NORTHEASTERN UNIVERSITY
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DEPARTMENT OF CO-OPERATIVE EDUCATION

Title

An Exploratory Study of the Relationship Between
Sound Reflectivity and Ocean Bottom Physical Properties

Submitted by

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Due on

January 29, 1962
(Date)

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(Name of Student's Co-ordinator)

Employed by

U.S.N./ Underwater Sound Laboratory
(Name of Firm)

Inspected and passed by Thaddeus W. Bell
(Signature of Firm's Supervisor)

Co-ordinator's Record

Title Approved by ______ Date ______
Date Received JAN 29 1962
Grade

4 Sunnieside Court

Waterford, Conn.

January 14, 1962

Mr. Joseph E. Barbeau

Northeastern University

Boston 15, Mass.

Dear Mr. Barbeau,

I am submitting the following report: "An Exploratory Study of the Relationship Between Sound Reflectivity and Ocean Bottom Physical Properties," for your review. This report is the product of a study I have conducted to determine the effect of ocean bottom physical properties upon reflected sound. Included in the following discussion will be the general results obtained, as well as recommendations intended to improve future studies. Although I have sought to define all technical references, some references alluded to cannot be clearly defined due to their confidential nature. I hope that this will not affect your understanding of this report.

Sincerely,

Bernard F. Cole

Bernard F. Cole

General Topic Outline

I. Assignment and Initial Investigation

A. Problem assignment

B. General correlation--measurements and grain size

C. Velocity-ratio method

II. Reflection from Water-Sediment Interface

A. Shallow water study in eastern Pacific

B. Deep water study in middle and eastern Atlantic

C. Agreement of studies

D. Theoretical reflection losses

E. Recommendation concerning future measurements

III. Penetration into the Bottom Sediment

A. Depth of penetration

B. Attenuation in varying sediments

C. Reflection and refraction

IV. Conclusion

A. Summary of study

B. Possible theoretical explanation

C. More recommendations

Definition of Terms

Amos: an oceanographic survey

Brass II : a sonar system

Density : $\frac{\text{wet weight of sediment-weight of sea water}}{\text{total volume of sample-volume of sea water}}$

Ø : median grain diameter in phi units -- $-\log_2$ dia. (mm)

Porosity : ratio of volume of voids (sea water in this case) between the grains of a sediment sample to the total volume of the sediment

Sand, silt, and clay : Wentworth grade scale of particle diameter: sand 2-0.062 mm, silt 0.062-0.004 mm, and clay, less than 0.004 mm

It is the purpose of this report to give a general idea of some of the factors which may affect sound waves coming into contact with the ocean bottom, and to set the stage for future investigations of these properties.

An Exploratory Study of the Relationship Between Sound Reflectivity and Ocean Bottom Physical Properties

Upon my return to the Underwater Sound Laboratory, I was assigned to aid Mr. Thaddeus Bell of the Systems Planning Staff by conducting a study of ocean bottom sound reflectivity. In an attempt to find some correlation between Amos and Brass II sonar bottom loss measurements and bottom composition, sediment cores from the Atlantic[1] were divided into two classes (cores containing sand or silt, and cores containing no sand or silt) and were compared with bottom loss measurements according to geographic position. The results obtained from this comparison indicate that areas containing sand or silt generally provide very good reflectivity, while areas containing no sand or silt provide reflectivity ranging from good to bad. From this general study it appears that reflectivity from sand or silt areas is more predictable than that from non-sand or silt areas.

1. D.B. Ericson, M. Ewing, B.C. Heezen, G. Wollin, Geological Society of America Bulletin, 72, 173,(Feb. 1961).

The relationship of this median grain size method of bottom loss prediction to Fry's water-sediment velocity ratio method[2,3] will be evident from the following discussion of the inter-action of the sediment layer velocity, porosity, and median grain size.

A physical analysis of shallow water sediments from the Pacific by Hamilton et al., (1956)[4], showed a correlation between the velocity, the porosity, and the median grain size of the sediment layer. A general increase in velocity with increasing median grain size and decreasing porosity was observed. It is interesting and significant that the same correlation was noticed in a physical analysis of Atlantic deep-sea sediment cores by Sutton et al., (1957)[5].

2. J. Fry, W.R. Raitt, Journal of Geophysical Research, 66-2, 589 (Feb. 1961).

3. J. Fry, USAG Journal, 11-2, 261 (April 1961).

4. E. Hamilton, G. Shumway, H. Menard, C. Shipek, Journal of the Acoustical Society of America, 28-1,1 (Jan. 1956).

5. G. Sutton, H. Berckhemer, J. Nafe, Geophysics, 22-4, 779 (Oct. 1957).

Although both studies showed a strong positive correlation to exist between the median grain size and the velocity, Sutton interprets the median grain size as directly affecting the velocity, but Hamilton explains the correlation as a result of the velocity-porosity relationship, and a strong negative correlation between the median grain size and the porosity. Sutton found the compressional wave velocity in the ocean bottom unconsolidated sediments studied to be well represented by:

$$v' = 2.093 - (0.0414 \pm 0.0060)\,\phi + (0.00135 \pm 0.00038)\,\gamma - (0.44 \pm 0.15)\,\eta$$

where

v' = compressional wave velocity in km/sec.

ϕ = median grain size in phi units

γ = % carbonate content[6]

η = porosity

6. Sutton found a positive correlation between the carbonate content and the velocity.

More complete measurements will be necessary to accurately establish the bottom loss as a function of these properties, however, for the present, a general classification of the bottom loss can be obtained by consideration of either the velocity, the porosity, or the median grain size.

Hamilton's study in the Pacific included reflection losses calculated from Rayleigh's equation as presented by Mackenzie[7]:

$$\text{Loss in db/ reflection} = 20 \log_{10} \frac{pq - \left[1-(p^2-1)\cot^2\phi\right]^{\frac{1}{2}}}{pq + \left[1-(p^2-1)\cot^2\phi\right]^{\frac{1}{2}}}$$

where
p is the velocity in sediment/ velocity in water

q is the density of sediment/ density of water

and
ϕ is the grazing angle at the bottom

Although the grain size is not directly accounted for in the above equation, a graphical representation of the theoretical reflection loss vs. the median grain size (Fig. 1) is in agreement with Amos and Brass II results. In both cases, areas containing sand show a

7. K.V. Mackenzie, U.S.N. Electronics Laboratory Report 229 (1952).

consistent reflection loss. The fact that the wide variation of theoretical reflection loss for silt areas does not appear in the Amos and Brass II measurements could be due to the classification of sand and silt into one category, and to the presence of sand in the cores containing silt. This loss variability in silt areas, however, was confirmed by later Naval Research Laboratory measurements.[8]

Since the reflection losses were theoretical, and were calculated from the velocity and the density of the sediment layer, it is difficult to determine any exact correlation between the bottom physical properties and the bottom reflection losses. It can only be concluded that a low porosity, high velocity, large median grain size sediment layer provides optimum reflectivity. For this reason, it is recommended that actual measurements of bottom loss be obtained in future studies, so that an exact correlation between the bottom losses and the bottom properties can be established.

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8. M. Davidian, "Report of NRL Progress—November 1961," 27.

Up to this point, this study has been concerned only with the effect of bottom properties upon reflectivity from the water-sediment layer interface. Since the depth of penetration of the bottom sediment at echo ranging frequency is probably much greater than commonly supposed, a discussion of the sub-surface reflection and sediment layer refraction effects on bottom loss is appropriate.

A recent verbal communication with the Hydrographic Office suggested that a frequency of 12 KC will occasionally penetrate to 300 feet into the bottom sediment, with a penetration depth of 100 feet not unusual. Since the depth of penetration generally decreases with increasing frequency, it is quite probable that a penetration depth of several hundred feet may be experienced in the operating frequency range of some sonar systems.

With the penetration of the bottom sediment layer, the bottom loss becomes dependent upon not only the velocity, porosity, and median grain size, but also upon the attenuation constant and the penetration depth of the sediment layer. Since Shumway found the attenuation to vary with the frequency,[9,10] this becomes still another factor deserving consideration.

The sediment attenuation measurements of Hamilton, who used Shumway's resonant chamber method,[11] indicate that the attenuation increases as the median grain diameter increases from coarse silt to fine sand. Sutton found this was also true for an increasing grain size from clay to coarse silt, thus implying that the attenuation increases as the median grain size increases from clay to fine sand. These findings were confirmed by Shumway, who established that the attenuation reaches a maximum at fine sand sediments, and then decreases again. Figure 2 shows the attenuation values obtained by Hamilton and Shumway for different median grain sizes.

From the inter-action of the median grain size and the other bottom properties, it can be shown that the least attenuation due to bottom properties occurs in

9. G. Shumway, Geophysics, 21-2, 305 (April 1956).

10. $a= kf^{1.8}$

11. G. Shumway, Geophysics, 25, 659 (1960).

small median grain size, low velocity, high porosity sediment layers. It should be kept in mind, however, that the attenuation will increase with increasing depth of penetration, and will increase very rapidly with increasing frequency. The unconsolidated sediment may also contain a gradient,[3,12] and therefore effect a rapid change in velocity and attenuation with a small change in depth penetration.

Although the sediment attenuation is affected by the penetration depth, this, in turn, is affected to some extent by the grazing angle. For a grazing angle of 90 degrees, the sound which penetrates into the sediment will be reflected from a sub-surface interface,but for other angles, the unconsolidated sediment gradient must be taken into account. This gradient may refract the sound back into the water, or may cause more or less reflection from a sub-surface layer interface than would normally be expected.

12. J.E. Nafe, C.L. Drake, Geophysics, 22-3, 523(July 1957).

Now that the bottom effects have been generally discussed, perhaps the two effects can be related. From the above study, it can be seen that a sediment providing poor reflectivity, is a sediment providing good sound propagation. For this reason, it is quite conceivable that the high reflection losses found over low velocity, small median grain size, high porosity sediment layers can be accounted for by the large amount of sound propagated through the water-matched medium, and the small amount of sound reflected. In the same manner, the low reflection losses experienced over high velocity, large median grain size, low porosity layers can be explained as a result of little sound being propagated through the medium, and a majority of the sound being reflected due to the water-sediment mis-match.

This theory, it should be noted, was based on a very limited amount of data, and is not necessarily correct. Since the amount of data was so limited, future measurements will have to be made in order to obtain a good prediction of sound reflection losses with bottom sediment type. It is recommended that these future studies include an investigation of the in-sediment and sub-surface reflection modes of propagation, as well as determining optimum equipment parameters such as frequency and angle. I hope that this exploratory study has helped to make future studies more valuable and has added to the present knowledge concerning ocean bottom sound reflectivity.

Sources of Information

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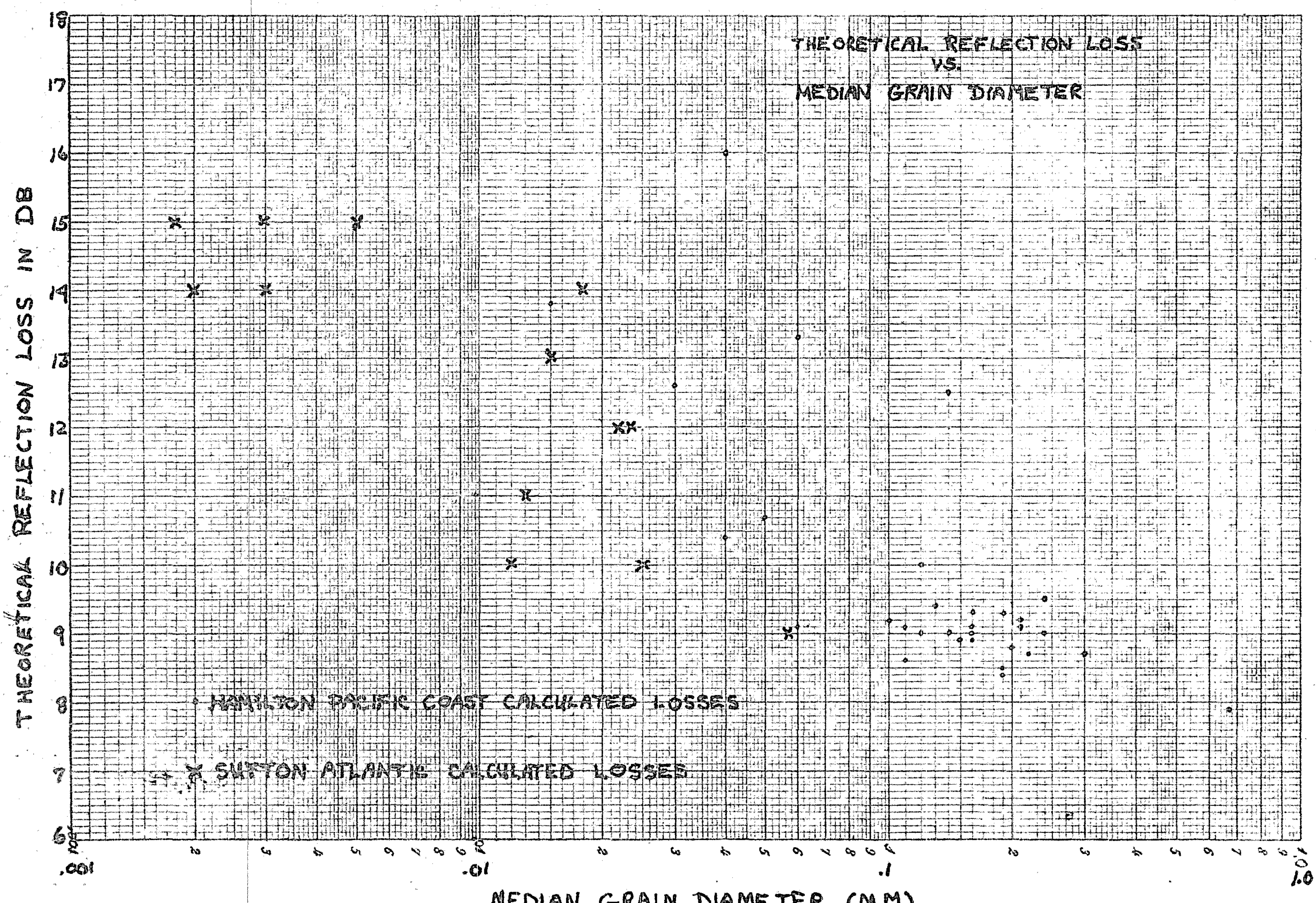
THEORETICAL REFLECTION LOSS
VS.
MEDIAN GRAIN DIAMETER
THEORETICAL REFLECTION LOSS IN DB
18
17
16
15
14
13
12
11
10
9
8
7
6
.001
.01
.1
1.0
MEDIAN GRAIN DIAMETER (MM)
HAMILTON PACIFIC COAST CALCULATED LOSSES
SUTTON ATLANTIC CALCULATED LOSSES

FIGURE 1

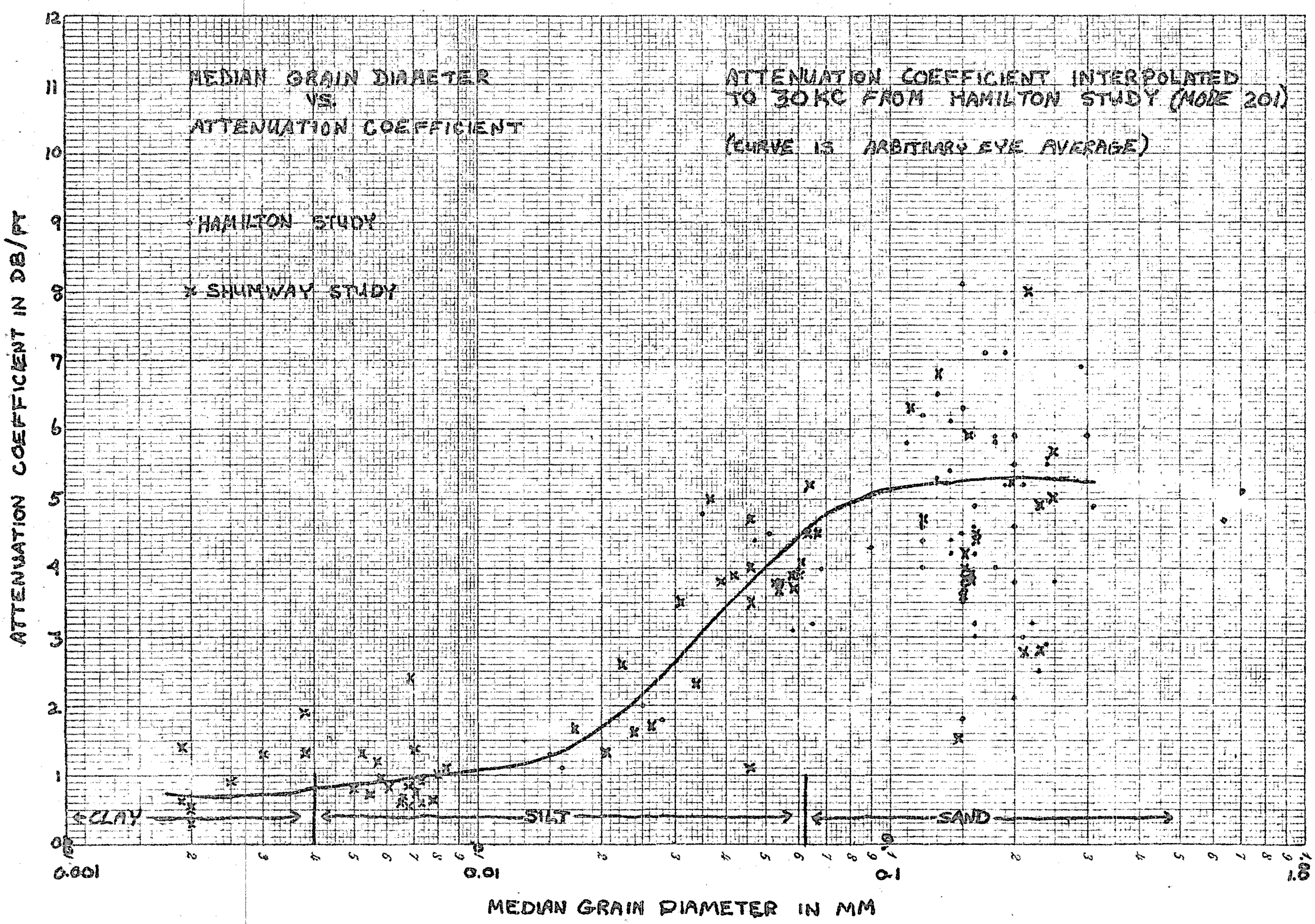
MEDIAN GRAIN DIAMETER
VS.
ATTENUATION COEFFICIENT
ATTENUATION COEFFICIENT INTERPOLATED TO 30 KC FROM HAMILTON STUDY (MODE 201)
(CURVE IS ARBITRARY EYE AVERAGE)
• HAMILTON STUDY
x SHUMWAY STUDY
CLAY
SILT
SAND
ATTENUATION COEFFICIENT IN DB/FT
MEDIAN GRAIN DIAMETER IN MM
0.001
0.01
0.1
1.0
0
1
2
3
4
5
6
7
8
9
10
11
12

FIGURE 2