

SIDE-SCAN SONAR : A PRACTICAL GUIDE

by B.W. FLEMMING

National Research Institute of Oceanology
Council for Scientific and Industrial Research
Stellenbosch, South Africa

ABSTRACT

The apparent lack in up-to-date literature of practical advice on operational aspects of side-scan sonar and the isometric reproduction of records calls for a more specific approach. The author discusses step by step every major feature that directly affects the composition of the resulting sonograph. Special emphasis is given to distorting factors, which have to be eliminated when draughting isometric maps from sonograph mosaics. A number of practical aids are presented in the form of distortion ellipses and true distance nomograms, which simplify the manual draughting process to a point beyond which only computerization would provide substantial improvement. Since computerization of the draughting process will not be available for many users in the foreseeable future, these aids are considered vital. Finally, the various features discussed, as well as geological interpretations of selected examples from the South African continental margin, are represented. The discussion is based on the EG&G Mark 1B side-scan sonar system.

INTRODUCTION

A major shortcoming of most up-to-date literature on side-scan sonar is the lack of practical information and advice to solve the numerous technical and operational difficulties discussed at such length. It is the aim of this essay to compile such information. Mathematical and other theoretical discussions are reduced to a minimum, this having been covered in detail by many authors and expertly summarized by LEENHARDT (1974). Special emphasis is therefore given to all those aspects that directly concern the composition and interpretation of sonographs.

From the start it should be noted that on two vital aspects information and experience cannot be fully passed on. Firstly, there is no fixed control

setting in order to achieve maximum clarity and resolution; continual adjustments are necessary. And secondly, accurate interpretation of the features recorded on the sonographs often remains a matter of argument. In both cases the operator will have to gain his personal first hand experience before achieving satisfactory results. Extensive test runs in well known areas and control dives by scientifically trained personnel have proved very successful.

This discussion is based on the EG&G Mark 1B side-scan sonar system which has achieved considerable distribution. However, with the exception of the nomograms (fig. 10 : 1-10) which are unique to this particular instrument, all other features discussed apply in general.

HISTORICAL BACKGROUND

Sound was first used to examine the sea-bed when WOOD and some colleagues developed the prototype echosounder in 1929 (WOOD *et al.*, 1935). Since then numerous adaptations have come into use, mainly in the form of bottom penetrating *low frequency* sound sources, today widely applied in the various marine seismic techniques. It was not until 1958 that sound was actually used to map geological surface features of the sea floor utilizing the back-scattering effect of *high frequency* sound waves (CHESTERMAN, CLYNICK & STRIDE, 1958). The first operable sideways-looking sonar was built by TUCKER & STUBBS (1961) at the National Institute of Oceanography in England and since then the instrument has undergone rapid development and improvement.

This period is documented by many publications discussing mainly the technical problems rather than practical applications. The articles by TUCKER (1966), CHESTERMAN *et al.* (1967), SANDERS & CLAY (1968) are good examples of this category. However, side-scanning achieves its maximum capability only when applied systematically! Sporadic recordings within the limits of reconnaissance cruises can provide valuable background information but will not suffice for detailed interpretations. Utilizing such information, specific problems can be defined on a local or regional scale for a systematic approach within the conventional survey procedure, thus optimizing and substantially improving costly scientific ventures. Example: dredge stations conventionally selected from echo sounder profiles never achieved more than 60% success along the South African coast whereas those selected from side-scan sonar records proved 100% successful!

Although the first systematic surveys were commenced as early as 1964 by CLAY, ESS & WEISMAN it was not until the end of the last decade that they became routine wherever the instrument was available. SANDERS *et al.* (1969), WONG *et al.* (1970) and CHESTERMAN *et al.* (1971) provide interesting examples of this nature. RUSBY (1970) discusses a side-scan sonar system specially adapted for long range deep-water surveys commonly known as the G.L.O.R.I.A. Project. This instrument can cover a maximum range of 22 km.

A comprehensive compilation of literature on the development and application of side-scan sonar can be found in BELDERSON *et al.* (1972). At the same time the book presents many excellent examples of sonar recordings (sonographs) and their geological interpretations thus providing a very useful reference catalogue. More recent examples of detailed side-scan surveys are discussed by NEWTON *et al.* (1973), BELDERSON *et al.* (1974), MCKINNEY *et al.* (1974), WERNER (1975), WERNER & NEWTON (1975), LAUGHTON & RUSBY (1975) and BRYANT (1975). First results of side-scan sonar investigations along the South African coast were presented by GENTLE (1973).

Side-scan sonar must be regarded as a major breakthrough — especially for marine geology — because, for the first time, it has become possible actually to map the surface features of the sea floor on a broad scale.

SYSTEMS ANALYSIS

Basically the side-scan sonar system consists of three units : a transducer which forms the underwater unit and is better known as the “fish”, a steel wire reinforced cable acting as transmission and tow cable simultaneously, and a dual channel recorder.

The *fish* consists of a streamlined, hydrodynamically balanced body about 1 m long containing two sets of transducers that scan the sea-bed

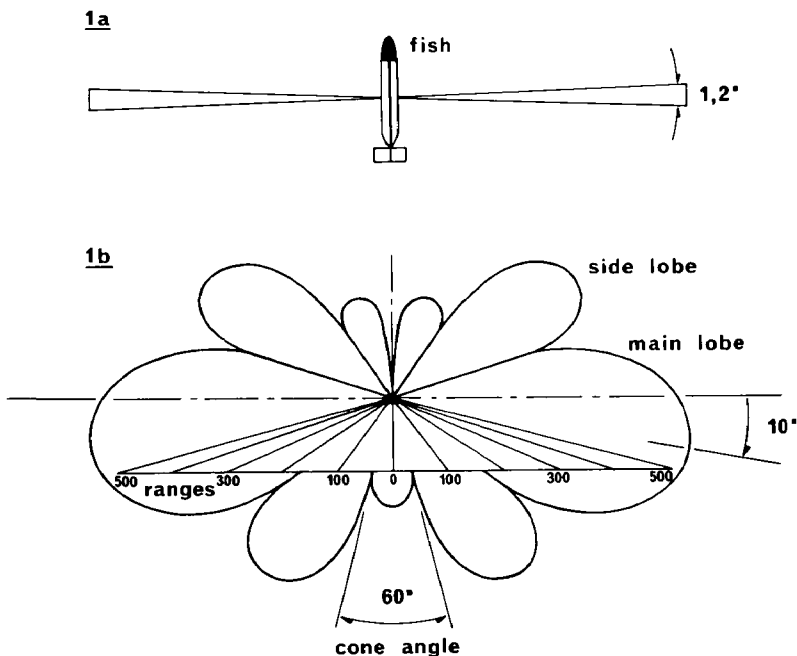


FIG. 1. — The sound lobes of the ultrasonic beam (exaggerated).
a. Plan view; b. Vertical section.

on either side. The ultrasonic beam is slightly depressed from the horizontal with the axis of the main lobe pointing 10° downwards (fig. 1b). The horizontal spread of the beam is narrowed down to 1.2° (fig. 1a). This ensures a reasonable transverse resolution even at the largest range (500 m).

The *transverse resolution* (R_t) is defined as the minimum distance between two objects parallel to the line of travel that will be recorded on paper as separate objects. This minimum distance is of course equal to the beam width at any particular point on the sea-bed, resulting in a steady decrease of the transverse resolution towards the outer sweep ranges (Table 1). This is a system-inherent effect that cannot be manipulated, and it is responsible for the apparent fading of recorded signals on the outer sweep ranges if individual features become smaller than the corresponding resolution. Example : at the point on the sea-bed marked by the 200 m range the transverse resolution will be :

$$R_t = \sin 1.2^\circ \times 200 = 4.19 \text{ m} \quad (1)$$

The vertical spread of the *main lobe* is normally 20° which together with the vertical *side lobes* will cover the whole distance from a point vertically below the fish to the limit of the maximum range, covering 500 m on each side (fig. 1b). Alternative settings are available for deep water surveys. Resulting from this coverage a certain vertical resolution is achieved depending largely on the range setting.

The vertical resolution or *range resolution* (R_r) is defined as the minimum distance between two objects perpendicular to the line of travel that will be recorded on paper as separate objects. Assuming that a minimum spacing of 1 mm on the recording paper is needed to plot two objects separately, the resolution will be $1/125$ of the range scale, the paper width per channel being 125 mm (Table 1). Example : if the range setting is 200 m, then the range resolution will be :

$$R_r = 200/125 = 1.6 \text{ m} \quad (2)$$

These limits of resolution define the maximum scale of reproduction of sonographs. Normally a strong reduction becomes necessary anyway, and even a $1/10\,000$ reproduction of a 200 m range record means reducing the width of the record by the factor 0.16. The whole process of reproduction, however, is not quite as simple as that because other distortions, caused mainly by varying ship speeds and heights of fish above bottom, involve a tedious process of correction before an isometric map is produced.

The sonar image is constructed by signals received through the main lobe as well as through the side lobes (fig. 1b), and obviously the side lobes, being less intense, will have inferior qualities regarding resolution, especially in the case of the small central lobe. Although large objects are recorded without difficulty, smaller ones may be vaguely defined or not recorded at all. For the correct interpretation of sonographs it is important to know how large this area of reduced resolution is. Since we are dealing with a sound lobe producing a cone, the width of this *cone area* is a function of the fish height above sea-bed (table 1). Furthermore, where the side lobes overlap with the main lobes, resolution is dramatically reduced, often resulting in a "white gap" close to the inner record margin of each channel.

TABLE 1
Inter-relationships between various parameters.

Height of fish above sea-bed (m)	Cone area per channel (m)	Suitable sweep ranges (m)					
		50	100	125	200	250	500
10 – 25	6 – 23	x	x	x	x	x	x
25 – 50	23 – 35	–	x	x	x	x	x
50 – 80	35 – 46	–	–	x	x	x	x
80 – 120	46 – 70	–	–	–	x	x	x
120 – 160	70 – 92	–	–	–	–	x	x
160 – 300	92 – 230	–	–	–	–	–	x
300 – 500	> 230	–	–	–	–	–	–
Transverse resolution (m)		1.05	2.09	2.6	4.19	5.2	10.4
Range resolution (m)		0.4	0.8	1.0	1.6	2.0	4.0
Optimum height of fish (m)		5-10	10	10-12	20	25	25-50

The *dual channel recorder* contains most of the electronics as well as the graphic mechanism. The transducer sends out short sonar pulses of 0.1 ms duration and the returning signals are amplified in the recorder and fed, in form of variable currents, to the helix electrodes which sweep out from the centre of the recording drum. The current passes through the recording paper to the printer blade-electrode and from there to earth. The current passing through the paper produces marks of varied intensity which are proportional to the strength of the incoming signals, thus reflecting the nature of the sea-bed (fig. 3). The recorded image is called the *sonograph* and, in a sense, it is remotely similar to a continuous high altitude aerial photograph.

Each returning signal is plotted on the paper at the position corresponding to the time it was received after the outgoing pulse. This position will shift across the paper proportionally to the selected sweep range. Each range is divided into equal time intervals which are automatically plotted as lines on the recording paper. These time intervals, defined as *slant ranges*, correspond to 25 m travel distances of the outgoing pulse. The 100 m range, for example, will show 4 such 25 m lines, and the 200 m range 8 lines. Doubling the range therefore means increasing the scan area roughly by the factor 2. This results in a reduction of all features recorded on the paper by the factor 0.5.

The instrument is calibrated such that by doubling the range the pulse rate is reduced by one half, and in order to avoid gaps on the recording paper the paper feed rate is also reduced by one half. In this way the longer travel times of the sonar signals are compensated for.

The stronger the returning signal, the darker will be the mark on the paper. This intensity of the return signal is a function of material properties as well as topography. Large objects (e.g. boulders, rock pinnacles, ridges and sandwaves) are not only good reflectors but also produce an *acoustic shadow* zone behind them where nothing is recorded, thus leaving white patches on the paper. The width of this shadow and the position of the object relative to the fish are utilized to calculate the height of such objects (fig. 2).

The *height of an object* (H_t) is equal to the product of the acoustic shadow length (L_s) and the height of the fish above sea-bed (H_f), divided by the sum of the acoustic shadow length and the range distance at which it is recorded (R_s). Thus :

$$H_t = \frac{L_s \times H_f}{L_s + R_s} \quad (3)$$

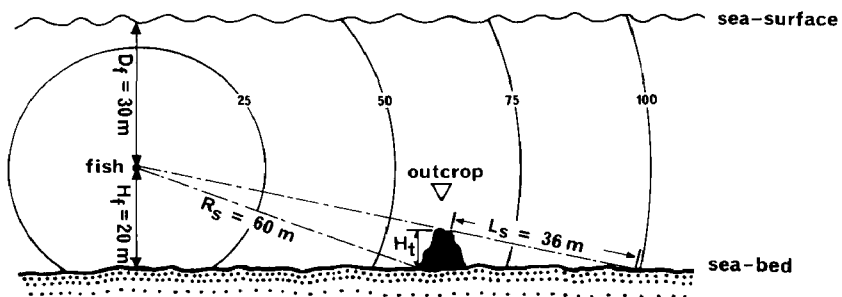


FIG. 2. — Calculating the height of an object :

$$H_t = \frac{L_s \times H_f}{L_s + R_s} = \frac{36 \times 20}{36 + 60} = 7.5 \text{ m}$$

The previous discussion has already indicated that the slant range (R_s) is not identical to the recorded distance along the sea-bed (fig. 2). In order to determine the exact position of an object or feature relative to the line of travel, the horizontal range has to be calculated using the theorem of Pythagoras. The *horizontal range* (R_h) or better the *true distance over ground* is equal to the square root of the difference between the squares of the slant range (R_s) and the height of the fish above sea-bed (H_f). Thus :

$$R_h = \sqrt{R_s^2 - H_f^2} \quad (4)$$

To speed up this operation of calculating true positions, tables, graphs or, even better, straightforward nomograms can be utilized. The author has draughted such aids, and their application is discussed later in this article. As long as the process of accurate reproduction of sonographs in map form is not computerized these aids are the quickest and most reliable means available.

Another typical feature of sonographs are the identical *depth profiles* recorded on both channels along the inner portion of the paper. Since the recorder plots time intervals of returning signals, it will also record the slant range corresponding to the vertical distance between the fish

and the sea-bed at its respective range position on the paper. Furthermore, the upward facing lobes of the sonar beam also record the *sea-surface*, which forms a reflecting horizon and appears as a thin undulating line at its respective range position on the paper. This line can easily be distinguished, and by adding the range distance from fish to sea-bed and fish to sea-surface the total water depth can be calculated (fig. 3).

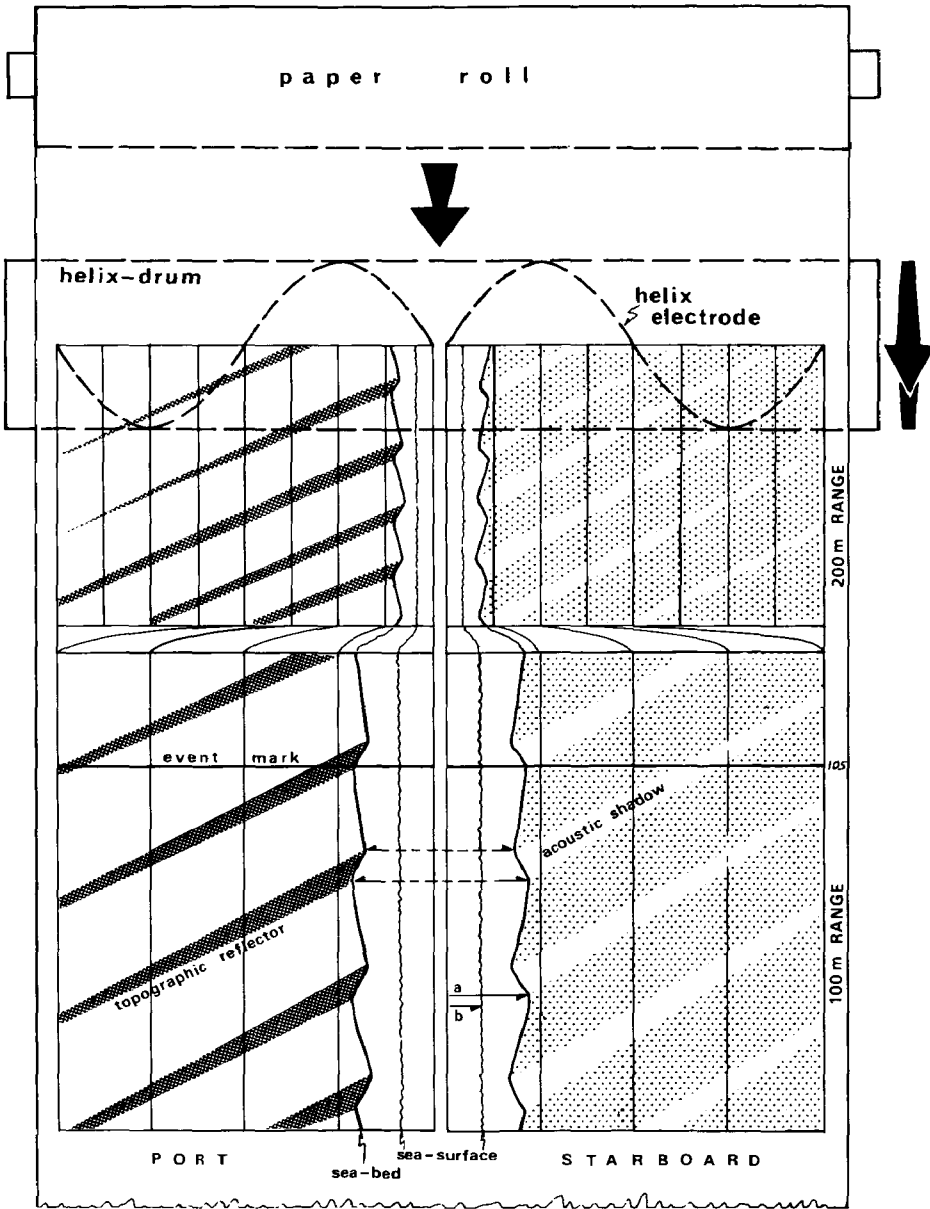


FIG. 3. — Schematic figure illustrating various recording principles :
 height of fish above sea-bed (a) = 20 m; depth of fish below sea-surface (b) = 10 m;
 total water depth (a + b) = 30 m.

The depth profile therefore does not necessarily record true changes in topography only, but will also record a change in the position of the fish relative to the sea-bed. However, since depth profile and sea-surface line are complementary, any change in the position of the fish will always be reflected by a shift of the sea-surface line, whereas true topographic changes will not affect the sea-surface line. This feature is very important because it gives complete control over the position of the fish, a factor that plays such a vital part in the correction of distortions.

OPERATIONAL PROCEDURES

Tow methods

The fish can be towed off the stern of a ship, off either side or even from off the bow. The method adopted depends largely on the objective of the survey and on the environmental conditions such as water depth, sea floor topography and swell conditions. During deep-water surveys the fish is best towed astern, because there it will be far below the surface well away from interfering propeller turbulence. In shallow water the fish is normally towed off port or starboard, where it will also be away from the propeller. However, care must be taken when turning the ship in order to avoid the fish slipping beneath the hull and possibly being damaged by the propeller. The cable should always be secured in a way that will allow quick recovery of the fish.

Tow procedure

- The most effective tow procedure can be summarized as follows :
- Lay out on deck as much cable as will be necessary to effectively scan the deepest parts of the survey area. This becomes unnecessary once a slip-contact cable winch is available;
 - Reduce ship speed to at most 5 knots before lowering fish into the water;
 - Connect fish and recorder, and lower fish into water;
 - Switch on first the recorder and then the trigger;
 - Adopt survey speed, and lower the fish while observing its position relative to the sea-bed on the recorder;
 - Stop lowering once the fish has reached optimum height above sea-bed; usually about 1/10 of the selected scanning range. Short ranges may necessitate raising the fish higher than the optimum, especially in rugged areas. Always maintain a good safety margin;
 - Proceed to survey, annotating event marks at selected time intervals. Adjust fish height above bottom as may become necessary. In emergency situations a sudden increase of ship speed will raise the fish very fast;
 - Increase ship speed when turning on profile in order to avoid the fish sinking to the bottom;
 - After completion of survey, pull in the fish until it becomes visible, then switch off first the trigger and then the recorder, and carefully hoist the fish aboard.

Navigation

Accurate navigation is of paramount importance when performing side-scan sonar surveys, because only then can the position of any recorded feature be accurately determined. Event marks annotated with time, position and control settings should be carefully entered into a special side-scan log. Event marks should not be spaced too far apart. If very accurate surveys are to be carried out then event marks spaced only 2 minutes apart may become necessary, especially when scanning at small ranges where paper feed rates are high. When operating at 200, 250 or 500 m ranges, 5, 10 or 15 minute event spacings will be sufficient. It should be noted that each event mark notes the position of the ship and not the position of the fish. The distance between fish and ship has to be subtracted from the on-line profile when plotting survey sheets.

In areas where automated navigation is not available a local system may have to be set up. Close inshore this is no problem, further out at sea however, new systems have to be introduced. Underwater acoustic triangulation utilizing transponder navigation seems very promising and has reached an advanced stage of development. Various systems and procedures are discussed by SPIESS *et al.* (1969), TYRRELL (1969), MUDIE *et al.* (1970) and KELLAND (1973).

INTERPRETATION OF SONOGRAPHS

Principles

A sonograph consists basically of a sheet of paper marked by shades of varying intensity and resolution. Features with sharp outlines alternate with vaguely defined areas in which subtle changes of tone may occur. To interpret these various appearances correctly we must be aware of the factors that can cause changes in tone or intensity on the recording paper.

There are two main sources of influence that may cause darkening of the recording paper. One is purely electronical, caused by manipulation of the control settings on the recorder. For each channel there are three manipulators. The *general* gain control will intensify all incoming signals evenly across the paper, whereas the two time-varied gain controls *initial* and *slope* gain selectively amplify certain parts of the record more than others in order to compensate for decrease of intensity due to frequency dispersion of the outer range signals.

The second main source is the incoming signals. Here we must distinguish between two types. One type of signal is caused by *material properties* depending on the relative reflectivity of the various materials on the sea-bed. Rock and gravel, for example, are better reflectors than sand and will therefore record darker. Sand, in turn, is a better reflector than mud, etc. The other type of incoming signal is caused by *topographic features*. Slopes facing the transducer reflect sound waves better than surfaces lying oblique to the sound beam and will consequently plot darker.

Material reflectors and topographic reflectors can therefore produce exactly the same effect on the recording paper, and it is often up to the operator to decide which he is dealing with. To do this accurately, he needs experience and preferably first hand knowledge about the particular reflecting patterns caused by various rock types, gravels, sands, and characteristic forms associated with them such as bedding, jointing, ripple marks, sand waves etc. Examples of these will be discussed later by interpretation of selected sonographs.

This delicate interaction between the various signals must constantly be comprehended. If the recorder controls were set such that a smooth sand surface would produce an even, light tone then all other features would record lighter or darker, depending on their relative reflectivity. This would eliminate a misinterpretation of electronically produced effects. Unfortunately, preselected control settings apply only in very smooth areas. In most other areas a continual adjustment of control settings is necessary in order to achieve maximum resolution by compensating for losses or gains in intensity caused by a change in the relative position of the fish above the sea-bed. This can hardly be eliminated without other complications. A careful note should therefore be made of all major changes of control settings by annotating them in the side-scan logbook.

Distortions

Having discussed in fair detail the major system-inherent and operational aspects of side-scan sonar, we can now proceed to factors causing distortions in the records. Sonographs do not normally represent isometric maps of the sea-bed, and various distorting factors have to be observed when reproducing sonograph mosaics in map form. Some practical aids will simplify this process.

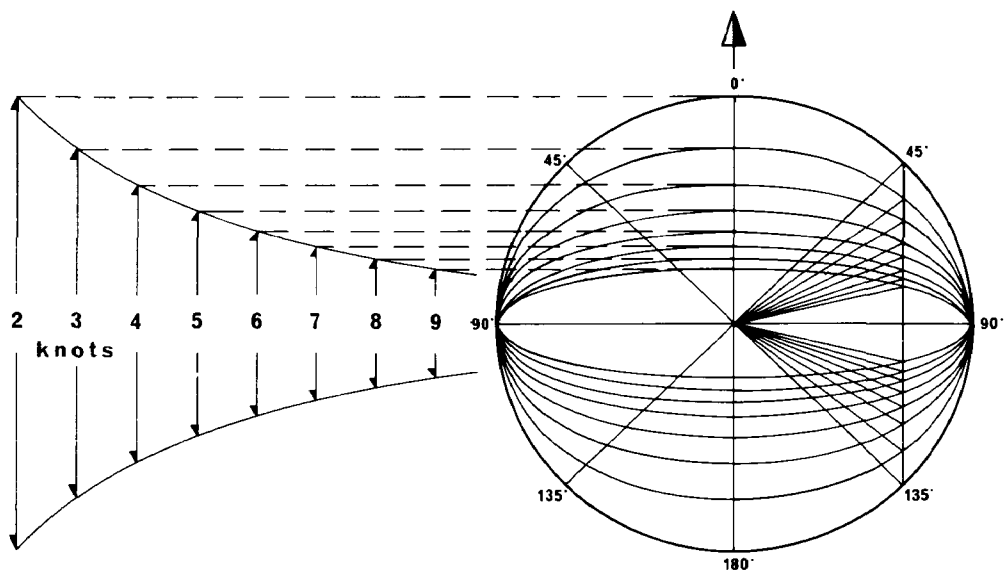


FIG. 4. — Construction figure of distortion ellipses with which the compression effect parallel to the line of travel can be corrected.

An obvious *distortion* will occur *parallel to the line of travel* due to variable ship speeds, resulting in a compression of all sonographs in this direction. The effect is best demonstrated by *distortion ellipses* (NEWTON *et al.*, 1973) which show in simplest form the progressive shortening of the on-line component with increasing speed. Fig. 4 illustrates how the various ellipses are constructed. At about 2 knots virtually no distortion occurs and the ellipse represents more or less a circle. The distorting effect on some common shapes of increasing speed is demonstrated schematically in Fig. 5. The distances covered by the ship in line of travel at various speeds per unit time are listed in Table 2.

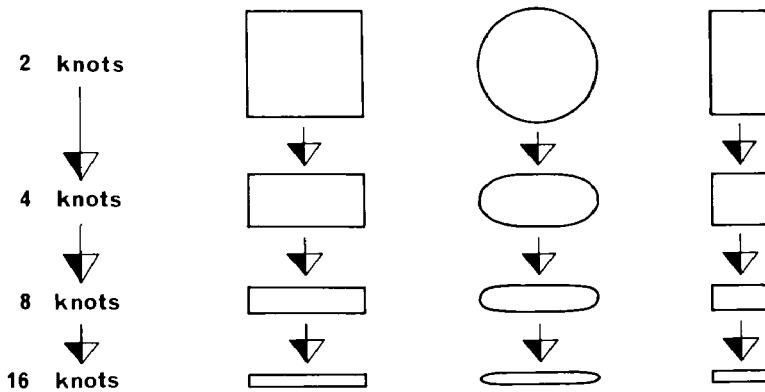


FIG. 5. — Distortion effects on some common shapes parallel to the line of travel caused by various ship speeds.

TABLE 2

*Distance over ground covered in line of travel
at various speeds per unit time*

knots	m/sec	m/min
2	1.028	61.68
2.5	1.285	77.10
3	1.542	92.52
3.5	1.799	107.94
4	2.056	123.36
4.5	2.313	138.78
5	2.570	154.20
5.5	2.827	169.62
6	3.084	185.04
6.5	3.341	200.46
7	3.598	215.88
7.5	3.855	231.30
8	4.112	246.72
8.5	4.369	262.14
9	4.626	277.56

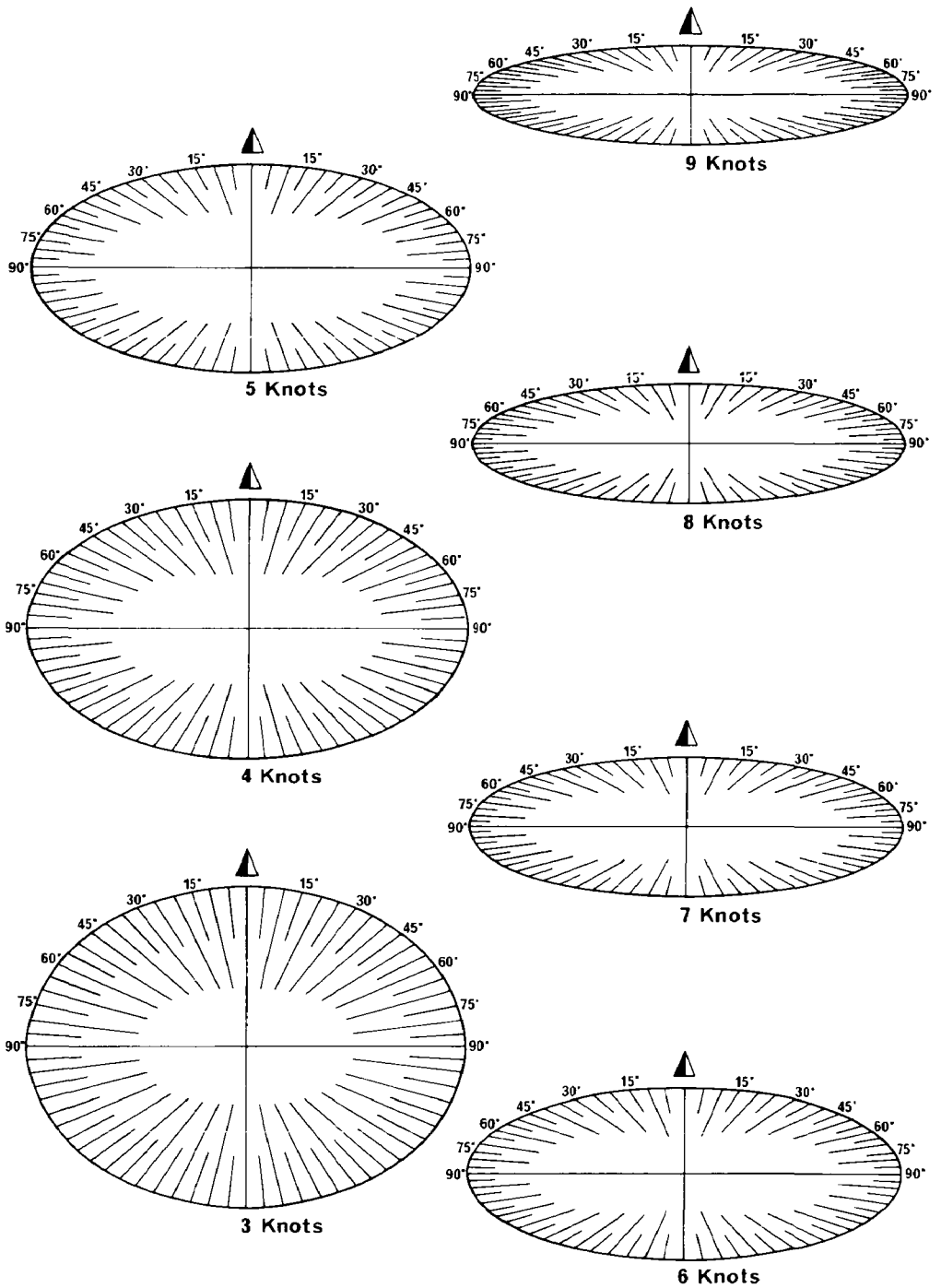


FIG. 6. — Distortion ellipses for various ship speeds.

Another aspect connected with the compressional effect is the distortion of all linear displays. A true angle of e.g. 45° off the line of travel at 2 knots reads in fact 63° at 5 knots and 74° at 9 knots. This effect too is demonstrated in Fig. 4. In order to eliminate these distortions when plotting isometric maps, the author has provided a series of distortion

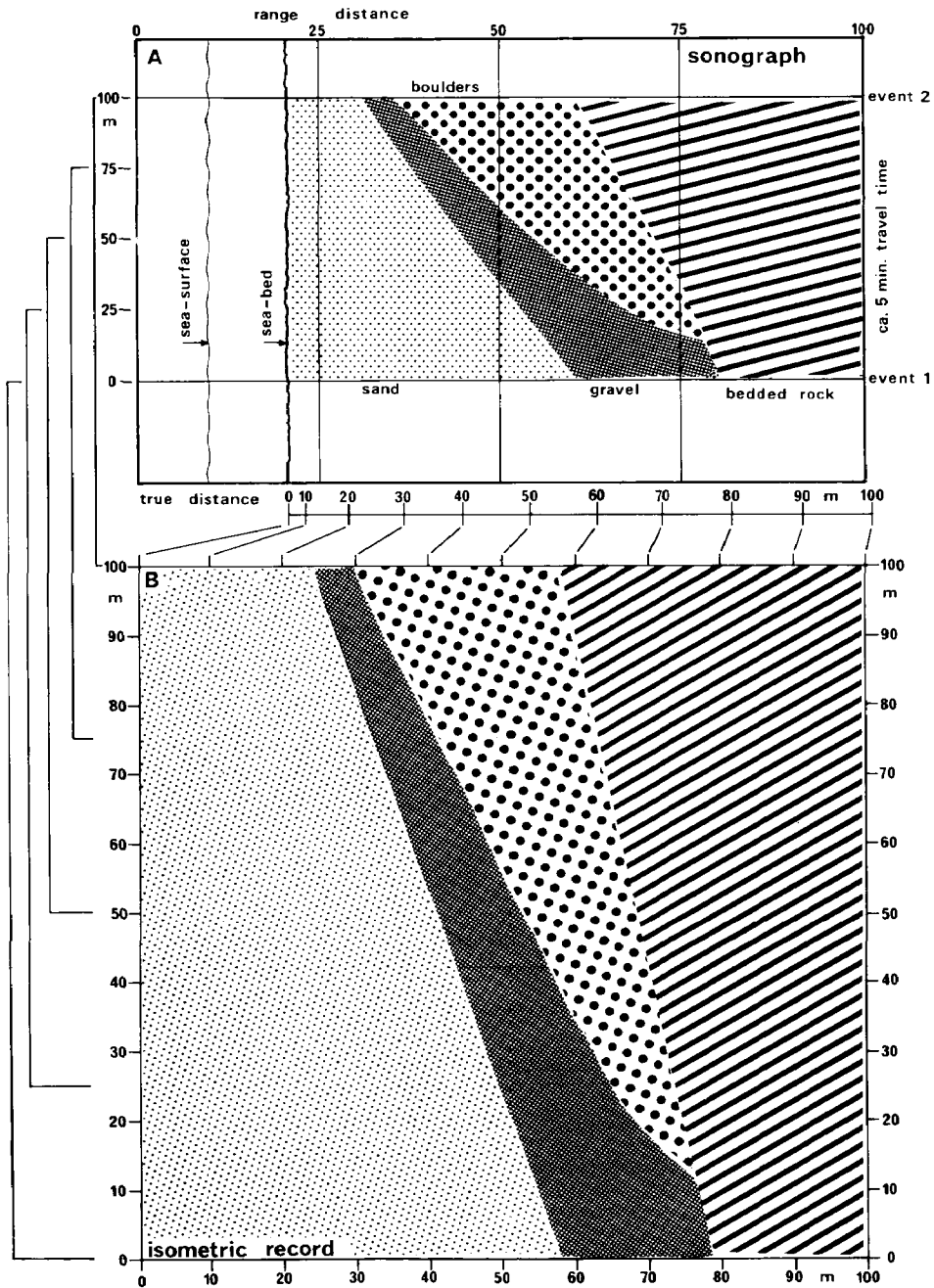


FIG. 7. — Converting a sonograph (A) into an isometric chart (B).
 Ship speed = 6 knots; Range = 100 m; Fish height above bottom = 20 m.

ellipses with their respective true angles for ship speeds between 3 and 9 knots (fig. 6). The result of such a correction is demonstrated in fig. 7.

The height of the fish above sea bed causes a lateral *distortion perpendicular to the line of travel*. Range distance and true distance over ground coincide only on a line horizontally abeam of the fish. Since the fish has to be towed some distance above the sea-bed, a certain amount of the recording paper is lost to the depth profile which plots at its respective range distance. The higher the fish is towed above the sea-bed the more paper is lost for actual recording (fig. 8). This can proceed until the smaller ranges are totally engulfed by the depth profile; e.g., the 50 m range will cease to record the sea-bed at a fish height of 50 m and more. The true distance therefore has to be fitted into the remaining part of the paper, beginning with 0 m where the depth profile begins to record the sea-bed.

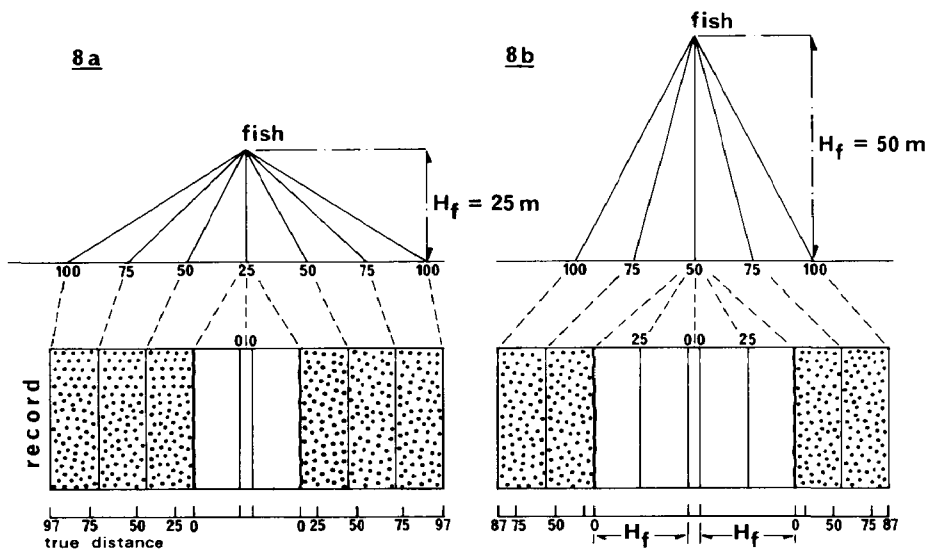


FIG. 8. — Lateral distortion caused by fish height above sea-bed.
a. Fish height = 25 m; b. Fish height = 50 m.

Furthermore, due to the obliquity of the sonar beam, equal true-distance intervals will not follow a linear scale on the sonograph. The short-range intervals are compressed and the far-range intervals slightly stretched. In order to correct this distortion, a linear correction has to be applied which will vary with fish height above sea-bed; ship speed does not affect this lateral component. Correction factors can be calculated and presented in table form or in graph form. The simplest form, however, is a direct conversion of these values into nomograms which can be used like rulers. For a certain fish height above sea-bed and the particular recording range, the respective nomogram is selected and superimposed on the record, thus allowing the true lateral distance to be read off directly. The author has prepared such nomograms for fish heights between 10 and 100 m above sea-bed and for all respective ranges (fig. 10 : 1-10).

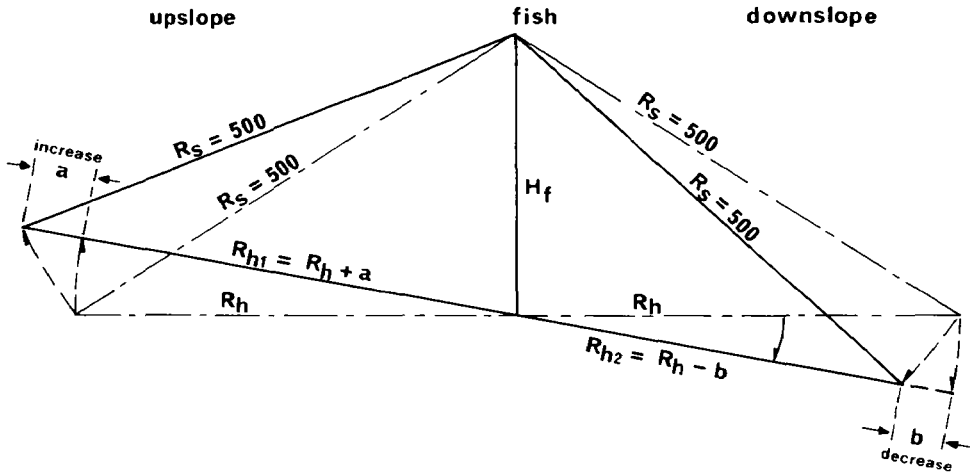


FIG. 9. — Lateral distortion caused by slope in sea-bed.
Upslope : $R_{h1} = R_h + a$; Downslope : $R_{h2} = R_h - b$.

These corrections apply strictly for plane sea-beds only, and other nomograms would have to be calculated and drawn for various slopes of sea-bed in relationship to fish height and range. Fig. 9 illustrates the complexity of distortions caused by sloping sea-beds; e.g. a 10° slope would increase the upslope component by ca. 13%, whereas the downslope component would be reduced by ca. 12%, thereby compressing and stretching the lateral distance on the respective channel. Commonly, sea-bed slopes rarely exceed $1^\circ - 2^\circ$, and correction of the resulting small distortion would hardly be worth the effort. Similarly, distortions caused by density gradients in the water column are normally small, and correction would become necessary only where large gradients are observed. In such cases detailed density surveys would have to precede the side-scan operation.

Interferences

There are three main sources of acoustic interferences which will produce characteristic patterns on the sonograph.

A *continuous interference* pattern overlying the sonograph is caused by *seismic instruments* run simultaneously with the side-scan sonar. The combination of surface mapping and sub-bottom profiling, however, yields valuable information for the marine geologist besides being more economic, and interference can be reduced considerably by running both instruments well apart.

A second type of *interference* is caused by *dense particle suspension* in the water column. Whenever suspension becomes dense enough the sonar beam is partially dispersed and partially reflected before it reaches the sea-bed, resulting in white gaps through all ranges, whereas the area within the depth profile is blackened. Similar effects, but in form of scattered dark patches with sharp outlines, are produced by shoals of fish.

A third type of frequent *interference* is caused by *ultrasonic waves* generated by passing ships. It forms a discrete pattern and can easily be distinguished from other interferences. It is similar to seismic interference without, however, being continuous. Examples of these main interferences are presented in the appendix.

CONCLUSION

Producing isometric maps from sonograph mosaics is a tedious and time-consuming undertaking, even when all the practical aids presented and discussed here are applied. BERKSON & CLAY (1973), HOPKINS (1972a) and SPOTTISWOODE & DOBSON (1975) discuss methods that will accelerate considerably the manual draughting process. However, when much detailed work is envisaged then computerization of the isometric reproduction process will become inevitable. In recent years a number of attempts towards this solution have been undertaken, and the most promising results so far have been achieved by workers at Bath University, England (HOPKINS 1972b, KELLAND & HOPKINS 1972, KELLAND 1972).

For practical reasons it is advisable to photograph all sonographs that display meaningful features and to store the negatives in a file system. This will ensure that records remain intelligible even after long storage, which has a clear detrimental effect on the quality of the original records.

SONOGRAPH EXAMPLES

To assist in the interpretation of the aspects discussed in this article, a number of selected sonographs are presented below in an appendix. Since all these sonographs are original recordings, hitherto unpublished, from the South African continental margin they contain valuable information about the geology and sedimentology of this area.

ACKNOWLEDGEMENTS

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REFERENCES

- BELDERSON, R.H., KENYON, N.H., STRIDE, A.H., STUBBS, A.R. (1972) : Sonographs of the Sea Floor. Elsevier Scientific Publ. Co., Amsterdam.
- BELDERSON, R.H., KENYON, N.H., STRIDE, A.H. (1974) : Features of submarine volcanoes shown on long range sonographs. *J. Geol. Soc. Lond.*, 130, pp. 403-410.
- BERKSON, F.M., CLAY, C.S. (1973) : Transformation of side-scan records to a linear display. *Int. Hydrogr. Rev.*, 50 (2), pp. 55-59.
- BRYANT, R.S. (1975) : Side Scan Sonar for Hydrography. *Int. Hydrogr. Rev.*, 52 (1), pp. 43-56.
- CHESTERMAN, W.D., CLYNICK, P.R., STRIDE, A.H. (1958) : An acoustic aid to sea bed survey. *Acustica*, 8, pp. 285-290.
- CHESTERMAN, W.D., ST. QUINTON, J.M.P., CHAN, Y., MATTHEWS, H.R. (1967) : Acoustic surveys of the sea floor near Hong Kong. *Int. Hydrogr. Rev.*, 44 (1), pp. 35-54.
- CHESTERMAN, W.D., WONG, H.K. (1971) : Bottom sediment distribution in certain inshore waters of Hong Kong. *Int. Hydrogr. Rev.*, 48 (2), pp. 51-69.
- CLAY, C.S., ESS, J., WEISMAN, I. (1964) : Lateral echo sounding of the ocean bottom on the Continental Rise. *J. Geoph. Res.*, 69 (18), pp. 3823-3835.
- GENTLE, R.I. (1973) : Sidescan sonar in marine geological investigations of the South African continental margin. *S. Afr. J. Sci.*, 69 (Dec.), pp. 360-367.
- HOPKINS, J.C. (1972a) : A note on methods of producing corrected side scan sonar displays. *Int. Hydrogr. Rev.*, 49 (2), pp. 100-106.
- HOPKINS, J.C. (1972b) : Tape recording of side scanning sonar signals. *Int. Hydrogr. Rev.*, 49 (1), pp. 59-70.
- KELLAND, N.C., HOPKINS, J.C. (1972) : Mosaics from high resolution side scan sonar. *Offshore Services*, Oct. 1972, pp. 34-35.
- KELLAND, N.C. (1972) : Preparation of isometric records from high resolution side scanning sonar data using the Bath University playback equipment. UCS Internal Report 72/23.
- KELLAND, N.C. (1973) : Assessment trials of underwater acoustic triangulation equipment. *Int. J. Naut. Archaeol. Underwater Expl.*, 2 (1), pp. 163-176.
- LAUGHTON, A.S., RUSBY, J.S.M. (1975) : Long-range sonar and photographic studies of the median valley in the FAMOUS area of the Mid-Atlantic Ridge near 37° N. *Deep-Sea Research*, 22, pp. 279-298.
- LEENHARDT, O. (1974) : Side scanning sonar - A theoretical study. *Int. Hydrogr. Rev.*, 51 (1), pp. 61-80.
- McKINNEY, R.F., STUBBLEFIELD, W.L., SWIFT, D.T.P. (1974) : Large-scale current lineations on the central New Jersey shelf : investigations by side-scan sonar. *Marine Geology*, 17, pp. 79-102.

- MUDIE, J.D., NORMARK, W.R., CRAY, E.J. (1970) : Direct mapping of the sea floor using side-scanning sonar and transponder navigation. *Geol. Soc. Am. Bull.*, 81, pp. 1547-1554.
- NEWTON, R.S., SEIBOLD, E., WERNER, F. (1973) : Facies distribution patterns on the Spanish Sahara continental shelf mapped with side-scan sonar. *"Meteor" Forsch.-Ergebnisse*, Reihe C, pp. 55-77.
- RUSBY, S. (1970) : A long range side-scan sonar for use in the deep sea. *Int. Hydrogr. Rev.*, 47 (2), pp. 25-39.
- SANDERS, J.E., CLAY, C.S. (1968) : Investigating the ocean bottom with side-scanning sonar. In MORGAN, PARKER (Eds.) : Proc. 5th Symp. remote sensing of environment. Ann Arbor, Michigan, Inst. Sci. and Techn., Willow Run Lab., Univ. Michigan.
- SANDERS, J.E., EMERY, K.O., UCHUPI, E. (1969) : Microtopography of five small areas of the continental shelf by side-scanning sonar. *Geol. Soc. Am. Bull.*, 80, pp. 561-572.
- SPIESS, F.N., LOUGHRIDGE, M.S., McGEHEE, M.S., BOEGEMAN, D.E. (1969) : An acoustic transponder system. *Int. Hydrogr. Rev.*, 46 (2), pp. 139-151.
- SPOTTISWOODE, J., DOBSON, M. (1975) : A fibre optic recording oscilloscope for the display of side-scan sonar and seismic data. *Marine Geology*, 18 (5), pp. M73-M85.
- TUCKER, M.J., STUBBS, A.R. (1961) : A narrow-beam echo-ranger for fishery and geological investigations. *Brit. J. Appl. Phys.*, 12, pp. 103-110.
- TUCKER, M.J. (1966) : Sideways looking sonar for marine geology. *Geo-Marine Technology*, 2 (9), pp. 18-23.
- TYRRELL, W.A. (1969) : Underwater acoustic positioning - Principles and problems. *Int. Hydrogr. Rev.*, 46 (2), pp. 117-137.
- WERNER, F. (1975) : Principios de interpretación del sonar lateral y ejemplos de aplicación en la plataforma continental Argentina. (In press, Argentina).
- WERNER, F., NEWTON, R.S. (1975) : The pattern of large-scale bed forms in the Langeland Belt (Baltic Sea). *Marine Geology*, 19 (1), pp. 29-59.
- WONG, H.K., CHESTERMAN, W.D., BROMHALL, J.D. (1970) : Comparative side-scan sonar and photographic survey of a coral bank. *Int. Hydrogr. Rev.*, 47 (2), pp. 11-23.
- WOOD, A.B., SMITH, F.D., McGEACHY, J.A. (1935) : A magnetostriction echo depth recorder. *T.I.E.E.*, 76, pp. 550-563.

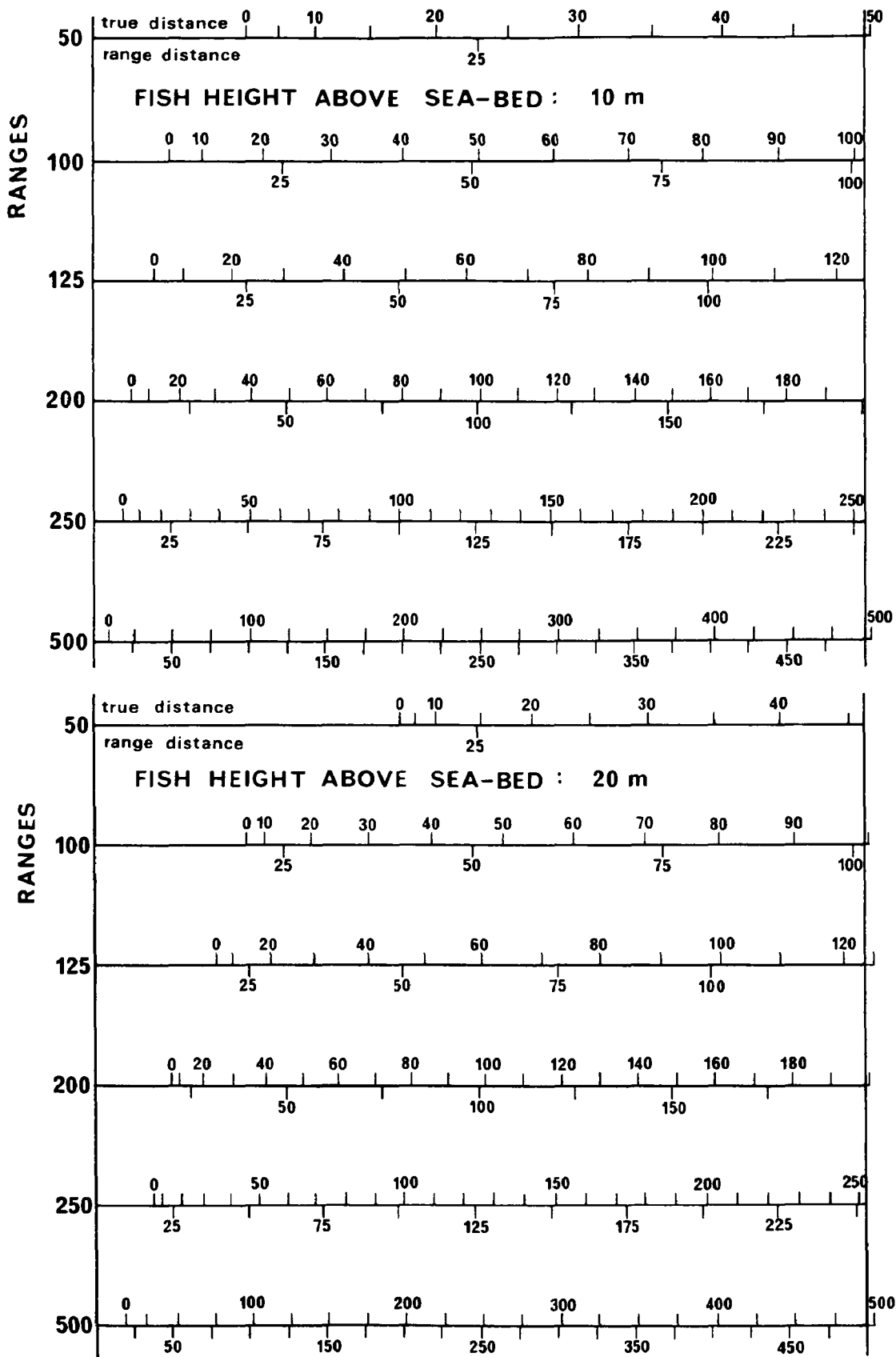
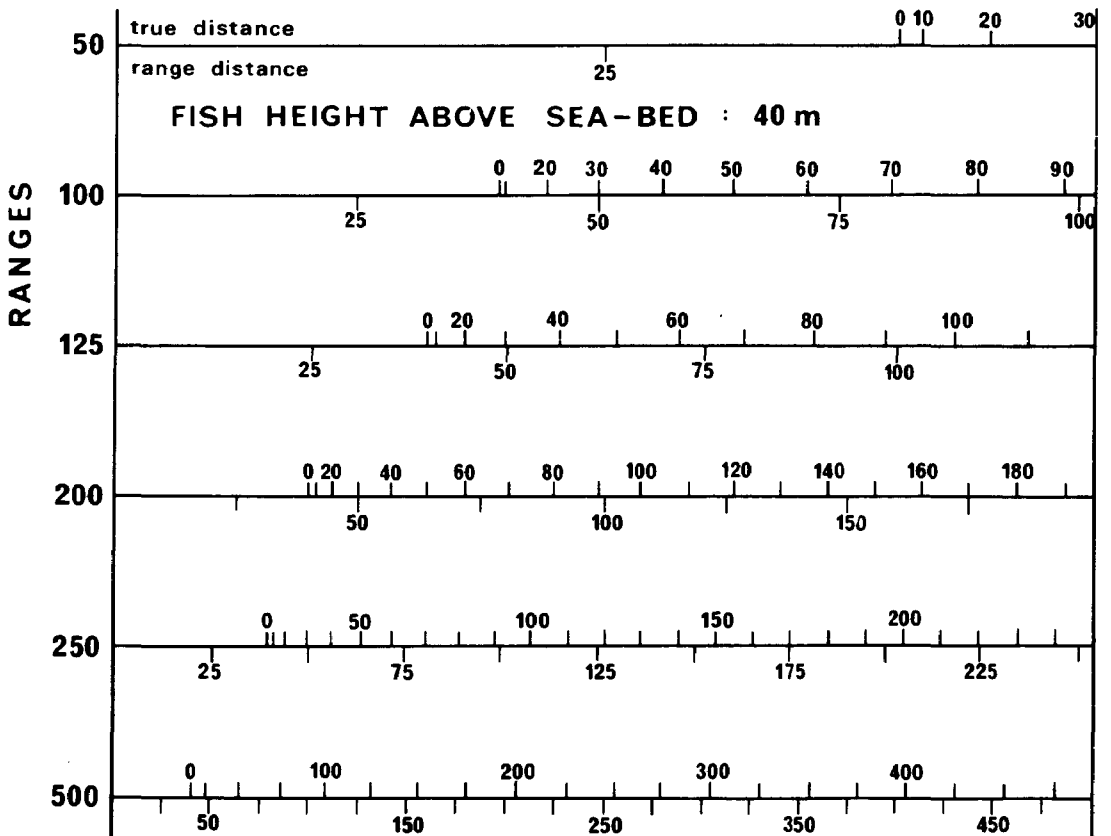
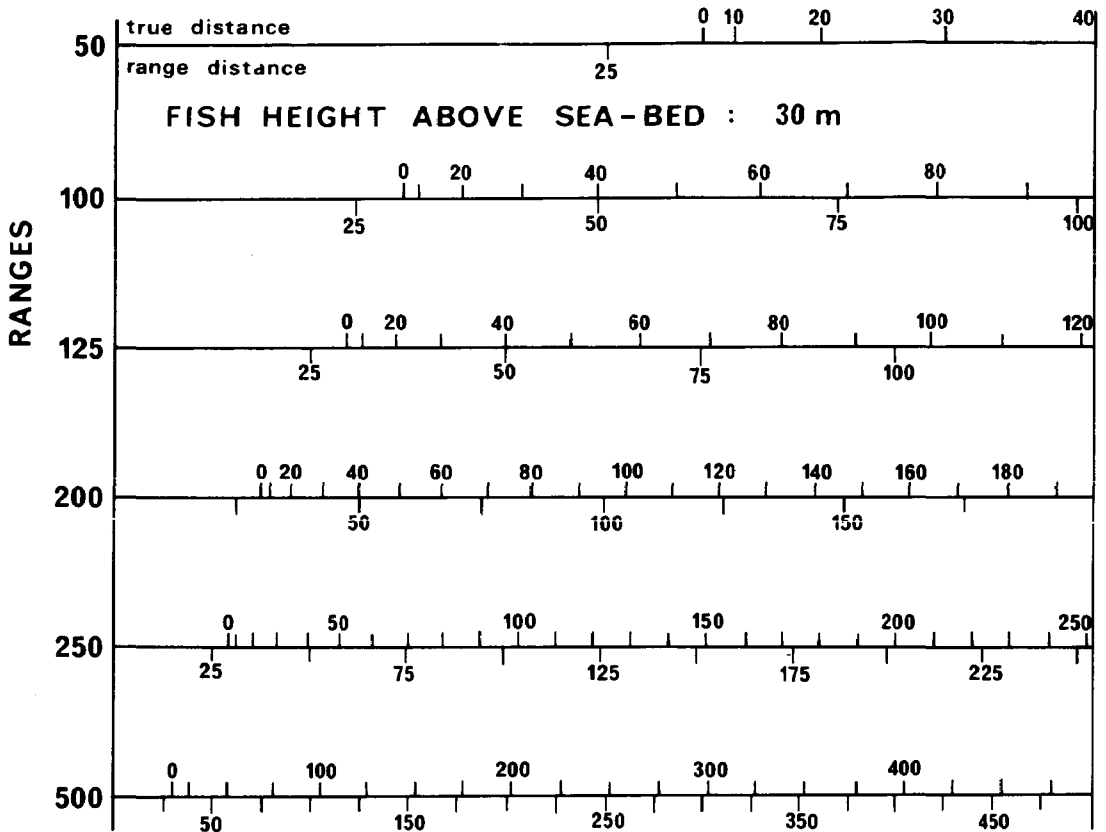
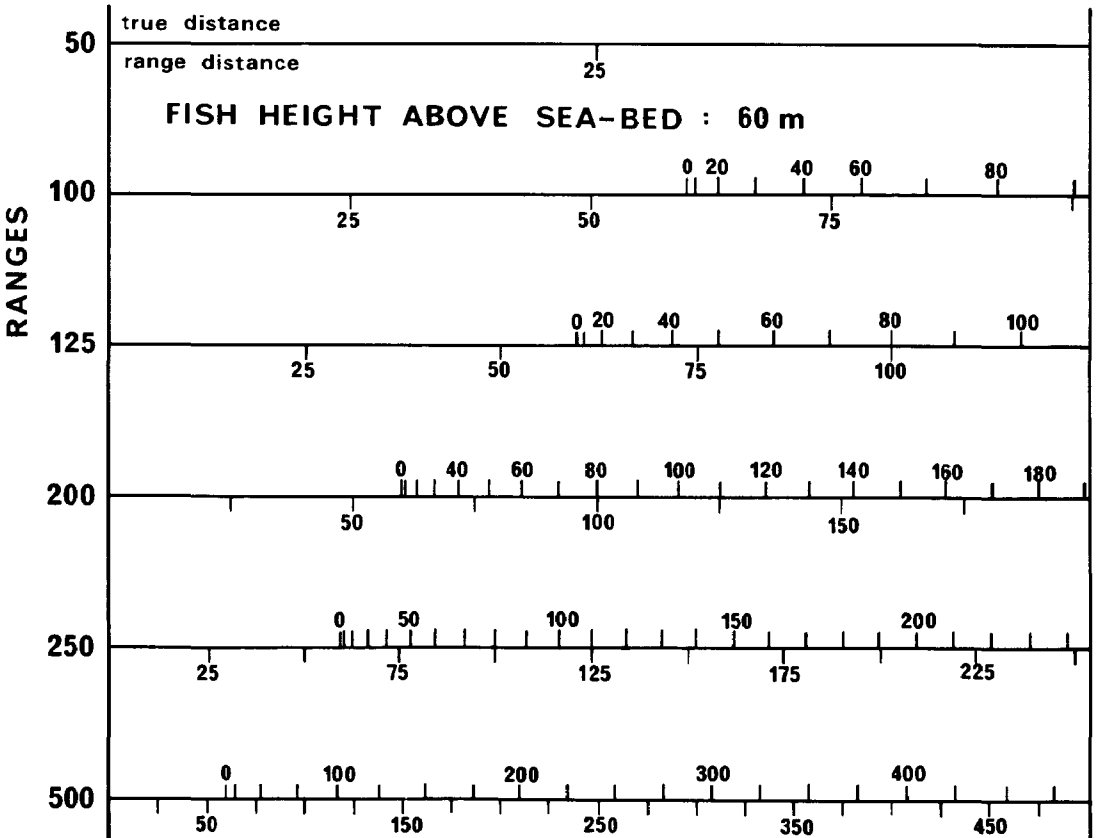
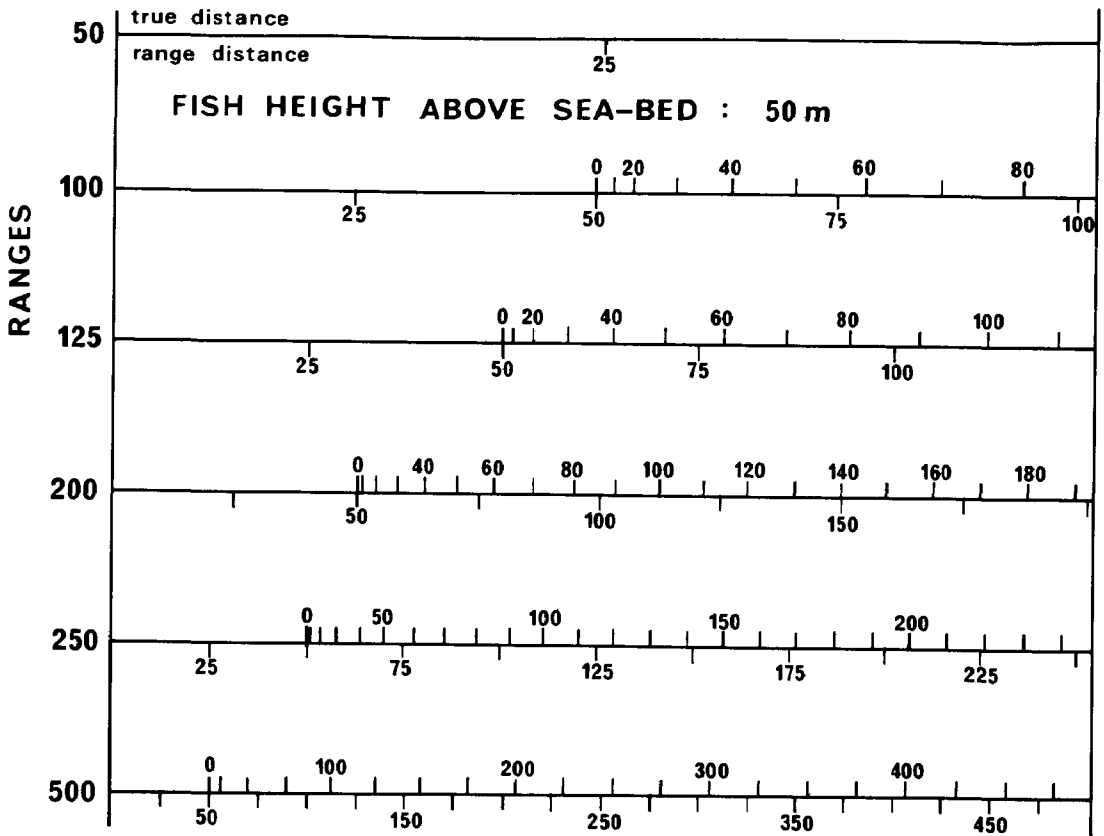
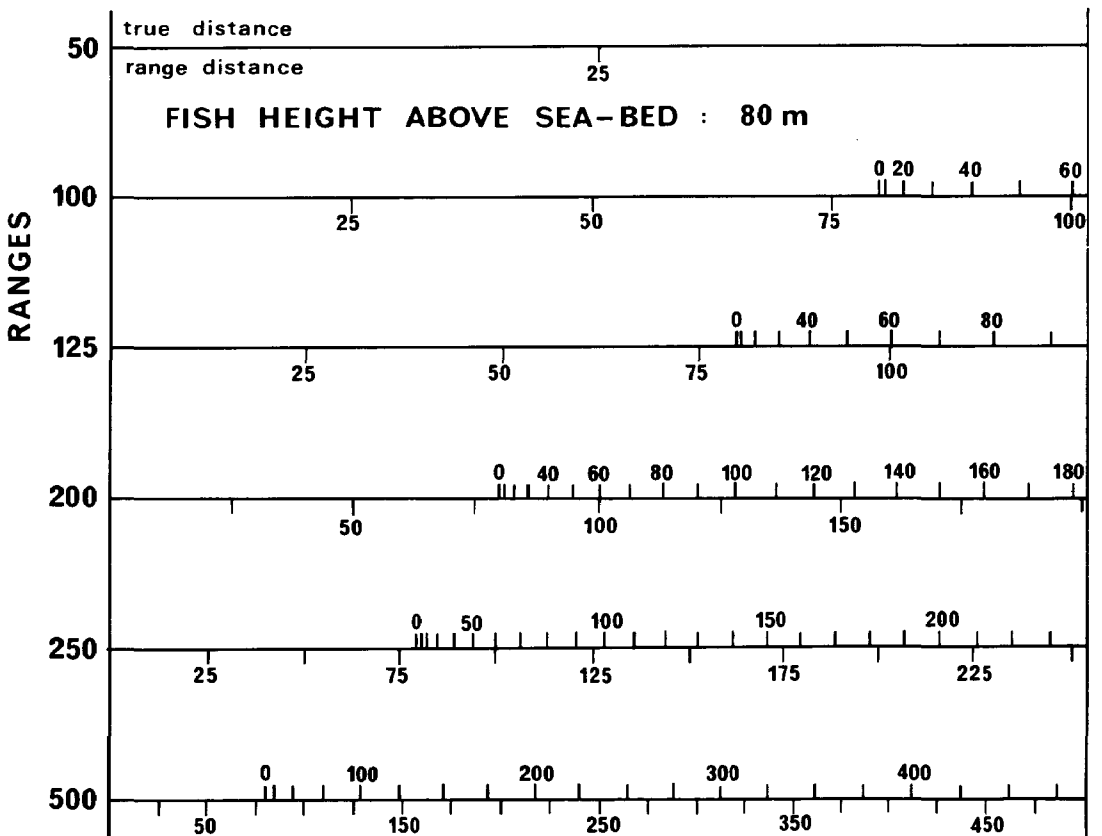
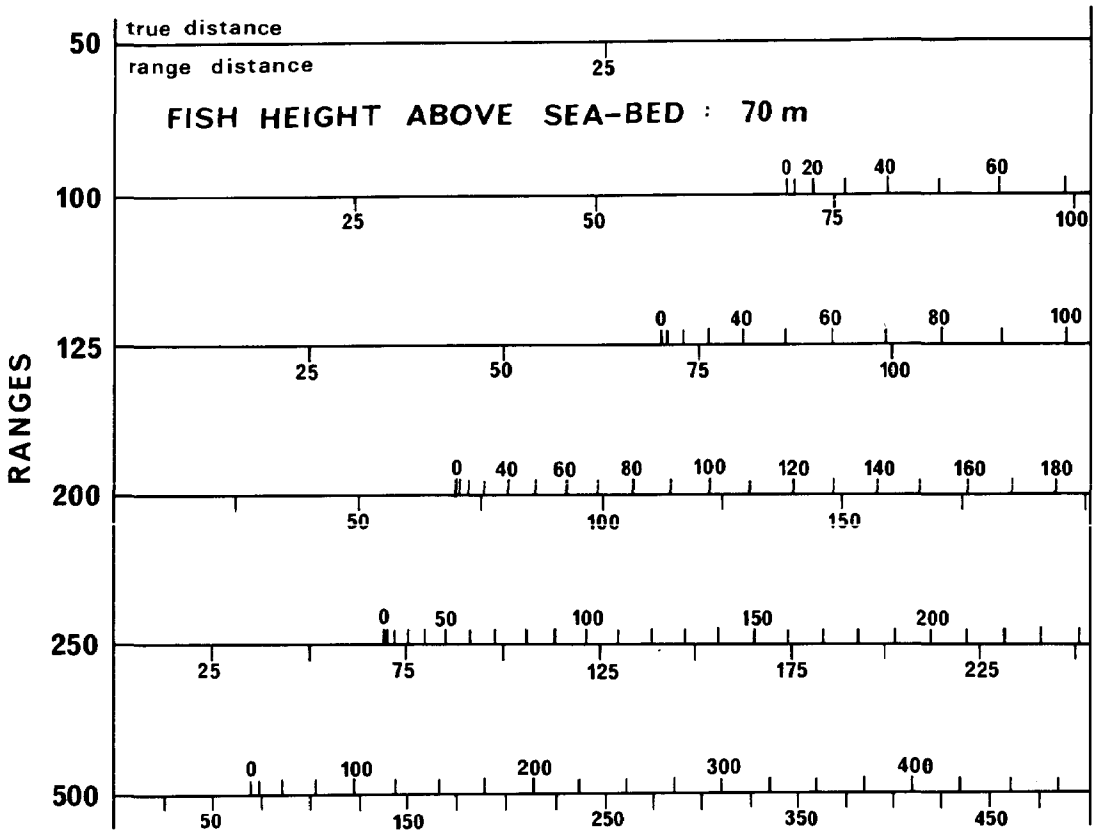
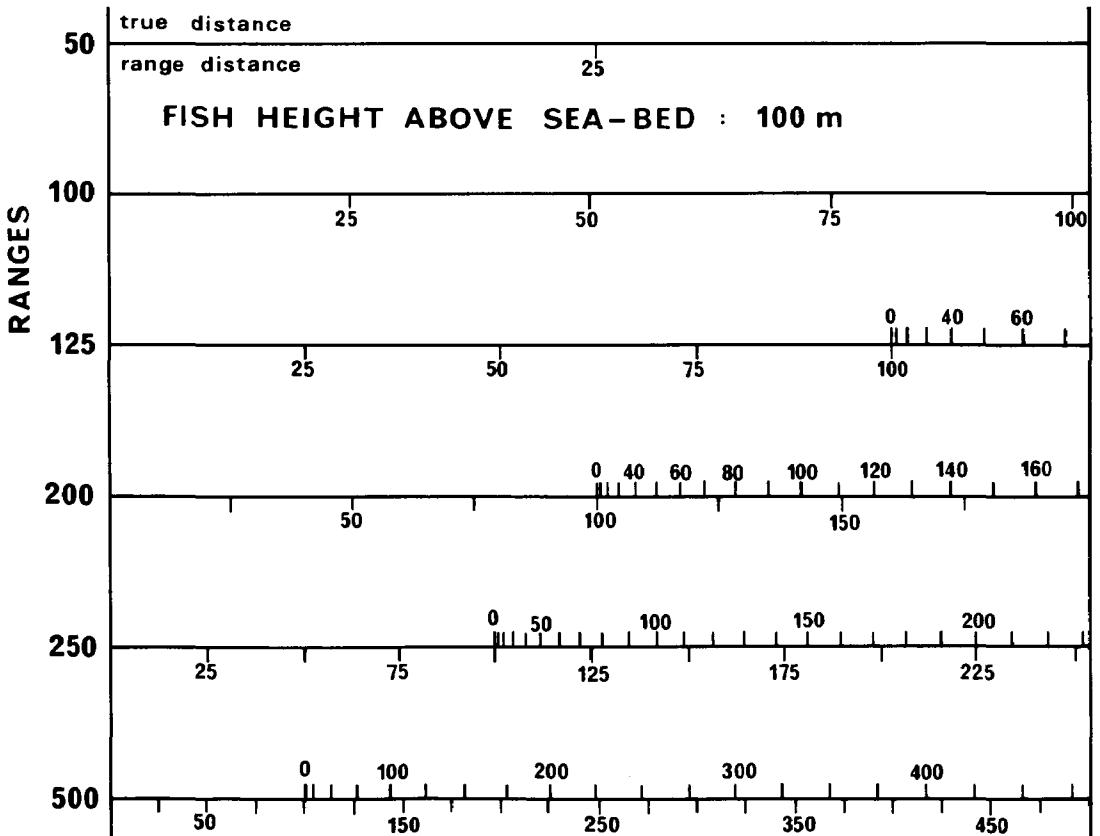
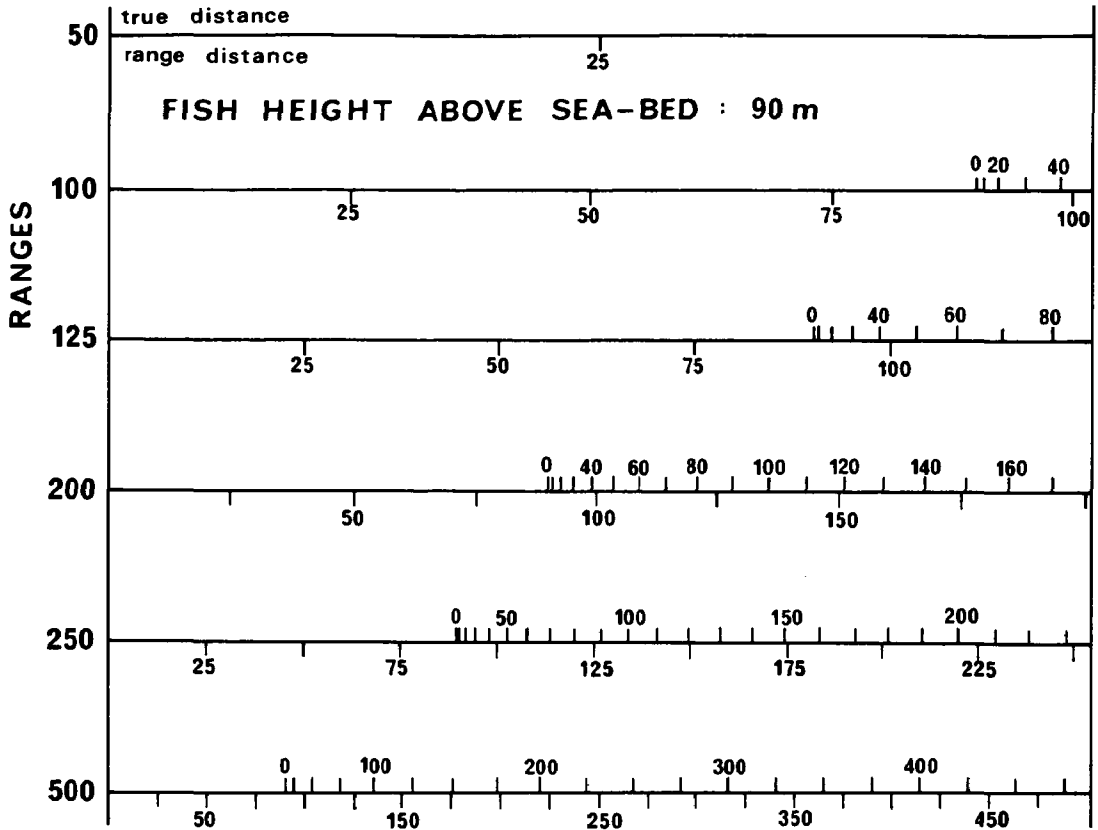


FIG. 10, 1-10. — Nomograms for conversion of range distances into true distances over ground (Scale 1/1).









APPENDIX

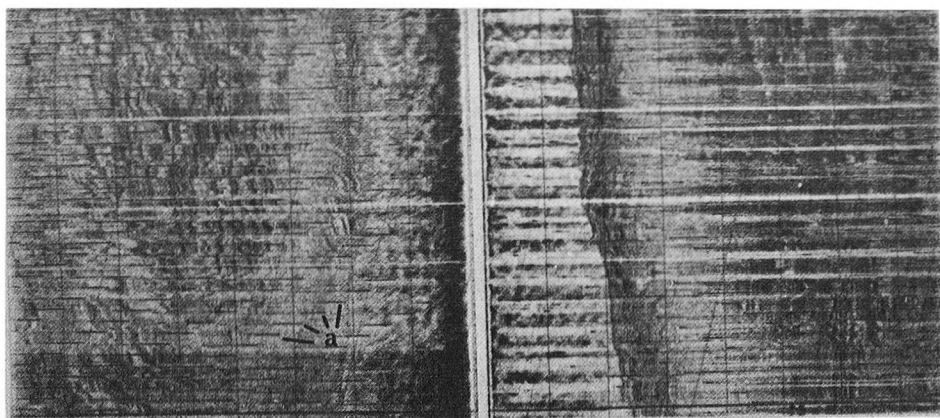


FIG. 11. — The continuous pattern of parallel dark dashes (a) are caused by a seismic instrument (boomer) run simultaneously with the side-scan sonar.

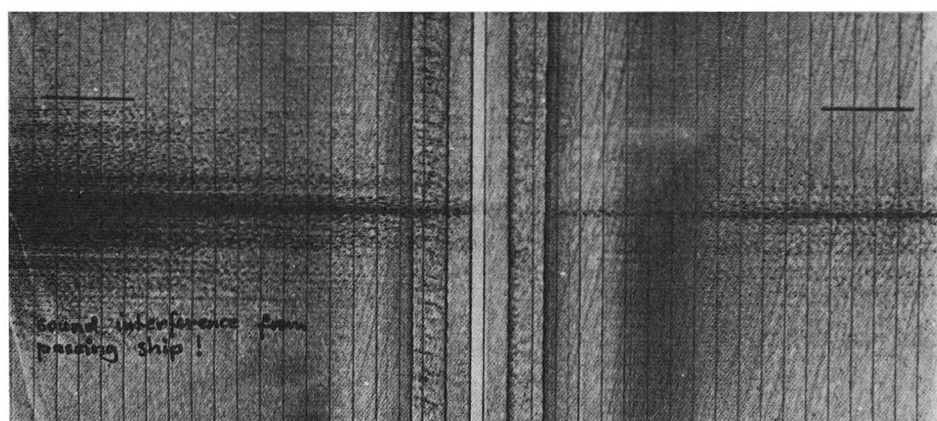


FIG. 12. — A typical interference pattern is caused by ultrasonic waves generated by a passing ship.

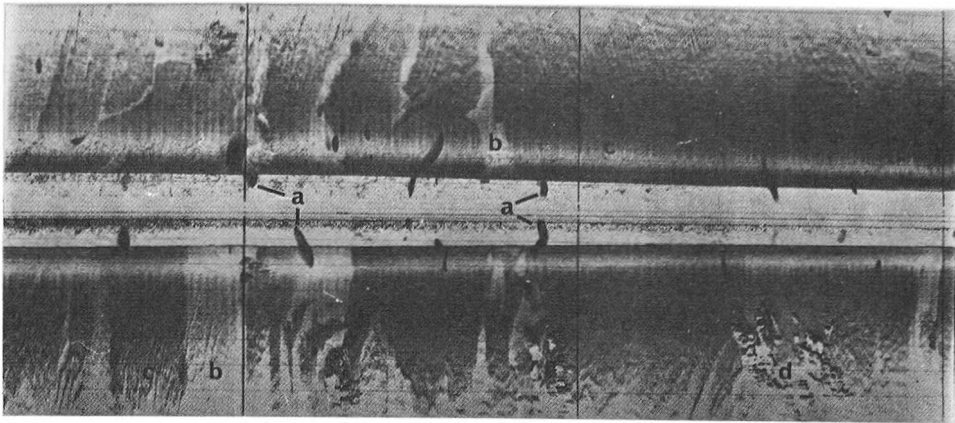


FIG. 13. — The sharply outlined, dark patches (a) are caused by shoals of fish. The light and dark sea-bed features (b = sand, c = gravel) are due to material reflectors and not topography, as indicated by the smooth depth profile. At lower right (d) isolated rock outcrops produce topographic reflectors associated with acoustic shadows.

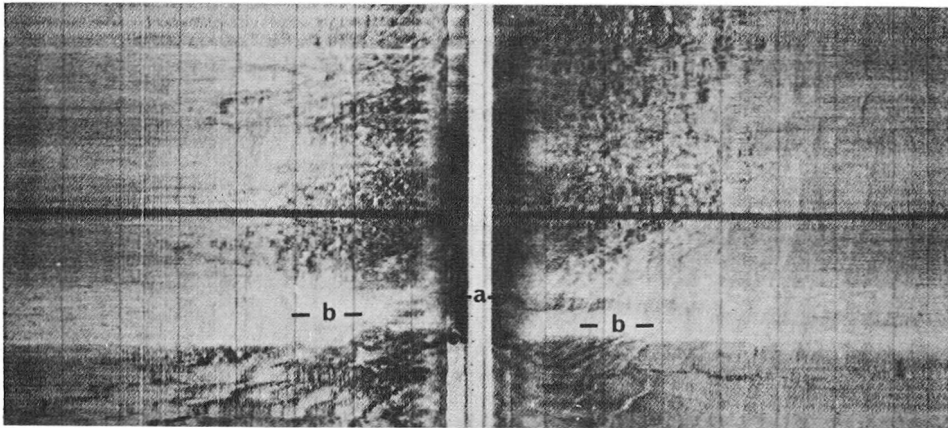


FIG. 14. — Dense particle suspension in the water column (a) forms a diffuse reflector which partially or totally obliterates the sea-bed. Where suspension is densest (b) it results in an acoustic shadow.

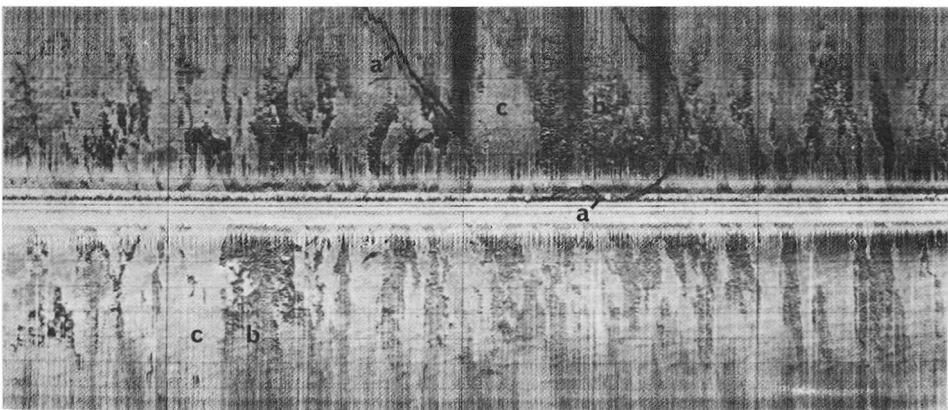


FIG. 15. — The turbulent wake of a small boat forms a reflecting trail (a). The pattern on the sea-bed is mainly due to material reflectors. A low calcareous abrasion platform (b) is partially covered by sand (c).

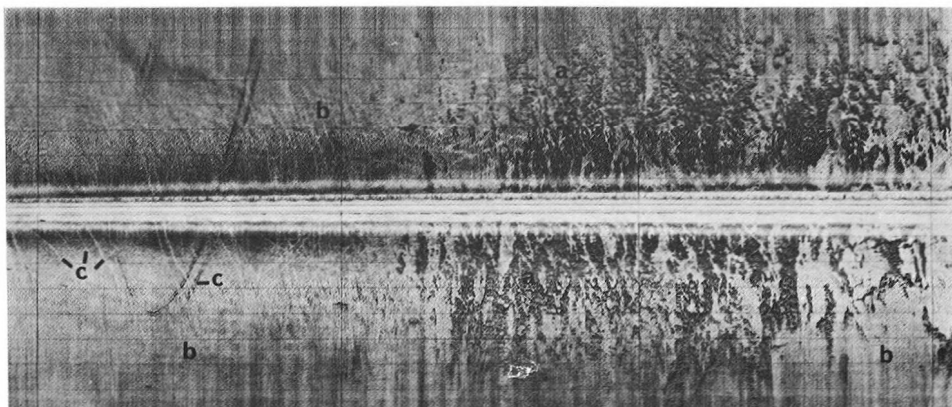


FIG. 16. — Material reflectors are here weakly emphasized by low topography (a = calcrete, b = sand). Very subtle changes in topography are often clearly recorded if they form a continuous linear pattern such as the traces of a suction dredger on the left (c).

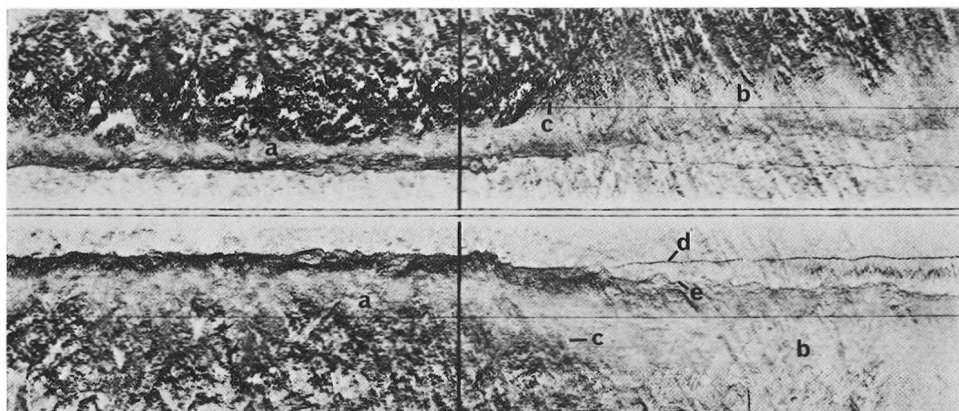


FIG. 17. — Similar materials are here strongly emphasized by high topography and structural differences (a = granite, b = shale, c = contact zone). Note the artificial slope in sea-bed caused by a change in ship speed which is indicated by a shift in the sea-surface line (d) and a corresponding shift in the opposite direction by the depth profile (e).

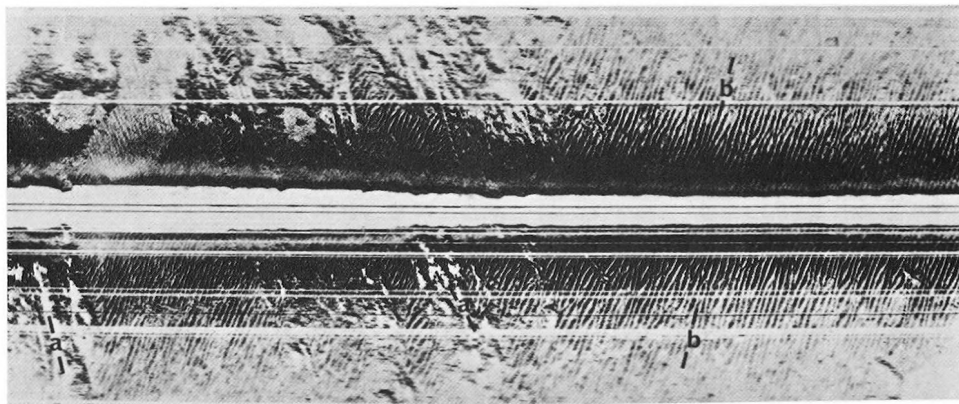


FIG. 18. — The strike direction of bedded rock is emphasized by corresponding acoustic shadows (a). Between outcrops extensive areas are covered by gravels displaying wave ripple marks (b). The wavelength is about 1.5 m. Note the bifurcation of individual ripples.

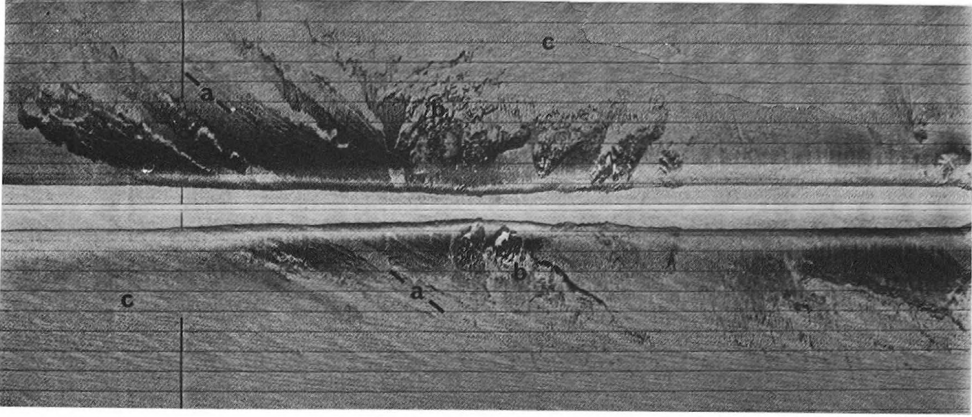


FIG. 19. — The dark reflectors are produced by low outcrops of bedded rock (a) which is partially covered by irregular algal reef bioherms (b). Both are partially blanketed by sand (c), indicating the reefs to be relict features. (Continental shelf off Natal, South Africa.)

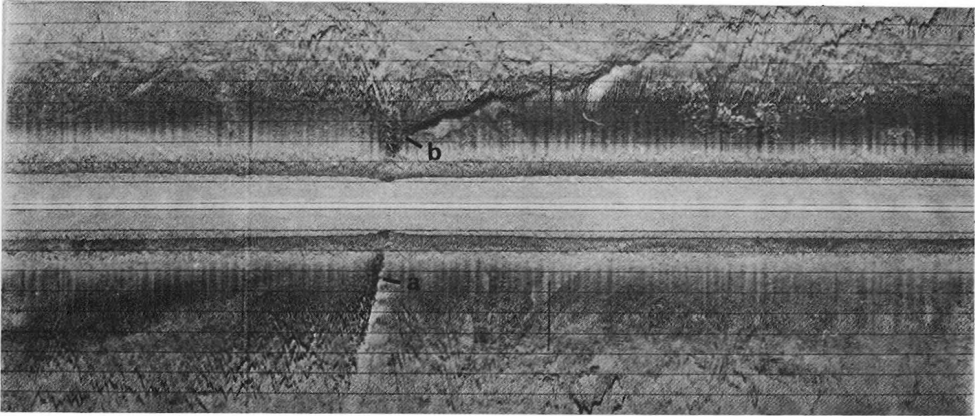


FIG. 20. — A fault associated with a dyke (a) truncates a bedrock bench (b). This feature on the African east coast shelf suggests that the bedrock may be a member of the Karroo System.

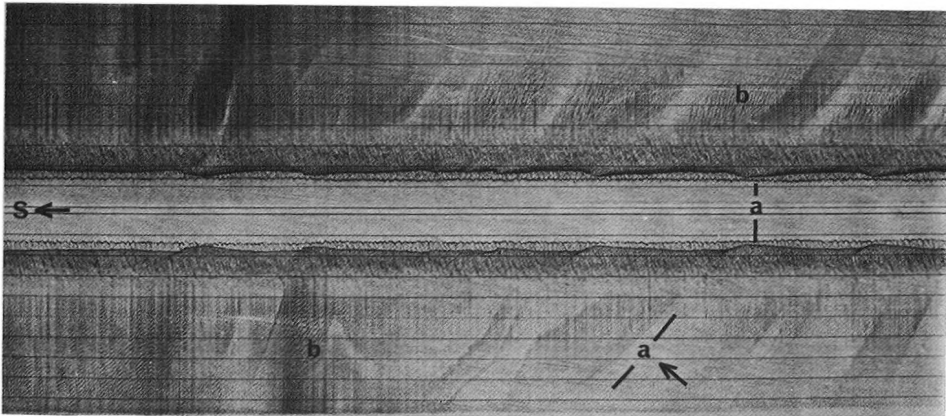


FIG. 21. — The east coast shelf of Southern Africa is characterized by large areas of underwater dunes, which are recorded as topographic reflectors (a). These dunes, moving south with the Mozambique Current, are up to 6 m high. Climbing megaripples (b) indicate fluctuations in the current velocities which result in smaller bed forms.



FIG. 22. — Dark reflectors are here produced by material (a) as well as topography (b) Large sand waves break up in the turbulent flow produced by the rough bedrock surface

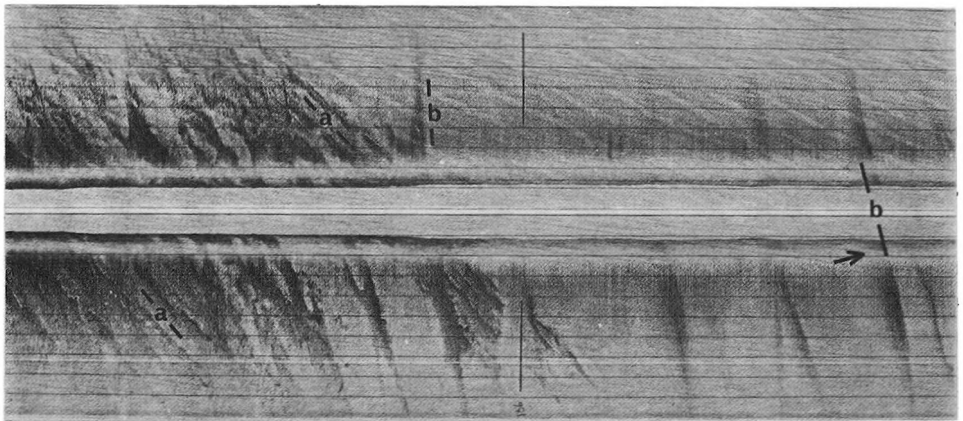


FIG. 23. — Material reflectors (a) and topographic reflectors (b) form an interference pattern due to different strike directions of bedded rock and low sand waves.

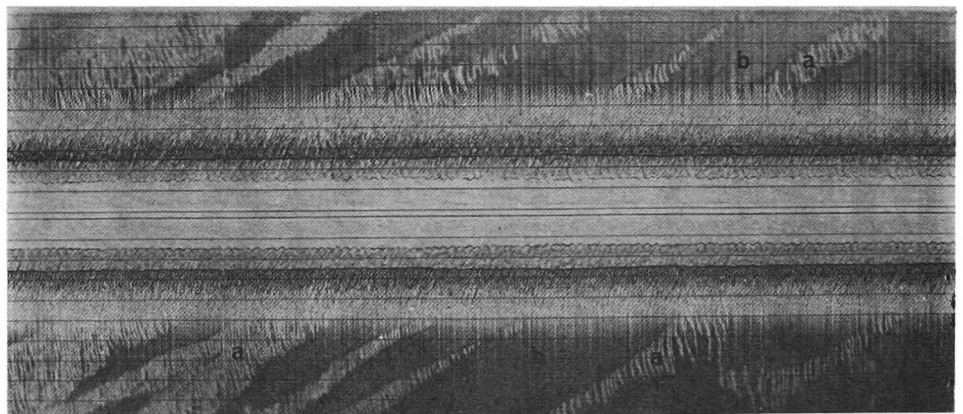


FIG. 24. — Sand ribbons with megaripples (a) overlie gravel (b). The arrangement and structure of the sand ribbons are indicative of strong near-bottom currents of *ca.* 2.5 knots (1.3 m/sec).