ACOUSTIC SURVEYS OF THE SEA FLOOR NEAR HONG KONG

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ABSTRACT

An asdic survey system has been developed for mapping the pattern of sediments of the waters of the Continental Shelf near Hong Kong. A fish-like body, towed from a ship, houses a magnetostriction transmitter sending pulsed ultrasonic sound at a frequency of 48 kc/s obliquely towards the sea bed. The resulting reverberation signals from the sea bed are received by the system and presented on a chart in a map-like form as the ship traverses parallel courses over the sea bed. The fan-shaped beam faces at right angles to the ship's course and illuminates a path 800 yards wide.

The nature of the surface of the sea floor is clearly delineated, and the position of rock outcrops can be identified. " Lloyd mirror " interference patterns are used to determine quantitatively the slope structures in certain areas, under calm water conditions.

This paper covers work carried out during 1964 by the Department of Physics at the University of Hong Kong.

1. — INTRODUCTION

Acoustic maps can now be obtained of the sediment patterns in the waters of the continental shelf, in water depths up to 100 fathoms. " Asdic " or " Sonar " transmitter/receiver systems are used in a fish-like towed body, which is suspended by a steel cable below the keel depth of the surveying ship, and the survey records are presented on a paper recorder on board the ship. It is the purpose of this paper to describe the experimental methods used, and to report typical results of surveys in waters of the

Continental Shelf of the South China Sea. These maps give the sediment patterns of these sea floor areas.

South of Hong Kong, the continental shelf extends outwards for about 100 miles, and the 100 fathom line runs roughly parallel to the coast. At the eastern end is the Pescadores Channel off Taiwan, and at the western end the southern tip of Hainan Island, Kwantung, China. From the 100 mile point to 250 mile from Hong Kong in a south-easterly direction, the sea floor drops steeply from 100 to 2 000 fathoms, at a gradient of approximately 1/34. Thereafter the deep water continues to the Philippines.

The sedimentary structure of the inshore area of the continental shelf of the South China Sea has received practically no study, although the Fisheries Research Laboratory at Hong Kong has made explorations with their research vessel *Cape St. Mary,* not however using asdic systems to help with these studies. Spot sampling of sediments with dredges or cores is naturally restrictive in scope, and is not necessarily statistically significant. It was therefore decided by the present authors to examine at first the inshore regions near Hong Kong and later to proceed to the deeper waters of the shelf.

2. — HISTORICAL DEVELOPMENT

The use of these acoustic aids to sea floor survey was first reported in 1958 by CHESTERMAN, CLYNICK, and STRIDE [1]. In the subsequent period from 1958 to 1965 there have been a number of interesting developments and refinements of the techniques, and various different experimental methods of housing the transmitting transducer. The recent developments described in this paper have been due to collaborative efforts between the original workers, and scientists at the National Institute of Oceanography, the firm of Smith & Sons (England) Ltd., Kelvin Hughes Division, and geophysicists from the British Petroleum Company.

In the earlier work of CHESTERMAN, CLYNICK and STRIDE [1] the transducer was mounted near the ship's keel in a roll-stabilized mounting, and the acoustic maps were presented with a curved range scale for distances up to 250 yards. (Typical pictures of small sand waves were given in, for example, figure 6 of the above reference). The next stage of the work was carried out on the research vessel *Discovery II* by TUCKER and STUBBS [2]. The equipment was much refined, the range increased to 800 yards, and again a hull-mounted and roll-stabilized transducer was used. TUCKER was interested in problems both in the field of marine geology and in fishery detection, and he used a frequency of 36 kc/s for his system, rather than the earlier value used by CHESTERMAN of 50 kc/s.

There are however certain disadvantages in hull-mounted sonar systems for this work, because of the difficulties of repairing faults in the transducer units and in transferring the equipment from ship to ship. For many reasons a towed-body system is much to be preferred, and it was partly because of this need for experimental convenience that SWALLOW and LAUGHTON [3] began to use towed bodies to house deep water echo sounders. Their objective was also to place the transmitter below the absorbing layer of air bubbles which are formed near a ship's hull in rough weather conditions. TUCKER and LAUGHTON used a body essentially the shape of an existing fish-like towed body (of length about 5 ft) to house a vertical echo sounder for their work, and this equipment did much valuable work at sea, and gave useful experience in handling these devices under a range of sea conditions.

In the next stage, these towed bodies were used to house asdic survey systems, in which the beam was directed at right angles to the long axis of the ship, so that a sea bed path 800 yards wide was illuminated parallel to the ship's course. STRIDE [4] discussed the problem of geological interpretation of the resulting records, and was able with his mapped data to consider questions of sediment transport for the sea floors around the southern area of Britain [5]. An important and extensive investigation of the sea floor south of Dorset together with a geological interpretation was made by DONOVAN and STRIDE [6] in 1961. Meanwhile STUBBS and LAWRIE [7] were examining sea bed ecological aspects of fish spawning grounds in work on the Ballantrae bank in the Firth of Clyde, Scotland.

STUBBS [8] has given a useful review on non-geological data presented on the recorders.

These researches led directly to the work discussed in the present paper. An oblique, sideways looking sonar in a towed body gave the same desirable flexibility for a survey asdic, as in the deep echo sounder system. TUCKER (National Institute of Oceanography) and HASLETT (Kelvin Hughes) engineered the first system in a commercial unit made for British Petroleum Company Limited. This first towed survey asdic unit was most successful, and was used for identifying oil pipe-line positions in the Persian Gulf. WHITTARD [9], in his studies of the geology of the Western Approaches of the English Channel, has carried out related investigations although as yet asdic data on the surface structure of the sediments has not been related to the underlying rock structures. The second towed survey asdic unit was made for CHESTERMAN, at the University of Hong Kong, for studies on the continental shelf of the South China Sea. Initial proving trials took place in Weymouth Bay in the autumn of 1963, and work commenced at sea in Hong Kong in early 1964. The present investigations are part of the research programme of the Department of Physics, University of Hong Kong, and this paper deals with results obtained during 1964 during the first four major sea trials.

3. — THE EXPERIMENTAL METHOD

3.1. The towed body

The acoustic transducer in the present system acts as both a transmitter and receiver. A magnetostriction resonator operates at a frequency of 48

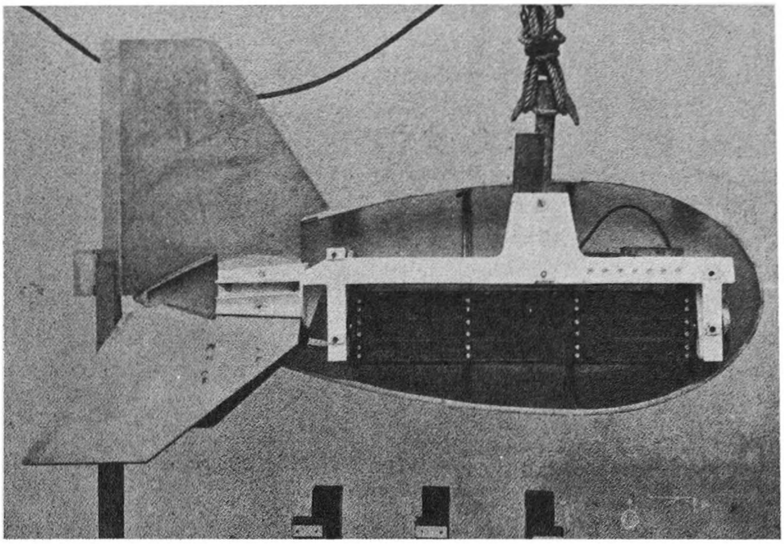


Fig. 1. — Transducer inside towed body

kc/s and uses a signal pulse length of 1 millisecond for the transmitter. The transducer is housed in a fish-like body shown in figure 1. The transducer can be rotated about a horizontal axis so that the axis of the acoustic beam can be directed from a horizontal position ($\alpha = 0°$) to a vertical position ($\alpha = 90°$). Normally the beam axis is depressed slightly from the surface, according to the water depth, and is arranged so that the axial ray strikes the sea bed at the maximum range chosen for study, usually 800 yards. The beam width to the first minimum is about 20° in elevation and about 2° in azimuth, and the wave-length of the acoustic radiation is approximately 3 cm. When prepared for towing at sea the towed body has an acoustically transparent window over the lower half of the " fish " and has fixed stabilising fins in position. Securely attached to the towing arm is a steel cable, up the centre of which pass the electrical conductors for transmission and reception of signals.

3.2. Ship-board Procedures

Ship-board procedures vary slightly from ship to ship. For safety reasons hoisting overboard from the stowage cradle on deck is normally carried out with a separate steel cable from an auxiliary winch. Just before streaming the body the weight is transferred to the steel towing cable which is " faired " with a rubber attachment to reduce hydrodynamic drag (figure 2). The ideal arrangement is for the fish to be well clear of the ship's side, so that ship's motion on launching and recovery does not cause impact damage. When the fish is carefully balanced and hydrodynamically stable, a straight and smooth tow is achieved; and because of the low drag of the system, the cable remains approximately vertical at towing speeds up to about 6 knots, and the fish is at a depth of 10 yards or so. It is best to choose a point of tow amidships so that pitching motion of the ship does not lead to undue instability in the motion of the body through the water. The flexibility of the cable ensures that the angular rolling motion of the ship is not significantly transferred to the body.

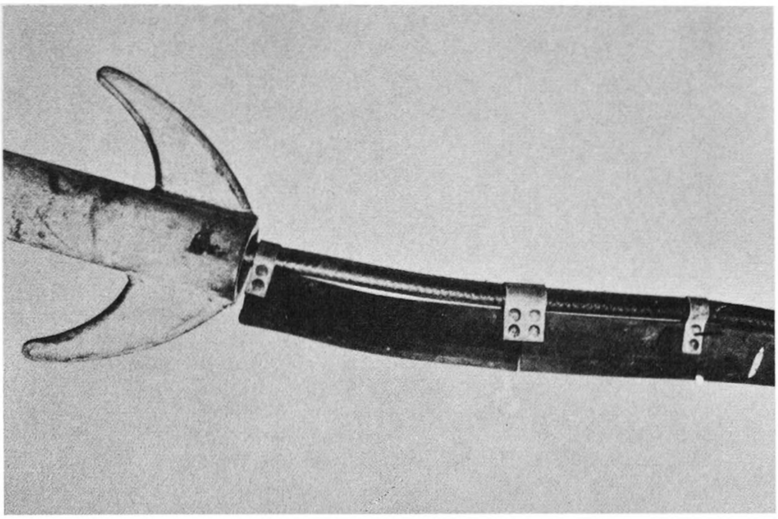


FIG. 2. — Rubber "fairing" on tow cable

One great advantage of a towed body rather than a keel-mounted set is that the direction of the travel of the body will be determined by the water-flow past the body. Thus the " crabbing " motion of a ship under wind forces will in general not be transferred to the body.

3.3. Navigational Procedures at sea

Accurate navigation at sea is of course crucial to the whole experimental procedure. Traverses across the chosen area of seabed should ideally be on parallel courses spaced at a distance apart to give a small overlap on each particular traverse. In inshore waters, at 800 yards on the range scale of the mapping recorder, and 600 yards between traverses, navigational errors will then be within the overlap limits. Where specialised navigational aids do not exist, then simultaneous sextant angles are taken on accurately known shore fixes. Where no shore points are visible, then radar fixes must be used, although this in general is at the cost of accuracy. Out of sight of land a radar buoy system must be laid.

3.4. Electronic system and mapping recorder

The function of the electronic system is to transmit a short pulse of acoustic energy towards the sea bed and receive the reverberation signals returning from the sediments, and present these signals on a paper record. Distance along the ship's track is represented by the linear movement of the recorder paper, and in the axis at right angles the reverberation signal

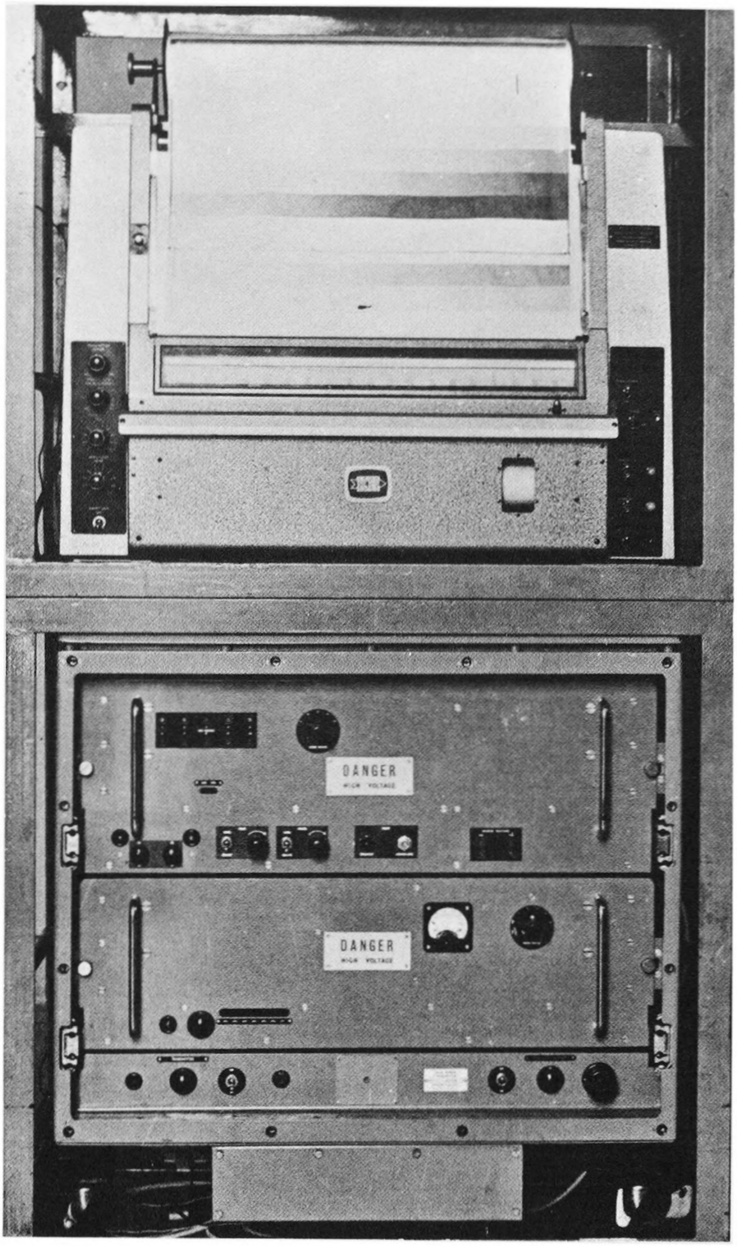


Fig. 3. — Mapping recorder and electronic system as fitted on board ship

is presented from a range zero to 800 yards. At this range the pulse repetition rate is one per second, and the pulse length 1 millisecond.

The electronic systems in this equipment are essentially as devised and reported by Tucker [2], the engineering was carried out by Haslett, and the equipment made in a tropicalized form for use in Hong Kong. The block diagram in figure 4 illustrates the principle of the system, and figure 3 illustrates the apparatus as fitted on board the ship. The upper unit is the mapping recorder (a modification of the Muirhead facsimile

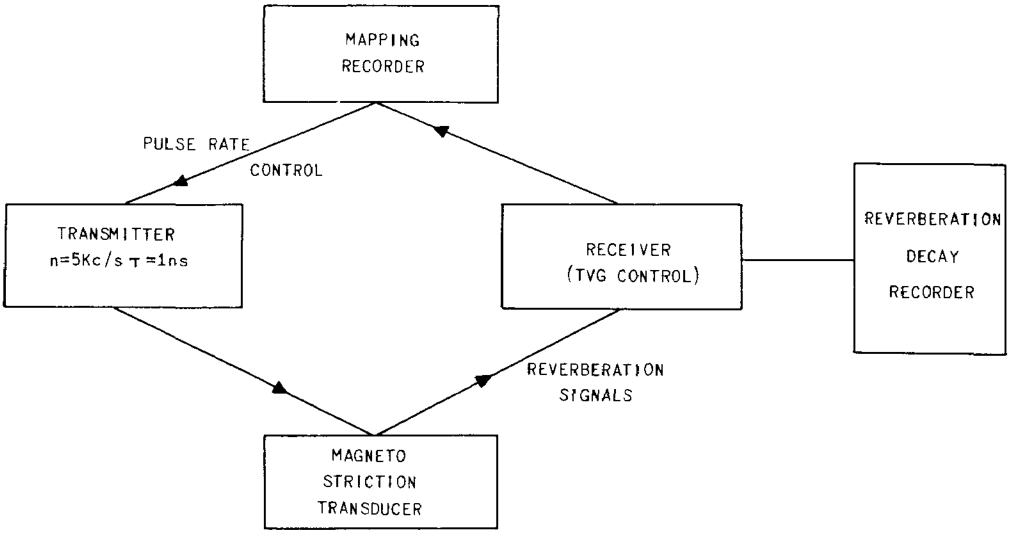


Fig. 4. — Block diagram for system

recorder) and the lower unit contains the transmitter unit and control systems.

The density of the marking on the paper recorder depends on the strength of the signal received from the seabed reverberation. The reverberation signal is processed by the electronic system via a time-varied-gain (TVG) amplifier so that the signal strength at the output stage is roughly independent of range. Thus a uniform signal is presented on the paper recorder if the seabed itself is uniform in character.

3.6. Acoustic Beam Characteristics

The transducer size in the towed body (figure 1) is 16 cm × 85 cm, corresponding, at 48 kc/s and a wave-length $\lambda = 3$ cm, to a size $5\,\lambda \times 27\,\lambda$. The beam width in the vertical plane is 9.35° to the first minimum and in the horizontal plane is 2.10° to the first minimum. Figure 5 illustrates the beam pattern in the vertical plane. When running at sea, the central axis of the beam is normally arranged to strike the sea bed at maximum range, whether chosen at 400, 800, or 1 600 yards. The setting of this angle of depression of the beam (α) is determined by the water depth.

It would be a great convenience to be able to change α without having to recover the " fish " on to the deck, but with the present model this cannot be done. Remote control of tilt angle α is an essential next step.

3.7. Paper scale effects

The width of the recorder paper, seen in the upper part of figure 3, is 48 cm and when this represents 800 yards the range scale is thus such

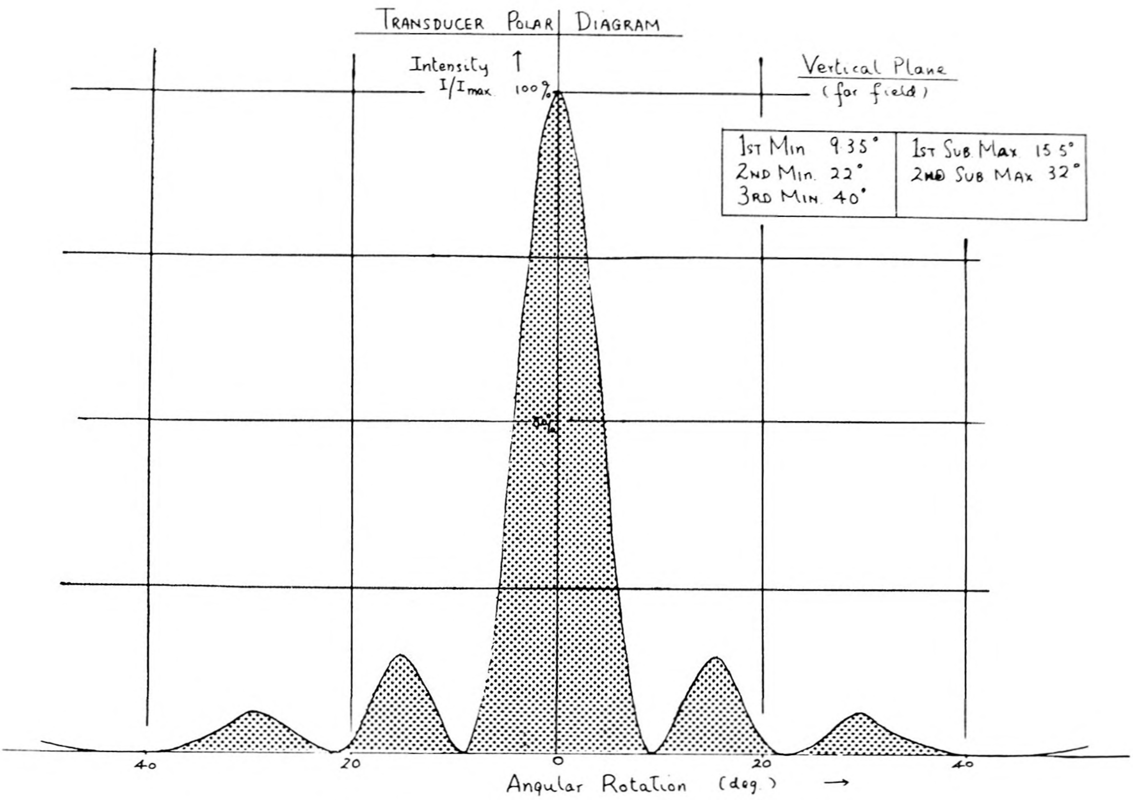


FIG. 5. — Transducer beam pattern in vertical plane

that 6 cm = 100 yards. A " true to scale " picture could only be achieved at a high speed of paper drive. The paper drive speed is such that the " scale distortion " S in the direction at right angles is given by

$$S = 1.25\ V$$

where V is the speed of the ship in knots. Thus only at a speed of 0.8 knot would the record be true to scale. Unfortunately course control is impossible at this speed so that surveying is normally carried out at about 6 knots, giving a scale distortion of 7.5/1. Thus, whilst a distance of 100 yards is then represented by 6 cm on the 800 yards range scale, on the vertical scale (direction of ship's course) 100 yards is represented by 0.8 cm.

4. — NATURE OF THE SEA FLOOR

4.1. Areas studied near Hong Kong

In the first four sea trials the areas studied were in the inshore waters near Hong Kong Island and in the sea inlets on the eastern coast of the New Territories.

Details of the cruises are as follows :

Dates 1964	Ship	General Area
16-28 January	*Cape St. Mary*	Lamma Channel Ma Wan Island
17-26 March	H.M.S. *Lanton*	Tolo Harbour Plover Cove Mirs Bay
11-15 May	H.M.S. *Dampier*	Lamma Channel Ma Wan Island
27 July - 7 Aug.	H.M.S. *Lanton*	Port Shelter Rocky Harbour

In these initial cruises the areas studied are shown in figures 6-10. Figure 6 shows the Lamma Channel region and other areas near Hong Kong Island. Figure 7 is an area heavily scoured with strong tides, in which the rock is often exposed. Figure 8 shows the Mirs Bay and Tolo Channel areas, a few miles south of the Chinese Mainland coast, and figure 9 the Plover Cove region, the site of the new large reservoir scheme, where the whole of Plover Cove will become a freshwater lake in the next few years. On a later sea trial the deeply indented region near Port Shelter shown in figure 10 was examined, since this is a region of considerable geological interest. In this paper features of interest in all these areas will be discussed. Figure 11 illustrates the position of the continental shelf area south of Hong Kong. Normally, reconnaissance runs are made over a large area first, and detailed studies are then made of interesting areas.

For detailed mapping purposes at sea, a survey is carried out by running a series of parallel traverses over the sea bed under study. The distance spacing of these traverses is generally at about 75 per cent of the chosen range scale on the paper, so that there is adequate overlap to deal with inevitable navigation errors. The maximum range of this equipment is normally about 1 200 yards, and beyond this the record tends to be noise-limited.

4.2.1. *Flat, uniform sediments*

In figure 12 the geometry of the system is shown. Here the ship is assumed to be steaming in a direction at right angles to the plane of the paper. The main beam illuminates the majority of the range scale and the secondary maxima and minima will appear on the record as dark and light patches. In this particular survey record the beam depression angle α was 4° for a water depth of 27 yards, so that the beam axis met the sea bed slightly inside the maximum of the range scale. Records like figure 4 are examples of the rather uniform density map which is obtained for a sea bed of this type.

4.2.2. *Effect of slope*

If the ship is sailing roughly above a given contour line of an undersea " hill " and the beam is looking either up or down the slope of the hill, then the density of the record will illustrate this. For instance figure 13 shows the density on the record shown when looking up a slope of 5° (figure 13b), compared with looking down the same slope of 5° (figure 13a). The areas formerly dark are now light.

4.2.3. *Rock outcrops and shoal areas*

Mapping of the extent of rock structures near reefs and the mapping of shoal areas can be carried out very effectively with this equipment. Rock structures of the type shown in figure 14 give strong " shadows " which are white on the records, since there is no reverberation signal from the area behind the rocks. Where the rock structures are extensive, their pattern can be seen by a mosaic of adjacent traces (figure 15). Outcrop of rock often occurs well outside the reef observed at the sea surface. Figure 16 shows a case in which rock structures extend 1 000 yards beyond the observed surface width of the reef of about 200 yards. Notice the indication by the secondary beams that the ship has passed very near to the end of the reef at station 99 on the record.

During one of the early research trials in Hong Kong with this survey equipment, a new uncharted shoal area was discovered in a main shipping channel, the Lamma Channel. This was named after one of the authors, and is illustrated in figure 17. The full extent of the area was mapped by observing, as shown in figure 18, from four directions, approximately NE, SE, SW, and NW; and then correcting scale distortions to produce a true-to-scale plot of the shoal, which is given in figure 19(a). An echo sounding traverse (figure 19(b)) showed that the shoal reached to within 20 yards of the surface at the point measured. Such mapping recordings as this can be obtained with great ease and accuracy during the course of normal survey investigations. They are clearly of great value in hydrographic surveys. Oblique photography of a typical trace gives an idea of scale correction of distortion (figure 20). The reason for this distortion was discussed in section 3.7 above.

4.2.4. *Boulder-strewn ground*

Of particular interest are the acoustic maps shown in figures 21 and 22. These were obtained in the Port Shelter area (figure 10) which lies to the eastern side of the New Territories. The many small patches of high density marking on these maps, which gives them a speckled appearance, are due to strong echoes from objects typically of the order of 2 metres in linear dimensions. The high density of paper marking suggests that these objects are individual rocks, and it seems probable that this area of the sea bed is strewn with boulders. This viewpoint is strengthened by the fact that boulders of about the same dimensions can be observed near the water line around Shelter Island.

4.2.5. *Complex maps due to sediment and contour*

There is one exceptionally interesting inshore area where strong tidal streams have led to extensive rock scouring and the exposure of strata and pinnacles. Here one is dealing with interpretation of a survey in which the pattern is due to both contour and bottom structure. Figures 23(a) and 23(b) show a part of this area seen from two opposite directions 180° apart. By choosing the appropriate tidal conditions, a detailed survey was carried out of this region at a speed over ground of only 2.4 knots, so that the scale distortion on the record was 3/1 instead of the usual 7.5/1. A detailed map can then be produced showing strata structure lines roughly parallel to the ship's course (figure 24). A careful survey of this area in respect of both contour and sediment is now in progress, including the construction of large-scale contour models of the sea floor.

4.3. **Recognition of non-geological features**

The discrimination of small objects on the sea floor with this type of asdic system depends on a number of factors. The strength of the signal must be above the reverberation background, and the signal processing procedures before presentation on the sensitive paper surface modify the signal/noise ratio. With this equipment individual objects of about 1 metre in extent can be recorded and this limitation agrees with the normally accepted criterion imposed by the linear pulse length, since $C\tau/2$ here becomes 0.75 m.

4.3.1. *Pipe-lines*

A water pipe-line, of diameter 2 metres, runs under the sea from the island of Lantao to Hong Kong and crosses the West Lamma Channel. This was often recorded during the surveys, as exampled in figure 25 where the course of the ship is roughly at right angles to the pipe-line. If the ship steams approximately parallel to the pipe-line, as in figure 26, it will be seen that there are high sides to the trench in which the pipe lies, and that these lie some 50 yards apart. The apparent change of direction of the pipe is due to an alteration of ship's course at station 123, the apex of the pattern. By station 126, the course is restored to the original objective distance of 400 yards from the pipe.

4.3.2. *Wakes*

The strong reflections due to the wakes of ships can be a serious disturbance to surveys. Figure 27 is an extreme example of this problem.

4.3.3. *Temperature Gradients*

Figure 28 illustrates strong ray refraction effects due to temperature gradients. Severe range restriction and " focussing " results from this water effect in summer conditions.

4.3.4. *Other features of uncertain origin*

A number of highly localised features have been found which have not been explained. Figure 29 is an example. This dark uniform line leads to the tip of an island, and is thought by STUBBS to be a wake. There is some doubt about this explanation, although repeated surveys over the same ground on subsequent occasions did not obtain the same feature again, lending validity to his explanation. A similar example in another area is shown in figure 30 — this was again near a land mass. Certain rope-like patterns have been obtained, of the type shown in figure 31, which are also not explained.

Care must be taken not to use too high transmitted power for the 400 yards range scale, since an additional echo can be recorded at the subsequent rotation of the helix.

5. — RELIEF MEASUREMENTS BY LLOYD MIRROR INTERFERENCE PATTERNS

5.1. Formation of the interference fringes

A number of workers in undersea acoustics have noted that interference patterns can be obtained under calm sea conditions with these sonar systems. These patterns are due to phase interference between the direct path to the sea bed and the path due to direct reflection at the sea surface, and are generally known as Lloyd mirror effects, by analogy with the well-known optical effect. HASLETT and HAINES [10] noted this occurrence in a review article, and STUBBS [8] has also illustrated the effect. SANDERS and STEWART [11] discussed this case of interference in calm, nearly isothermal water. They studied these effects at the Pacific Naval Laboratory in Vancouver, Canada. In the present work, the authors examine the method in detail as a means of measuring small contour changes on the seabed at oblique range distances of up to 800 yards.

The fringe systems are produced by interference between the wave fronts of energy transmitted directly to a point on the sea bed and the wave front reaching the sea bed after one reflection at the sea surface : these two paths are also available for the energy returning to the transducer. Multiple reflections of the transmitted energy between the sea surface and sea bed are also possible but, so far, the present results show that interference effects involving a multiple-reflected beam seem to be absent, presumably because in these cases the intensity fluctuations on the acoustic record are too small to be observed.

The formation of the fringes will first be considered, and then a relationship between fringe spacing and sea floor slope established. This result will be used to analyse acoustic records containing interference fringes.

5.2. Qualitative effects of slope

For acoustic radiation of the wave length used (3 cm) the sea surface must be flat to perhaps $\pm 10\,\lambda$, or 30 cm. This represents some condition between an " oily calm " and Sea State 1. When steaming slowly into these sea conditions the record changes from the uniform appearance shown in the lower part of figure 32 to the fringe patterns shown in the upper portion where, by station 73, the fringe patterns are well established. Careful measurements of the fringe spacing distinguish a normal pattern for a flat sea bed and the much closer fringe spacing when there is an upward slope (figure 33). When there is a downward slope (figure 34) fringe spacing increases rapidly with range, and the angle of the slope can be calculated. Where highly complex patterns exist, detailed contour analysis can be made (figure 35). In certain conditions this Lloyd mirror interference analysis permits contour patterns to be studied in conjunction with reef structures (figure 36).

5.3. Quantitative determination of contour patterns

Quantitative analysis of contour patterns can be made by an analysis of these acoustic interferograms. Consider now the formation of these fringe patterns.

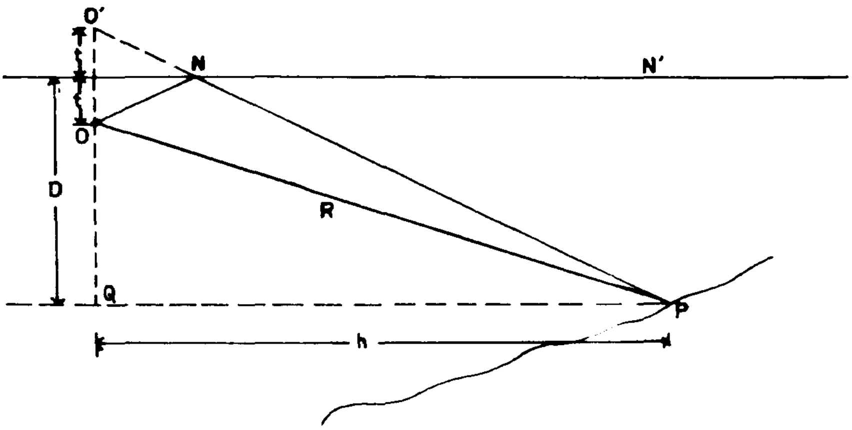


FIG. 37. — Geometry of Lloyd mirror system

The geometry of the situation is as shown in figure 37.

NN′	is sea surface
QP	is the sea bed
P	is a point on the sea bed, a distance R from the transducer O
O′	is the mirror image of O at the sea surface
R	is the range given on the acoustic record
h	the horizontal distance QP.

The transducer O is at a depth *t* below the surface.

The two paths between O and P are (OP) and (ON + NP). Since NO = NO′, the path difference is given by :

$$\Delta = \overline{O'P} - R$$

Now

$$\overline{O'P^2} = \overline{(D + t)^2} + R^2 - \overline{(D - t)^2}$$

$$\therefore \overline{O'P^2} = 4tD + R^2$$

Thus

$$\Delta = \frac{2tD}{R}$$

by expansion and ignoring terms higher than first degree in $\left(\frac{t}{R}\right)$

With no phase change at the surface reflection, the condition for an amplitude maximum is :

$$m\lambda = \frac{2tD}{R}$$

where

λ = wave length

and

m = integer giving the fringe order.

There are four possible paths for the energy to pass from O to P and return; i.e. OP — PO, OP — PNO, ONP — PO, and ONP — PNO.

Regardless of how the energy is shared by these four paths, the situation for phase re-inforcement, and hence maximum intensity on the acoustic record, is given by :

$$\Delta = m\lambda$$

For minimum intensity

$$\Delta = (2m + 1)\,\lambda/2$$

Thus the peak densities on the record will occur when

$$\frac{2tD}{R} = m\lambda \qquad (i)$$

Now the fringe spacings can be read directly from the acoustic records. With a flat sea bed, normal parallel plane Lloyd mirror interference occurs; with downward slopes the spacings will increase as range increases; and looking up a slope the fringe spacings will decrease. Quantitative information on the sea bed contour *at oblique distances up to 800 yards from the track of the ship* can therefore be obtained.

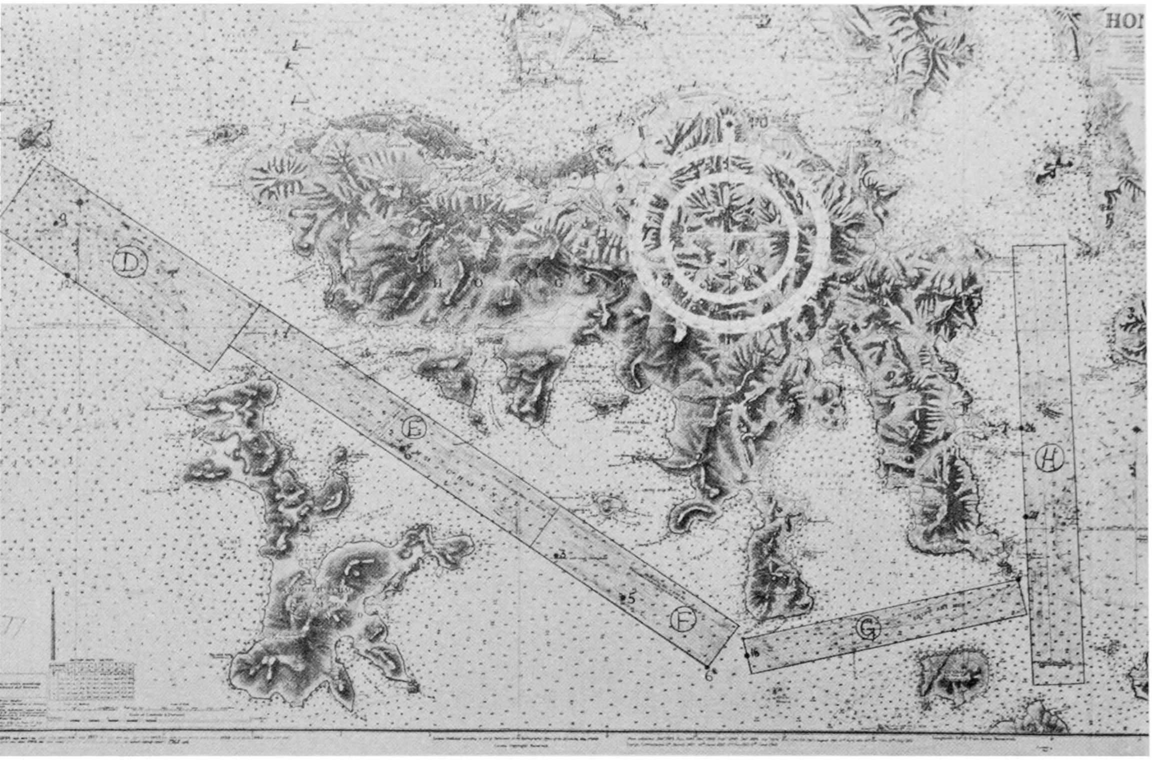


FIG. 6. — Lamma Channel

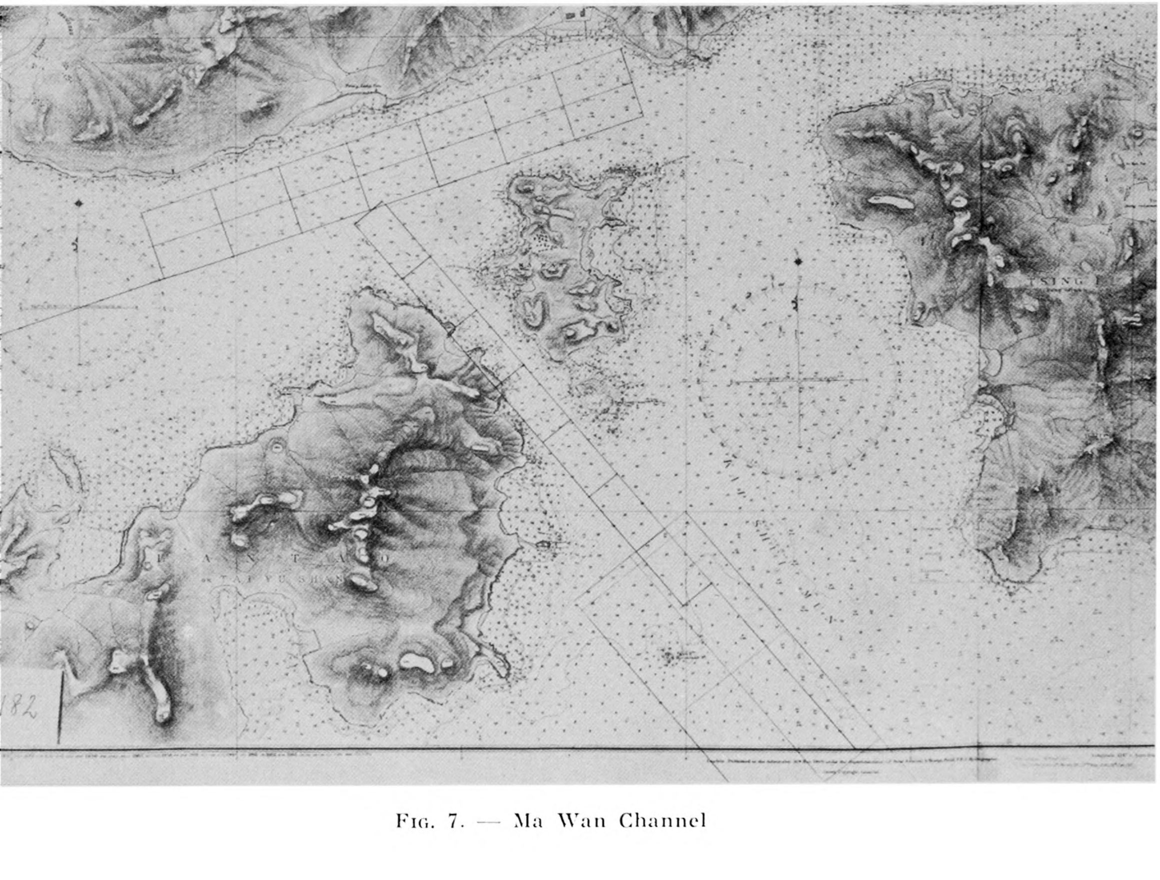


FIG. 7. — Ma Wan Channel

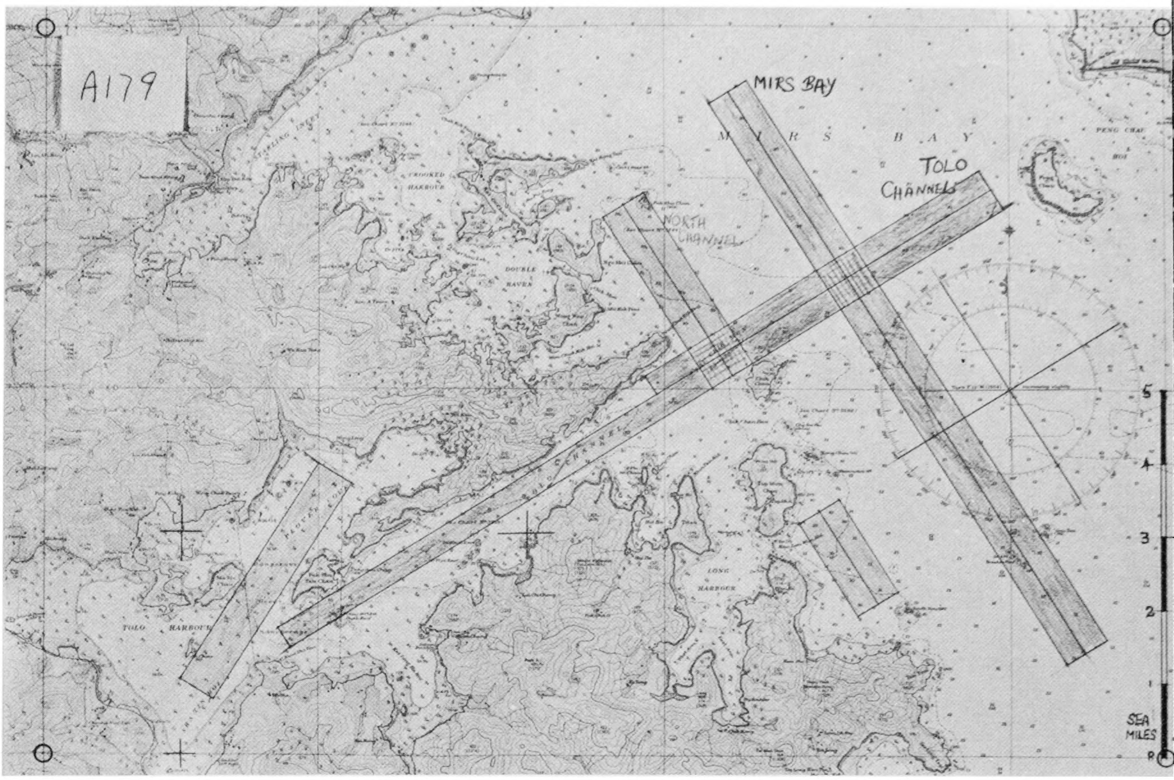


FIG. 8. — Mirs Bay and Tolo Channel

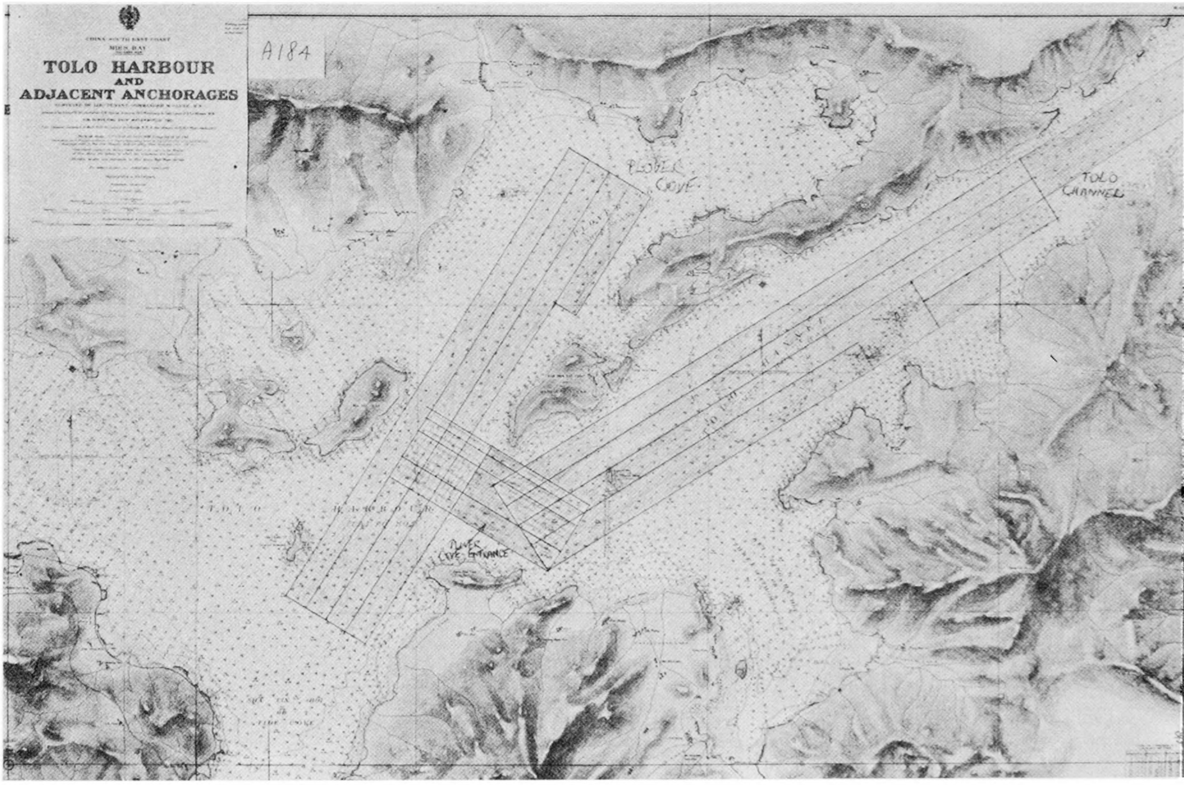


FIG. 9. — Plover Cove

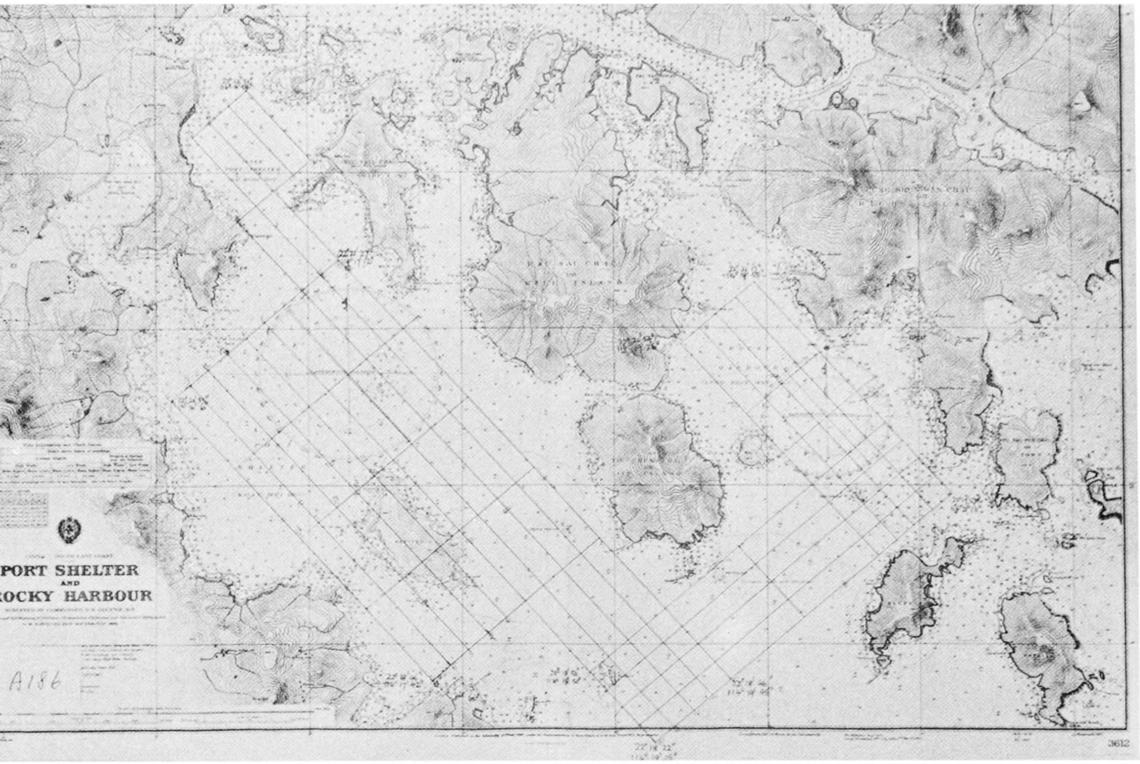


Fig. 10. — Port Shelter and Rocky Harbour

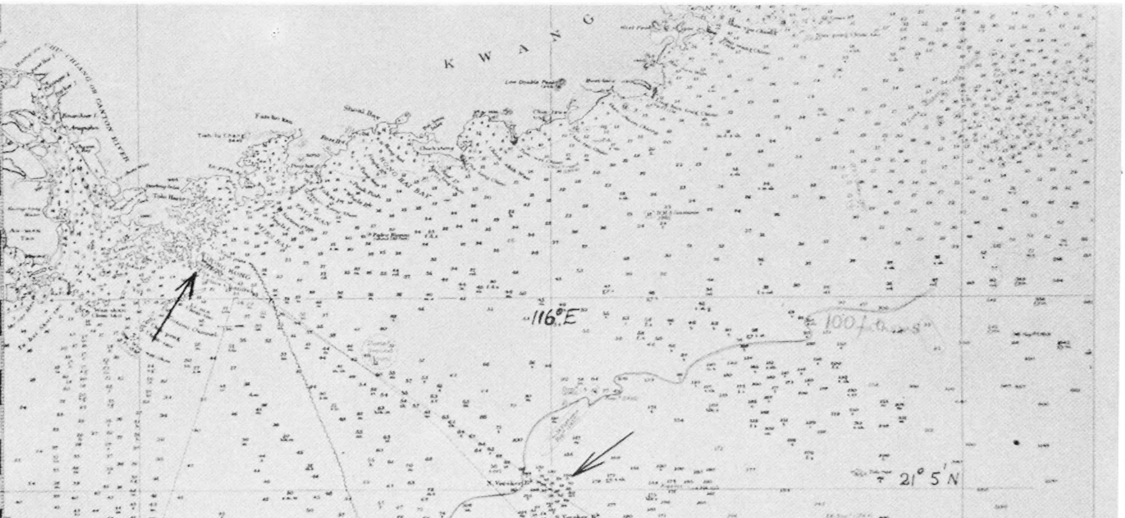


Fig. 11. — Continental shelf area south of Hong Kong

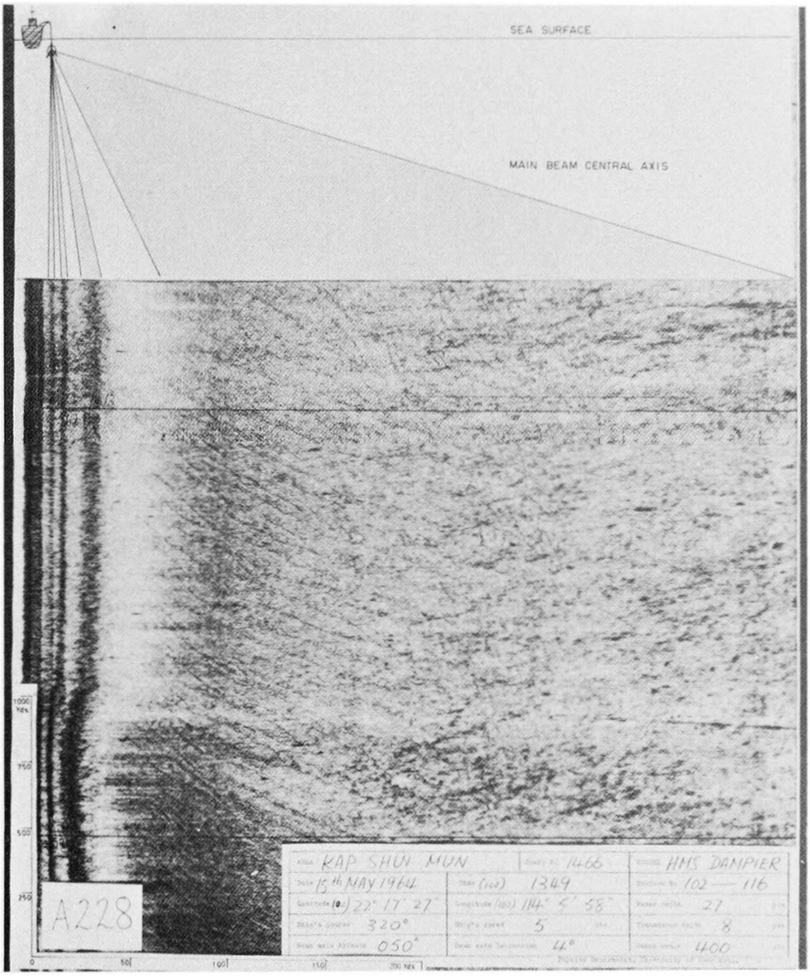


Fig. 12. — Asdic survey of a flat uniform sea bed

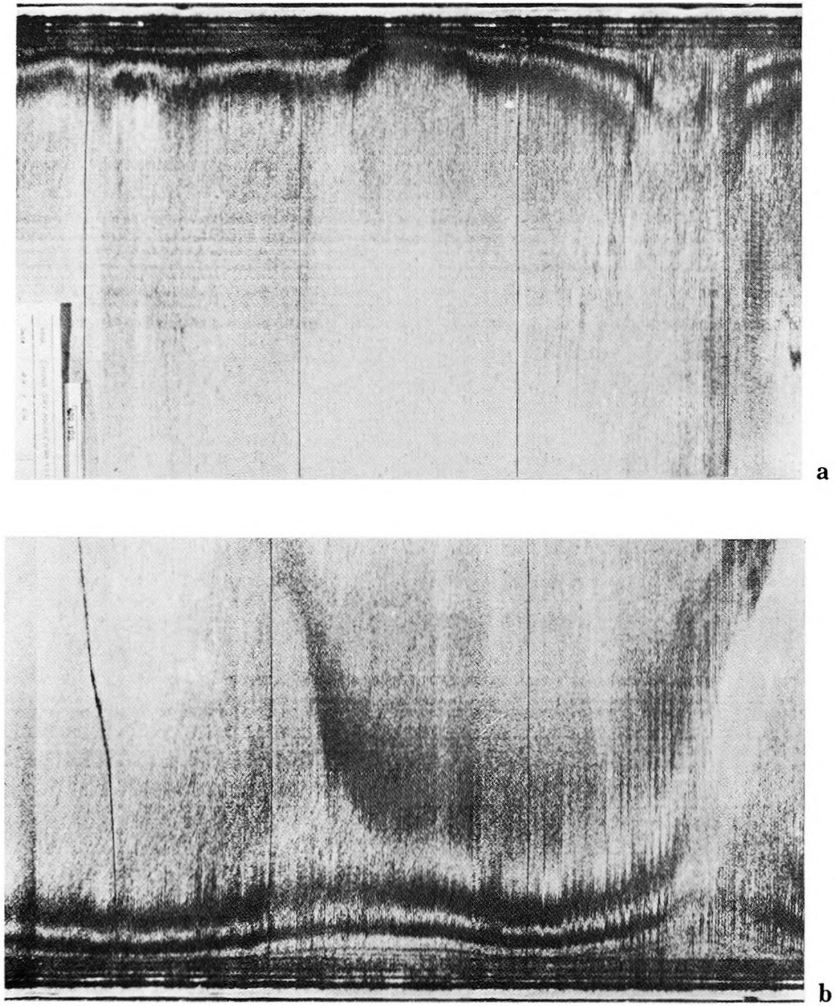


FIG. 13. — *a*) Beam looking down a slope of 5°;
b) Beam looking up a slope of 5°.

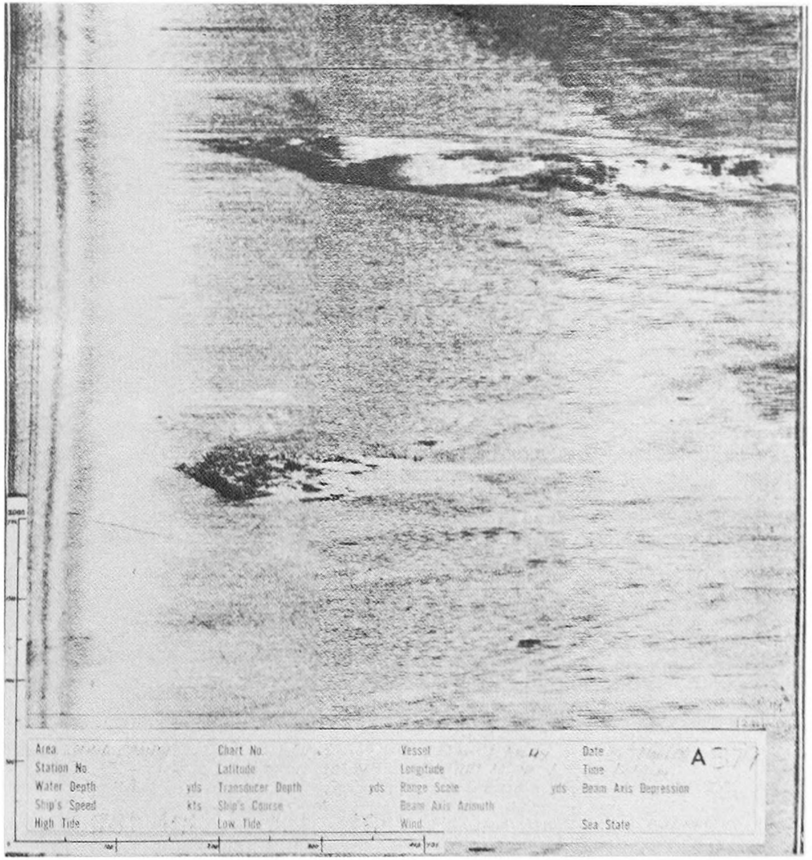


FIG. 14. — "Shadows" behind shoal area

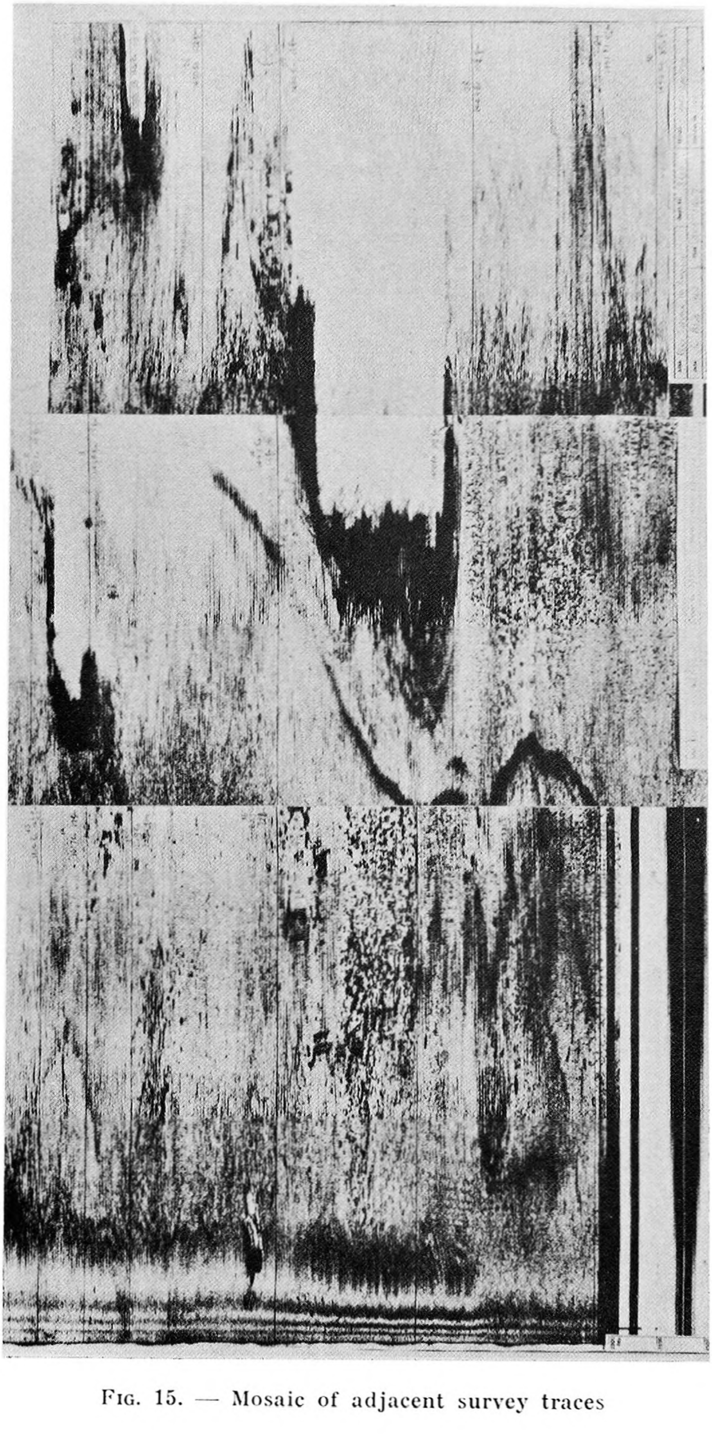


FIG. 15. — Mosaic of adjacent survey traces

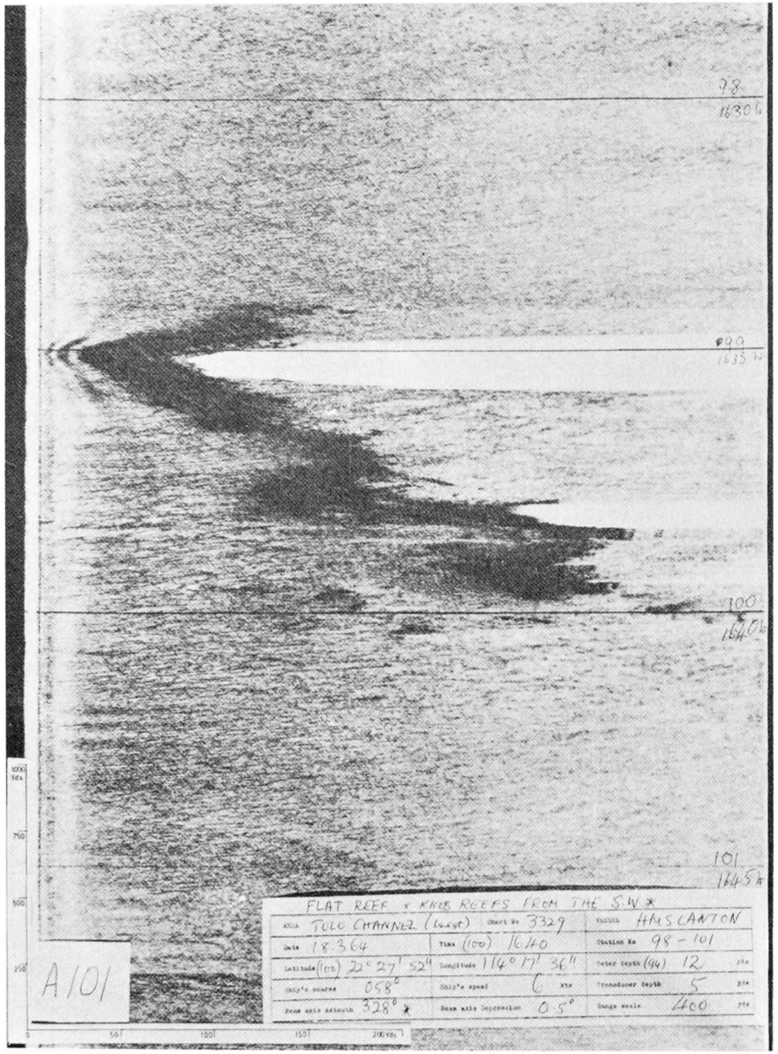


Fig. 16. — Flat & Knob reefs in Tolo Channel

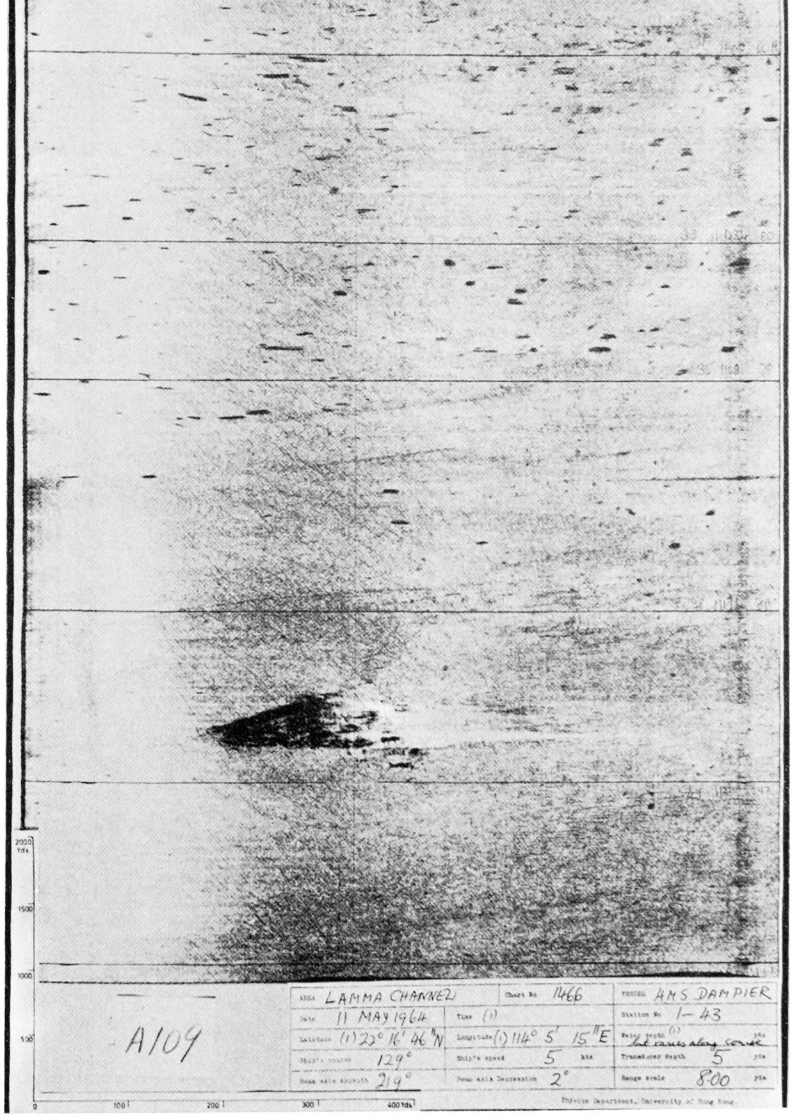
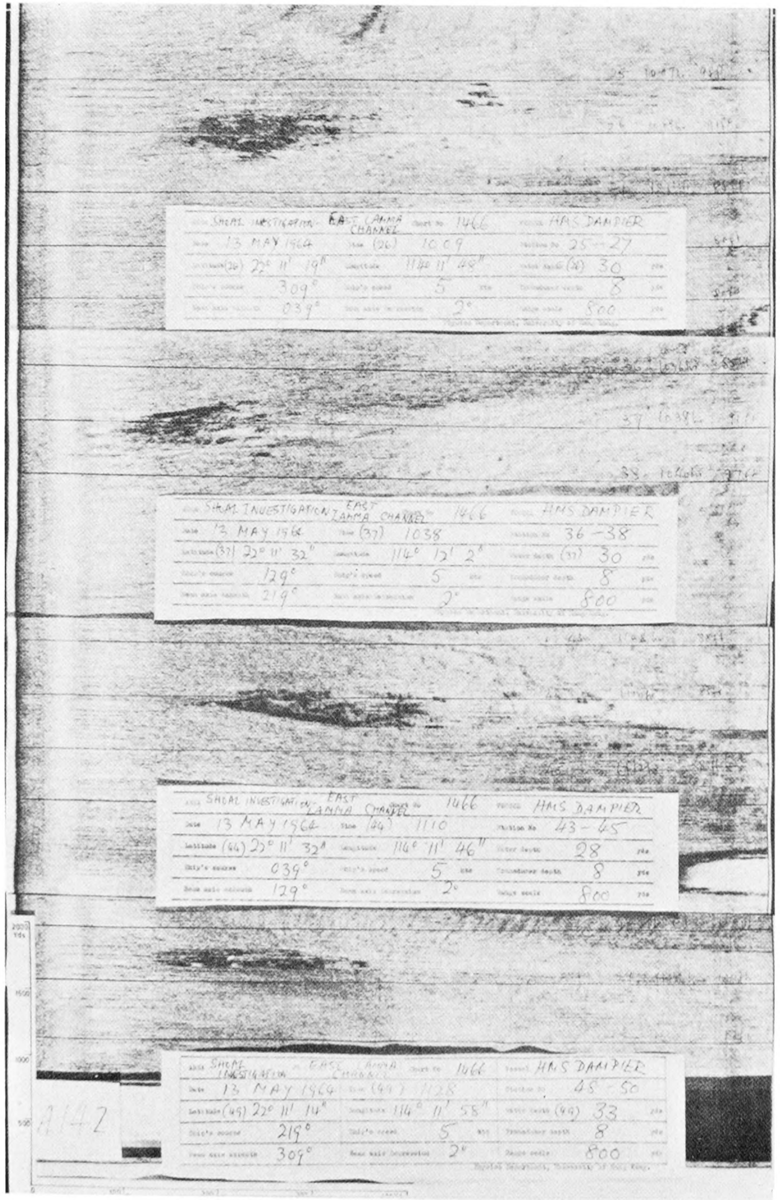


Fig. 17. — "Chesterman Shoal" in the Lamma Channel



Area	SHOAL INVESTIGATION EAST LAMMA CHANNEL	Chart No	1466	Vessel	HMS DAMPIER
Date	13 MAY 1964	Time	(26) 1009	Station No	25 – 27
Latitude	(26) 22° 11' 19"	Longitude	114° 11' 48"	Water depth	(26) 30 yds
Ship's course	309°	Ship's speed	5 kts	Transducer depth	8 yds
Beam axis azimuth	039°	Beam axis depression	2°	Range scale	800 yds

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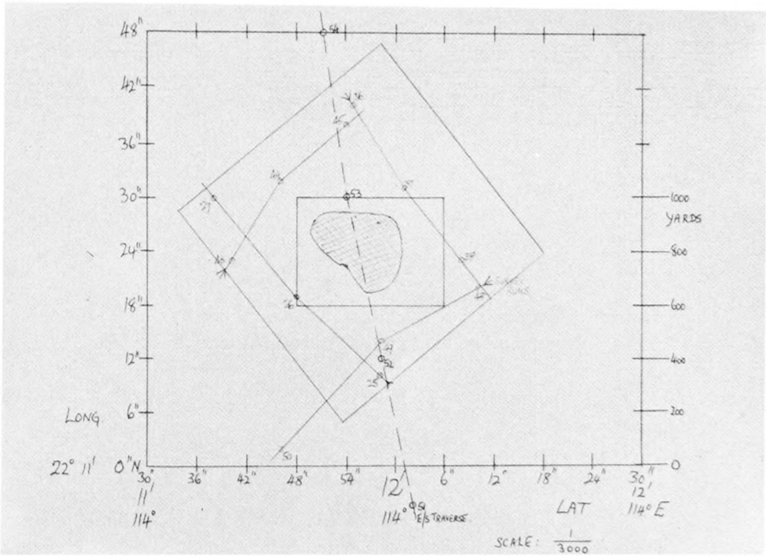
Area	SHOAL INVESTIGATION EAST LAMMA CHANNEL	Chart No	1466	Vessel	HMS DAMPIER
Date	13 MAY 1964	Time	(37) 1038	Station No	36 – 38
Latitude	(37) 22° 11' 32"	Longitude	114° 12' 2"	Water depth	(37) 30 yds
Ship's course	129°	Ship's speed	5 kts	Transducer depth	8 yds
Beam axis azimuth	219°	Beam axis depression	2°	Range scale	800 yds

Physics Department, University of Hong Kong.

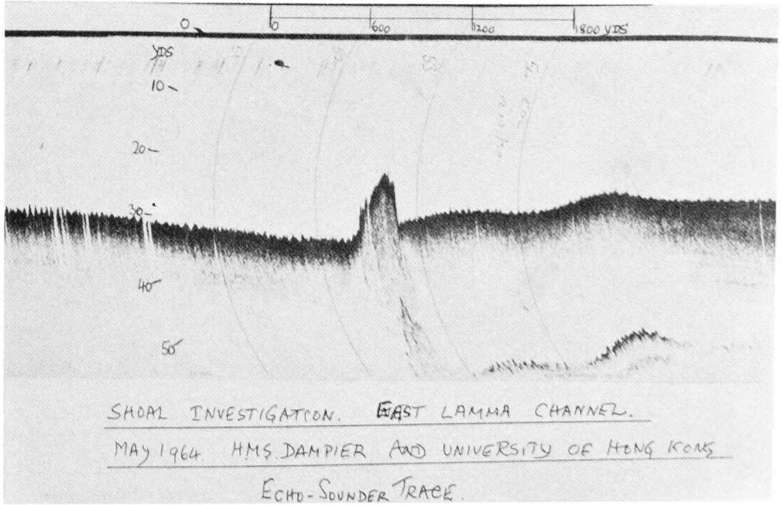
Area	SHOAL INVESTIGATION EAST LAMMA CHANNEL	Chart No	1466	Vessel	HMS DAMPIER
Date	13 MAY 1964	Time	(44) 1110	Station No	43 – 45
Latitude	(44) 22° 11' 32"	Longitude	114° 11' 46"	Water depth	28 yds
Ship's course	039°	Ship's speed	5 kts	Transducer depth	8 yds
Beam axis azimuth	129°	Beam axis depression	2°	Range scale	800 yds

Area	SHOAL INVESTIGATION EAST LAMMA CHANNEL	Chart No	1466	Vessel	HMS DAMPIER
Date	13 MAY 1964	Time	(49) 1128	Station No	45 – 50
Latitude	(49) 22° 11' 14"	Longitude	114° 11' 58"	Water depth	(49) 33 yds
Ship's course	219°	Ship's speed	5 kts	Transducer depth	8 yds
Beam axis azimuth	309°	Beam axis depression	2°	Range scale	800 yds

Physics Department, University of Hong Kong.



a) True-to-scale plot of shoal



b) Echo-sounder trace across shoal

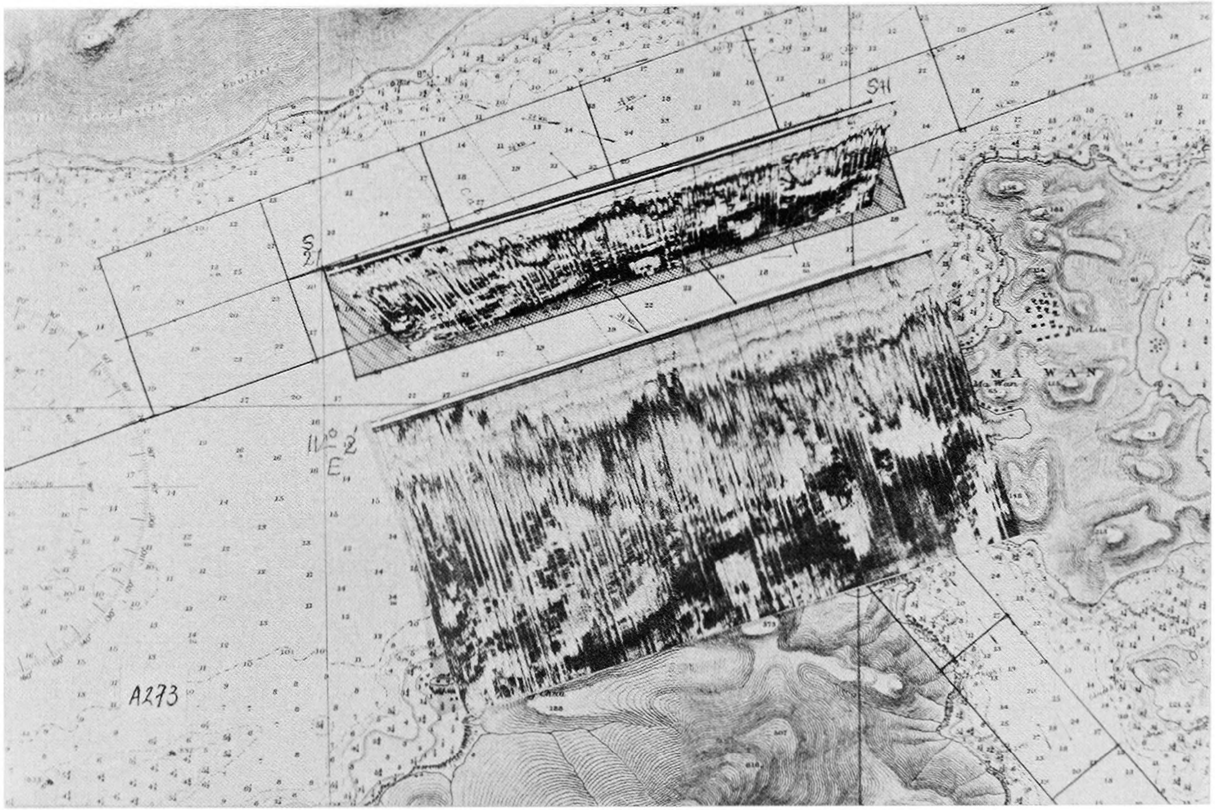


Fig. 20. — Oblique photography of survey record

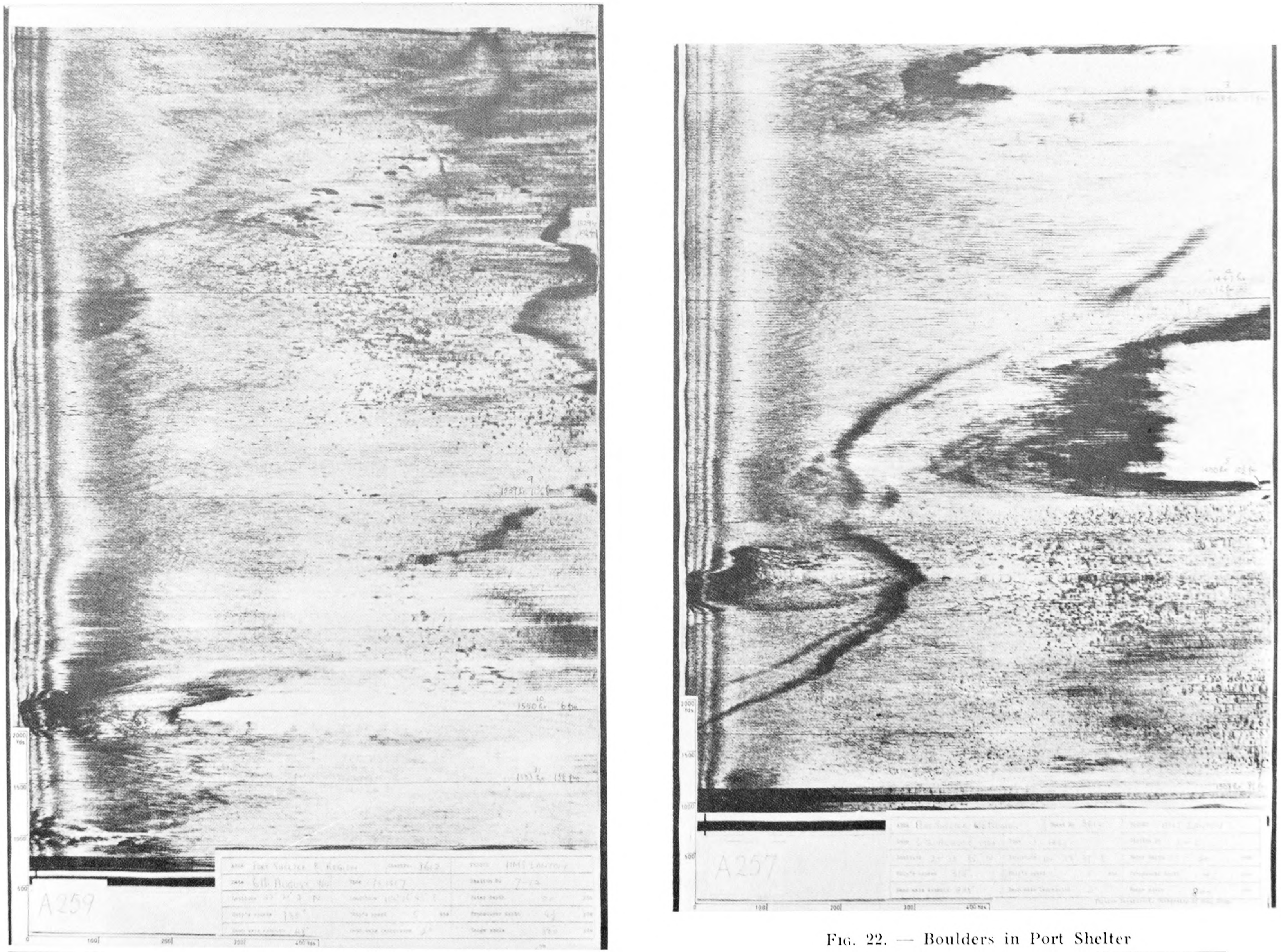
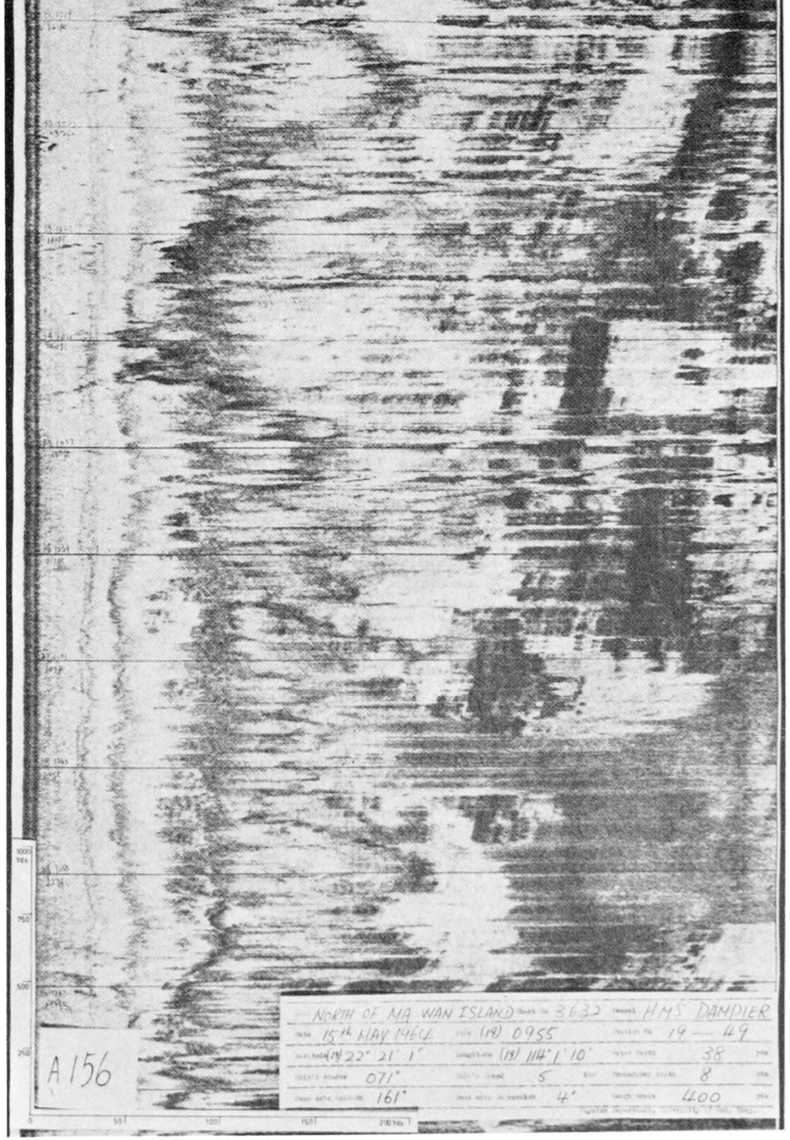


FIG. 22. — Boulders in Port Shelter

FIG. 23

a) Ma Wan rock structures, looking NNW
b) Ma Wan rock structures, looking SSE



A 156

NORTH OF MA WAN ISLAND 3632 HMS DAMPIER
15th MAY 1964 (19) 0955 19 — 49
(19) 22° 21' 1" (19) 114° 1' 10" 38
071° 5 8
161° 4° 400

FIG. 24. — Detailed survey at slow speed

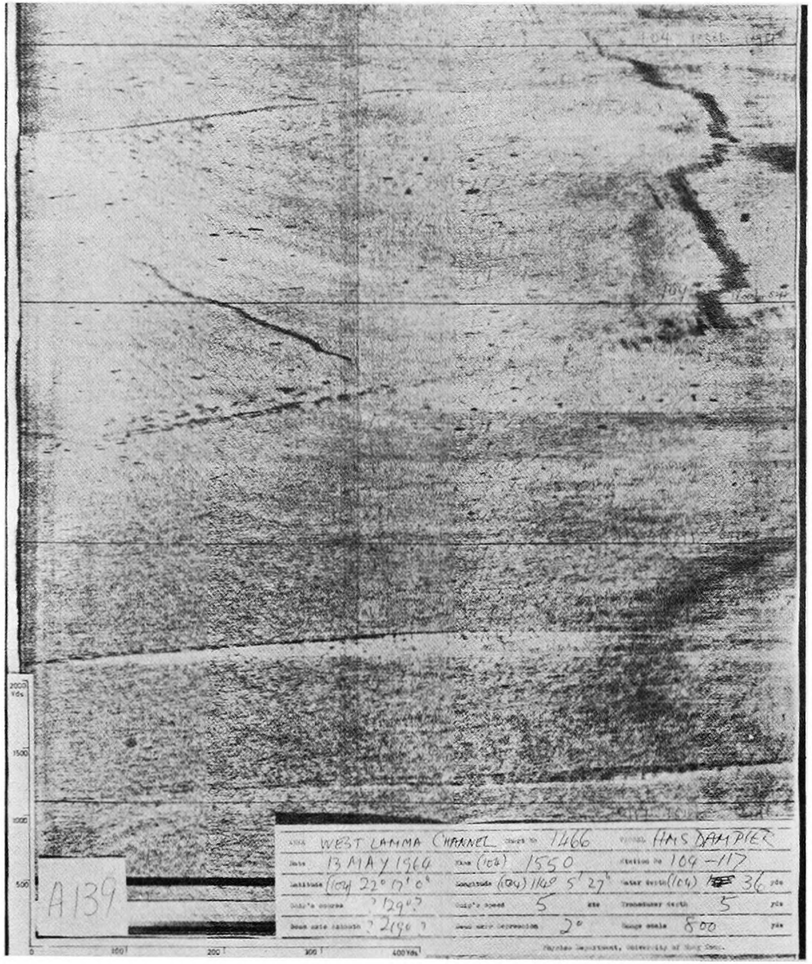


Fig. 25. — Pipe-line crossed by ship approximately at right angles

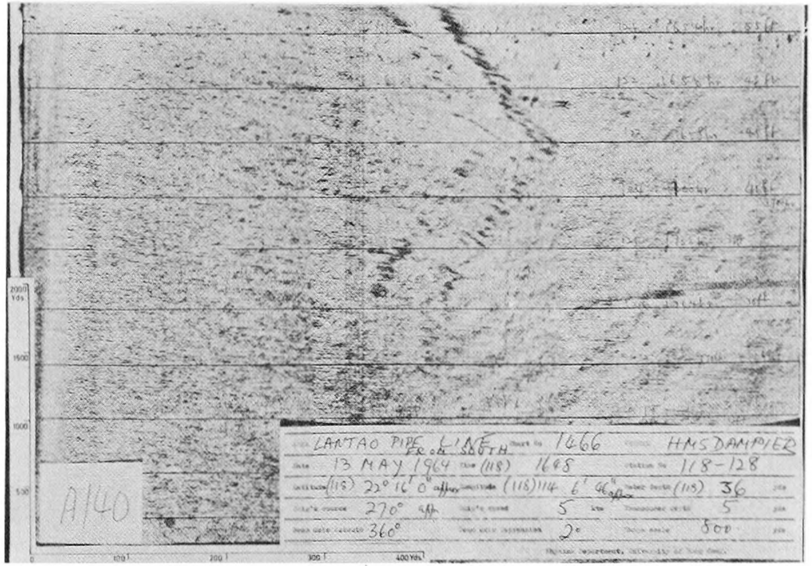
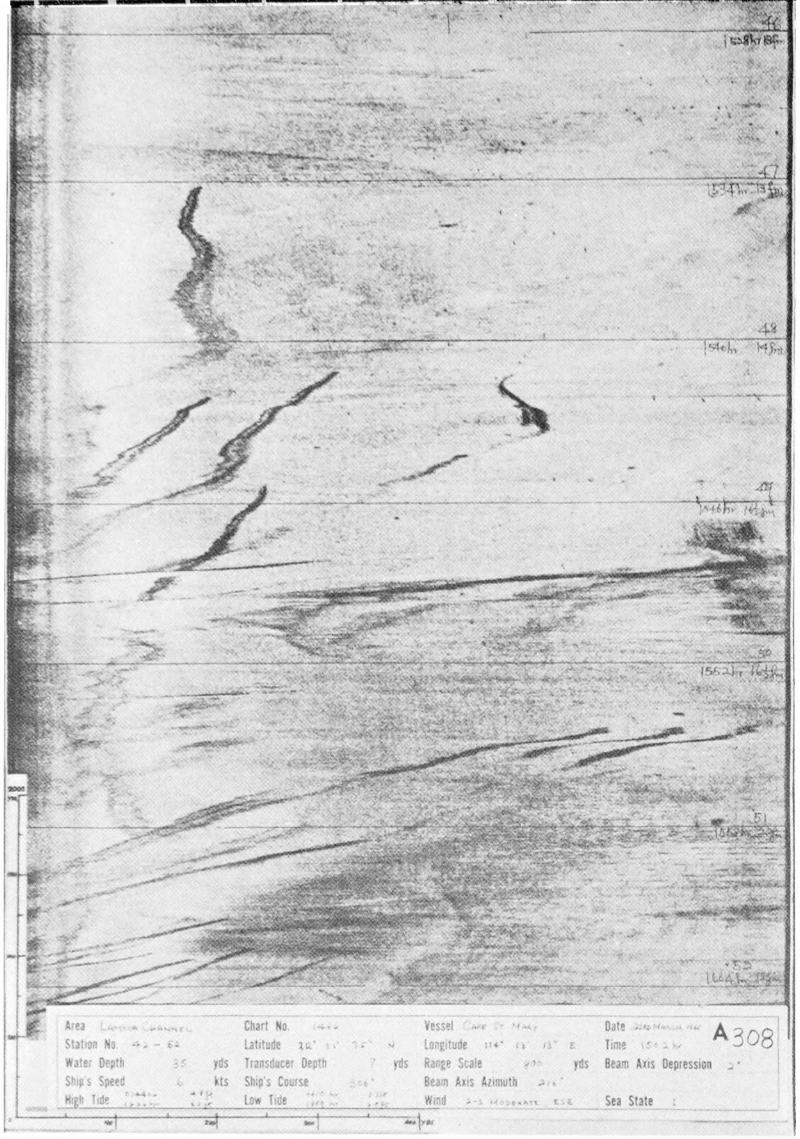


Fig. 26. — Pipe-line roughly parallel to ship's course



Area Lamma Channel
Chart No. 1466
Vessel Cape St Mary
Date 22nd March 196
Station No. 42 – 62
Latitude 22° 11' 15" N
Longitude 114° 13' 13" E
Time 1502 hr
Water Depth 35 yds
Transducer Depth 7 yds
Range Scale 800 yds
Beam Axis Depression 2°
Ship's Speed 6 kts
Ship's Course 306°
Beam Axis Azimuth 216°
High Tide
Low Tide
Wind 2-3 Moderate ESE
Sea State 1

Fig. 27. — Patterns due to wakes of ships

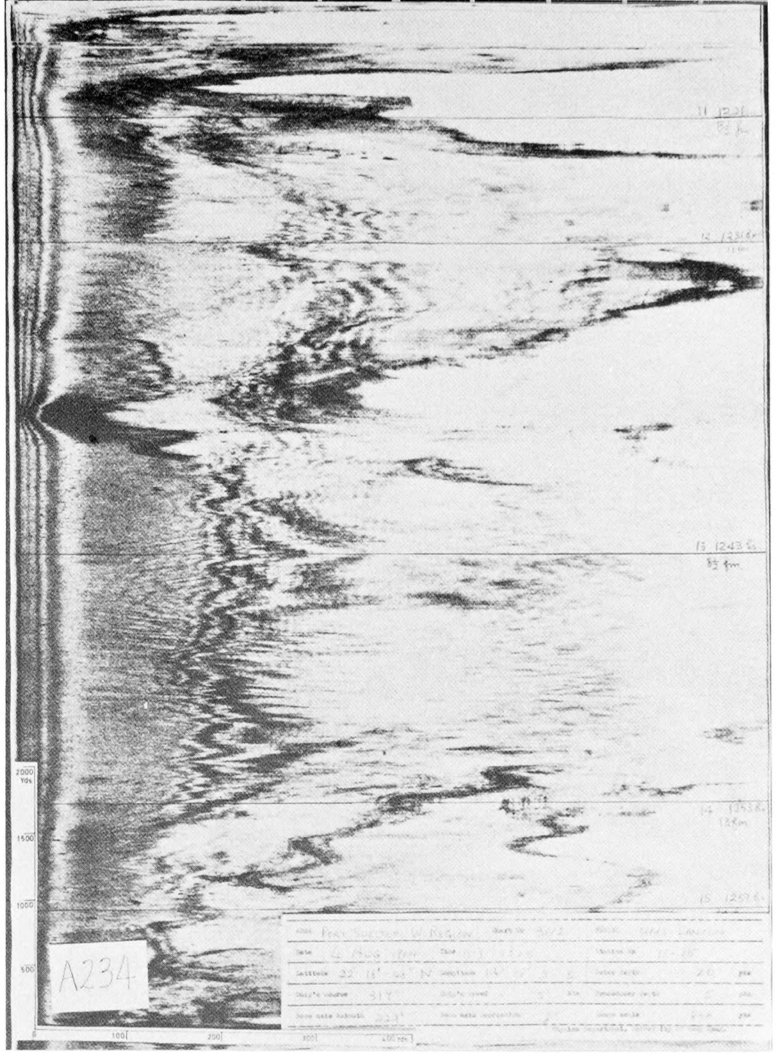
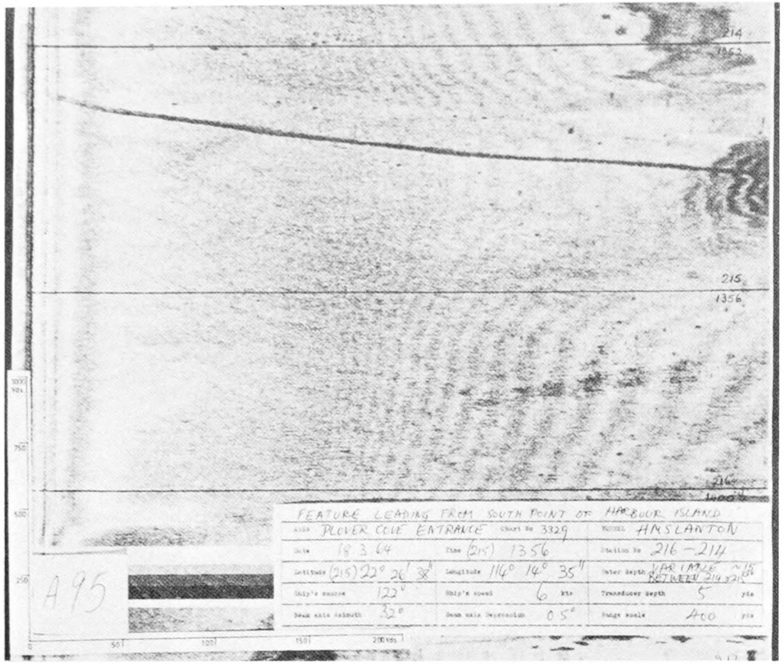


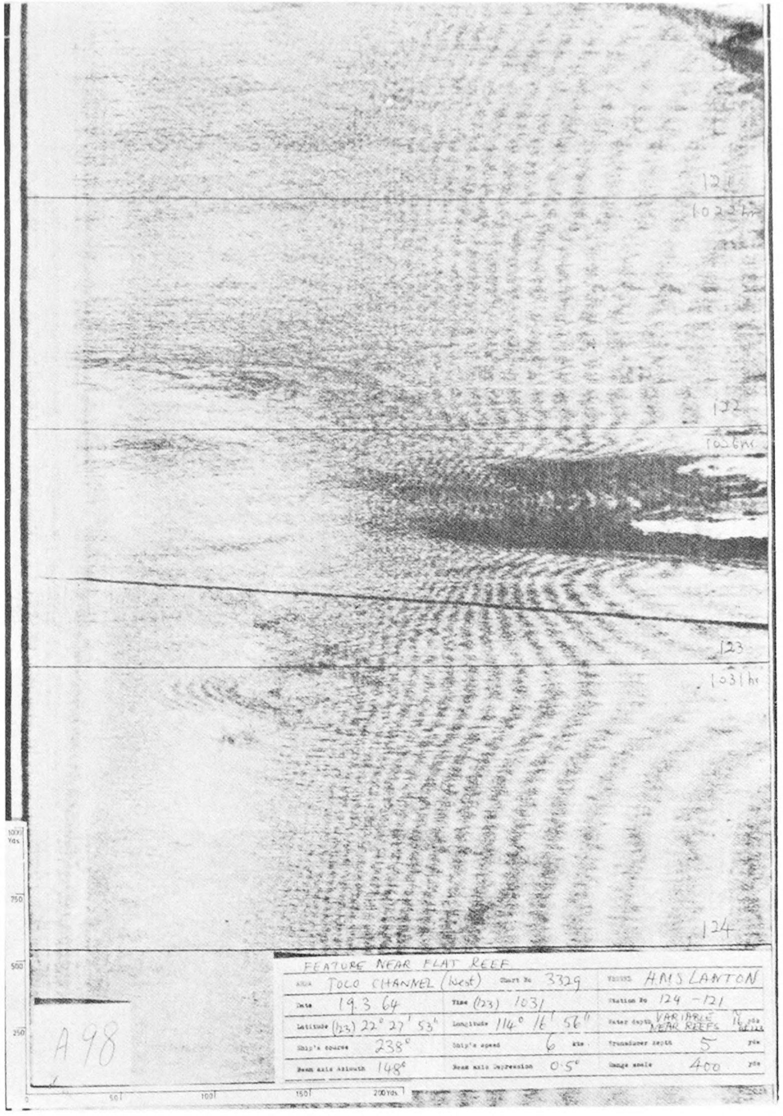
Fig. 28. — Temperature gradients leading to severe range restriction



FEATURE LEADING FROM SOUTH POINT OF HARBOUR ISLAND

Area	PLOVER COVE ENTRANCE	Chart No	3329	Vessel	HMS LANTON
Date	18 3 64	Time	(215) 1356	Station No	216 – 214
Latitude	(215) 22° 26' 38"	Longitude	114° 14° 35"	Water depth	VARIABLE BETWEEN 214 & 215 ~15 yds
Ship's course	122°	Ship's speed	6 kts	Transducer depth	5 yds
Beam axis Azimuth	32°	Beam axis Depression	0.5°	Range scale	400 yds

Fig. 29. — Linear feature at Plover cove entrance. (Note also Lloyd mirror)



FEATURE NEAR FLAT REEF

Area	TOLO CHANNEL (West)	Chart No	3329	Vessel	H.M.S LANTON
Date	19.3 64	Time	(123) 1031	Station No	124 – 121
Latitude	(123) 22° 27' 53"	Longitude	114° 16' 56"	Water depth	VARIABLE NEAR REEFS ~16 yds
Ship's course	238°	Ship's speed	6 kts	Transducer depth	5 yds
Beam axis Azimuth	148°	Beam axis Depression	0·5°	Range scale	400 yds

Fig. 30. — Feature near Flat Reef (Note also Lloyd mirror)

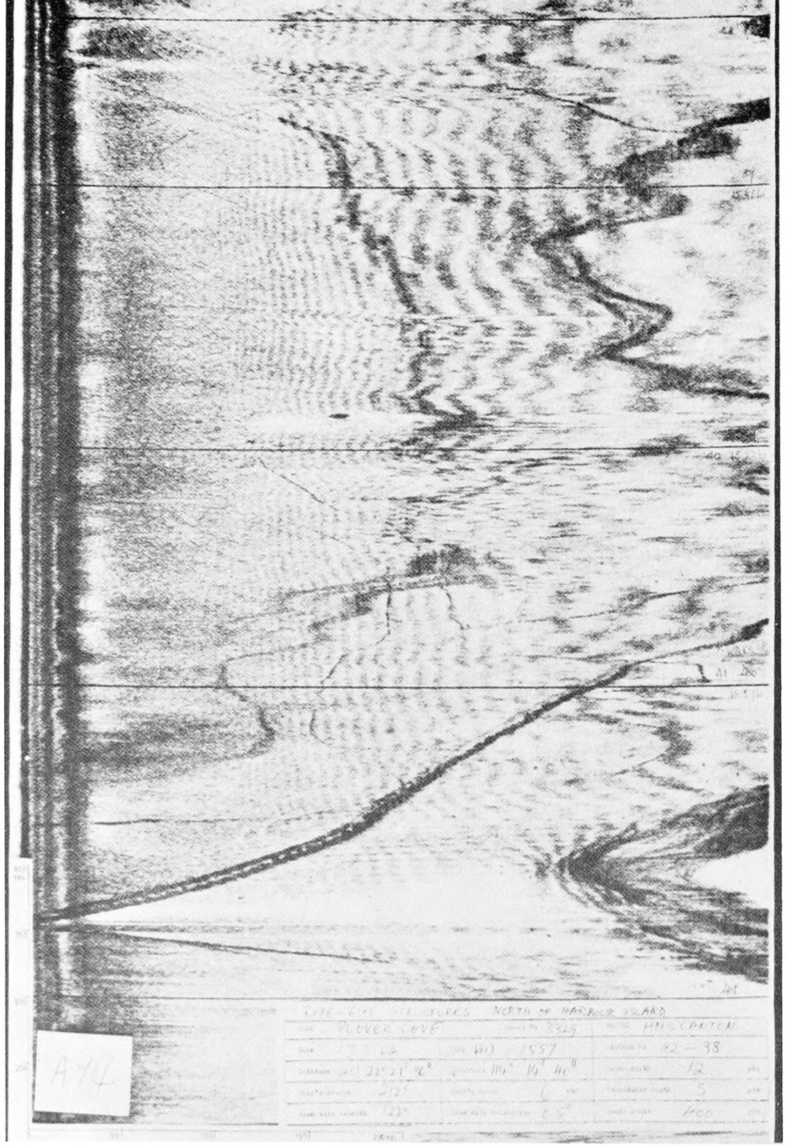


Fig. 31. — "Rope-like" patterns of unknown origin

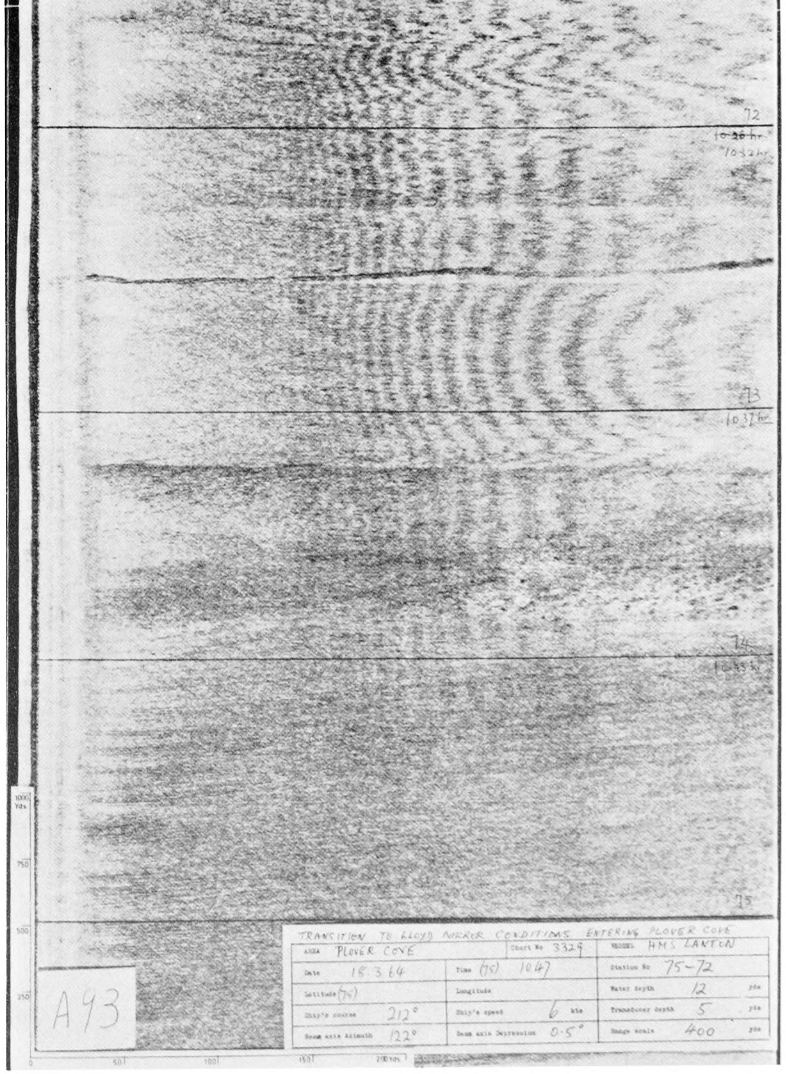
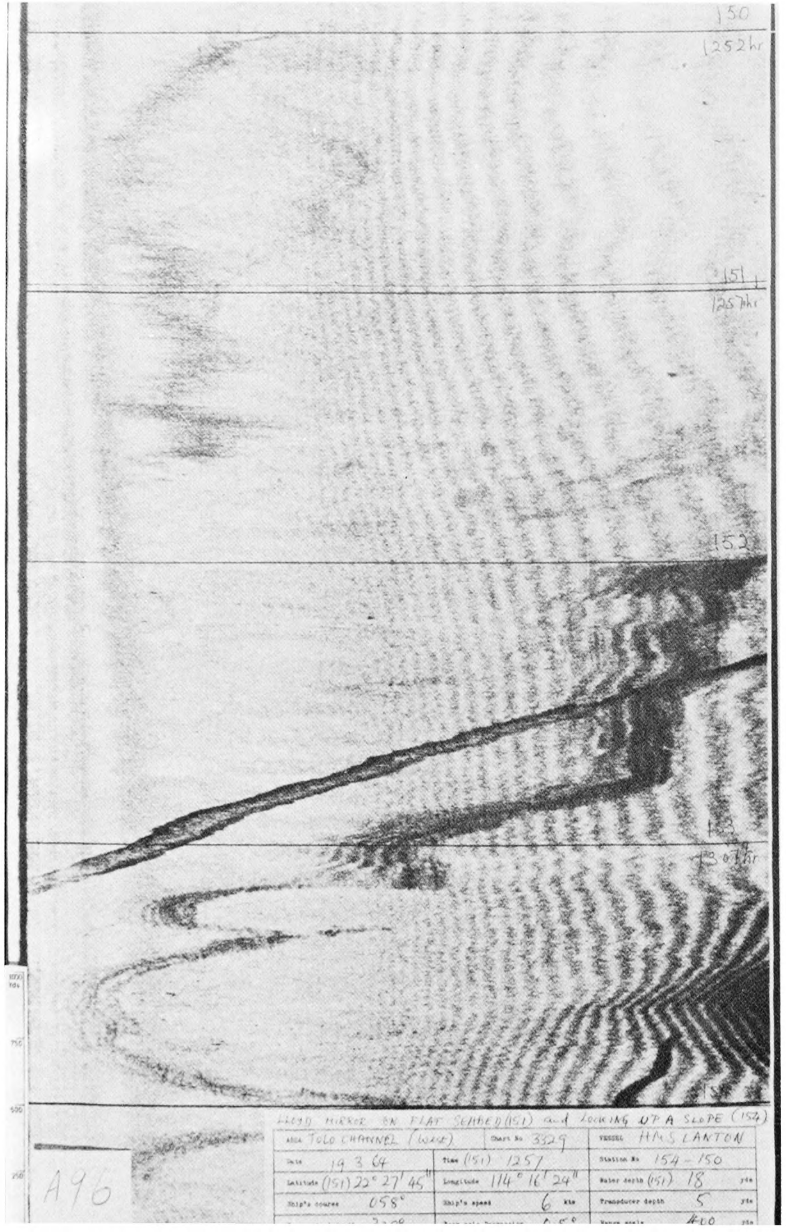


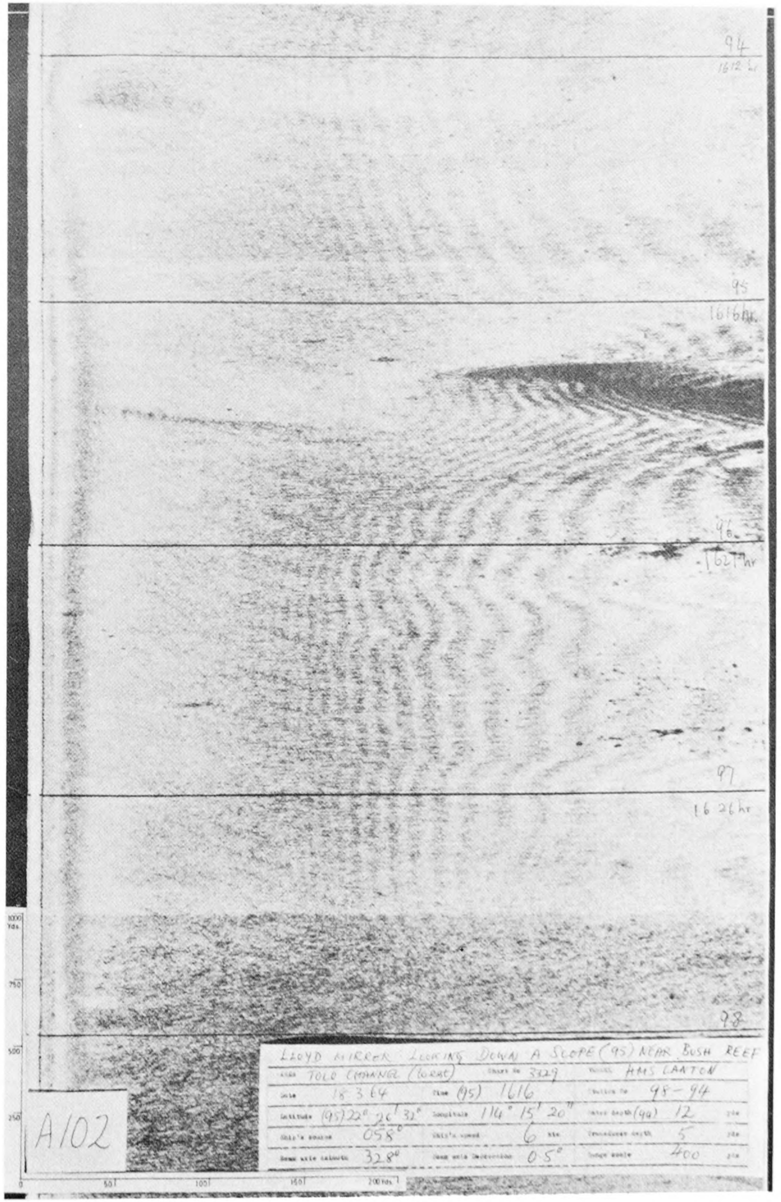
Fig. 32. — Formation of Lloyd mirror patterns on passing from rough to smooth water



LLOYD MIRROR ON FLAT SEABED (151) and LOOKING UP A SLOPE (154)

Area TOLO CHANNEL (West)	Chart No 3329	Vessel HMS LANTON
Date 19 3 64	Time (151) 1257	Station No 154 – 150
Latitude (151) 22° 27′ 45″	Longitude 114° 16′ 24″	Water depth (151) 18 yds
Ship's course 058°	Ship's speed 6 kts	Transducer depth 5 yds
[illegible]	[illegible]	[illegible] 400 yds

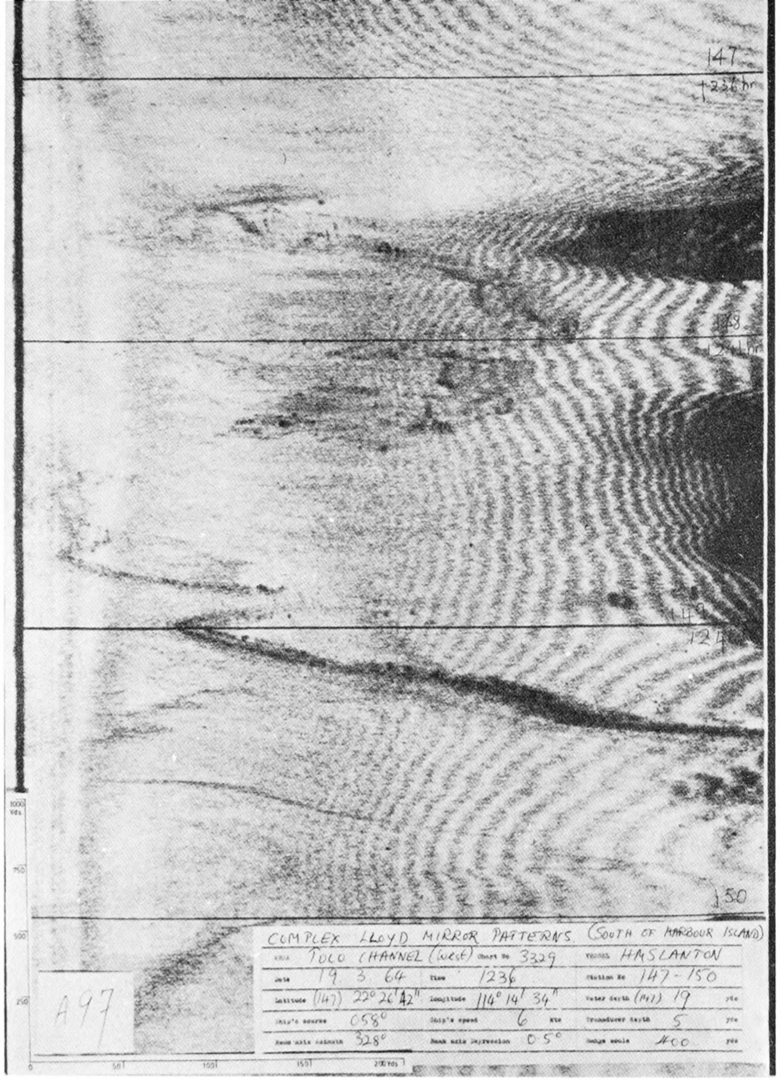
A96



LLOYD MIRROR LOOKING DOWN A SLOPE (95) NEAR BUSH REEF

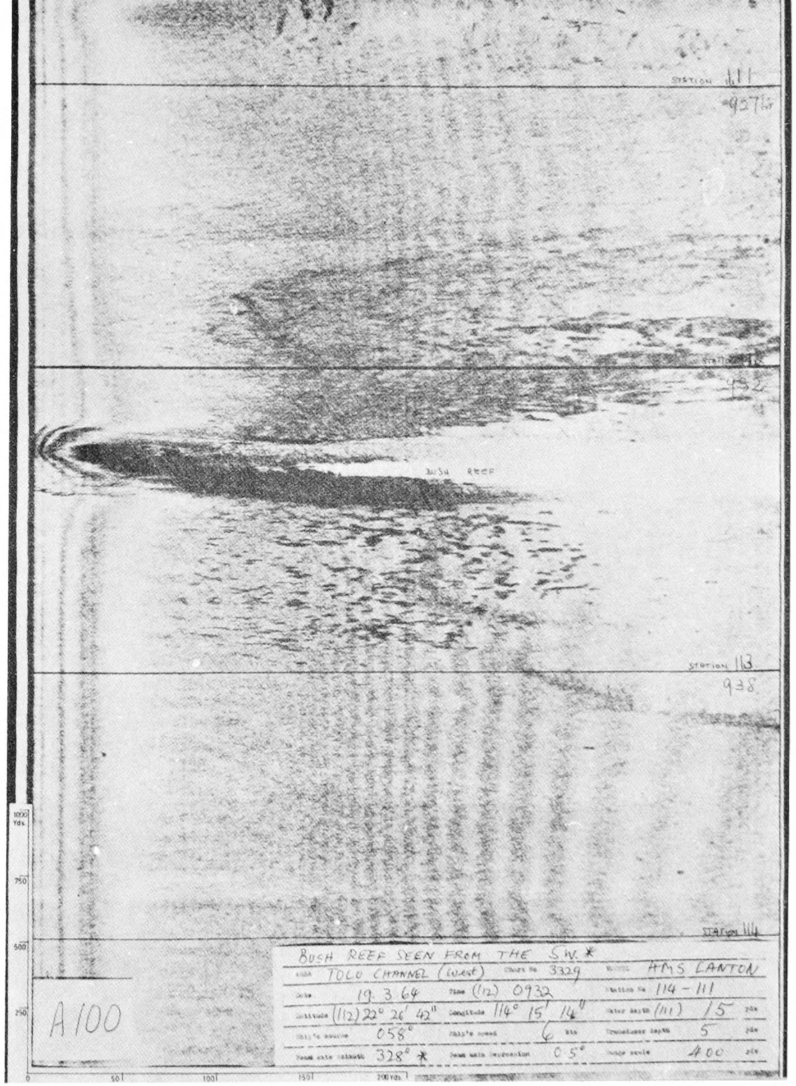
Area TOLO CHANNEL (West)	Chart No 3329	Vessel HMS LANTON
Date 18 3 64	Time (95) 1616	Station No 98 – 94
Latitude (95) 22° 26′ 32″	Longitude 114° 15′ 20″	Water depth (99) 12 yds
Ship's course 058°	Ship's speed 6 kts	Transducer depth 5 yds
Beam axis azimuth 328°	Beam axis depression 0.5°	Range scale 400 yds

A102



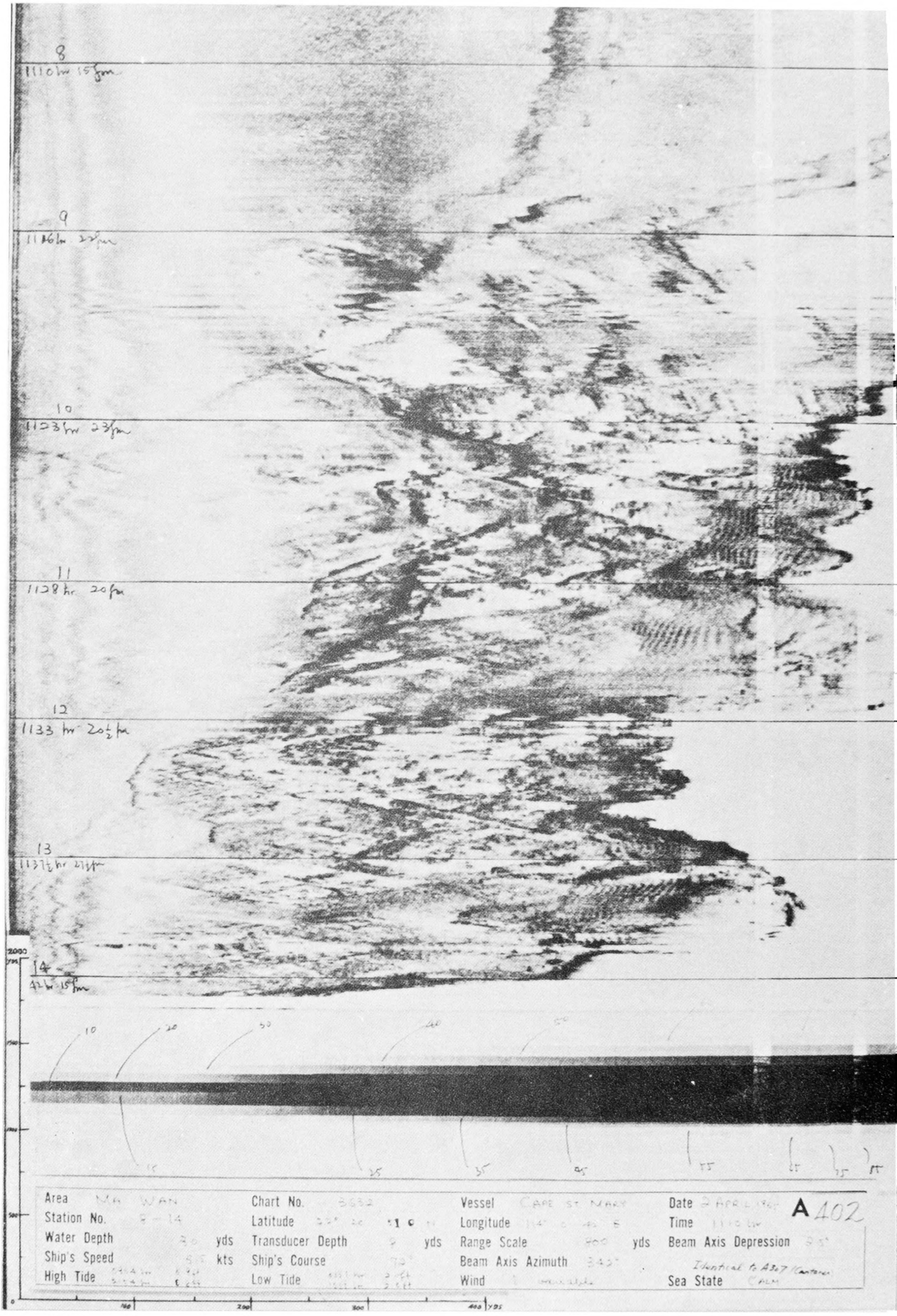
COMPLEX LLOYD MIRROR PATTERNS. (SOUTH OF HARBOUR ISLAND)
Area TOLO CHANNEL (West) Chart No 3329 Vessel HMS LANTON
Date 19. 3. 64 Time 1236 Station No 147-150
Latitude (147) 22° 26' 42" Longitude 114° 14' 34" Water depth (147) 19 yds
Ship's course 058° Ship's speed 6 kts Transducer depth 5 yds
Beam axis azimuth 328° Beam axis depression 0·5° Range scale 400 yds

FIG. 35. — Complex fringe patterns



BUSH REEF SEEN FROM THE S.W. *
Area TOLO CHANNEL (West) Chart No 3329 Vessel HMS LANTON
Date 19. 3. 64 Time (112) 0932 Station No 114 - 111
Latitude (112) 22° 26' 42" Longitude 114° 15' 14" Water depth (111) 15 yds
Ship's course 058° Ship's speed 6 kts Transducer depth 5 yds
Beam axis azimuth 328° * Beam axis depression 0·5° Range scale 400 yds

FIG. 36. — Fringe patterns near a reef structure



Area MA WAN	Chart No. [illegible]	Vessel CAPE ST MARY	Date 2 APRIL [illegible]
Station No. 8 – 14	Latitude [illegible]	Longitude [illegible] E	Time 1110 hr
Water Depth [illegible] yds	Transducer Depth [illegible] yds	Range Scale 400 yds	Beam Axis Depression [illegible]
Ship's Speed [illegible] kts	Ship's Course [illegible]	Beam Axis Azimuth [illegible]	Identical to A307 (Canton)
High Tide [illegible]	Low Tide [illegible]	Wind [illegible]	Sea State CALM

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FIG. 42. — Inject signal system for reverberation measurements

240°–260° LHA ARIES 60°–80°

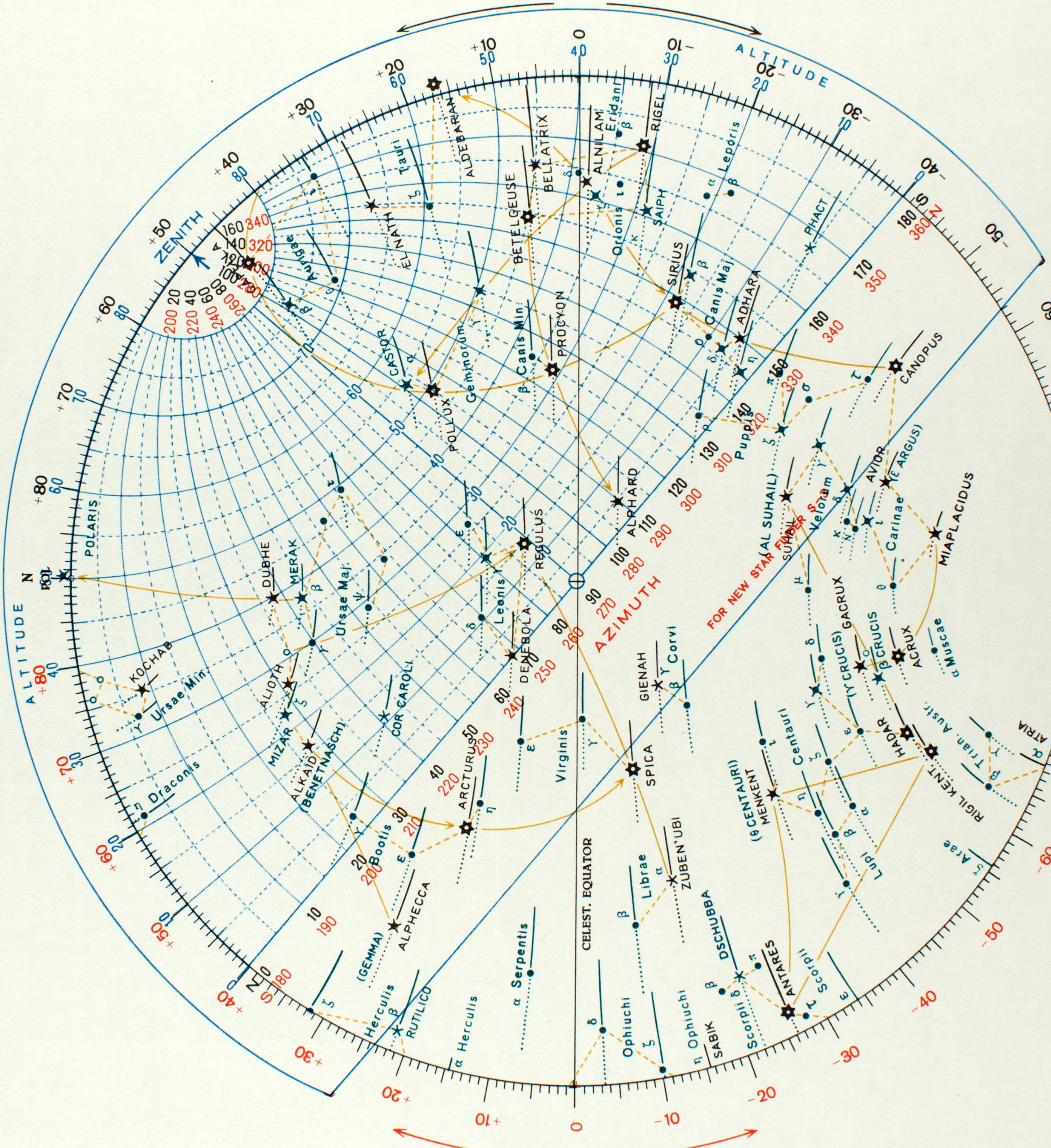
180°–360° AZIMUTH AZIMUTH 0°–180°

Star Chart No.

EXPLANATION

STAR SYMBOLS and NAMES		POSITIONS OF STARS for the values of LHA Aries	OTHER SYMBOLS	
Magnitude: I II III IV, V		240° 250° 260° 60° 70° 80°		
✡ ★ ★	SELECTED STARS	……★——	——	Connections in constellation
★ ★	OTHER REGULAR NAME STARS	……★——	- - - -	Alignments
✖ ● ○	Other Constellation Name stars	●		

WHEN AZIMUTH FIGURES ARE BLACK — PUT THE ZENITH of the template ON THE LATITUDE of this scale



PUT THE ZENITH of the template ON THE LATITUDE of this scale — WHEN AZIMUTH FIGURES ARE RED

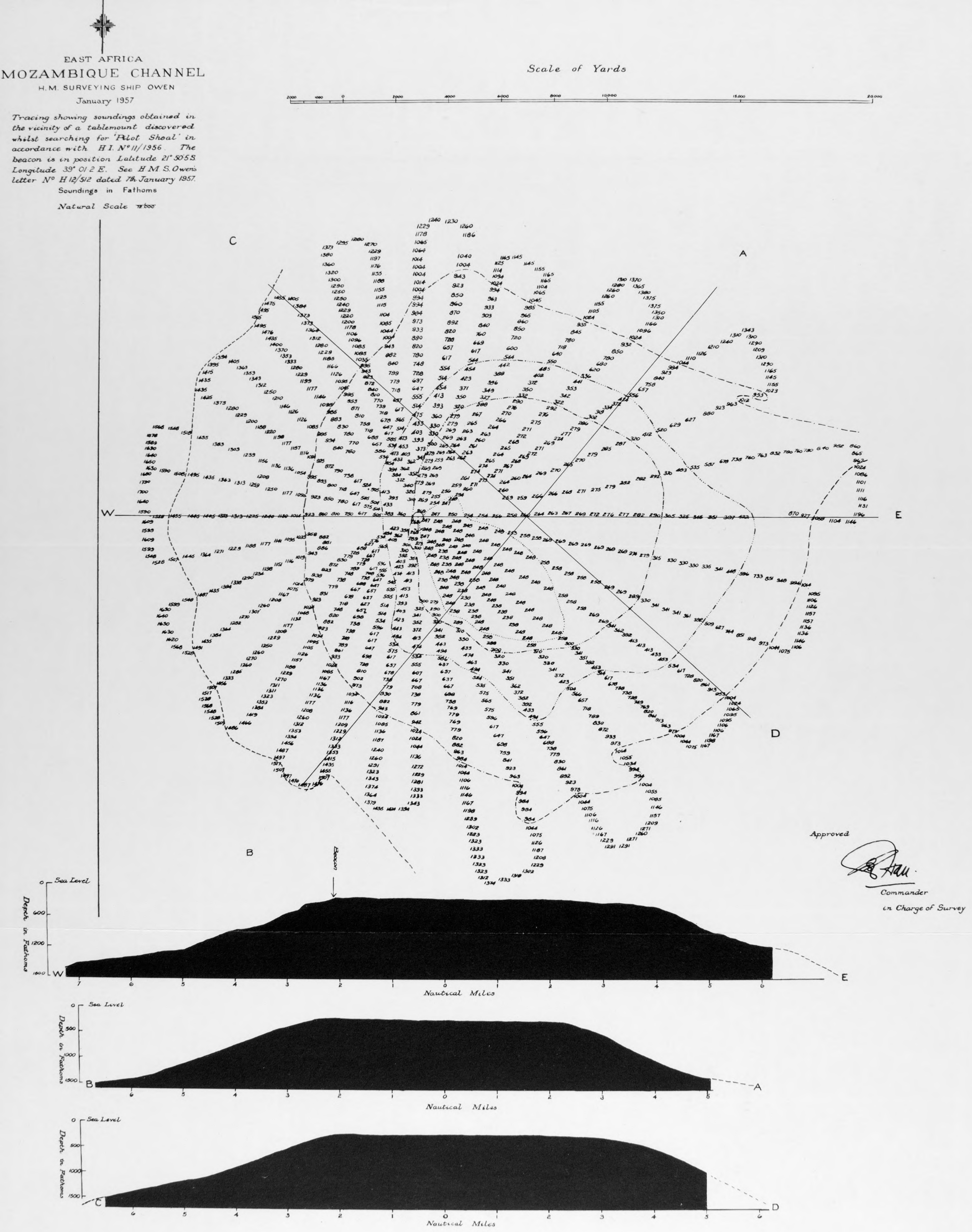

EAST AFRICA
MOZAMBIQUE CHANNEL
H.M. SURVEYING SHIP OWEN
January 1957
Tracing showing soundings obtained in the vicinity of a tablemount discovered whilst searching for 'Pilot Shoal' in accordance with H.I. Nº 11/1956. The beacon is in position Latitude 21° 50'5 S. Longitude 39° 01'2 E. See H.M.S. Owen's letter Nº H 12/512 dated 7th January 1957.
Soundings in Fathoms
Natural Scale
Scale of Yards
2000
1000
0
2000
4000
6000
8000
10,000
15,000
20,000
A
B
C
D
W
E
Beacon
Approved
Commander
in Charge of Survey
Sea Level
Depth in Fathoms
600
1200
1800
W
E
7
6
5
4
3
2
1
0
1
2
3
4
5
6
Nautical Miles
Sea Level
Depth in Fathoms
500
1000
1500
B
A
Nautical Miles
Sea Level
Depth in Fathoms
500
1000
1500
C
D
Nautical Miles

Fig. 3

AFRICA

MOZAMBIQUE CHANNEL

Tracing showing soundings obtained in accordance with H.I. No. 11/56, during search for Pilot Shoal, charted in Lat 21° 15′ S., Long. 38° 57′ E.

H.M. Surveying Ship OWEN

January 1957

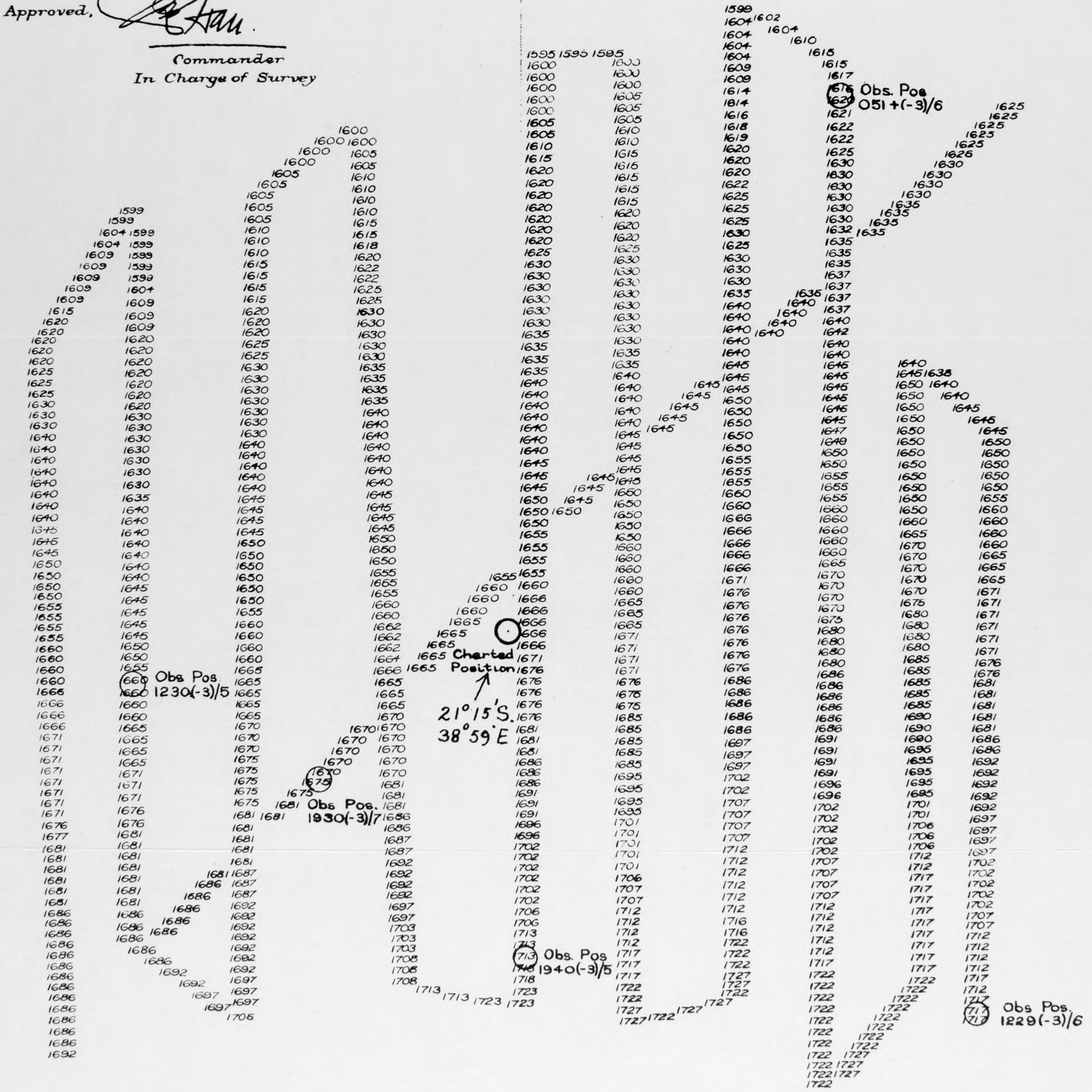
SOUNDINGS IN FATHOMS

corrected for velocity of sound in water from H.D. 282

Natural Scale $\frac{1}{290,592}$

Approved,

Commander
In Charge of Survey



Scale of Distance

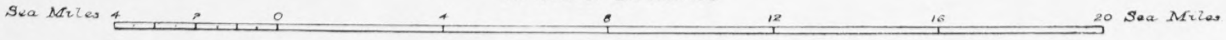
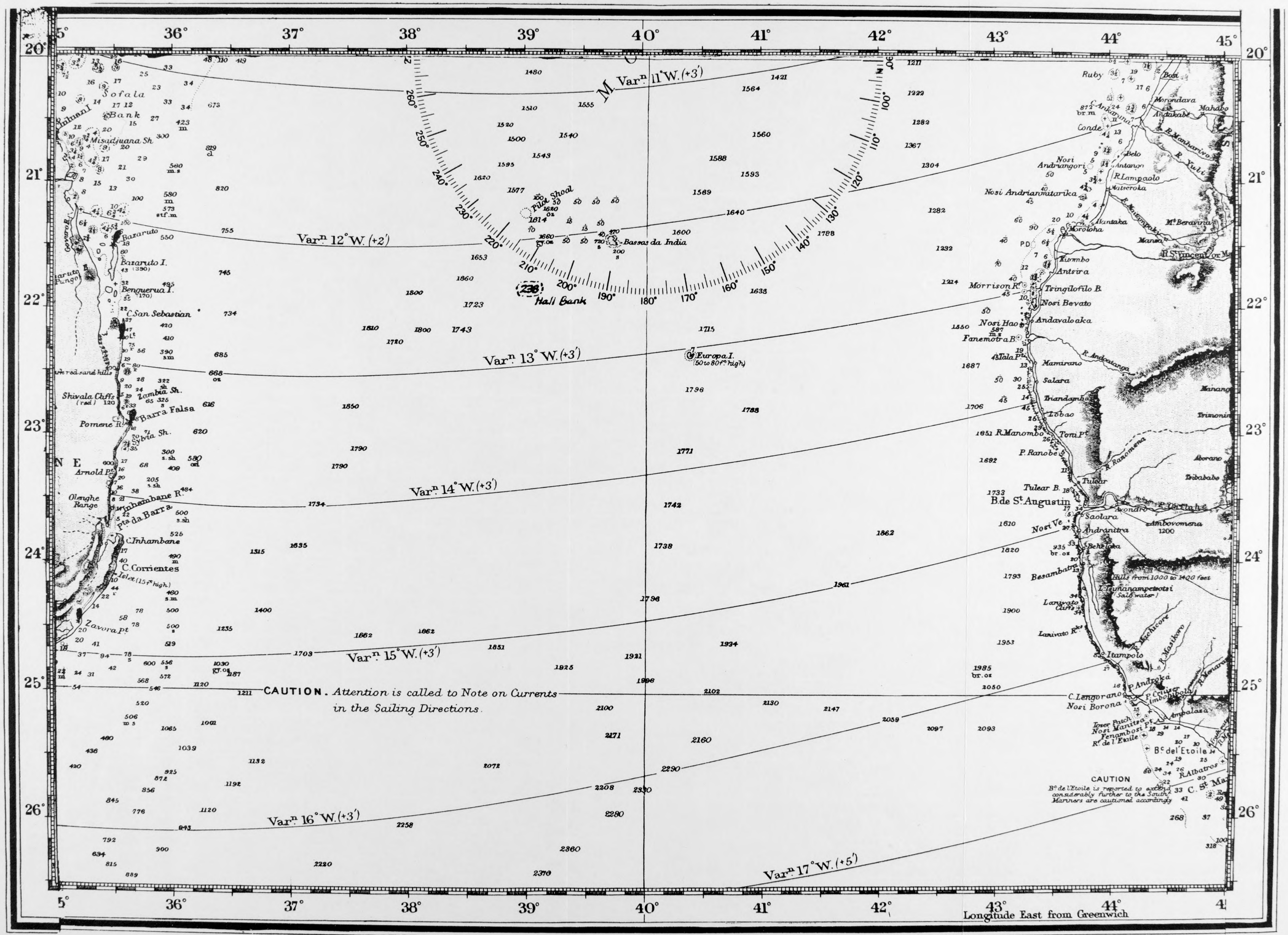


Fig. 2



Small corre

London.— Published at the Admiralty 21st Oct. 1882, *under the Superintendence of* Captain Sir Frederick J.

Price 8s. 6d.

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Fig. 1

Equation (*i*) may be written as

$$m = \left(\frac{2t}{\lambda}\right)\left(\frac{D}{R}\right)$$

For a fixed value of water depth D, the value of the constant $(2t/\lambda)$, for $t = 5$ yards and $\lambda = 3$ cm, will be about 150. This value can also be determined experimentally. If the depth D is precisely known at a particular station during a survey, then the fringe order m may be determined unambiguously.

Equation (*i*) leads to the relationship

$$\frac{dm}{d(R^{-1})} = \frac{2t}{\lambda}\left(D - R\frac{dD}{dR}\right)$$

in which $\frac{dD}{dR}$ is the slope of the sea bed.

Thus for a flat sea bed :

$$\frac{dm}{d(R^{-1})} = \frac{2t}{\lambda}D$$

Experimental measurement of a number of graphs for fringe order m against reciprocal range R^{-1} gave values for $2t/\lambda$.

With an established value for $2t/\lambda$, contour determination reduces to a determination of the fringe order m at various points on the survey record. This can be done by three different ways. In the first method, a station point with known depth is chosen, and the range measured on the record. By direct substitution, m can then be calculated. Since, for neighbouring fringes, m changes by ± 1, m can be determined for every fringe.

The second method applies only to flat sea beds. The fringes on the record can be numbered arbitrarily by consecutive integers. If these numbers are then plotted against the corresponding reciprocal range, 1/R, a straight line will be obtained with gradient equal to $1/m$R. Therefore m can be determined. The total experimental error in m in this determination is about 3 per cent, so that the error is less than 0.5 per cent for m 15. m is thus unambiguously determined.

The third method can be used where the area is not flat and no depth data is available. An appropriate fringe can be traced to an area where either of the first two methods apply. m for this particular fringe can then be found, and that for other fringes calculated, remembering that changes in m for neighbouring fringes are always ± 1.

The resolution of the system is theoretically very good, but practically, however, the resolution seldom exceeds 0.5 yard. The method therefore is good for detecting depth changes, in spite of the fact actual depth can often not be very accurately determined.

Figure 38 illustrates typical plots of the reciprocal range 1/R against fringe order m for the situation of level, upward-, and downward-sloping

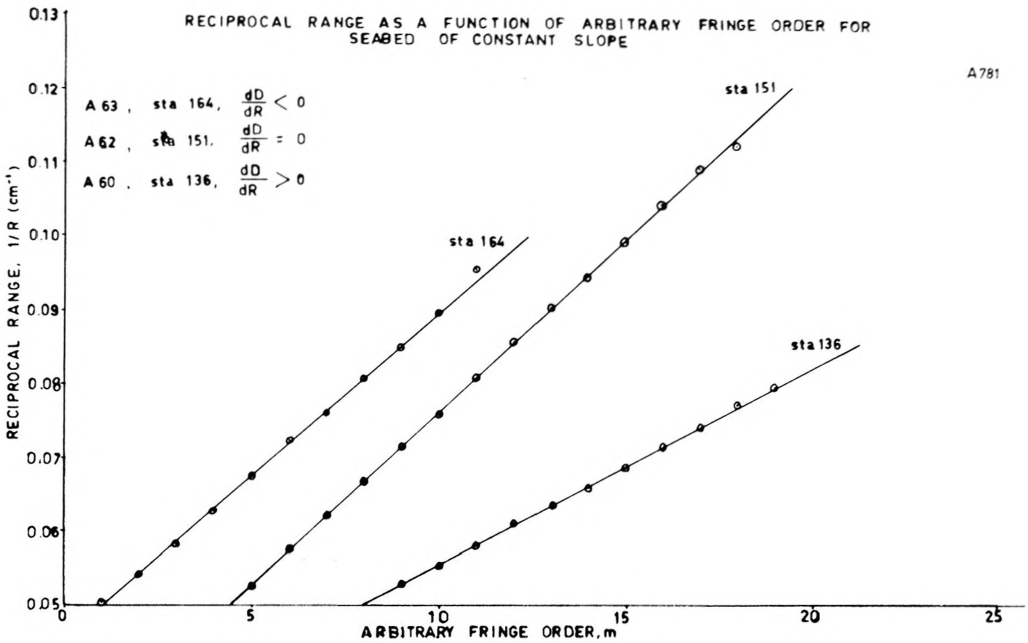

Fig. 38. — Reciprocal range plots against fringe order

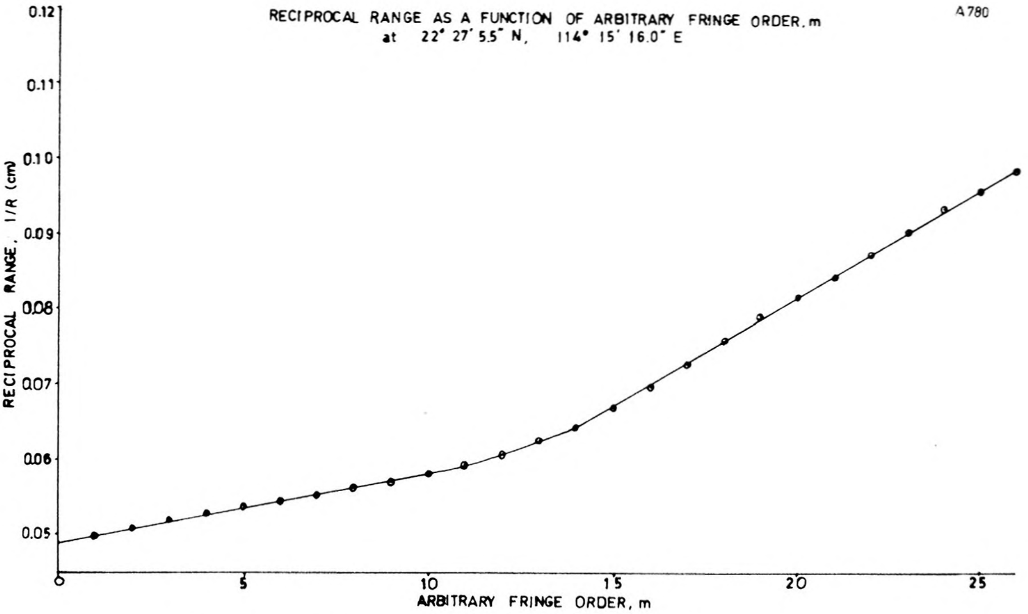

Fig. 39. — Reciprocal range plots for a variation of slope

seabeds. Here the three slopes are uniform along the path seen. Where a variation occurs, as in figure 39, the slope changes. From the type of analysis one-yard contours may be plotted, as shown in figure 40.

For calm inshore waters, there may well be hydrographic application of this method.

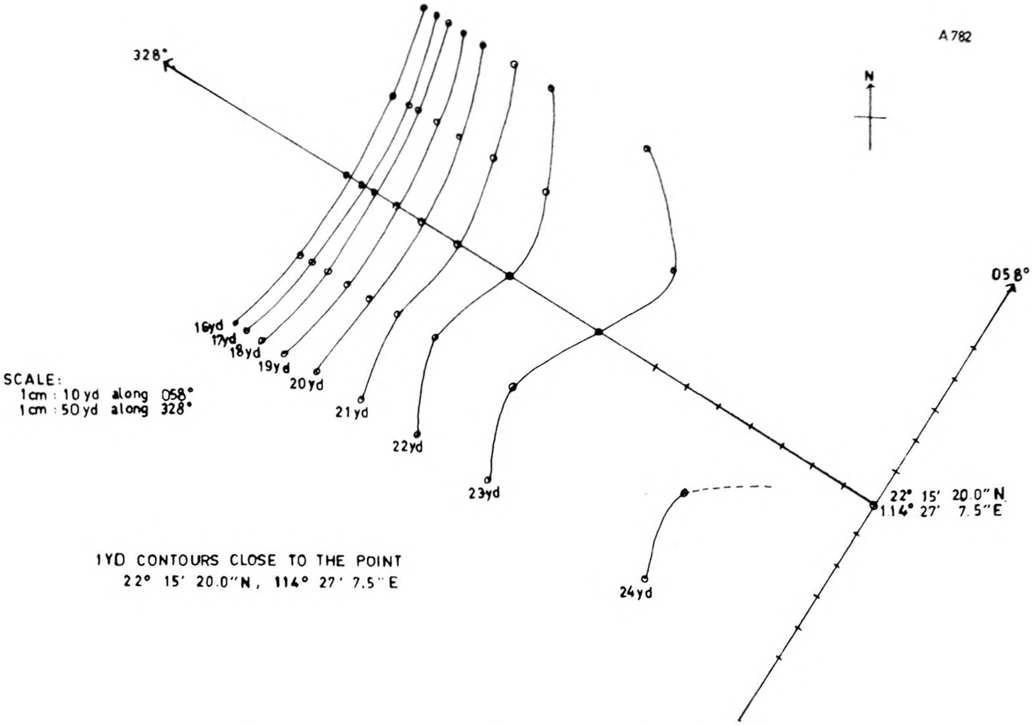

FIG. 40. — Contour analysis from Lloyd mirror fringes

6. — REVERBERATION DECAY MEASUREMENTS

The strength of the reverberation signal received at the transducer face will decay rapidly with time from the instant of the transmitted pulse. The situation is analogus to the decay of the sound from a pistol shot in a concert hall reverberation measurement. Reverberation decay measurements can be made at sea in parallel with the recording of acoustic maps.

6.1. Method of study

The received signal is examined before the time-varied-gain stage of the amplifier. A Bruel and Kjoer Level Recorder (Type 2305) is used with a logarithmic potentiometer having a range of 50 dB, and this produces a record of the signal in the form shown in the figure 41(a), idealised in the form shown in figure 41(b). The time-varied-gain section of the amplifier has a characteristic shown in figure 41(c), so that the resultant output across the survey mapping recorder is as shown in figure 41(d). Thus density of the trace is reasonably independent of range — a desirable and indeed essential characteristic of the system.

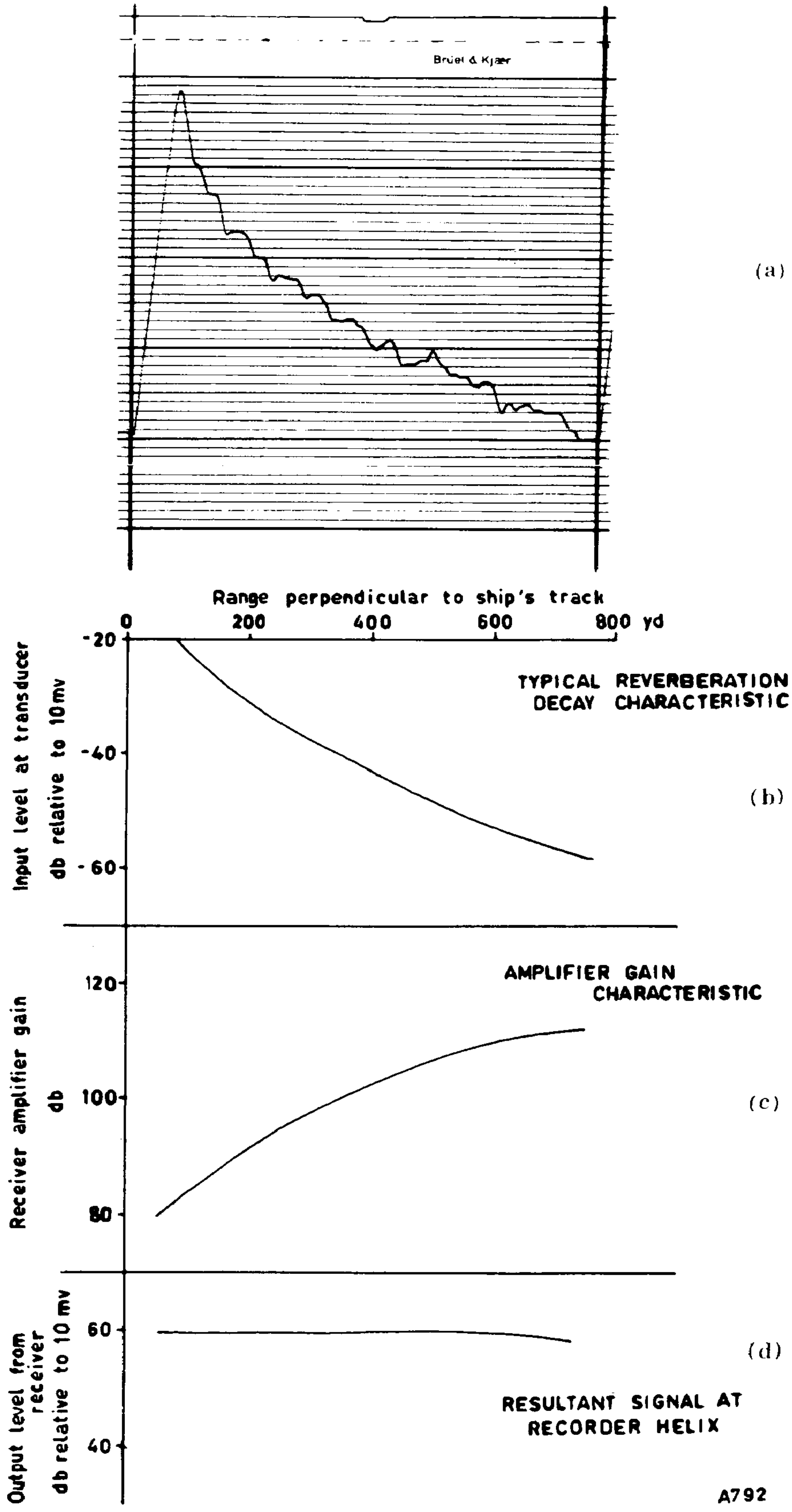

FIG. 41. — Reverberation decay measurements

6.2. Indication of sediment types

For an uniform, flat sea bed of sand, the reverberation decay curve will be reasonably smooth, and will fall through a level range of 50 dB or so in passing from 50 yards to 1 000 yards. The shape of the curve will be determined principally by the inverse square law and the attenuation coefficient for the 50 kc/s radiation in the sea, normally about 12 dB per kiloyard.

The actual quantitative value of reverberation at, say, the 400 yards range point, will be determined by the sediment character. This value will accordingly rise through the sequence : mud, sand and mud, fine sand, coarse sand, gravel, rocks and coral. A number of workers have made quantitative studies of these effects in shallow water reverberation [12], and the present authors are continuing these studies with a view to determining the type of sediment based on accurate measurement of this signal. For purely scattering sea beds, where the particle size of the sediment is well below the wave length of the radiation (3 cm), there is a good chance that this identification can be achieved.

Figure 42 illustrates calibrated inject signals on a normal survey record. This assists in the identification of sediment materials.

7. — ACKNOWLEDGEMENTS

These investigations have been carried out as part of the research programme of the Department of Physics, University of Hong Kong. We are grateful for the help of Mr. I. W. McLean and others of the Physics staff in connection with the work at sea.

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We are most grateful for permission given to us by H. M. Government of Hong Kong for the use of the Fisheries Research vessel *Cape St. Mary*. The willing cooperation of the Captain and crew greatly assisted in the smooth running of the trials.

The Royal Navy has been most generous in allowing the use of various ships for this work. H.M.S. *Dampier* conducted detailed trials in the Lamma Channel, and H.M.S. *Lanton* explored Plover Cove, Tolo Channel, and the Port Shelter regions. It is a pleasure to thank the Commodore-in-charge, Hong Kong, for allowing the University these facilities.

Mr. A. H. Stride (National Institute of Oceanography) has made valuable criticisms of this paper in the course of its preparation.

REFERENCES

[1] Chesterman, W. D., Clynick, P. R., and Stride, A. R. (1958) : An acoustic aid to sea bed survey. *Acustica*, **8**, 285-290.

[2] Tucker, M. J., and Stubbs, A. R. (1961) : A narrow beam echo ranger for fishery and geological investigations. *Brit. J. Appl. Phys.*, **12**, 103-110.

[3] Laughton, A. S. (1964) : (National Institute of Oceanography). Private communication.

[4] Stride, A. H. (1961) : Geological interpretation of asdic records. *International Hydrographic Review*, **XXXVIII**, No. 1, 131-139.

[5] Stride, A. H. (1963) : Current swept sea floors near the Southern half of Great Britain 1963. *Quart. Journ. Geol. Soc. London*, Vol. 119, 175.

[6] Donovan, D. T., and Stride, A. H. (1961) : An acoustic survey of the sea floor South of Dorset and its geological interpretation. *Phil. Trans. Roy. Soc. Lond.*, Series B. 244, 299-330.

[7] Stubbs, A. R., and Lawrie, R. C. G. (1962) : Asdic as an aid to spawning ground investigations. Extrait du *Journal du Conseil International pour l'exploration de la mer*, Vol. 37, No. 3, 248-260.

[8] Stubbs, A. R. (1963) : Indentification of patterns on asdic records. *International Hydrographic Review*, **XL**, No. 2, 53-68.

[9] Curry, D., Martini, E., Smith, A. J., & Whittard, W. F. (1962) : The geology of the Western approaches of the English Channel. 1. Chalky rocks from the upper reaches of the continental slope. *Phil. Trans. Roy. Soc. Lond.*, Series B. 245, 267-290.

[10] Haines, R. G. (1963) : Developments in ultrasonic instruments. *International Hydrographic Review*, **40**, No. 1, 49-57.

[11] Sanders, F. H. and Stewart, R.W. (1954) : Image interference in calm, near isothermal water. *Can. Jour. Phys.*, **32**, 599.

[12] Spitzer, L. (1960) : *Physics of sound in the sea.* Part 2, Chapter 15. Reverberation. National Research Council, U.S.A.