved not only to be cost-effective but also highly successful in locating the underwater objects of archaeological importance. However, position location with high precision should form the integral part of these surveys to make a better definition and presentation of the objects located during the surveys.

Geophysical surveys were undertaken over the continental shelf of Visakhapatnam in connection with our R and D investigations and the mineral exploration. The magnetic surveys over the inner shelf recorded some isolated sharp magnetic anomalies off Bhimilipatnam, Samalakonda and Pudimadaka Bays at the water depths varying between 8 and 20 m (Rao, 1988). The peak to peak amplitude of these anomalies ranges between 40 and 80 nT. The shape and nature of these anomalies do not appear to have been produced by any normal geological formations and they might have been produced by some isolated objects. No Side Scan Sonar and diving operations are conducted in these areas to confirm that these anomalies are caused by objects of archaeological significance.

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