The Research Laboratory for Archaeology

Cape Andreas Expedition 1969

by

Jeremy N. Green B.Sc., B.A.,

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SUMMARY

The first part of this report deals with the work carried out in Cyprus by the Research Laboratory for Archaeology Cape Andreas Expedition. The purpose of this expedition was to survey the sea bed around Cape Andreas and the Klidhes Islands for wrecks and artifacts of archaeological interest. The survey methods used to locate and chart the underwater depth contours are described together with the methods used to search for the wrecks. A description of the wreck sites located and artifacts raised is given, and the more interesting examples are illustrated. The location of the various anchors are shown on a large scale map together with the wreck deposit positions. The more interesting anchors are described and illustrated.

The second part of the report describes the various instruments developed by the Research Laboratory for Archaeology for underwater surveying. These instruments are compared with other instruments available for the same purpose; the principles of operation of all the instruments are described and the commercial applications outlined. Development projects for the various Laboratory Instruments are discussed and their relative commercial merit compared with other instruments. Research work and field trials, carried out at Cape Andreas and other sites during 1969, are described.

Summary

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INTRODUCTION

Before describing the activities of the expedition at Cape Andreas it is relevant to discuss why Cape Andreas was selected for an underwater archaeological survey. Firstly the Research Laboratory for Archaeology has enjoyed a friendly relationship with the Department of Antiquities in Cyprus for a number of years, and has been involved in various underwater projects in Cyprus for the previous two years. In 1967 an expedition led by M. Katzev of the University of Pennsylvania Museum undertook a reconnaissance survey around the coast of Cyprus to locate areas of underwater archaeological interest (Bass & Katzev 1968). Dr. E. T. Hall, the director of our Laboratory, and myself were invited to join this expedition. One of the areas visited by the expedition was Cape Andreas and in less than one week three wrecks were located. Before further survey work could be carried out the Expedition was invited by a Kyrenian sponge diver, A. Cariolou to inspect a wreck at Kyrenia. This wreck in 27 metres of water proved to be in an excellent state of preservation, and a survey was immediately carried out (see Green *et al* 1967) with the intention of excavating in the following year.

Thus Cape Andreas remained relatively uninvestigated and appeared to be the most promising site in Cyprus. At the end of the 1968 season at Kyrenia it was decided to organise a survey expedition for the following year to search systematically around Cape Andreas for wrecks.

Since the main interest in wrecks, from the archaeological point of view, is to survey and to excavate, there is a maximum depth beyond which it becomes uneconomic and dangerous to do this work using conventional compressed air diving techniques. The general limit is about 50 metres, as at greater depths excessive decompression times and increasing effects of nitrogen narcosis restrict work. Therefore any search planned for Cape Andreas would for the moment be limited to water shallower than 50 metres. Inspection of the Admiralty Chart No. 796 of the area showed that the 50 metre contour encloses an area approximately 500 metres wide by 8km long, (See fig 1). It was immediately clear that a considerable proportion of the area could be covered in the period of a normal expedition.

It was obvious however that a large scale map of the area was needed, and as no suitable map was available, the Department of Lands and Surveys provided us with aerial photographs, (see Plate 1), from which a 1:5000 map was constructed. The Admiralty chart did not provide enough information of the depth to enable the 50 metre contour to be located accurately on the large scale map, so that the first priority of the expedition would be to conduct a hydrographic survey of the area.

Various plans were discussed on how most effectively to conduct the underwater search but it was decided to inspect the area and find out the local conditions before deciding on how to operate the divers' survey. On the first of July the Expedition departed for Cyprus.

ACKNOWLEDGEMENTS

Jeremy Green

I would first like to thank Dr. E.T. Hall for his constant encouragement and assistance in the organisation of this Expedition, together with the assistance and facilities provided by the Research Laboratory for Archaeology. My thanks to Shaun Wittaker who organised the surveying, David Squire who catalogued and photographed the pottery and Nick Hawley who printed the photographs. Also to the other members of the expedition, both diving and non-diving members, Keith Harvey, Ian Hunter, Tom Lampl, Keith Murrey, Miss Pamela Phizacklea, Miss Myra Stanbury, Pat Sutor. Special thanks are due to Martin Gledhill who took on the tedious task of treasurer and to Miss Anne Corben for her help in correspondence and maintaining the expedition record book.

For the work in Cyrpus I would like to thank Christomos Athenasi, without whose help we would not have achieved what we did. Also Nikos Charalambos, the local Customs Official, who helped us on numerous occasions, and the members of the Apostolos Andreas Monastery whose gifts of fruit and vegetables were sincerely appreciated. I would like to thank Andreas Cariolou for his advice and assistance and finally Dr. Vassos Karagorgis the Director of Antiquities for helping us to obtain permission to work at Cape Andreas and thus making the whole thing possible.

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The Royal Geographical Society	£ 50 (plus loan of £500 worth of equipment)
The Society of Antiquities	£ 25
The Institute of Electrical and Mechanical Engineers	£ 20
George Wimpey & Co. Ltd.	£ 10 10
The Rubery Owen Trust	£ 7 7

We wish to acknowledge the help and co-operation of the Westminster Bank, Oxford in the handling of the expedition account.

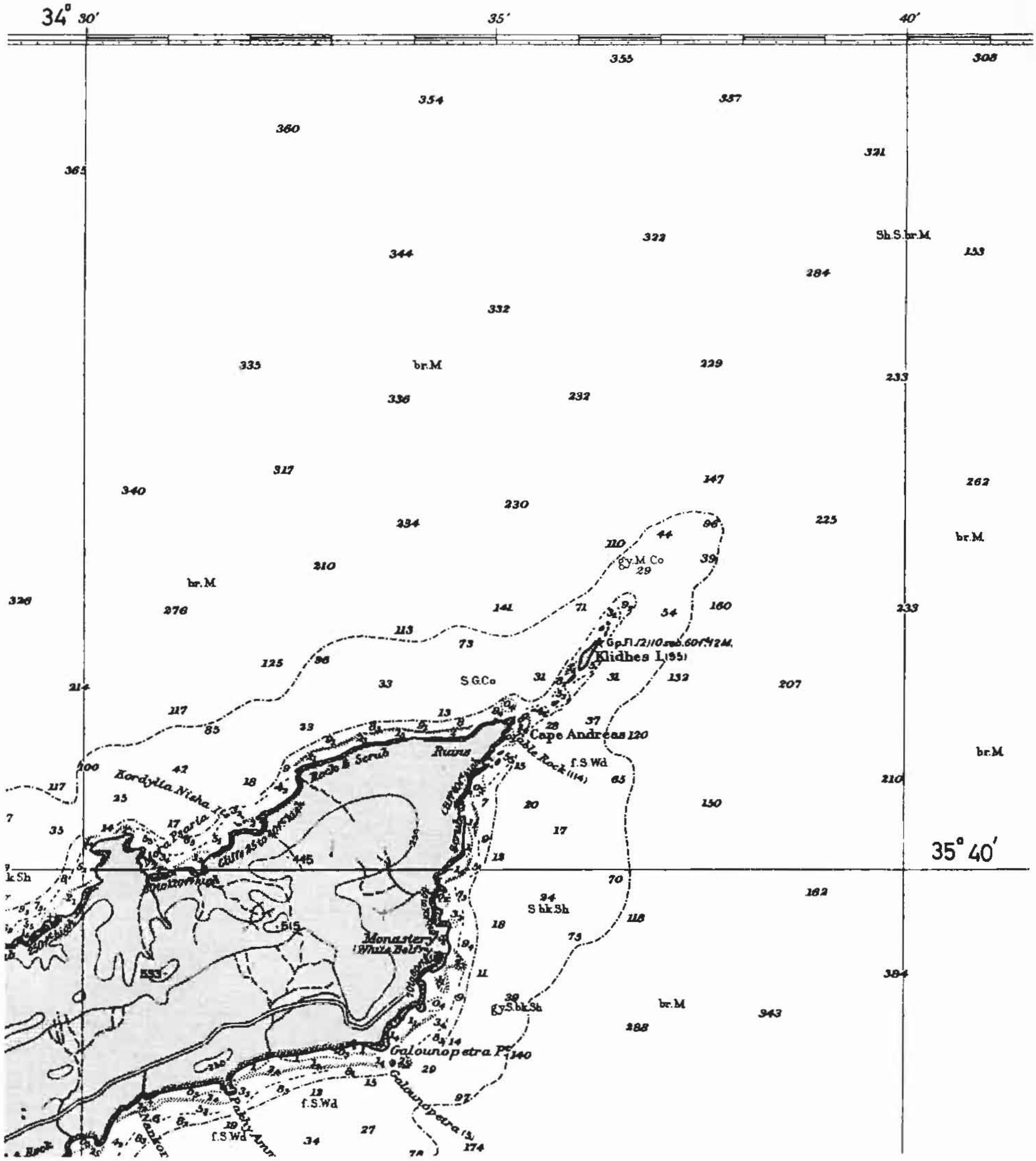


Fig. 1
Cape Andreas, taken from Admiralty Chart 796
N.E. Cyprus, Stazousa Point to Cape Eloea. Natural Scale 1: 100,000

Chapter 1 THE AREA

Cape Andreas lies at the north eastern extremity of Cyprus at the end of the Karparsia Peninsula. A chain of islands, the Klidhes, extends from the Cape following the axis of the peninsula. The Monastery of Apostolos Andreas is situated on the southern side of the peninsula approximately 3 kilometres from the Cape; from the monastery a motor road leads to the nearest village Risokarpaso.

Cape Andreas is described in the Geography of Strabo as follows : "Then to a promontory and a mountain. The mountain peak is called Olympus and has a temple of Aphroditê Acraea which cannot be entered or seen by women. Off it and near it lie the Cleides as also several other islands." The mountain peak is presumably the table rock located exactly at the extremity of the Cape, it is referred to by the locals as the 'Castle'. There is little evidence left of the temple of Aphroditê except for a few foundations and a marble column drum. The remains of a lime kiln at the foot of the 'Castle' indicate the fate of the temple. Around the base of the 'Castle' Neolithic settlements and hut circles may be seen. The expedition camp was established on the North of the Cape on the rocks overlooking a small bay. The bay was used as an anchorage for the boats, except when the wind was from the North when anchorage was made in the lee of the Cape.

The ten islands that extend from the Cape are uninhabited, as is most of the area around the Cape. The first island is separated from the mainland by a narrow channel only a few metres wide, and it was just possible to take the rubber boat through the channel in calm weather. This island is a rough 'hog's back' shape and is of a coarse conglomerate rock. It is the second largest of the ten islands and has very sparse vegetation. The second island is flat, being just a few metres above sea level. The third island or 'high' island is about 15 metres high and made of very hard rock with numerous fissures and small pools, from which sea salt is collected by the local fishermen. On the highest point of this island a prominent rock has been whitewashed; we were unable to find the reason for this, but it serves as a very distinctive land mark from the sea. The fourth and fifth islands are again flat and similar to the second island. The sixth, or 'lighthouse' island is the largest and about 70 metres high with an automatic lighthouse situated on the Eastern end. This was the only island with signs of habitation and reasonable vegetation. The presence of reeds on the northern side of the island indicates the existence of fresh water, also in this area are numerous pottery sherds of unknown date. The group of four islands at the end are all low lying and mark the most easterly projection of Cyprus and the Klidhes Islands. This then was the area that we investigated; the following pages outline the work carried out by the expedition both on land, on the sea and under the sea.

Chapter 2. SURVEYING

Shaun Wittaker

a. Introduction

As already mentioned little cartographic information was immediately available to the expedition concerning the North-Eastern tip of Cyprus around Cape Andreas, apart from Admiralty Charts at a scale of 1:100,000 (see fig. 1), which cover the area, but not in great detail. From the large scale map constructed from the aerial photographs by N. Hawley at the Laboratory it was planned to plot the positions of the underwater contours and station points accurately

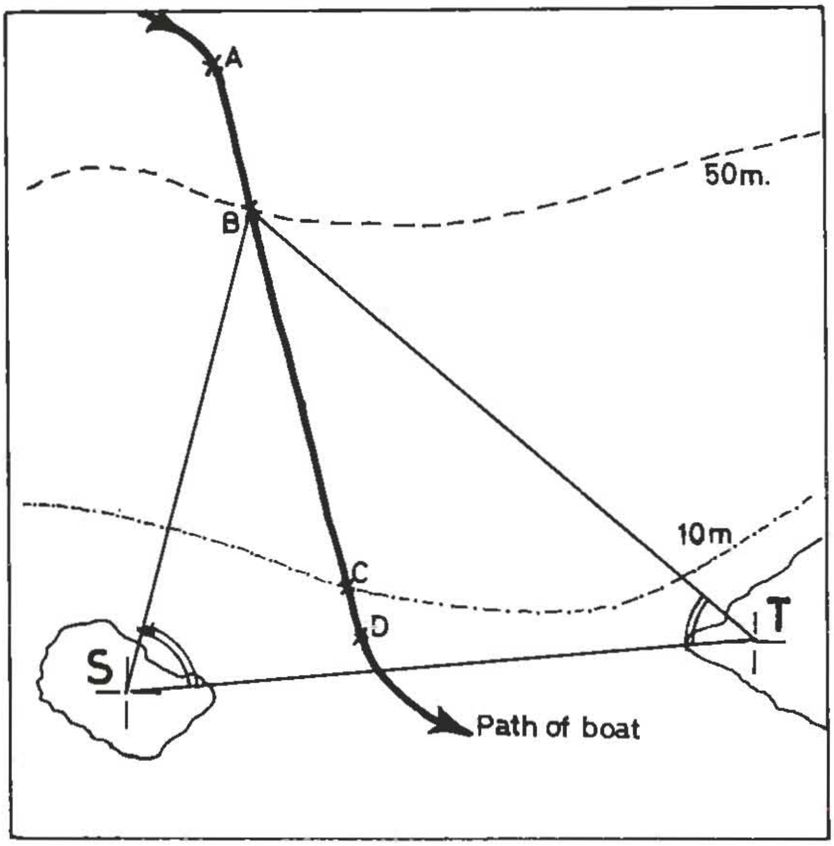


Fig. 2a
Theodolite stationed at T Sextant at S, position of 50 metre contour B is located by measuring angles TŜB and SŤB.

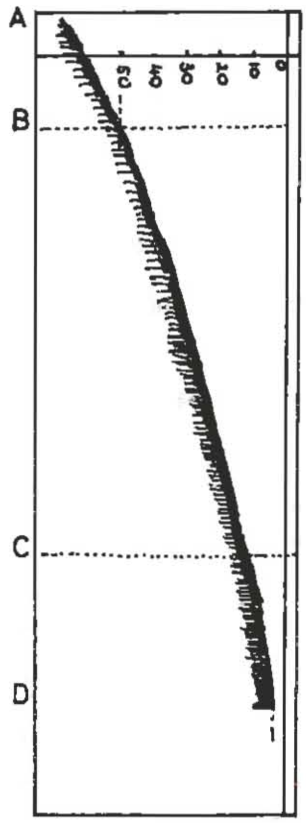


Fig. 2b
Echo sounder trace corresponding to path of ship 50 metre and 10 metre depths marked.

and more importantly, to record the location of the wrecks. From this base map showing the extent of the mainland and islands around Cape Andreas, it was possible to superimpose the detailed information which came out of the surveying.

b. Hydrographic Survey

Once station points had been established it was possible to continue the surveying and attempt to delineate the depth contours of the sea bed around the mainland and islands. For our purposes we only required knowledge of the underwater contours above 50 metres, since this was the range of the survey.

Technique for the Hydrographic Survey

Using a Ferrograph 'Offshore' 500 Echo-Sounder placed on a fishing boat we adopted a straight-forward method of determining and plotting underwater depth contours. While a theodolite and sextant were positioned on predetermined station points T and S (see fig 2a), straight-line runs were made with the echo-sounder from the 50 metre to 10 metre contour points. The boat commenced its run at A, beyond the 50 metre contour, its speed and direction remaining as constant as possible, and upon reaching the 50 metre contour B, a flag was raised on the boat. At this point the position of the boat was simultaneously recorded by the theodolite and sextant operators, (see fig. 2a). At the same time the echo-sounder trace Fig. 2b was marked so that the point at which the run began, B, was known and could be co-ordinated later with the readings of the theodolite and sextant.

Thus the position of the 50 metre contour was established by measuring the angles $T\hat{S}B$ and $S\hat{T}B$, and when transferred to the map, the intersection gave the 50 metre contour.

This system was continued throughout the echo-sounding with an average of 4 or 5 runs before it was necessary to move the theodolite and sextant to different station points as the boat went out of range.

After each echo-sounding session the co-ordinates of each run, were entered in the log book along with the reference number of the echo-sounder trace. The individual positions of each reading were then plotted on the map. To do this it was necessary to know the distance ST; determinations of these distances are described below. Assuming the distance ST is known the distance of each run was then measured. By correlating the distance on the map with the lengths of each run on the echo-sounder trace and by using proportional division, it was possible to plot the depths of the contours for every 10 metres between the 50 and 10 metre points.

Thus for each run plotted on the map there were the 50, 40, 30, 20, 15 and 10 metre points and all that remained was, when every run had been mapped, to join up the individual depth points to establish the complete pattern of contours around Cape Andreas (see fig. 3).

These echo-sounder runs gave a satisfactory picture of the lie of the sea bed although they did not reveal the small reefs and isolated submerged rocks of which there are a considerable number.

The validity of this technique depends on the boat travelling at a constant speed and in a straight line. For this reason the echo-sounding survey was only carried out on days when the sea was calm. It also depends on instantaneous signalling from the boat while readings were taken by the sextant and theodolite. The error was reduced to a minimum by taking the reading immediately the flag was raised on the boat, and by having an experienced boatman who had had considerable practice beforehand.

c. **Land Surveying**

After the station points had been established in the echo-sounding survey, it was necessary to survey their position so that they could be mapped and used to construct the hydrographic contours. The station points were surveyed in the normal fashion using reference objects which were clearly visible on the map drawn from the aerial photographs. Unfortunately there were only two reference objects which provided accurate positions on the map, namely the lighthouse on the largest of the ten islands and a small crop of rocks breaking the sea surface to the South of the third and fourth islands.

We used tachometry between the station points to measure the horizontal distance and to plot these points on the map. Secondary station points had to be established in this process because of great distance between the primary station points which created difficulties in sighting and taking accurate readings from the ranging pole. Tachometry was used primarily to verify the scale of the map made from the aerial photographs, since initially we were unsure of the correct distance between the islands as indicated by the scale.

After the echo-sounding and tachometry had been completed, the next stage was to map the swim lines which were completed and to locate any wrecks or artifacts which were discovered in the area. For this information, the same station points were used employing the theodolite and sextant to take readings on marker buoys which were anchored off-shore locating the extent of the swim lines and the position of finds.

Two major problems were incurred in the execution of the survey. The first was the need to carry out all surveying using the theodolite, during the early hours of the day, due to the heat haze near the ground which through the optical system of the telescope rendered accurate readings impossible. The second was the practical impossibility of continuing the tachometric survey across the length of all the islands. This was due to the fact that the distance between islands 2 and 3, and 3 and 4 exceed the 120 metre tachometry range of the theodolite. For this reason we relied on the intersection of readings taken from two points to give the position of these particular station points.

As a result of this work, which constituted a considerable amount of expedition time, the objectives of the surveying work were successfully attained. Detailed information on the hydrographic characteristics of the Cape Andreas coast was established together with the position of the wrecks and artifacts located. This information is not only useful for providing easy reference for relocation and investigation, but will be helpful for interested parties who may wish to follow up this work at a later date.

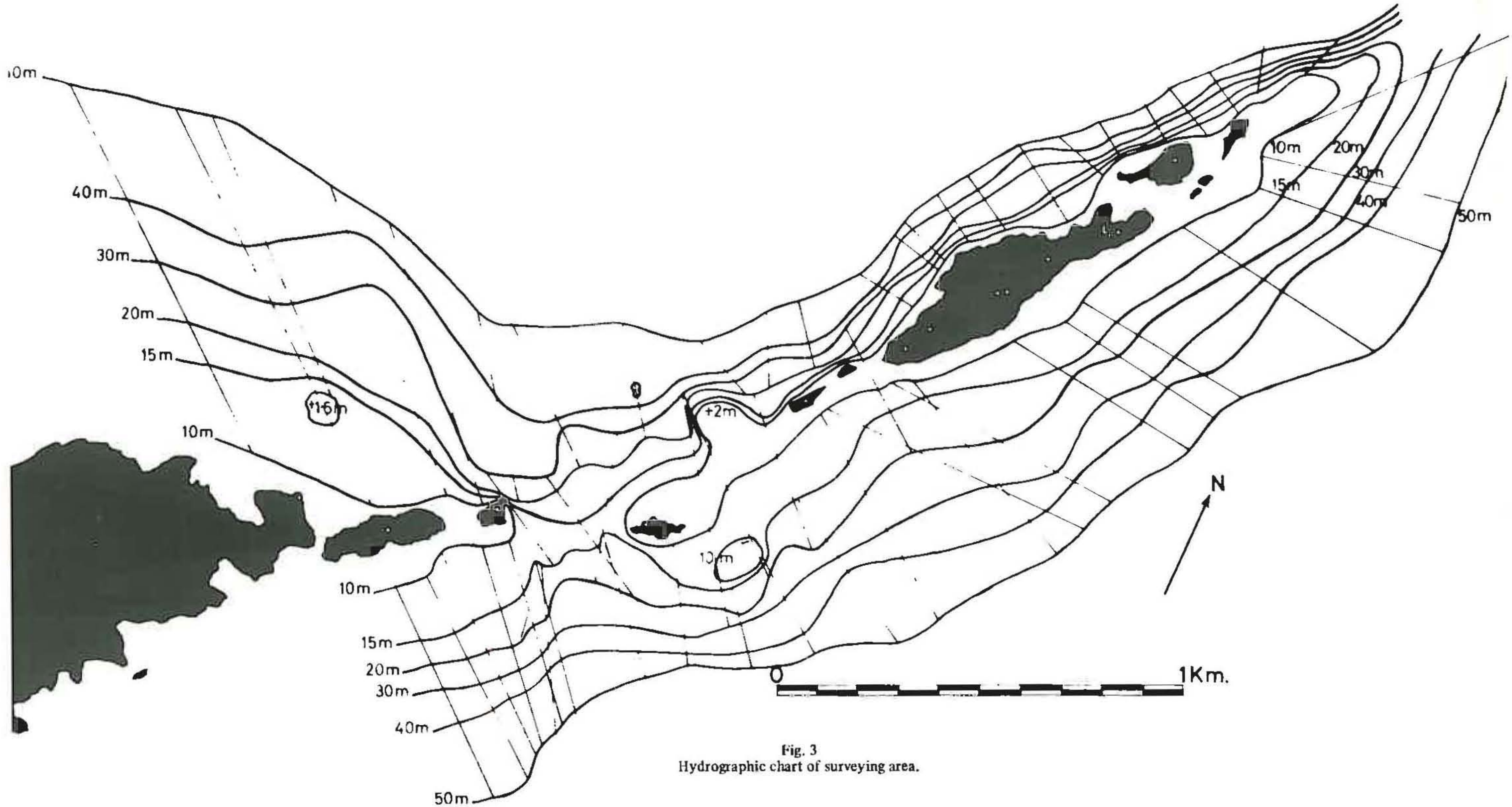


Fig. 3
Hydrographic chart of surveying area.

Chapter 3. THE UNDERWATER SEARCH

Jeremy Green

Several methods are available for locating archaeological wrecks, but fundamentally there are two alternatives; either one can search with divers, or one can use instruments. Unfortunately electronic methods are extremely expensive and our expedition was limited to using divers. However, as the search area was reasonably small and well defined, searching the sea bed with a small group of divers would, in this case, be very effective.

The methods of divers' search used at Cape Andreas were devised from a system described by S. Wignall in his report of the Search for the Santa Maria de la Rosa (see Wignall 1968). This technique was devised by Lt. Commander J. Gratton, R.N. and consists of a swim line with divers stationed at regular intervals along the line. The line is free to follow the general direction of the current, corrections can be made by a surface controller in a boat, who signals via a marker buoy line attached to various divers. The positions of the beginning and end of the swim line are determined by land transects. This system was excellent for searching the Blasket Sound in Ireland, as demonstrated by the eventual location of the Santa Maria de la Rosa; however each new situation presents a different set of problems, and as one would expect, Cape Andreas was no exception.

Firstly there was a 30 centimetre mean spring tidal range, and thus no tidal current, what little current there was usually ran in the same direction for several weeks. Secondly the area of search was so narrow that in most cases it was

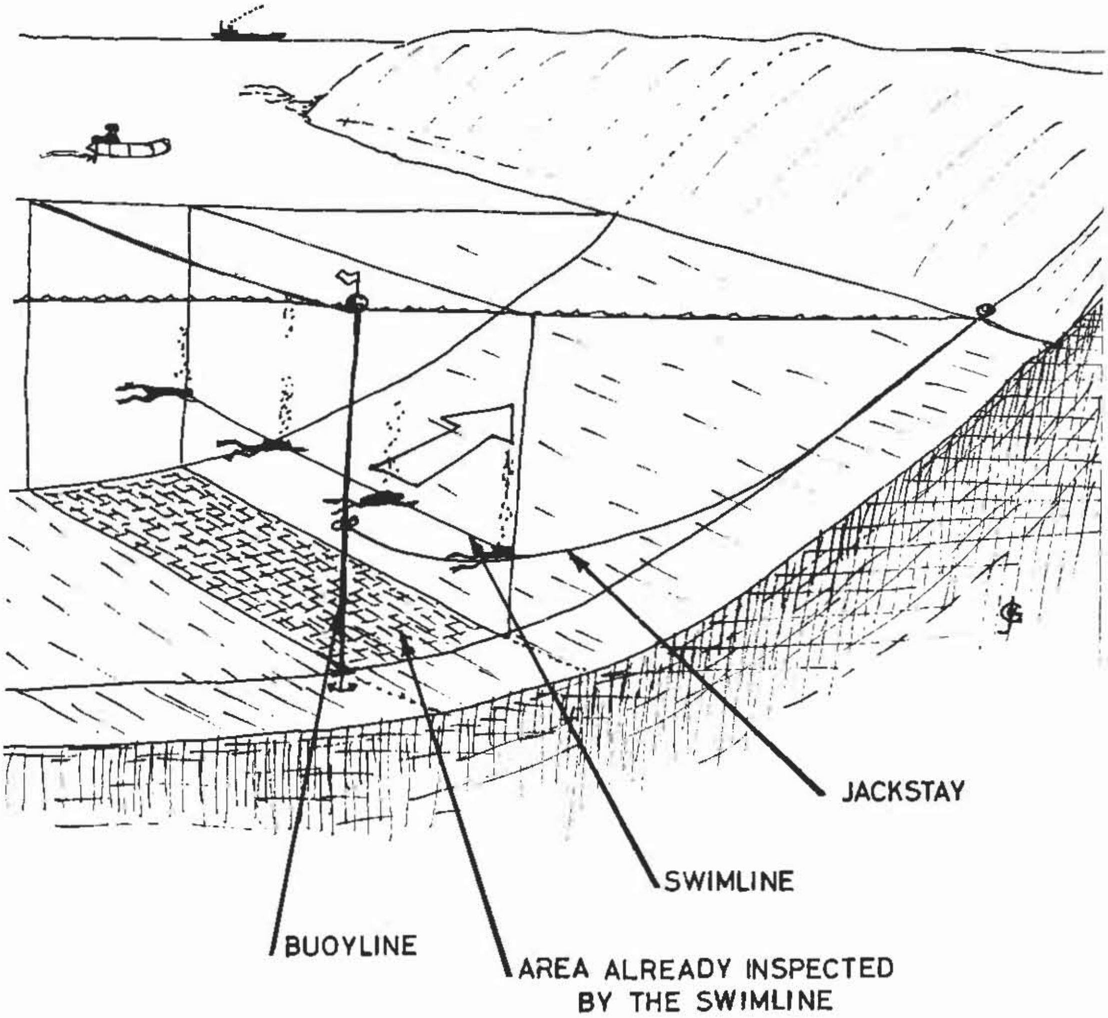


Fig. 4
Diagram of four man swimline

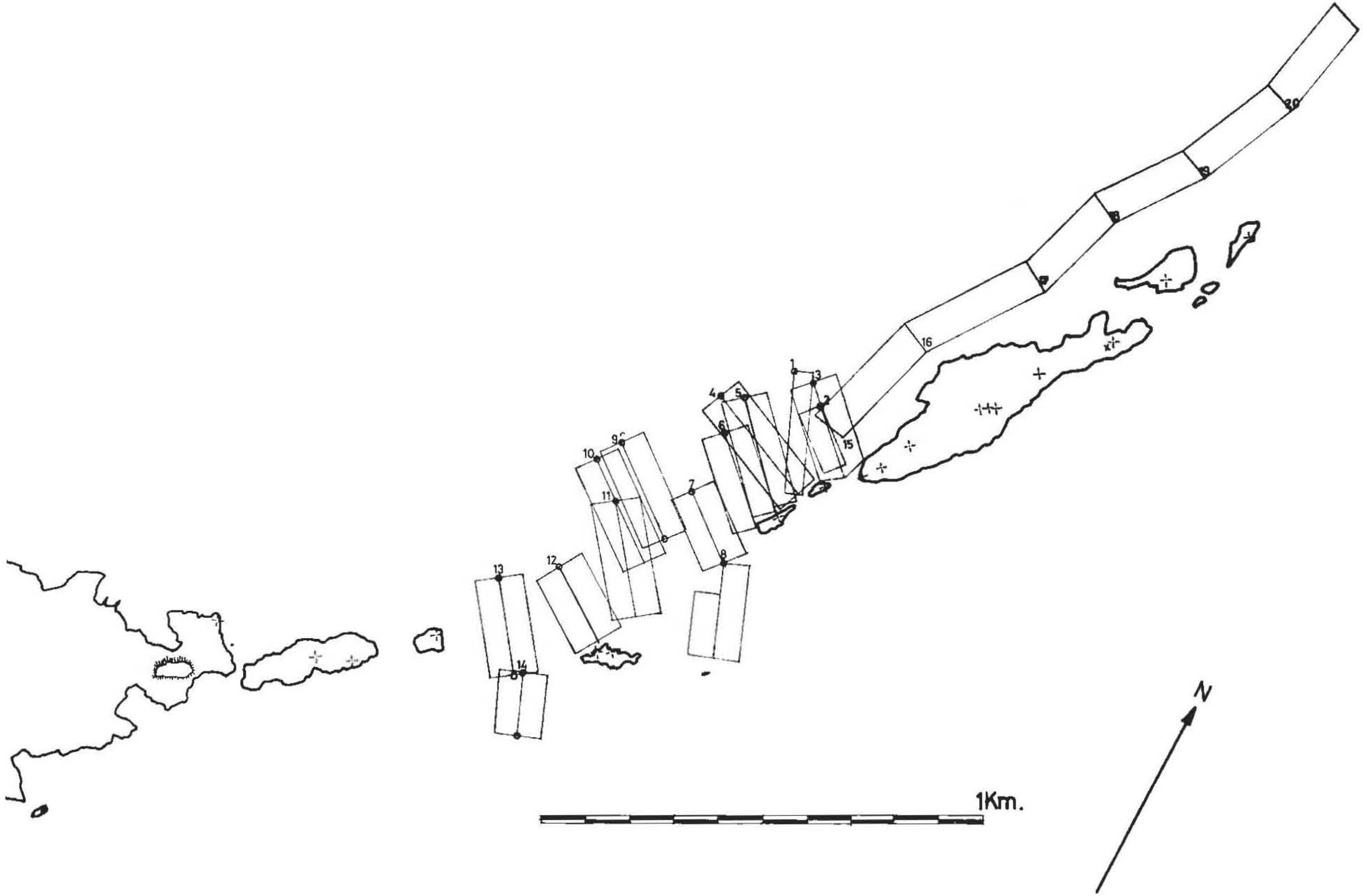


Fig. 5
Area covered by swimline survey.

possible to swim from the 50 metre contour to the shore in less than twelve minutes. As the maximum operating depth would be 10 metres above the sea bed, i.e. 40 metres, the computed dive time taking two safety factors was 13 minutes. Therefore the most sensible system seemed to be to operate the swim lines from the 50 metre contour to the shore line. Most of the divers, although trained to third class diver's standard, were to a certain extent novices, and thus it was important to keep the system as simple as possible. The eventual system adopted was that the swim line was guided by a jackstay stretched from the buoy marking the position of the 50 metre contour to the shore, so avoiding signal problems. The end diver on the swim line followed the jackstay and kept the swim line at right angles to it.

With such a small number of divers, eight in all, it was decided partially for safety, partially for simplicity, to use four divers on a swim line, the first group searching on one side of the jackstay, the second group on the other side. The visibility was usually very good, 30 to 40 metres in the horizontal direction, therefore to have a good visual overlap, divers were spaced at 20 metre intervals, making the total length of the swim line 60 metres, and the width covered approximately 80 metres (the arrangement for a 4 man swim line is shown in fig. 4). The swim lines were started at the end of the fifth island on the North side, with each successive swim line positioned 160 metres to the West; the beginning and end of the jackstays were surveyed using the theodolite and sextant as described in the section on Surveying Methods.

The procedure, after laying the buoy and jackstay, was to take the four divers out in the high speed inflatable boat, kitted up and ready to dive. The swim line was coiled on a drum and marked at 20 metre intervals, and the leading diver was dropped at the buoy holding the end of the swim line. The boat then ran parallel to the shore and the swim line was reeled out, as each marker passed out of the boat, a diver would drop into the water and swim to it. When all the divers were stationed on the swim line in the water, the leading diver would give the signal to dive. At this point all the divers would dive down to approximately 35 metres, the leader following the buoy anchor line, and picking up the attached jackstay line at approximately 25 metres. The whole line, then stationed at 35 metres, 10 metres above the sea bed, swam inshore. The lead diver following the jackstay kept the swim line at right angles to this, the remaining divers ensuring that the swim line was straight and taught. (see fig. 4).

After completing fourteen swim lines and covering the area up to the third island, it was decided to make a brief search along the North of the sixth island, up to and including the last islands. Because the 50 metre contour was so close to the island the swim lines were operated parallel to the shore. The approximate distance of the 50 metre contour from the shore was 150 metres. However, there was a steep cliff face falling away from the 10 metre contour, so that a single swim line was able to cover the area from the 50 metre contour up to the base of the cliff which was approximately 25 metres from the shore. This search which covered a distance of 1,200 metres or an area of nearly 10^5 square metres was completed in six swim lines. The total area surveyed in 26 dives covered an area of 6×10^5 square metres. The expedition compressors both failed on numerous occasions and our total effective diving time was reduced by 75%. Had we been operating with constant compressed air we would theoretically have been able to cover an area well in excess of $2km^2$.

During periods when there was no diving a snorkel survey was organised to investigate the shallow water around the islands. The same swim line principle was used to keep the swimmer's relative positions constant, and during the six week period at Cape Andreas we were able to survey all of the shallow water from 0 to 10 metres around the islands.

The finds are described in the sections on wreck sites and anchors, but it suffices to say that using the swim line technique eight wrecks and 56 anchors were located. No wrecks were found in good preservation, but as we were only able to survey approximately one quarter of the intended deepwater area, we feel that it is likely that deepwater wrecks do exist. It is hoped to continue this work at a later date and complete the search of the area.

Chapter 4. THE WRECK SITES

David Squire

All the wreck deposits found in 1969 lie on rock in quite shallow water (less than 25m. deep).

However, although none of them are in good enough condition to justify the labour and expense of excavation, neither are they so badly broken up as to be unworthy of study. In particular the looped handles and bronze objects are of interest and it is likely that the 'Y' shaped anchor 17–28 is the first one to have been found in association with a wreck deposit. All the sites are shown in fig. 6.

Nearly all the artifacts raised were badly concreted and had to be carefully chipped and scraped clean before the profile or any detail was revealed.

It should be pointed out that what follows is a preliminary report and little more than a statement of what the expedition found; a fuller report on the pottery will come later.

Site 1

Several lumps of concreted shards lay among large boulders in 4–6m. of water. Some lumps were composed of a mixture of fragments with handles and body shards clearly visible (plate 2), while others consisted mainly of amphora bases (plate 3).

Site 10

The wreckage lies 9–15m. deep on a rocky bottom strewn with large stones (see plate 4). There was such a variety of amphora fragments present that it was not immediately clear whether the site represented the destruction of one ship or more. The positions of sample artifacts were therefore plotted in the hope that this information would lead to a better understanding of the site, and it now seems likely that at least four ships were wrecked here between 6th century B.C. and 8th century A.D.; a bronze object was also found (plates 21, 22 and 23, and fig. 23).

Site 12

Many scores of roof tiles were strewn on the rocky bottom between 8 and 18m., (see plate 5) and the site clearly represents the destruction of a ship carrying these as cargo. The two bronze objects (plate 20, fig. 22), which were found on the deposit and three iron anchors found nearby are dealt with in the appropriate sections.

Site 14

Roof tiles were found scattered, together with some amphoras, at 25m. on a slightly sloping rocky bottom at the base of a submarine cliff. From the number of them one may conclude that they represent a cabin roof and not a cargo. Two types of joining tile but only one style of roof tile were present (see plate 6 and fig. 9).

Site 15

Widely scattered debris was found in the shallows South of the Cape. The site appears to be only an anchorage, but of interest are a stone object and concreted iron ring.

Site 16

Pottery and roof tiles lie concreted together in 7–9m. of water on a rocky bottom. Small bowls and tiles are concentrated at the East end of the site (see plate 7) while tiles and amphoras lie to the West.

Several minute pieces of green glass were found among one of these pieces of concretion when it was raised, and nearby a fragment of clear glass was found.

Site 17

Large piles of heavily concreted amphoras lay at a depth of 7–10m. (see plates 8 and 9). Small 'hour glass' shaped amphoras were prominent, suggesting a date near the seventh century A.D. for the wreck. Unfortunately there was not

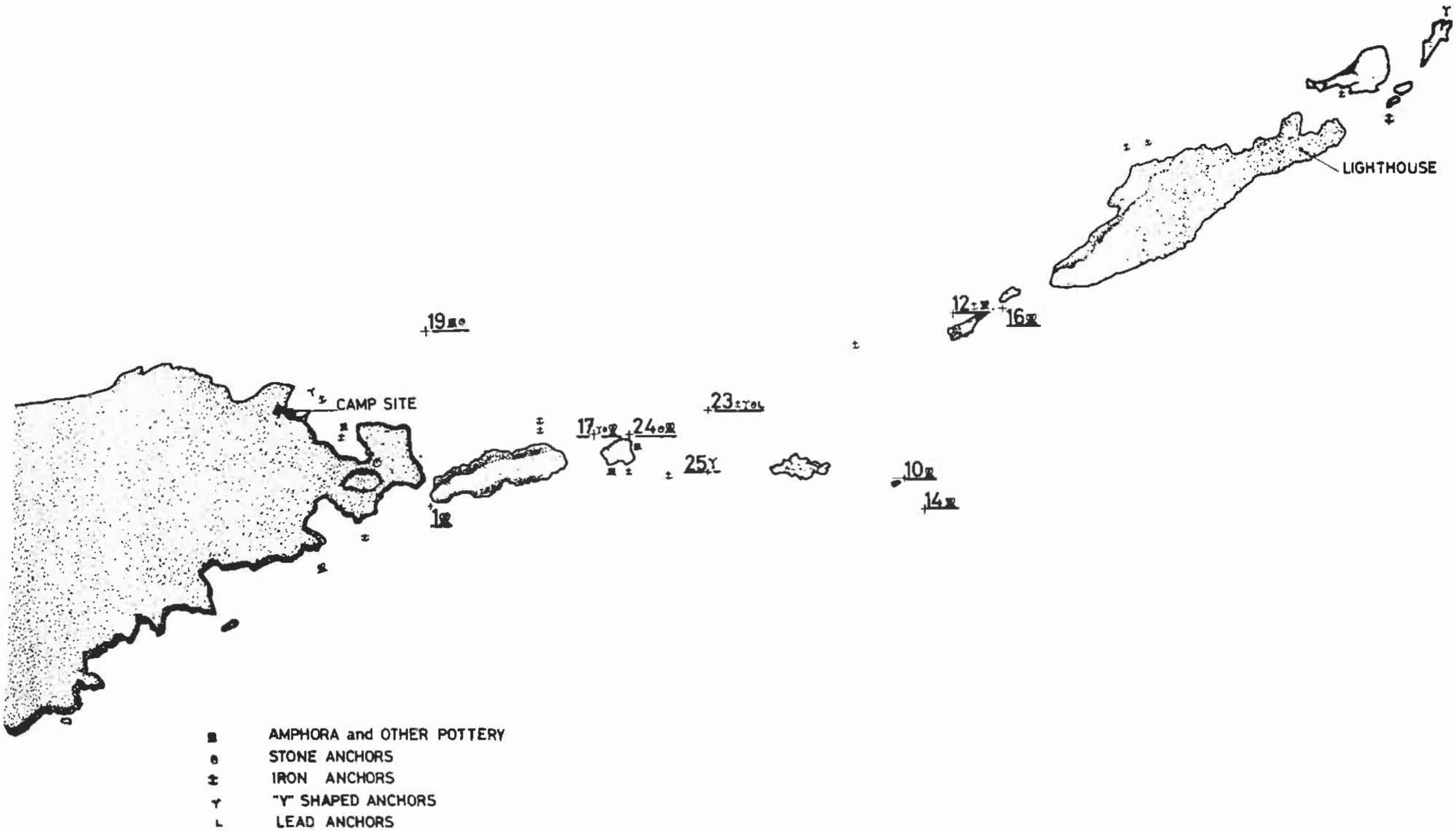


Fig. 6
Sites located in 1969.

time to chip one of these out from the surrounding concretion so only loose fragments could be raised.

Associated with this wreck deposit were four stone anchors and one small 'Y' shaped anchor. These are dealt with in the anchor section.

Site 19

On the Eastern side of a reef are two stone anchors and on the West are two heaps of heavily concreted and badly broken pottery (see plates 10 and 11). Both piles are about 5m. across, 8m. apart and in 9m. of water on a rocky bottom.

Looped handles are common on the site and one of these was raised along with a neck (?) or spout (?) and an amphora foot. A third stone anchor rests on one of the piles.

Site 24

Here wreckage has tumbled down a cliff and been caught in gullies and on ledges from 10–25m. Pieces of terracotta boxes (see plate 12) (possibly sarcophogi) are prominent among the cargo; however, they are badly smashed and although it is possible to reconstruct the end profile it is not feasible to estimate their length.

A complete small 'hour-glass' amphora was recovered from the sand at the base of the cliff and amphora necks and a foot were also raised. A stone anchor was also found on the site.

Chapter 5. POTTERY

David Squire

Note

All drawings are by the author and the reduction is 1/5. The number given at the beginning of each note about the figures is the number marked on the object; all material recovered has been deposited at the Cyprus Museum, Nicosia.

As this is a preliminary report, there has not been time to study the pottery and thus no attempt has been made at interpretation.

Figure 7. Pottery from site 10.

1. (CA69 10/4). Looped handle in light buff fabric. There were several similar pieces on the site and the two other examples which were raised were the same size and made of the same fabric, but differed slightly in proportions.

2. (CA69 10/3). Amphora neck in mid red fabric.

3. (CA69 10/6). Upper part of an amphora in dark red fabric.

4. (CA69 10/10). Bowl in creamy buff fabric.

5. (CA69 10/11). Small bowl in mid red fabric. Several similar small bowls were on the site and another which was raised was identical.

6. (CA69 10/7). Neck of a small jug. The fabric is creamy buff and of interest are the knob on the handle and raised decorations on either side.

7. (CA69 10/8, 10/14 and 10/15). Reconstruction of a lekanis. The fabric is mid brown/black with brown and black grits. There were several other fragments of similar vessels on the site.

8. (CA69 10/12). Small jug in fine dark red fabric.

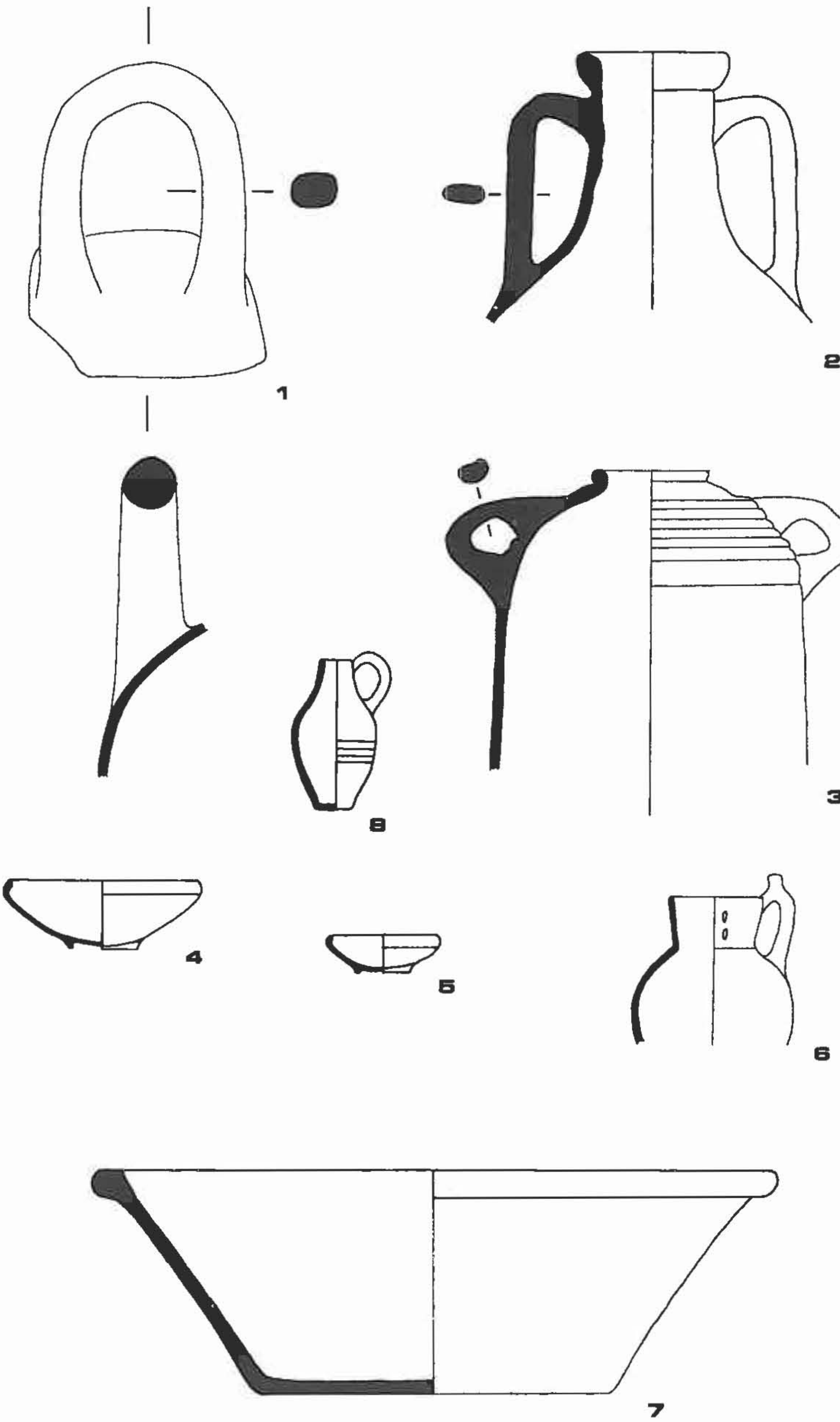


Fig. 7
Pottery from site 10.

Figure 8. Pottery from site 10.

1. (CA69 10/1). Amphora neck in mid buff fabric with a few brown and black grits. There is a groove in the handle.
2. (CA69 10/5 and 10/9). Reconstruction of neck and handles of an amphora. The fabric is brick red. There is a trace of bitumen in the groove around the neck – apparently for sealing a cap in place.
3. (CA69 10/16). Amphora neck in dark red fabric.
4. (CA69 10/7). Amphora neck in mid brown fabric.

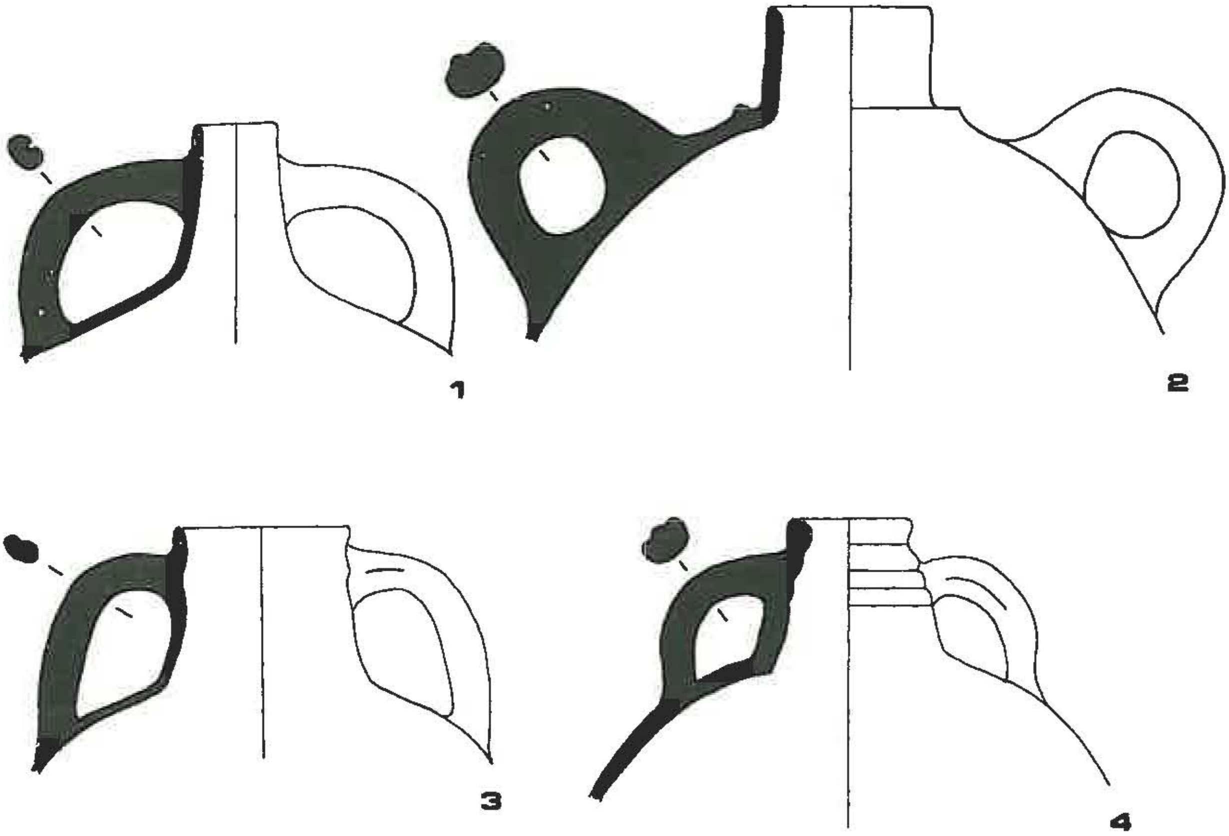


Fig. 8
Pottery from site 10.

Figure 9. Pottery from sites 12 and 14.

1. (CA69 14/1). Tile in light buff fabric.
2. (CA69 14/2). Joining tile in light buff fabric. Tapered at one end.
3. (CA69 14/3). Section of a fragment of joining tile. The fabric is the same as 1 and 2 above.
4. (CA69 14/4). Amphora neck in mid brown fabric.
5. (CA69 12/1). Section of tile fragment. The fabric is reddish brown with scattered brown and black grits.
6. (CA69 12/3).
7. (CA69 12/3). Sections of tile fragment in mid red fabric with many black grits.
8. (CA69 12/2). Section of joining tile fragment. The fabric is the same as 5 above.
9. (CA69 12/4). Section of tile fragment. The fabric is the same as 6 and 7 above.

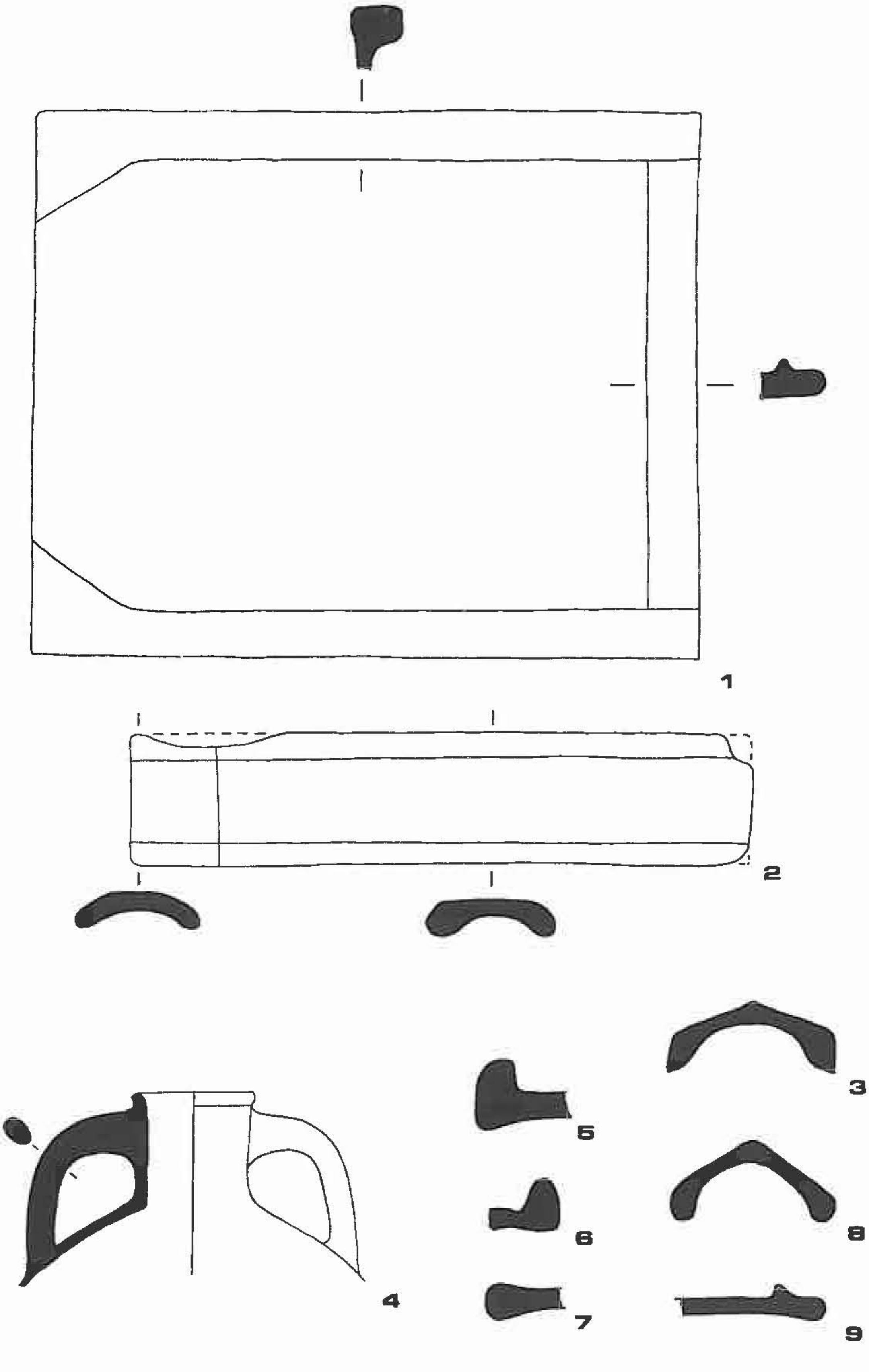


Fig. 9
Pottery from sites 12 and 14.

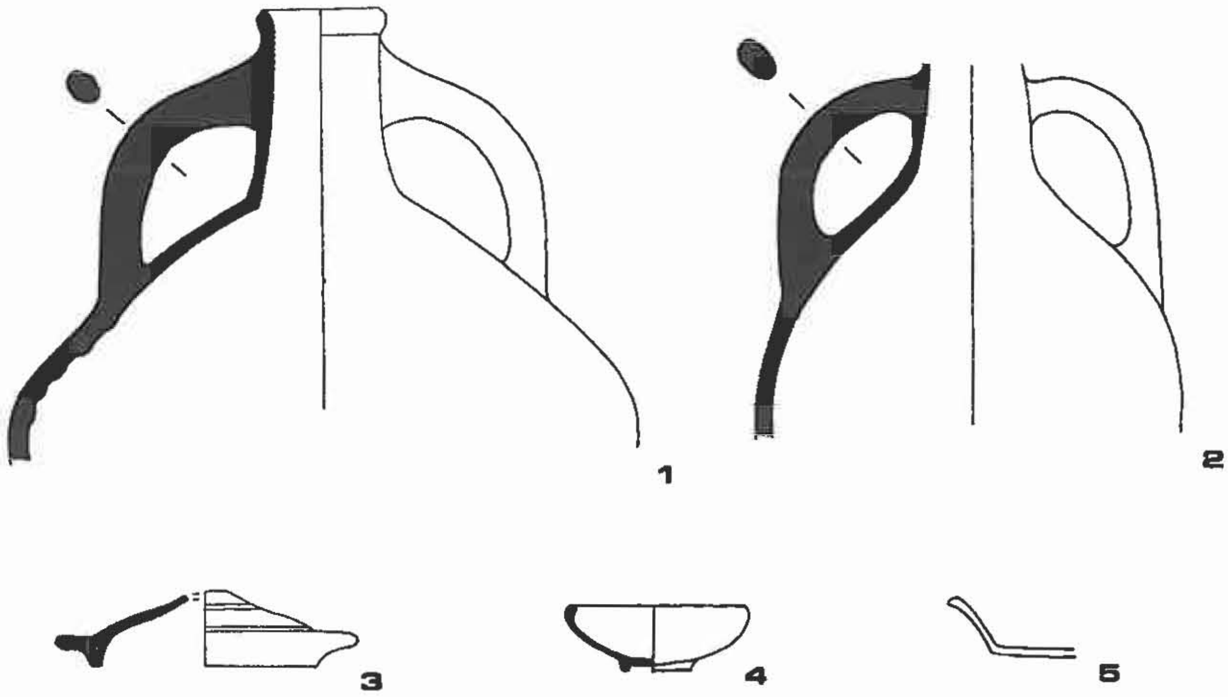


Fig. 10
Pottery from site 16.

Figure 10. Pottery from site 16.

1. (CA69 16/7). Reconstruction of the upper part of an amphora. The fabric is light brown.

2. (CA69 16/8). Amphora neck in reddish brown fabric. The lip is missing.

3. (CA69 16/1). Lid in fine mid/dark red fabric, with traces of black paint. A knob on the top appears to have been broken off.

4. (CA69 16/2). Bowl in fine dark red fabric. There were a number of similar bowls visible in the lumps of concretion on the site.

5. (CA69 16/3). Corner of a glass dish. The glass is clear and colourless and there were no bubbles. It was found at the edge of some concretion, whereas some minute fragments of green glass were found inside a lump of concretion which was dismantled.

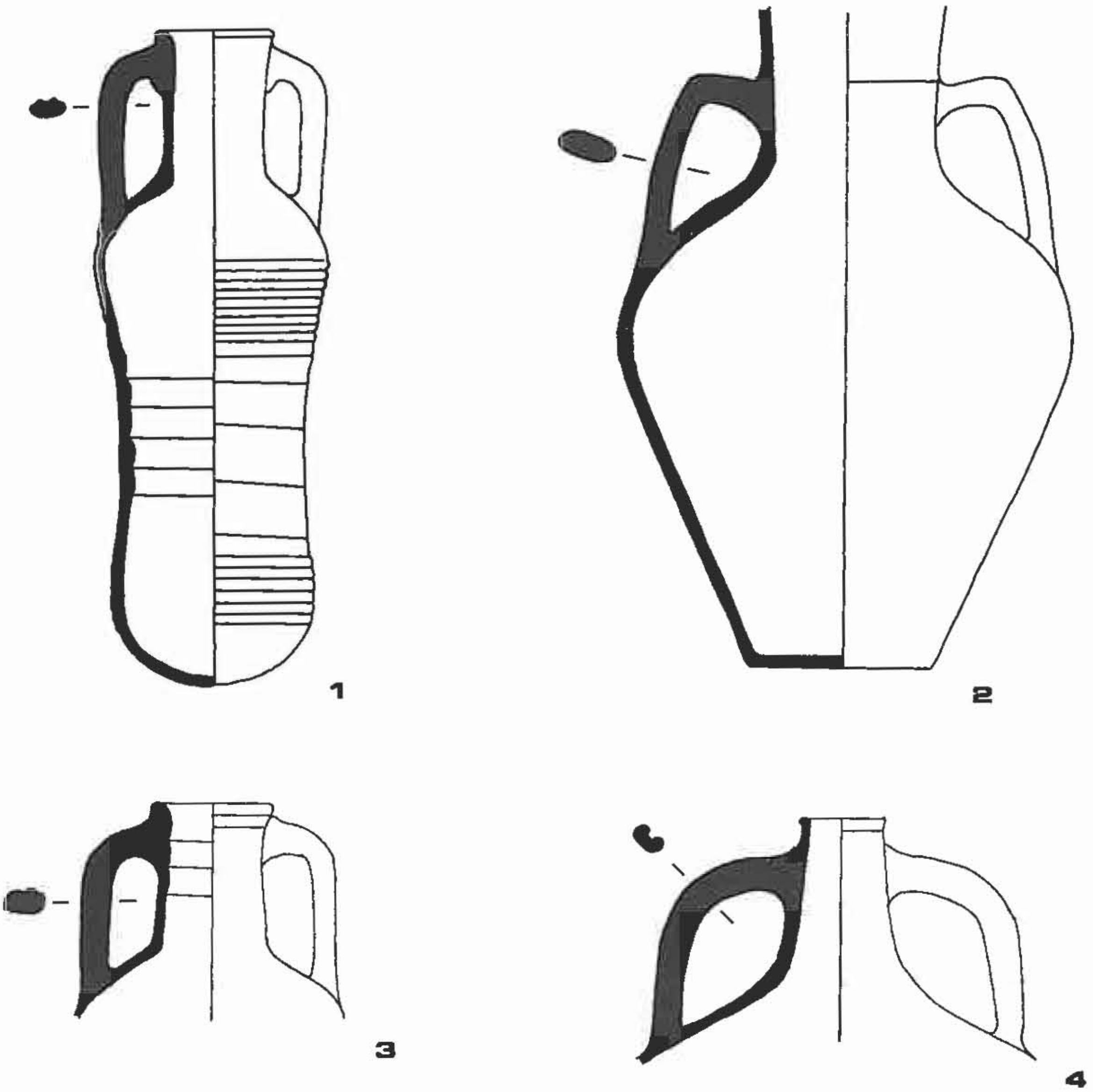


Fig. 11
Pottery from site 17.

Figure 11. Pottery from site 17.

1. (CA69 17/1 and 17/4). Reconstruction of an amphora. The fabric is light reddish brown with a few brown grits. Many more amphoras of this type lie broken and concreted together on this site.

2. (CA69 17/6). Domestic amphora in buff fabric with brown grits. The lip is missing. This amphora was found at the deepest part of the site and was not concreted on the sea bed; there was a modern fracture across the body.

3. (CA69 17/2). Amphora neck in reddish brown fabric with black grits. The form is similar to 1 above.

4. (CA69 17/3). Amphora neck in mid red fabric with a few grey grits.

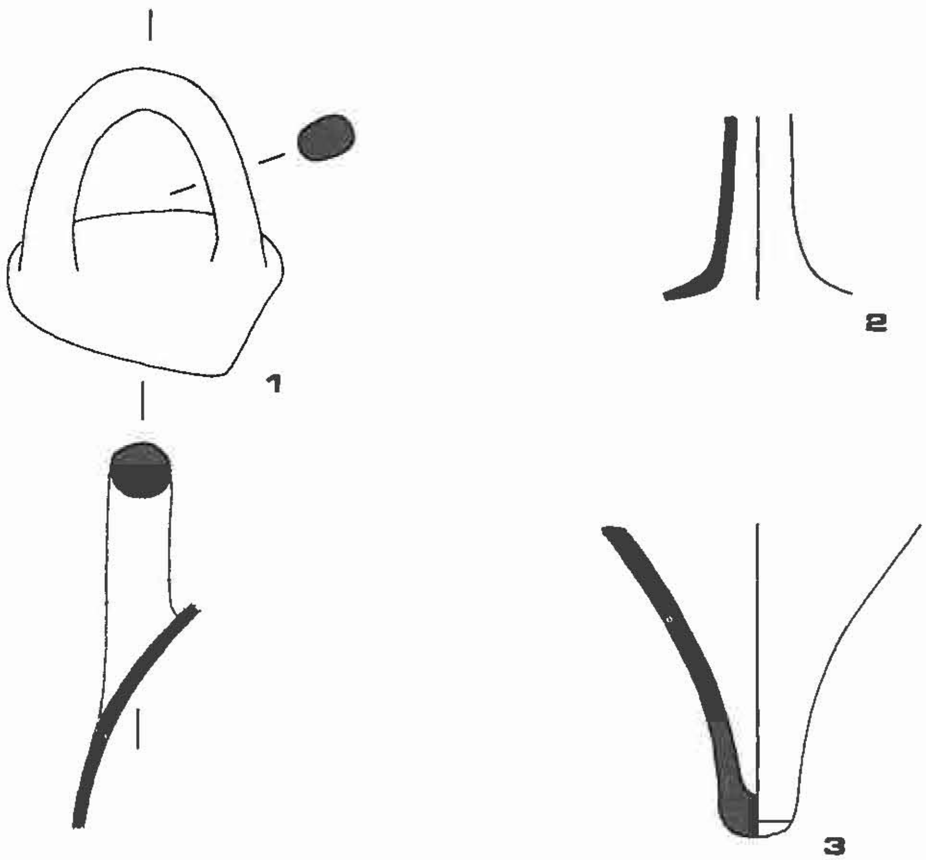


Fig. 12
Pottery from site 19.

Figure 12. Pottery from site 19.

1. (CA69 19/1). Looped handle. Reddish brown fabric with black grits.

2. (CA69 19/3). Neck (?) or spout (?) in reddish brown fabric.

3. (CA69 19/2). Amphora foot. Dark brown fabric with scattered black grits.

Figure 13. Pottery from site 24.

1. (CA69 24/1). Amphora in creamy buff fabric. This was found in the sand at the bottom of the cliff.

2. (CA69 24/3). Amphora neck in dark red fabric. This was found lying loose at the top of the cliff whereas other pieces mentioned here were recovered from gullies running down the cliff.

3. (CA69 24/2). Amphora neck. The fabric is reddish brown with grey and brown grits.

4. (CA69 24/5). Amphora foot in reddish brown fabric with a few brown grits.

5. (CA69 24/4). Amphora neck. The fabric is light brown with brown and black grits.

6. (CA69 24/8). Section of terracotta box end. The fabric was light red with scattered brown grits. This piece was 38 cm wide although other ends had slightly different widths. It was not possible to reconstruct a complete box because there were some missing side sections.

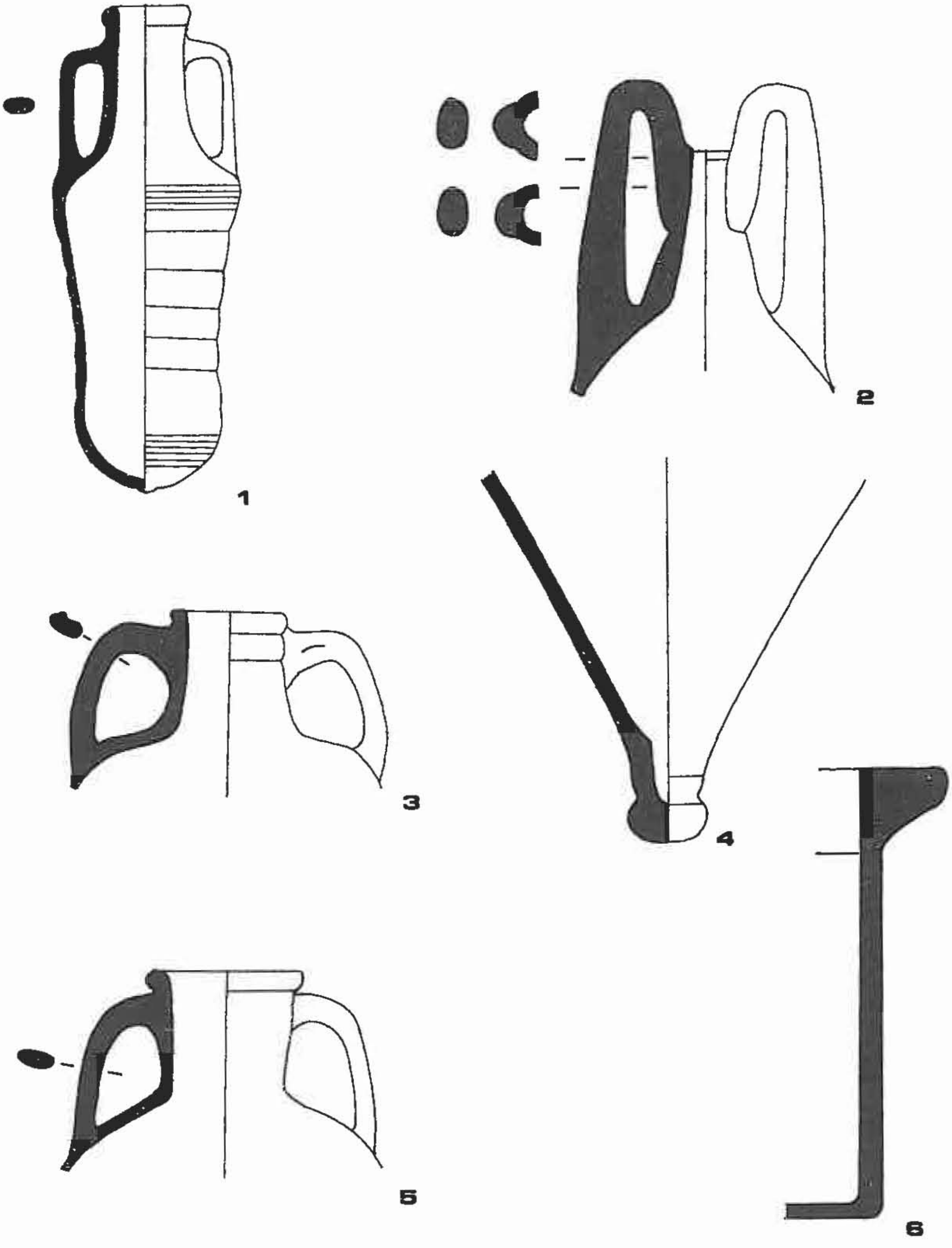


Fig. 13
Pottery from site 24.

Chapter 6. ANCHORS

Jeremy Green

A total of 56 anchors were located by the underwater search techniques; the locations of the anchors of particular interest were plotted by triangulation as described in the section on surveying. Photographs of the selected anchors were taken and measurements recorded. At one particular site a large number of anchors of varying types were located. This site (No. 23) was at a point where a rugged submarine cliff rose abruptly out of a flat sand sea bed, the anchors were mainly lodged in the rocks at the base of the cliff. The site covered an area 150 metres long by 50 metres wide, (see fig. 14).

The discovery of this site was made when the end diver on a swim line passed over anchors 1, 2 and 3 (see fig. 14). When this finding was investigated it was discovered that twenty-one anchors in all were located in the area. A systematic but unfortunately brief survey was made of the anchors, measurements and photographs were taken and the position of the site carefully recorded.

The majority of anchors were iron, three of these were of unusual construction having a 'Y' shaped appearance (No. 10, 12 and 17). Two unusually large anchors (No. 5 and 6) with shanks approximately three metres long were lodged in the base of the cliff. Six lead anchors were found. No. 1, 3 and 4 were of Roman type. The lead anchor No. 7 was of unusual construction, found partially buried in the sand at the base of the cliff. This is thought to be part of the stock of an anchor. This anchor is of particular interest since at the invitation of the Director of the Kyrenia Wreck Excavation the author was asked to conduct a metal detector survey around the extremities of the wreck. This survey was carried out early in the season before the start of the Cape Andreas survey; one large target was located at the north end of the wreck. Subsequent excavation revealed some lead objects. On returning to Kyrenia during the season the author was shown the objects, one of which was very similar to the lead object No. 7 found at Cape Andreas. It is now thought that the other parts of anchor 7 may be buried in the sand around the position where No. 7 was found, and a search with the metal detector would be of great interest. Three other lead objects 13a, 13b and 17 were found; these are all of similar construction, although different from No. 7, and together with No. 7 would not immediately be recognised as anchors unless they had been found in this particular site.

(N.B. The scale of the drawings of the anchors varies, all the lead and stone anchors are drawn at 1/10 full size, but the iron anchors are at 1/25 full size; in all the drawings a scale is included.)

The Sites

Site 12:– On the lower slopes of wreck site No. 12, three large iron anchors were located. The wreck site consists mainly of Corinthian type tiles and therefore one would not immediately associate the iron anchors with this particular wreck, since it is possible that the anchors were of a much later date. However, there are several interesting factors involved with the position of the anchors. They all lie on the rocks well above the sandy sea bed and point in the direction of the wreck and the island; the largest anchor 12–1 is shown in plate 19. Assuming that the anchors were cast from a ship about to strike the island, their position and size indicates that the ship would have been exactly over wreck site No. 12 and thus dangerously close to the rocks (the anchors are only 50 metres from the island). Either the anchors belonged to the wreck No. 12 or else they belonged to a ship that escaped striking the rocks by some extremely lucky chance.

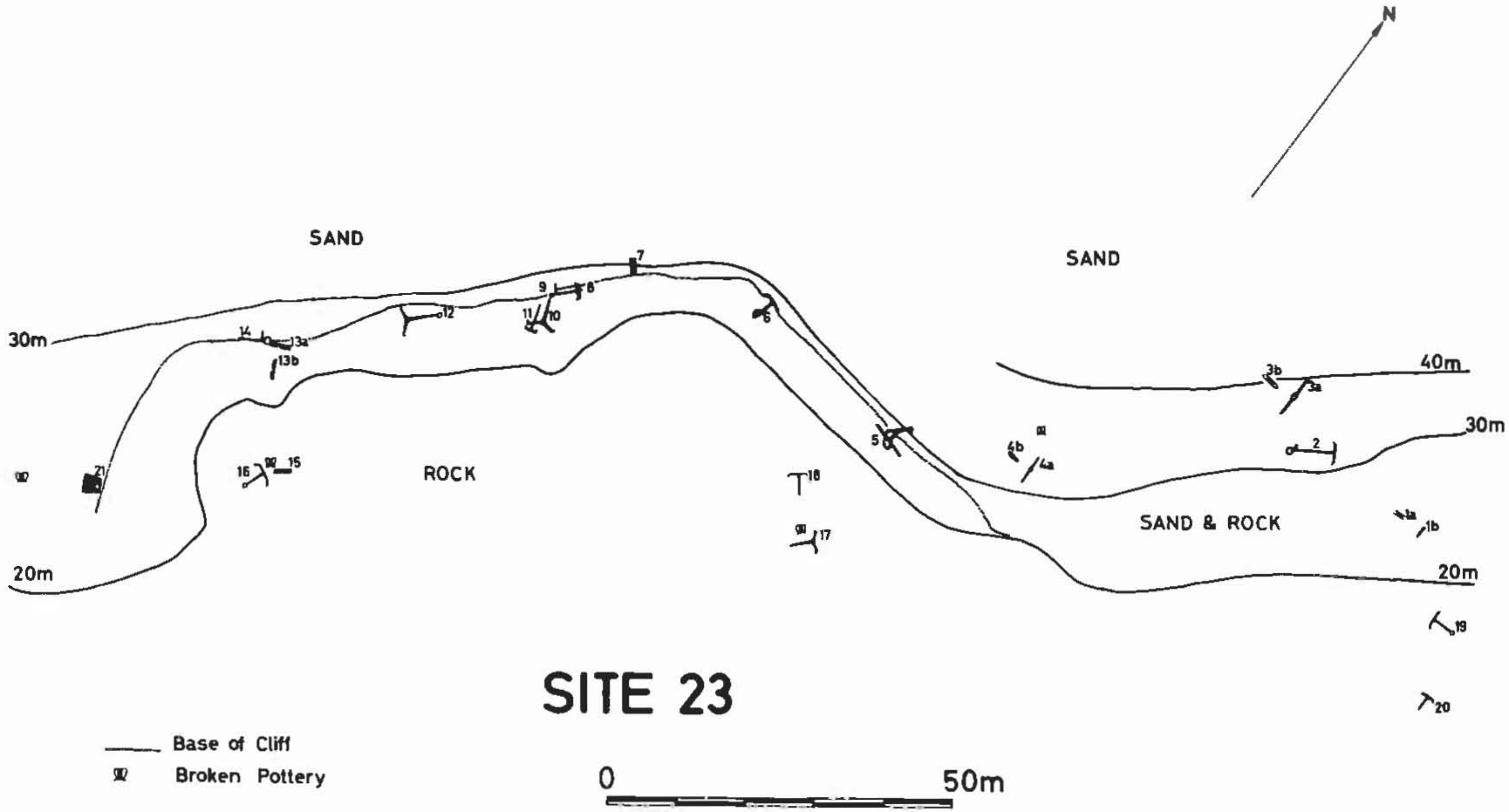
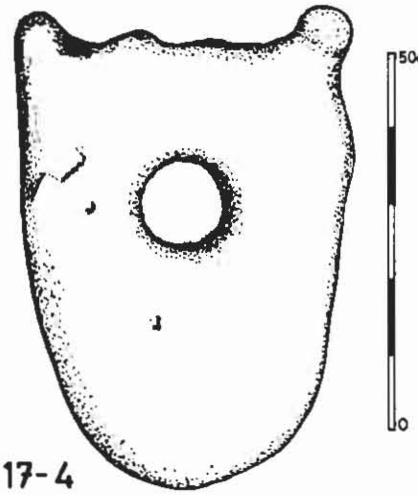
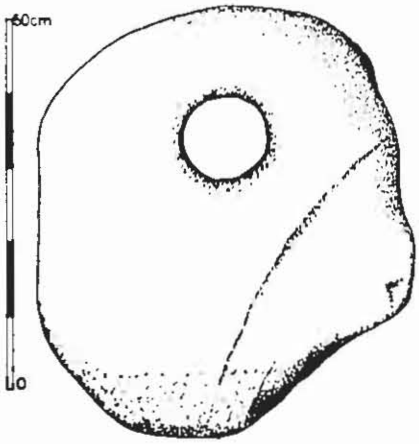


Fig. 14
Plan of site 23.

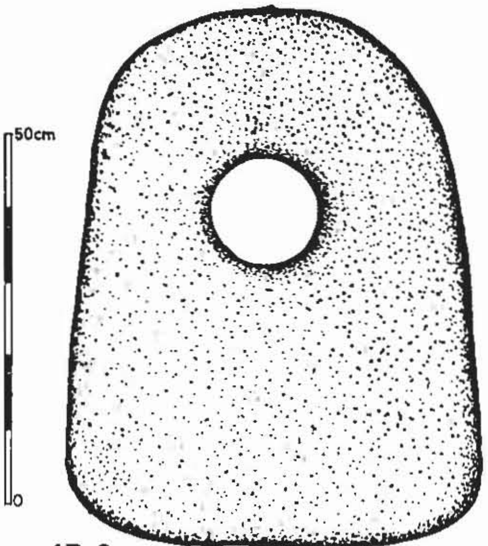
Anchor Catalogue



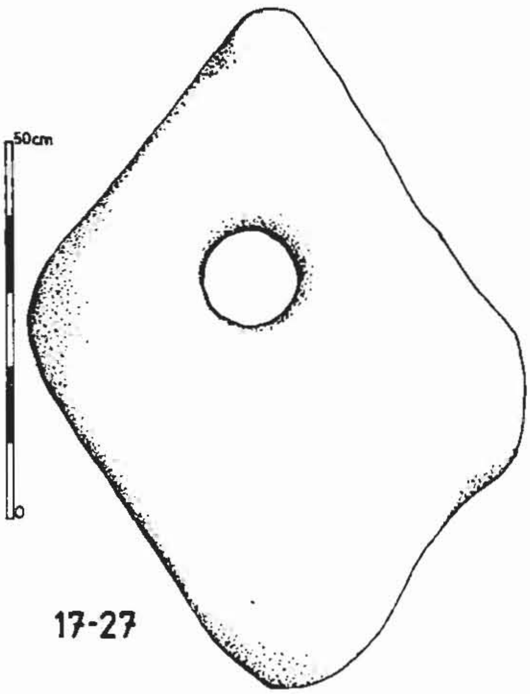
17-4



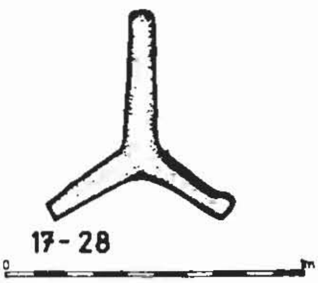
17-5



17-6



17-27



17-28

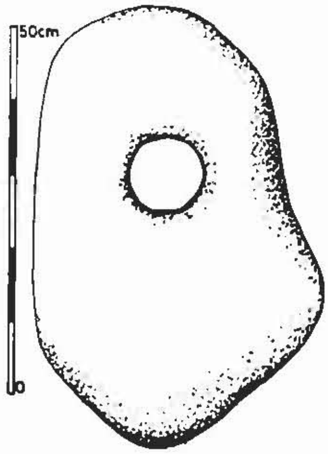
Site 17

17 - 4	Fig. 15	Stone Anchor.
17 - 5	Fig. 15	Stone Anchor.
17 - 6	Fig. 15	Stone Anchor.
17 - 27	Fig. 15	Stone Anchor.
17 - 28	Fig. 15	Iron Y shaped Anchor.

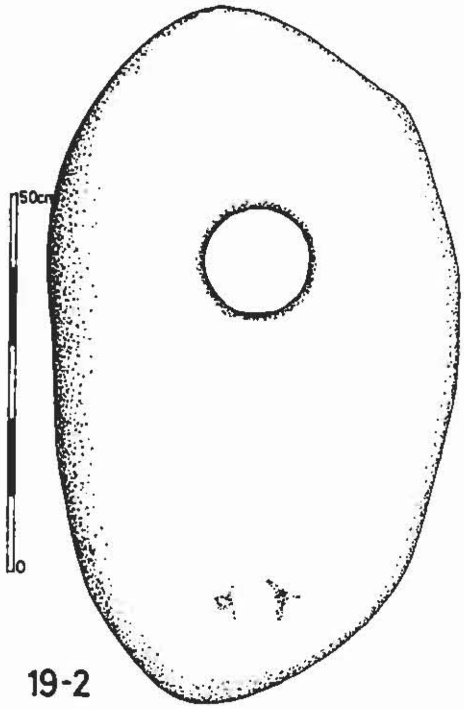
Fig. 15
Anchors from site 17.

Site 19

This site together with anchors was originally located in 1967.



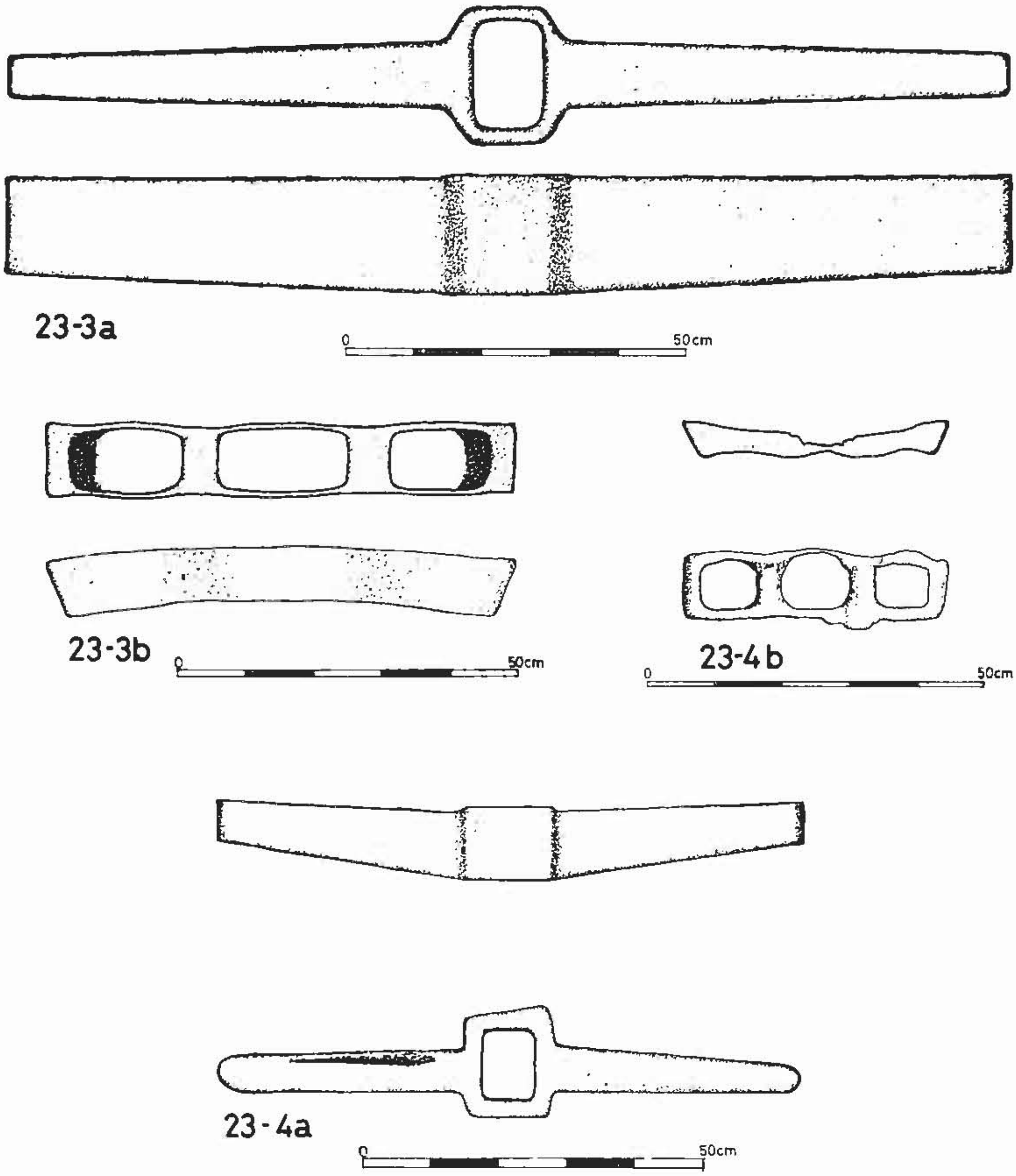
19-1



19-2

Fig. 16
Anchors from site 19.

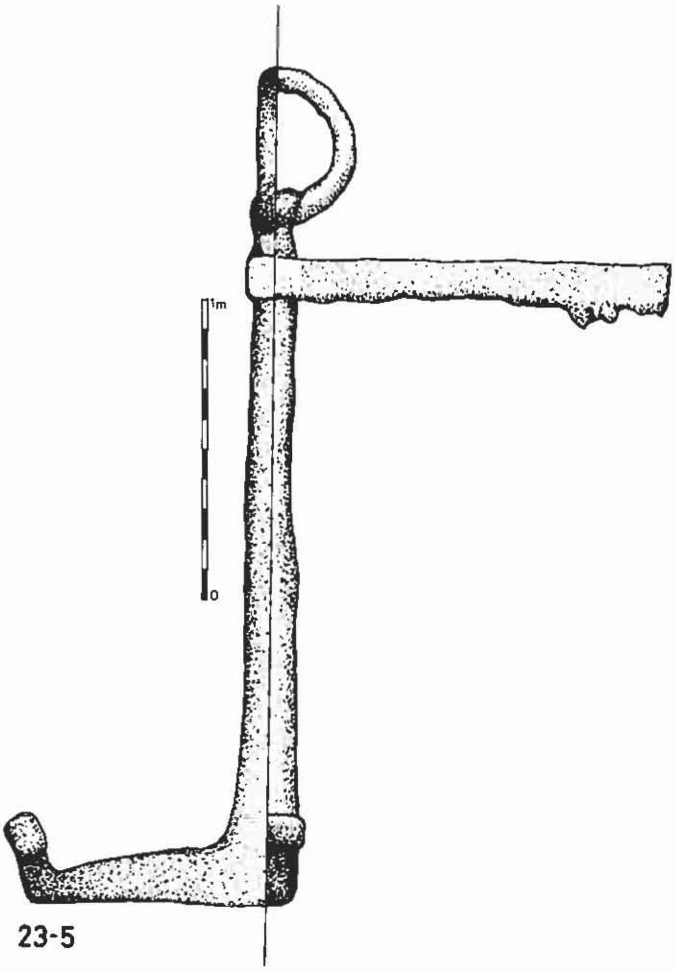
19 - 1	Fig. 16	Stone anchor on E side of reef.
19 - 2	Fig. 16	Small oval stone anchor near 19 - 1
19 - 3		Small stone anchor on amphora shards (see Plate 10).
19 - 4		3 holed anchor on E side of reef.



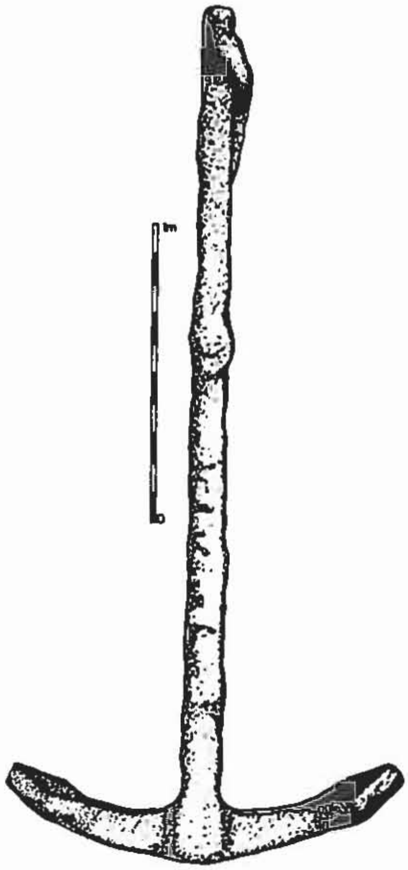
Site 23

23 - 1		Fragments of stock and joining piece of lead anchor of Roman type.
23 - 2		Iron. Shank 180cm. Arms 53cm. Depth 35 metres.
23 - 3a and b	Fig. 17, Plate 13	Lead Anchor of Roman type. Stock and joining piece in good condition but concreted into rocks. Compass bearing from joining piece to centre of stock 75°. Depth 37 metres.
23 - 4a and b	Fig. 17	Lead Anchor of Roman type. Stock and joining piece in poor condition, anchor raised (Catalogue number Stock 23/1 Joining Piece 23/2). Compass bearing joining piece to centre of stock 70°. Depth 27 metres. Stock has hollow cavities.

Fig. 17
Anchors 23-3 and 23-4



23-5



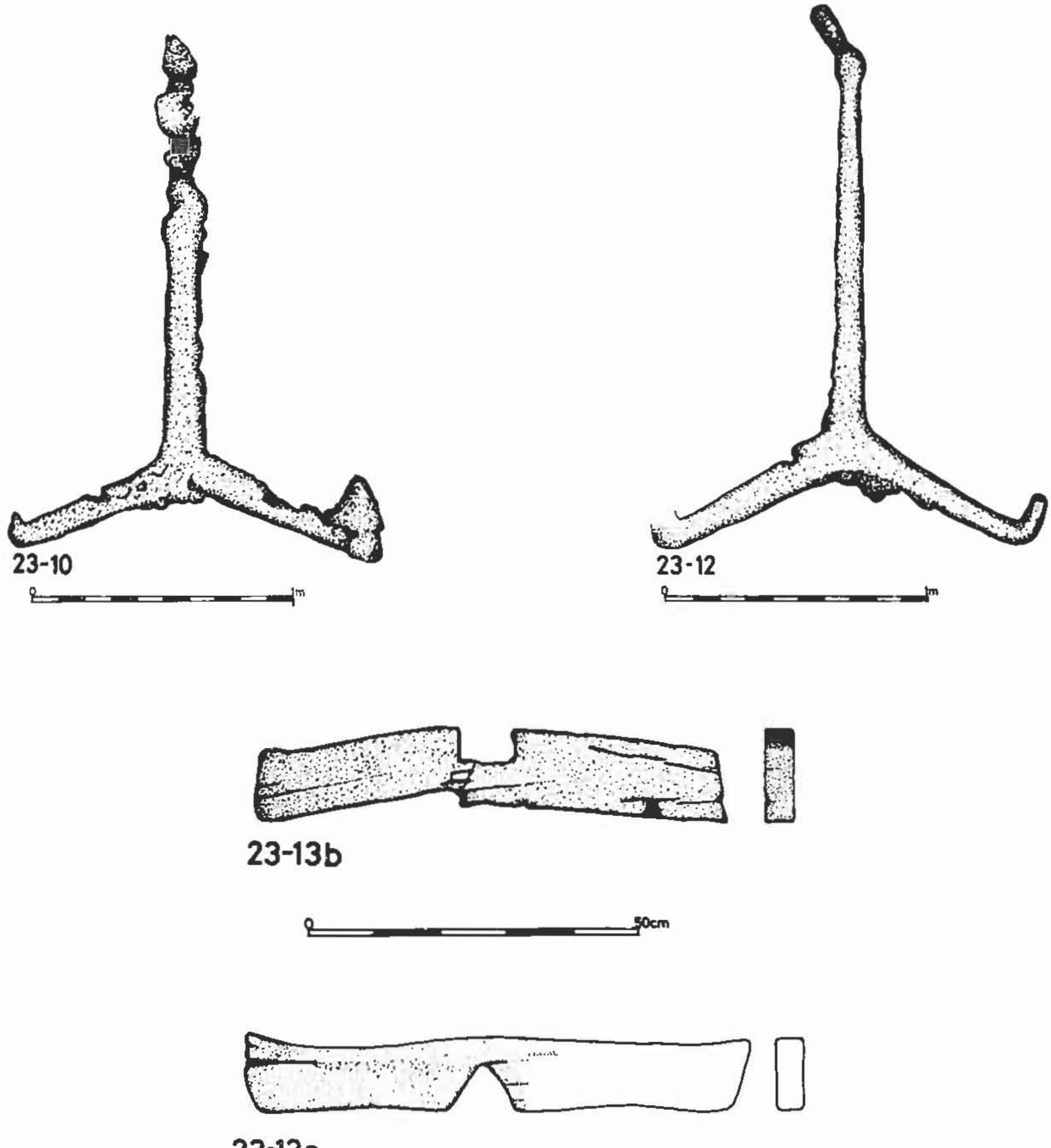
23-6

23-7 0 50cm

Site 23

23 - 5	Fig. 18, Plate 14	Large iron anchor with ring, stock, arms and flukes concreted. Flukes have enlargements at their ends. Arms straight and at right angles to shank. Depth 27 metres.
23 - 6	Fig. 18, Plate 16	Large iron anchor, stock missing, ring, shank and stock concreted. Arms slightly curved with diamond shaped flukes. Depth 28 metres.
23 - 7	Fig. 18	Lead anchor, bar shaped with keyhole section and hole in top centre. Found partially buried in sand, leaning against rock face in vertical orientation. Depth 28 metres. Raised Catalogue No. 23/3.

Fig. 18
Anchors 23-5, 23-6 and 23-7.



Site 23

23 - 8 23 - 9 23 - 10 23 - 11	Fig. 19, Plate 16	Four iron anchors in a complex. Anchor 8 lies in approximately E-W direction with arms to East, underneath partially buried No. 9 with one arm visible at opposite end to arms of No.8. Iron Y shaped anchor lies with shank at 120° to No. 8 and arms at the far end, small flukes or dogs at the end of the arms. Anchor 11 lies parallel and underneath No. 10.
23 - 12	Fig. 19, Plate 17	Iron Y shaped anchor lies horizontally on rock face, arms pointing away from A8-11 complex.
23 - 13a and b	Fig. 19, Plate 18	Two lead objects bar shaped with notch in centre, axis of bars at right angles 13b lying above and vertical with respect to 13a and cliff face.

Fig. 19
Anchors 23-10, 23-12 and 23-13.

Plate 1. Composite aerial photograph of Cape Andreas

Plate 2. Pottery handles at site 1.

Plate 3. Amphora bases at site 1.

Plate 4. Amphora at site 10.

Plate 5. Tile fragments at site 12.

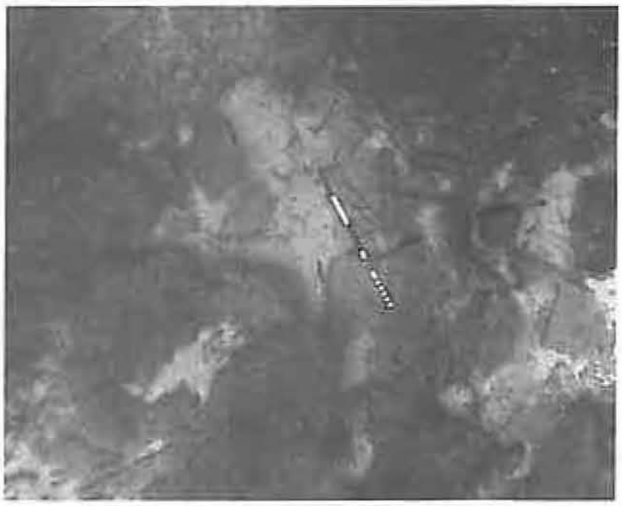


Plate 6. Tiles at site 14.

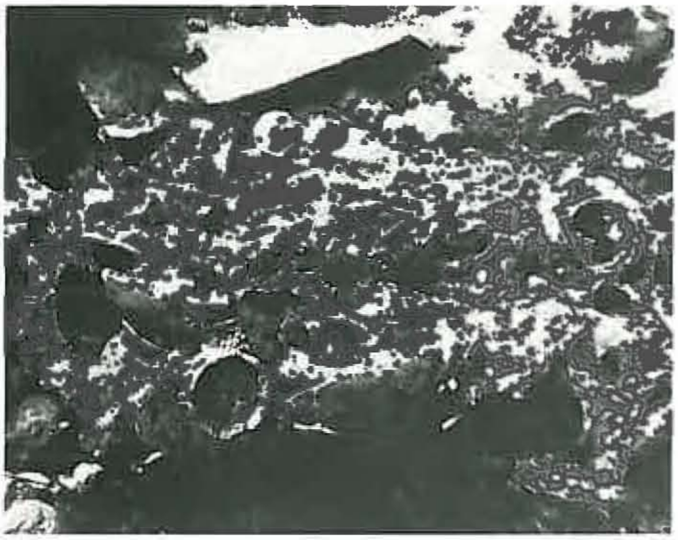


Plate 7. Concreted bowls and tile at site 16.

Plate 8. Amphora shards at site 17.

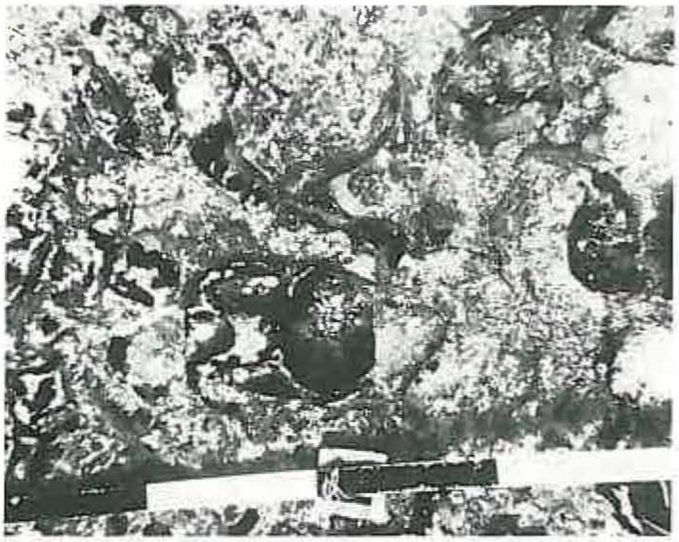


Plate 9. Amphora shards at site 17.

Plate 10. Shards and stone anchor at site 19.

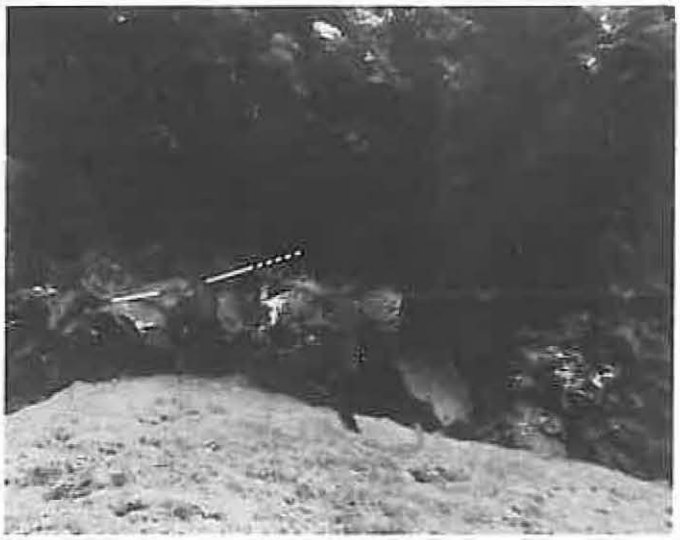


Plate 11. Shards at site 19.

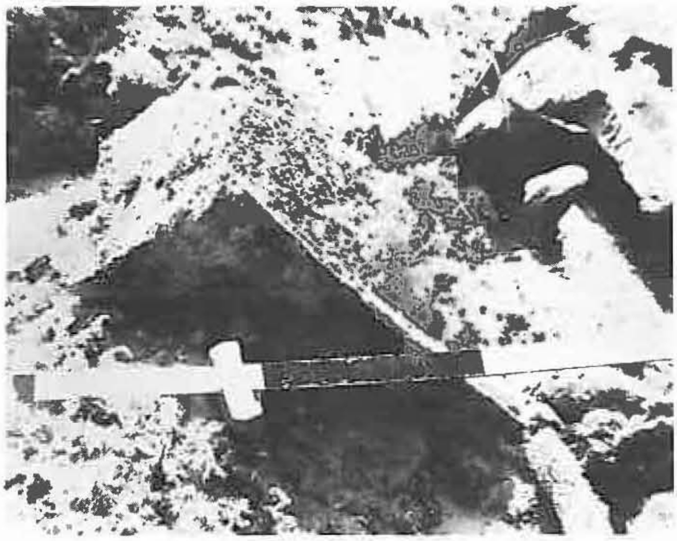


Plate 12. Terracotta box end at site 24.


Plate 13. Lead anchor 23-3.


Plate 14. Iron anchor 23-5.

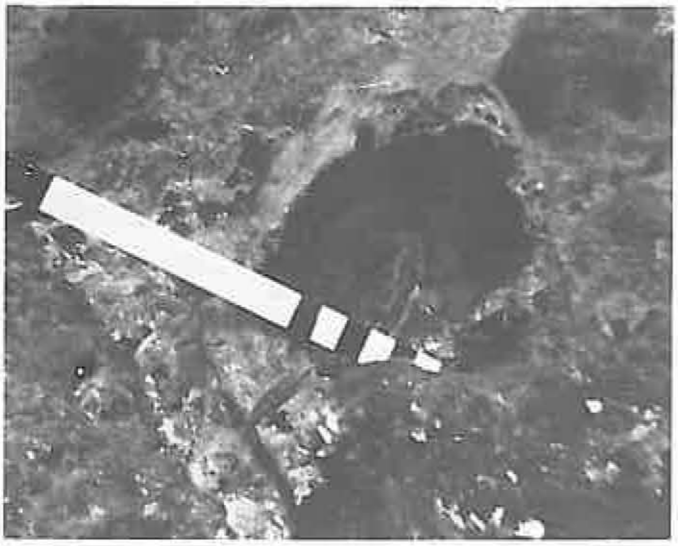


Plate 23. View of slot in base of bronze object.

Plate 24. Overhang in wave-cut platform with shallow cave.

Plate 25. Submarine pothole.

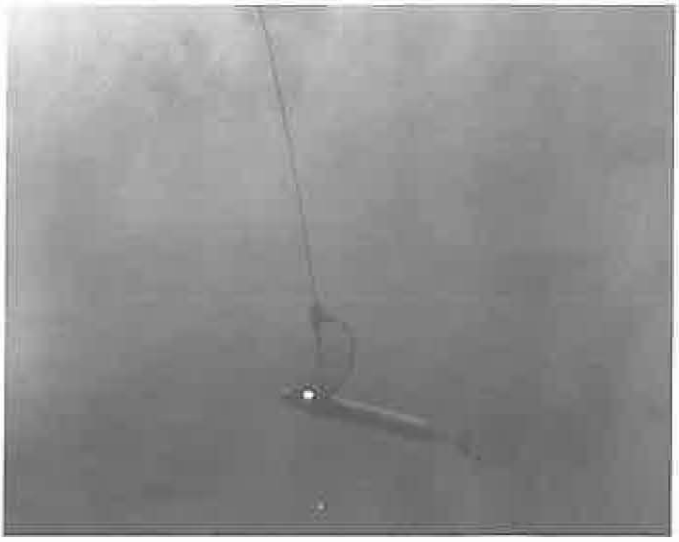


Fig. 10 Photograph at new "fish" under trials.


Plate 15. Iron anchor 23-6


Plate 16. Iron anchors 23-8, 9, 10 and 11.


Plate 17. Iron anchor 23-12 with 23-11 in view.


Plate 18. Lead anchors 23-13 a and b.

Plate 19. Iron anchor 12-1

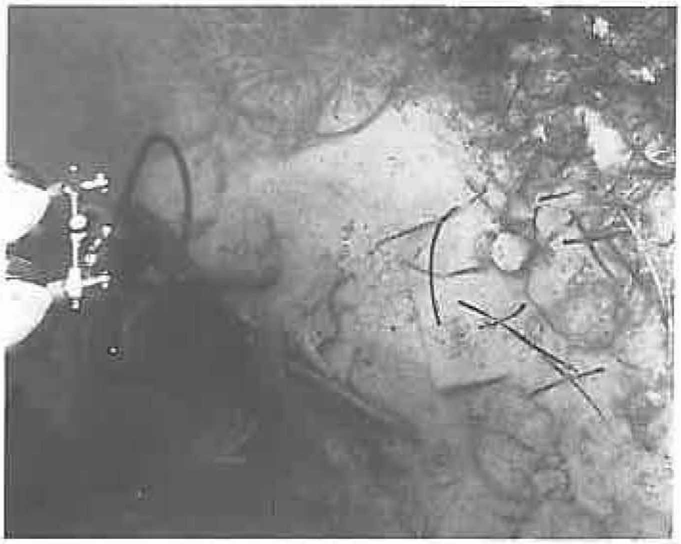
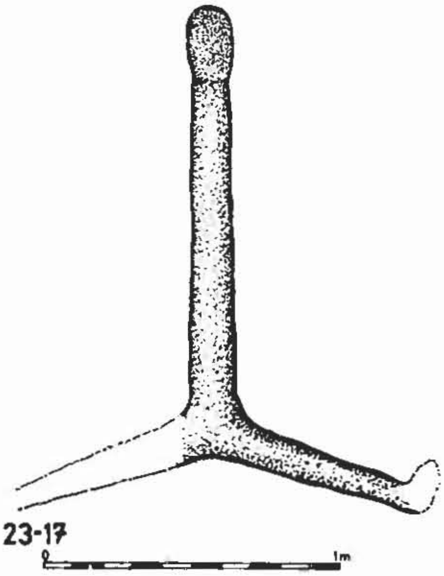


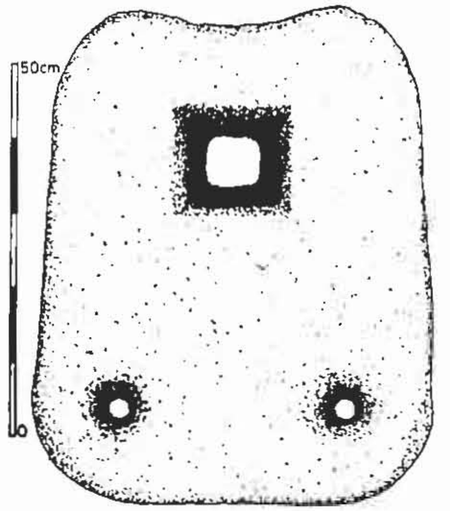
Plate 20. Recording bronze box dimensions at site 12.

Plate 21. Side view of bronze object at site 10.

Plate 22. End view of bronze object showing "fingers".



23-17



23-21

Site 23

23 - 14		Iron anchor fragment. Ring 25 cm OD. 17 cm ID. Stock on one side 45 cm. Shank broken at 125 cm.
23 - 15		Iron Anchor.
23 - 16		Lead object similar to A 13a.
23 - 17	Fig. 20	Iron Y shaped anchor located in gulley vertically above A5 on top of cliff face.
23 - 18		Iron Anchor.
23 - 19		Iron Anchor.
23 - 20		Iron Anchor.
23 - 21	Fig. 20	Stone anchor of 3 hole type. Depth 21 metres.

Fig. 20
Anchors 23-17 and 23-21.

Site 24

Sarcophagus Wreck

24 - 1	Stone anchor located at base of cliff.
24 - 2	Stone anchor in gulley with boxes.

Site 25

100 metres in southernly direction from 23, at a depth of 10 metres is a site containing two stone anchors and a Y shaped anchor.

25-1	Iron Y shaped anchor.

Miscellaneous Anchors

21 - 1	Fig. 21	Y shaped anchor off castle point.
26 - 1		Y shaped anchor off N.E. corner of Island 10.

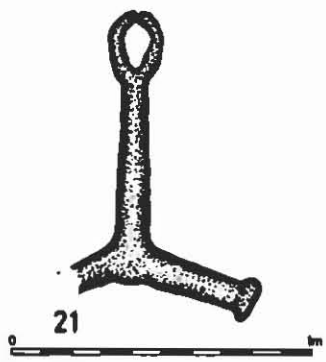


Fig. 21
Anchor 21.

Chapter 7. BRONZE OBJECTS

Jeremy Green

Three bronze objects were found associated with wreck deposits. Site 12 contained 2 of these objects: one a small curved section of bronze about 5mm thick and about 10cm long by 5cm diameter. The other object located at the deepest point in the wreck appeared at first inspection to be part of a buried box. Careful excavation showed that in fact only the parts remaining above the sand were intact and the rest had rotted away (see fig. 22 and plate 20).

Wreck site 10 contained the other object, one of the most curious discovered at Cape Andreas. Its function and purpose remain a mystery. It is tubular in section with eight or more "fingers" at one end running parallel to the axis of the object. These "fingers" are regularly spaced around the circumference of the object but are irregular in length (see plate 21 and 22). At the opposite end to the "fingers" is a hollow tube the exposed section of which, has broken away, and the end of which is not clearly defined. Inside the tube is a blank face from which the "fingers" project. In this face is a slot running across the diameter of the face approximately 1cm wide and indeterminate in depth (see plate 23). Illustration of the object is difficult because of its complex nature but it is hoped that the drawing and photographs will give some idea of its shape and size (see fig. 23).

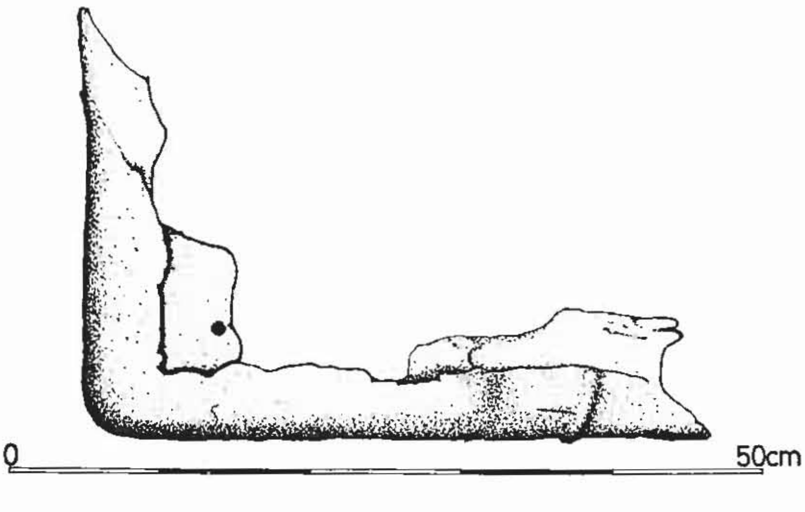


Fig. 22
Bronze object from site 12.

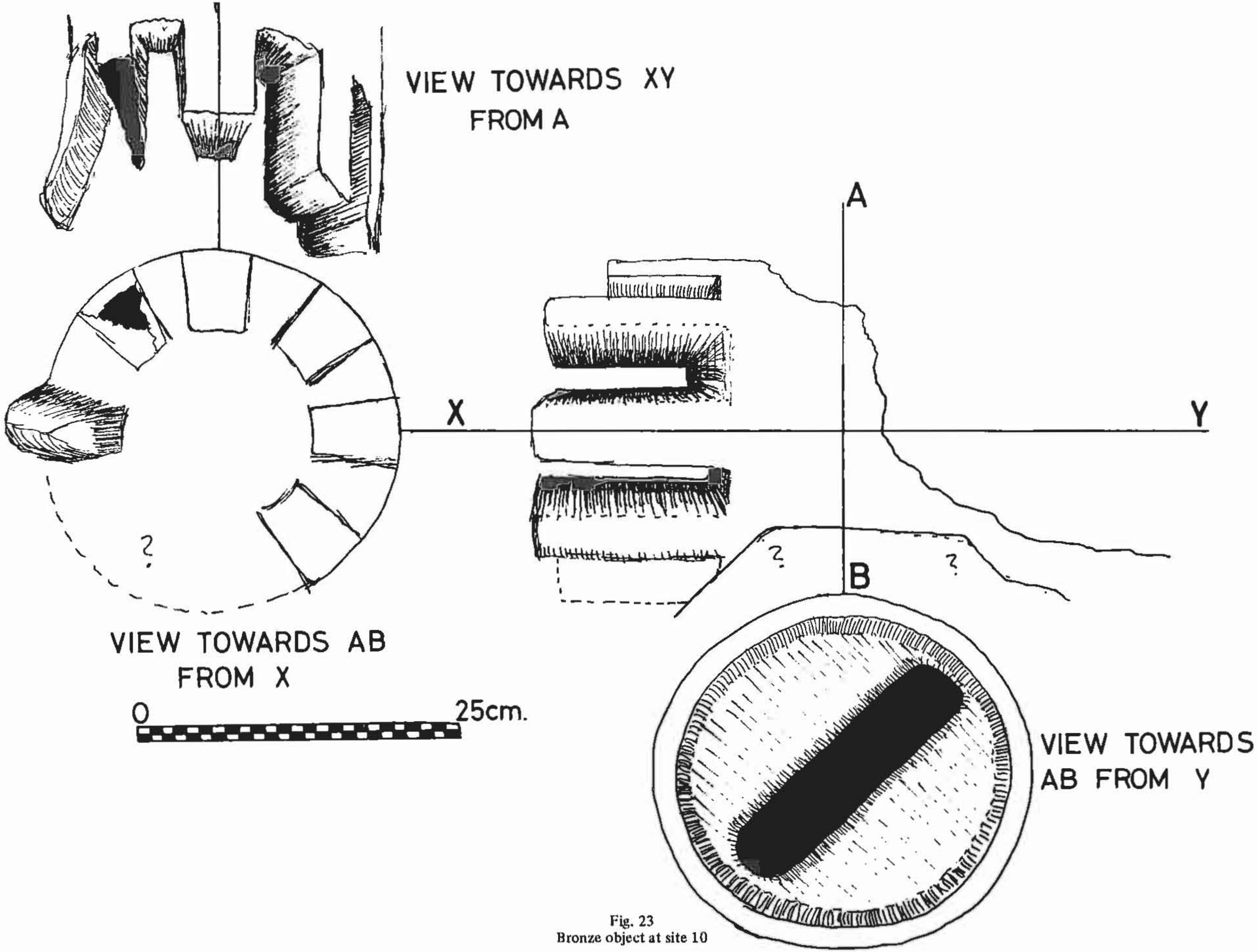


Fig. 23
Bronze object at site 10

Chapter 8.
SOME OBSERVATIONS ON THE GEOLOGY AND COASTAL GEOMORPHOLOGY OF THE AREA

Patrick Sutor

General description of landscape, geology and vegetation

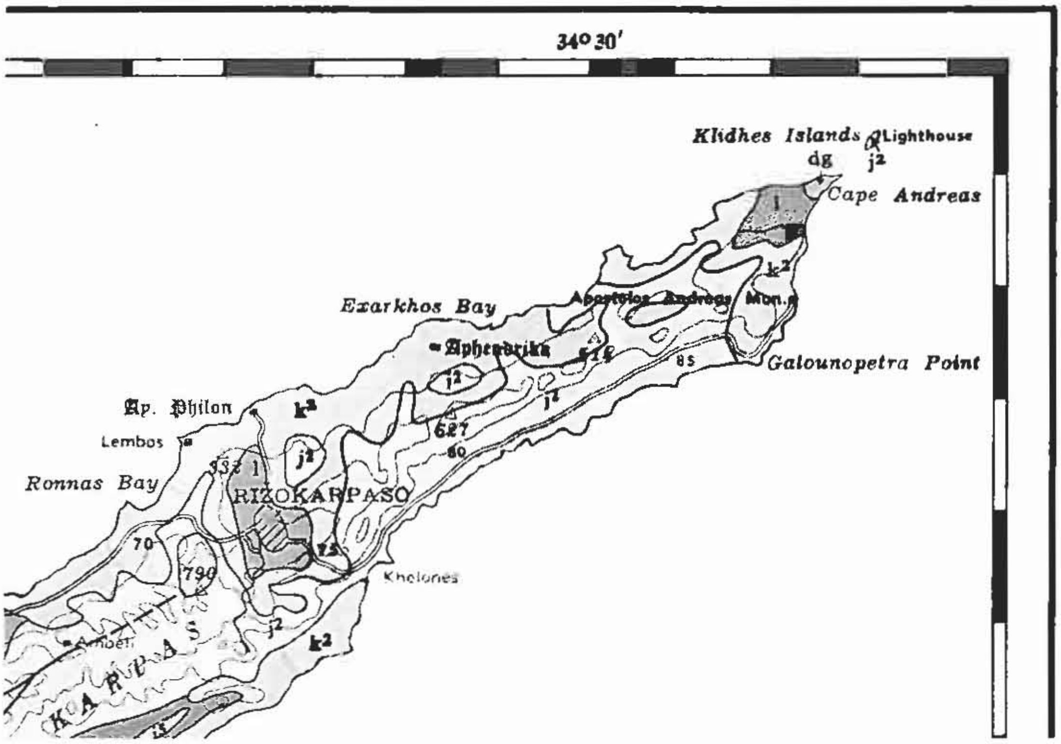


Fig. 24
Geological Survey Map of Cape Andreas.

The geology of Cape Andreas is both complex and poorly recorded. Cyprus has only partially been mapped on a large scale, and Cape Andreas is not one of these areas. The area is however covered by the 1963 1:250,000 sheet, part of which is shown in fig. 24; the description of the various formations is as follows.

1	alluvial deposits with sandy limestones, sands and conglomerate.	Farglomerate	Pleistocene 2–10 m.years
k_2	fragmental and shelly limestones with subordinate brown marl.	Athalassian and Nicosia formation	Upper Pliocene and Upper Miocene 11–25 m.years
j_2	Sandstones, limestones, greywracks, conglomerate.	Kythrean	Middle Miocene 35 m.years
dg	Recrystallized and brecciated limestones.	Hilarian limestone	Upper Cretaceous to Upper Carboniferous 135–150 m.years.

The Cape is dominated by a large block of recrystallized and brecciated limestone, this is Mesozoic, i.e. considerably older than the surrounding rocks of the mainland area, which are Miocene. South and East of the 'Castle' is an area of gravels, shell bearing marine sandstones and sand; these are Pleistocene. On the North coast of the Cape this belt extends several hundred metres inland before being replaced by a red latentic soil, which supports thick but dry magnis-type vegetation.

The islands vary in composition, the first island is both geologically and physically an extension of the mainland, being the same height as the mainland cliffs. It is made up of limestones with some conglomerate rocks which support sparse grasses and scrubs on the highest sections.

The Lighthouse or sixth island is composed of Kythrean formations dating from the middle Miocene; limestones, sandstones and conglomerates predominate. Large areas are covered by grass, spinifexes, and other rough scrub, while a type of reed or bamboo grows in a particularly sheltered part. The same range of rocks is found on the four remaining islands (Nos. 7, 8, 9 and 10), the largest of which supports a very thin vegetation.

The third island is largely Miocene limestone, with some conglomerate. Parts of the limestone are covered with small black rock droplets probably solidified lava.

The remaining islands are low and often awash and may be better described as high reefs. They all resemble each other and are probably Miocene limestone although this is not certain.

All the islands rise abruptly from a gently sloping sandy sea bed, and there are no gradually sloping beaches. The depth of the adjacent sea bed varies from 5 to 25 metres.

Geomorphological features observed

Wave-cut platforms

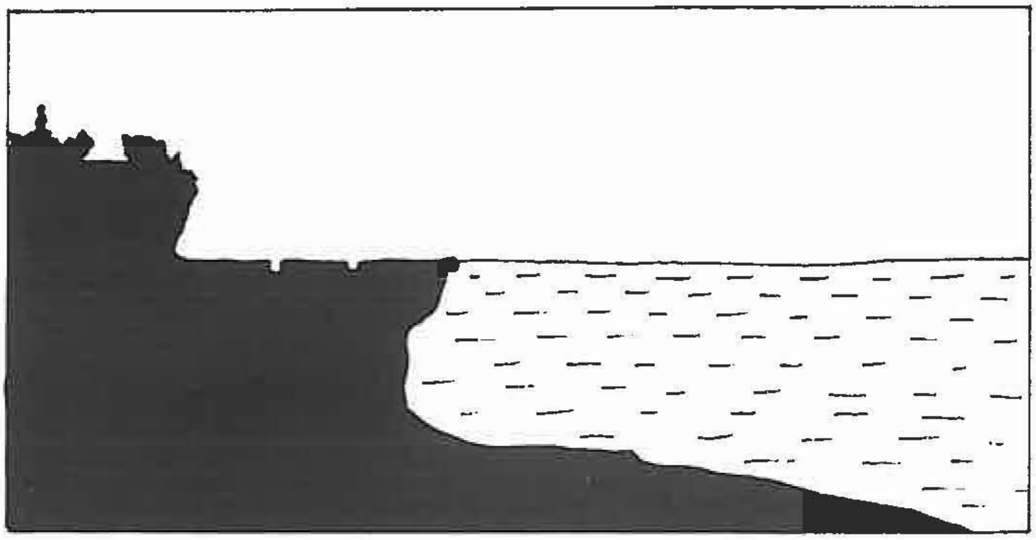


Fig. 25
Profile of typical wave-cut platform

A platform varying between 2 to 7 metres wide is found along much of the North coast of the Cape, and along both sides of the first and sixth islands. Where there is no protective beach material, cliffs are worn at the back of the foreshore and a platform is exposed in front of this. Although the tidal range was approximately 30 centimetres, the platforms are just uncovered at low water and covered by several centimetres at high tide.

Wave scouring may be partially responsible for this formation, although the high salinity and acidity at low water caused by evaporation may also play a part. It is interesting to note that the platforms mainly occur on the North coast and they all have a sharp vertical drop at their extremity (see fig. 25). Occasional overhangs are noticed, in the lower parts of which shallow caves in the soft rock under the relatively stronger strata are observed (see plate 24). Another feature of these overhangs is a small but pronounced lip just on the seaward edge of the platform, a few centimetres wide. It is probably organic in origin, perhaps the calcareous algae (*Terarea tortuosa*) which is typical of the Mediterranean.

Stratification features

In many places alternating bands of hard and soft rocks are exposed at varying angles, and underwater caves are quite common along the steep cliffs below the wave-cut platform. These are generally quite small and not very deep, although one was found on the North side of the lighthouse island, which extended for about 10 metres into the rock.

The headland, where the station point was established has diagonally sloping strata and in one place the softer rock below has been eroded through, thus creating a funnel which in time could develop into an arch. A similar formatioon on the first island has developed a 'blow-hole', as the fissure is underwater.

Corrosion hollows or lapies

Guilcher (1954) described a sequence of corrosion hollows and pools with overhanging edges in limestone formations. Very similar features are observed along the North coast of the Cape, especially around the camp. The hollows are often filled with the sea water if located near the water's edge, where they are filled by spray. Otherwise further away, salt takes the place of sea water, due to the high evaporation rate and the fact that the pools are only filled during storms. Near the water there are intricate networks of sharp pinnacles interspacing the pools, which are known as coastal lapies. This sequence of features with the rocks becoming jagged near the water's edge implies that this is the result of the corrosive effect of sea water. The wave-cut platform is generally smooth and shows a marked contrast to the adjacent rock. Small hollows were observed in these wave-cut platforms; these may be due to sea-urchins, although they were not very common in the area.

Submarine pot holes

Smoothly rounded holes were observed on the sea floor at a depth of about 6 metres, some of them being as deep as they were wide with steep sides (see plate 25). They resemble pot holes found in river-beds in typical karst limestone scenery, which are formed by the abrasive action of stones trapped in some existing depression in the rock. It is possible that the same mechanism could be responsible for this type of formation.

Chapter 9.
CONCLUSIONS

The main purpose of the 1969 expedition to Cape Andreas was to locate well preserved deep water wrecks and in this respect the expedition failed. In the area we searched it would be expected that such wrecks may exist, but this is all a matter of chance. As we were only able to search approximately one quarter of the area because of breakdowns of our compressors, it is hoped that a further season's work will reveal deep water wrecks. Incidentally the trouble with the compressors also restricted the amount of test work that could be accomplished and limited the number of specimens that were collected.

Nevertheless, we were able to locate eight wreck sites and 56 anchors some of which are thought to be very rare. Certainly the number of 'Y' shaped anchors is a unique find, as is anchor site 23 with such a vast quantity and variety of anchors. Of the wreck sites the large quantity of tiles discovered is of interest, as are the number and distribution of wrecks.

As the search is only partially complete it is hoped, if funds can be raised, to search the remaining area. The whole of the South side of the island and part of the North side are yet to be searched. It would indeed be unfortunate to leave such a rich interesting area only partially investigated. Now that the surveying of the submarine contours has been completed, and the technique of diver search has been perfected it is possible that the rest of the area may be completely surveyed in a season. The main expedition requirement would be a large capacity compressor which was reliable.

For this reason this report is only preliminary in nature. Little time has been available to follow up the dating of the material. Our main intention has been to produce a report of the finds as quickly as possible to be circulated to all interested archaeologists for their comments. Should we be fortunate enough to return to Cape Andreas it is hoped to produce a full and comprehensive report on the archaeology of the wreck sites and finds. We hope that this report of the work of the 1969 Expedition will justify a subsequent expedition to complete this work.

One of the greatest problems in organizing an expedition is the raising of funds; of the money raised for the 1969 Expedition approximately one third was purely from archaeological sources for archaeological work. The remainder was for test work of Laboratory instruments, especially the determination of the towing characteristics of the new magnetometer fish, which is described in Part 2. It is, I think, important to realise that the two fields of work are to some extent complementary. The function of the Laboratory is to develop instruments that have application to underwater archaeology, and it is incidental, although important, that these instruments have commercial applications. Expeditions provide an ideal opportunity to test instruments in the field under working conditions and to determine their faults, limitations and problems. Furthermore, any underwater work of scientific nature increases the knowledge of the environment and serves to indicate fields of research which would not be intuitively obvious. The Laboratory is fortunate in having its feet in two camps, one in the archaeological field, and the other in the field of the more physical sciences. It is also hoped that the non-specialist members of the expedition, who are generally undergraduates, will not only increase their diving ability, but more important, increase their application of underwater technology, archaeology and the role of the physical sciences that apply to underwater archaeology.

PART 2. by Jeremy Green

LIST OF FIGURES PART 2

INTRODUCTION

Readers who have glanced at the following pages may have been suprised at the contents, as it is unusual to find archaeological reports with sections on scientific survey equipment. However, there is a growing application in archaeology for the use of such equipment in field work, and in underwater archaeology this is particularly true. Because of the technical difficulties involved with working underwater, archaeologists tend to utilize as many aids as are economically possible to improve the efficiency of their work. The most notable example of this has been at Yassi Ada, in Turkey, where Dr. George Bass of the University of Pennsylvania Museum has, in his many seasons' work utilized various systems ranging from a two-man submarine, to an underwater photogrammetric system (see Bass 1968).

Examination of the list of contributors to the 1969 Cape Andreas Expedition in Part 1 (Acknowledgements) will show that the majority of the finance for the expedition was raised from sources that have little or no direct interest in archaeological work. The main interest is in the scientific work involved with the instruments developed by the Research Laboratory for Archaeology and their commercial applications. The expedition programme included substantial test work of these instruments and the following chapters outline this work and for the sake of completeness describe other instruments in the same field. The nature of test work tends to yield little written results; the various experiments conducted are described, but it would be impossible to record all the small observations of design faults, handling problems etc. that were discovered. It is sufficient to say that in the six weeks at Cape Andreas considerable experience was gained in the problems involved with both the proton magnetometer and the metal detector.

The descriptions of the principles of operation of the various instruments are kept as simple as possible, in order to maintain a reasonable continuity in the report. Technical descriptions of the various instruments are indicated in the references. The following pages outline some of the various instruments used for metal location and their problems of operation, particular attention being devoted to the three instruments developed by the Laboratory.

Chapter 1. MAGNETOMETERS

The magnetic field intensity at a point in a magnetic field may be described by a vector, since the intensity has both magnitude and direction; the direction of the Earth's magnetic field may be determined quite simply with a compass needle. The horizontal component of direction or inclination may be indicated by a standard compass, the vertical component or declination by a dip circle. The absolute value of intensity is not easy to measure, and to do so an intricate piece of electronic equipment, known as a magnetometer is required. It should be noted that the simple torsion magnetometer may be used for laboratory work, but in order to determine the intensity to a high degree of accuracy in the field as well as the laboratory, electronic methods are required.

For practical purposes magnetometers fall into three categories, depending on the principle of operation that determines the field intensity. These three types of instruments are know as the proton, fluxgate and optically pumped magnetometers. One of the more important applications of magnetometers is to determine the position of spatial anomalies in the Earth's magnetic field; these anomalies indicate the presence of materials, generally ferrous which, due to their magnetic effect disturb the distribution of the local magnetic field. Because anomalies have spatial distribution it is often simpler to use a gradiometer magnetometer rather than an absolute instrument.

The gradiometer is essentially two absolute magnetometers combined in one instrument, operated at a fixed distance apart to measure the difference in field strength or gradient between the two points. The gradiometer is a much simpler instrument to construct than an absolute instrument, since it is only necessary to measure the difference in field intensity, the absolute value of field strength being irrelevant. As the principles determining the field strength are the same for both the absolute and gradiometer instruments, the following discussion will be confined to the absolute instruments.

The Proton Magnetometer

If a single proton is placed in a magnetic field of strength H, provided the field is not parallel to the spin angular momentum vector of the proton, the proton will process at a frequency f, where f is given by the Larmour Theorem

$$f = \frac{\mu H}{2 \pi p}$$

where p is the spin angular momentum and μ is the magnetic moment of the proton. Therefore if the frequency f can be determined the value of H may be calculated. The original concept of using nuclear magnetic induction to determine the Earth's magnetic field was suggested by Block, Hansen and Packard in 1946. Water or any hydrogen-rich hydrocarbon liquid contains a large proportion of protons. Such a liquid in the Earth's magnetic field has a proportion of protons that are pecessing at the Larmour frequency but the precession has no phase coherence. In order to detect the precession frequency it is necessary to give the precession a phase coherence. To do this a certain proportion of proton dipoles must first be aligned in a particular direction and then simultaneously be released to precess about the Earth's field. In order to impart a direction to the proton dipoles, a strong magnetic field (100 oersteds) is applied to the liquid; this field is generated by a coil wound round the bottle containing the liquid; the coil also serves to detect the precession signal. The application of the polarization field causes the protons to precess about this field at a frequency of about 2MHz. The process of random motion tends to cause interactions between the precessing dipoles so that after a finite time, a proportion of the dipoles have lined up with the field direction. Thus at the end of polarization a small proportion of the dipoles are orientated in the direction of the applied field and are not precessing; there is in fact a constantly changing population of dipoles that have this orientation. If the field is now switched off very rapidly, faster than the precession frequency for the Earth's field (2KHz), those dipoles which were orientated in the direction of the applied field will start precessing with a coherent phase, since they all started in the same spatial position relative to the Earth's field. This effect is naturally strongest when the applied field is at right angles to the Earth's field, since the torque causing the precession is at a maximum.

The signal is gradually reduced as kinetic interactions with other dipoles due to thermal agitation gradually disorientate the phase coherence. During this period the phase coherent dipoles induce an AC signal in the coil, the frequency of which is the precession frequency. It is therefore simply necessary to measure this frequency for a short period of time in order to determine the field strength. In the absolute system the frequency is measured to a high degree of accuracy against a crystal clock standard, in the gradiometer the difference in frequency between the two detector heads is measured. It suffices to say that if the frequency is measured to a high degree of accuracy for a short period of time after switch off of the applied field, the local magnetic field strength may be determined. This type of instrument has been widely used for archaeological work on land (see Atkin 1958).

The Fluxgate Magnetometer

This instrument unlike the proton magnetometer is directional, and measures the field component through the axis of a mu-metal core. The simplest method of describing the principle of operation of a fluxgate is to outline the operation for a cylindrical core unit. In this system, a primary excitation voltage is applied to two coil windings arranged in antiphase on two parallel mu-metal rods. The secondary winding is wound over the top of the two rods, and in this way no primary signal or odd harmonics are included in the secondary, as the primary windings are in series opposition.

The excitation voltage can either have a sine wave or a square wave form; the latter is outlined below as it is simpler. This description is a simplified version of the description given in Alldred (1964).

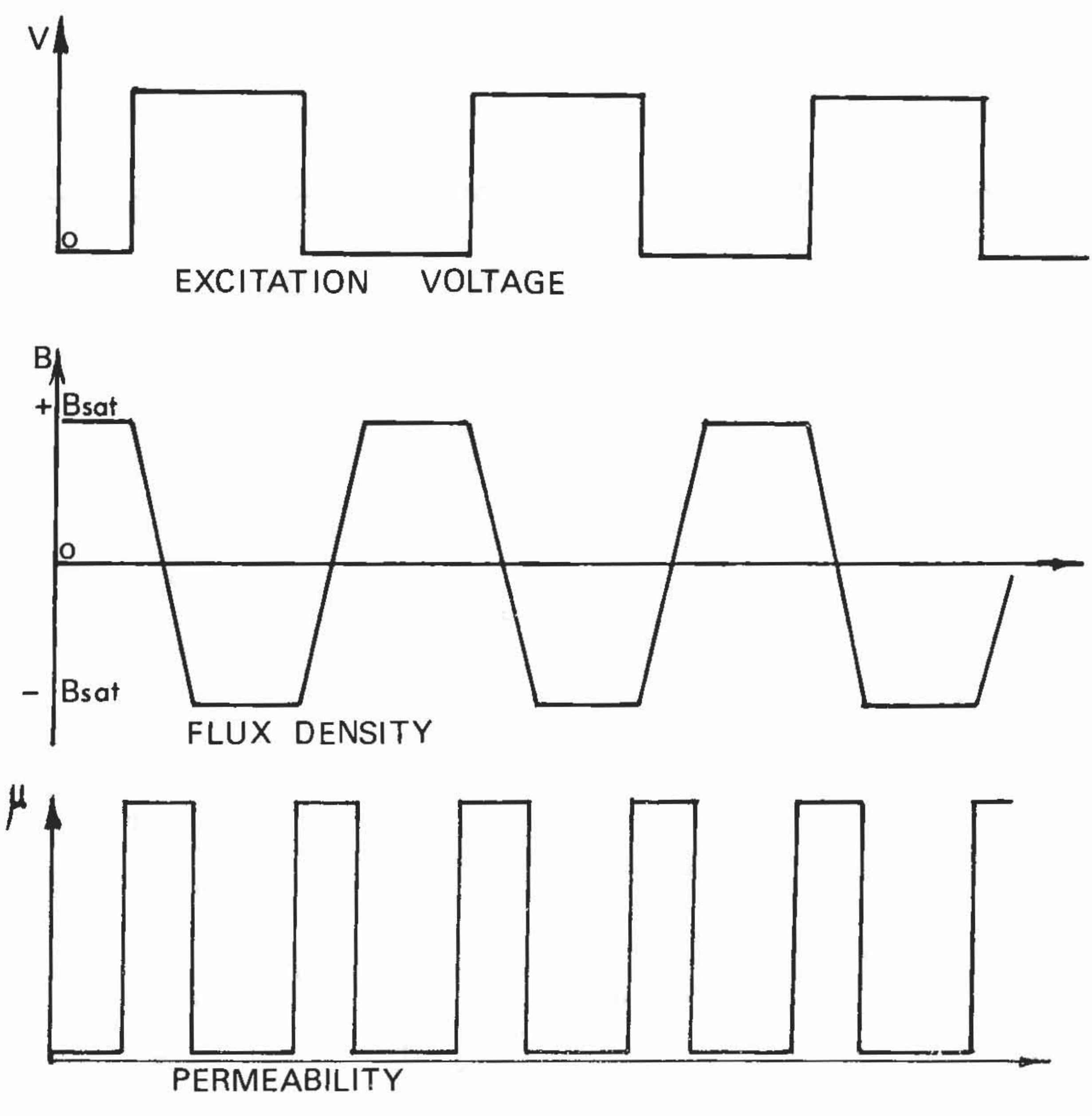


Fig. 1
Simplified wave forms for Fluxgate Magnetometer

During the period when the excitation voltage causes current to flow in the coil, the flux density increases until it reaches saturation at $+B$sat. In the second half of the cycle the flux density reverses and saturation occurs at $-B$sat. Thus in each cycle of excitation the core is saturated twice. The permeability is maximum when the core is unsaturated and minimum during saturation. In a steady field H the flux density in the core is $H(t)$ and this will induce a voltage in the secondary which is proportional to H and has a frequency of twice the excitation frequency. By suitable filtering it is possible to observe this signal and from measurement of the amplitude, determine the field strength.

There is a second type of instrument which is not strictly a fluxgate; this system has a coil wound on a ferrite rod, the coil forming the inductance of a tuned circuit. Changes in the Earth's field strength in the ferrite alters the value of the inductance, thus changing the value of the resonant frequency. By careful measurement of the resonant frequency it is possible to determine the field strength.

Optically Pumped Magnetometers

The operating principles of an optical magnetometer are complex. Essentially light is used to excite a vapour into high atomic energy level states. If the vapour is subjected to an alternating field, the frequency of which can be adjusted to cause resonance, then the resonance can be used to provide a measurement of the local field intensity.

The arrangement of the system is as follows, an electrode-less alkali vapour lamp provides a source of light (let us assume that the vapour is rubidium). This light is made up of several lines, one pair of which are the $D_1 D_2$ lines (7800 Å 7948 A). The D_2 line is filtered out by means of an interference filter and the remaining D_1 line is then circularly polarized and passed through a cell containing rubidium vapour, in a direction approximately parallel to the magnetic field direction. The 7800 Å circularly polarized light causes transitions in the Zeeman sublevels so that for the $2S_{1/2}$ state a large population of atoms will exist in the M_F3 sub level. This corresponds to orientation of the atoms in the direction of the field, and this orientation is almost 100% if circularly polarized light is used.

The atoms can be disorientated if an alternating field is applied to the excited vapour at a frequency corresponding to the energy difference between a pair of sub levels. The direction of the applied alternating field must be normal to the local field. Atoms pass into lower sub levels with dipoles precessing about the Earth's magnetic field at the Larmour precession frequency. The depumped atoms are re-excited into the higher Zeeman sublevels, by the D_1 light, resulting in absorption of light in the vapour. The light transmitted through the vapour decreases as the frequency of the applied field approaches resonance of the Larmour frequency. Thus by monitoring the transmitted light with a photocell and feeding this constant signal level back to the oscillator it is possible to arrange the system with suitable electronics so that the oscillating field is self adjusting for varying field intensities. Measurement of the harmonic frequency gives the value of the magnetic field strength, from the Larmour precession frequency formula. This description is a simplified version of an article by Parsons and Wiatr 1962.

Chapter 2. SEA-GOING MAGNETOMETERS

The proton magnetometer developed at the Research Laboratory for Archaeology has been modified for sea-going use (see Hall 1966). The design of such instruments requires the consideration of several problems.

1. The detector head must stream in the water in a stable manner otherwise changes in signal strength may occur and mechanically induced electrical noise generated.

2. The cable must be long enough to position the detector head outside the magnetic field of the towing vessel.

3. The cable must be strong enough to stand the strain of towing the "fish", be especially designed for low microphonic pick up and of low resistance to prevent loss of polarizing current.

The original system was to tow the detector head on a long coaxial cable; the head was designed for low drag and high stability, the "fish" being streamed near to the surface, and the magnetic field intensity measured at a repetition rate of 1 sec.$^{-1}$ using a fast proton liquid. The intensity was displayed on a continuous chart recorder and the whole operation of the instrument after setting up was automatic, (see Hall 1966).

The most common application for the sea-going magnetometer is to detect the presence of ferrous objects. The size of the anomaly in the Earth's magnetic field *H* in gamma created by a spherical ferrous object of mass *M* kg, is given by the formula:

$$H = \frac{10M}{d^3}$$

where *d* is the distance from the detector head to the object in metres.

(N.B. 1 gamma = 10^{-5} oersteds)

Hence it is possible to predict if it is feasible to locate a ferrous object where the distance from the detector head to the sea bed (assuming the object is on the sea bed) is known. The formula is theoretical and applies to an ideal dipole; in practice objects are far from ideal but the calculation serves to determine the order of magnitude.

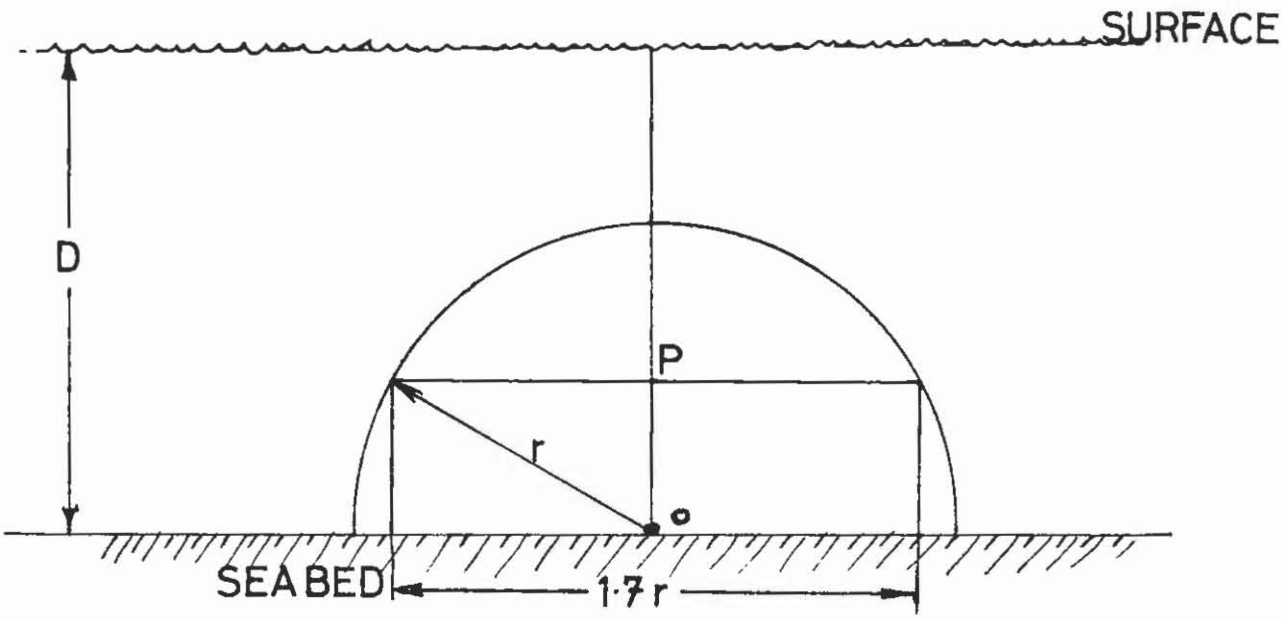


Fig. 2
Detection range geometry for seagoing magnetometer

There are various general rules that apply to the operation of magnetometers at sea. These rules together with the local conditions should be carefully considered before starting the survey. One of the main operating problems is the changes in velocity of the "fish" over the sea bed when streaming with and against the current. Say the tidal velocity is v and the ship's velocity in the water is V. Then when streaming with the tide, the velocity over the sea bed is $V + v$ and $V - v$ when streaming against the tide; care should be taken under these conditions that the speed of the "fish" over the sea bed is not too great. If the distance covered by the "fish" between magnetometer readings is greater than twice the detection range the object may not be detected.

Another problem is that of the selection of the depth of operation of the "fish". Clearly the closer the detector head* is to the object the greater the ease of location. However, this does not mean that the "fish" should necessarily be on the sea bed. Consider an object O, (see fig 2) located on the sea bed, depth D; if the detection range is r, then if the "fish" is at depths greater than $D - r$ there is a finite chance of locating O, (as clearly the "fish" must operate in this depth range to locate O). If the "fish" is at P where OP=$\frac{r}{2}$, or the area effectively searched by the instrument is a strip

$$2\sqrt{r^2 - \frac{r^2}{4}} = 1.7r \text{ wide}$$

Thus the difference between operating the "fish" at P and at O, is a 15% reduction in search area; as it is much safer to operate the fish with a good depth of water beneath it, clearly P is a better situation. A good rule of thumb is therefore to operate the "fish" at half the detection distance above the bottom. An extremely useful addition to the system would be an echo sounder mounted on the "fish", this would enable the operator to adjust the height of the "fish" above the sea bed quite accurately instead of by guesswork.

*The terms "fish" and detector head are in this case synonymous, the detector head being in fact the bottle containing the proton liquid together with the detecting coil. This is encased in a streamline watertight housing known as the "fish".

Chapter 3. PROTON MAGNETOMETER RESEARCH

The two greatest problems in operating the sea-going proton magnetometer are encountered in trying to increase the speed of search and the depth of streaming of the detector head. The first problem is inherent in all proton magnetometers; the relaxation time of the liquid limits the repetition rate of the system, since it takes a finite time for the dipoles to align with the applied field during polarization. Although the counting time can be reduced by sophisticated electronics, it is impossible to reduce this polarization time much below 0.5 sec. without losing signal strength. The second problem of increasing the depth of the detector head is however, a design problem. Applications of magnetometers in deep waters require increasing the streaming depth; the simple addition of weight to the present system has been singularly unsuccessful in increasing the depth by any appreciable amount, unless an inordinate amount is used. There are two reasons for this, firstly, the diameter of the cable is large (~1 cm), thus, creating a high drag, secondly the towing position on the detector head is fixed in a horizontal direction, thus any weight placed on or near the head will induce a bending moment about the point of application and this will tend to incline the axis of the head to the direction of the flow thus imparting a very high drag.

One of the magnetometer research projects at the Laboratory in the past year has been to design a deep-towing detector head. The specification of such a system is that the head should tow at 30 to 40 metres depth in a stable manner with a weight that is reasonably easy to handle.

The greatest drag in the old system, occurred along the length of the towing cable, therefore the cable diameter had to be reduced. In order to do this it is necessary to discard the coaxial cable system, as any reduction in diameter increases both the microphony and the electrical resistance. Therefore it is necessary to reposition the preamplifier and the polarization switch, from the electronics unit, to the detector head, electrical connections being made with a four-cored armoured cable. A suitable armoured phosphor bronze cable was selected with a diameter of 6.5mm the cable was fitted with a phosphor bronze anchoring termination so that any load applied to the cable was imparted directly to the armouring and not to the cable sheath. This termination also served as the electrical termination so that the electronic unit in the detector head could be connected and disconnected from the cable. For further details see diagram, (fig.3).

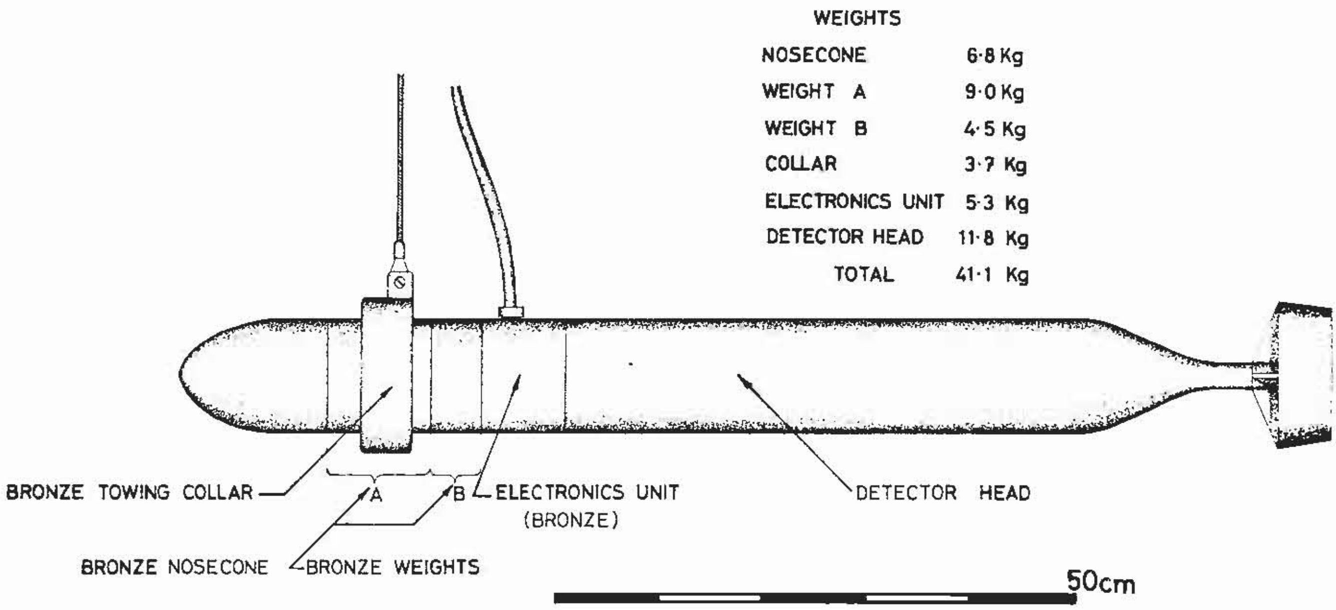


Fig. 3
New magnetometer "fish".

The construction of the streamlined weight of the head unit for the "fish" was entirely in phosphor bronze. This was for two reasons, firstly, it is non-magnetic and secondly it has a high specific gravity (9.7). The phosphor bronze was machined into a series of detachable streamlined weights. These could be attached at will to the electronics compartment and detector head assembly. Careful measurements were made before construction of the detector head assembly, to determine the minimum distance that the detector head bottle would operate from the phosphor bronze, without eddy currents disrupting the proton precession. This distance (15cm) was not too great to prevent the construction of the detector head assembly in the tail section of the "fish". A phosphor bronze collar was constructed to clamp round the nose section, so that the "fish" could be towed at the centre of gravity with various weight configurations (see fig.3 for further details).

The whole unit was taken to Cyprus for field trials and evaluation. Because time was limited it was hoped to determine the depth performance using a pressure transducer mounted in the "fish". Unfortunately due to mishandling in the preliminary field trials in the U.K. the transducer was flooded and subsequently failed to operate. As the delivery time was too great to order another transducer in time, the depth determinations were made by divers during the work at Cape Andreas. Consequently although the results are perfectly satisfactory, it was not possible to investigate the depth capabilities below about 30 metres due to excessive decompression problems and the shortage of compressed air at Cape Andreas.

A small electrical winch was purchased for evaluation of its handling capabilities of the cable, as it was obvious that thin diameter cable was going to present difficulties in man-handling. A small fishing boat was hired from Kyrenia, (the K.22); this boat was skippered by a local Kyrenian fisherman Christomos Athenasi who provided invaluable advice on the handling of the "fish". The winch was mounted on the transom of the K.22 and a 12 volt, 36 Amp-hour car battery provided the power. This was supplemented by a small electrical generator which charged the battery constantly. The winch was provided with a small chain-gypsy and a 10cm (approx) diameter windlass. The "fish" was lowered over the side of the boat and allowed to stream at varying cable lengths.

The first set of determinations were made with just the nose cone and an aluminium spacer, the spacer being required to position the towing collar at the centre of gravity of the "fish". The "fish" was lowered to a depth of 80 metres and the ship then steamed along a measured 50 metre course at a fixed speed. At the end of the course a pair of divers on shot-line tethered to the inflatable rubber boat, observed the depth of the "fish" as it passed, by means of a depth gauge. Various runs were made at a fixed speed, with varying lengths of cable; a check was kept on the speed by noting the times of covering the 50 metre course. Thus for a given set of cable lengths the depth of the "fish" was recorded for a given speed. The speed was then increased and a second set of determinations made. After this all the weights were added to the "fish", the collar adjusted to the centre of gravity and determinations for the two speeds repeated. Finally, the smaller of the weights was removed and determinations repeated for an intermediate speed.

The results are drawn on graphs, fig 4-9; cable lengths are plotted against depth of "fish" for various velocities and

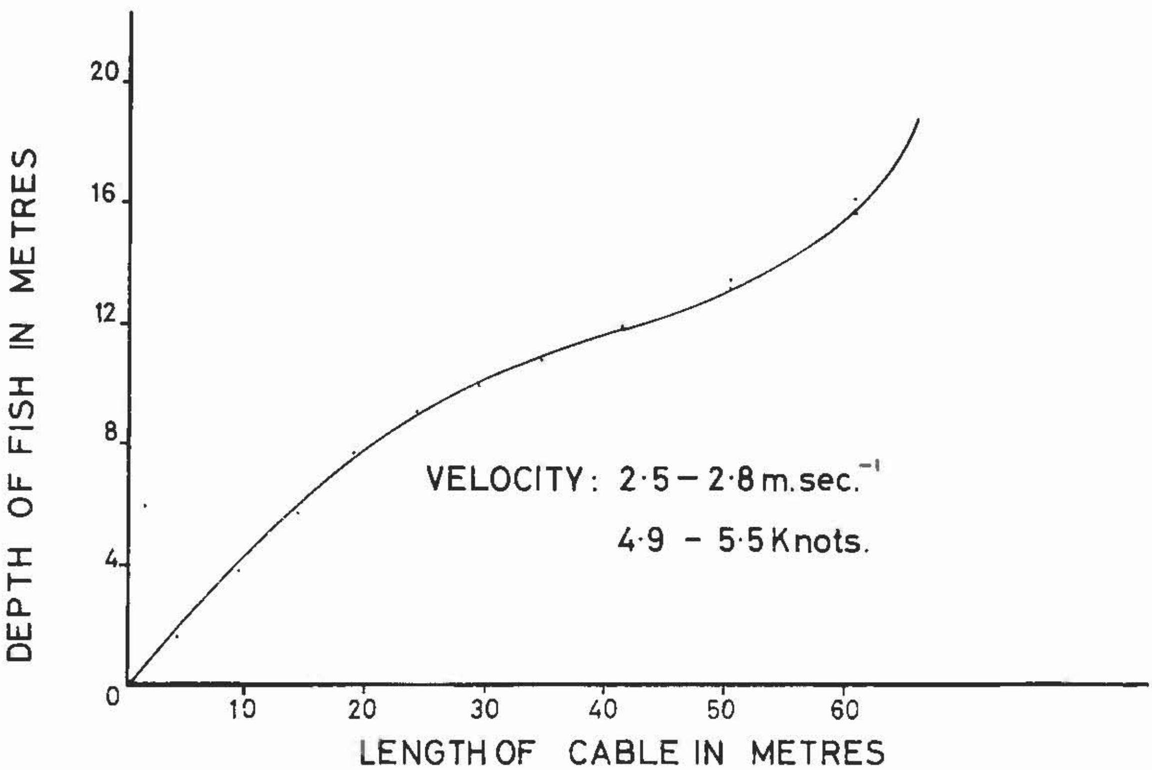


Fig. 4
Run 3, nose cone and aluminium spacer.

weights. In figs 8 and 9 the curves do not pass through the origin because approximately 5 metres of cable was removed during repairs.

It was found that the winch was ideal for handling this type of cable and this meant that the operation of the "fish" with the heavy weights was possible. However, supplementary power was required for the winch as it was unable to raise the "fish" on batteries alone more than about three times from 80 metres. The electrical generator supplementing the power was ideal for recharging the battery and it was generally run continuously whilst at sea. With this system no problems were found with the power.

Great care has to be taken when bringing the "fish" on board and putting it over the side; on one occasion the "fish" was dropped a few feet into the water with a kink in the cable. This caused the armouring to break through the P.V.C. sheath. Repairs took about two hours using standard tools to rewire and remount the cable termination. The "fish" was observed to be perfectly stable under all towing conditions observed (see fig.10), no oscillations were observed in the cable except for a single nodal oscillation between the winch and the surface of the sea. (amplitude about 1 cm).

Various turning manouvres were tried out; it was found that two different methods were satisfactory, firstly slowing the boat down and turning in a very small circle. This should only be attempted when the depth is greater than the cable length out. It was found that turns could be made very rapidly, although it took some distance before the "fish" re-attained its normal towing height. The second method of turning in a wide arc at normal speed was also found satisfactory, the "fish" tending to adopt a shallower towing depth due to its increased velocity.

One structural problem was encountered. This was in the construction of the fibre glass detector head assembly where cracks appeared in the surface of the fibre glass and appeared to be quite deep. These cracks may be due to faulty resin compound or to the high temperatures encountered in Cyprus. This is to be modified and the detector head assembly mounted in a nylon tube with tail fin screwed on and the air spaces filled with resin. A second fault in the design is the electrical connection arrangement; at the moment a flying lead from the "fish" plugs into the cable termination. This is to be reversed, as it is extremely likely that inadvertently the "fish" may be picked up by the electrical lead thus straining the O ring seal and causing leaks.

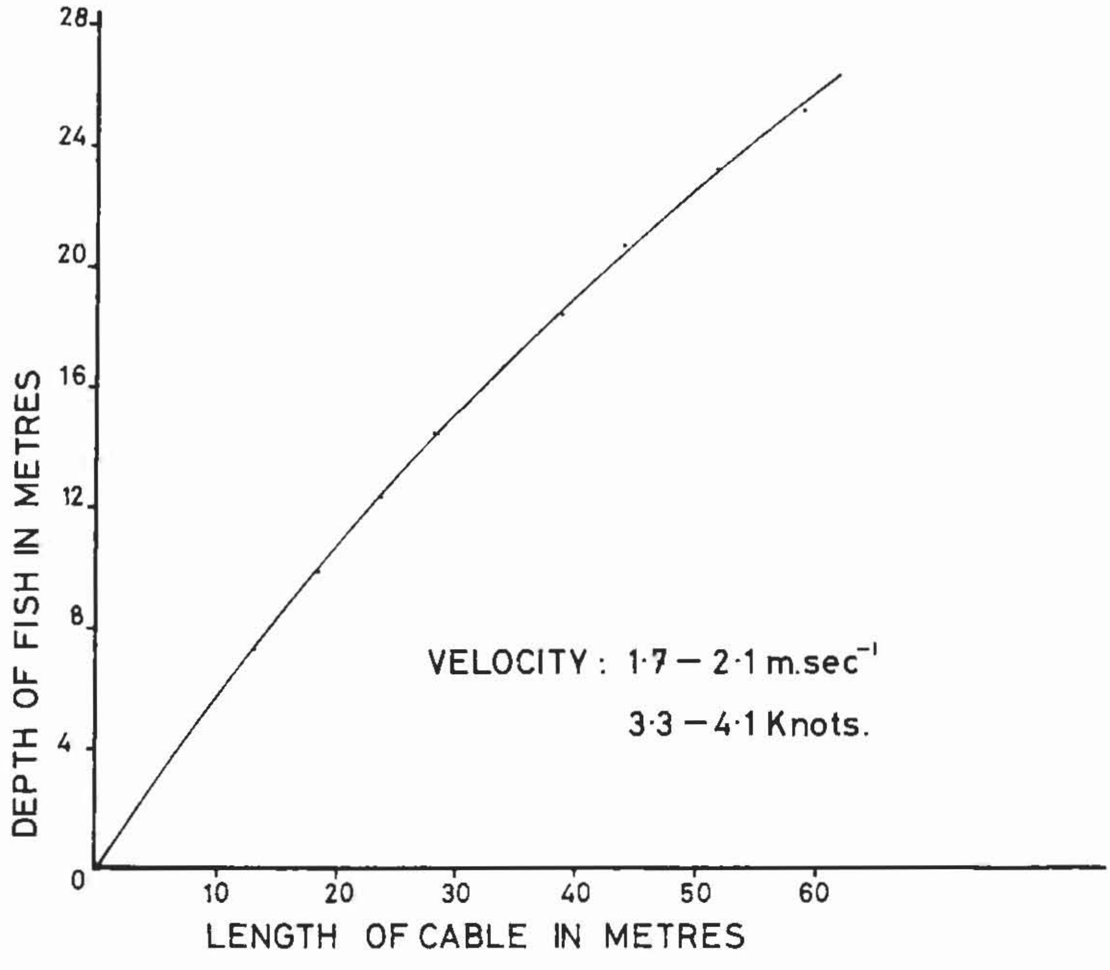


Fig. 5
Run 4, nose cone and aluminium spacer.

One additional modification mentioned above would be to mount an echo-sounder on the "fish"; this would enable the height of the "fish" above the sea bed to be determined and would be extremely useful in maintaining the correct height for efficient search. It is thought that either the complete electronics unit could be mounted in the "fish" with the transducer fitted into bronze electronics unit and the read-out being passed up to the surface, or to have the electronics at the surface and feed the transducer power down the electrical cable.

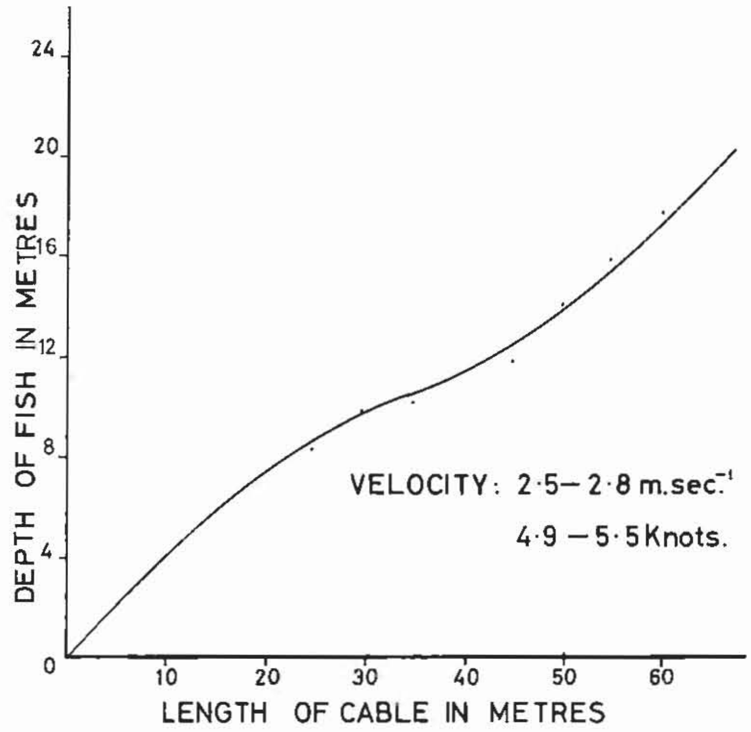


Fig. 6
Run 5, nose cone and aluminium spacer.

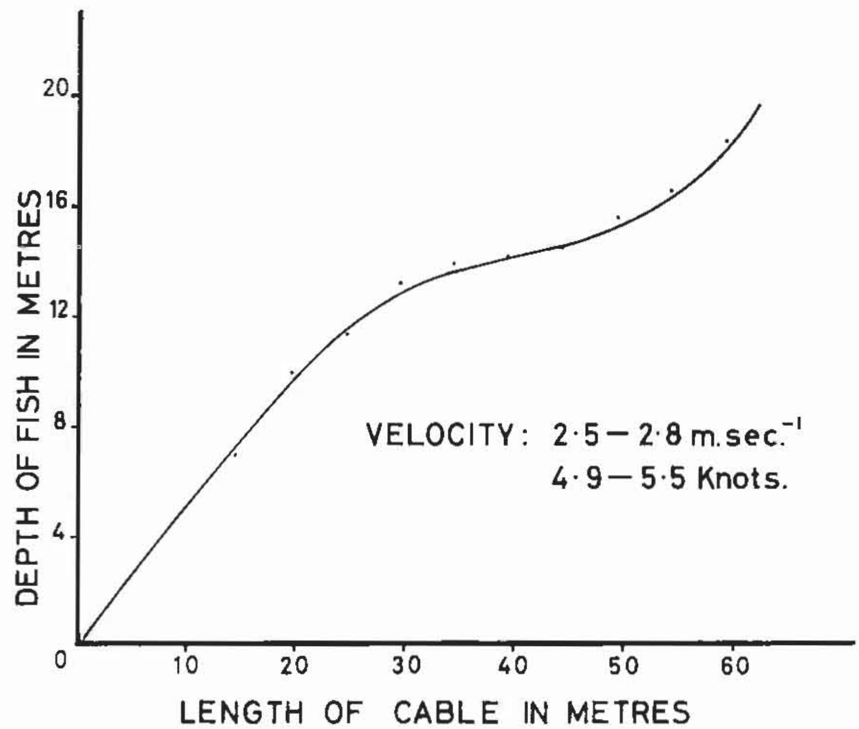


Fig. 7
Run 6, nose cone plus weights A and B.

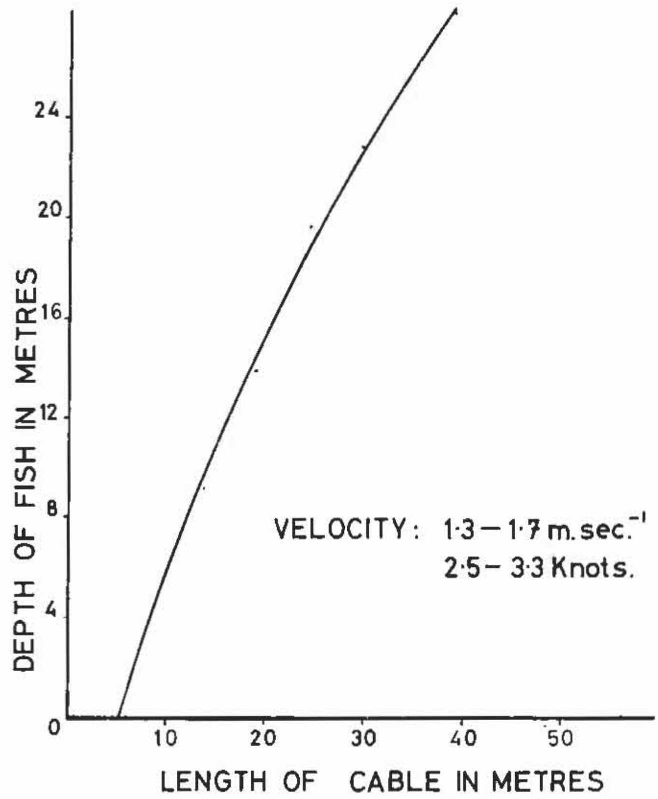


Fig. 8
Run 7, nose cone plus weights A and B

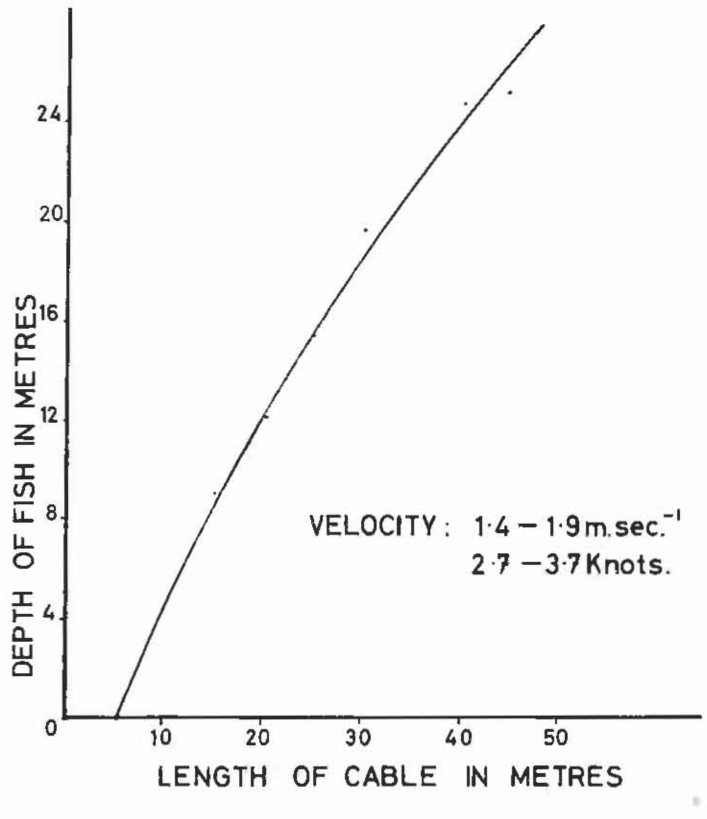


Fig. 9
Run 8, nose cone plus weight A.

Chapter 4. METAL DETECTORS AND THEIR UNDERWATER APPLICATION

Instruments that come under this classification are extremely diverse in their principles of operation. Basically metal detectors excluding magnetometers fall into five classifications:

1. Pulsed induction, (eddy current detection) instruments.

2. Beat frequency, (inductance change detection) instruments.

3. Induction balance, (phase change detection) instruments.

4. Transmitter receiver, (induction change detection) instruments.

5. Spontaneous potential instruments.

Pulsed Induction Instruments

This type of instrument has been worked on in the Research Laboratory for Archaeology. The original instrument was developed by C. Colani at the Laboratory see: (Colani 1966, Foster 1968). Since then the instrument has been developed and modified at the Laboratory, resulting in two types of instruments, one for land archaeological use and one for underwater use. The principle of operation of the system is as follows: when a magnetic field set up by a direct current in a coil is rapidly switched off, eddy currents are induced in any metal objects within the field, due to the collapse of the magnetic field. These eddy currents set up their own decaying magnetic fields which in turn induce a small signal in the coil. This signal can be amplified and displayed so that the presence of metal can be determined. This system works for all conductors and the detection is related to distance by an inverse sixth power law. Because of the shape of the coil and the field generated, the instrument is most sensitive in the axis of the coil. The repetition frequency of the current pulses is 22 $sec.^{-1}$ and the current 8 amps. The sequence of events is shown in fig. 11, sampling pulses S_1 and S_2 serve to cancel out background noise. The signal detected by the receiver during sample pulse S_1, is fed into a differential integrator which subtracts the background noise received during S_2 from signal and noise received during S_1.

There are five possible ways of improving the sensitivity of the instrument:-

1. Increasing primary current.

2. Increasing turns ratio.

3. Increasing speed of switch off of primary current.

4. Decreasing delay between current cut-off and sampling.

5. Increasing diameter of coil.

Increasing primary current is perhaps the most worthwhile procedure, as it is only limited by the characteristics of the transmitter switching transistor; at the present time the Laboratory instruments are operating at 20 amps primary current. Increasing the turns ratio does two things, it increases the sensitivity and increases the inductance. As the inductance is proportional to the square of the turns ratio the inductance rapidly becomes very large for increasing turns. Now the larger the inductance the longer the time taken for the primary current to reach maximum and the larger the back e.m.f. on switch off. This back e.m.f. creates a reverse voltage across the emitter-collector junction of the transistor, which if too large will destroy the transistor. It is very difficult to find a high collector current transistor which will stand a back e.m.f. of several hundred volts. Speed of switch off is limited by transistor characteristics and circuit design and has been optimized to 20 μ sec. Delay between cut off of current and sampling, depends on recovery time of amplifier and decay time of the back e.m.f., 40 μ sec being the earliest sampling yet achieved.

Increasing the diameter of the coil leads to a greater detection distance and also a corresponding increase in inductance (if turns are kept constant). The largest coils so far used are in the order of 2 metres in diameter.

What of the instrument in sea water? The first effect noted was that the sea water, because of its conductance, contributes a signal. This is known as the "sea water effect", the decay is shown in fig.12. Any metal object whose signal at any time is smaller than the "sea water effect" will not be detected. However, often metal objects have much longer time constants than the "sea water effect" and are thus detectable. Another interesting phenomenon which

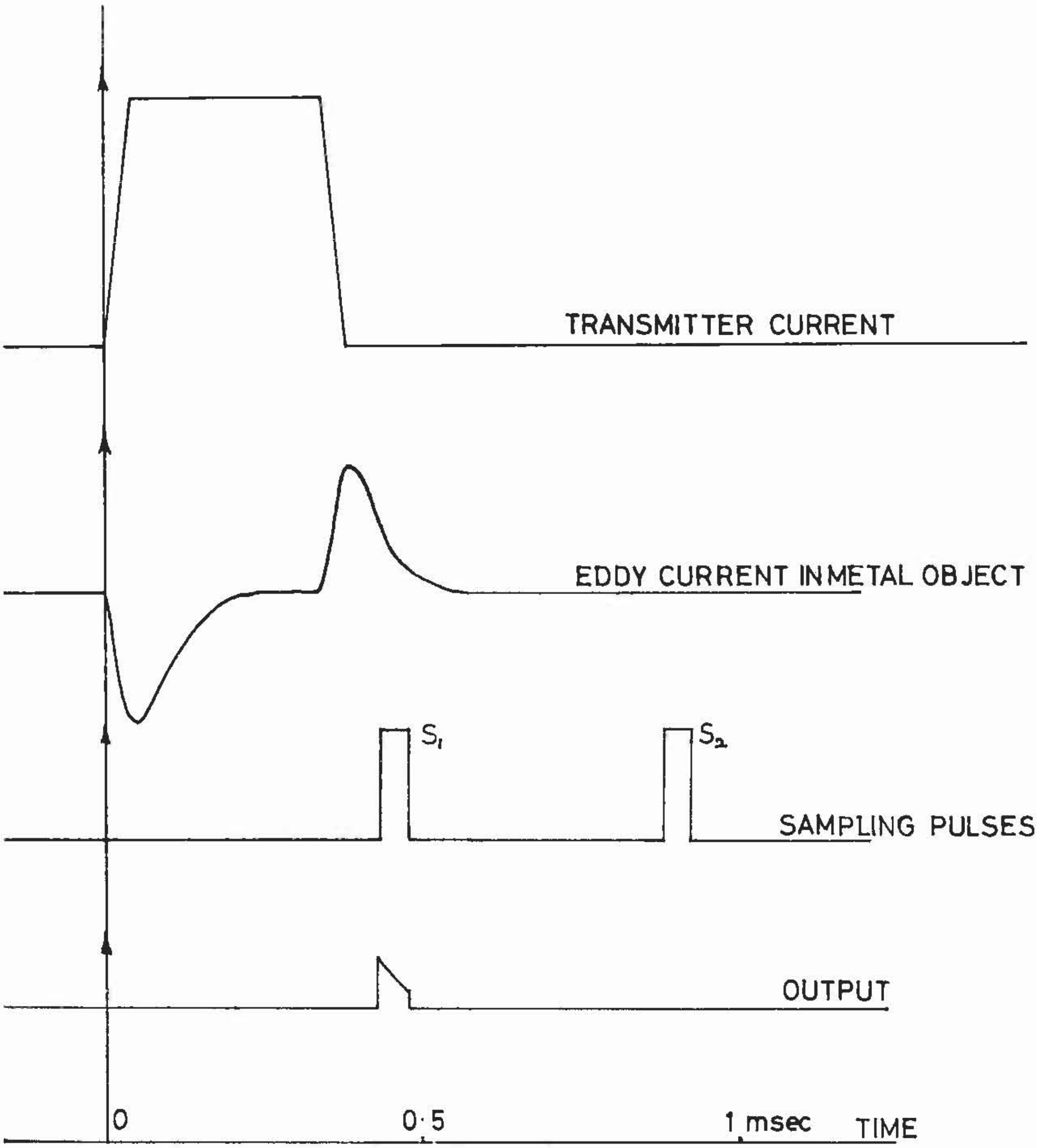


Fig. 11
Sequence of events in operation of pulsed induction eddy current metal detector.

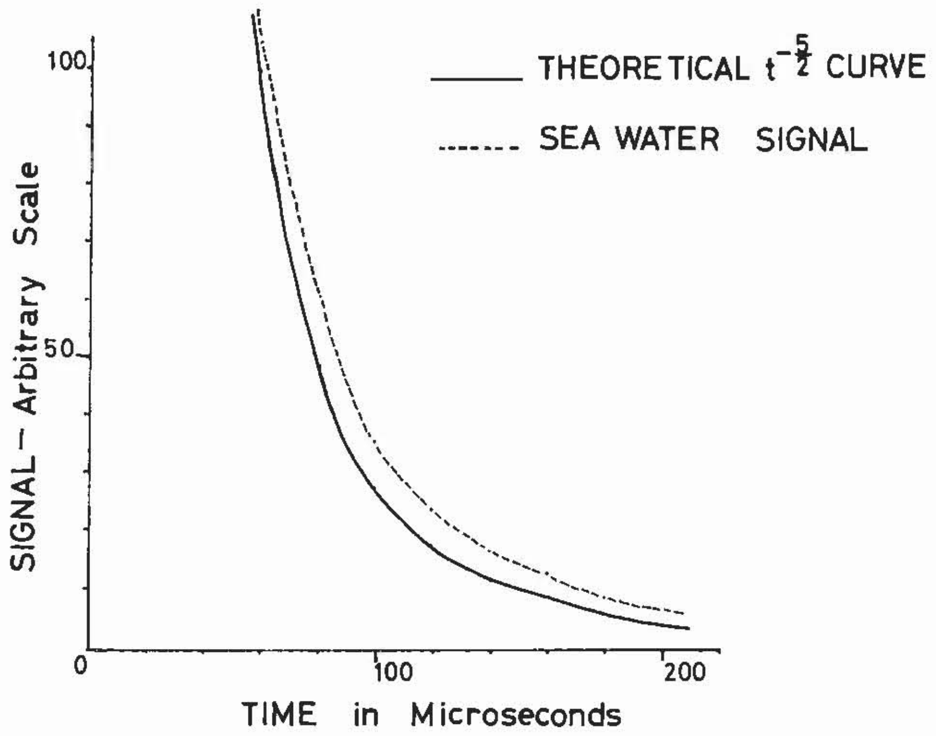


Fig. 12
Plot of theoretical decay curve for sea water signal = $t^{-5/2}$
with experimentally determined decay curve for sea water

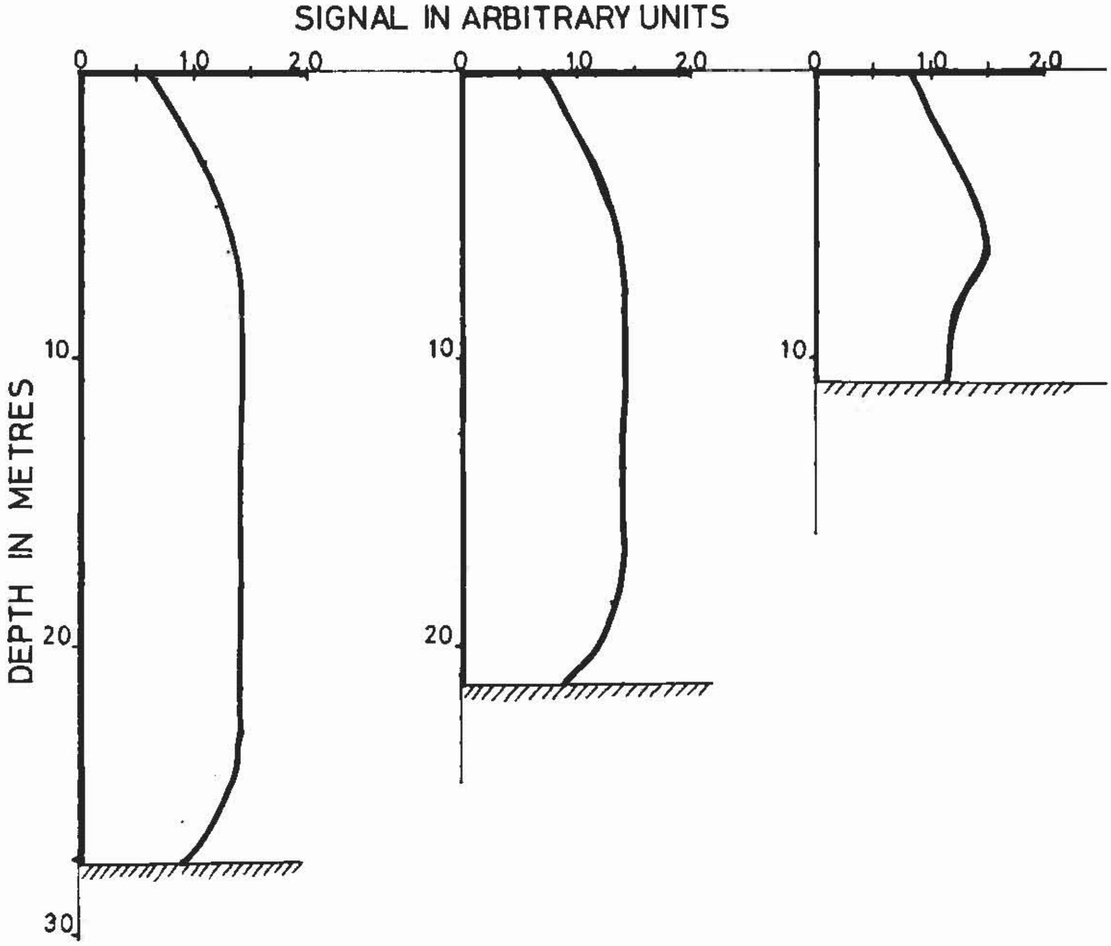


Fig. 13
Variation of sea water effect with depth, note the reduction of
signal on approach to bottom and surface.

causes problems with the instrument is the variation of the "sea water effect" in relation to the height of the coil above the sea bed; this is shown in fig. 13. A decrease in amplitude of the effect is noted as the coil either approaches the sea bed or the surface of the sea. This diminution of the effect is attributed to a reduction in water mass contributing to the effect on one side of the coil, and it may be seen that the water mass at 10 metres from the coil is influencing the signal. By operating the instrument at a constant height above the sea bed or better still on the sea bed, the effect is constant and this signal can be backed off by suitable potentiometric devices.

It has been stated that ferrous/non-ferrous discrimination can be achieved by studying the decay characteristics of the induced eddy current. Non-ferrous materials were thought to have purely exponential decay characteristics, ferrous material non-exponential. Experiments conducted at the Laboratory by Mr. Eric Foster have shown that this is generally not true. By taking the logarithm of the decay curve electronically, exponential signals will produce linear curves and non-exponentials non-linear curves. He was able to show that both ferrous and non-ferrous materials produce both exponential and non-exponential curves. A selection of examples are shown in fig. 14, showing the logarithm of decay curves for a variety of objects. Large non-ferrous objects give non-exponentials as do large ferrous objects, small ferrous and non-ferrous objects give exponentials. Thus at present it seems unlikely that pulsed induction methods can be used to discriminate ferrous and non-ferrous material.

Beat Frequency Instruments

This type of metal detector is one of the simplest instruments to construct, unlike the pulsed induction instrument which has good penetration, but poor resolution for small objects, this instrument has poor penetration but can resolve very small objects. The principle of operation is that a coil, often only a single turn of wire, forms part of a tuned circuit of an oscillator. In the presence of no metal, a variable oscillator is adjusted to give a beat frequency by combining the signal with a reference oscillator. When the coil is brought into the vicinity of metal the inductance value changes due to the presence of metal and causes the resonant frequency to change, thus changing the beat frequency. In general the value of inductance goes up for ferrous objects and down for non-ferrous, so that ferrous/non-ferrous discrimination can be achieved by noting the direction of the change of the beat frequency.

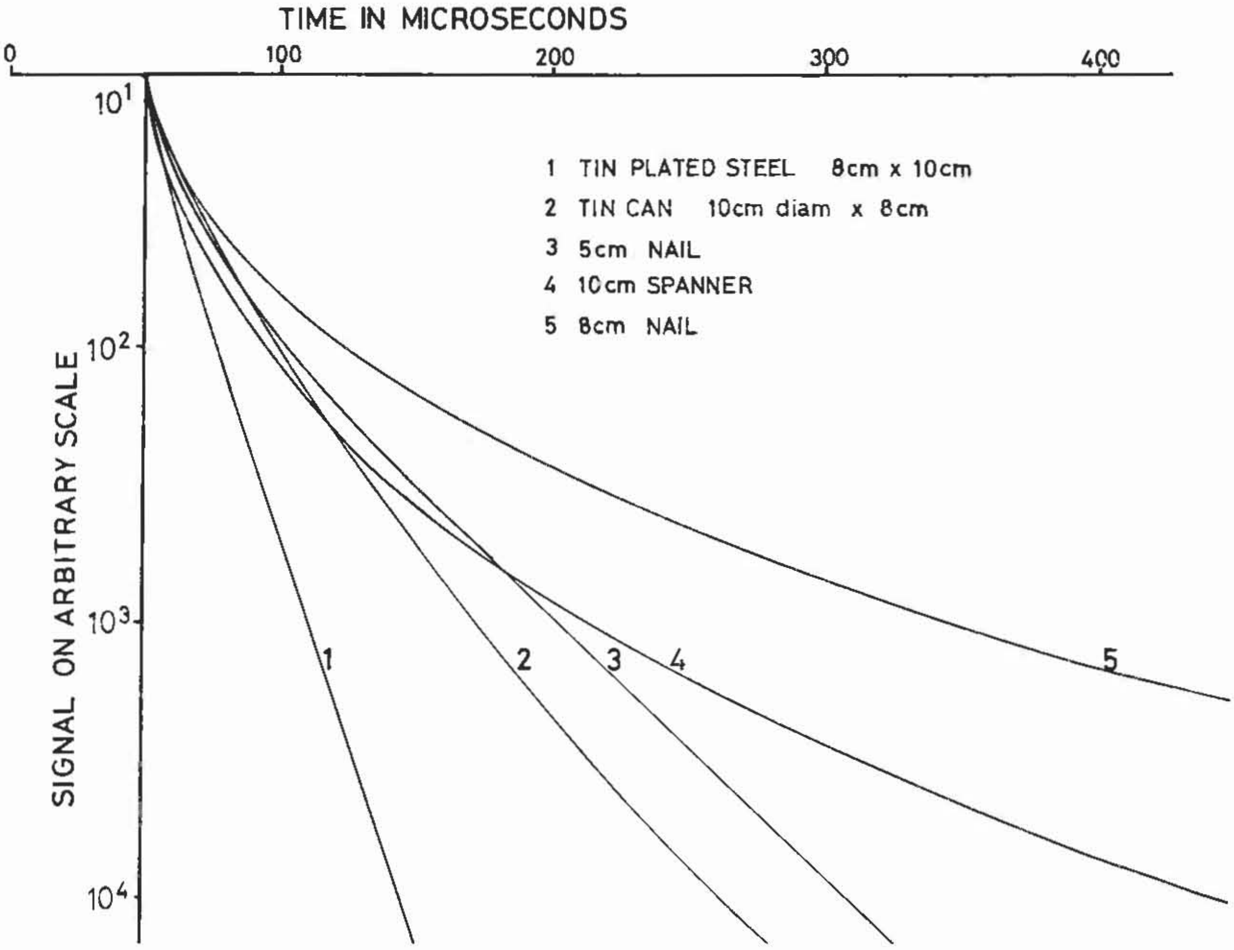


Fig. 14
Logarithmic decay curves for various ferrous objects.

Induction Balance Instruments

In this system a transmitter coil is wound in two parts on either side of the receiver coil; by winding the coils in series opposition and carefully adjusting the position it is possible to arrange that no signal is induced in the secondary. In the presence of a metal object, the signal re-radiated by the metal object has generally undergone a phase change, so that it is detected by the receiving coil. By analysing the phase change it is possible to deduce information on the nature of the metal object and ferrous/non-ferrous discrimination can be achieved.

Transmitter-Receiver Instruments

In this type of instrument the coupling between two coils is removed by mounting the coils at right angles to each other so that no signal is detected when metal is not present. Introduction of a metal object alters the coupling between the two coils thus causing a signal to be induced in the receiver. Good penetration can be obtained with this system but it has poor resolution.

Spontaneous Potential Instruments

This type of instrument is the oldest and simplest type of metal detector, but it is also the least understood. It will only operate in water, where the dissolved ions from a metal object generate an electrical potential.

Two electrodes are placed in the water, one type of arrangement being to tow a cable across the sea bed with one electrode at the end of the cable and the other some distance up the cable. If a high impedance voltmeter is connected to the electrodes the potential between them may be monitored. Thus it is possible to locate the position of potentials due to metal objects. It is doubtful, however, if this system will locate buried metal objects.

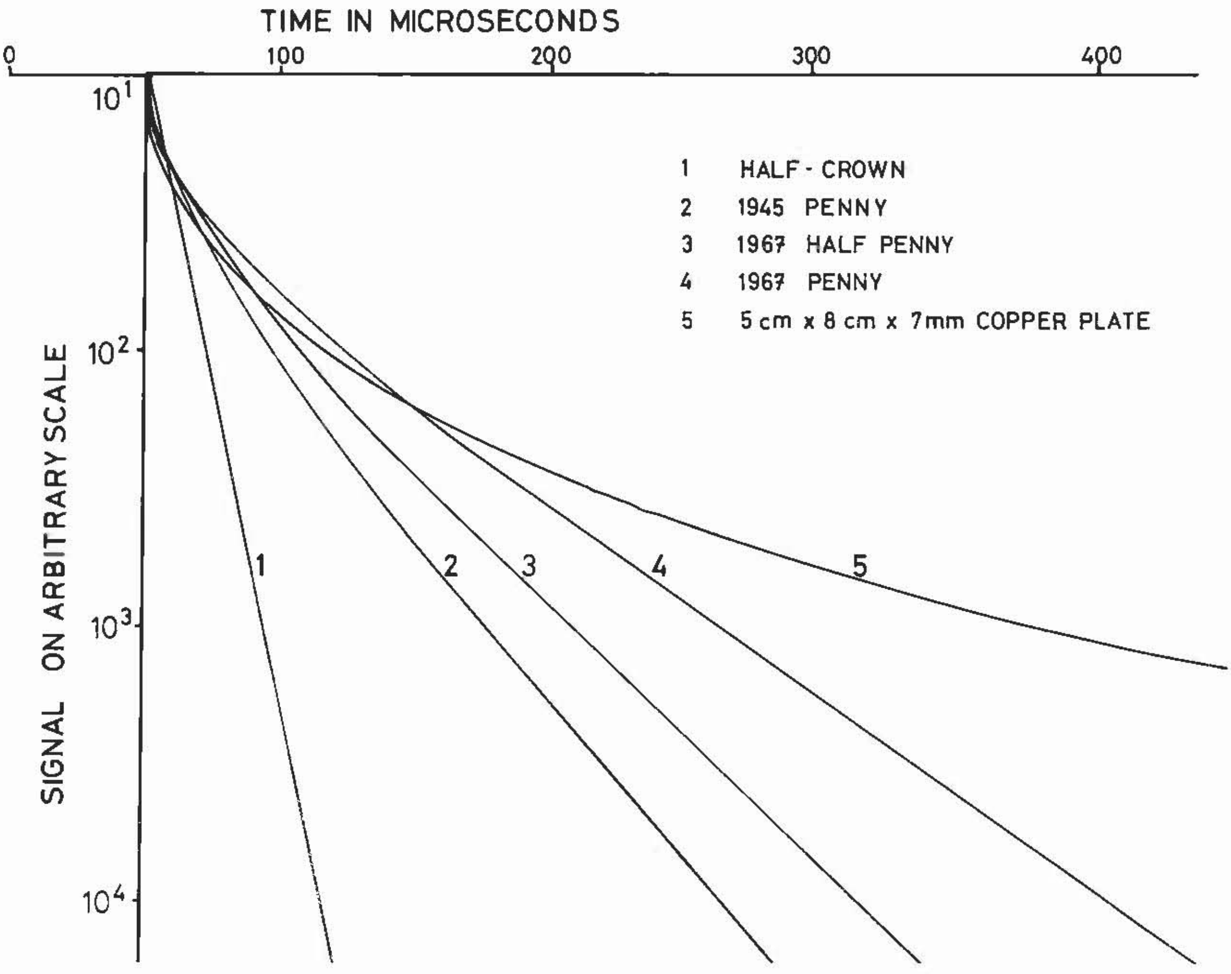


Fig. 15
Logarithmic decay curves for various non-ferrous objects.

Chapter 5. THE MARINE APPLICATIONS OF METAL DETECTORS

It is clear from the previous chapters that magnetometers and metal detectors have different applications. Magnetometers may be used to search large areas of the sea bed for ferrous material, whereas metal detectors can only be used in localized areas to pin-point both ferrous and non-ferrous material. From the archaeological point of view, marine magnetometers are the ideal instruments to locate the position of iron ships that have been wrecked. In 1966, Dr. Hall using a proton magnetometer located three battleships, the Bouvet, the Ocean, and the Triumph, that had been sunk in the Dardanelles in 1915. Some five days were occupied in the location of the three wrecks, (see Hall 1966). Unfortunately iron wrecks are but a brief chapter in a long history of shipwrecks, the earliest known wreck that has been excavated sank about 1200 B.C. at Cape Gelidonia off the Turkish Coast, (see Bass 1967). Such a ship carried little or no iron and therefore cannot be located with a magnetometer. Wrecks in the classical period often carried amphoras, where the thermoreminant magnetism of the pottery can be detected with a magnetometer, but the anomaly is so small that it is impractical to search for such wrecks with a magnetometer.

If the site of a classical wreck is known, often much of the cargo is buried beneath the sand, and a close plot magnetometer survey will yield information on the extent of the pottery cargo and the approximate positions of ferrous objects. This procedure was carried out on the Kyrenia shipwreck together with a metal detector survey, (see Green *et al* 1968). By using the magnetometer in the same way as a land magnetometer survey and building up a contour diagram of the magnetic anomalies, information was obtained on the nature and extent of the buried cargo. In conjunction with the metal detector survey it was possible to pinpoint objects that could be considered to be ferrous (indicated on both the magnetometer and metal detector) and objects that might be non-ferrous (indicated on the metal detector, but not on the magnetometer).

Moving into the Middle Ages, when ships had more iron in their construction, and notably later when the ships were using iron shot and iron guns, the magnetometer again becomes useful to search for wrecks. Often when such ships have been broken up and scattered over a large area, a magnetometer can be used to locate areas of high ferrous concentrations. These areas later may be systematically searched with a metal detector to pinpoint exactly the position of metal objects, so that efficient air lift procedures can subsequently be carried out.

Once a wreck site has been located, by far the most useful instrument is the metal detector; the Laboratory instrument which has been used on a variety of sites has proved to be a valuable instrument before, during and after excavation. For example in Ireland, at the invitation of Mr. Syd Wignall, the Laboratory conducted a metal detector survey around the ballast stones of the wreck of the Armada ship, the Santa Maria de la Rosa. It was hoped that the survey would indicate the location of the cannon of the ship. Numerous targets were located but nothing indicating the presence of cannon, and it is now concluded after excavation that the cannon lie elsewhere (see Green and Martin 1970). As described in Part 1 of this report, on the Kyrenia wreck, a large concentration of lead objects were located with the metal detector outside the excavation area which otherwise may have been missed. It is clear that such an instrument is a very useful tool for the underwater archaeologist, for both surveying and excavating.

The commercial applications of metal detection are similar to the archaeological applications, although generally the subjects are usually large and often iron, thus being ideal for the magnetometer. One particular field which is of great importance at the moment is pipeline location; since pipelines are constructed of iron, both magnetometers and metal detectors can be used to locate their position. Once a pipeline is buried under the sand the most efficient location technique is with a magnetometer. However, if the depth the pipeline buried beneath the sand is required, a metal detector must be used. By calibrating the metal detector against the pipeline under investigation, it is possible to draw a signal against distance (from the coil to the pipeline) graph. Then by measuring the maximum deflection of the signal over a buried section of pipeline it is possible to determine the depth of burial. Thus a diver, using the metal detector, may follow a buried pipeline determining its depth of burial as he progresses over great distances. Much of the field work for this application was carried out in the Solent at the instigation of Mr. J. Brookes of Mobel Marine. Mobel Marine now have the first instrument and are contracting to survey companies, and have determined depths of burial for 3.5m gas pipelines up to 1m.

This pipeline work leads to the development of a towed version of the diver-operated metal detector, for work solely on pipelines. In this case the coil is towed across the seabed on a long coaxial cable and the instrumentation is housed on board ship with a chart recorder output. By again calibrating the instrument first, it is possible by measuring the peak heights as the detector passes over the buried pipeline, to determine its depth of burial. Thus the Laboratory has been involved in the development of two complementary instruments, which have practical applications in both the archaeological and commercial fields.

Chapter 6. UNDERWATER NAVIGATION

The problem of navigating a towed "fish" at sea is an extremely complex one. The general requirement when operating a magnetometer for instance, is to know the precise coordinates of the "fish". With tidal currents and winds it is often impossible to predict exactly where the "fish" is in relationship to the towing vessel. However, there are several ways of locating the position of the "fish", the simple solution being to operate the "fish" close to the ship. This means with a magnetometer, that the vessel must be made of wood and have a small engine; in such a case the coordinates of the vessel determined by some means, (e.g. Decca Hifix) serve as the coordinates of the "fish". Anomalies may then be plotted on Track-Plotter, their extent determined and the vessel may be repositioned over the centre of the anomaly without difficulty. This however, is a specific solution, not a general one. Survey vessels are usually large and made of iron, precluding the close operation of the "fish" to the vessel, and the detector head is often required to operate in deep water. In the case of iron ships, the "fish" must operate at a distance at least twice the length of ship away. If the operation is in shallow water, the "fish" may be buoyed or slung below a rubber boat, in this case the navigation may be obtained by attaching the Hifix antenna to the buoy or rubber boat. However, with deep water work, a navigation problem arises; one novel solution to this problem is to operate the "fish" vertically below the survey vessel, by drifting with the current, but this may not be practical in all circumstances.

So after exhausting these possibilities, we are finally faced with determining the position of the "fish" by some other method. Sonar techniques are at present the only other obvious way of locating the position of the "fish". Two techniques may be used, either to locate the position relative to two or more fixed sonar transponders, or to locate the position with respect to transponders on the towing vessel. There are merits in both systems. Firstly, locating the position with respect to fixed stations, means that the position is uniquely determined, whereas with the latter system, the position of the boat has also to be determined and from this the true position of the "fish" computed. The fixed position system means sonar transporter buoys must be firmly positioned making the whole system bulky, and difficult to handle, whereas with the shipboard system the sonar arrays can be slung on booms from the ship.

The fixed position navigation system has been studied by the Laboratory and two experimental versions constructed. The first prototype has been described elsewhere (Hall 1966). The second improved system was constructed by the author. The basic principle is two channel sonar ranging with two radio sonar buoys anchored at approximately the corners of the survey area A and B, see fig. 16. They are arranged so that radio signals from the

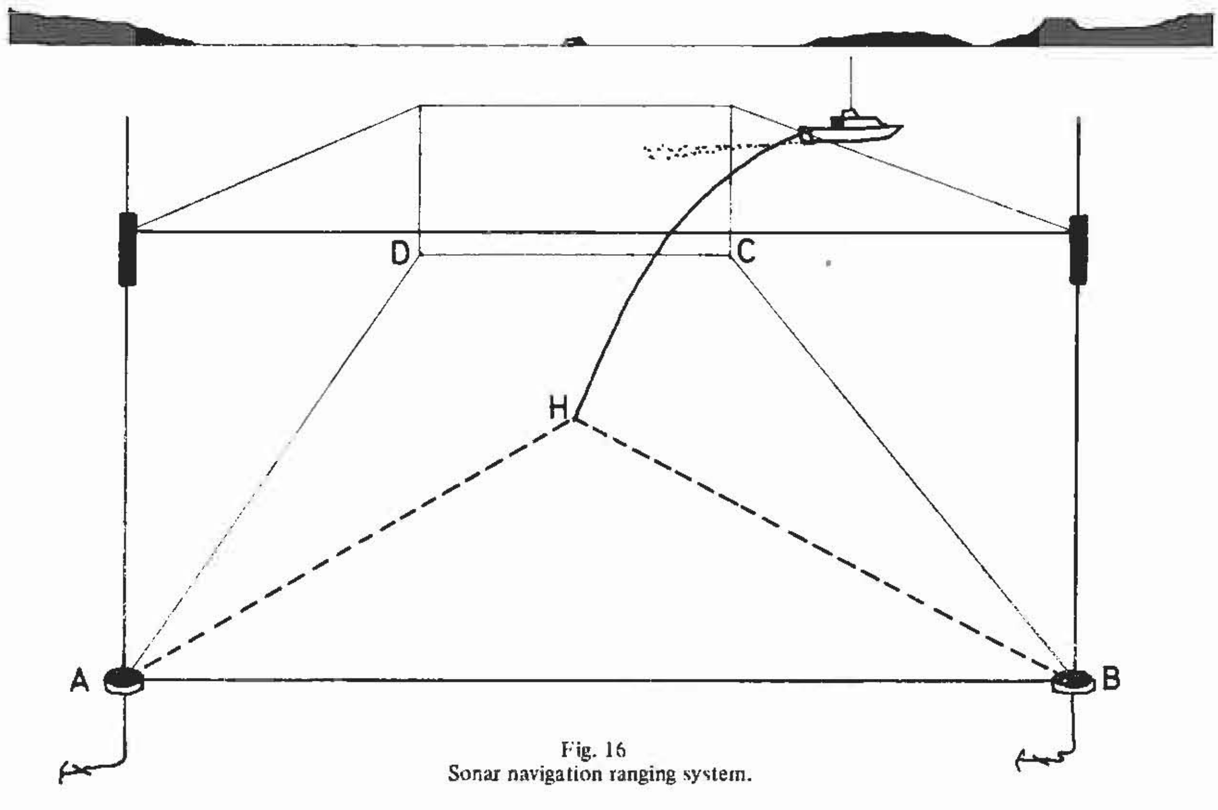


Fig. 16
Sonar navigation ranging system.

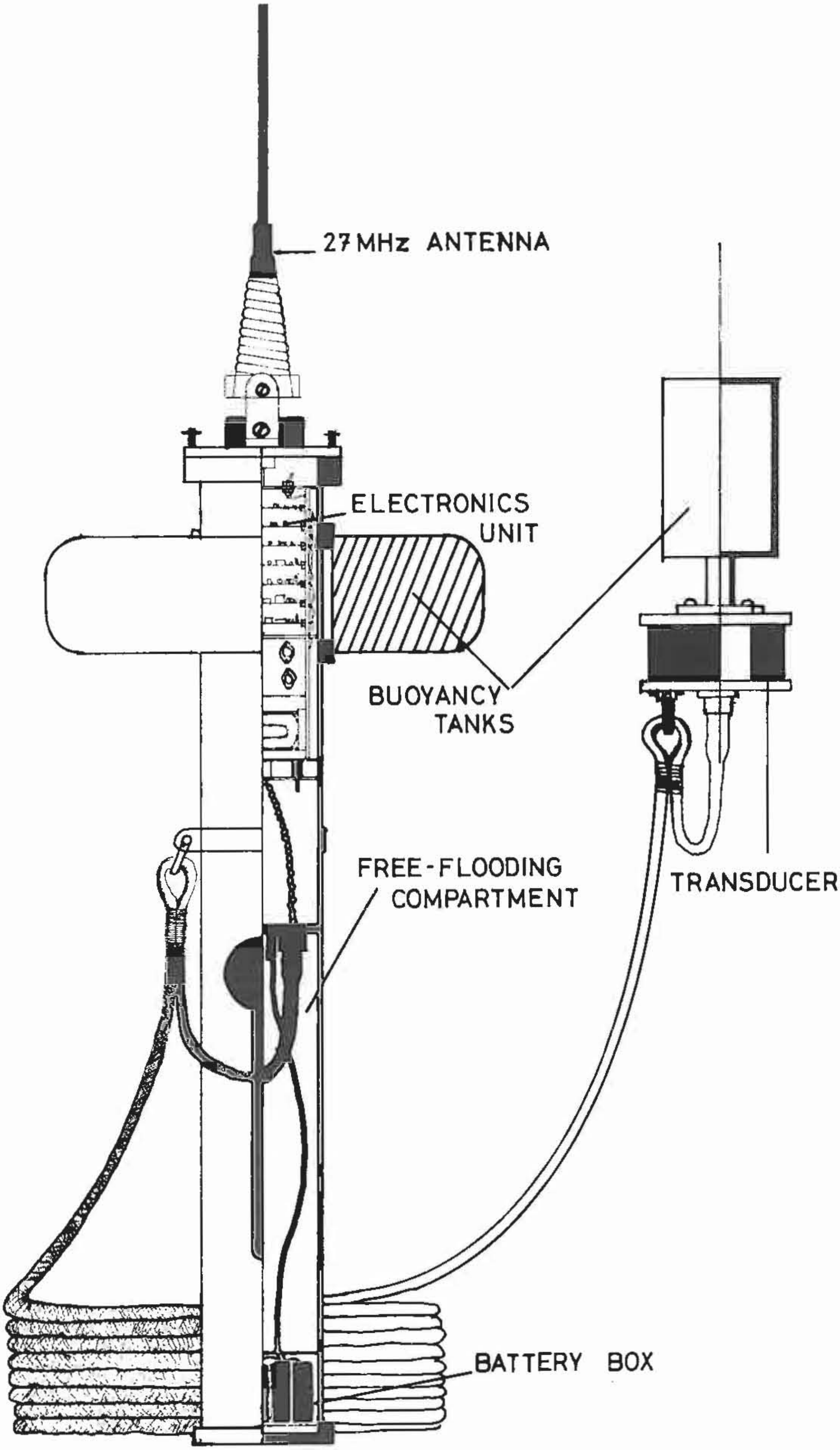


Fig. 17.
New radio-acoustic buoy

survey vessel can be coded in such a way that each buoy can be separately commanded to emit an acoustic ping. The time taken for the sonar ping to travel from the transducer to a hydrophone H attached to the "fish" is directly proportional to the distance. By measuring the time of flight of the sonar signals from the two transducers to the hydrophone (distances AH and BH), the position of the "fish" is then determined in a horizontal plane. By operating the "fish" at a constant depth and positioning the transducers at the same depth, it is not necessary to determine the position in three dimensional space. The problems with the first experimental system were:

1. Cross talk between radio channels to the buoys.

2. Short radio range.

3. Short acoustic range.

4. Mechanical design of buoys unsuitable.

The radio was a 27MHz model control system with 2 and 3KHz audio command channels, and at short range these two channels interfered with each other. Therefore the radio command systems were modified to operate on pulse width command, also the power of the radio was increased from a few milliwatts to the order of 1 watt.

The transducers were originally magnetostrictive; these were changed to electrostrictive, thus enabling the power to be increased to about 500 electrical watts. With the increased power drive and the ceramic transducers, it was hoped to obtain acoustic ranges in excess of 10km.

The mechanical design of the whole radio buoy system was changed: instead of a cast aluminium housing, fibre glass was used, with an electronics unit that can be plugged in and out of the buoy with great ease (see fig.17). The separate electrical and mechanical cables running to the transducer and anchor were changed, and a composite cable was utilized having an electrical cable wound in the centre of the rope, thus making the laying operation much simpler.

The main design problem with the present system is the radio link. 27 MHz is not a good frequency for use over medium ranges of 10-20km, a higher frequency would be more suitable. Apart from this the system awaits sea trials, and one of the greatest problems with the system is to find a suitable test area. The sea water area must be calm enough to conduct trials for extended periods. Unfortunately in the U.K. bad weather and strong currents make the work difficult. This is one reason why so much of our test work has been carried out in Cyprus where good weather for months on end can be guaranteed.

The shipboard system uses a pinger mounted on the "fish" and two hydrophones mounted on booms off the side of the boat. The times taken by the ping to reach the two hydrophones give the bearings and distance of the "fish" in relationship to the line of the transducers. However, with this system the horizontal distance from the "fish" to the ship is difficult to determine, the distance determined is that from the "fish" to the transducer, and although the length of cable is known, it is not easy to compute the horizontal distance.

In conclusion it may be stated that sonar navigation is a complicated procedure only undertaken in special circumstances. It is thought that the system developed by the Laboratory gives a good information return for the particular application of operating a magnetometer, but it requires that the "fish" and transducers are operated at the same depth. The use of such a system can only be justified for an extremely detailed survey of a large area (10km square or larger) as continued repositioning is a long and arduous process. With extended testing facilities and interest from industrial sponsors, this system could be perfected and made into a reliable sonar navigation system, with application in many fields apart from magnetometer surveying.

CONCLUSIONS

The three instruments developed by the Laboratory and described in this report all have commercial applications; the metal detector and the proton magnetometer are manufactured by Littlemore Scientific Engineering Company (ELSEC) which is associated with the Laboratory. The sea-going proton magnetometer is widely used by commercial surveying and marine salvage companies, and is sold throughout the world. Although not as accurate as some magnetometers it has been found that for marine work the sensitivity is more than adequate. It is generally not practical to operate a proton magnetometer at sea with a resolution greater than one gamma (10^{-5} oersted) and this is well within the capability of the Laboratory instrument. The fundamental problem with proton instruments is that their repetition rate cannot exceed about 1 sec^{-1} thus limiting the speed of search. Fluxgate instruments, although operating continuously have orientation problems that require great stability and thus are generally not practical. Optically pumped magnetometers are extremely sophisticated instruments, and therefore expensive and generally not economical for most commercial and marine application.

Improvements in the proton magnetometer detector head design are underway at the moment, and it is hoped in the near future that these will be commercially available for deep water work. With the new 'head' it will be possible to improve the resolution to small ferrous objects such as telephone cables and also deep pipelines.

The underwater metal detector has also been manufactured for the commercial market; the new system was developed for an application required by Mr. J. Brookes of Mobel Marine Diving Company. This application is for the location and determination of burial depth of pipelines. Mobel Marine have contributed towards the development and now operate the instrument for survey work on pipelines. With the present instrument it has been possible to locate 1 metre diameter gas pipelines buried up to a depth of 3.5 metres.

A towed version of the metal detector is being developed for an application suggested by Decca Navigator, who require to determine depth of burial of pipelines whilst working from a survey vessel and not with divers. This instrument will, it is hoped, break the monopoly of the "Shell Fish" which is available only for hire and at a considerable charge. The Laboratory instrument together with "Shell Fish" will be the only commercially available instrument on the market at the moment which may be used to determine the depth of burial of pipelines.

The sonar navigation system has commercial applications but at the present moment it is not available as it is still undergoing modification and has so far generated little commercial interest apart from curiosity.

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