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DUAL CHANNEL SIDESCAN SONAR

USES AND OPERATION IN HYDROGRAPHIC SURVEYING

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This Paper was written at the direction of the Hydrographer of the Navy for the guidance of the Commanding Officers of Her Majesty's Surveying Ships and Craft in the use of sidescan sonar, and has been published as Professional Paper No. 24 (Hydrographic Department, 1977). The author also submitted it as his thesis for the final examination for Fellowship of the Royal Institution of Chartered Surveyors.

The paper forms a logical extension to an earlier paper on the use of sonar for hydrography published by the author in 1972 [1].

INTRODUCTION

1. Dual Channel Sidescan Sonar (DCS-3) was introduced into the British Hydrographic Service in 1970. It is now accepted as being an essential aid to modern hydrographic surveying, to the extent that no survey on the Continental Shelf is considered complete that has not included a comprehensive DCS-3 sweep.

2. Since its introduction, considerable experience has been gained in both the operation of DCS-3 and the interpretation of sonographs. Making the most of DCS-3 is as much an art as a science. The science lies in the correct tuning of the recorder (see paragraphs 7 and 8), a delicate matter involving the adjustment of a number of interdependent controls. This requires patience and a certain amount of intuition. The art lies in the subjective interpretation of the sonograph. A well-tuned DCS-3 being towed at the optimum height above the seabed (paragraph 11) at slow speed (paragraph 13) will give a clearer picture of the seabed than any system hitherto available to the surveyor. However, wrecks and obstructions of navigational significance will not necessarily stand out clearly from their surroundings. In certain conditions of depth, seabed slope or highly reflective sediment, a shoal may not throw a shadow, or the return signal from a small obstruction may be swamped.

3. The ability to recognise the tell-tale thread-like shadows, the woolly squiggles and intensely dark pinheads, which are frequently the signatures of hitherto undiscovered wrecks, only comes with experience. The

same applies to the correct geological interpretation of the sonograph. It is hoped that the illustrations in this paper will assist with wreck recognition, the principal concern of the hydrographic surveyor. A study of References [2], [3] and [4], allied to the fruits of experience, should improve the surveyor's assessment of bottom texture.

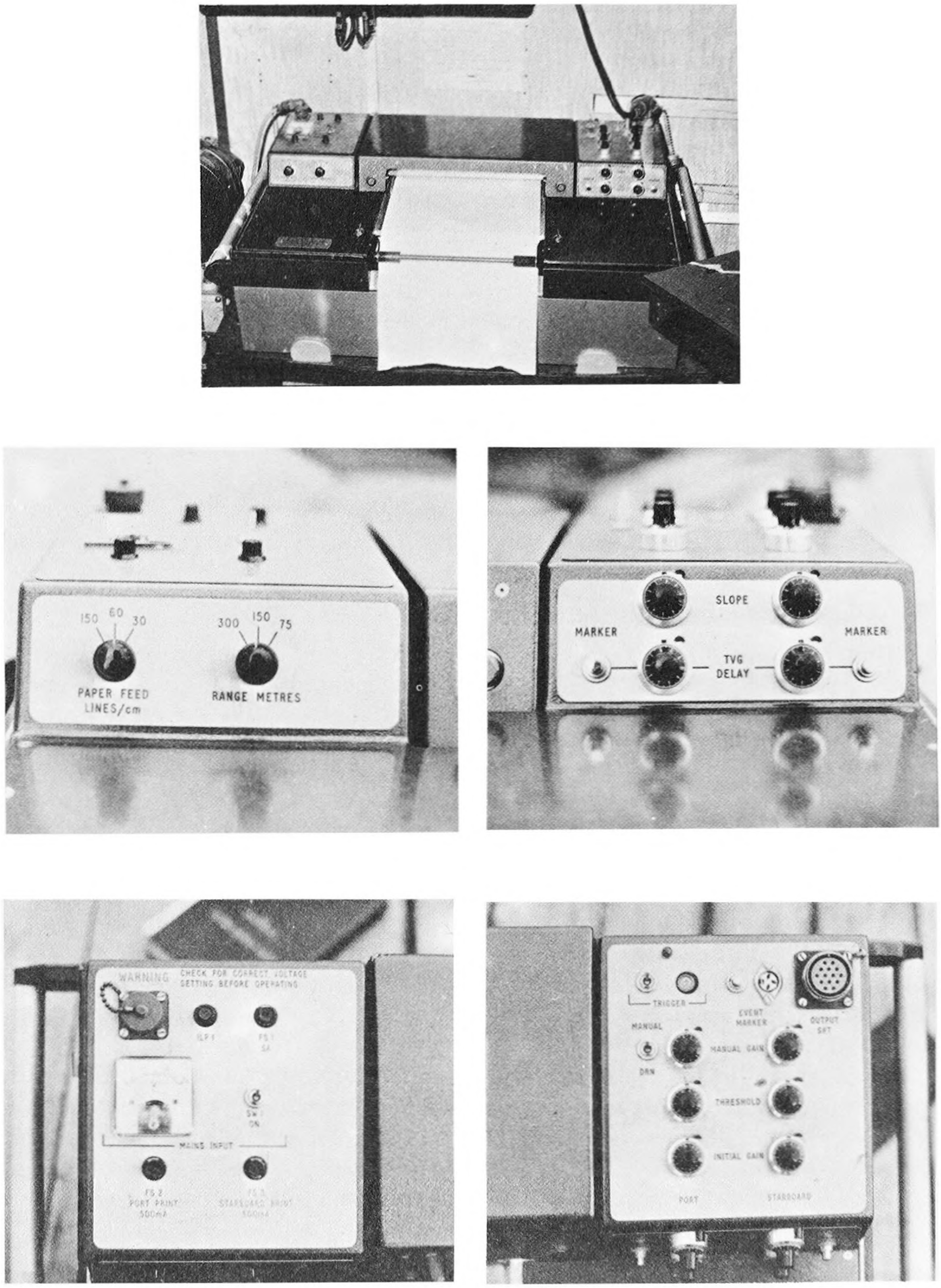


FIG. 1. — *Top* : OAL recorder as fitted in HMS *Fox*.
Centre and bottom : OAL recorder - exterior controls.

4. Aims

The aims of this paper are :

a) To provide full understanding of the DCS-3 systems in current service, their application to the survey task and their limitations.
b) To supply guidance on the interpretation of sonographs.
c) To complement manufacturers' handbooks in areas where these publications provide only a sketchy treatment of an important topic, e.g. the streaming and recovery of the towfish.
d) To interpolate the manufacturers' handbooks and to relate problems specifically to HM Surveying Ships and Craft.

5. The Equipment

This paper deals with the high definition short range DCS-3 systems currently in service in the Royal Navy. These are the American Edgerton, Germeshausen and Greir (EG&G) systems (*) and the newly introduced British equivalent marketed by Offshore Acoustics Limited (OAL) (**). As the systems are mutually compatible, and there will only be a gradual phasing out of EG&G equipment, characteristics of both systems are given at Annex A and references made where appropriate in the text below. Comprehensive operator's handbooks are supplied with each system, and these should be read in conjunction with this paper which deals principally with operational considerations. In general, where the paper conflicts with the handbook on a technical matter, advice in the handbook should be followed.

SETTING THE SYSTEM TO WORK

THE RECORDER

6. Pre-use Checks

These are carried out before the towfish is connected and are fully described in the handbooks. Once the towfish is connected on deck with the recorder switched on, the port and starboard transducers should be stroked alternately. This will produce continuous black marking of the appropriate recorder channels and it proves continuity before a towfish is streamed. Final tuning of the system can only take place under way *in the area of intended operations.*

7. Tuning

The mechanics of this operation are covered in the handbooks which should always be consulted. The surveyor must decide what he is looking for, and how best to display it, bearing in mind the topography and composition of the seabed and the height of the towfish above it. The dynamic

(*) EG&G, Environmental Equipment Division, 151 Bear Hill Road, Waltham, Mass. 02154, U.S.A.
(**) OAL, Waverley Electronics Ltd., Waverley Road, Weymouth, Dorset, England.

range of the recording paper severely limits its ability to contrast two highly reflective subjects. This is partly compensated for by the ACT/DRN circuits (paragraph 10). For hydrographic applications it has been found best, even during the area search, to tune for a rather high overall gain to highlight shadows. The recording paper will therefore show quite black at near range and a pronounced pink at far range.

8. The Controls

The tuning of the sonar beam demands a thorough understanding of the function of each control. The strength of the return signal varies inversely with the square of the slant range and directly with the material reflective properties of the target, its aspect and its size. The tuning process therefore involves manipulation of the Time Varied Gain (TVG) circuitry. The interdependent INITIAL and SLOPE controls, as their names suggest, affect the first 20 % of the record and the 20 % to 50 % band, respectively. These are adjusted against a previously established overall gain or sensitivity to achieve the desired result. The object is to obtain an even trace across the paper, without loss of information below the threshold or by burning of the paper.

9. Adjustment during survey

The characteristics of the recorder trace will vary with the height of the towfish above the seabed and bottom reflectivity. A constant watch must be kept on the recorder, and the controls adjusted to give a good trace. It is generally possible to satisfy hydrographic requirements by adjusting the overall gain alone, and by varying the amount of tow cable to maintain the fish at an optimum height above the bottom. However, in dramatically changing topography adjustment of all three controls is sometimes required. A record of control settings should invariably be maintained.

10. "Hands-Off" tuning

Due to the large range of signal densities arriving at the towfish and the inherent compromises necessary in tuning the sonar beam, the best results are achieved only by constant attention to tuning. However, when DCS-3 is used in the hydrographic rather than the geological role some loss of texture contrast is acceptable, and this permits the application of "Hands-Off" techniques. In the latest EG & G recorders this is provided by Automatic Contrast Tuning (ACT) which may be switched in or out at will. This adjustment allows strong targets to stand out without obscuring the weaker ones. A similar facility exists in the OAL system, and is called Dynamic Range Normalisation (DRN).

THE TOWFISH

11. General

Because of the narrow horizontal beam width (less than 2°) of the DCS-3, good transducer stability in azimuth is essential. The towed transducer system not only achieves this effectively and inexpensively, but also confers additional advantages. The transducer can be maintained at its optimum height above the seabed (10% — 20% of the range in use) in depths of up to 150 metres. It can also, even in relatively shallow water, usually be set to run below the thermocline. Veered at long stay, the sonar will continue to operate in adverse weather unaffected by "quenching". The inherent disadvantage of a towed system is the possibility of the towfish striking an obstruction or running into the seabed. In long stay operations there is also increasing uncertainty in the exact position of the towfish.

12. Streaming and Recovery

Apart from the functional check prior to streaming mentioned above (paragraph 6) no adjustments are required in the towfish itself (but see Annex A for beam width and depression options with EG&G type 272 towfish). The normal precautions necessary when handling any towed sensor should be observed and care taken to use only approved and tested rigs (see figs 2-10). Streaming and recovery should not be attempted in

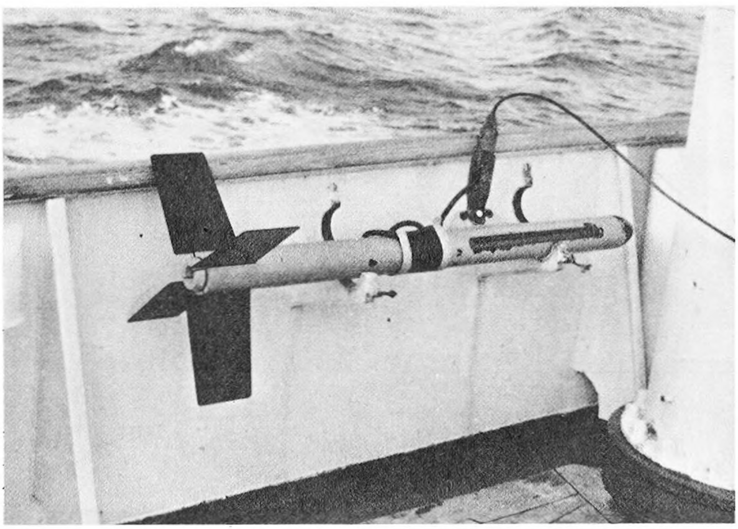


FIG. 2. — OAL towfish showing towing cable securing arrangements.

heavy weather, and speed during these operations should not exceed 6 knots. The double armoured towing cable should be handled with great care, in a seamanlike manner. It should not be worked under strain on any drum with a diameter of less than 21 inches (53 cm). Continuity to the recorder should be maintained when veering or hauling the cable to enable the Officer-of-the-Watch to maintain a constant check on the height of the fish above the seabed. In ships not fitted with slip ring winches or reels this is best achieved by flaking out the maximum anticipated length of towing cable required and working the fish from these flakes rather than from the stowage reel.

13. Towing Considerations

To ensure detection of small targets, towing speed should not exceed 7 knots over the ground (paragraph 32) and at no time should the speed through the water be more than 10 knots. The most effective way of rapidly raising the towfish is to increase speed, and thus a speed margin for this eventuality should always be allowed. The ratio of wire out to fish depth seems to vary for individual instruments and is of course also determined by the ship's speed through the water. In Coastal (CSV) and Inshore Survey Craft (ISC) the towfish is sufficiently below the wake, at normal sonar speeds, with 100 metres and 50 metres of wire out respectively. For short stay operations, i.e. not much wire veered, the gradient of the cable may be assumed to be 1:10 thus the fish will run at a depth equal to 10 % of the

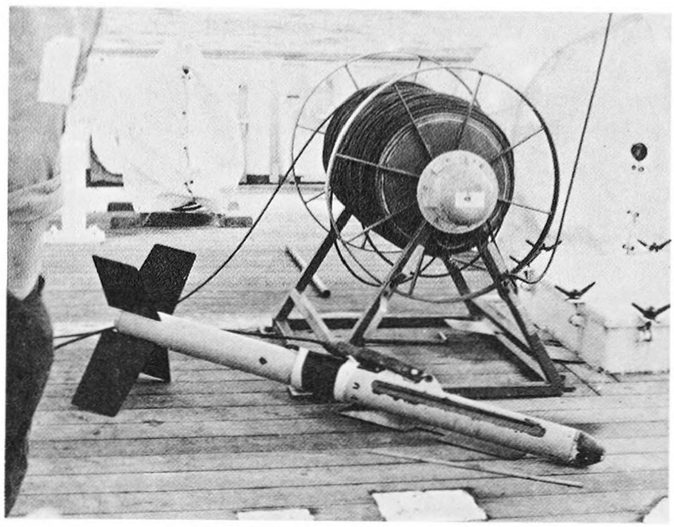


FIG. 3. — OAL towfish and slip-ring stowage reel.

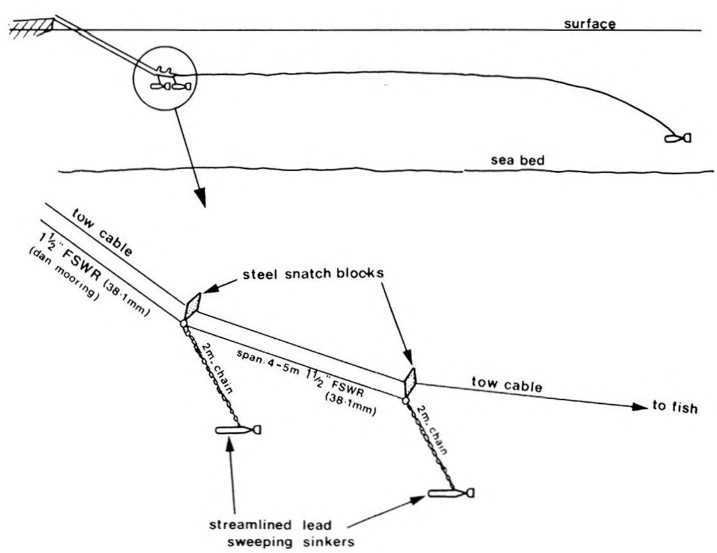


FIG. 4. — Depressor rig for Sidescan Sonar towfish. (FSWR = Flexible steel wire rope).

amount of wire streamed. In deep water, speed must be progressively reduced once the fish is at maximum stay (approximately 600 metres of wire veered) to maintain the optimum fish height, or else a depressor must be used. The use of depressors as supplied by manufacturers however is not recommended. They suffer from a number of disadvantages, the principal one being that in an emergency they prevent the rapid raising of the fish by increasing speed. The system of sinkers, illustrated in fig. 4 was devised in HMS *Fox* and overcomes this limitation. It has been found to depress the fish some 15 metres below its normal running depth at maximum stay (700 metres in *Fox's* case) and to permit an increase in speed of about 1 knot. It has also been used successfully in an ISC in general depths up to 60 metres when the towing cable was veered to 120 metres and the sinker wire to 60 metres.

14. Towing Rigs

The simplest and generally most effective method is to stream the towfish from aft, well clear of ship noise and with a good catenary in the cable to stabilise the fish and decouple it from ship's motion. There is no alternative to this method for long stay operations, but in shallow water consideration might be given to shifting the point of tow forward either to the fo'c'sle or abreast the bridge. Successful bowsprit rigs have been devised in both CSV and ISC. That in the ISC is markedly effective and very simple to contrive. The rigging of a bowsprit in a CSV, with a high flared bow and solid bulwarks, is a major evolution and probably not justified. In this case short stay working for investigations and shallow water work is better delegated to a boat.

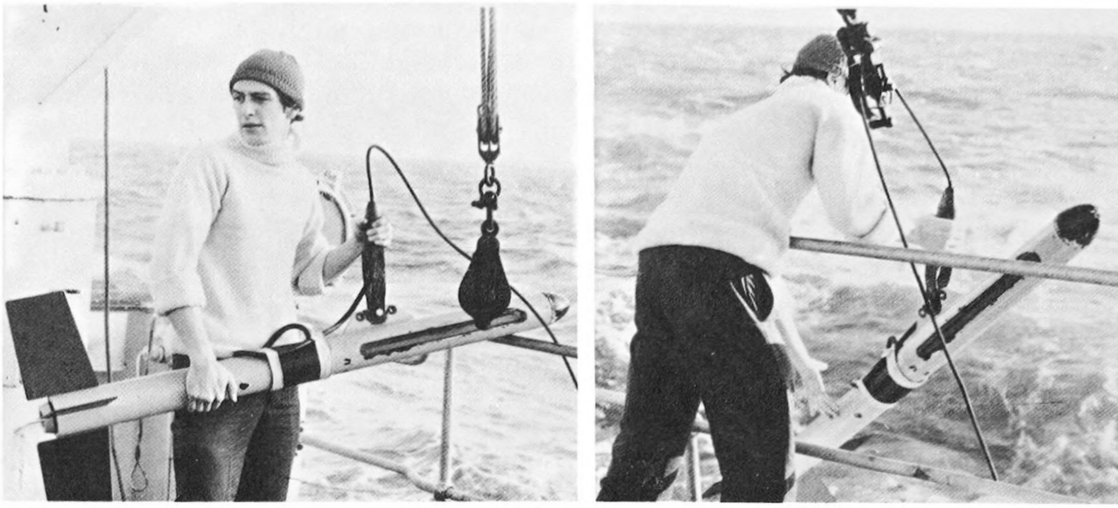
15. Advantages of Forward Tow Rigs

Short stay rigs from forward have the following advantages :

a) Increased ship mobility.
b) Reduction in the chances of the fish striking the bottom or the feature being investigated (e.g. fouling a wreck).
c) More precise positioning of the towfish.

16. Safety of the Towfish

a) *Precautions on the Bridge*. As with any surveying operation involving towed sensors it is essential, before commencing a DCS-3 sweep, to establish a good rapport with local fishermen. This not only minimises the risk of fouling their gear but may also lead to a useful exchange of information on wrecks and fisherman's fasteners. The Officer-of-the-Watch must have available a contoured plotting sheet on the scale of the survey showing significant spot soundings. The contours themselves are insufficient since they embrace soundings down to only 1 metre more than the adjacent contour below. Thus a 40 metre patch may contain a 31 metre high point. The Officer-of-the-Watch should then establish the depth of the fish below the surface; a direct readout is usually possible from the sonar trace but may otherwise be obtained by subtracting fish height from echo sounder



FIGS 5 and 6. — Launching the OAL towfish in a coastal survey vessel.

depth. It is helpful to refer to the fish depth as "keel depth" as this is effectively what it is. To the "keel depth" add the acceptable underkeel clearance, 15-25 metres depending on bottom topography and the reliability of contours and spot soundings. This provides a *danger depth* which should be recorded on every new page of the deck book and placed squarely before the sonar operator. The danger depth should be constantly updated by the Officer-of-the-Watch. Close attention must be paid to the recorder whenever cable is being veered. A record of wire streamed must be maintained in the deck book, not only to assist in plotting the towfish but also for the information of the Officer-of-the-Watch and recovery party.

b) *Precautions on the Quarterdeck.* (See also paragraph 12). The cable must be clearly and permanently marked at intervals of 50 metres out to

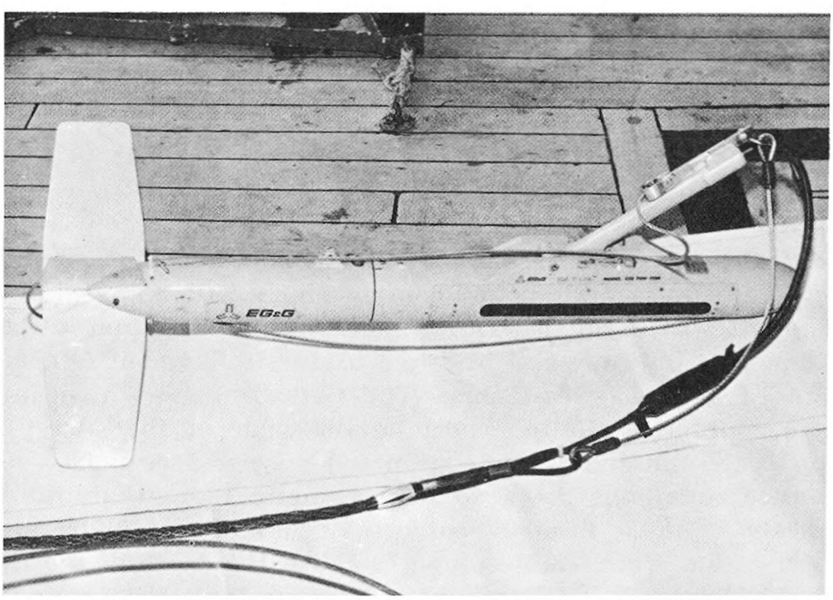


FIG. 7. — EG&G Type 272 towfish.

300 metres and at 100 metres intervals thereafter. Ideally a meter block should be incorporated in the towing rig. Specific instructions should be issued to the sonar party on careful handling of the towfish in and out of the ship when recovering and streaming. The use of a shot mat or other fender is recommended to prevent damage to the towfish from striking the ship's counter or transom. The standard methods of securing the various towfish to their cables are shown in figs 2 & 7. These should invariably be followed, and the tenets of good seamanship adhered to at all times. Methods of stopping up the inboard end of the cable will vary between ships but any rig should incorporate a preventer capable of taking the weight of the tow in an emergency. Good communication between bridge and quarterdeck is essential.

c) *Towfish recovery line*. Ships have been supplied with 300 metres of 4.5 mm diameter "Glowline" and small marker floats to attach to their towfish to aid recovery should the fish become detached from the main tow cable. Experience at sea indicates that in water depths up to 100 metres no adverse effects on the towing characteristics of the fish are experienced with lengths of recovery line equal to between 2 and 4 times the depth of water. On the contrary, there is a stabilising effect on the fish which minimises yaw. A further advantage conferred by this rig is that the drag from the recovery line prevents the fish from surging under the ship's counter during streaming and recovery. The use of this system is impracticable in deep water operations as much larger floats and greater lengths of recovery line are required. The use of a safety float in depths over 100 metres may therefore be at the discretion of the Officer-in-Charge. In lesser depths its employment should be mandatory.

OPERATING PROCEDURE

GENERAL

17. Once the towfish is running at the correct depth and the recorder is properly tuned for the area of operation, consideration can be given to the effective deployment of the system as a whole. This section discusses operating procedures and equipment limitations. It also offers practical advice on how to obtain optimum results.

18. Confidence Checks

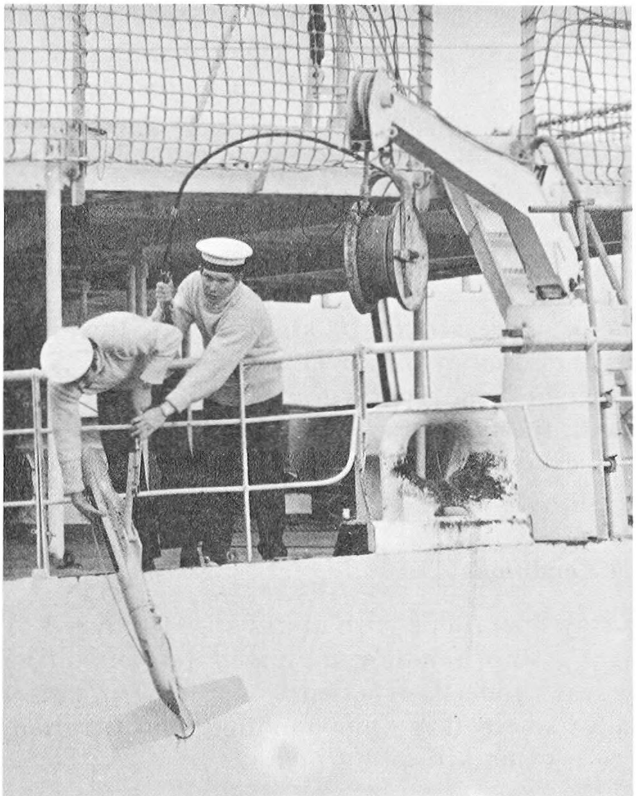
In some areas of extensively uniform seabed, performance checks are recommended at regular intervals to establish that the system is still functioning satisfactorily. In the absence of any man-made targets such as wrecks, platforms and navigational buoys, use can be made of sea surface returns and the ship's wake. If the fish is hauled up to near the surface and a turn executed at speed a wake echo should be produced on the channel on the inside of the turn. The recording of fish echoes and trawl board scours are further indications that all is well. Should a continuous seabed feature, for example a sandwave passing under the ship, be "mirrored" on one channel then the channel displaying the weaker signal is suspect (figures 13 & 14, see pp. 52-53).

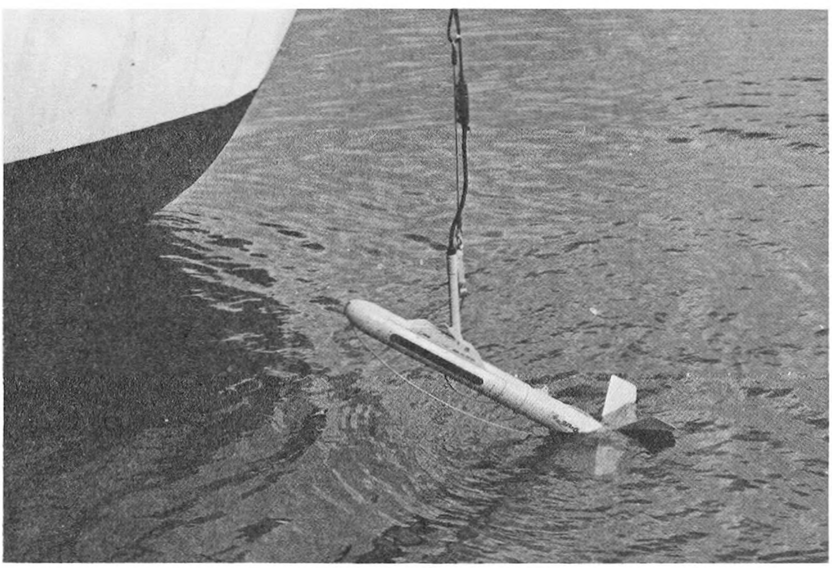
FIG. 8. — Streaming arrangements in HMS *Hecla*.

19. Factors affecting the sonograph presentation

a) *Electronic*. All present-generation sonar systems are strictly display limited. It is therefore essential that nothing be permitted to degrade the record further. Constant attention to tuning (paragraph 9) is the first requirement. The next is the elimination of any locally induced interference patterns. This can sometimes be achieved by providing an overside earth to the recorder. Care must also be taken to ensure that the jumper cable from the recorder to the quarterdeck is run clear of any sources of HF electronic emissions. Mutual interference from other towed sensors can only be eliminated by varying lengths of tow. They will otherwise have to be tolerated unless it is possible to stream different sensors on alternate survey lines. Stable power supplies are a further necessity.

b) *Mechanical*. On the mechanical side of the recorder, the following points need attention. The helix accumulates a deposit of paper residue which will eventually "white out" vertical bands of the record (figure 16, lower). The helix blade should therefore be cleaned with the tip of a wooden or plastic spatula at least once a watch at a convenient moment when the recorder can safely be switched off. Care is also required in setting the blade pressure on the endless loop electrode to avoid another source of "white out". Over-setting the gain will cause burning of the paper at near range and may cause excessive wear on the helix blades and the endless loop electrode (upper blade). If a high gain setting is necessary then an increase in paper speed will alleviate electrode wear and incidentally improve presentation.





FIGS 9 and 10. — Launching the towfish in HMS *Hecla*.

SHIP HANDLING

20. Normal Towing

By adopting the towed transducer the sonar beam is largely free of the effects of pitch, roll and yaw imparted by the ship's motion. Of the three components, yaw has the most effect on sonar cover and must therefore be minimised if possible, or allowed for when planning line spacing. Any increase in speed should be gradual and any adjustment to the length of the towing cable should be made as smoothly as possible. In some ships, at low speeds in a quartering sea, hand steering has been resorted to in an attempt to smooth out the yaw.

21. Turning

Speed should be increased to 10 knots before turning at the end of a survey line and the amount of wheel limited to 10°. This will prevent the fish losing "height" on the turn when at long stay. With shorter amounts of wire out, the tendency of the towfish to drop once the ship has swung through 90° decreases. On exceeding 180°, except with a very gentle turn, the fish will drop dramatically.

22. Wind and Sea Conditions

During long stay operations with ship's speed reduced to maintain the correct fish "height", ship handling may well present difficulties in high winds and heavy seas. Indeed, experience in northern waters during 1976 showed that in adverse weather ship handling considerations rather than sonar performance became a limiting factor.

TARGET DETECTION

THEORETICAL CONSIDERATIONS

23. The sonar equation

The strength of the signal returned by a given target is governed by a number of factors related by a complex equation referred to as the sonar equation. The modified version of this equation is given in Annex B. The difficulty in applying the sonar equation lies in the definition of target strength and relating this to the physical size of objects for which the surveyor is searching. It does however provide guidance in determining specifications for a sonar system.

24. The beam geometry

It is possible, however, to define a physical dimension, ignoring signal losses and acoustic properties. Consideration in these terms forms the basis for the approach in Annex B to the problem of minimum target size, and is helpful provided the limitations are understood. For a fuller treatment of all the theoretical considerations LEENHARDT [5] should be consulted. On page 71 of this reference, however, the author has failed to appreciate that during the transmission of a given number of pulses (designated N in Annex B and K in [5]) the ship only traverses a distance derived from the expression $Vt\,(N-1)$, or $V/N\,(K-1)$ using LEENHARDT's terms.

PRACTICAL CONSIDERATIONS

25. Effective Sonar Range (ESR)

In good sonar conditions the ESR for DCS-3 has been found to be about 250 metres, although good targets have been detected at maximum range (300 metres). However a marked negative sound velocity gradient may cause a further significant reduction in ESR. Where possible the towfish should always be set to run below the thermocline. The 500 metres range scale on the EG&G 259-3 recorder should not be used, as it is doubtful whether the system is capable of working to full effect at that range, and the pulse repetition rate is low. Better results will be obtained in the 250 metres range scale with its enhanced scanning rate and much improved resolution. The final choice of range scale must remain a matter for the judgment of the Officer-in-Charge; but the sonar conditions will play an important part in forming his decision (see also Annex A).

26. Contacts under or very near to Towfish

The following factors must be considered when assessing the probability of detecting small contacts close to the towfish :

a) Size of target in relation to speed of advance (see Annex B).
b) The back-scatter from the seabed is at its maximum under the towfish. Bottom returns may therefore mask those from a small contact, especially if the object does not present its most acoustically "photogenic" aspect.
c) The acoustic "shadow" is at a minimum when an object lies beneath the towfish.
d) Certainly for EG&G systems, and to a lesser extent for the OAL version, the manufacturers admit that there is an area under the towfish, defined by a 60° cone, in which there is a low probability of detecting small objects. There is also loss of signal where the side lobes overlap the main beam. The lightening of the record at between 30 metres and 60 metres slant range confirms this.
e) With the fish running between 30 and 40 metres above the seabed severe distortion in the presentation of the initial 75 metres slant range occurs. This effect is clearly shown in FLEMMING's nomograms [2].

27. Pulse Repetition Rate

An increase in pulse repetition rate, although resulting in a decrease in nominal range, gives an enhanced resolution and decreases the minimum target size liable to detection. Conversely search speed can be increased without increasing the minimum target size. However this option will only be available when the less rigorous category of sonar sweep has been ordered, one which does not require potential targets to be scanned from opposite directions.

CONDUCT OF DCS-3 OPERATIONS

SONAR AREA SWEEPS

28. Purpose

Before discussing the operational use of DCS-3 it is necessary to be quite clear about what the sonar sweep is intended to achieve. Its purposes may be summarised as follows :

a) *Bathymetry.* The sonograph will generally give the surveyor a very good indication of the seabed topography between his echo sounder profiles. Skilful interpretation will therefore permit economy in the running of interlines. However, it should be recognised that on a bland but undulating seabed, shoal soundings on adjacent lines may still be the only indication of a "high spot" in between them. Conversely, the need for interlines over a rocky seabed may not always be apparent from an inspection of the sounding tracing; whereas the sonograph will clearly show such a potentially dangerous area.

b) *Wrecks, Obstructions and Pinnacles.* It is in the detection of man-made obstructions and pinnacle formations that DCS-3 really proves its worth, for without its aid such hazards would frequently escape detection. Thus the emphasis in the planning of DCS-3 operations is clearly on the effective deployment of the system in this role.

c) *Seabed Texture.* The present generation of DCS-3 were designed with the needs of the geologist very much in mind. This accounts for the multiplicity of tuning controls and the reluctance of manufacturers to adopt the "Hands-off" philosophy (paragraph 10). However, the tuning requirements for the system's various roles occasionally conflict (paragraphs 9 and 10) and the recorder's controls may not always be set to produce the optimum geological picture. Nonetheless, it was clearly shown by HM Surveying Ships *Fox* and *Fawn* in the North Channel survey of 1972 [4] that very satisfactory results can still be obtained. An assessment, albeit subjective, of seabed texture, even by a non-specialist, is very worthwhile. If the sonographs are supported by comprehensive bottom sampling their value will naturally be enhanced.

29. Scanning directions

From paragraph 26 above it follows that the sonar sweep of a critical area must ensure that the seabed beneath the towfish, and out to some 50 metres beyond it, is scanned by the adjacent sweep. This will also mean that all obstructions are scanned at least twice and from opposite directions. This is important because the aspect of a target contributes significantly to the quality of the acoustic return and so does its range. Furthermore, a sloping seabed will return a stronger signal when viewed "uphill", and hence a target may contrast less obviously from this direction.

30. Category of Sonar Sweep

The sonar sweeps with DCS-3 may be defined as either rigorous or normal. The rigorous sweep would meet all the requirements set out above; whereas if the possibility of overlooking smaller obstructions could be accepted the sweep might be ordered such as to ensure total insonification of the seabed from one direction only. With present equipment a rigorous sonar sweep would dictate a line spacing of 200 metres, whereas line spacing could be opened to 375 metres or possibly 450 metres to meet the less rigorous requirements. In deep water, over a regular bottom, it is highly probable that redundant sounding lines will have to be run to ensure the required sonar cover.

31. Line Spacing (see also Annex A)

The following additional factors should also be taken into account when determining the spacing of sonar lines to achieve the cover ordered in the Hydrographic Instructions for the survey.

a) The amount of towing cable streamed, and hence the increasing uncertainty in the position of the towfish.
b) Cross-tide effects (taking account of the worst case of maximum offset to the towfish in opposite directions on adjacent lines).
c) The overall accuracy of the Navaid in use, and its fixed and variable errors.
d) Plotting accuracy as determined by the scale of the survey.
e) The difficulties of maintaining the planned track at slow speeds in adverse weather.
f) Range losses due to negative sound velocity gradients (paragraph 25).

32. Ship's Speed

Line spacing, speed over the ground and target size are all interrelated (see Annex B). Other factors which may bear on the speed of advance are as follows :

a) The speed required to maintain the fish at the required height off the seabed for a given amount of wire streamed.
b) Ship handling characteristics.
c) The strength of the cross-track component of the tidal stream.

In general the speed of advance should not exceed 7 knots, although best results will be obtained with speeds of between 5 and 6 knots.

33. Direction of Lines

a) *Recommendations.* Where possible, and especially when the fish will be towed at very long stay, survey lines should be schemed to run within 20° of the direction of the tidal stream. However in order to accurately delineate contours it may be necessary to run some "cross" sounding lines.

b) *Advantages.* Running the lines along the direction of the tidal stream will minimise some of the uncertainty in determining the position of the towfish, and possibly allow a reduction in the amount of overlap between the adjacent sweeps. This direction will also probably coincide with that of the general run of the contours in an area, and thus the danger of the fish running into a shoaling bottom will be diminished. The fish height is therefore more likely to remain constant without adjusting speed or amount of wire streamed. This will have the added advantage of not requiring undue adjustment to the tuning of the recorder.

INVESTIGATIONS

34. General

Sidescan sonar, providing as it does the underwater equivalent of continuous oblique aerial photography, allows the surveyor to classify contacts with considerable confidence. In many cases he is also able to establish the orientation, length and height of an obstruction (paragraph 51). It may well be possible, from careful analysis of the sonograph and close sounding, to obviate the need for wire sweeping (e.g. when the sonar plainly shows a wreck to be lying on its side or to have been comprehensively dispersed). Indeed such is the confidence expressed in DCS-3 results that, in cases where the sonar height of an obstruction exceeds that derived from echo sounding, it is the resulting sonar least depth that will appear on the chart. However an echo sounder "on top" must always be obtained to establish position. Wreck investigations with DCS-3 can be absorbing and time consuming unless, like any other survey operation, they are carried out methodically and economically.

35. Purpose

The purpose of an investigation is to position and classify the obstruction, and then to discover its significance as a danger to navigation. The criteria which determine the scope of an investigation are a function of general water depths and anticipated usage. Apart from the needs of surface vessels the surveyor may have to bear in mind the requirements of submersibles and, in some cases, oil production platforms in transit. The method outlined below is the most exacting one although its total application will not always be required. Only the Officer-in-Charge, with his local knowledge and with the purposes of his survey in mind, can decide on the amount of effort and time which he is able to devote to a given investigation. Whenever sea conditions and general depths permit, consideration should be given to allocation of investigations to ship's boats. This is likely to be especially cost effective in large surveying vessels, and to a lesser extent in CSV and ISC.

36. Investigation Methods

a) *Spurious Contacts.* A single pass over the vicinity of the contact, with the recorder switched to the same range as that used in the area search, should suffice to disprove most spurious contacts. However, to be certain, it is advisable to re-run that portion of the area search track along which the contact was first detected.

b) *Pinnacles.* To recover a pinnacle contact the inital relocation should be carried out in the searching mode as above, care being taken to "stand off" the suspected area sufficiently to avoid an inadvertent "on top" by the towfish. Once existence of the feature has been established, then the recorder can be set to the investigation mode, the height of the fish adjusted to allow for the reduced range in use and the ship's speed reduced to minimise distortion of the sonograph (paragraph 50 b). It is usually possible to distinguish a pinnacle or rocky ridge from a man-made object. As sonar heighting is less satisfactory in these cases, no time should be lost in commencing saturation sounding, or drift sweeping where necessary.

c) *Wrecks*. The procedure for the recovery and initial investigation of a wreck contact will be identical to that for locating a pinnacle. In the case of a wreck, however, close sounding should be deferred until the best possible sonar "picture" has been obtained. By following the method given below it is often possible to pinpoint precisely the highest point of a wreck and thereby significantly reduce the time devoted to close sounding.

37. Wreck Investigation

The first run past the wreck in the investigation mode will, if successful, provide a good relative position and approximate orientation of the wreck. Thereafter the aim is to run the sonar parallel to the line of the wreck at about mid-range on the recorder. To ensure that the best shadow effect is obtained a further run should be made along the opposite side of the wreck. When operating at short ranges attention must be paid to the effect of tidal stream in offsetting the towfish from the ship's plotted track. It should be possible to complete a full investigation in under three hours, including the necessary close sounding. The practice of leaving the sonar down while close sounding a wreck is a dangerous one, and provided wrecks are quite close together it might be preferable to complete all sonar work, recover the fish and then start close sounding. The advantages of assigning the sounding to a boat are self-evident.

INTERPRETATION OF SONOGRAPHS

38. General

The sonograph from a well-adjusted DCS-3 system provides the Officer-in-Charge with a wealth of information about the seabed in his survey area. The purpose of this section is to offer guidance on the sort of contacts which will merit a second look. The prudent surveyor would naturally wish to examine all the anomalies on the sonograph but a lack of time will inevitably preclude this. It is hoped that the illustrations at the end of this paper, allied to his own experience, will assist him in the important task of selecting potential dangers for investigation.

39. Types of contact

The sonograph will reveal indiscriminately the presence of both dangerous and non-dangerous contacts. It will also display noise, such as that emitted by another sensor, and thermal noise present in the surrounding water. Non-dangerous contacts would be fish, fresh-water springs, gas leaks, thermal upwelling and scours left by dredging or trawling operations. Care will be needed in classifying these, if time is not to be wasted in fruitless examination. A dangerous contact by definition will be one which protrudes substantially from the seabed and casts an acoustic shadow (paragraph 42). Thus the absence of a shadow provides the first clue to a mid-water contact. A very compact shoal of fish may cast a shadow, but it will be detached from the shoal echo. A scour, or pock mark, will show white nearest the towfish, with perhaps a dark "lip" where its further side presents a good reflective surface to the sonar beam. Most spurious contacts will lack the definition and intensity of marking produced by a man-made object or a rock.

40. Wrecks and Man-made Obstructions

The most common manifestation of man-made obstructions, certainly in UK waters, is the shipwreck. In the future, industrial refuse from offshore operations may take on increased significance. In both cases it should be realised that only a very small part of the ship or structure may protrude above the seabed; by virtue of being solidly anchored, however, such protrusions present a very real hazard.

41. Pinnacle Rocks and Coral Heads

Pinnacle rocks are unlikely to exist in isolation and will probably be associated with a rocky, irregular seabed and a rugged shoreline. They may therefore be difficult to discern amid the strong signals returned by this type of topography. However, such areas will have the distinctive appearance of a "lunar" landscape on the sonograph and should be closely interlined. The Officer-in-Charge will need to weigh the importance of locating dangers against the risk to the towfish when deciding whether or not to leave the towfish down while running any such interlines. Coralline structures might exist in waters as deep as 200 metres, but their porous composition and attractiveness to shoals of fish make them good targets. Nigger heads may well exist in isolation, but will usually rise from a sandy bottom and consequently show up well on the sonograph. DCS-3 surveys in the West Indies demonstrated the facility with which such dangers can be detected.

THE SONOGRAPH PICTURE

42. Wreck Signatures

From the illustrations it is evident that no two wrecks have the same signature, and that intuition has occasionally supplemented interpretative skill in the assessment process. Certain common features are apparent however, and taken singly or in combination provide the vital classification clues. These are as follows :

a) Intensive marking of the paper.
b) Clear cut shadow.

c) Shadow often associated with wispy comet-like tails, probably scour spoil.
d) General size, even if the echo is faint and without a shadow, due possibly to the wreck having been dispersed, or to poor tuning (see figure 18, top).
e) Cross-talk between channels.

43. Other Considerations

A potentially dangerous wreck may be overlooked on the sonograph for one of the following reasons :

a) At normal sonar searching speed the sonograph is considerably distorted (paragraph 50 b). In addition the aspect of the wreck presented to the sonar beam may be a narrow one. It may therefore only be illuminated by the minimum number of transmissions necessary to make a discernible mark on the paper. Thus it is wrong to disregard a contact solely because of its small size and "un-wrecklike" appearance.
b) Some contacts will inevitably be partially obscured by scale lines or fix marks.
c) A wreck lying "end-on" to the sonar beam on an irregular bottom may be very difficult to pick out. It may be only the shadow which gives it away, and even the shadow is likely to be far less conspicuous than that from a wreck broadside on. Particularly close scrutiny of the sonograph is therefore necessary in such areas.

44. Examination of the Sonograph

For best results the sonograph must be examined systematically and preferably independently by both the Officer-in-Charge and an assistant. The following technique is suggested :

a) A cursory inspection, marking obvious contacts.
b) A close look at the centre of the record which represents the seabed under the towfish and close to it.
c) A more searching look at the whole record, checking points listed in paragraph 43 above.

45. When examining the centre of the record direct comparison should be made with the echo sounder trace. An "on top" may be more evident on the latter, but may possibly have been overlooked when inking in, or not recognised as a wreck. The presence of scours is often detected this way (fig. 19, lower). Holding the sonograph up to the light often reveals the faint smudges which later prove to be wrecks. Care should be exercised in the use of a light box or tracing table for this purpose, since exposure to excess heat may damage the record or degrade its keeping properties.

46. As a general rule, unless the system is grossly out of adjustment, a danger will be displayed in some form on the sonograph. When a known wreck apparently escapes detection on adjacent lines suspicion should be aroused. The relevant sonograph should be carefully re-examined bearing in mind the foregoing paragraphs. Similarly, if a wreck is detected on one line only, it is always worth double checking the sonograph from the adjacent line. Any contact, however "un-wrecklike", which is detected on adjacent lines will certainly merit investigation.

47. Bottom Texture

The sonograph is open to a variety of interpretations dependent on the skill of the observer. Bottom texture should therefore be assessed by a single, experienced, individual. However it is important to realise that a similar change in the recorder signal level could arise from a lithological change as from a variation in the shape (morphology) of the seabed. The untrained observer should be able to detect areas of sandwaves, sand ripples and sand ribbons. To distinguish the subtle gradations in texture between coarse sand and gravels and between different rock formations requires considerable experience and References [2], [3] and [4] should invariably be consulted when attempting such interpretation.

48. Annotation of sonar trace during survey

The Officer-of-the-Watch should supervise the sonar operator and be alert to extraneous manifestations such as recorder blemishes, other ships' wakes, fishing activity, etc. Much heart searching in the chartroom will be avoided by timely annotation of the sonograph by the Officer-of-the-Watch. He should also note when known wrecks or obstructions are not detected and mark up the relevant section of the record to this effect. Significant contacts should also be marked up by the operator or Officer-of-the-Watch. However, when annotating the sonograph great care must be taken not to obscure the record. Fix numbers, symbols and comments should only be written on the blank outer edges of the paper.

THE INVESTIGATION SONOGRAPH

49. General

To make the best use of the sonograph obtained during an investigation it is necessary to either remove or allow for the inherent distortion of the sidescan display. These distortions only need be borne in mind but not applied during the assessment of the area search records; but they assume particular significance when more precise measurements are to be obtained. Subsequent analysis is made much simpler if the distance run between fixes is recorded on the sonograph at the end of each investigation. Alternatively, speed made good and paper speed should be recorded (paper speed equals pulse repetition rate divided by lines per centimetre). Course made good should also be noted on the sonograph of each investigation run.

50. Distortions

The principal distortions are as follows (for a fuller treatment see FLEMMING, 1976 [2]) :

a) The recorder displays slant ranges as equidistant two-way travel time intervals, and is calibrated for a speed of sound in water of 1 500 metres per second. At the ranges of interest with present equipment, the error in assumed sound velocity is not significant. The difference between slant range and plan range however, especially close to the fish, can be considerable and should be taken into account in the rectification process. Furthermore, due to the obliquity of the sonar beam, equal true distances will not follow a linear scale on the paper.

b) There is a compression effect parallel to the line of travel caused by the dissimilarity, except at certain very low speeds, between the vertical and horizontal scales. With the EG&G recorders which are supplied with a preselected paper feed of 60 lines per centimetre, a display free from major distortions is only possible when the ship's speed over the ground is 2 knots. If the 30 lines per centimetre option on the OAL recorder is utilised, then this speed increases to 4 knots. Hence the importance of attempting to run the towfish parallel to the line of the wreck.

c) Yawing of the towfish will also cause distortion of the record, and this is an unknown quantity. However, it is not of practical significance in obtaining approximate dimensions of a wreck. In the graphical solution proposed below, the towfish is assumed to follow the ship's head.

51. Measurements

For practical purposes measurements can be made along the track (vertically) and will be proportional to the distance run over the ground. Lateral measurements should be corrected for obliquity and confined to the direction at right angles to the track. The solution of the sonar heighting problem is unaffected by distortion since it employs slant ranges. To determine the orientation and length of the wreck which does not lie parallel to the ship's track, rectification will be needed. The simplest solution to this problem is by means of a large scale "Tartan" plot on which the extremities of the wreck are positioned by bearing and distance from the towfish. It will be necessary to maintain a record of the variations in ship's head throughout each investigation and also to note the distance of the towfish from the fixing position.

PROCESSING SONAR DATA

INTRODUCTION

52. The general requirements for sonar records are covered in the British Admiralty's General Instructions for Hydrographic Surveyors (GIHS) [6], and the following paragraphs are only intended as amplification of these instructions. Different ships will devise their own methods for processing sonar data. However the system outlined below has proved itself at sea and is offered for consideration by those confronting DCS-3 for the first time.

53. The records may be divided into those which must be submitted to the Hydrographic Office in accordance with GIHS, and working records kept by the ship as an aid to working up the data. Since sounding and sonar operations will normally take place concurrently for most if not all the survey, the sounding book is the best place to record relevant sonar data (figure 11). A separate book should be maintained for investigations.

Smg Revs/Pitch	Base Course	Ships Head	Wire out (m)	Remarks – Sea State	DANGER DEPTH
Pitch 10	040	045	100 m	Sea State 3 on the beam	50 m
6 Kts	040	046	100m	Merchant ship passed 1 cable clear on	
				starboard side.	
5 Kts	040	048	80m	Listed wk. № 1 not seen.	
				Fix 0206·1 №1 buoy detected stb. 200 m.	
5·5 Kts	040	047	90 m		
Pitch 20					
DP				a/c Stb. 10° wheel	

FIG. 11. — Sounding book - a specimen page.

PERMANENT RECORDS

54. The Sonograph

The sonograph must be marked up simultaneously with the echo sounder trace, and the beginning and end of each roll should carry a comprehensive title. In addition to the usual information this title should include the type of sonar, range scale in use, the length of towing cable, and the ship's speed made good. It should be remembered that the deck book and sonograph may become separated in Office, and there is merit in including sufficient information on the latter to enable it to stand alone for analysis and checking purposes.

55. The Deckbook

This book should be made out in the normal manner for sounding on the lefthand page. The suggested layout for the righthand page is shown in figure 11. It should be noted that no attempt is made to record contacts as they occur. Experience has shown that this is better carried out in the chartroom (paragraph 60).

56. Investigation Book

This book should contain sufficient information to allow the investigation to be reconstructed in Office. It should also contain a positive statement as to the results of the investigation, particularly where the contact was a non-dangerous bottom feature or some feature or obstruction other than a wreck.

57. The Sonar Tracing (GIHS, para 1228).

This tracing is becoming increasingly important and provides a good aid to assessing the quality of the sonar search. As with any tracing, it is impossible to lay down rigid guidance for its completion, but in this case the importance of providing the key or legend should be stressed. Since all modern sonars are metric, a scale of metres should be included. With DCS-3 the classification of non-submarine or non-wreck contacts is much more certain than with searchlight sonars. There has therefore been a tendency to omit non-dangerous contacts from this tracing. It is thought that for future reference all contacts which merited a second look, unless spurious, should be shown.

58. Bottom Texture Tracing

When submitting this tracing it should be remembered that it may have to stand alone as the only record available to a number of users outside the Hydrographic Department. The tracing should therefore normally conform to the overall requirements of a "tracing-on-completion" with abbreviated title rather than those of a "tracing-to-accompany" the fair sheet. As the majority of recipients will be working from a dyeline copy, textures are better distinguished by descriptive legend, and the use of colour washes should be avoided. There is some difference in the quality of the record obtained from the various DCS-3 systems, and the particular equipment used should be quoted in the title. This will also be of assistance to outside agencies who may be unaware of the systems in use within the Hydrographic Service. A written description of the seabed throughout the survey area should be included in the Report of Survey.

59. The Report of Survey.

The sonar section of the Report of Survey must contain sufficient detail to enable the effectiveness of the Sonar Area Sweep and any investigations to be assessed in Office. It is important, with such a variety of DCS-3 systems in use, that full details of the particular equipment be given. The use of percentages when indicating the sweep coverage can be ambiguous. It is better to state distance apart of sonar lines and the range used. A brief outline of how line spacing and speed of advance were decided and an account of the method used to determine the sonar conditions should also be included. Any observations made for determining sound velocity profiles should be forwarded with the records of the survey. Mention should also be made of the effect of ship's motion on the fish's towing characteristics and details given of towing arrangements and amounts of wire streamed. Any unusual sonar manifestations with an explanation of their probable causes should also be reported.

WORKING RECORDS

60. Sonar Contact Book

As the trace is examined (paragraph 44), significant sonar contacts and the limits of changes in seabed texture or topography should be recorded in a work book (figure 12). Experience has shown that it is better to record everything in this book, even if a positive classification of a contact as non-dangerous can be made at first glance. When both the Officer-in-Charge and his assistant have reached this stage, they should compare notes. Initial classifications must be agreed and any omissions rectified.

Contact No.	Fix	Port/Stb.	Range (m)	Distance from fish to fixing point (m)	Description of contact	Classification	Action
Julian	Day No	192 .	Roll No	17, Fi	xes 0001 to 0900Z		
General	quality	of trace,	recorder	blemis	hes (if any) or interference	patterns	
1	0106·5	P	200	120	Small intense mark with	Poss. wk.	INVESTIGATE
					shadow.		
2	0130-0140	P/s	0-200	120	Rough bottom	Sand Ridges	N.F.A.
3	0200-0215	P	100-300	120	Marked change in	Rocky patch	Interline
					reflectivity. Good relief		
4	0406·2	S	150	120	Faint mark. No shadow		see next line

FIG. 12. — Sonar contact book - a specimen page.

61. Sonar Contact Plot

A tracing to fit the track plot should be made, showing all known wrecks and obstructions in the area, significant contours and natures of the bottom where available. Sonar contacts and bottom texture information can then be abstracted on to it from the Sonar Contact Book. Certain contacts will then be seen to reinforce each other, others to indicate known hazards and some perhaps to relate to topographical or textural changes. As a further aid to classification the Sonar Contact Plot can be overlaid on the sounding tracing. This contact plot will form the original graphic from which the bottom texture tracing can be drawn. It will also carry information required for the sonar tracing (paragraph 57).

FINAL ASSESSMENT

62. From an appraisal of the Sonar Contact Plot and the sounding tracing it will be possible to revise some classifications and to determine which contacts require further investigation. Since a full investigation is a time-consuming process, time in the chartroom devoted to careful analysis of contacts is well spent. Contacts to which the Officer-in-Charge ultimately decides to return can be categorised into those requiring a detailed examination, and others for which perhaps a "quick look" will suffice. Presented in this form a pattern for the investigation phase of a survey will emerge which should enable the Officer-in-Charge to make the most economical use of his ship's time.

CONCLUSION

63. The DCS-3 systems described in this paper were not specifically designed for the extensive area searches necessary on the relatively small scale surveys conducted by HM Surveying Ships. However experience has shown that, properly used, they can supply a long-felt requirement to detect significant obstructions between lines of soundings. When operating DCS-3 nothing should be taken for granted and the surveyor should always be questioning and checking his equipment for optimum performance. The use of a towfish requires the development of remote monitoring techniques, as it is clearly impractical to be constantly handing the sonar for this purpose. There is no simple solution to this problem; only experience allied to the surveyor's commonsense and innate professional scepticism will resolve it.

64. DCS-3 operations depend on the reiteration of two basic questions :

a) How do I know the system is functioning ?

b) What do I go back for ?

This paper will have succeeded in its purposes if the need to ask the first question is instilled into all surveyors, and if it has gone some way towards answering the second.

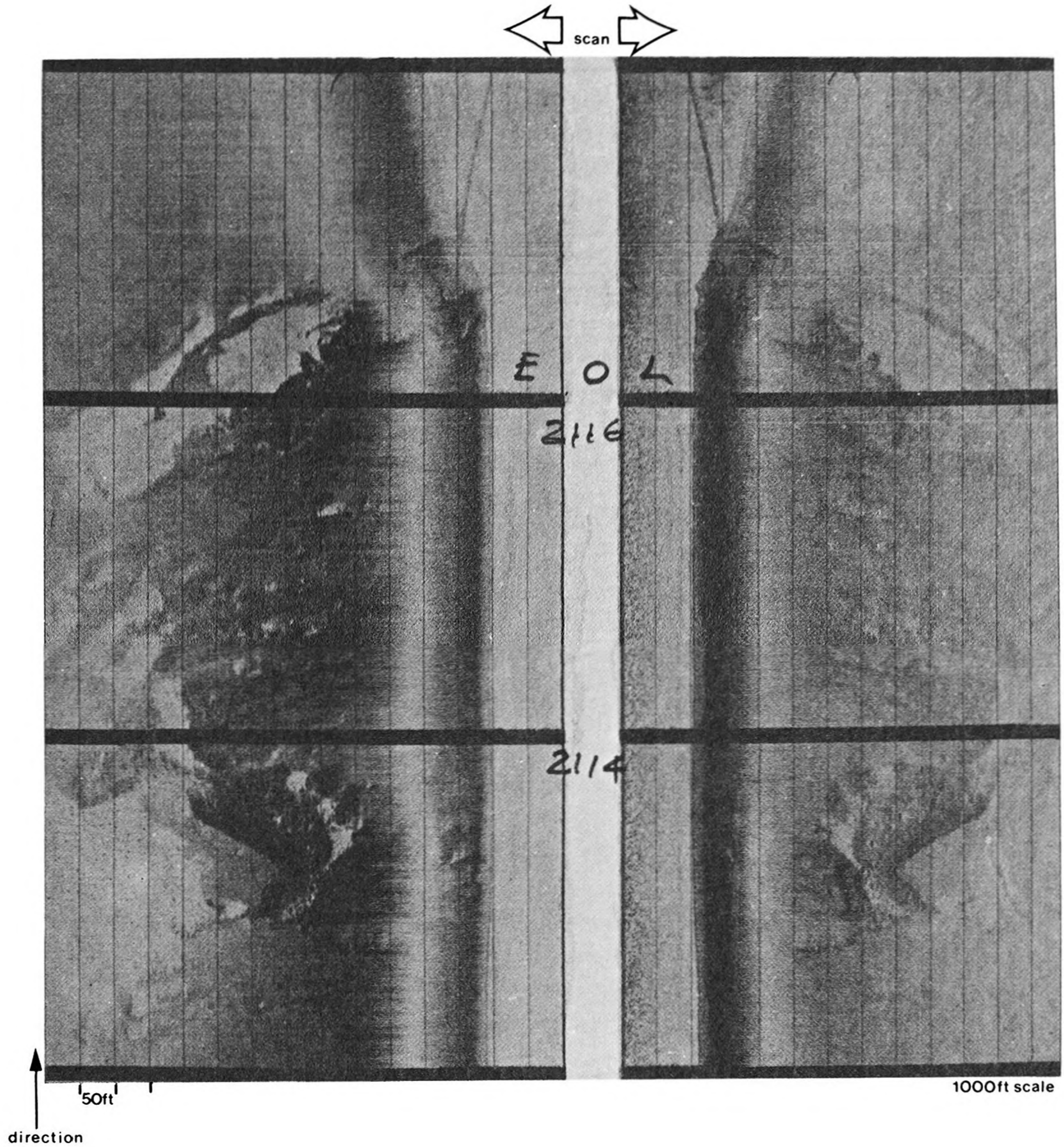
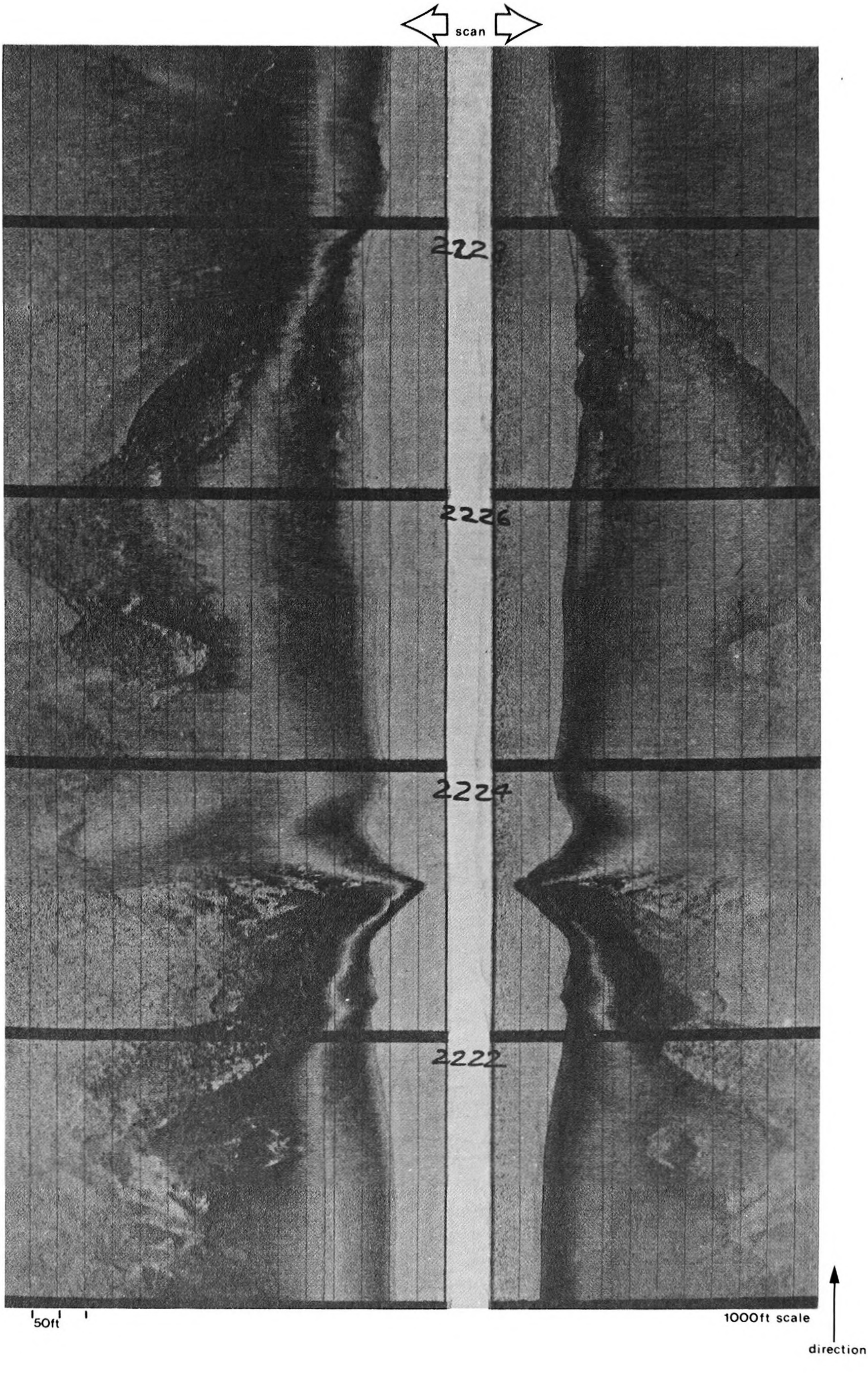


FIG. 13 (*above*) and FIG. 14. (*opposite*). — Two illustrations of the "mirror" effect which occurs when the amplifier on one channel (in this case the starboard one) is defective. Quite small features on the port channel can be seen to be faithfully, if faintly, reflected to starboard. Major features, which probably lie across the track, are only seen on one channel. The port channel is well tuned, and sea bed irregularities can be discerned out to almost maximum range.


scan
2228
2226
2224
2222
50ft
1000ft scale
direction

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[1] RUSSELL, I. C. (1972) : Precision hydrographic surveys in the North Sea. *Int. Hydrog. Review* XLIX (1), pp. 15-30.

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[3] BELDERSON, R. H., KENYON, N. H., STRIDE, A. H., STUBBS A. R. (1972) : *Sonographs of the sea floor.* Elsevier Scientific Publishing Co., Amsterdam.

[4] The floor of the North Channel, Irish Sea; a sidescan sonar survey. IGS Report No. 76/7. Institute of Geological Sciences, Gray's Inn Road, London WC1.

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ANNEX A

DCS-3 SYSTEMS — CHARACTERISTICS AND ALLOWANCES

1. General

DCS-3 systems in service in HM Surveying Ships and Craft are the American EG&G Marks 1A and 1B and the British OAL. The components of the two EG&G systems are completely interchangeable. The British and American systems can also utilise each other's components, but only by employing special printed circuit boards (PCB) and interconnecting cables. As far as possible ships are supplied with either OAL or EG&G equipment. Replacement components will, it is hoped, maintain the initial homogeneity. However, it would be unrealistic to rule out the possibility of hybrid systems developing, and the conversion kits provide for this eventuality.

2. System Characteristics

a) *The Recorder*

	EG&G 1A (259-1/2)	EG&G 1B (259-3)	OAL
Power Input	24-30 V DC, 4-8 A depending on range scale		110 V or 230 V ± 10 % AC at 50 or 60 kHz at 200 VA maximum
Range Scale	250, 500, 1 000 ft	50, 100, 125, 200, 250, 500 m	75, 150, 300 m
Range Resolution......	1/250 of full scale (see note 1)		
Recording Paper	Alphax Type A, to be demanded from Naval Stores, quoting Federal Stock No. 0623-7520-106-1455		
Paper Presentation.....	5 in (127 mm) each channel		
Paper Speed (see note 2)	80, 60, 40 lines per/cm (200, 150, 100 lines/inch)		30, 60, 150 lines/cm
Scale Line Interval (Adjustable)	50 feet	25 metres	15 metres
Dimensions	28 cm high 84 cm wide 44 cm deep		33 cm high 102 cm wide 46 cm deep
Construction	Laminated glass-reinforced plastic case		Array ribbed alloy case
Weight	38 kg		59 kg

NOTES :

1. The Range Resolution claimed represents 0.5 mm on the paper, but a more realistic figure is 1 mm, ie. approximately 1/125 full scale.

2. The EG&G Recorder is supplied with the paper speed set at 60 lines per cm. This can only be altered internally with the recorder dismantled. For the OAL, paper speed selection can be made using an external control with the recorder running.

b) *Transducer Assembly* (Towfish)

	EG&G 1A (268-2)	EG&G 1B (272)	OAL
Operating Frequency . . .	105 kHz, ± 10 kHz		98-115 kHz
Pulse Duration	0.1 millisecond		0.1 millisecond
Peak Output (reference 1 μ bar at 1 m)	118 dB	128 dB	130 dB
Vertical Beam Pattern .	40° tilted down 10°	20° or 50° tilted down 10° or 20°	45° tilted down 10°
Horizontal Beam Pattern (to 3 dB points)	1°	1.2°	1.5°
Operating Depths	365 m	600 m	130 m
Dimensions – Length . .	127 cm	118 cm	137 cm
Tail	30.5 cm	30.5 cm	46 cm
Dia	10 cm	7.4 cm	10 cm
Safety		fitted safe-T-link	quick release tailfins
Weight	18 kg	25 kg	16 kg

c) *Cables* (for both systems)

1) Doubled Armoured Steel :
   - Diameter 0.95 cm
   - Length 150 m or 600 m
   - Strength 5 000 kg
   - Weight 0.35 kg per m

2) Lightweight, Rubber Flexible :
   - Diameter 1.2 cm
   - Length 50 m
   - Strength 400 kg
   - Weight 0.3 kg per m

3. Practical Considerations

For most purposes the performance of the various systems is the same. However it is well to note certain differences in the characteristics which may affect the way that a particular system is used.

a) *Power.* The OAL and EG&G 1B have the greater power output, but an effective sonar range of 250 m (see paragraph 25) should still be assumed.

b) *Beam Width.* The variation in horizontal beam widths is not significant, and the vertical beam widths for the EG&G 1A (268-2) and OAL transducers are also nearly the same. The vertical beam angle and depression options with the EG&G 1B (272) transducer are a considerable advantage and should be utilised as suggested in paragraph 4 below.

c) *Range Scale.* The EG&G 1B (259-3) recorder, with its wider choice of range scales, confers greater operational flexibility, and advantage should be taken of this. However care will be needed in planning the line spacing of ships with different recorders working on the same survey (see paragraph 5 below).

d) *Towfish.* The greater weight of the EG&G towfish may mean that less cable will need to be streamed to enable the fish to run at a given depth.

e) *Paper Speed.* The faster the paper speed the less will be the distortion of the sonograph from compression effects (see paragraph 50 b). Contacts will also appear slightly more elongated and more likely to attract the eye, although slight increase in overall signal gain may be required. It is therefore recommended that the 30 lines/cm and 40 lines/cm speeds be selected on the OAL and EG&G recorders respectively.

4. Vertical Beam Angle and Depression Options (EG&G 272 towfish)

There are a total of four combinations possible in the choice of beam angle and depression and the surveyor will need to consider which one best suits his requirements. For shallower work (under 40 m) where the fish must be close to both the surface and bottom, the 20° beam depressed 10° is the recommended configuration. For surveying in very deep water, when the fish cannot be set at its optimum height above the seabed, the use of the 50° beam depressed 20° should be considered. The wider beam will involve some loss of power, however.

5. Effect of Choice of Range Scales on Sonar Line Spacing.

In the following table it has been assumed that a rigorous sonar sweep (see paragraph 30) will be ordered on all survey scales above 1:50 000, and on that scale as well out to a water depth of 50 metres at least.

TABLE I

	OAL and EG&G 259-1/2 (note 1)		EG&G 259-3	
Survey scale	Sonar line spacing (S)	Range scale on recorder (R)	(S)	(R)
1 : 12 500	62.5 m	75 m	62.5 m	100 m
	125 m	150 m	125 m	200 m
1 : 25 000	125 m	150 m	125 m	200 m
1 : 50 000	200 m	300 m	200 m	250 m (note 2)
	250 m	150 m	250 m	200 m
	up to 450 m	300 m	up to 450 m	250 m (note 2)
1 : 75 000	375 m	300 m	375 m	250 m
	up to 450 m	300 m	up to 450 m	250 m

NOTES :
1. The scales given refer to OAL only.
2. Limiting conditions for rigorous and normal sweeps respectively.

6. Equipment Allowances

Each ship will normally carry the following DCS-3 equipment and spares. They will also be supplied with the appropriate operator's handbook(s) :

1 Recorder.
2 Towfish.
2 Armoured tow cables (only one supplied to ISC).
1 Lightweight tow cable.
1 Set of interconnecting cables and interchangeability printed circuit boards (PCB).
1 Slip-ring reel with inboard connecting cable to recorder (in ships not fitted with slip-ring winch and permanent cable run).
1 Onboard spares kit.

ANNEX B

DCS-3, THEORETICAL CONSIDERATIONS IN DETERMINING PROBABILITY OF TARGET DETECTION

1. General

In what follows, the target size is defined as the length (l) of the aspect presented normal to the sonar beam. The minimum number of returns required to make a discernible mark on the paper record is taken to be five, Examples in table I are for 300 metres (R_m) range scale. The velocity of sound in sea water (C) is assumed to be 1 500 metres per second and the beam angle (θ) taken as 1.25° (an average for the three different systems in use).

2. Terms and Units

Beam Angle	θ radians
Beam Width (Spread)	B_w metres
Pulse Interval	t sec
Pulse Rate	F pps
Ship Speed (over the ground)	V m/sec
Selected recorder nominal range	R_m metres
Velocity of Sound in Sea Water	C m/sec
Slant Range	R_s metres
Range to beam crossover points	R_c metres
Target length	l metres
Ship travel between pulses	d metres

3. Equations

a) $$F = \frac{C}{2\,R_m} \text{ pulses per second}$$

or $$t = \frac{1}{F} \text{ seconds}$$

b) Ship travel between pulses (d) = Vt, and therefore distance travelled during transmission of N pulses (D) = Vt (N − 1). This expression defines the minimum target size liable to detection at zero range.

c) Because θ is a very small angle, beam width can be derived from the expression :

$$B_w = R_s\,\theta$$

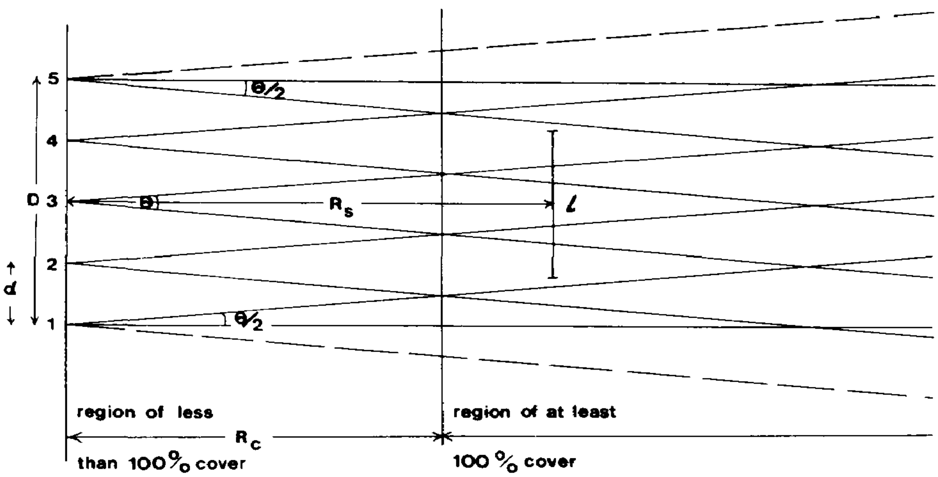


FIG. 15

d) Due to the beam spreading, the minimum target size which can still receive N pulses diminishes with range. At the point where the beam width is equal to the distance travelled during the transmission of N pulses (D), every target receives N pulses. Between this point and zero range it is only possible to calculate precisely the maximum size of a target (l) that cannot possibly receive N pulses. From figure 15 this will be seen to be the one which lies just inside the leading edge of the beam from the first pulse and is not quite insonified by the trailing edge of the last (N[th]) pulse (fifth in diagram).

Therefore $l = D - \left(R_s\frac{\theta}{2} + R_s\frac{\theta}{2}\right)$ and by substitution from (b) above :

$$l = Vt\,(N - 1) - R_s\,\theta$$

e) The range (R_c) at which all targets must be at least partially insonified is that at which beam width (B_w) is equal to the distance travelled between pulses, or when from (b) and (c) above;

$$Vt = R_c\,\theta \qquad \text{whence } R_c = \frac{Vt}{\theta}$$

4. **Table I**

Ship's Speed (over ground)		Size of target (l), in metres, missed at given ranges						R_c	Range at which all targets receive 5 pulses
Kt	m/sec	0 m	50 m	100 m	150 m	200 m	250 m	(m)	(m)
4	2.06	3	2	1	–	–	–	40	150
5	2.57	4	3	2	1	–	–	50	190
6	3.08	5	4	3	2	1	–	60	225
7	3.60	6	5	4	2	1	–	65	270
8	4.11	7	6	4	3	2	1	75	305

THE SONAR EQUATION

5. Terms and units

The strength of the signal returned by a given target is governed by a number of factors related by an equation referred to as the sonar equation. The complete sonar equation is too complex for this discussion so a modified version will be used. The following terms are involved :

Source level (S_L) — The intensity of the outgoing signal (expressed in decibels).

Attenuation (A_t) — The loss in intensity due to spreading and other factors (expressed in decibels).

Target strength (T_s) — The proportion of signal returned toward the source by a target (expressed in decibels).

Directivity index (D_i) — The increase in signal-to-noise ratio due to the beam pattern of a receiving transducer (expressed in decibels).

Signal from target (S_t) — The intensity of the signal from a given target at the output of the receiving transducer (in volts).

Sensitivity of receiving transducer (H_s) — The measure of the transducer's ability to translate an acoustic signal into an electrical signal (expressed in decibels, reference 1 volt/μ bar).

6. The equation

The signal from target (S_t) is equal to the sensitivity of the transducer (H_s) plus the directivity index (D_i) plus target strength (T_s) plus source level (S_L) less the two-way attenuation. The sonar equation therefore is :

$$S_t = H_s + D_i + T_s + S_L - 2A_t$$

7. Attenuation

The attenuation is related principally to the squares of the distance the signal has to travel from the transducer to the target (and back to the transducer) or the square of the slant range [$A_t \sim (R_s)^2$]. There are also losses due to absorption and scattering but these are generally small at the short ranges which are involved in sidescan systems discussed in this paper (about 2 dB/100 metre). By referencing to 1 metre, attenuation can be expressed in decibels at 20 Log R_s in metres; thus the attenuation at 100 metres would be 20 Log 100 = 40 dB due to spreading loss, plus another 2 dB from absorption and scattering for a total A_t = 42 dB. At 500 metres A_t = 20 Log (500) + 500 × 2 dB/100 = 20 × 2.7 + 10 = 64 dB.

Annex — Sonograms

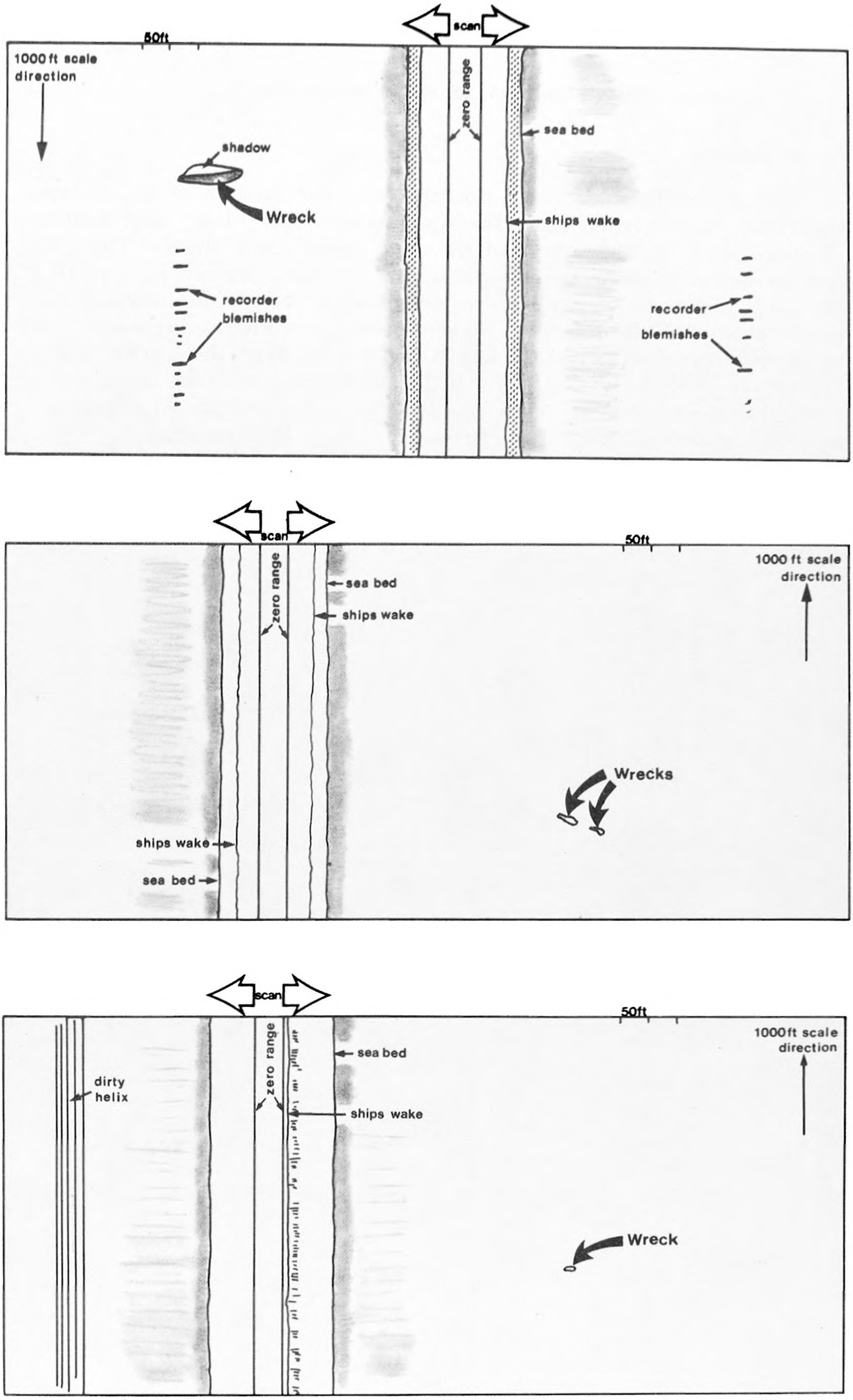
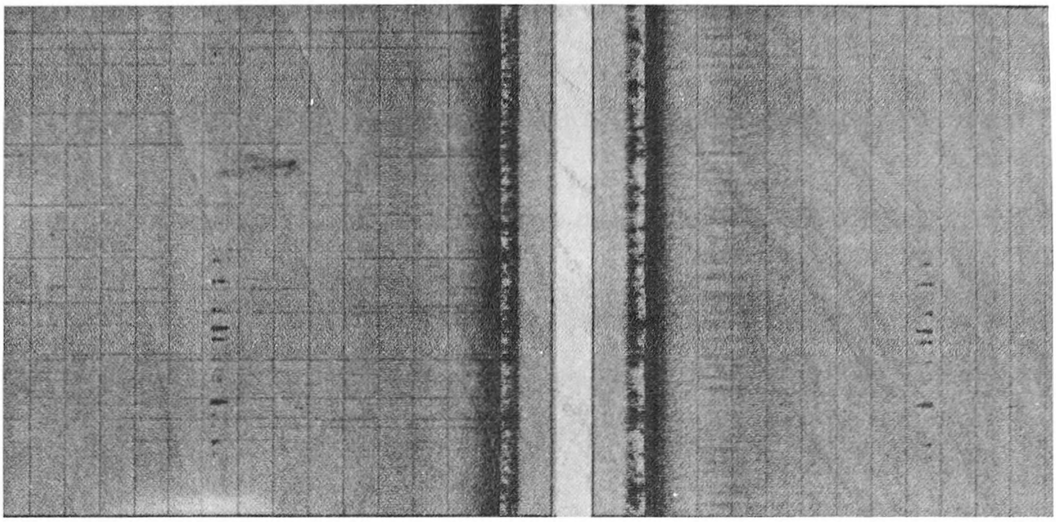
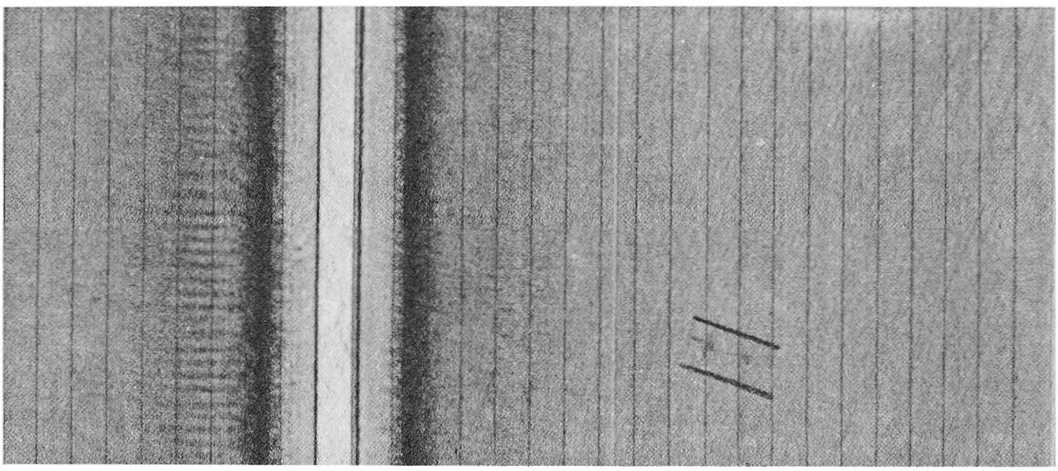
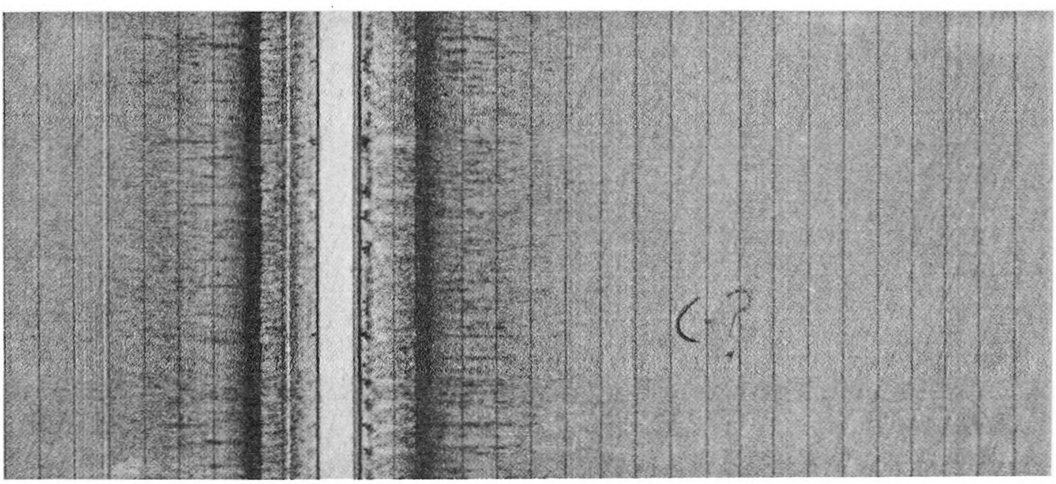


FIG. 16. — Wreck of the *Aarsten* (see also figure 17) (439 tons, length 145 ft, beam 27 ft, draught 12 ft). The wreck lies 045°/225° with a height of 3.4 m and length of 44 m. It has been dispersed.

Top : Speed made good was 7 knots and course 020°. Note the "feathery" trace from scour spoil, and the very intense marking from the wreck itself.







Middle : Speed made good was 6 knots, course 310°. This wreck lies "end-on" to the sonar beam. The recorder was slightly overtuned, so that the contrast between the wreck and the sea bed is poor.

Bottom : Speed made good was 7 knots, course 130°. The echo is almost obscured by the scale line; once again the clue to identification is the intense marking and very faint "tail".

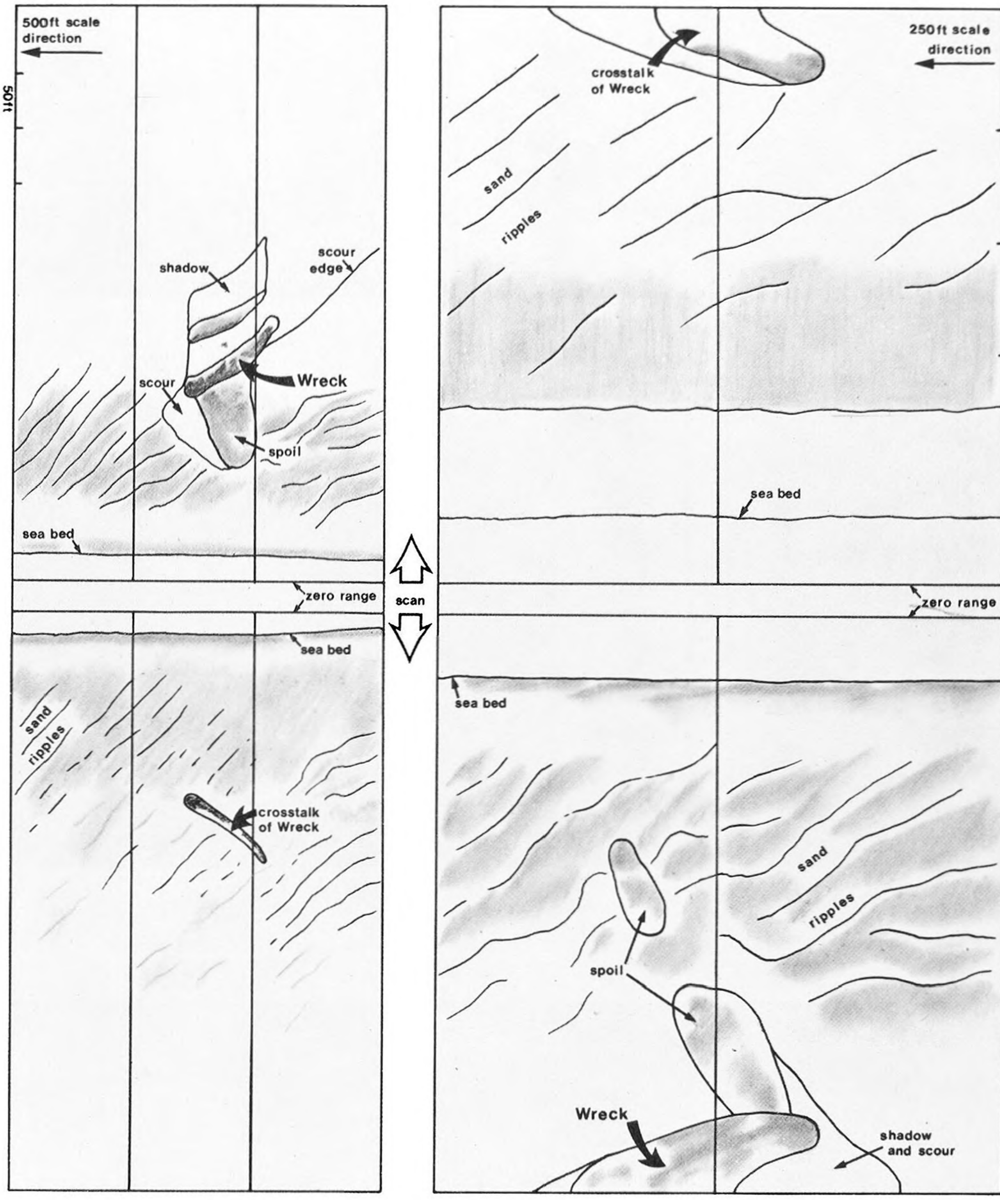
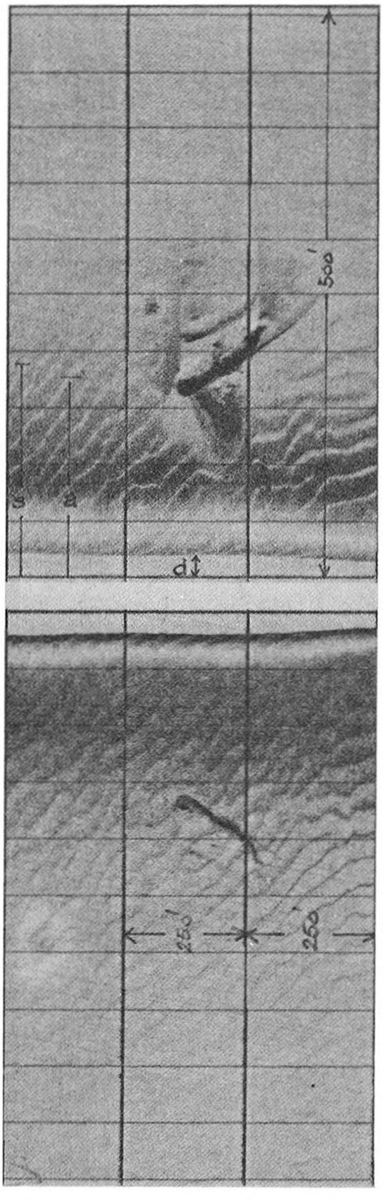
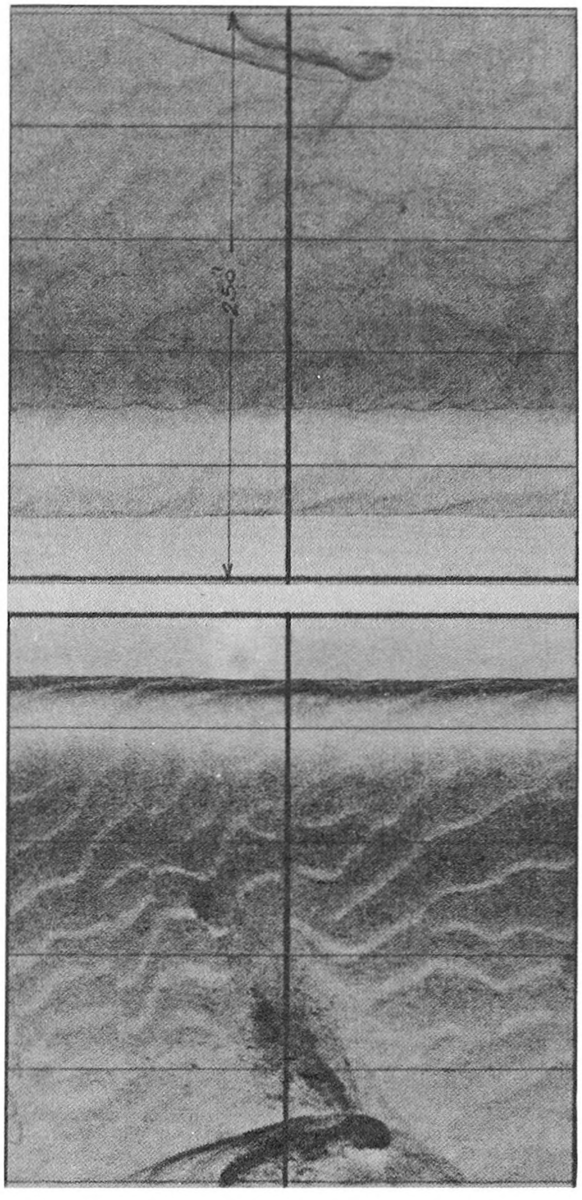


FIG. 17. — Wreck of the *Aarsten* (see also figure 16).

Left : A good example of the significant improvement in presentation when pulse rate is increased and speed slightly reduced. The severe "cross-talk" might indicate that the port channel was defective, but continuity of the sandwaves under the towfish prove that this is not so.

Right : A good example of the reflective discontinuity of the spoil and surrounding sea bed. This provided a useful pointer to draw attention to the wreck in the searching mode (1000 ft scale).


500'
d
250'
250


250'

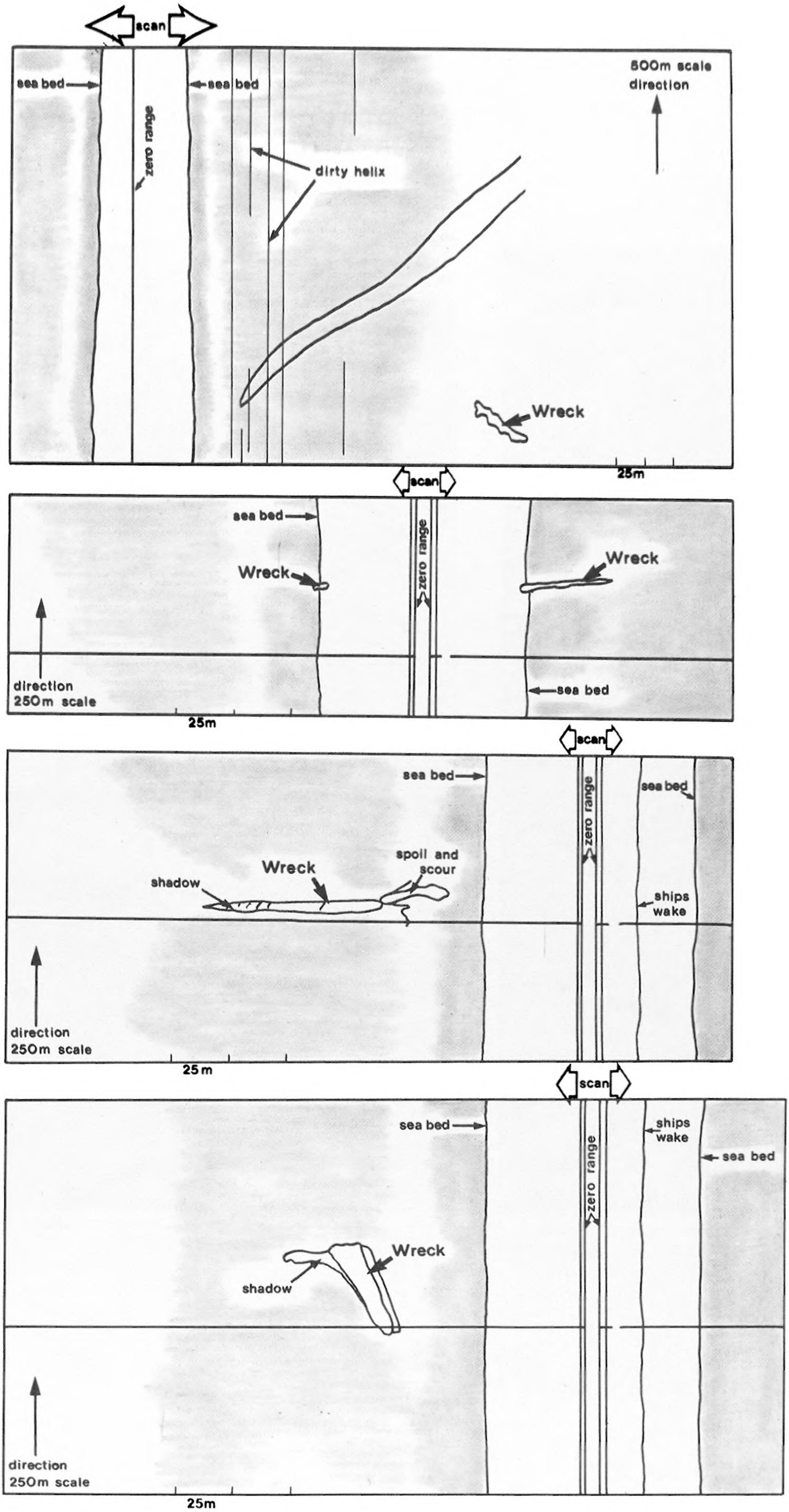
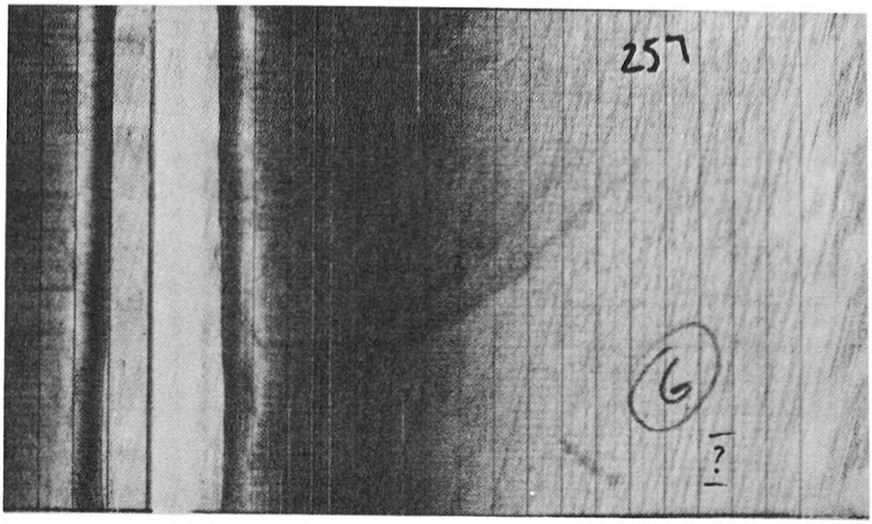
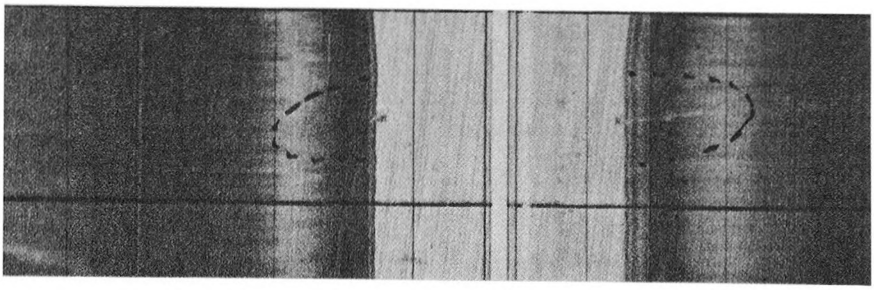
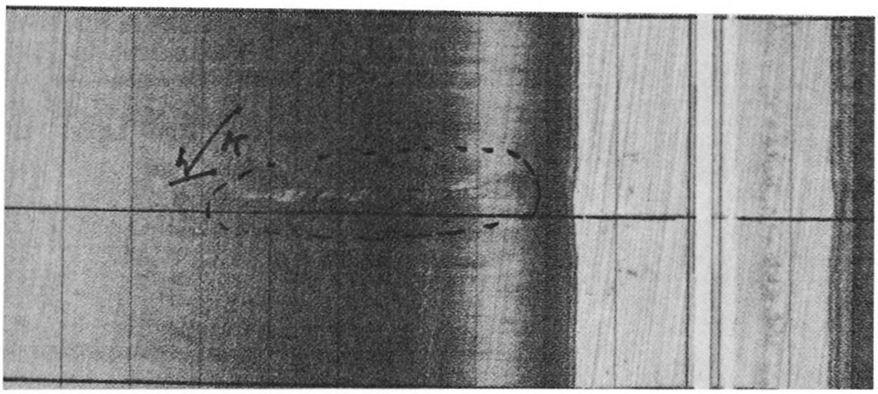


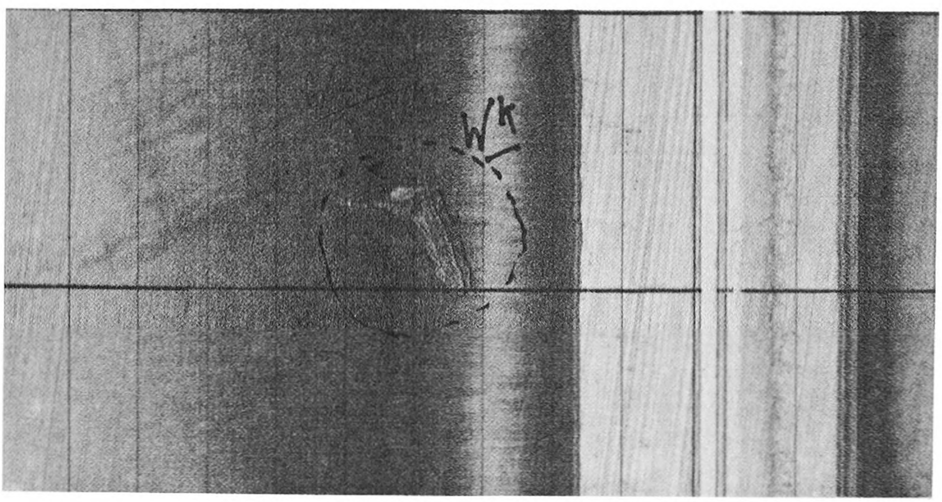
FIG. 18. — An unknown wreck, lying 070°/250°, 85 m long and 4-5 m high.

Top : The fish is too close to the sea bed (25 m instead of 50 m or more). In consequence, difficulty has been experienced in tuning the recorder across the full width of the paper. A poor return from this large wreck at 300 m supports the view that a range of 500 m is over-optimistic (see paragraph 25).









Centre : A good example of distortion under the towfish.

Lower centre : The "end-on" case. On an irregular sea bed difficulty might be experienced in distinguishing the wreck.

Bottom : The towfish was too high off the bottom to give a good shadow at this range.

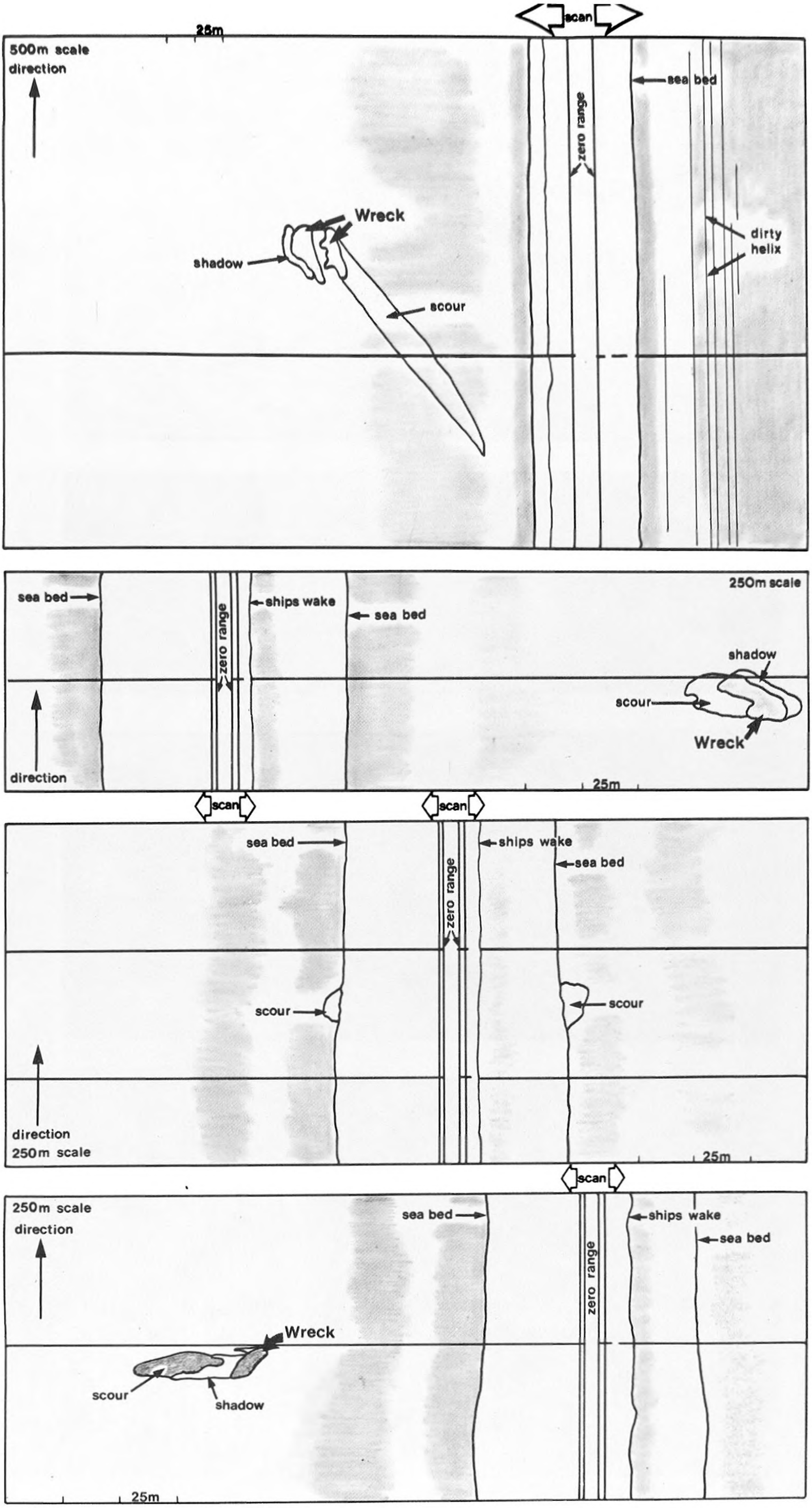
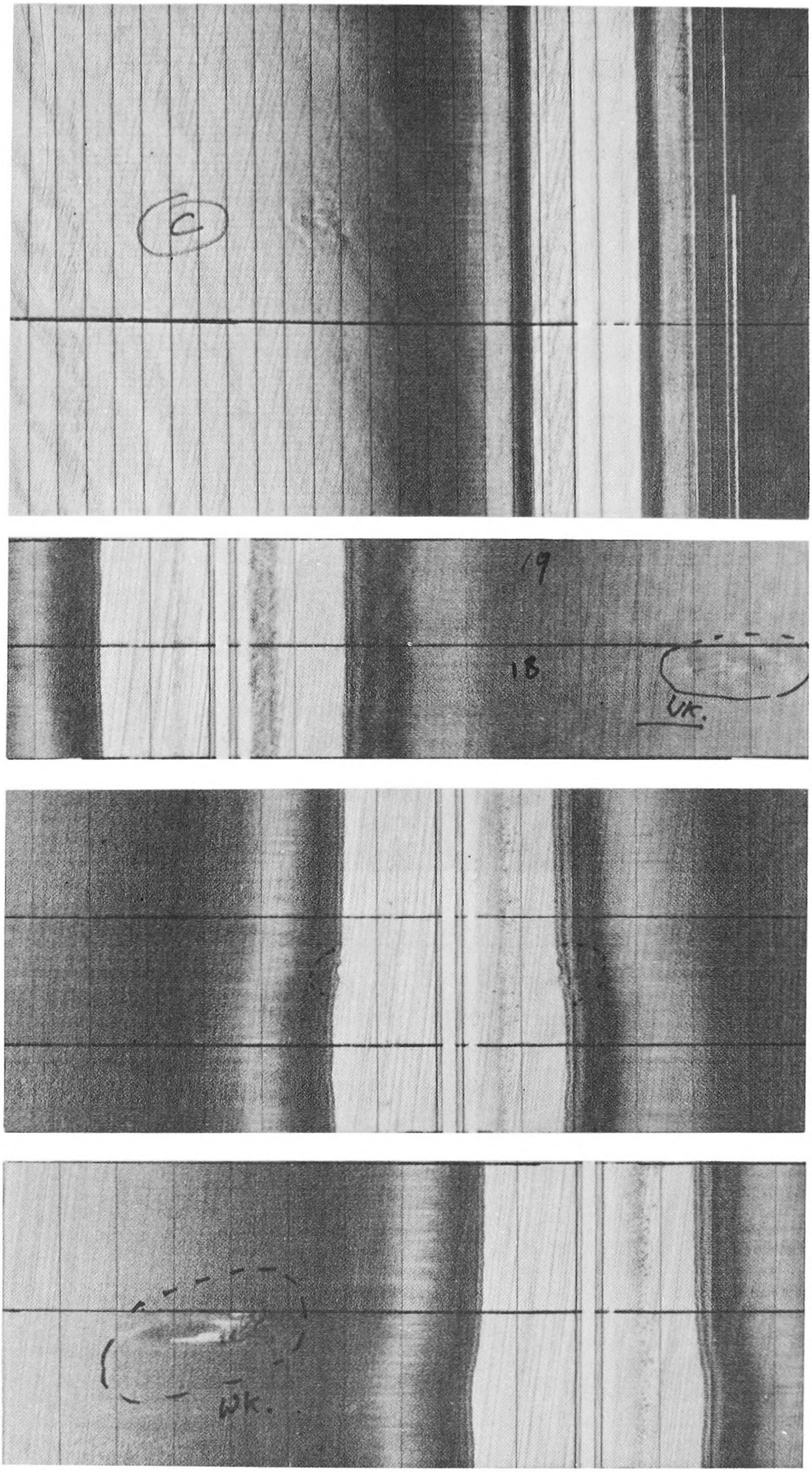


FIG. 19. — An unknown wreck, lying on the lip of an extensive scour. The orientation is 170°/350°, the length about 60 m and height about 5 m. Probably dispersed.

Top : The wreck is only just discernible at 225 m; the recorder was however well adjusted. This is an example of the inherent danger of relying on the 500 m range scale.



Centre : The wreck is slightly more apparent, but the towfish was too high for the range in use and the overall gain should have been reduced for the shorter range.

Lower centre : A good example of a scour, but no other indication of the wreck.

Bottom : Here the wreck is in very nearly optimum relationship to the towfish.

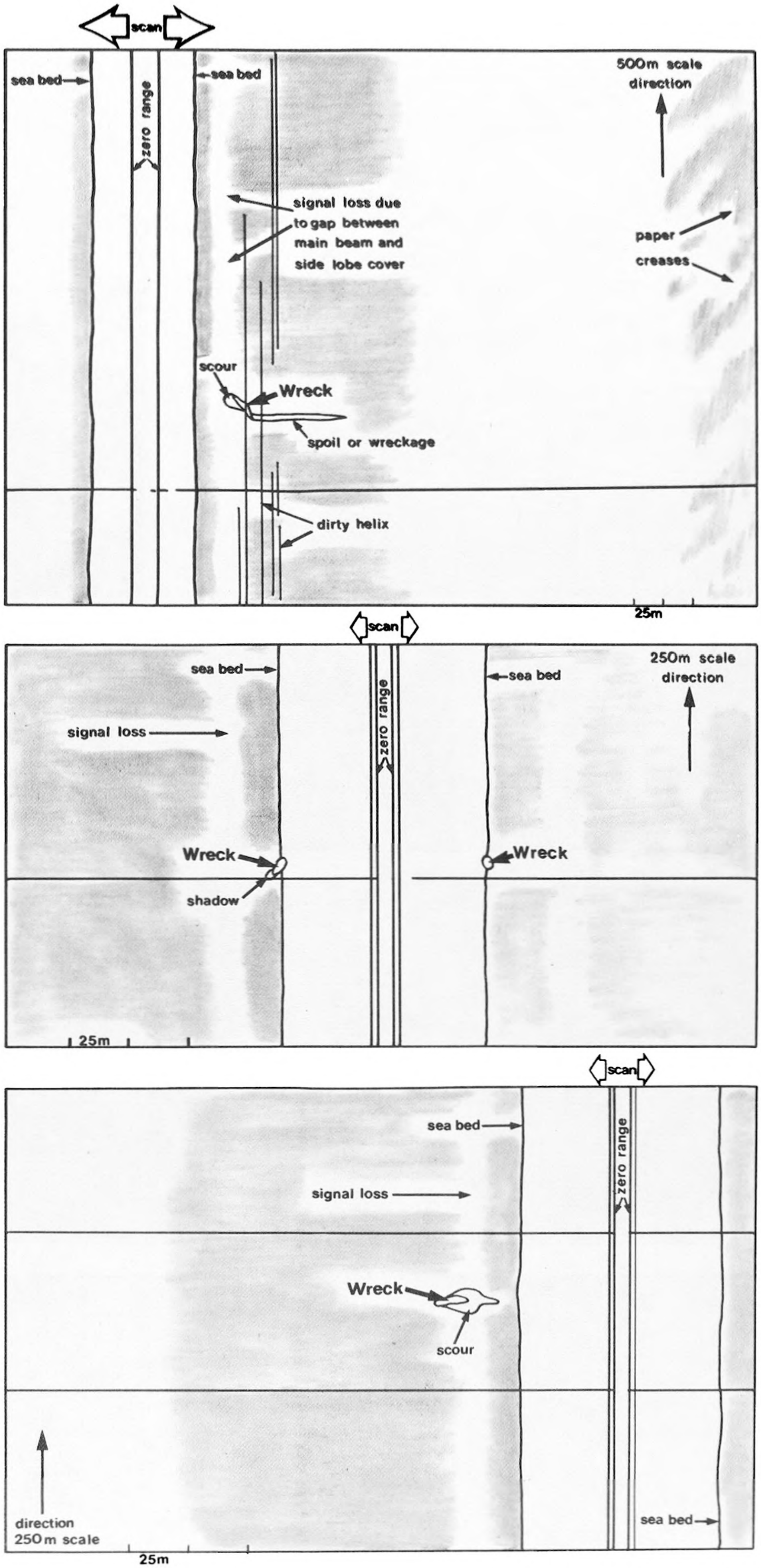
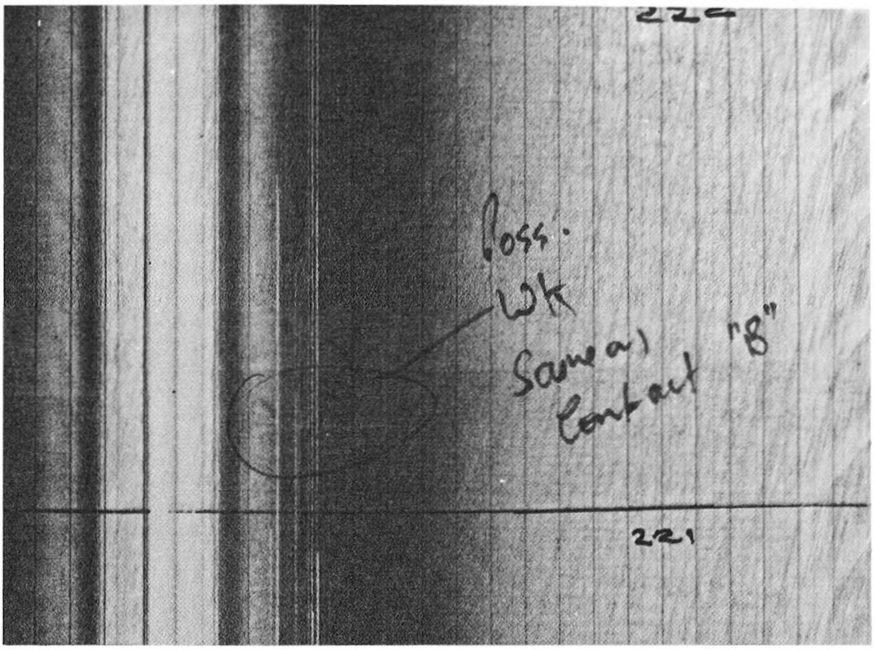
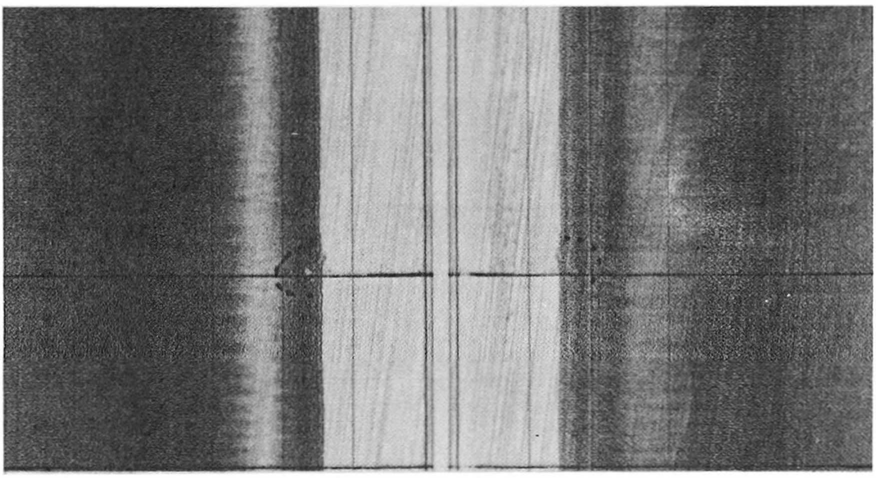
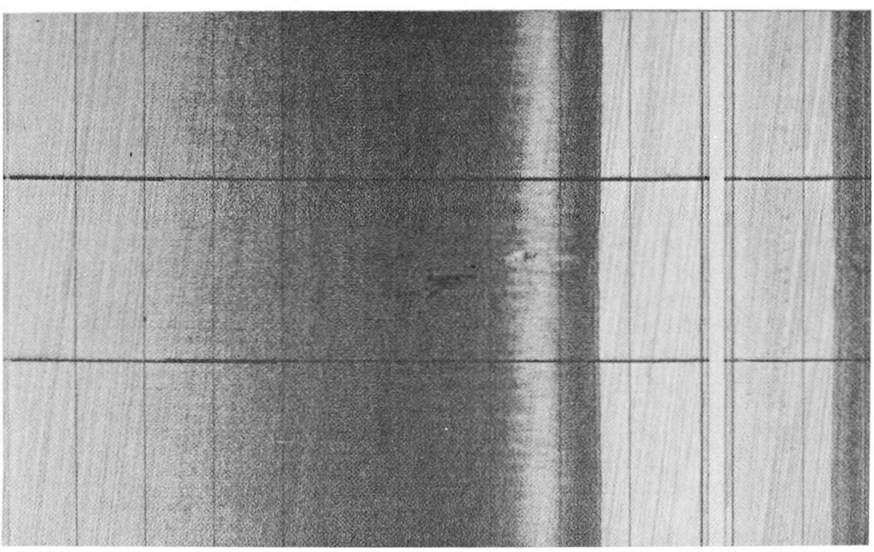


FIG. 20. — An unknown wreck, possibly an aircraft.

Top : If this had been another 25 m off track, the signal from this wreck might have been swamped by seabed reflections. However, note the elongated lightening of the record away from the wreck, which may still have given a clue.







Centre : A very good example of an "on top". Note very faint echoes just off the sea bed.

Bottom : Another case, similar to the one shown at the top of the page, of a highly reflective target lying close to the track, on the edge of the side lobe. Paradoxically, the weaker signal here has made detection possible. There are no seabed returns, and only weak echoes are displayed.

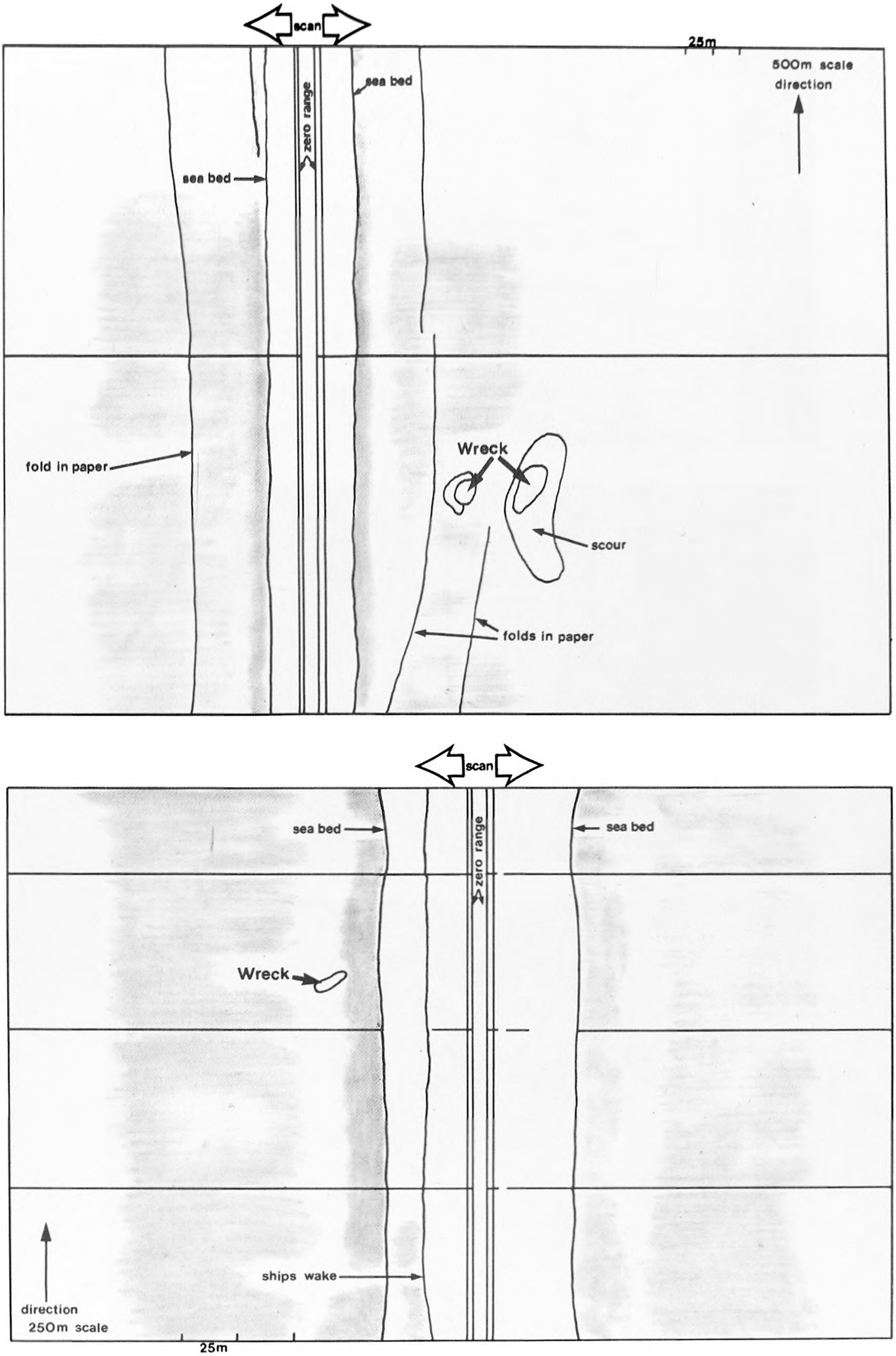
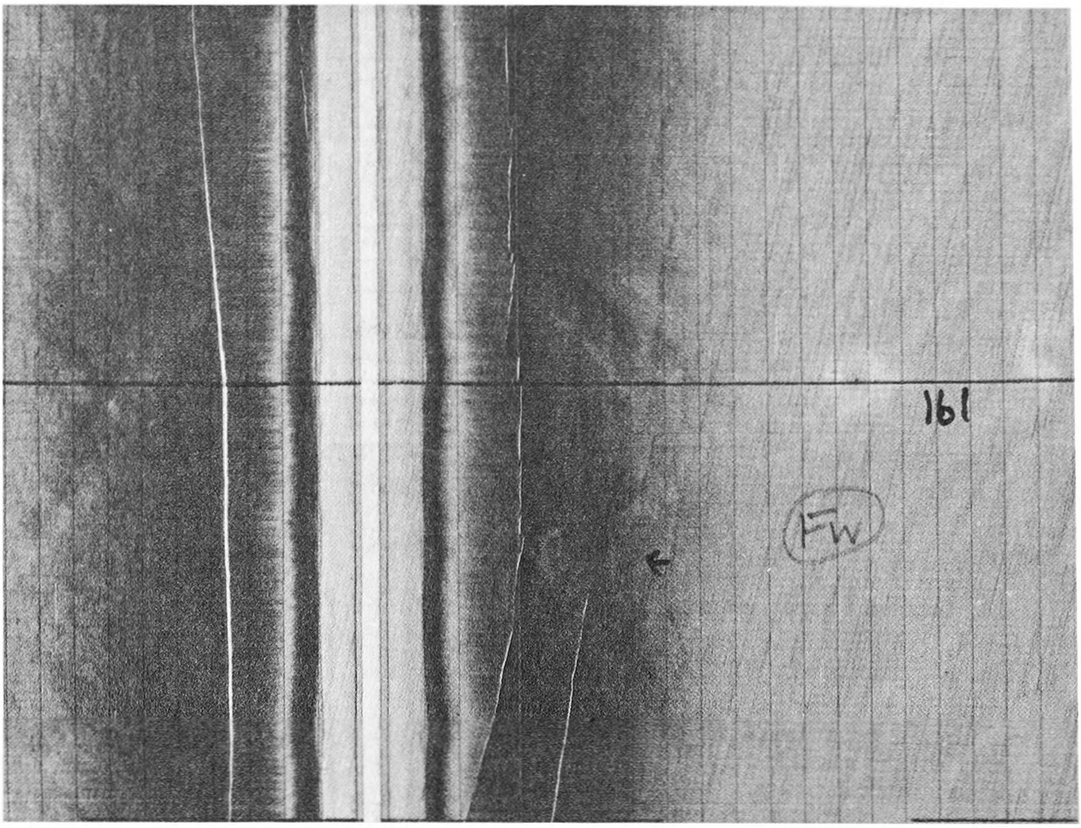
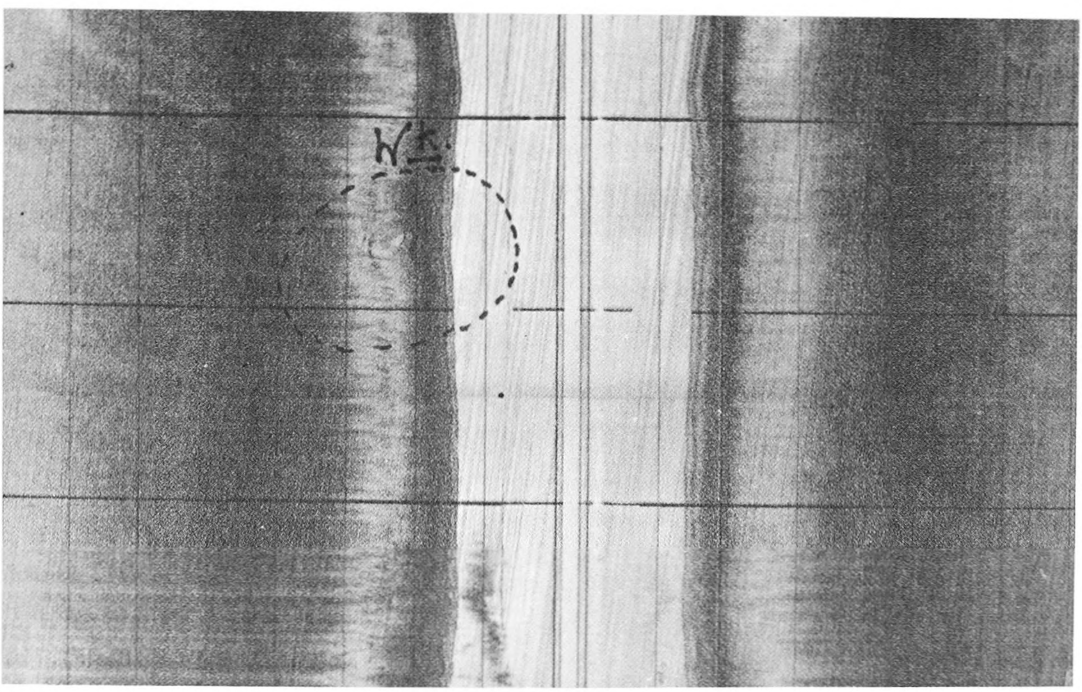


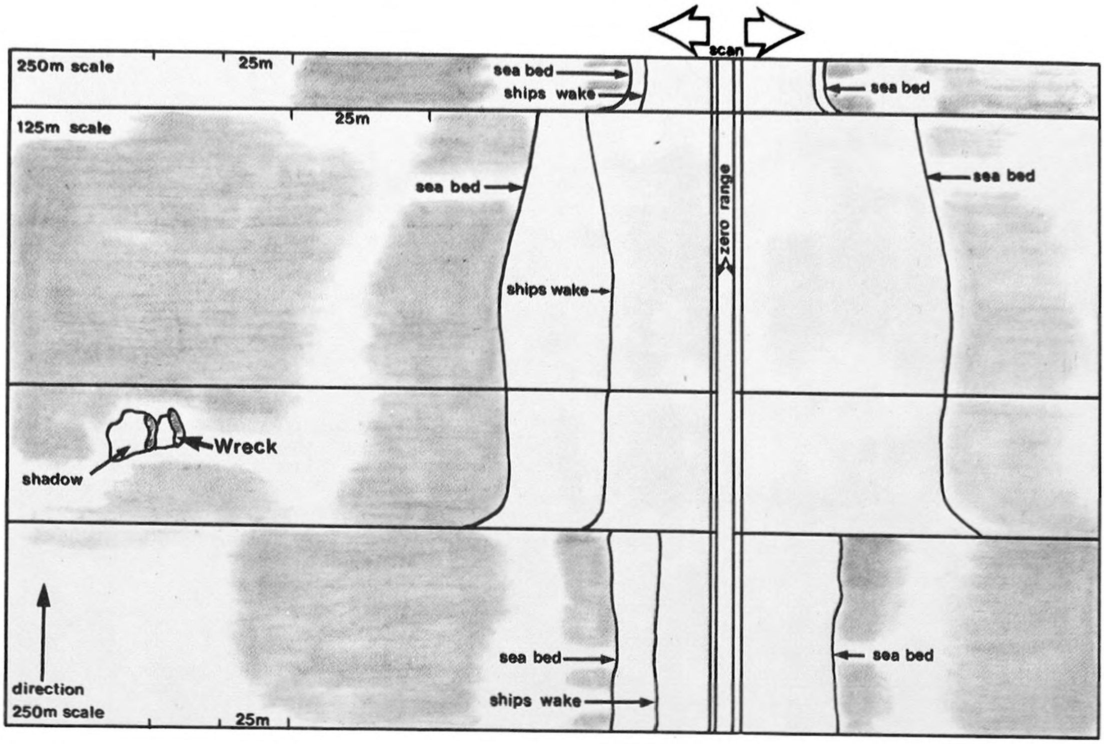
FIG. 21. — An unknown wreck lying on the edge of a "hollow" in the seabed, possibly a rocky outcrop. (See also figure 22).

Top : The towfish was too close to the bottom, and the recorder gains were too high for the best results.

Bottom : The wreck is only just discernible in an area of weak side-lobe cover.


161
FW


WK.



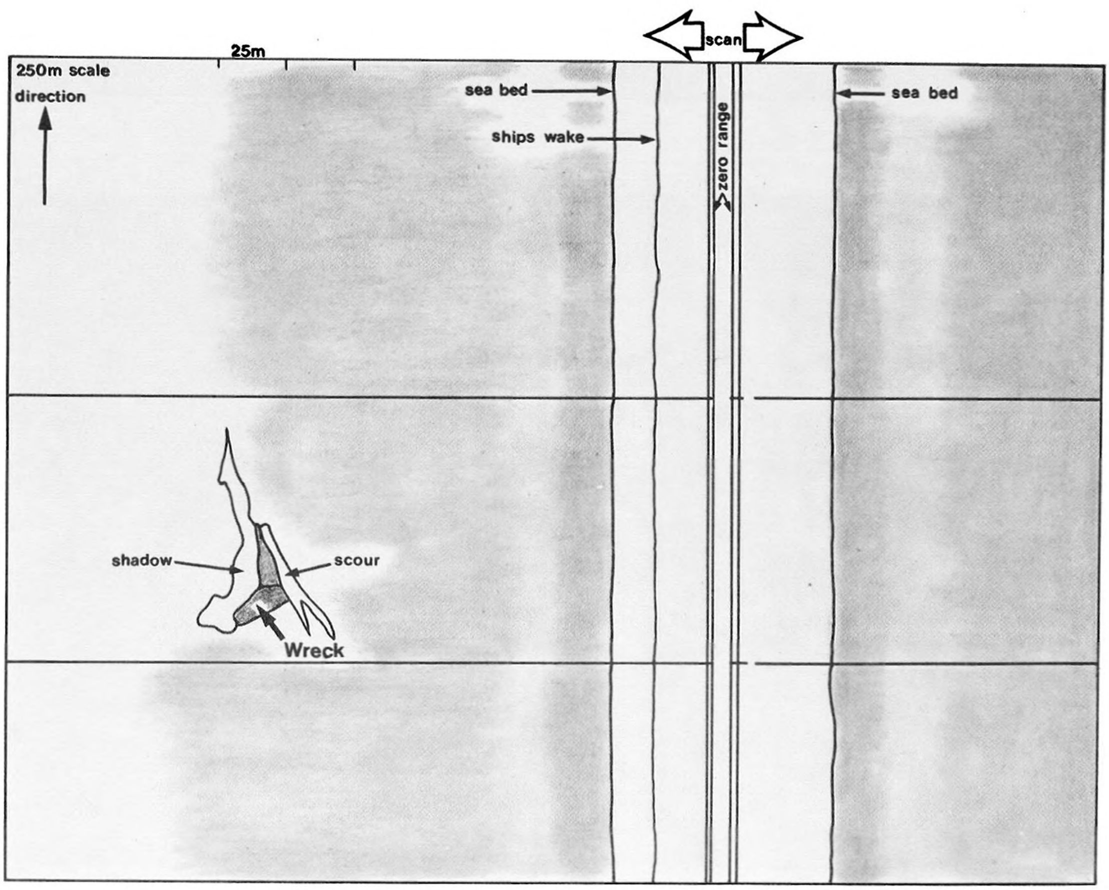
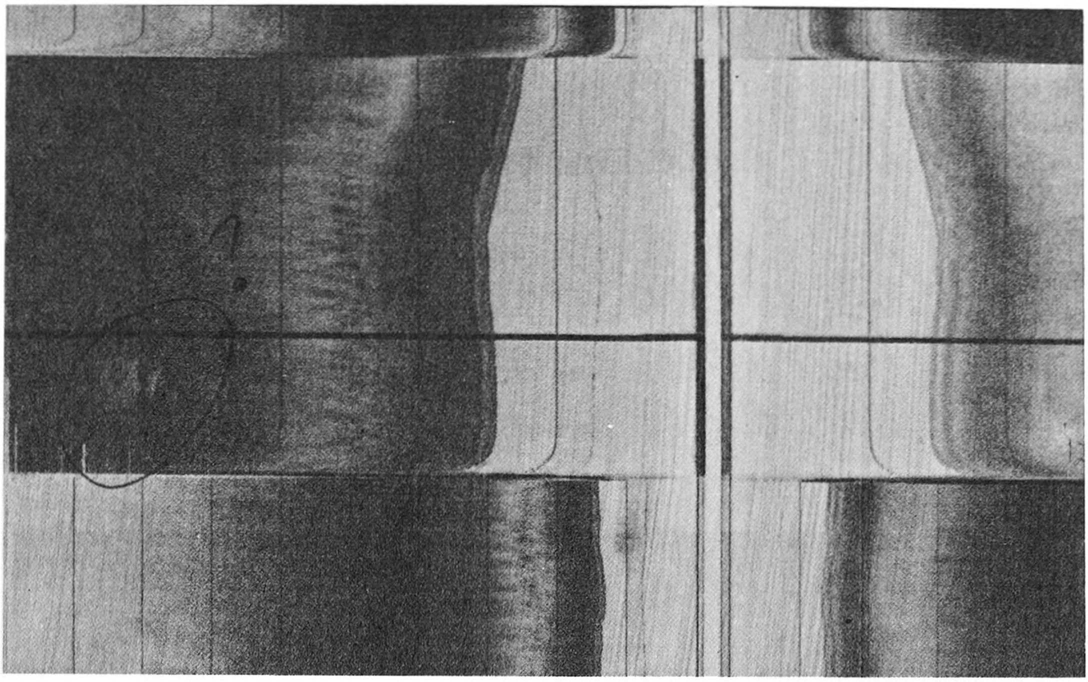
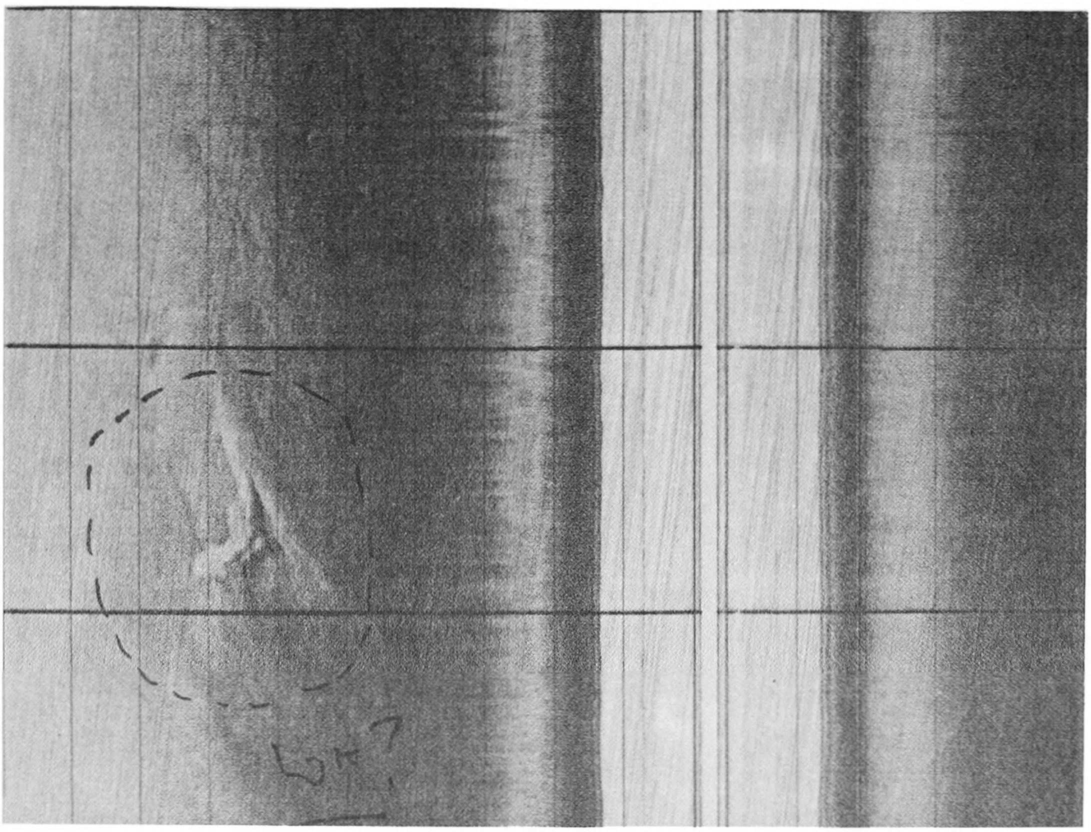


FIG. 22. — An unknown wreck (same as in figure 21).

Top : The recorder should have been re-tuned for best results in the 125 m range scale.





Bottom : Here the contact is in optimum relationship to the towfish, although the overall gain is slightly too high.

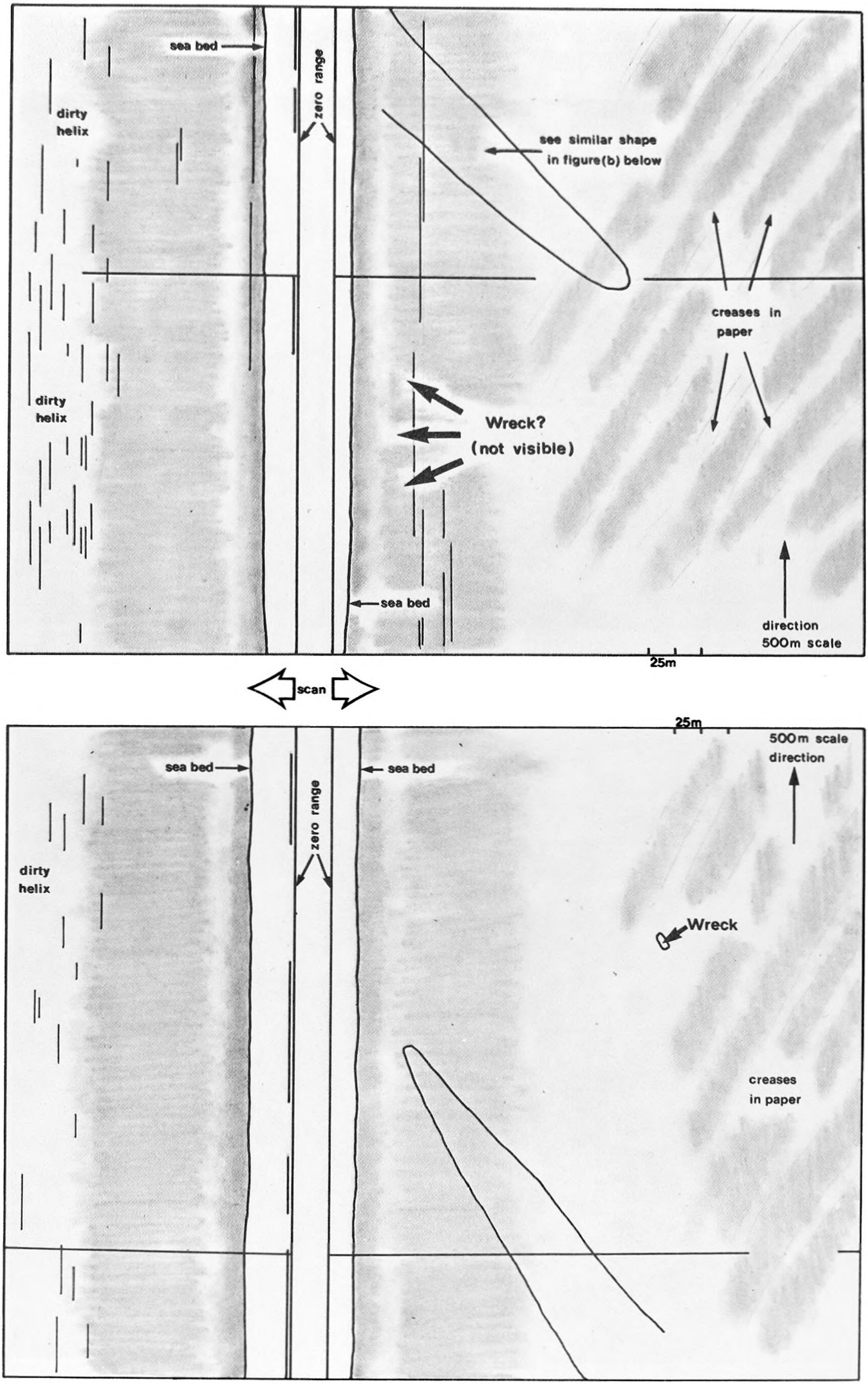
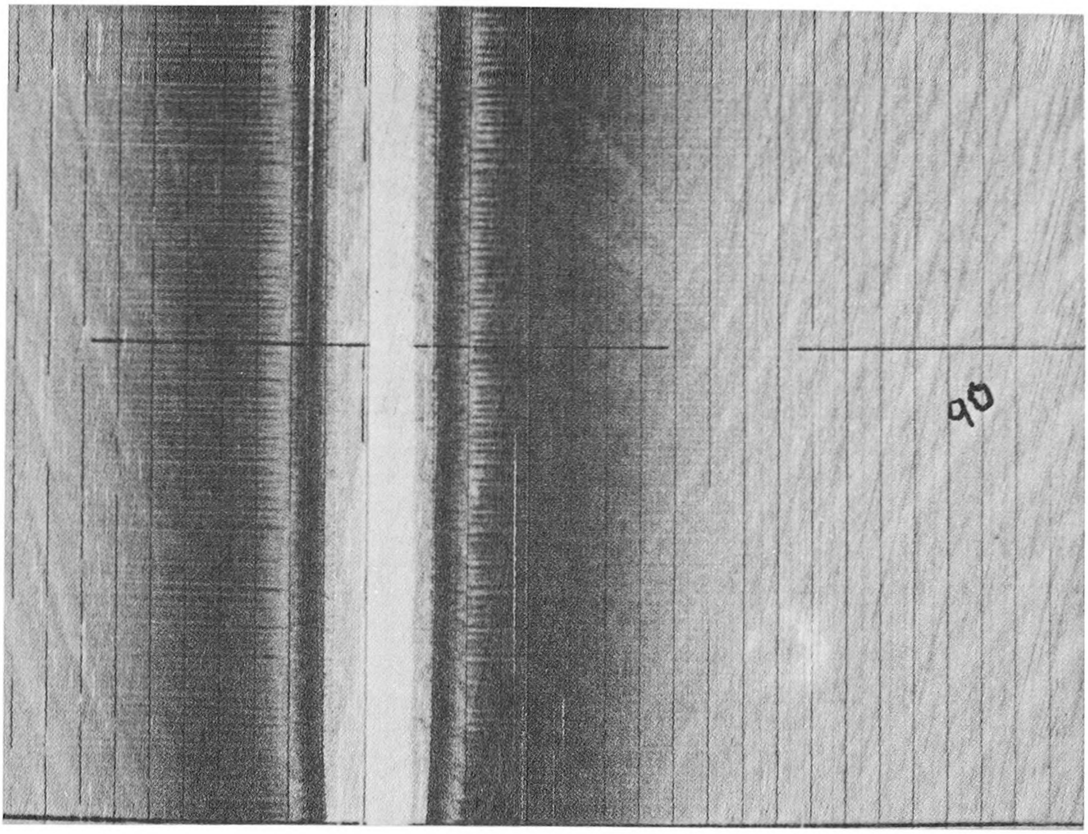
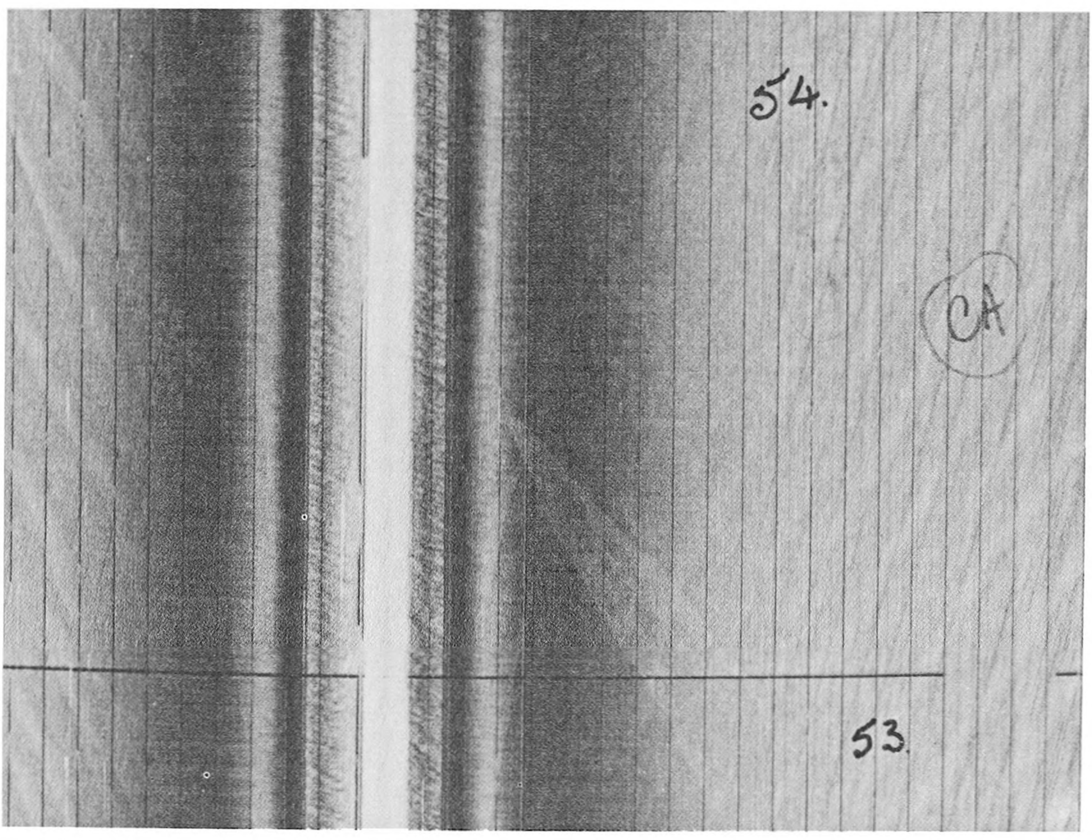


Fig. 23. — Wreck of the *Saint André* (see also figure 24), a fishing vessel of 68 tons which is still intact, about 25 m long, 4 m high and lying 060°/240°.

Top : Gains set too high. The returns from the seabed have totally obscured those from the wreck.





Bottom : Good detection of small wreck at 320 m; but a further demonstration of the disadvantages in using the 500 m scale. The general depth was 47 m and therefore it was impossible to run the towfish at the optimum height off the seabed and hence to tune the record across the full paper width.

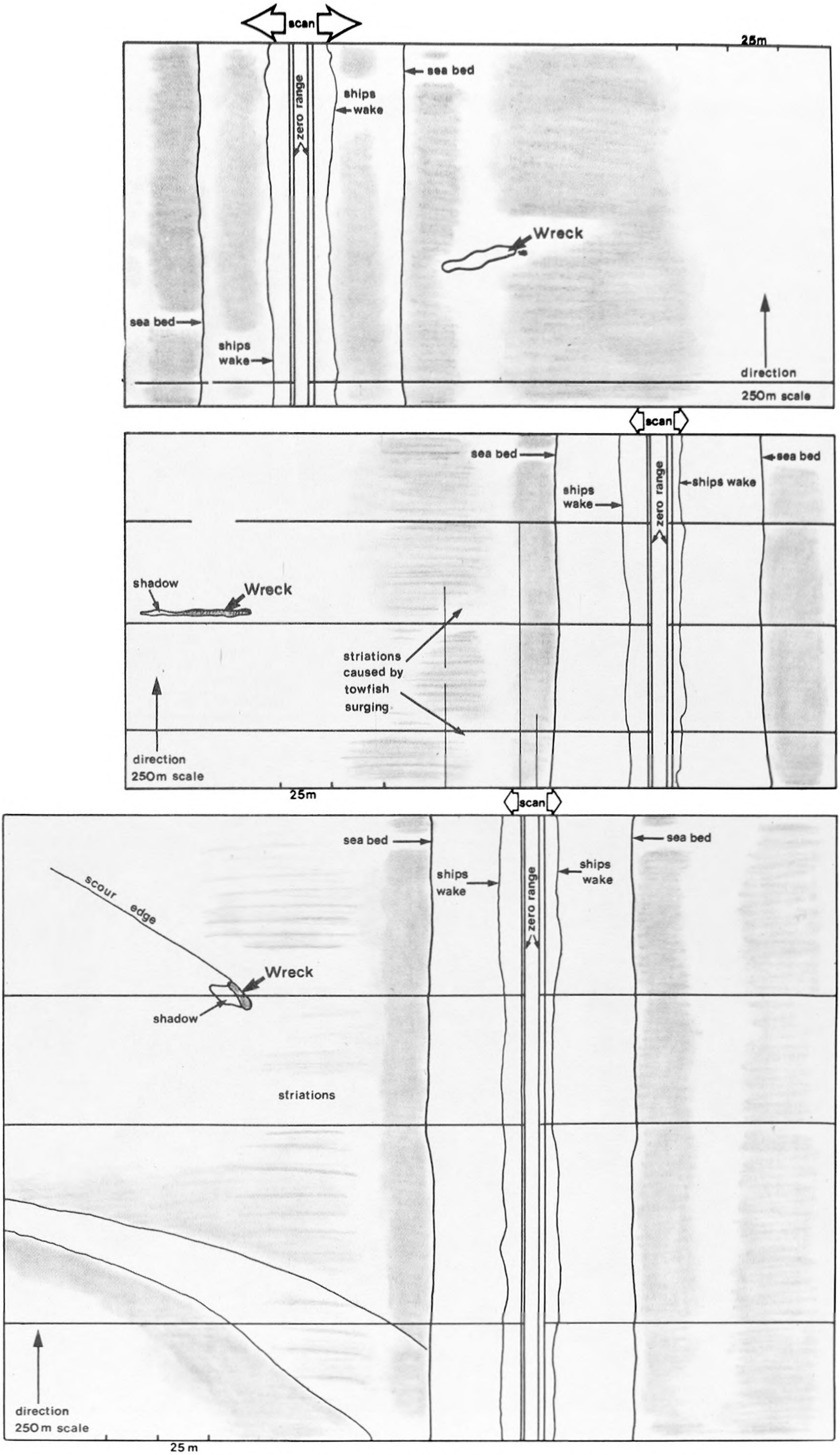
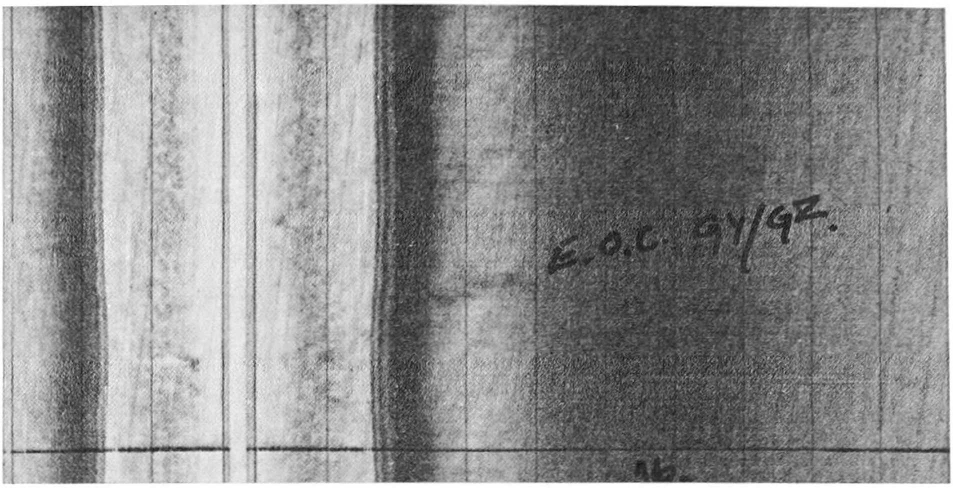
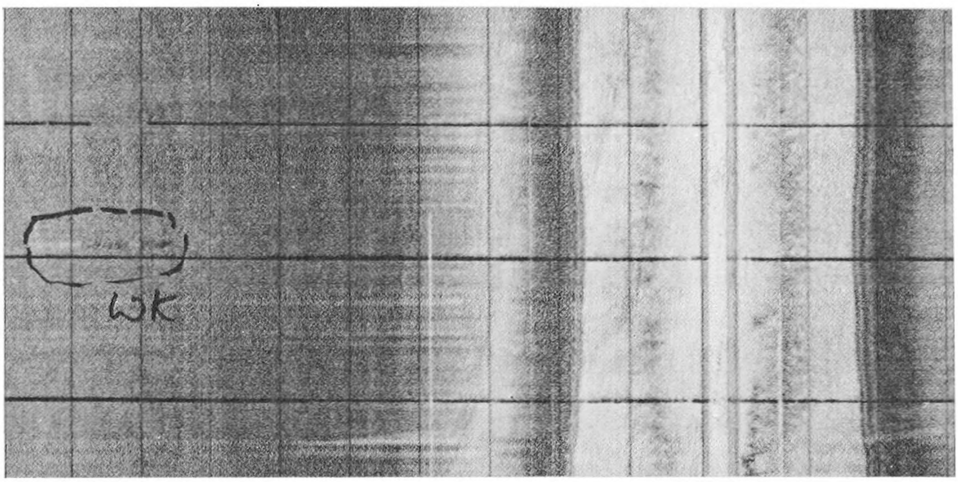


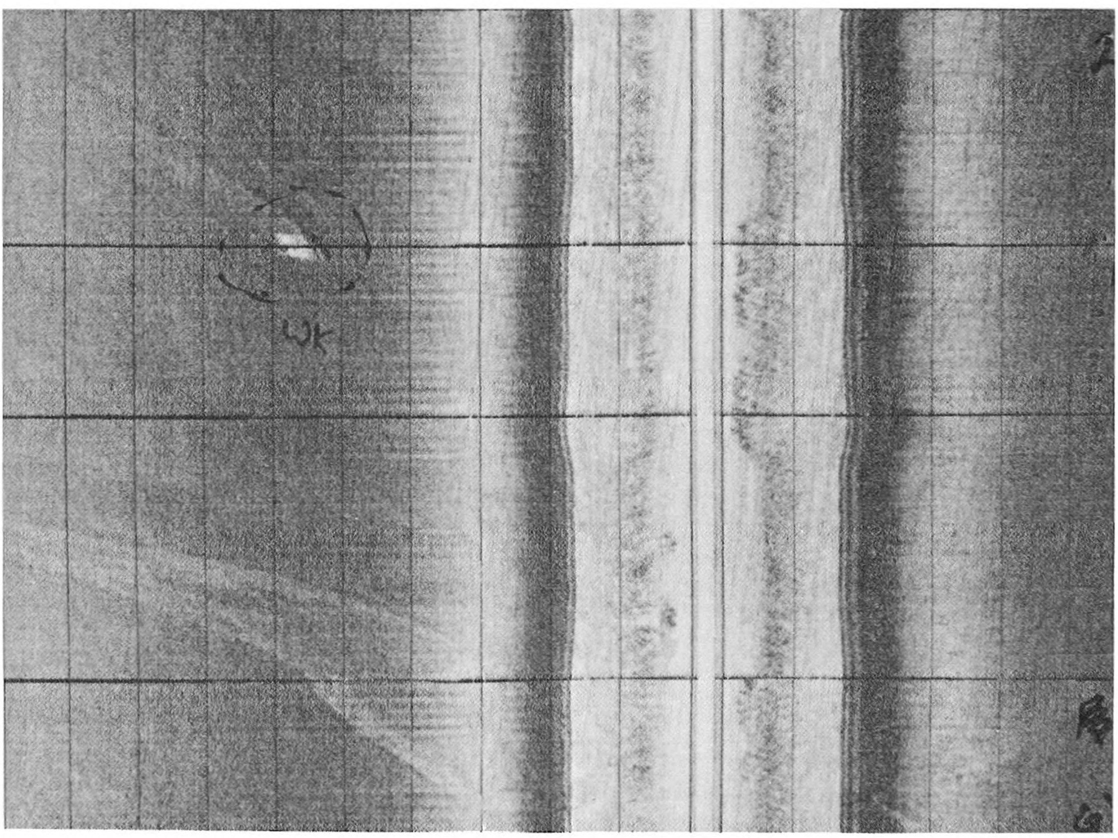
FIG. 24. — Wreck of the *Saint Andre* (see also figure 23).

Top : A barely discernible contact, close under the towfish.

Centre : A good "end-on" picture which emphasizes that care is needed in scrutinising the sonograph for this type of contact.







Bottom : The set was well tuned for the investigation mode; the towfish could have been nearer the seabed but was otherwise well placed.

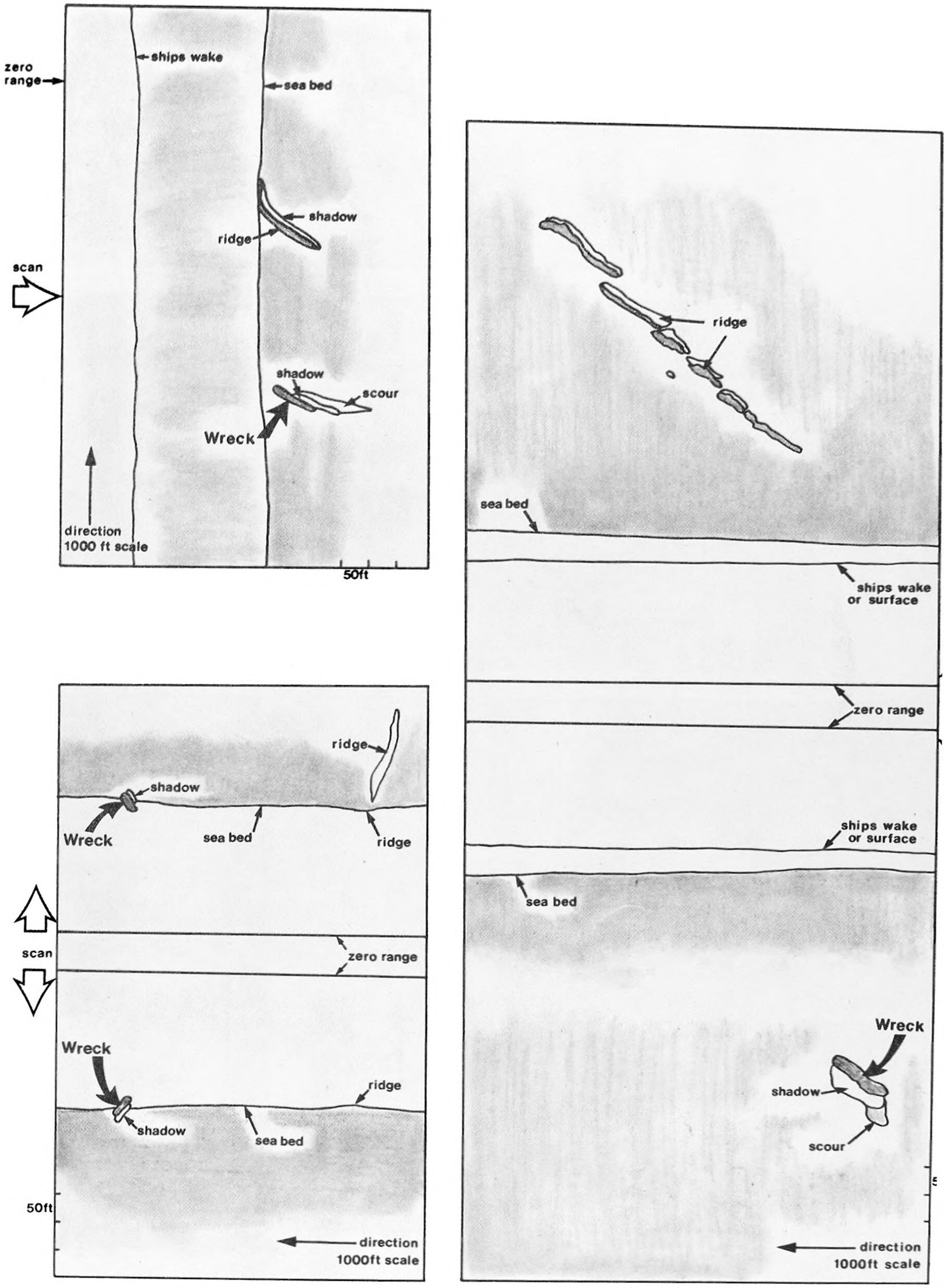
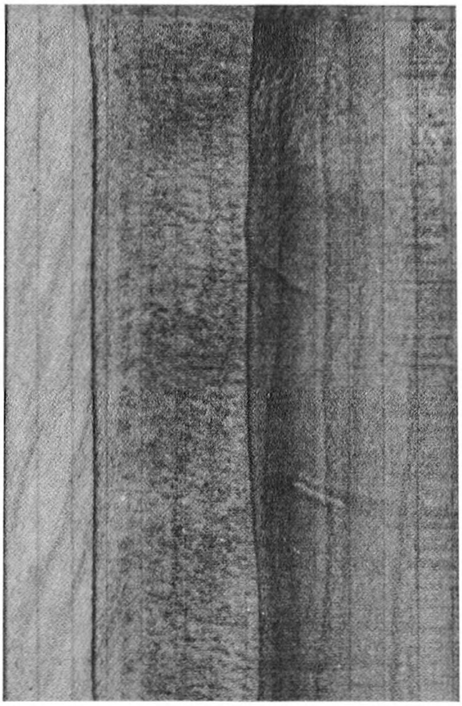
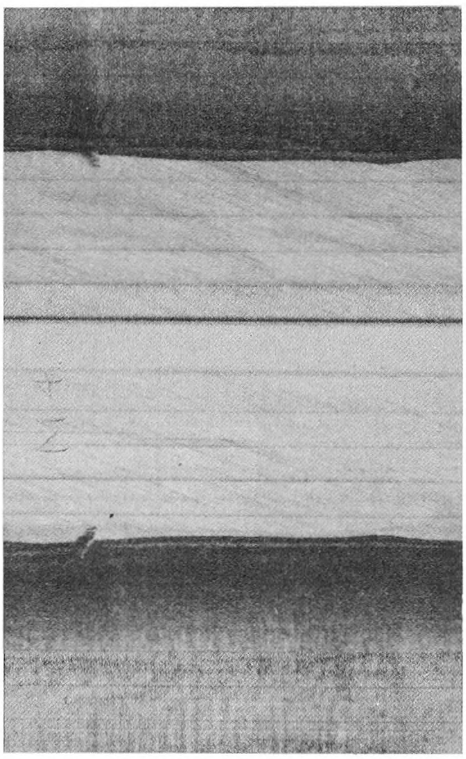
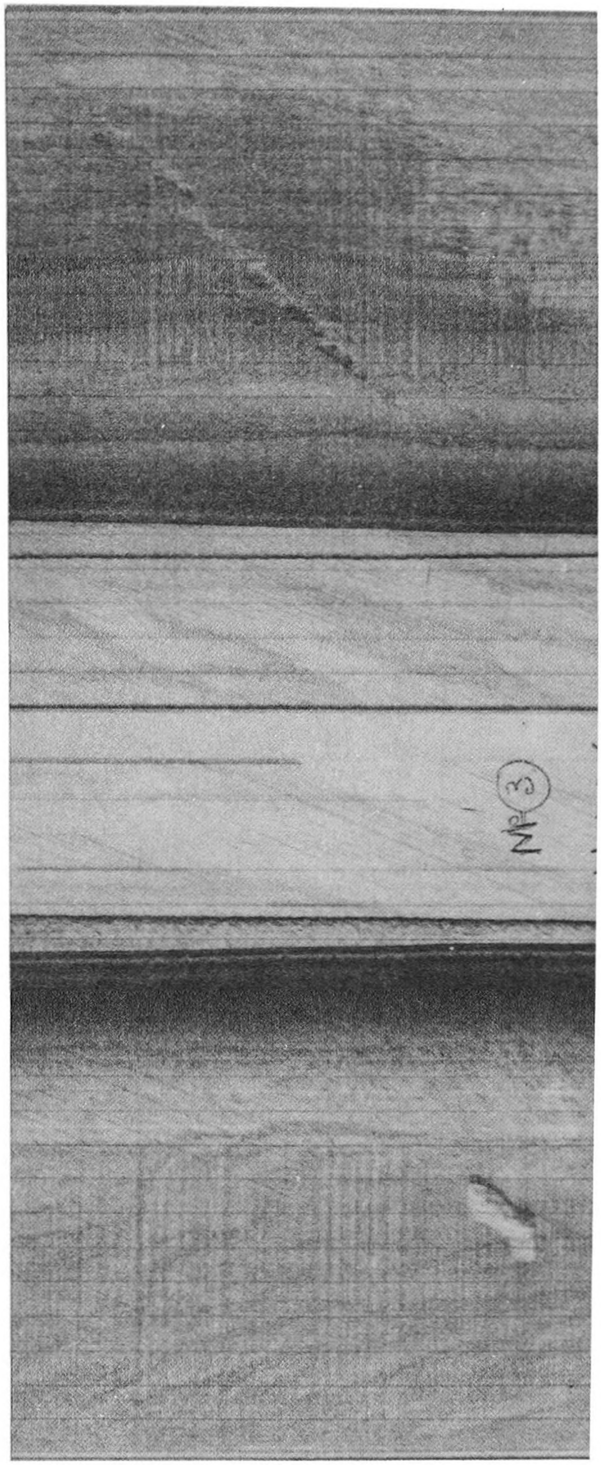


FIG. 25. — Wreck of the *Almanace*, 4500 tons gross, standing about 11 m high.

Top left : Speed made good was 7 knots. The towfish was 350 ft above the seabed, hence there is considerable near-range distortion. A poor shadow, but sufficient to distinguish the wreck from the ridge.







Bottom left : Speed made good was 7 knots. Good on-top. Note that this small contact represents a moderate sized ship.

Right : Speed made good was 5 knots. The set was well tuned to give firm outline and shadow. The wreck is readily distinguishable from the seabed features.

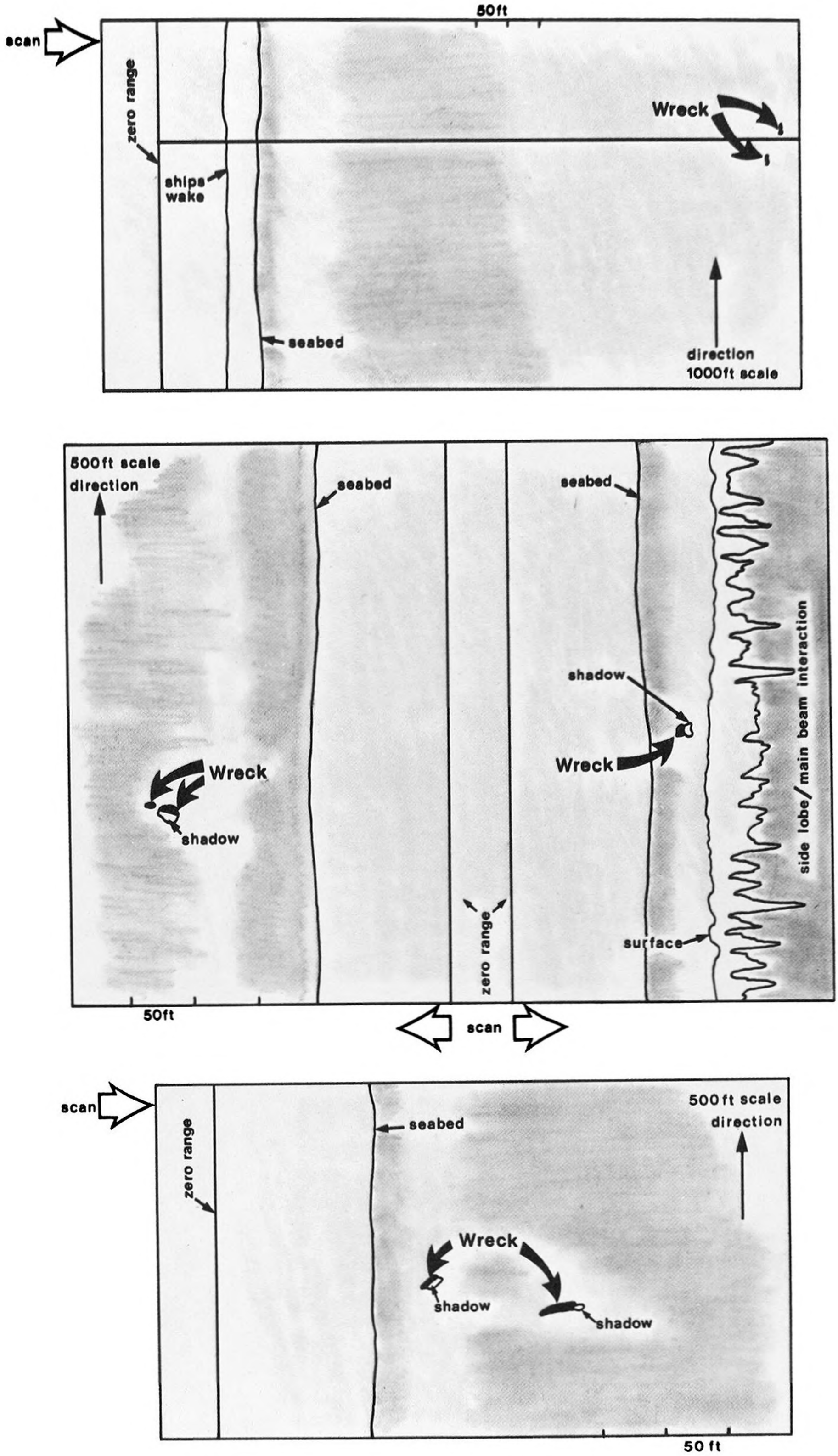
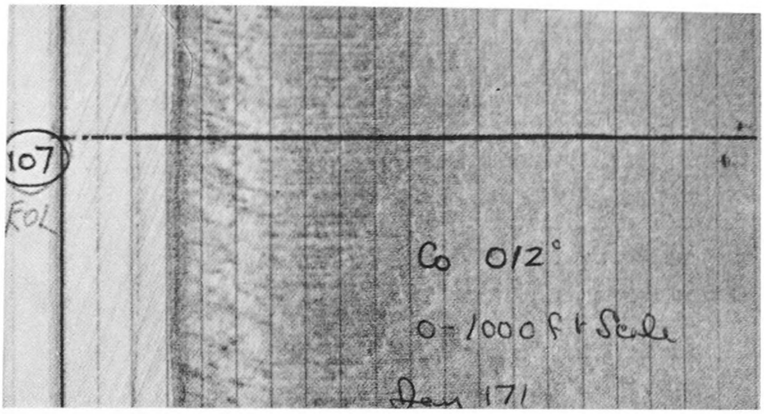
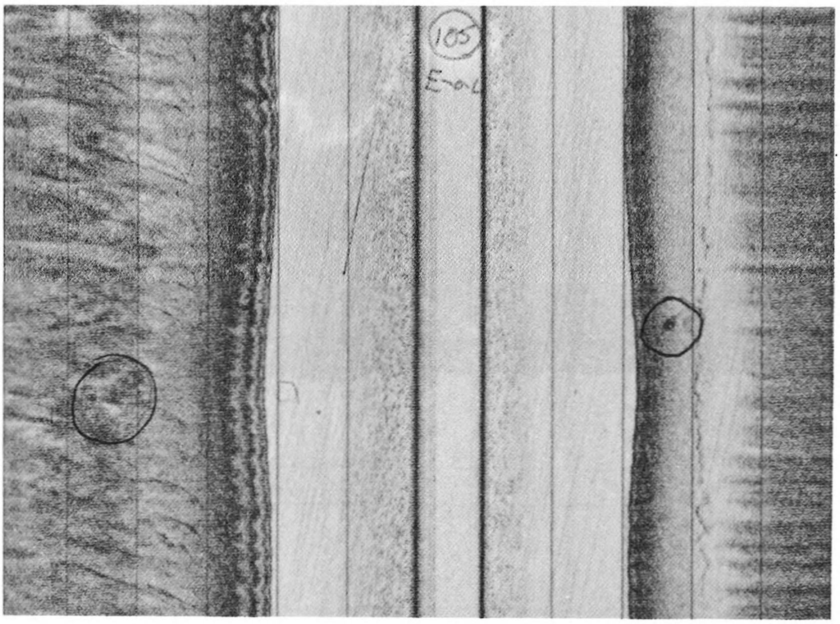
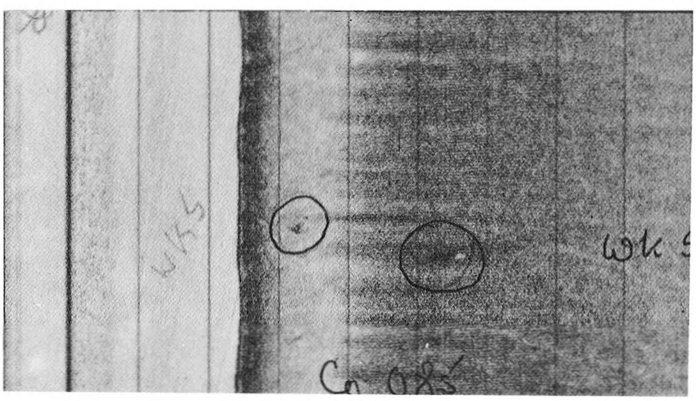


FIG. 26. — Wreck of the *Dove of Oban*, with wreckage scattered over 150 ft. One piece is approximately 40 ft long and 4 ft high.

Top : A good example of a well tuned set, resulting in a small, low-profile wreck at maximum range in good contrast to the seabed.







Centre : The ship has passed between two portions of wreckage at a speed made good of 6.5 knots. A good example of near-track detection of small objects, but highlights the difficulty of appreciation on search mode (1000 ft scale) record.

Bottom : Speed made good was 7.7 knots. The contacts are barely discernible. Note the tiny tell-tale shadow on the right hand contact.

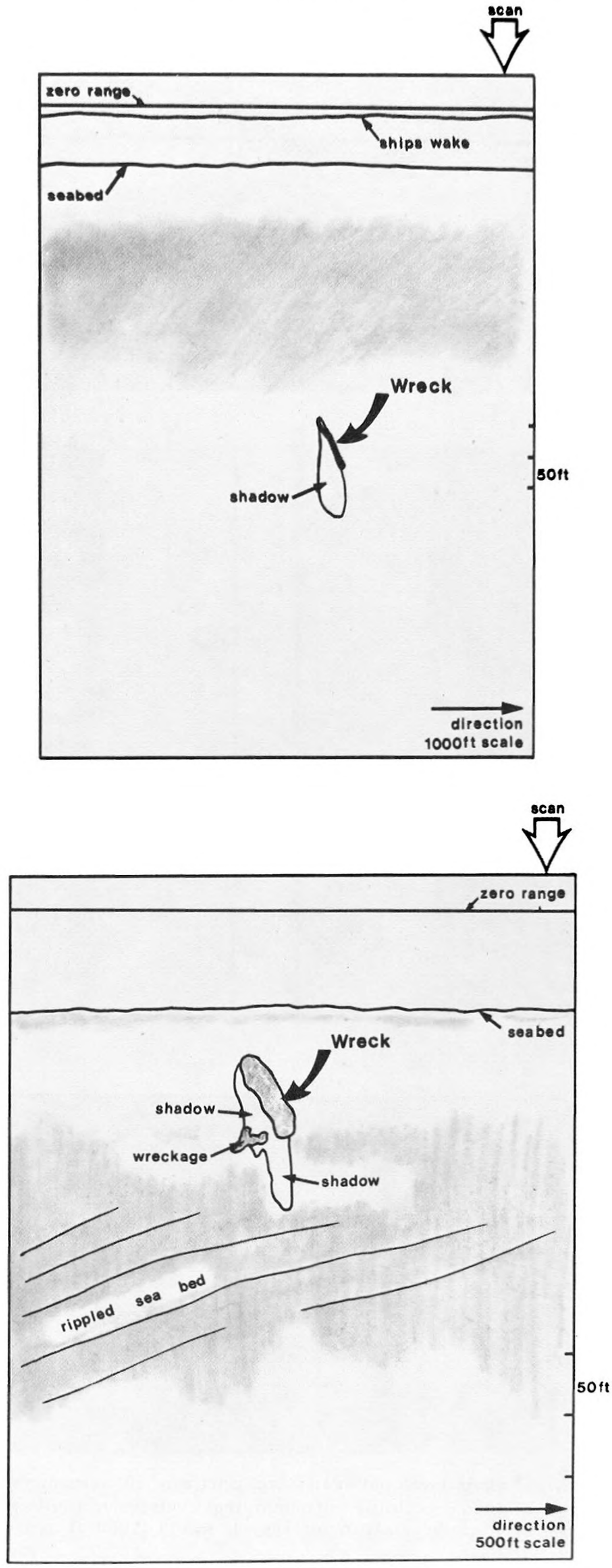
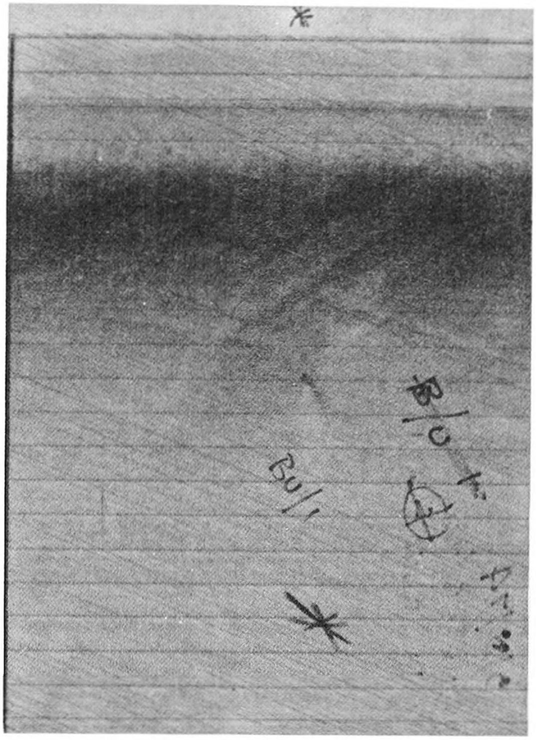
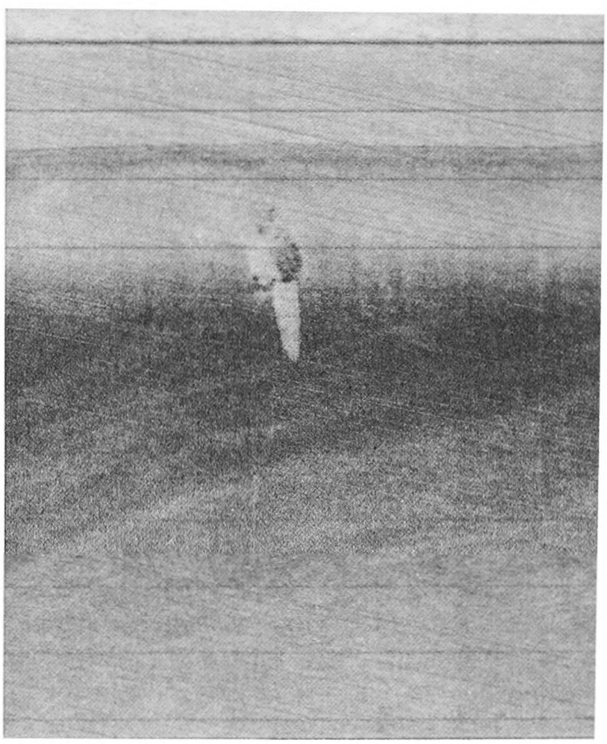


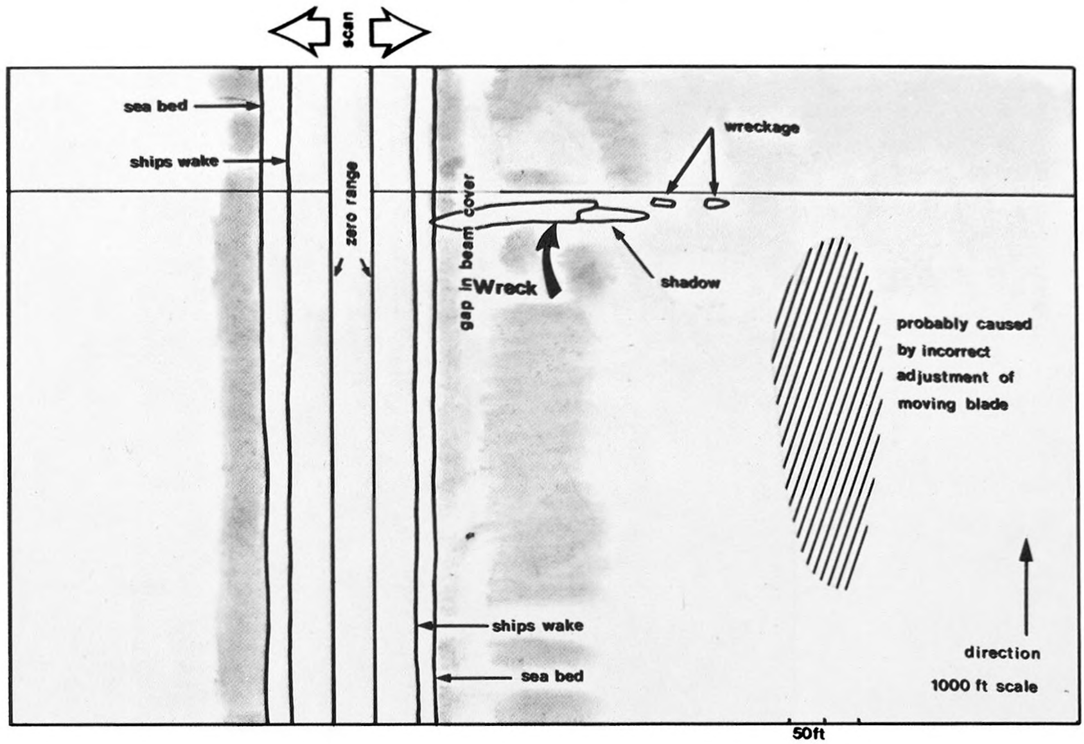
FIG. 27. — An unknown wreck, lying "end-on" to the ship's track. Height approximately 6 m.





Top : Speed made good was 7 knots approximately. Note the very faint echo and barely discernible shadow.

Bottom : The echo is distorted near the track. Note the poor return from an area of side lobe interference.



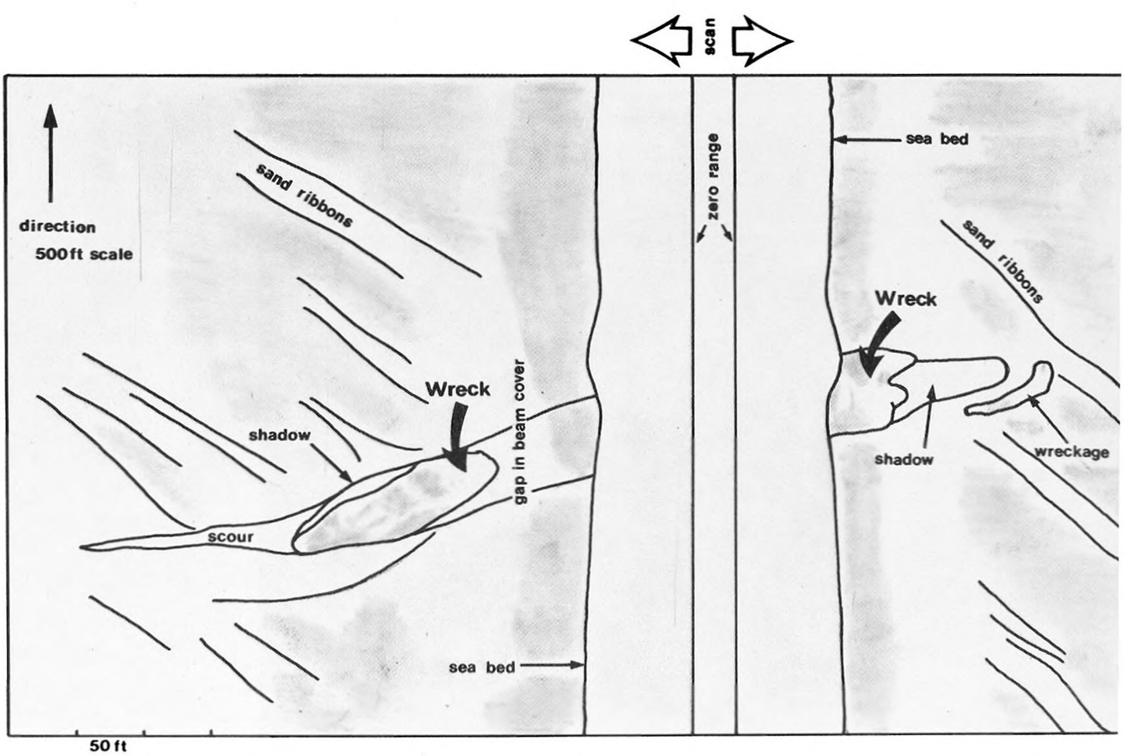
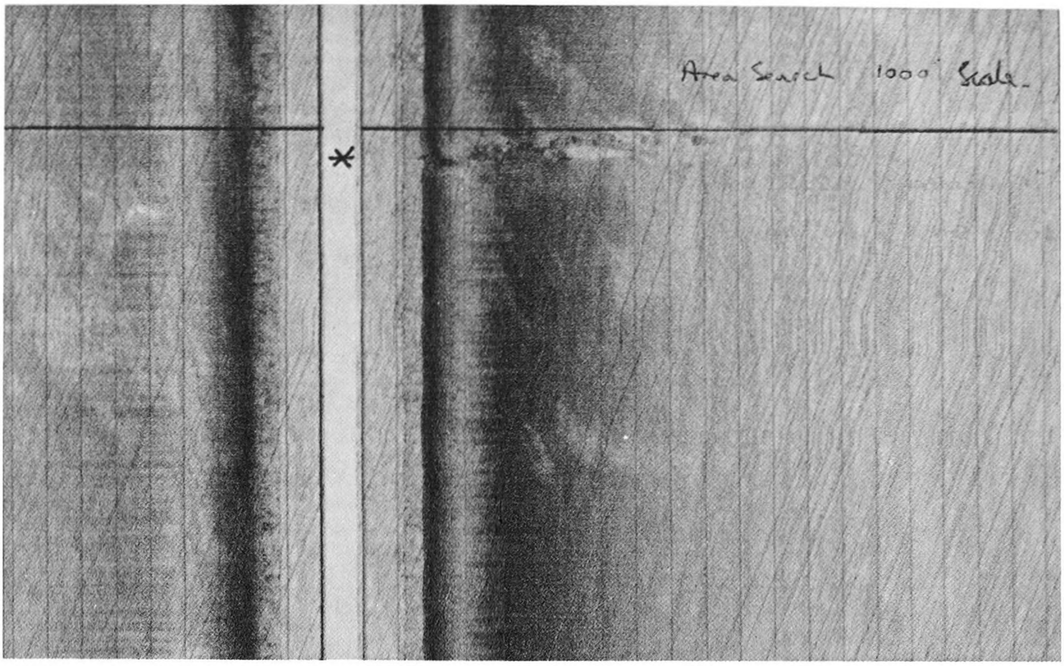
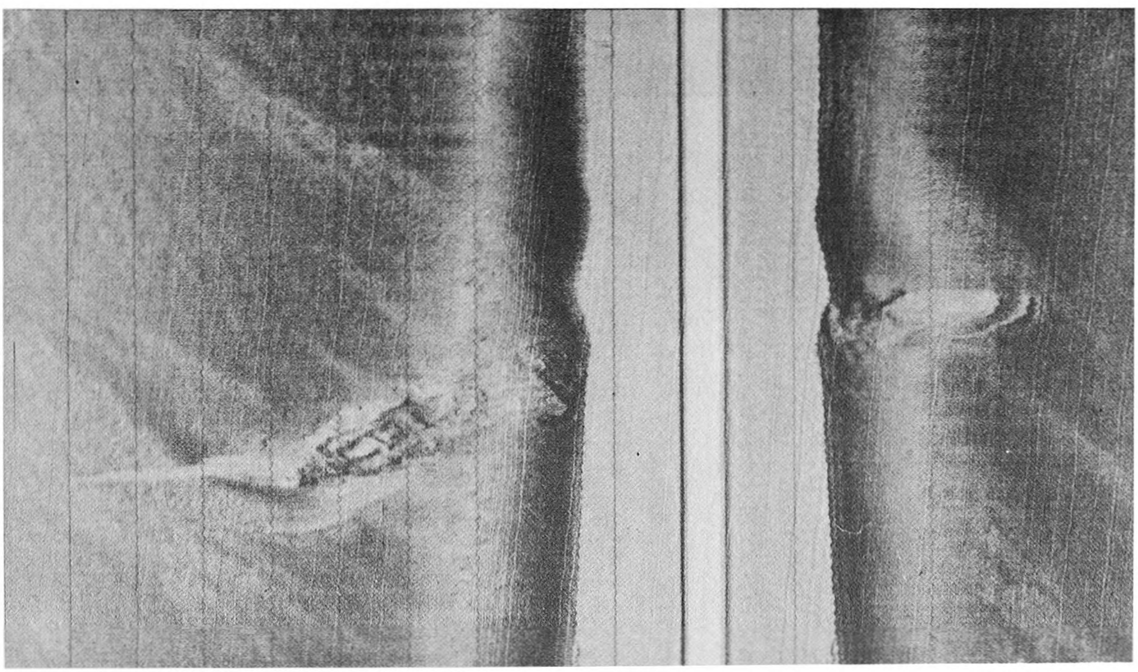


FIG. 28. — A large unknown wreck, 90 m long and standing 10 m high.

Top : Speed made good was 6 knots approx. A good example of near-field distortion, and of the probable gap in the sonar beam between the main and side lobes.

Bottom : A further example of the loss of signal close to the towfish.


Area Search 1000' Scale
*



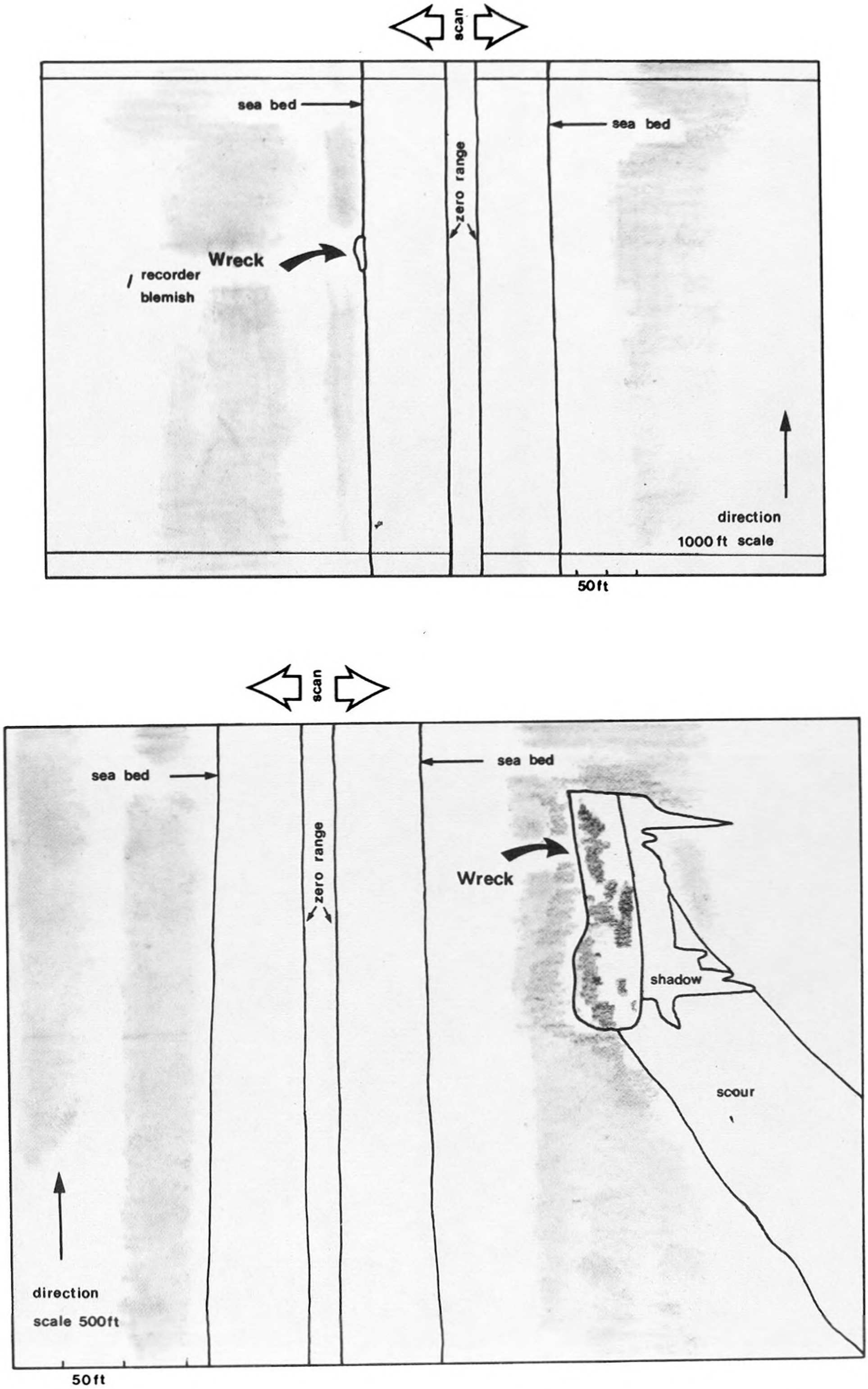
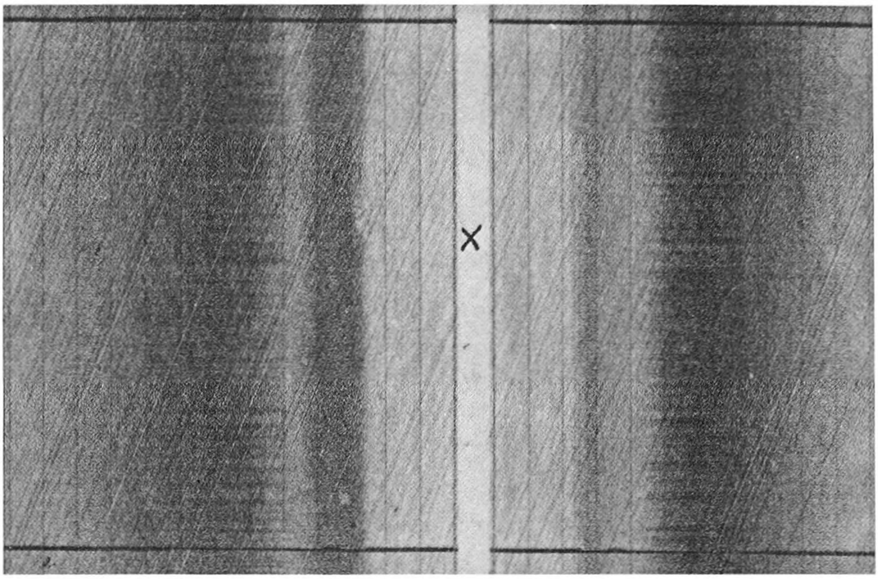
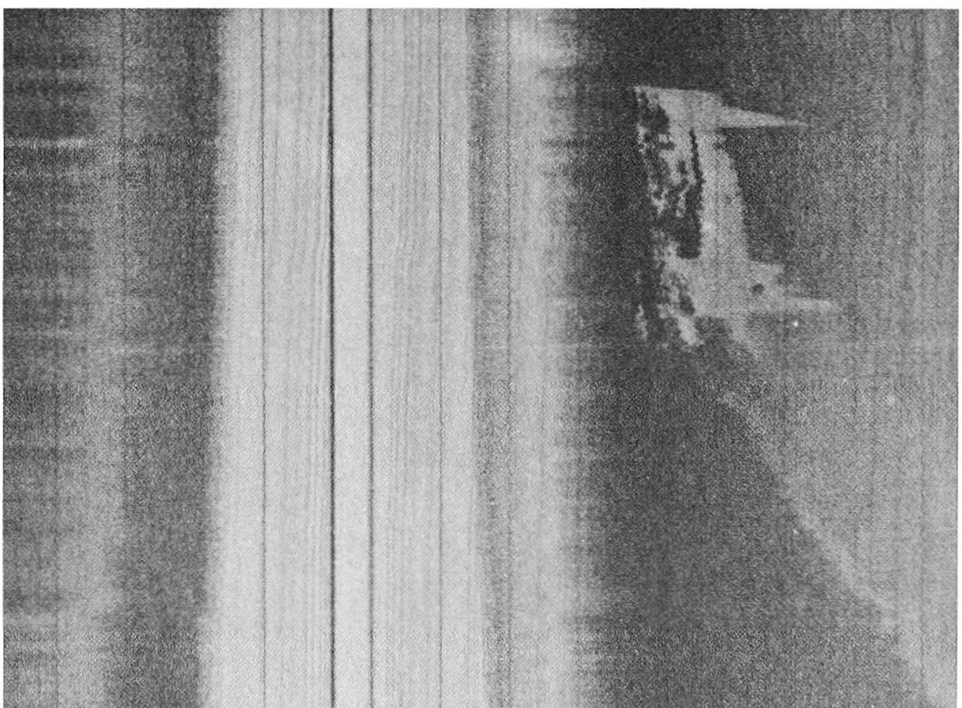


FIG. 29. — An unknown wreck lying in an East/West direction, 300 ft long, and about 27 ft high.

Top : Speed made good was 6 knots. This wreck lay just off the towfish track and parallel to it, so it is a very good example of the effects of scale distortion.

Bottom : The target was in optimum relationship to the towfish.





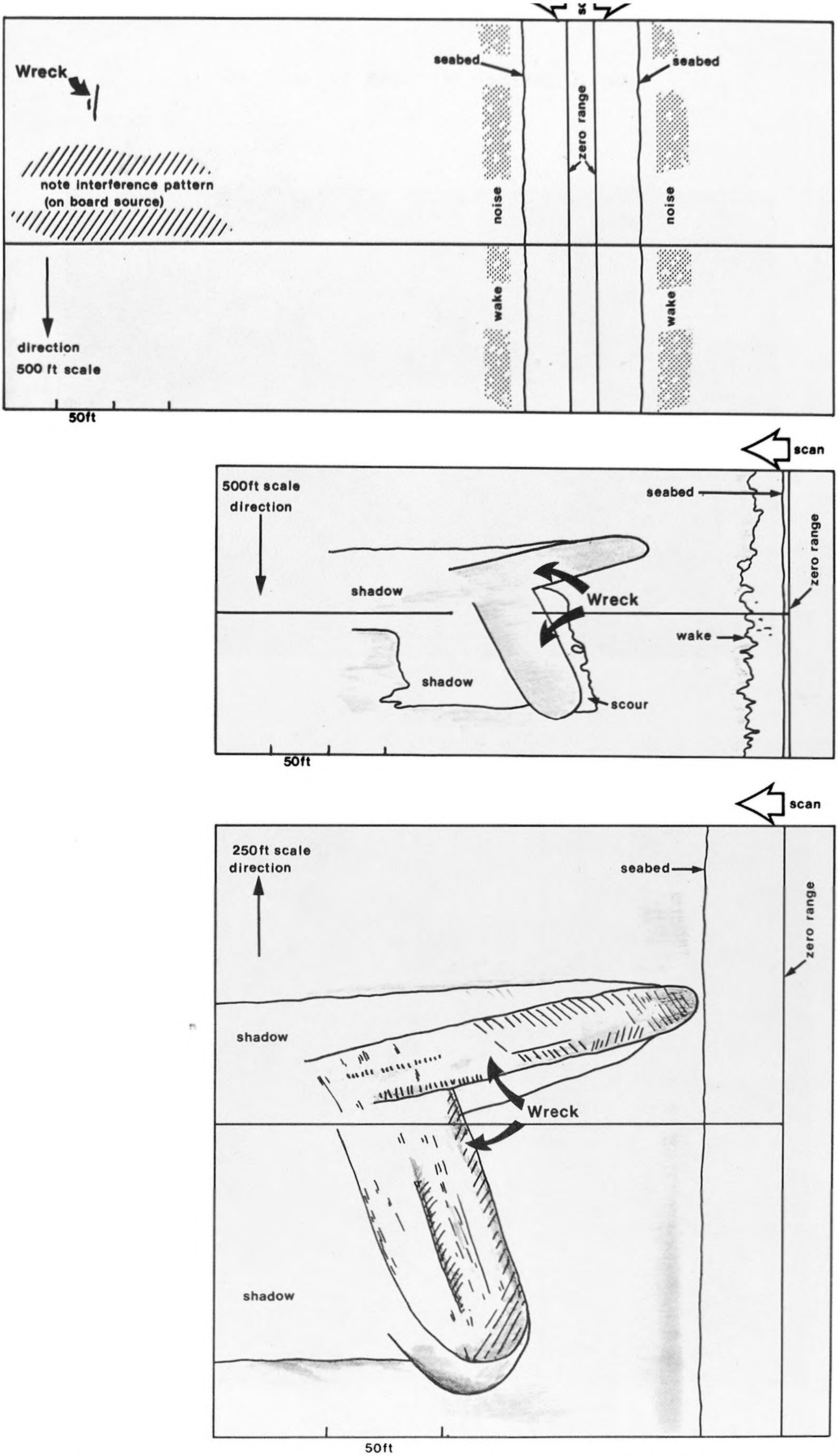
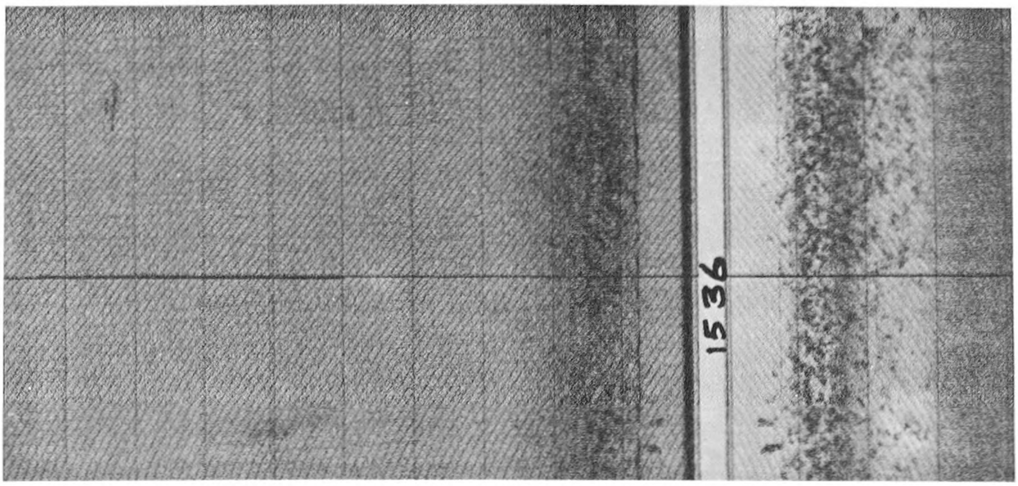
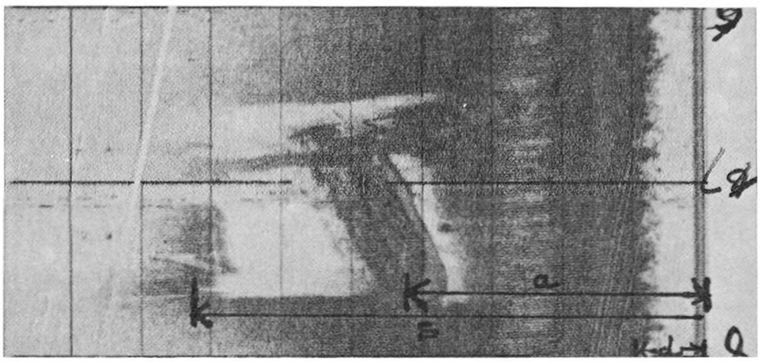
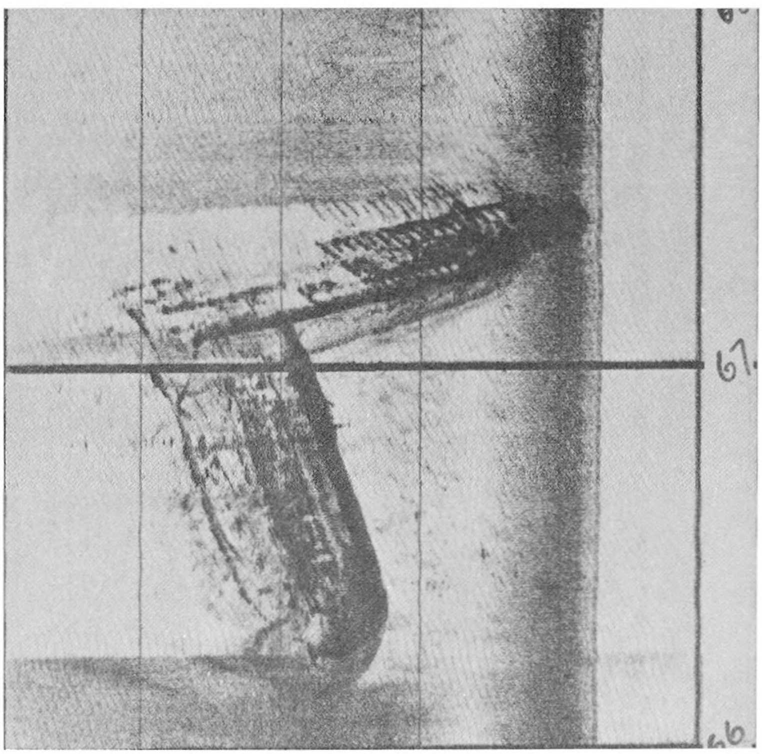


FIG. 30. — Wreck of the *San Tiburcio*, a 6000 ton tanker, length 413 ft (126 m), beam 53 ft (16 m) and draught 31 ft (9.5 m). The wreck lies on its side approximately parallel to the searching survey tracks, and stands 12 m off the seabed with the wreck partially buried.

Top : Speed made good was 8.5 knots approx. The wreck would have shown up better if the set had been tuned for a lighter far-range display. The seabed is of smooth sand and mud.







Centre : Too much gain at near range where the bottom returns swamp those from the wreck. The far field could have been better tuned to clarify the shadow limits.

Bottom : Plenty of wreck detail, but excessive enlargement cuts off the shadow and precludes determination of height.

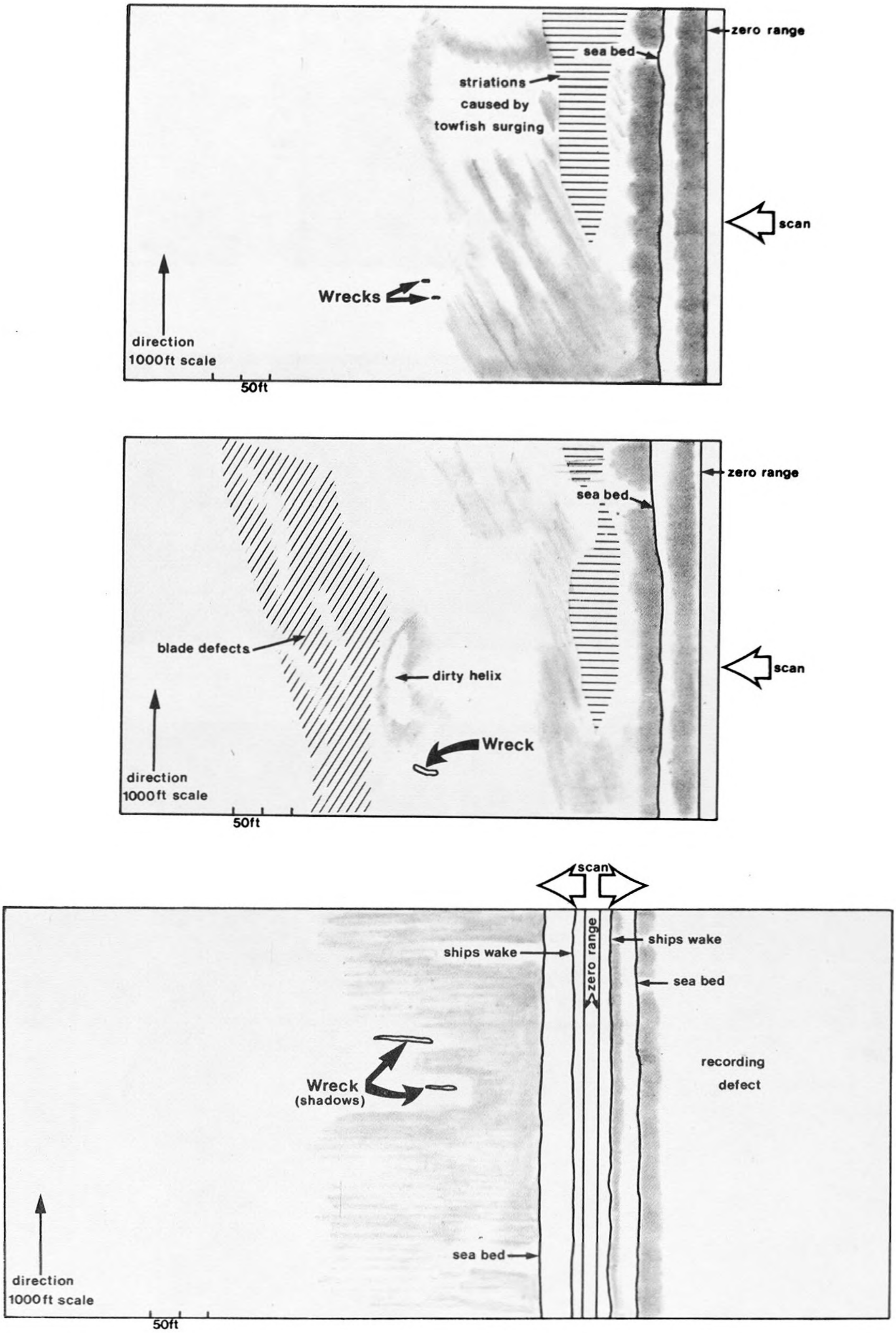
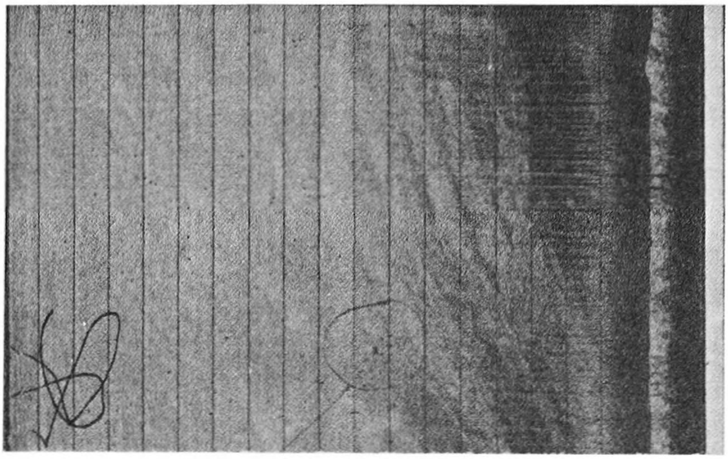
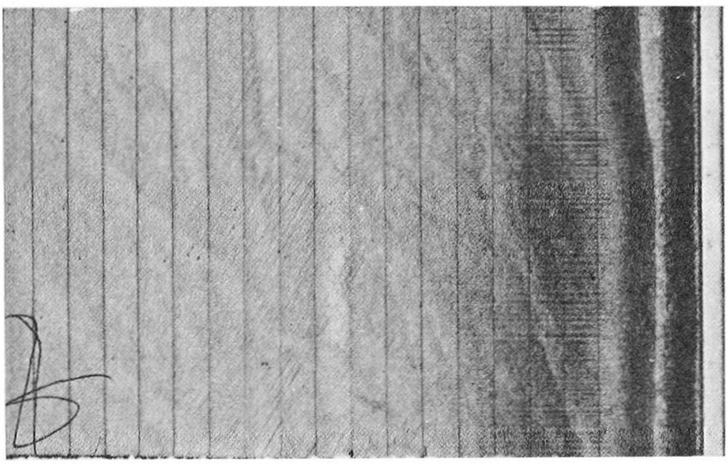
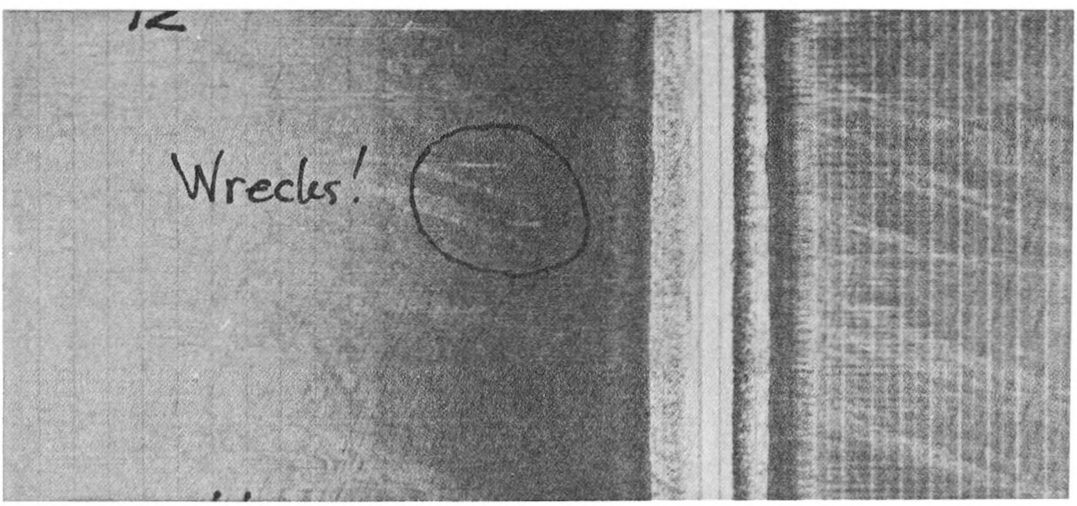


FIG. 31. — Wreck of the *Avanturine* (see also figure 32), a steam trawler of 300 tons. The wreck is in two parts, the length of the major portion being 35 m and its height 6 m. The smaller portion is wreckage from a boiler-room explosion and is comprised of shipside plating, boiler tubes, etc. The wreck lies on its starboard side, with its bows towards the north east, i.e. diagonal to the survey tracks (top and centre figures).



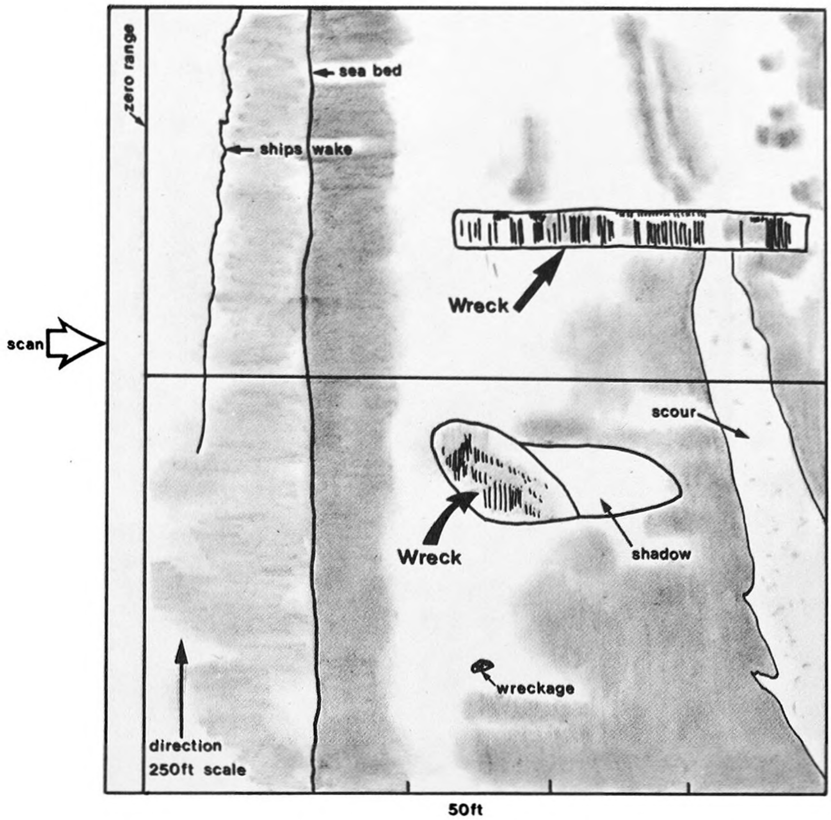




Top : Speed made good was 7.9 knots, on course 260°. Note the minuscule mark on the paper at this speed. The suspicious feature is the intensity with which the returning signal has marked the paper.

Centre : Speed made good was 5.1 knots, course 080°. An extremely weak return, barely sufficient to attract the eye.

Bottom : Speed made good was 6 knots approx. The towfish was close under the keel of the Inshore Survey Craft. The near-field tuning was too dark, hence an acoustic shadow is the only indication of a wreck.



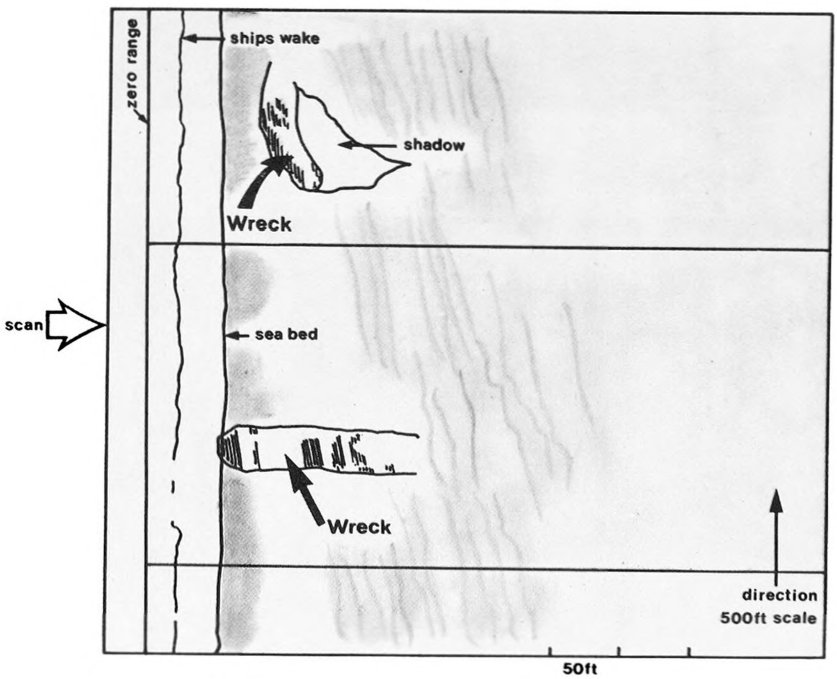
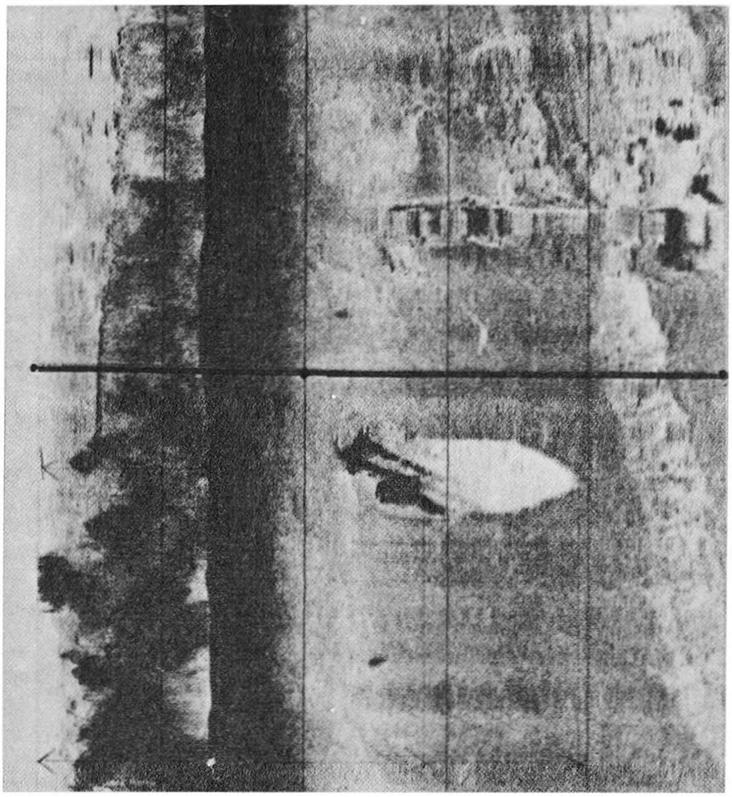
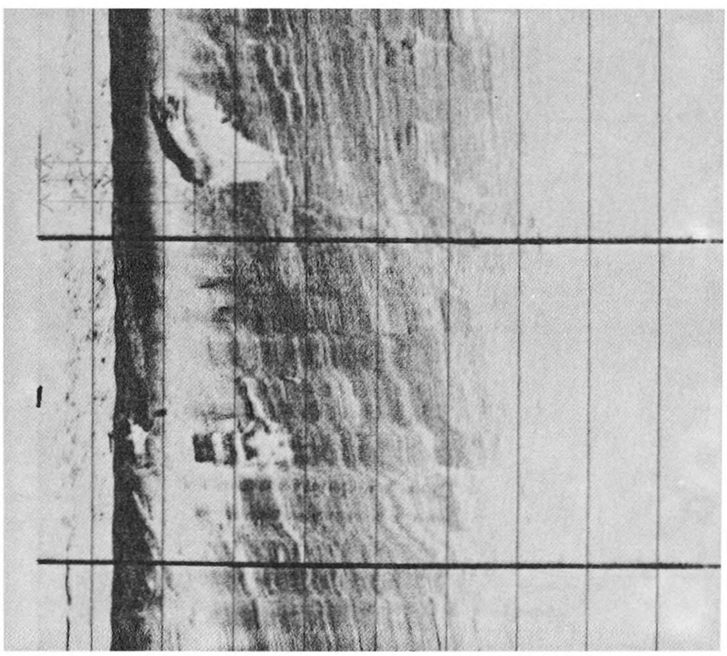


FIG. 32. — Wreck of the *Avanturine* (see also figure 31).

Top : A good example of detail obtainable from close examination.

Bottom : A better orientation; note the surprisingly good shadow close under the towfish.





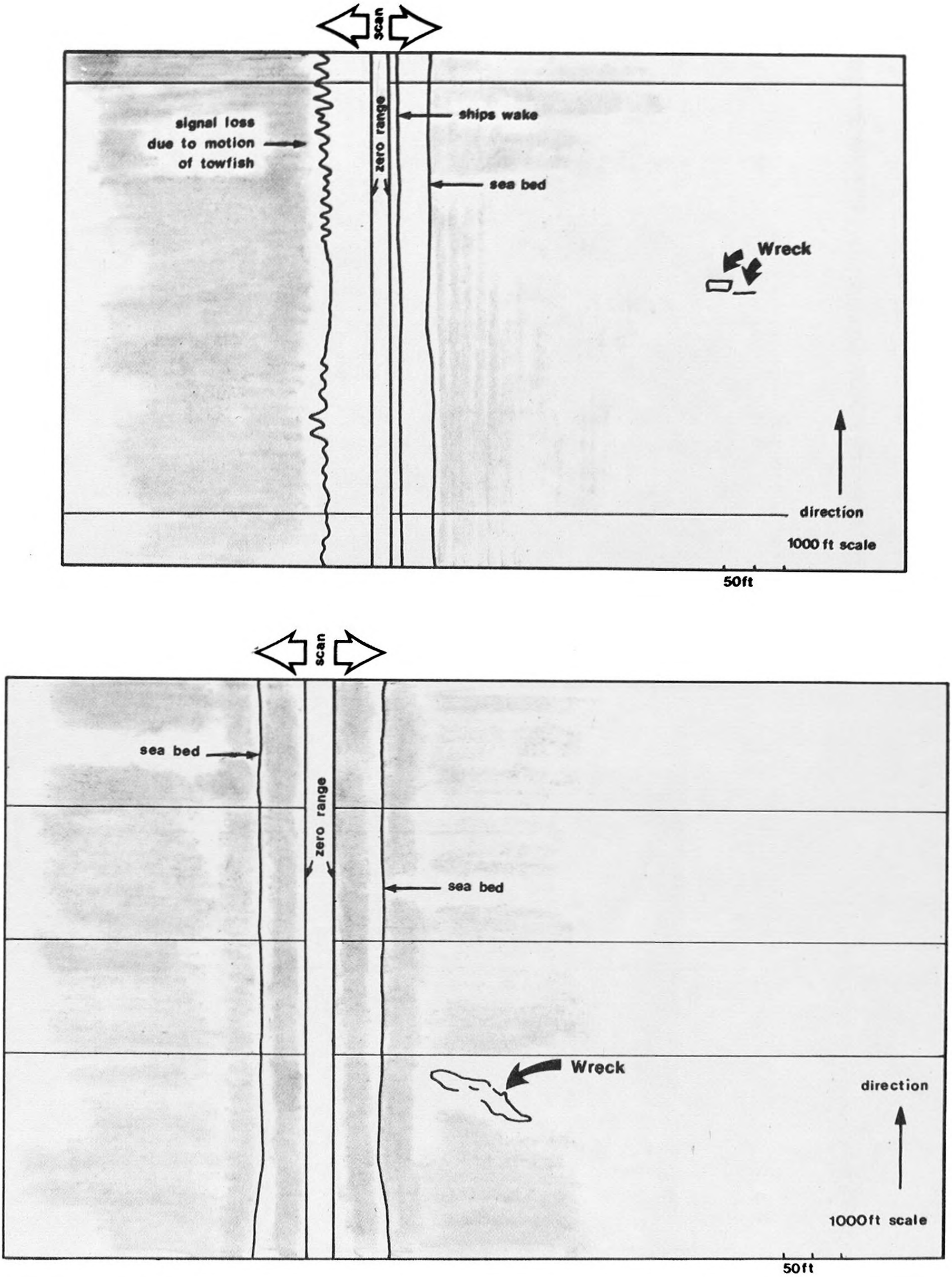
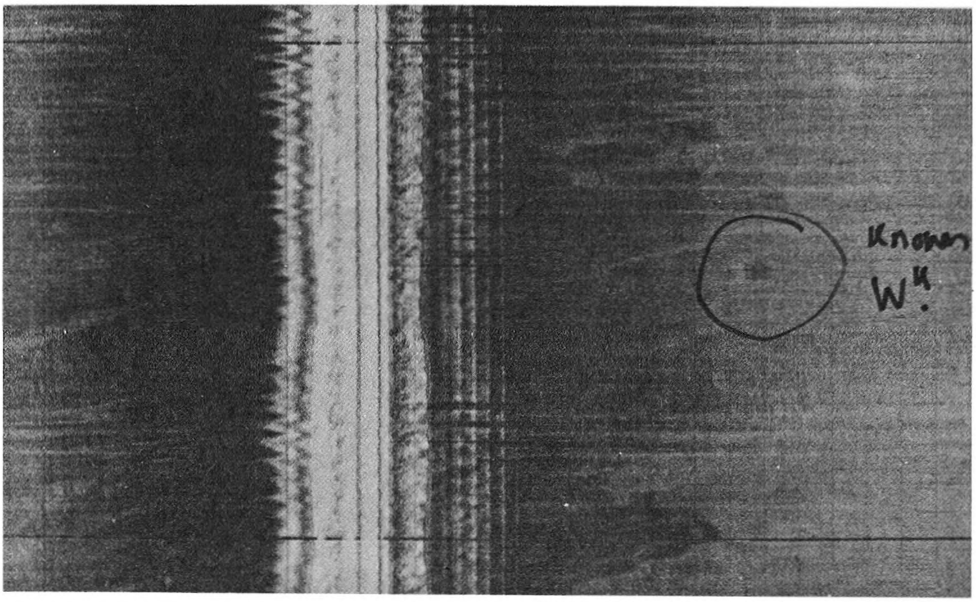
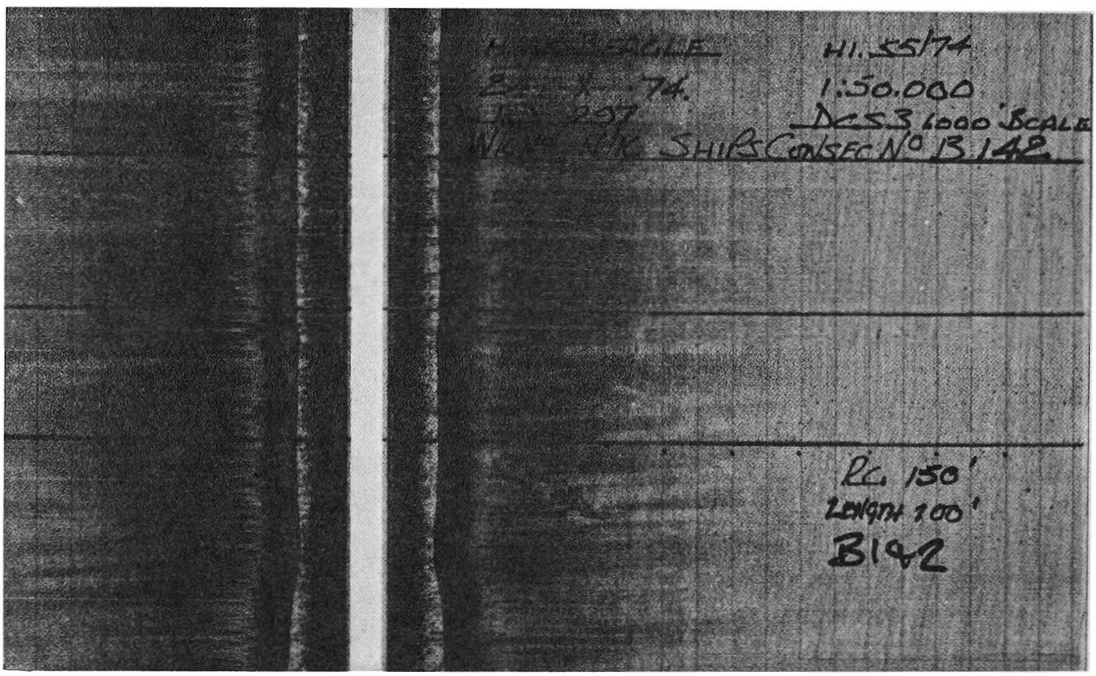


FIG. 33. — An unknown wreck lying on an irregular seabed. It is 100 ft long and about 6 m high, and appears to have been dispersed.

Top : Speed made good was approximately 6 knots. The towfish was streamed from a bowsprit in an Inshore Survey Craft and was running below the keel beneath the bridge. In general the gain was too high, and near-range detection was jeopardized by ship's motion in steep seas. The mid-range detection was good, though rather faint.

Bottom : This is an example of very bad tuning; the initial gain is far too high, and results in the near-range object being almost totally obscured.


Known
Wk.


HI. 55/74
1:50.000
DCS.3 6000' SCALE
SHIPS CONSEC No B 142.
RC. 150'
LENGTH 100'
B142

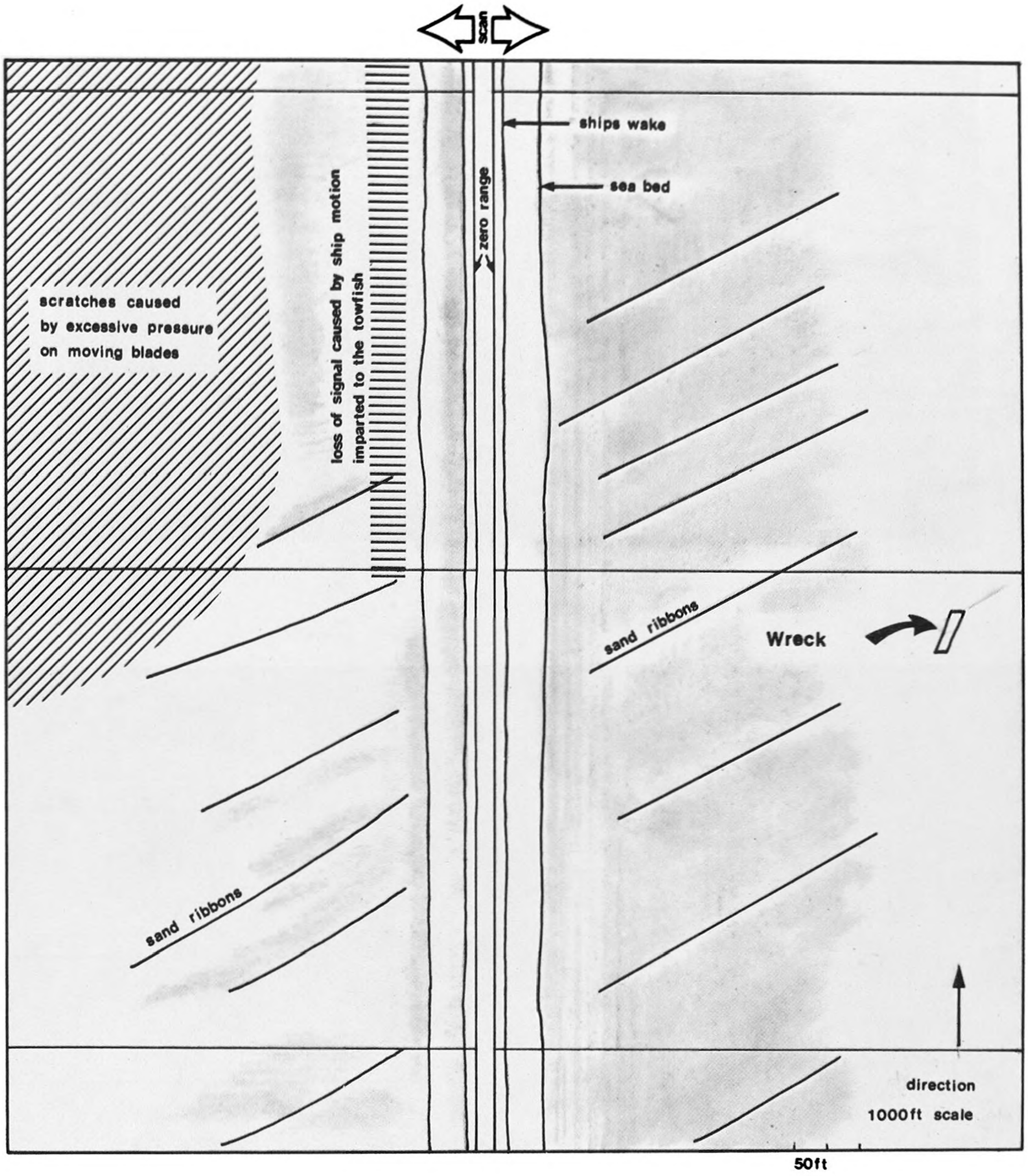
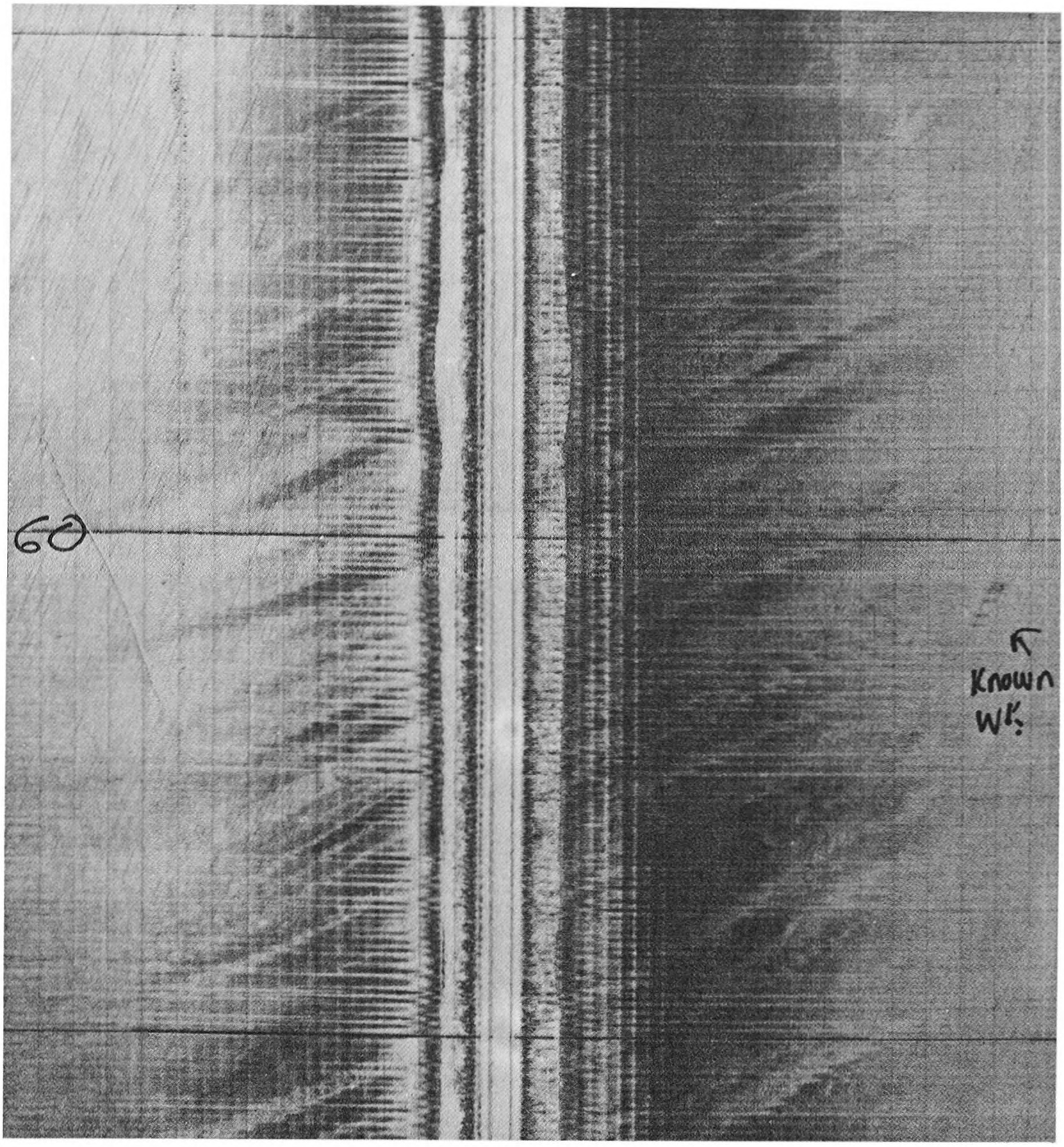


Fig. 34. — An unknown wreck of height approximately 4 m. Speed made good was probably about 6 knots. The towfish was streamed from a bowsprit in an Inshore Survey Craft and was running below the keel beneath the bridge. The near-range detection was jeopardized by the ship's motion in steep seas, but there was good, although faint, far-range detection.


60
Known
Wk.

"... the next and most necessary improvement of hydrographic charts will, in great part, depend on improvements in the application of *submarine phonotelemetry*. Too many dangers and aids far from the coast and which are of great importance to navigation, are in positions which are at present badly determined or determined by methods of insufficient accuracy. The result is the great number of doubtful positions (P.D.) which still exist and which constitute a veritable task for hydrography. The present and the near future of Hydrography are allied in great part to acoustic methods, *i.e*, to acoustic sounding and to phonotelemetry. Acoustic sounding, which represents a real revolution in hydrographic methods, and which constitutes the greatest and most valuable conquest of Hydrography, is already in daily use. It is through it that the true knowledge of the real form of the suboceanic terrestrial relief, so little known at the present day (although this seems paradoxical in this century of progress) will be gained. We are confident that a like brilliant future awaits phonotelemetry".

Captain L. TONTA, Director of the I.H.B., in the *Hydrographic Review*, V (1), May 1928, p. 124.