DIRECTIONAL ECHO SOUNDING ON HYDROGRAPHIC SURVEYS

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ABSTRACT

Results obtained by using directional sounding equipment are presented together with a discussion and illustrations. It is shown that directional traces can be considered slope-corrected and that they exhibit other characteristics which can be utilized to advantage on hydrographic surveys in deep ocean areas.

DISCUSSION

Effective application of echo sounding equipment utilizing standard wide cones of acoustic energy (approximately 60 degrees) is being accomplished with cognizance of the composite-type effect of the profile achieved on the recording instrument. This effect can be attributed to the width of the outgoing beam of sound, the recorded profile representing the first returns to the transducer. In the case of certain slopes this may or may not be the true depth under the ship; it is instead indicative of the shortest distance between a reflecting surface and the hydrophone. Where situations exist that cause this slope effect, the true depth can be computed through slope-correction procedures. Where only a general slope is involved, it is usually a simple matter to portray true depth by the graphic method of slope-correction, although it is admittedly a time-consuming process. That characteristic of the wide-beam echo sounder which causes slope effect also causes a multiplicity of side echoes to be recorded in areas of rugged terrain. Slope-correction procedures cannot cope with the mass of conflicting data in this case with any semblance of reasonable accuracy. As SHALOWITZ and others have determined, it is virtually impossible to represent the true bottom by slope-correction procedures in areas of very complex and irregular topography, despite the fact that working approximations must be attempted on occasion.

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Although directional echo sounding has been used to a limited extent in the past, it is only recently that extensive surveys have been conducted with this type of sounding equipment. The results presented in this study were obtained by vessels of the U. S. Navy Hydrographic Office in various parts of the world. Lorac and Shoran were used as position control, since large scale surveys demanding fairly tangential bottom coverage require control systems sufficiently accurate to permit closely spaced lines of sounding (50-100 metres). In addition to adequate position control, directional transducers must be stabilized for roll and pitch to allow the beam of acoustic energy to be directed vertically. Directional transducers have proven a failure in some instances in the past because they were so fixed to the hull of the ship that the slightest roll or pitch made them insensitive to the few echoes returning from the bottom (GALWAY, 1951). The stabilization of the directional transducer used in this study was accomplished by means of gyro-driven potentiometers, one for roll and one for pitch. These potentiometers control servo-amplifiers which direct hydraulically-actuated pistons to compensate for pitch or roll.

A valuable assist in this type of survey is the simultaneous operation of the stabilized, narrow-beam (directional) transducer with the standard wide-beam transducer, with the respective profiles presented on individual recorders. A large transducer used with the standard Sonar Sounding Set results in a 6 ½-degree cone of sound at — 10 db at 34 KC operation This equipment, when operated concurrently with another sounding unit employing a standard, smaller transducer, results in a 60-degree cone of sound at — 10 db at 12 KC operation. This latter transducer is non-directional and is fixed to the hull of the ship. Directional use of the stabilized transducer is facilitated by varying the frequency output, 12 KC through the narrow-beam head results in a 16-degree cone of sound (fig. 1). The standard sounding unit transmits 800 watts of pulsed electrical energy which is converted in the transducer into acoustical energy of the same frequency by an array of ammonium dihydrogen phosphate (ADP) crystals.

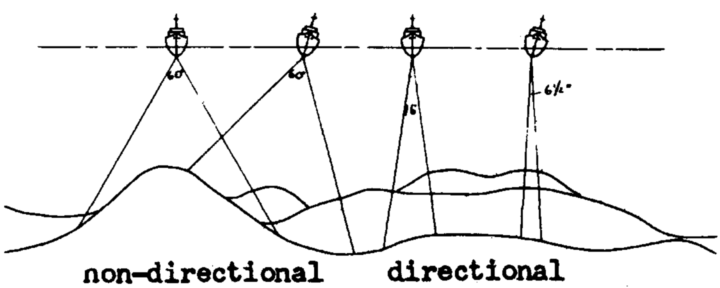
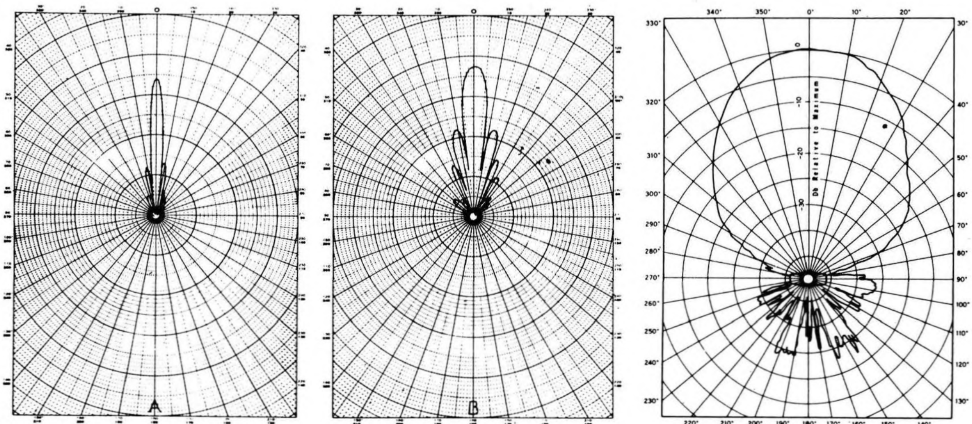


FIG. 1
Directional echo sounding covers less area almost directly under the ship.

The echoes reflecting from any surface having an acoustic impedance different from that of water, such as the ocean bottom, fish, etc. are reconverted by the piezo-electric capability of the ADP crystals into electrical energy subsequently amplified for presentation. The directional transducer is approximately 91.60 centimetres in diameter as compared with 25.40 centimetres for the wide-beam head. By increasing both frequency and transducer head diameter, narrowing cones of energy result. At the — 10 db points, the transmitting directivity patterns of both the directional and non-directional transducers are shown in fig. 2.



6½ degrees 16 degrees 60 degrees

Fig. 2

Transducer directivity patterns at — 10 db.
The polar diagrams indicate direction at 0 degree directly downward.

When 34 KC operation is chosen, the directional system can be used concurrently with the wide-beam system, the resultant profiles being represented on individual Precision Depth Recorders (Luskin, Ewing, Heezen and Landisman, 1954, *Deep Sea Research* 1, 131-140). The 6 ½-degree beam width is preferred while conducting intensive survey operations in limited areas and the wide beam width is preferred in other situations. In terms of depth to which each beam width can successfully sound, the slope and speed of ship both play important roles, as will be explained later.

It is necessary to consider the efficiency of the directional transducer from its function as a hydrophone as well as a projector. This cannot be represented as a fixed value, but is dependent on such variables as depth, topography, water noise, etc. (Horton, 1957). All of these variables, together with the speed of the ship and gain-control operation, affect the visual presentation.

The actual width of the outgoing sound cone approaches its theoretical value of 6 ½ degrees, but this will frequently vary. It can be calculated that this width varies only in the amount of ± 2 degrees. Knowing the slope in a given area, the actual half-cone width is determined from the following diagram (fig. 3).
From this diagram,

$$\tan \theta = \frac{d \cos \varphi - d' \cos \theta}{d' \sin \theta - d \sin \varphi}$$

and,

$$\frac{d'}{d} = \cos (\theta - \varphi)$$

The value of φ was computed to be between 3 ½ and 4 ½ degrees in approximately 65 % of the cases tested. That it varied at the most from

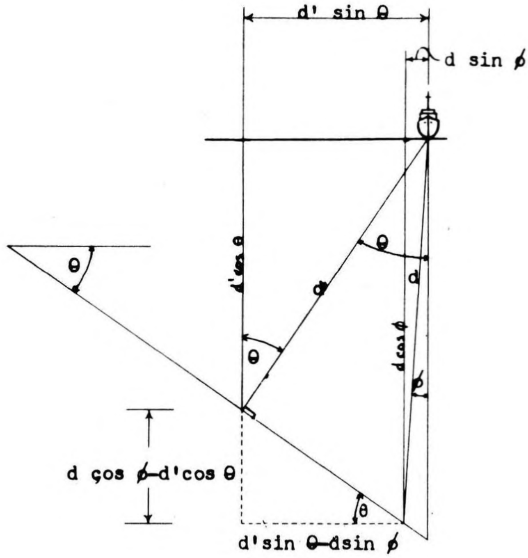


FIG. 3

d = recorded depth from narrow-beam
d' = recorded depth from wide-beam
θ = slope of bottom
φ = semi-angle of directional beam width

3 to 5 ½ degrees is a good indication of correlation between actual and theoretical values, since the possible cumulative error in determination from incomplete foreknowledge of *exact* slope-angle and measurement tolerances is quite large. The cone width is primarily a function of transducer diameter and frequency; however variations in power supply will also cause it to vary. The beam width is, therefore, between 6 and 8 ½ degrees at all times. The reverse calculation is also possible; that is, assuming a half-cone width of 3 ½ degrees, the slope angle can be determined by an examination of the two sets of traces, applying observed values of *d* and *d'* to the formulae.

Simultaneous operation of the two transducers is entirely feasible. A typical pair of traces resulting from such use is shown in fig. 4. All echograms shown are delineated in increments of 20 fathoms (36.58 metres). Note that multiple side echoes preclude measurement of the bottom profile at several points on the wide-beam trace; compare this with the associated narrow-beam trace. The type of topography shown in fig. 4 is difficult to present properly, although this particular trace is a good one. The identical trace, but recorded 2 500 metres deeper would not show side echoes as distinctly, but would appear more nearly as a solid profile. Note the differences in both shape and depth at points A, A' and C, C'. Note also the difference in hyperbolic effect due to cone width and the lack of side echoes on the narrow-beam trace. Additional examples are shown in figs. 5 and 6.

Sounding very rugged terrain by non-directional means often produces traces having ambiguous information. Even when assured of proper gain control, it is not always possible to interpret the results based solely on the strength of the return. This condition is observed in fig. 7.

Of course, some of the wide-beam characteristics of echo sounders are most useful. That depths can be recorded while off to one side of a feature

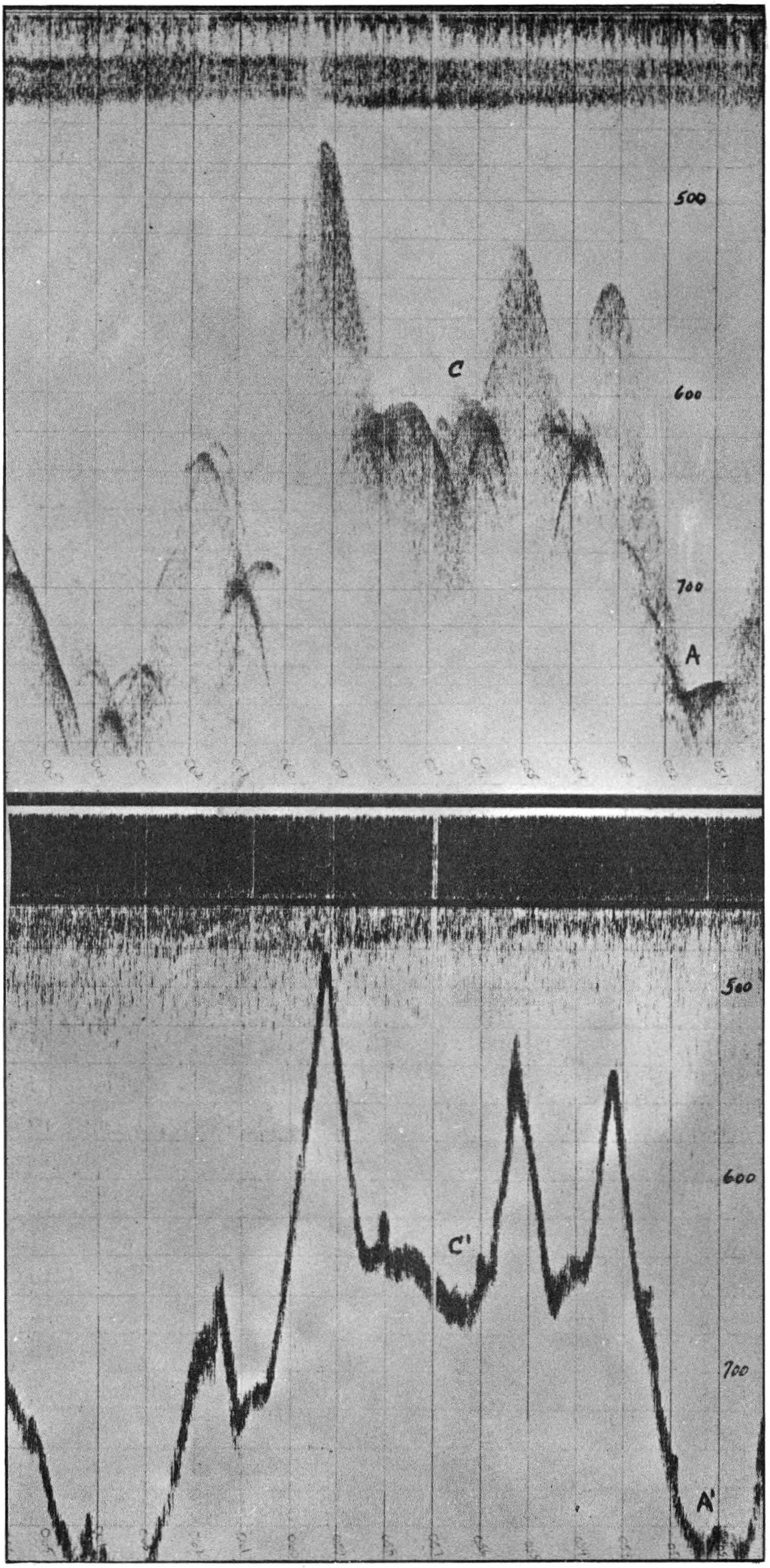


Fig. 4
Non-directional (above) and directional traces recorded simultaneously.

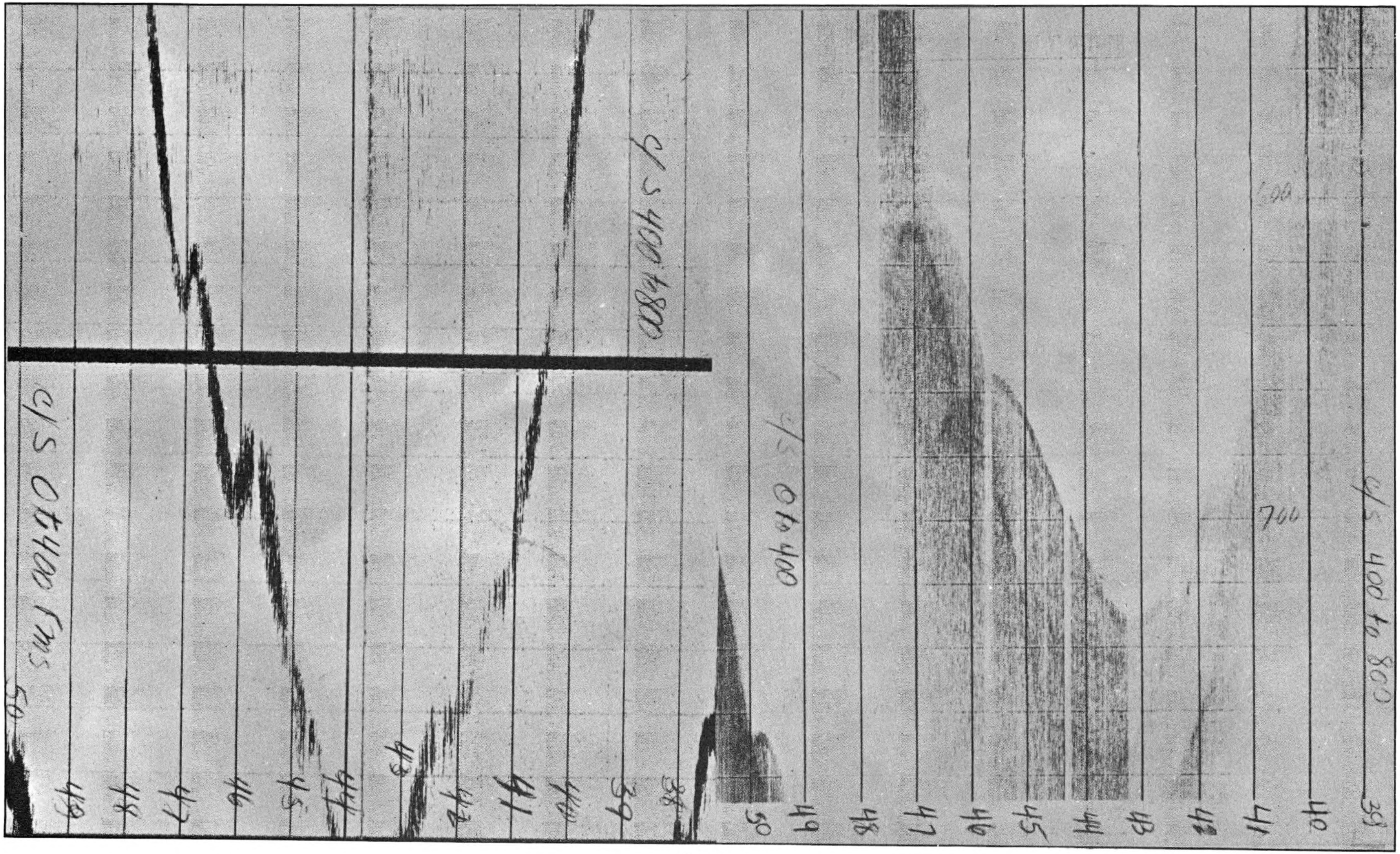


Fig. 5
Along steeper cuts and valleys, directional traces exhibit readings deeper by as much 100 than wide-beam traces (right).

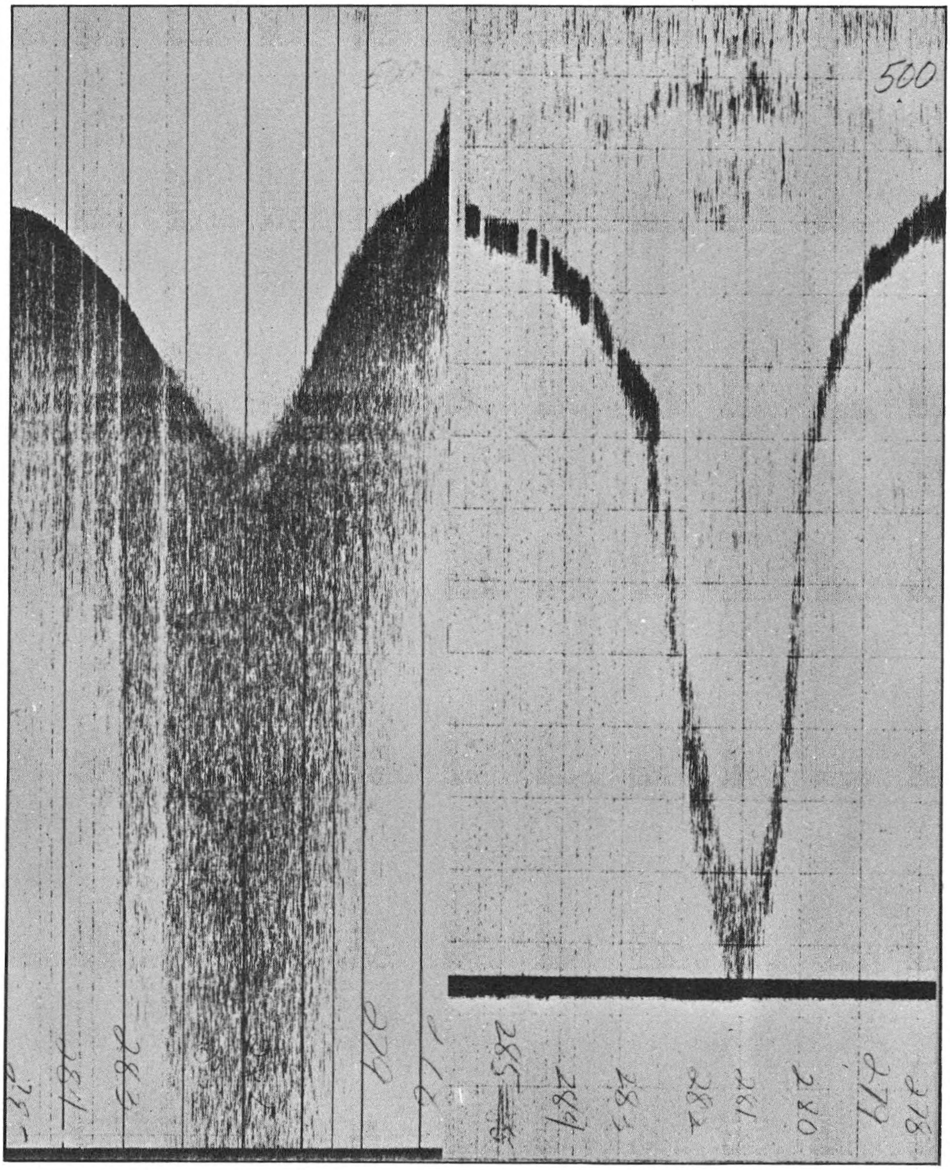


Fig. 6
The directional trace (right) indicates true shape to a greater degree than is possible with the wide-beam equipment.

is often the only means of initial detection. Although recorded at a greater depth than if the ship had been directly over it, a position of a feature such as a seamount can be found by having the ship make several crossings near it and plotting lines of position at right angles to the ship's track through the position at which the minimum depth is recorded. Intersection of these lines of position will then give an indication of the location of the seamount. Also, differences between known and observed depths can indicate distance, albeit in several directions, if the top of the feature is known to be recording. The deeper this feature lies, the farther

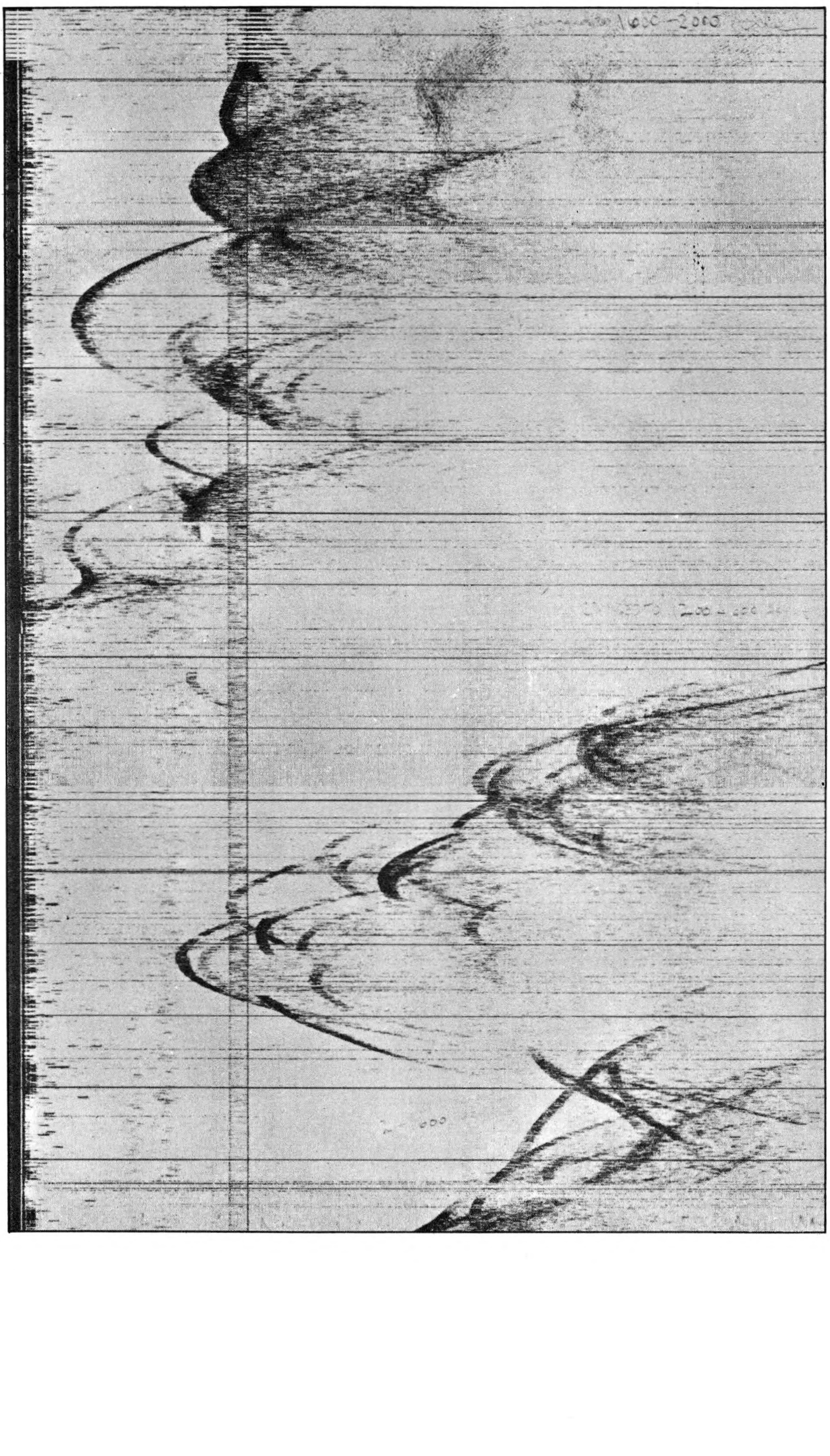


Fig. 7

Trace resulting from deep areas being sounded by the wide-beam transducer.
It is quite difficult to identify that portion of the bottom directly under the ship.

the distance from which the ship can pick it up on its recorder. When searching particular areas for complete coverage, no purpose is served if any but wide-beam sounding equipment is used; for surveys over gentle or slightly rolling terrain, the wide-beam technique is adequate and in some respects, even superior; for example, the same area coverage can be obtained with fewer lines.

Simultaneous operation of directional and non-directional sounding equipment is desired as a check upon the latter and for the production of standard hydrographic data. From the repeatability standpoint, therefore, soundings to be shown on standard charts can be recorded at the same time that directional charts are produced. An interesting use to which simultaneous recording can be put is as an aid to positioning by bathymetry. When a feature such as a seamount is represented at identical depths on both the directional and non-directional recorders, the ship's track has been directly over that seamount. In this manner, it is possible to corroborate, refute or correct a ship's track. As an example, if a dead-reckoning track is extended toward an area that contains several well-defined seamounts, the horizontal distance from the top of the recording point can be obtained by observing the difference in depth between that shown on the wide-beam recorder and the known minimum depth of the feature. If it happens that the dead-reckoning track passes directly over one or more of the seamounts, this will immediately be apparent by observing identical minimum depths to the top of the feature being indicated on both of the recorders. That depth is then correlated with the known minimum depth of the seamounts on the chart. As long as the top of the seamount is known to be recording, the difference in depth indicated on the individual recorder will be a measure of distance.

In the past, it has been considered that no trace would result from directional sounding over a slope greater than the semi-angle of transmission spread, although weak traces did, upon occasion, manifest themselves under these conditions (HERDMAN, 1955). It has been the experience of the writer that slopes up to 30 degrees can be successfully sounded using directional equipment if (*a*) those slopes are not overly deep, and (*b*) the ship's speed is properly adjusted. It is probable that stabilization allows the transducer to remain at an angle sensitive to specular reflections, which are present to some extent on all slopes. At 2 200 metres, for example, slowing the ship from 9 knots to 6 knots retains the trace that might disappear at the former speed. Similarly, a 25-degree slope that shows a good return at 1 650 metres would probably disappear at 2 700 metres, ship's speed notwithstanding. One solution to the trace retention problem when sounding steep slopes is to use the 16-degree cone. In this case, steep slopes can be sounded to well over 3 700 metres, but simultaneous operation is impossible because 12 KC is put through both transducers. Figure 8 shows a 29-degree slope at 0-1 450 metres, sounded with 6 $\frac{1}{2}$-degree beam width. The trace is a good one at this depth range; it would be less distinct at 2 700 or 2 900 metres, with ship's speed constant. Slowing the ship would help retain the trace. In this case unless the 16-degree cone width were utilized (or, of course, the non-directional beam) the trace would disappear. In very rugged terrain, therefore, steepness of slope, depth, and ship's speed become factors which affect good trace

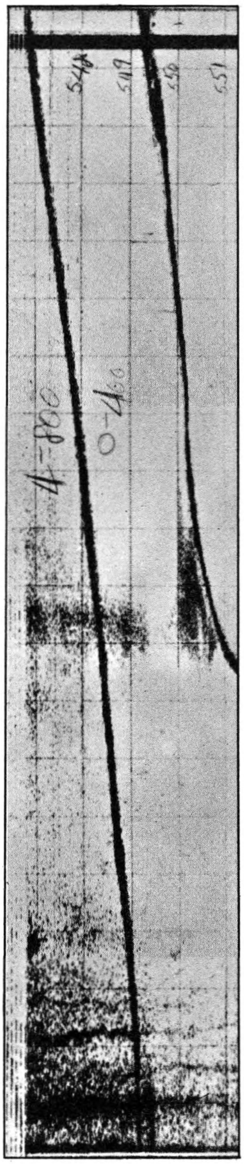


FIG. 8
Slopes as steep as 30° can be sounded with the 6 1/2° cone of the directional head, given certain depths and speeds.

presentation. Although the 6 ½-degree beam width can sound flat or gentle topography at depths of 3 600-4 000 metres, no advantage would be gained by its use in these situations.

Figure 9 shows identical charts of the same area, based respectively on directional and non-directional sounding. These recordings must be obtained simultaneously, as an exact duplication of the ship's track is not possible even with the most accurate control. Where the shape and minimum depths of certain features are almost identically represented on

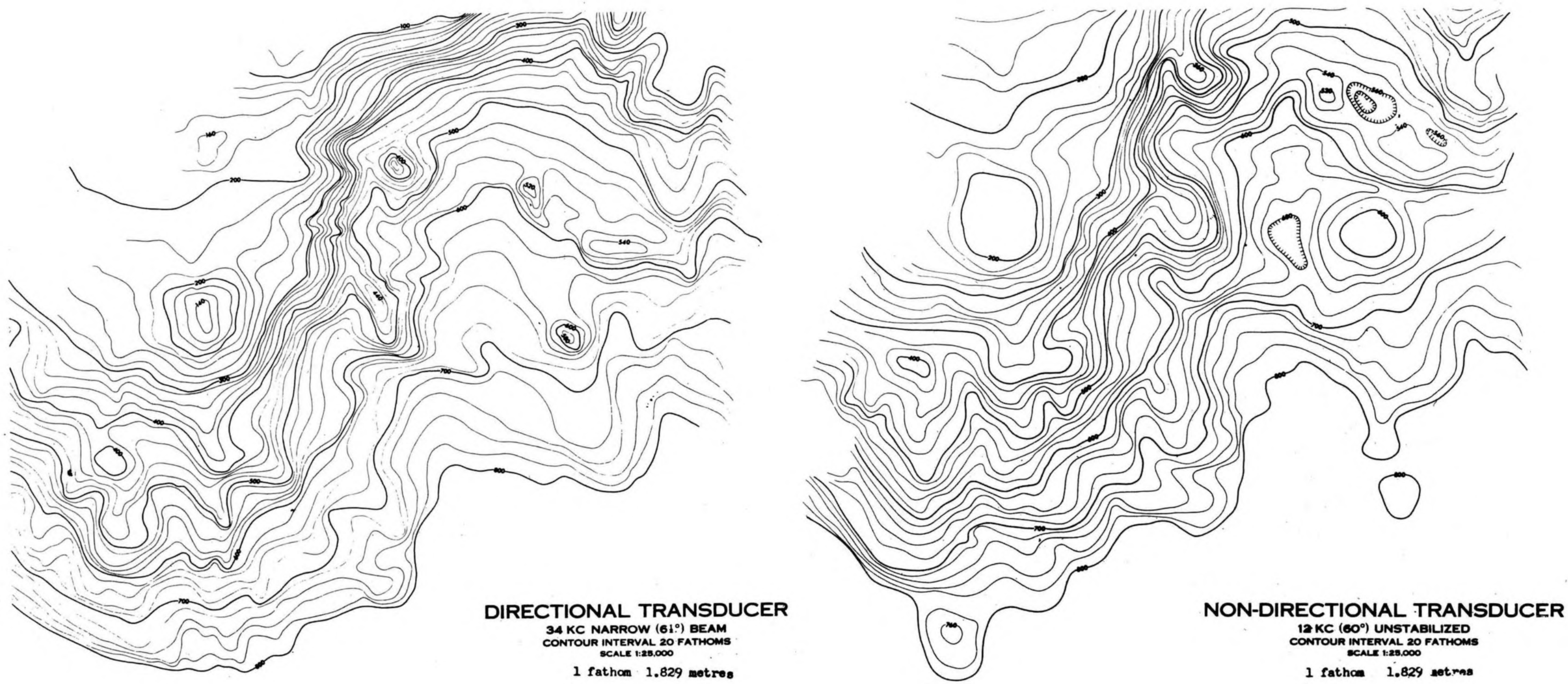


FIG. 9

Contour charts of the same area recorded simultaneously. Not all of the differences can be attributed to width of the outgoing beam of sound. Factors such as personal interpretations, distance between transducers on the hull, etc., also enter into the picture. The directional contours are the more accurate ones, however, in terms of shape and depth.

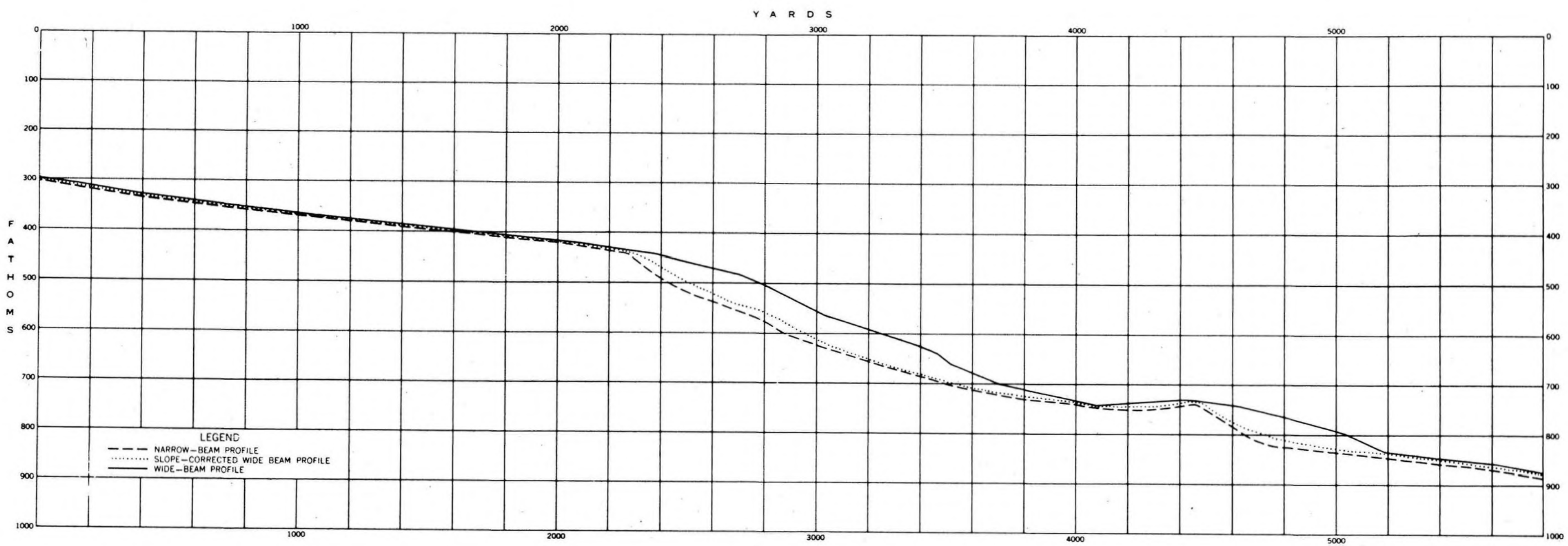


FIG. 10

Diagram indicates the relationship between the uncorrected wide-beam profile, the corrected wide-beam profile, and the narrow-beam profile. There is no vertical exaggeration. If the section is taken normal to the slope, and if the wide-beam trace is interpreted and slope-corrected properly, such correlation is usually found to be good. Since slope effect is present even on the narrow-beam (directional) trace, exact duplications of profiles are not expected.

both charts, it indicates that the ship's track had passed directly over that feature. The directional chart not only portrays the topography more accurately relative to position, but also presents a more detailed and precise picture in terms of depth and shape. When lines of directional sounding have been correctly positioned relative to adjacent and cross-check lines, it is possible to construct a highly accurate bathymetric chart. If it is necessary for a vessel to use directional results as an aid in navigation, then those charts the information is correlated with must be slope-corrected beforehand.

As an aid in echograph interpretation, narrow-beam profiles are used to excellent advantage by the persons who process great numbers of such data. In the course of scaling and plotting soundings, it is extremely difficult to choose between conflicting bottom information in areas of complex topography. When directional results are available, they become valuable aids to true bottom determination. In several of the accompanying illustrations, it is doubtful if anyone could distinguish the true bottom from an examination of the wide-beam traces alone. From the practical standpoint, such data can be processed by personnel who need not have great technical competence. That this is of importance can be attested to by those involved in intensive survey operations, where great amounts of data must be evaluated and processed on a continuous basis. From the standpoint of eventual chart production, contouring is facilitated to an extent whereby it can be more readily accomplished with correct geomorphological relationships in mind.

If the directional trace shows what is, in effect, a slope-corrected profile, then the corrected wide-beam profiles should show good correlation with the associated narrow-beam profiles. Fig. 10 shows such a combination of profiles at a scale of 1/1. These are random selections, the only consideration being that the ship's track be perfectly normal to the slope so that correction could be accomplished from the trace itself. It is always demonstrable that good correlation can be achieved, given an initial wide-beam profile free from possible misinterpretation.

CONCLUSION

There is reason to believe that further applications of directional sounding data will be of help to many persons interested in deep-sea sounding. It may be possible, for example, to use cross-lines on the superimposition of directional and non-directional contours in conjunction with observed values on the individual recorder to accurately fix a ship's position. Further investigations of such effects are being continued.

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