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SOME TRANSMISSION CHARACTERISTICS OF BOTTOM-REFLECTED SOUND.(U)
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INTERIM REPORT

SOME TRANSMISSION CHARACTERISTICS OF BOTTOM-REFLECTED SOUND

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Preface

The underwater sound transmission data gathered by the Listening Section of the University of California Division of War Research have been further analyzed, and the results of one of these analyses is the subject of this report.

Some of the phenomena which affect directly-transmitted and surface-reflected signals also have an effect on bottom-reflected signals. Image interference among various components of bottom-reflected signals is displayed by the very low frequencies under favorable conditions, while attenuation and refraction apparently obscure interference effects at the high frequencies. Interference patterns are much better developed in calm seas where reflection from the surface is more uniform. It was found that bottom type becomes quite significant as the wavelength is decreased.

The original theoretical work on bottom reflection interference presented here was done by Dr. R.W. Young and T. McMillian. Miss Jane Smith prepared the illustrations, and she and Mrs. Mary Miller collaborated with the author in the analysis of the data. The report was prepared by T. McMillian.

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Introduction

With the exception of those cases where sound channels exist, the transmission of underwater sound to extreme ranges is possible in most cases only because much of the energy which strikes the ocean bottom is reflected back into the water. In many cases several successive reflections from surface and bottom may occur before the sound wave finally reaches the receiver. Thus, an understanding of the bottom reflection phenomena is important.

This study is concerned chiefly with those signals which have experienced only a single reflection from the ocean bottom, and possibly one or two reflections from the surface. However, signals experiencing any number of reflections may be handled in a similar manner.

Theory

There are four possible paths over which sound may travel from a source to a receiver, both located below the surface of the water, and still be reflected from the bottom but once. These four paths are those marked r_3, r_4, r_5, r_6 *in figure 1.** In the figure, R is the horizontal range, a is the source depth, b is the receiver depth, and D is the water depth.

Sound traveling along any of these paths may be affected by various phenomena such as divergence, attenuation, refraction, and reflection. Also, when the four signals reach the receiver, they may combine in such a manner as to produce an interference pattern.

Systematic range dependent variations in the sound field at the very low frequencies led to the belief early in the program that bottom reflection interference effects were sometimes observed. An equation was developed in "Underwater Sound Transmission at Sonic Frequencies" (UCDWR Report No. M448) for representing these interference effects, and it has been found useful in this analysis. The equation may be written as

$$-A = 10 \log \mu^2 + 10 \log 4 \sin^2 \Delta_1 + 10 \log 4 \sin^2 \Delta_2 - 10 \log \left[1 + \left(\frac{2D}{R}\right)^2 \right], \quad (1)$$

where A is the transmission anomaly relative to the horizontal range. In general, the transmission anomaly is the transmission loss in excess of that predicted by inverse square divergence along the sound path. However, present formulation was necessary because for other reasons experimental data were plotted relative to the horizontal range. The bottom amplitude reflection coefficient is μ, and Δ_1 and Δ_2 are given by the following equations:

$$\Delta_1 = \frac{2\pi a}{\lambda\left[\left(\frac{R}{2D}\right)^2 + 1\right]^{\frac{1}{2}}}, \quad (2)$$

*Figure 1 is the same as figure 7 in "Underwater Sound Transmission at Sonic Frequencies," UCDWR Report No. M448, dated 30 September 1946.

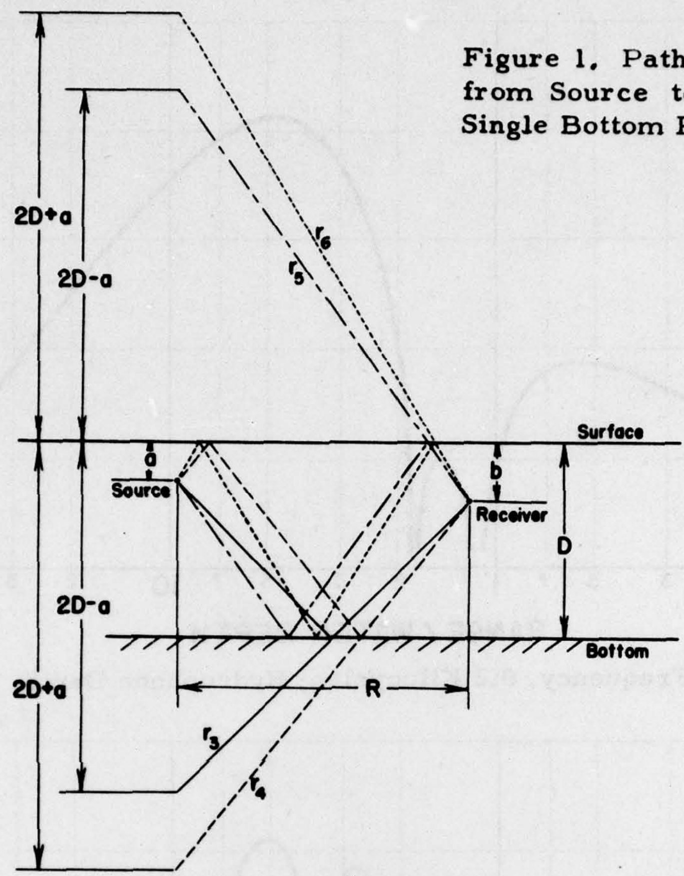

Figure 1. Paths of Sound Rays from Source to Receiver for Single Bottom Reflection.

and

$$\Delta_2 = \frac{2\pi b}{\lambda\left[\left(\frac{R}{2D}\right)^2 + 1\right]^{\frac{1}{2}}} \quad . \qquad (3)$$

The symbols a, b, R, and D were defined above in connection with figure 1.

Because of the approximations made in developing equation 1, it is subject to the restrictions that $D \gg a$, $D \gg b$, and $(R^2 + 4D^2)^{\frac{1}{2}} \gg 20\pi ab/\lambda$. The anomaly, A, has been plotted against the ratio of the horizontal range to the water depth (R/D) for various frequencies and hydrophone depths, and some of these curves for the lower frequencies are shown in figures 2 to 6. The velocity of sound used was 4860 feet per second and the source depth was 14 feet for all these figures.

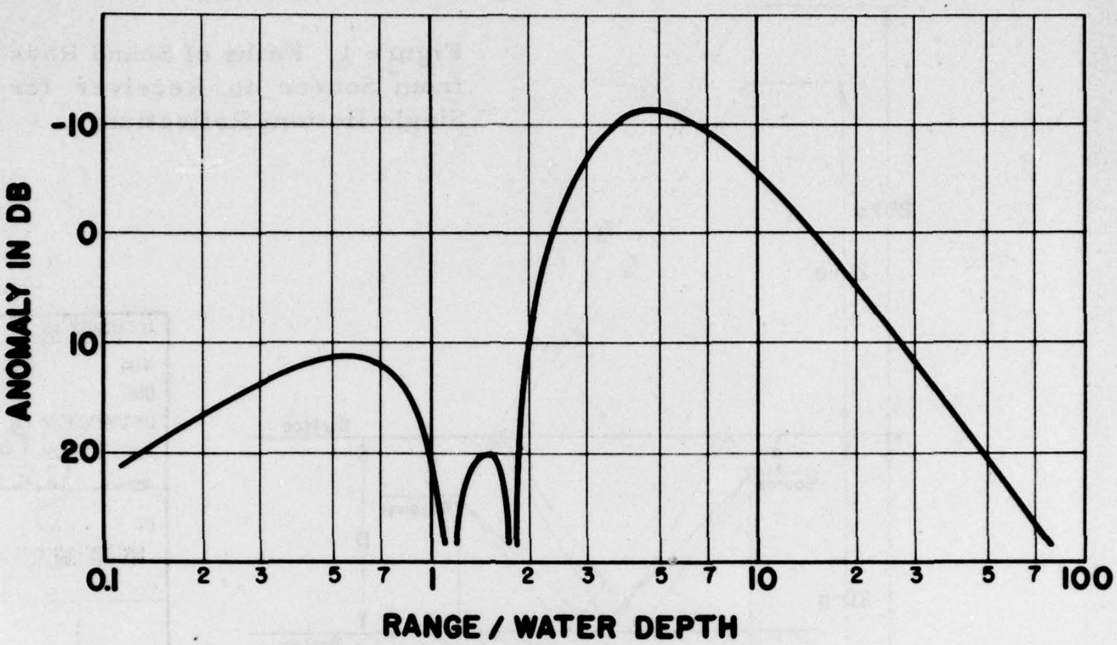

Figure 2. Frequency, 0.2 Kilocycles; Hydrophone Depth, 16 Feet.

≈ .64 λ

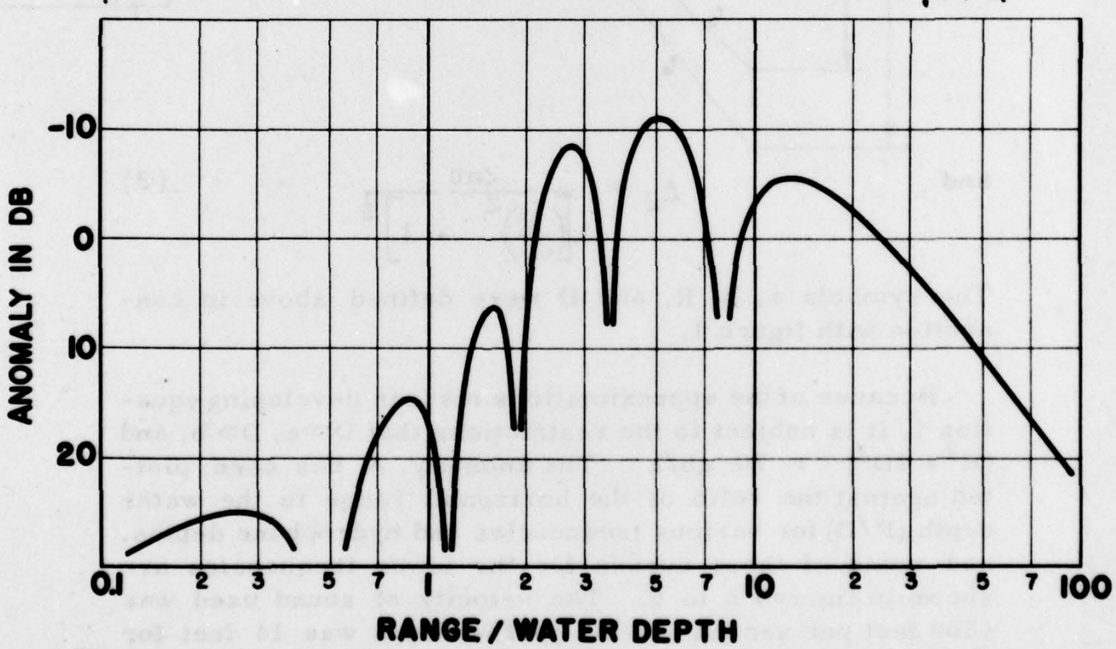

Figure 3. Frequency, 0.2 Kilocycles; Hydrophone Depth, 50 Feet.

2 λ

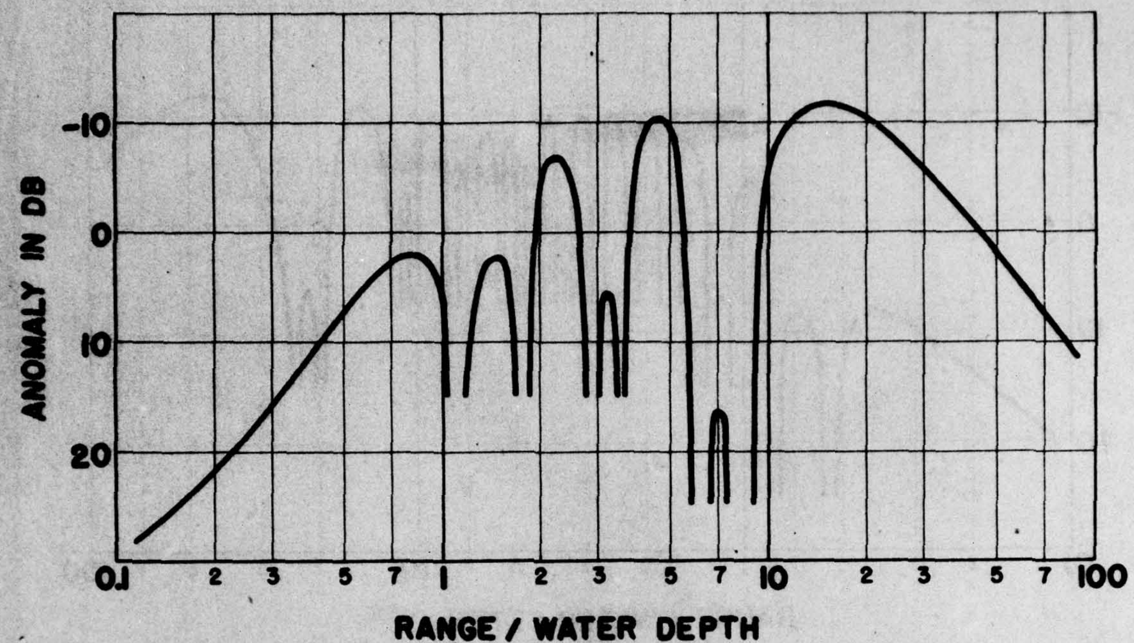

Figure 4. Frequency, 0.6 Kilocycles; Hydrophone Depth, 16 Feet.

1.9 λ

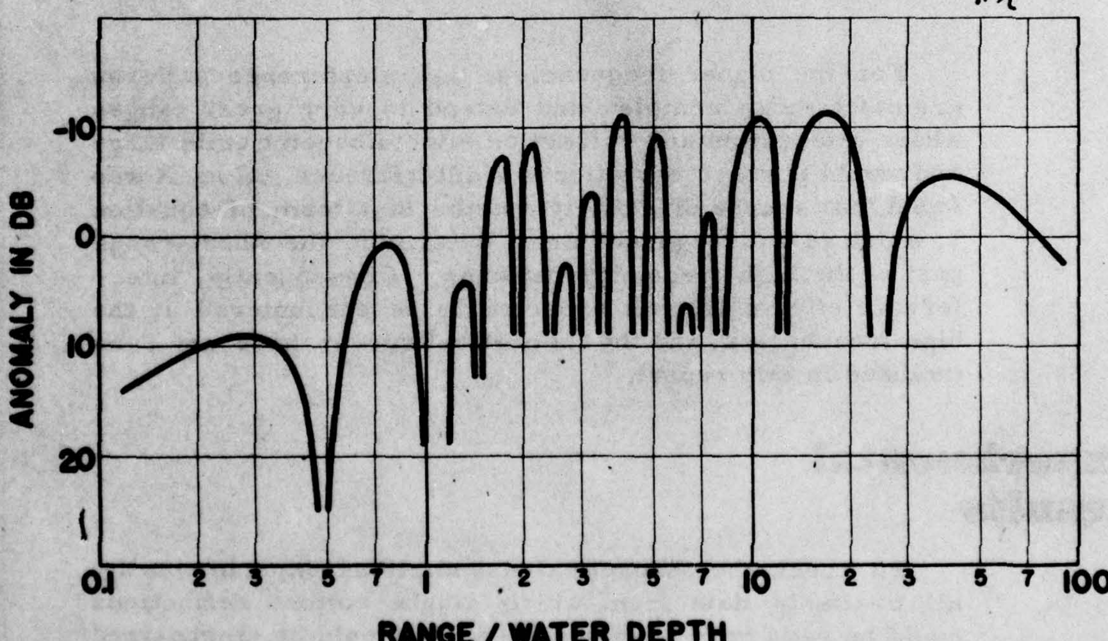

Figure 5. Frequency, 0.6 Kilocycles; Hydrophone Depth, 50 Feet.

6 λ

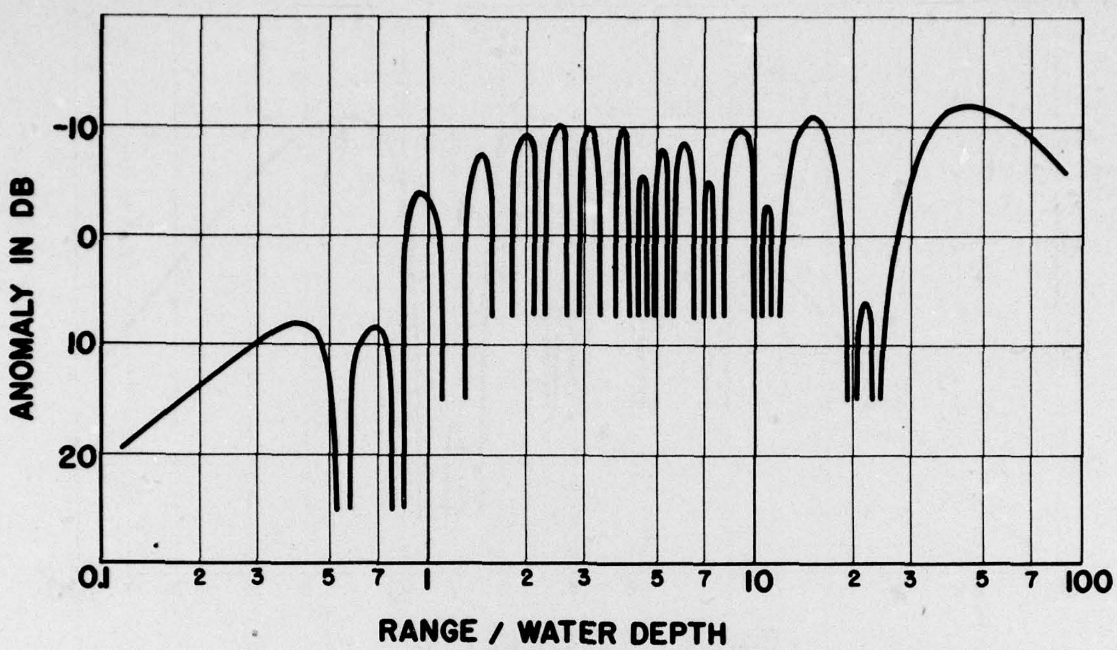

Figure 6. Frequency, 1.8 Kilocycles; Hydrophone Depth, 16 Feet.

2.7λ

For the higher frequencies, the interference patterns are much more complex and extend to very great ranges where attenuation and refraction effects become quite large and would obscure any effects of interference. Also, it was found that source directivity and the last term of equation 1, which is a divergence term, determine the short-range part of the high-frequency patterns. Consequently, interference effects are not expected to be encountered at the high frequencies, and the theoretical curves have not been included in this report.

Experimental Results

To check the theoretical assumptions experimentally, all available data from which single bottom reflections could be read have been analyzed. It should be emphasized that only those signals which have experienced a single reflection at the bottom are considered. Where multiple reflections are concerned, the characteristic shape of signals experiencing only a single reflection is obscured. Unfortunately, most of the data were taken in water either too shallow or too deep to obtain good bottom reflections. Therefore, observations are based on a limited number of runs in most cases, and any conclusions must necessarily be tentative. Some features could not be checked at all because of this paucity of data.

Frequencies of 0.2 kc., 0.6 kc., 1.8 kc., 7.5 kc., and 22.5 kc. were included in this study. Details of the experiment have been given previously.[1,2] The source depth for the three lower frequencies was 14 feet and that for the two higher frequencies was 12 feet. Receiving hydrophones were at 16 feet, 50 feet, and 300 feet. The signals, a series of 200-millisecond pings, were recorded on an oscillograph installed on the drifting receiving ship, while the source ship opened and closed the range.

The bottom-reflection anomalies for two individual runs made in quiet water are shown in figures 7 and 8. The theoretical curve is shown superimposed in each case, and in figure 7 signals which have experienced two reflections from the ocean bottom are also shown (open circles) with the corresponding theoretical curve. The interference patterns for signals reflected twice from the ocean bottom are the same as for those reflected once, except that they are shifted to twice the range. Part of a third reflection pattern was also present on this run, but it is not included. On some runs parts of 10 to 12 reflection patterns have been identified.

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1. Sonar Data Division, UCDWR, "Sea-Going Equipment for Sonic Transmission Studies," UCDWR Report No. M446.

2. Sonar Data Division, UCDWR, "Processing Low-Frequency Sound Transmission Data," UCDWR Report No. M414.

The theoretical curves have been shifted vertically for best fit where necessary, thus arbitrarily selecting the bottom-reflection coefficient, μ. No horizontal adjustment was made, however.

Average curves of anomaly vs. ratio of range to water depth for signals reflected once from the ocean bottom have been prepared for each of the five frequencies and for two hydrophone depths. The individual anomaly vs. range curves were shifted horizontally by an amount proportional to the water depth before the average curves were prepared.

Figures 9 and 10 show two of the average curves for 0.2 kc. with hydrophone depths of 16 and 50 feet. The dashed line in each case shows the theoretical curve of equation 1. Interference patterns in calm water were much better developed than were those in rough seas. A few runs made in very rough water were omitted from figure 9 because the pattern for these runs was quite confused.

The average experimental curves for 0.6 kc. and for 1.8 kc., shown in figures 11 to 14, are in only very general agreement with the interference theory. Therefore, the theoretical curve is not shown. This is the expected result, since any irregularities of surface, bottom, water depth, or projector depths would distort the pattern and the averaging process would smooth out the peaks and valleys of these complex curves. At 1.8 kc., many of the runs were too short to check the theory adequately.

No effect of attenuation and no dependence on bottom type or refraction conditions was found at 0.2 kc., 0.6 kc., or 1.8 kc., although the data were originally separated by these parameters.

At 7.5 kc. and 22.5 kc. some dependence on bottom type was observed (see figs. 15 to 17). Runs taken over rock bottoms and over sand bottoms were practically identical, while those taken over mud were considerably different.

They were not only at a lower level but were of a different shape. These curves seem to indicate that the bottom-reflection coefficient is dependent on angle of incidence and that this dependence is in turn affected by the bottom type.

These data were originally separated by refraction conditions, but no dependence on refraction could be found except in the case of two runs for which both 7.5 kc. and 22.5 kc. were recorded. These runs were taken in water which was practically isothermal near the surface (less than 0.1 degree Fahrenheit change in temperature in the first 80 feet), and the averages of the two runs only are shown by the dotted curves in figures 15 and 17. These runs are extended to greater ranges than those taken with downward refraction, although runs taken under conditions of only very slight downward refraction were apparently the same as those for which sharp downward refraction existed. Nevertheless, these high-frequency curves are sharply cut off at ranges much shorter than those predicted by the interference theory and this reduction in signal must be caused by attenuation (absorption and scattering) and refraction. The effect is larger than has normally been attributed to attenuation, as defined here.

The data presented in figures 7 to 17 were all taken in relatively shallow water (35 to 150 fathoms). Data taken in deep water were also analyzed, but in almost all cases the runs were not of sufficient length to show distinguishing features of interference or other phenomena. This does not necessarily mean that the runs were short, since in 2000-fathom water a range to water depth ratio of 10 corresponds to a range of 40,000 yards.

A few deep water runs at 0.2 kc. with the hydrophone at 16 feet extended to ranges of sufficient length to show the trend of the curves. These runs indicated that the interference pattern existed at these depths but that it had been slightly flattened out and the peak pushed to greater ranges. These data were not shown because not enough usable runs were available to make the results significant.

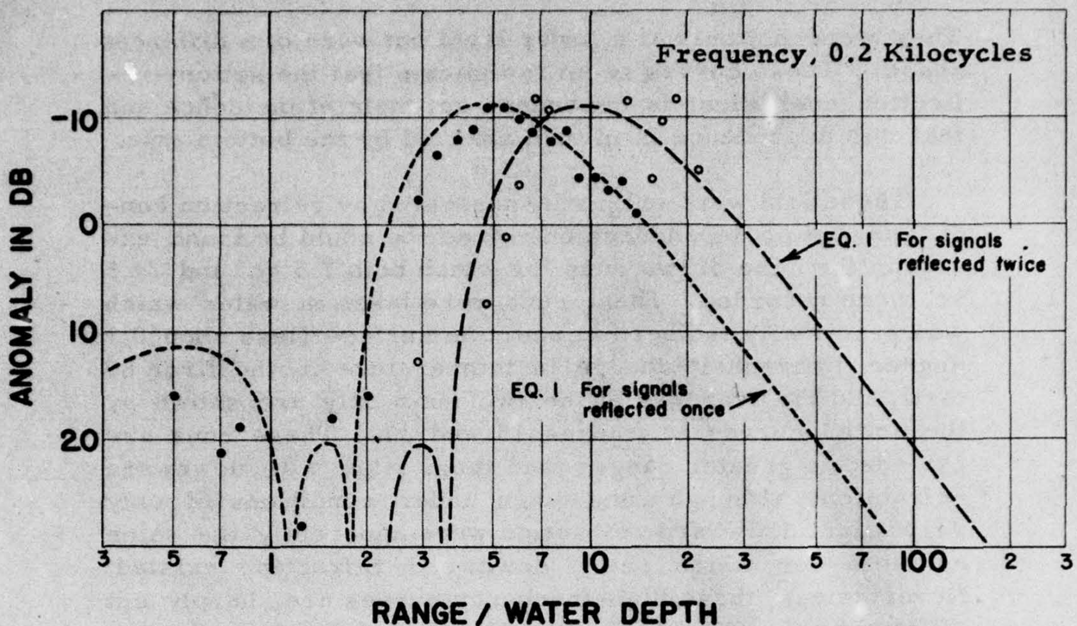

Figure 7. First and Second Bottom Reflection Anomaly-- Hydrophone Depth, 16 Feet.

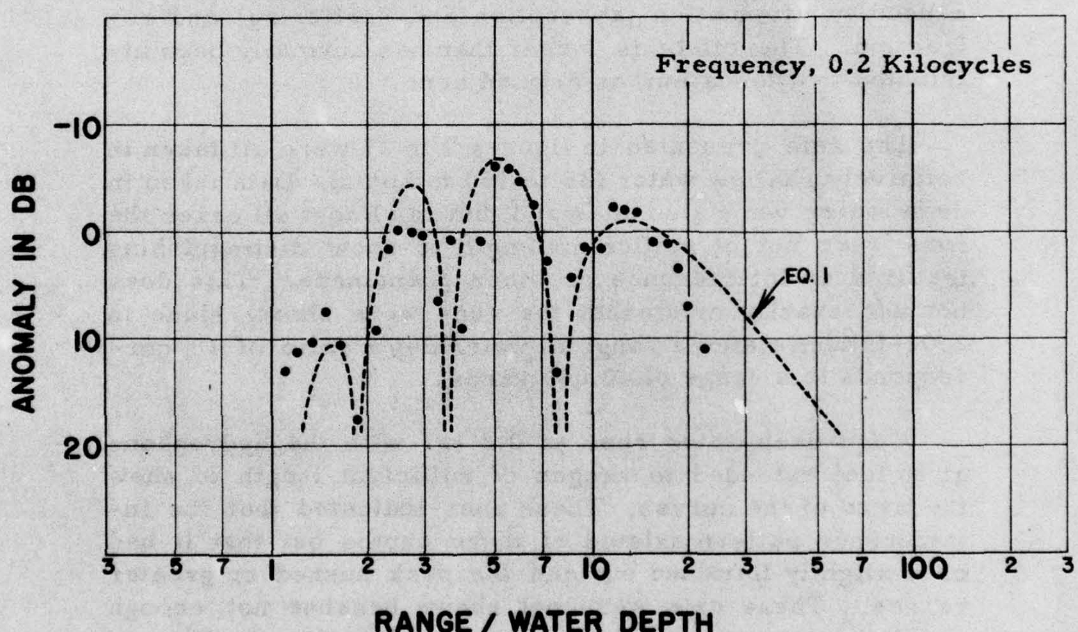

Figure 8. Bottom Reflection Anomaly-- Hydrophone Depth, 50 Feet.

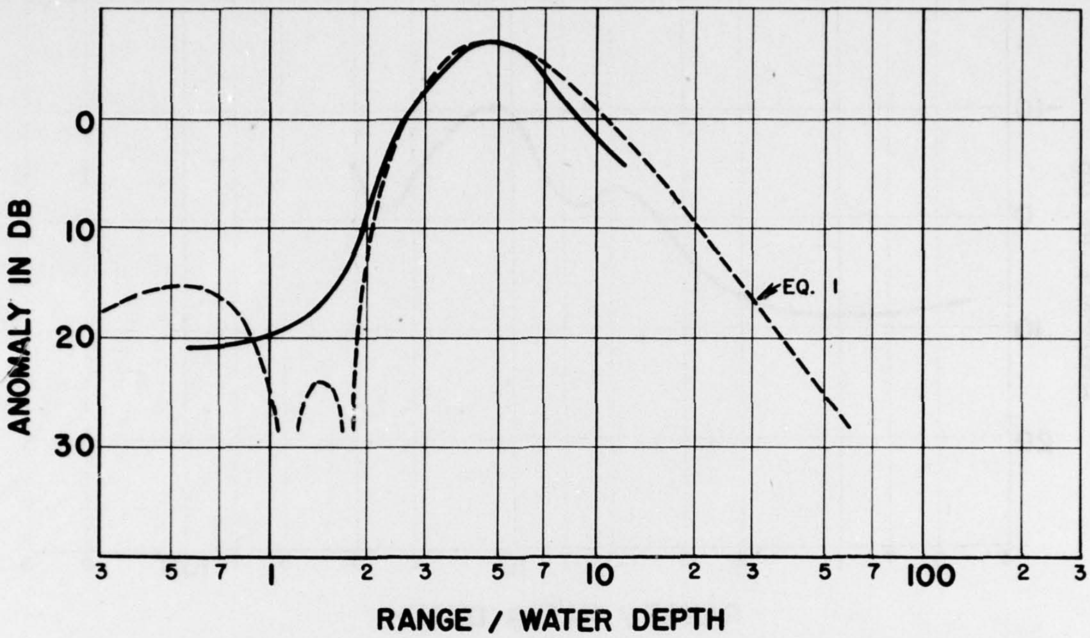

Figure 9. Frequency, 0.2 Kilocycles; Hydrophone Depth, 16 Feet.

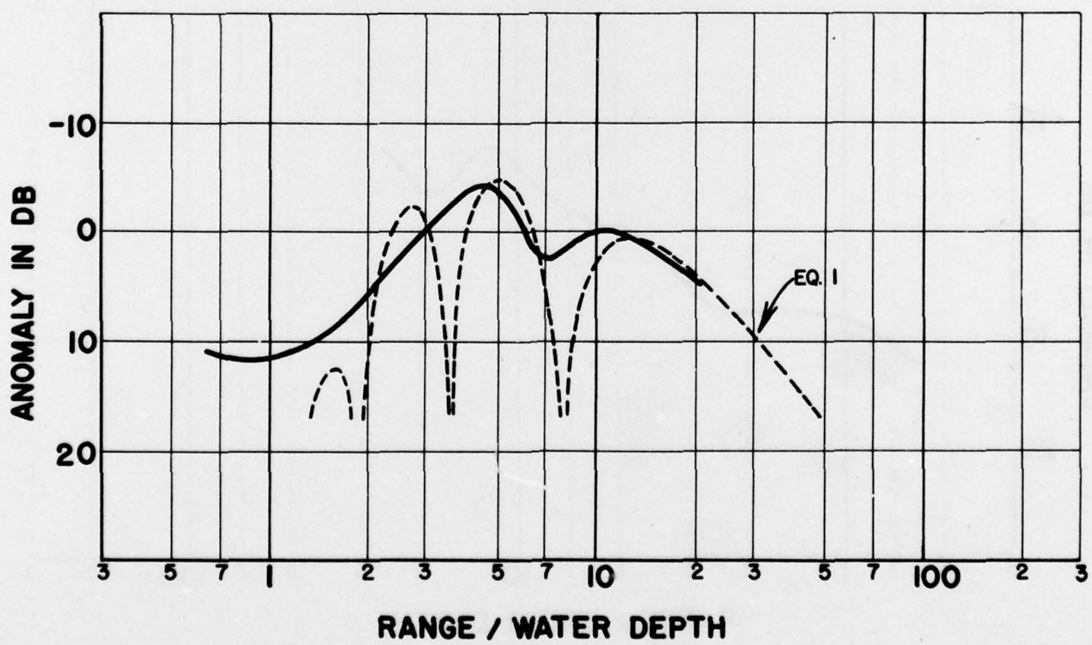

Figure 10. Frequency, 0.2 Kilocycles; Hydrophone Depth, 50 Feet.

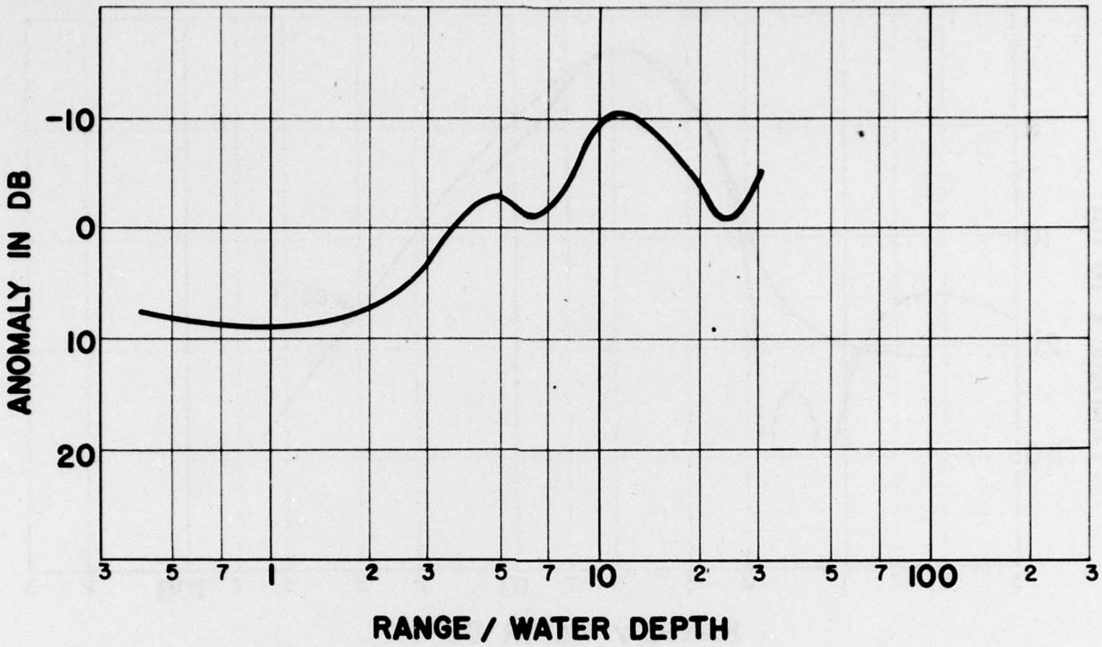

Figure 11. Frequency, 0.6 Kilocycles; Hydrophone Depth, 16 Feet.

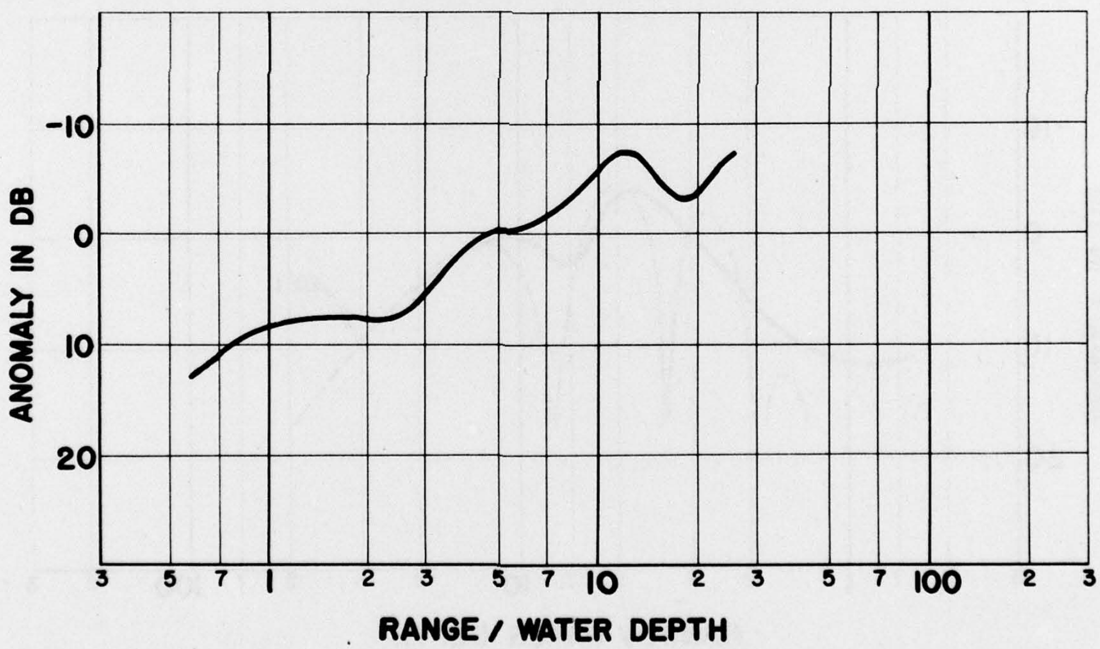

Figure 12. Frequency, 0.6 Kilocycles; Hydrophone Depth, 50 Feet.

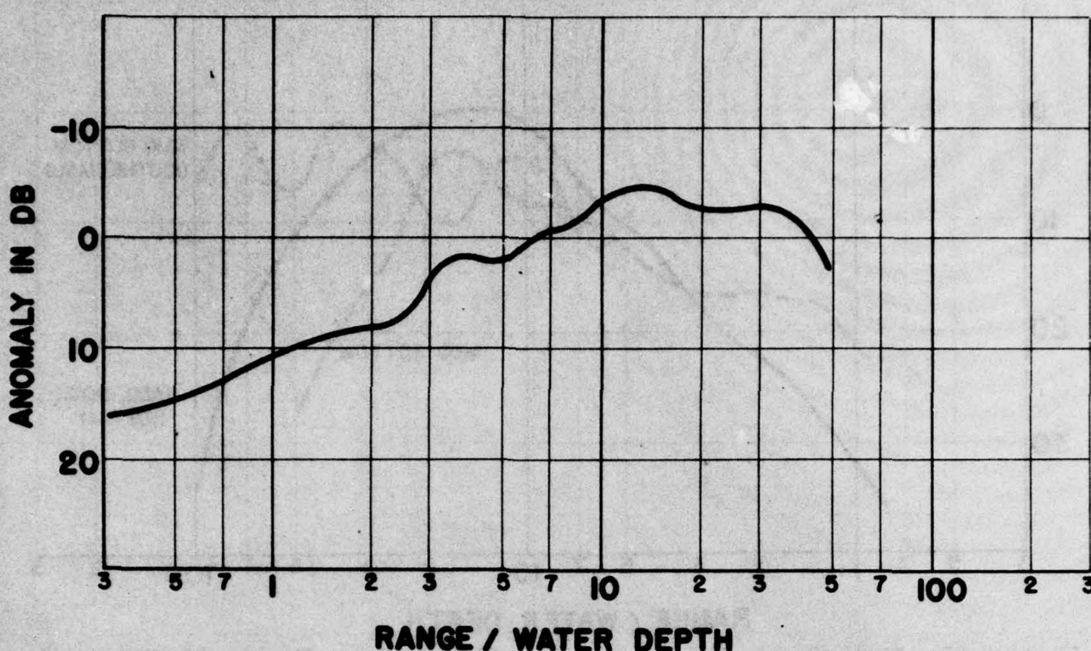

Figure 13. Frequency, 1.8 Kilocycles; Hydrophone Depth, 16 Feet.

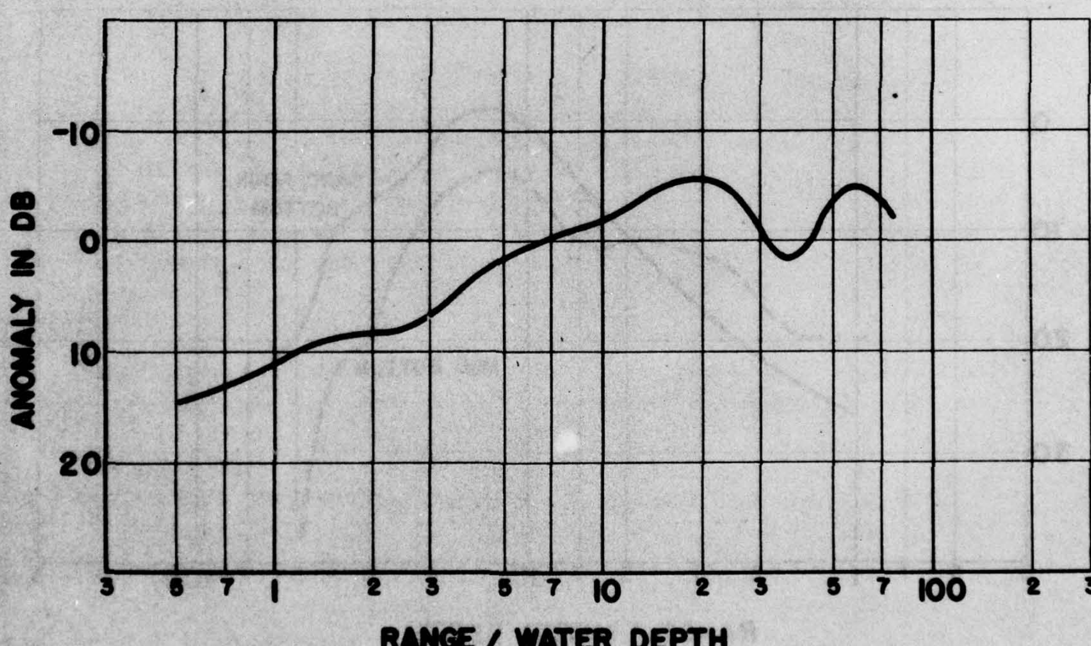

Figure 14. Frequency, 1.8 Kilocycles; Hydrophone Depth, 50 Feet.

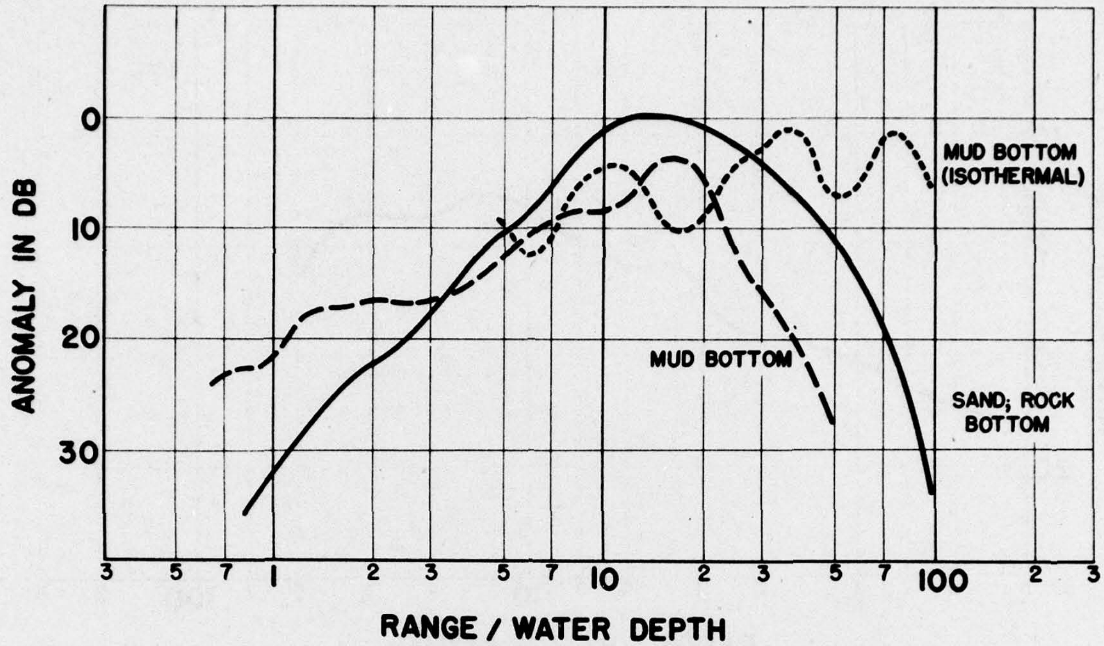

Figure 15. Frequency, 7.5 Kilocycles; Hydrophone Depth, 16 Feet.

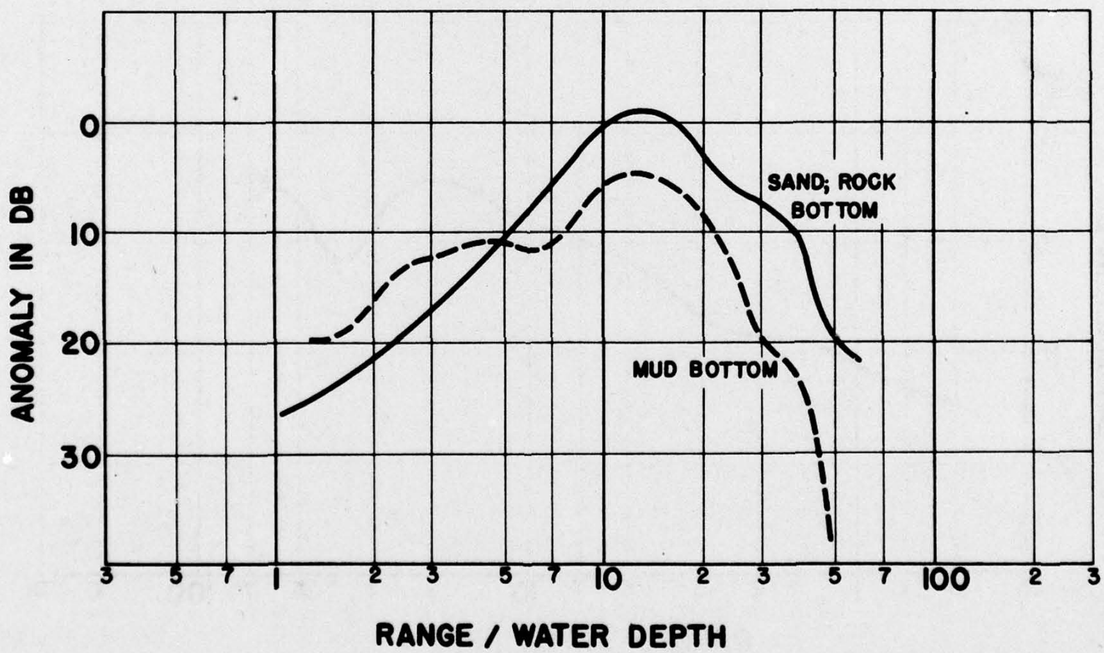

Figure 16. Frequency, 7.5 Kilocycles; Hydrophone Depth, 50 Feet.

AVERAGE EXPERIMENTAL BOTTOM REFLECTION ANOMALY

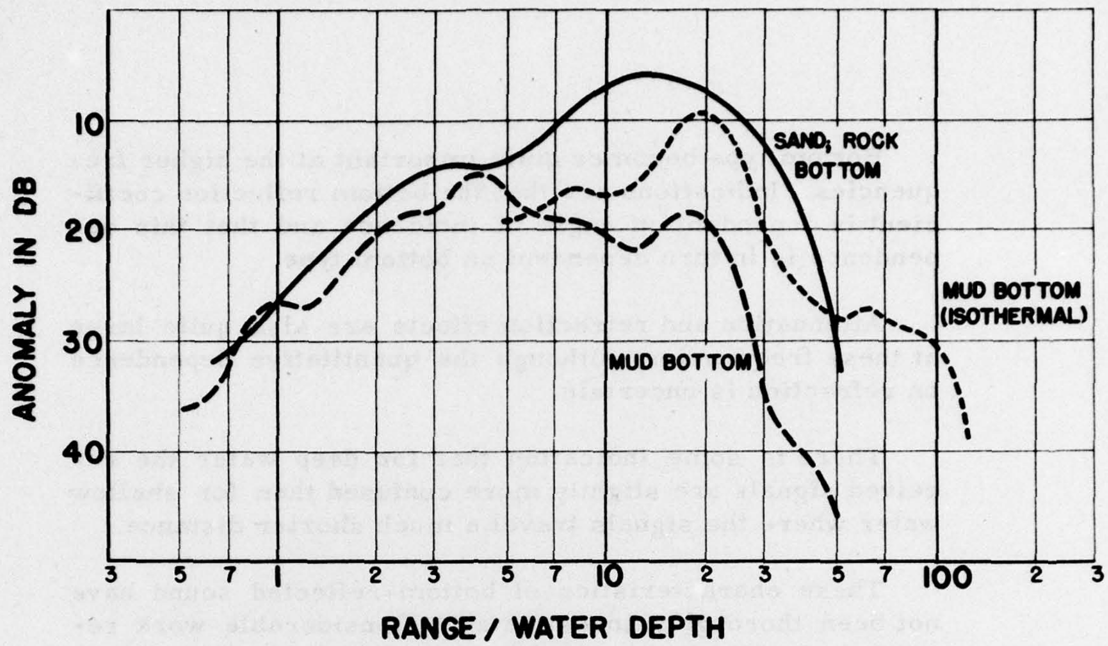

Figure 17. Frequency, 22.5 Kilocycles; Hydrophone Depth, 50 Feet.

Summary

From the limited amount of usable data available for this study, it is apparent that bottom-reflected signals are affected by many of the phenomena which affect directly-transmitted signals as well as some which are not encountered near the surface.

Interference effects have been demonstrated to occur at low frequencies with shallow hydrophones if the sea is calm. As the frequency, hydrophone depth, or projector depth is increased, the number of loops of the pattern is increased and the pattern is extended to greater ranges. Therefore, interference effects become more difficult to obtain experimentally. In very calm isothermal water some of the more complex patterns could probably be obtained.

Bottom type becomes quite important at the higher frequencies. Indications are that the bottom reflection coefficient is dependent on angle of incidence and that this dependence is in turn dependent on bottom type.

Attenuation and refraction effects are also quite large at these frequencies, although the quantitative dependence on refraction is uncertain.

There is some indication that for deep water the received signals are slightly more confused than for shallow water where the signals travel a much shorter distance.

These characteristics of bottom-reflected sound have not been thoroughly investigated. Considerable work remains to be done before definite conclusions can be reached. Plans have been made to conduct experiments in the near future which are specifically designed to answer some of the problems involved. When these problems are solved, more study should be given to the manner in which the various bottom-reflected signals are combined to produce the "steady state" signals, which are the ones normally measured in shallow water.