LOW-FREQUENCY BOTTOM BACKSCATTERING STRENGTHS MEASURED USING SUS CHARGES

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1. INTRODUCTION

In a series of at-sea measurements beginning in 1988, we have used broadband SUS (Signal, Underwater Sound) charges to measure direct-path bottom backscattering strengths in a variety of deep-water locations around the world. These scattering strengths have been measured over a frequency range from about 70 Hz to about 950 Hz and for grazing angles between 25 and 55 deg. In this paper we give an overview of the sites at which we have collected backscattering data and discuss the experimental technique used to obtain the data. We then present representative scattering strength results from a number of sites and give some general conclusions about the results.

2. DESCRIPTION OF EXPERIMENTS

The measurements reported in this paper were made as a part of the Critical Sea Test series of at-sea experiments, which is sponsored by the U.S. Space and Naval Warfare Systems Command. During this series of tests, broadband bottom backscattering strengths using SUS (Signal, Underwater Sound) charges were obtained over the Norwegian Basin and the Aegir Ridge, the Icelandic Basin near Hatton Bank, over the Bermuda Rise and the Hatteras Abyssal Plain in the western Atlantic, over the Aleutian Abyssal Plain in the Gulf of Alaska, and over the Ionian Abyssal Plain and the Malta Ridge in the central Mediterranean.

During each at-sea measurement, SUS charges were deployed from the aft end of a research vessel at an interval of about one every three minutes. Ten to twenty shots were dropped at a typical site. The receiver was a horizontal towed array attached to the same vessel. Drag plates were attached to each SUS to slow its descent to the detonation depth, so that when the charge went off it was nearly underneath the towed array. In this manner we achieved a quasi-monostatic geometry—there was a vertical separation between the source and the receiver but little or no horizontal separation. For measurements carried out in deep water, the differences between the incident and scattered angles are small, so these measurements may be considered to be monostatic.

The data from these measurements were usually analyzed from 70 Hz up to about 950 Hz at the harmonics of the fundamental bubble pulse frequency of the SUS charges. In the processing, the calibrated hydrophone data for each SUS shot were first transformed to the frequency domain and were then beamformed using Hamming shading. The FFT size was chosen to give a time resolution of 0.25 s and thus a bandwidth of 4 Hz for each data point. The resulting time series for all the shots collected during a run were visually examined for problems, and a self-consistent subset of the shots were then combined to give an average reverberation curve. The analysis software calculated the geometric parameters of the scattering process such as mean grazing angle as a function of time and scattering area. These were then combined in the active sonar equation with the average reverberation time series, the source level, and the transmission loss to and from the bottom to give scattering strength as a function of grazing angle and frequency.

3. BOTTOM SCATTERING STRENGTH RESULTS

Each bottom scattering strength plot given in this section shows a set of scattering strength curves for a single site and a range of frequencies. Also included on each plot is the Mackenzie scattering curve (i.e., Lambert's law with a constant of -27 dB) as a reference. The grazing angles for which data are shown range from an upper limit of 50 to 60 deg (corresponding to the time when the first fathometer returns from the water-sediment interface no longer dominate the reverberation) to a lower limit around 27 deg (when the second fathometer return comes in). Except for the data from the Ionian Abyssal Plain, the results are all taken from the broadside beams of the horizontal line array. In addition, the data reported all come from areas that are very flat, with one exception which will be noted. The uncertainties in the scattering strengths are about ±4 to 5 dB.

Figures 1 and 2 show scattering strengths obtained at a site between the Ionian Abyssal Plain and the Messina Cone in the central Mediterranean. Figure 1 shows the results for the broadside beam, while Fig. 2 shows the results at the same site for a beam 39 deg forward of broadside. The best sediment data for this area comes from the results for Deep Sea Drilling Project site 374 [1], in which the upper 300 to 400 m of sediment are described as "mainly hemipelagic muds, marls, and sapropels, with intercalations of sand and silt layers." Examination of Fig. 1 shows that the curves for all frequencies are rising much faster than Lambert for increasing grazing angles. Figure 2, however, shows the higher frequency curves, at least, to be very Lambert-like in slope, and even the lower frequency curves show much less increase with increasing grazing angle. The most reasonable interpretation of these data is that, up to at least 45 deg, the "true" backscatter, defined as coming from the main beam, generally has a Lambert-like slope as a function of grazing angle, but that subbottom scattering of energy entering the sediment at higher grazing angles can dominate the "true" return. Energy that penetrates into the sediment and scatters off subbottom features will experience a delay due to the travel time in the sediment and come back at a later time than energy that scatters off the surface. Since grazing angles are assigned based solely on travel time to and from the water-sediment interface, this has the effect of making subbottom scattering from a high incidence angle show up as enhanced scattering strengths at lower grazing angles. The off-broadside results of Fig. 2 show little evidence of these subbottom paths due to the Hamming suppression of sidelobes. This interpretation is supported by the observation that the contamination effect (i.e., the departure from a Lambert-like slope) is biggest at the lowest frequencies, where energy penetrating into the subbottom suffers the least attenuation. While this effect is seen at several sites in the Ionian Basin, we observed a few sites in the Basin where the broadside and off-broadside results are not very different, suggesting that the size of this effect is variable and depends on local sediment conditions.

Two other observations on the results in Figs. 1 and 2 are appropriate. First, the scattering strengths generally increase with decreasing frequency at all grazing angles and at all Ionian Basin sites. Second, comparisons of broadside and off-broadside results at all sites (Ionian Basin and otherwise) indicate that by 30 deg grazing angle, the high incidence-angle contamination effects have largely disappeared, and the results are beam-independent.

Figure 3 shows bottom backscatter results for a site on the Bermuda Rise in the western Atlantic. This area has been characterized as having a thick sediment cover composed largely of pelagic clays. The results for the Bermuda Rise show the lowest scattering strengths near 1 kHz of any site we have surveyed, with only the Norway Basin coming close to the low scattering levels. Further, these low levels lead to the largest differences between our lowest frequencies and our highest frequencies of any of the sites we have surveyed. The direction of the frequency dependence is the same as in the Ionian Basin, with scattering strength decreasing as frequency increases. The overall curve shapes are somewhat steeper than Lambert on the broadside beam results shown.

On the same test as the Bermuda Rise results were obtained, we also measured three sites in the Hatteras Abyssal Plain. The results for one of these sites are shown in Fig. 4. The sediment in this area is known to have a substantial turbidite component (see, for example, Prince *et al.* [2]). In addition, Laine, Damuth, and Jacobi [3] have characterized the area as having a 3.5-kHz echo type of distinct echoes (Damuth type IA), as opposed to the generalized echoes of the Bermuda Rise. Examination of Fig. 4 shows results that are different from any of the approximately 40 other sites we have surveyed, in that this is the only site we have measured where the frequency dependence is inverted, with the scattering strengths increasing with increasing frequency. In fact, the results for frequencies below 200 Hz are the lowest of any site we have measured. This site is also unusual in that the lower frequencies show curve shapes that are similar to Lambert, while the higher frequencies are flatter than Lambert. Apparently the presence of substantial turbidite deposits is dominating the acoustic scattering properties. At another site (not included here) in the Hatteras Abyssal Plain, coming from a small area that Laine, Damuth, and Jacobi characterize as having hyperbolic echoes (Damuth type IIIB), the frequency dependence is U-shaped, with a minimum scattering strength around 500 Hz. It may be that whatever is giving rise to the hyperbolic echoes is deep enough in the sediment to affect strongly the low frequency scattering but has little effect on the high frequency scattering, which is likely to be dominated by surface sediments.

Figure 5 gives scattering strengths for a site in the Norway Basin. It is in an area where the upper sediments are characterized by Vogt [4] as foraminiferal clay, marl, or ooze. The direction of the frequency dependence is the same as the Ionian Basin and the Bermuda Rise, with a substantial spread in scattering levels between the lowest and highest frequencies. The highest frequencies are generally Lambert-like in shape up to about 45 deg, even for the broadside beam results shown, while the lower frequencies are presumably more strongly affected by subbottom returns. The results for this position may be contrasted to the results shown in Fig. 6 from a site on the west edge of the Aegir Ridge, about 20 nmi SSW of the first site and directly over a bathymetry peak. Though the sense of the frequency dependence for the Aegir Ridge site is the same as in the Basin, the spread in levels as a function of frequency is less, and the levels are higher by 10 to 15 dB at 30 deg grazing angle. This is probably due to the thinner sediment cover found in the Aegir Ridge.

Typical results for the Aleutian Abyssal Plain are given in Fig. 7. At this site, there is about a 100-m thick layer of fine-grained pelagic sediment lying on top of about 300 m of turbidites that form part of the Zodiac Fan. The scattering strengths from this area generally show little frequency dependence between 500 and 1000 Hz, then increase slightly with decreasing frequency. The grazing angle dependence is roughly similar to Lambert below 40 to 45 deg. However, some of the sites surveyed showed clear evidence of pronounced subbottom features, with large increases in scattering strength at low frequencies that disappeared at higher frequencies. In addition, one site showed the same U-shaped frequency dependence as was seen in the Hatteras Abyssal Plain.

The final site for which results are reported is in the Icelandic Basin. Figure 8 shows one data set from a position just north of Hatton Bank. Extrapolation from measurement sites closer to Iceland suggest that the sediment is largely mud with a high basaltic sand/silt fraction. As for the Aleutian Abyssal Plain, there is little frequency dependence at any of the sites in this region, though the lower frequency results tend to be slightly higher than the higher frequency results. Most of the sites surveyed showed a roughly Lambert-like dependence on grazing angle below 40 deg. However, there is as much as 10 dB variability in the scattering levels between sites only about 30 nmi apart, with one site showing scattering strengths declining with grazing angle faster than Lambert to levels about 5 dB below Mackenzie at 30 deg grazing angle.

The frequency dependence of the various sites is summarized in Fig. 9. This summary was made by choosing representative data sets from each site and plotting the scattering strengths at 30 deg grazing angle. As previously noted, the majority of the sites measured showed a decrease in scattering strength with increasing frequency, though for a substantial number of sites this decrease was small. Of the 36 sites for which we have measurements, two show a U-shaped dependence and only one (in the Hatteras Abyssal Plain) shows an increase with increasing frequency.

BOTTOM BACKSCATTERING STRENGTHS MEASURED USING SUS CHARGES

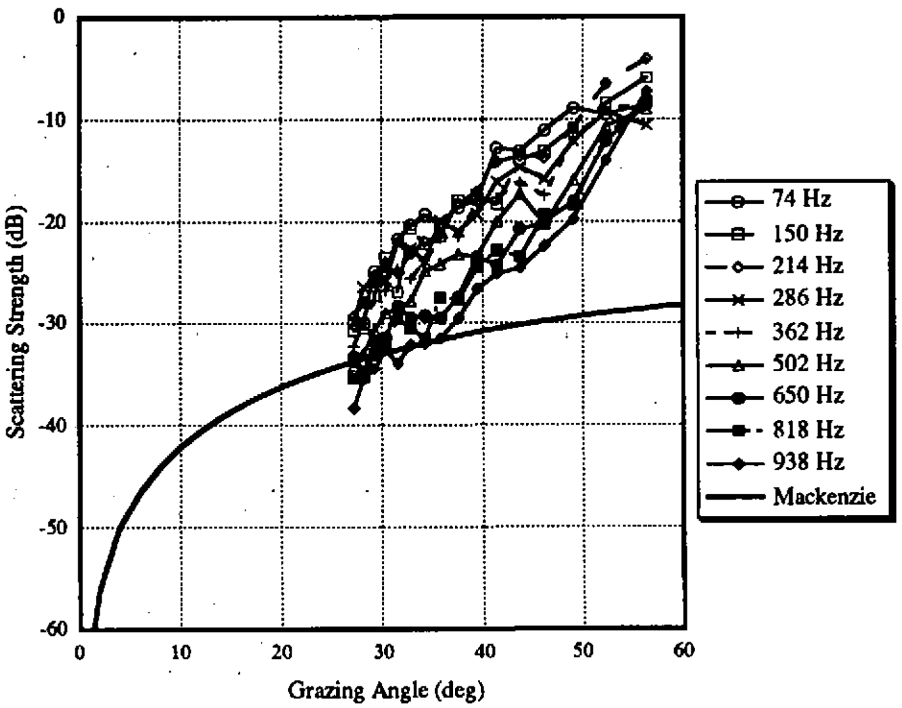

Fig. 1—Bottom scattering strengths from the broadside beam taken at 36° 28' N, 18° 9'E, near the Ionian Abyssal Plain

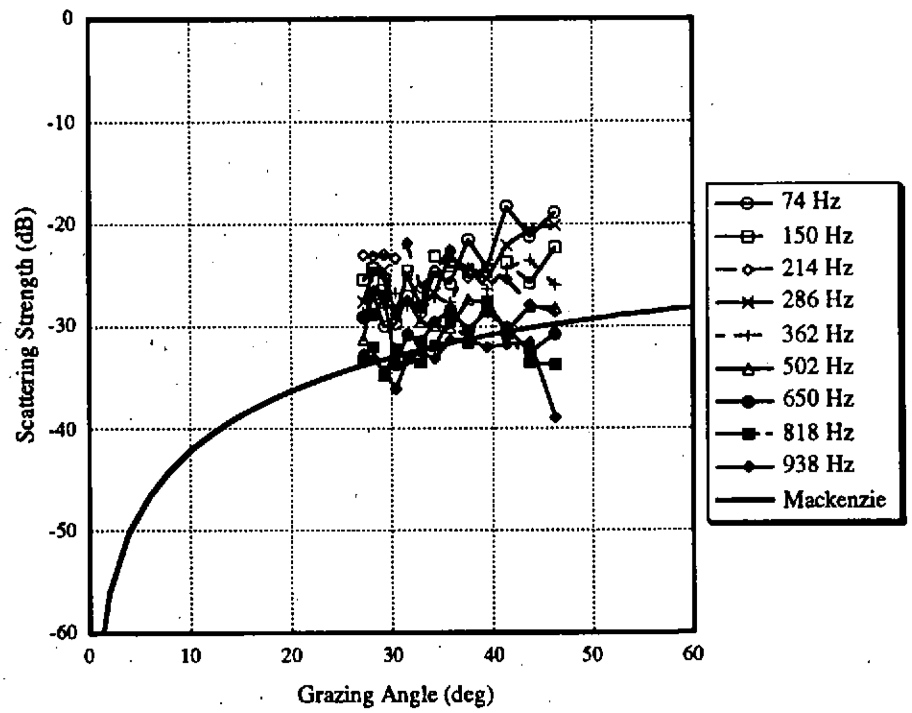

Fig. 2—Bottom scattering strengths from a beam 39 deg forward of broadside at the same position as Fig. 1

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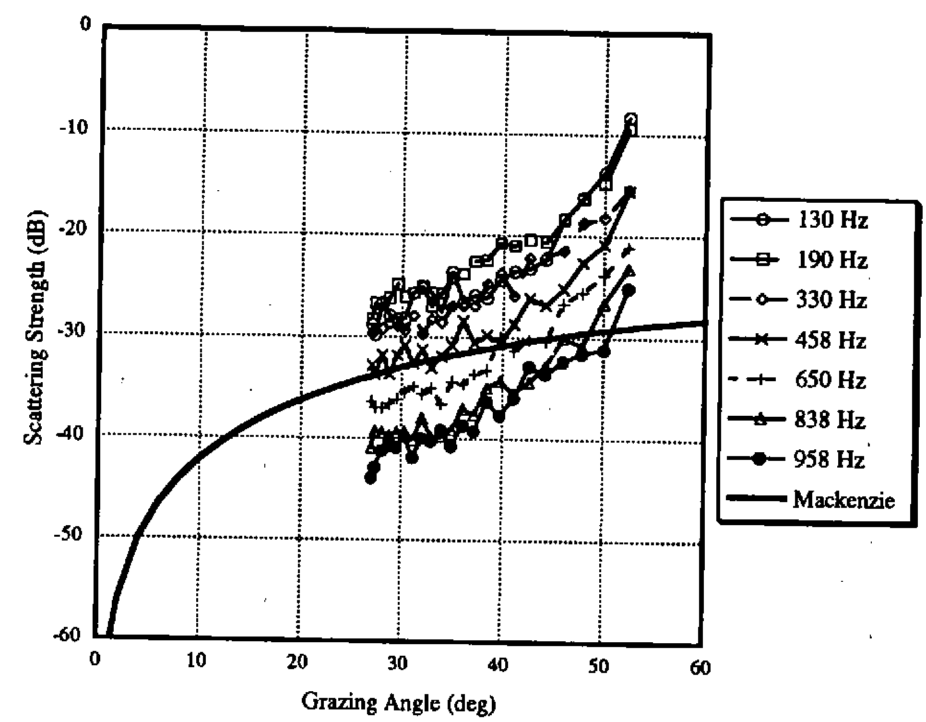

Fig. 3—Bottom scattering strengths taken at 29° 4' N, 68° 31' W, on the Bermuda Rise

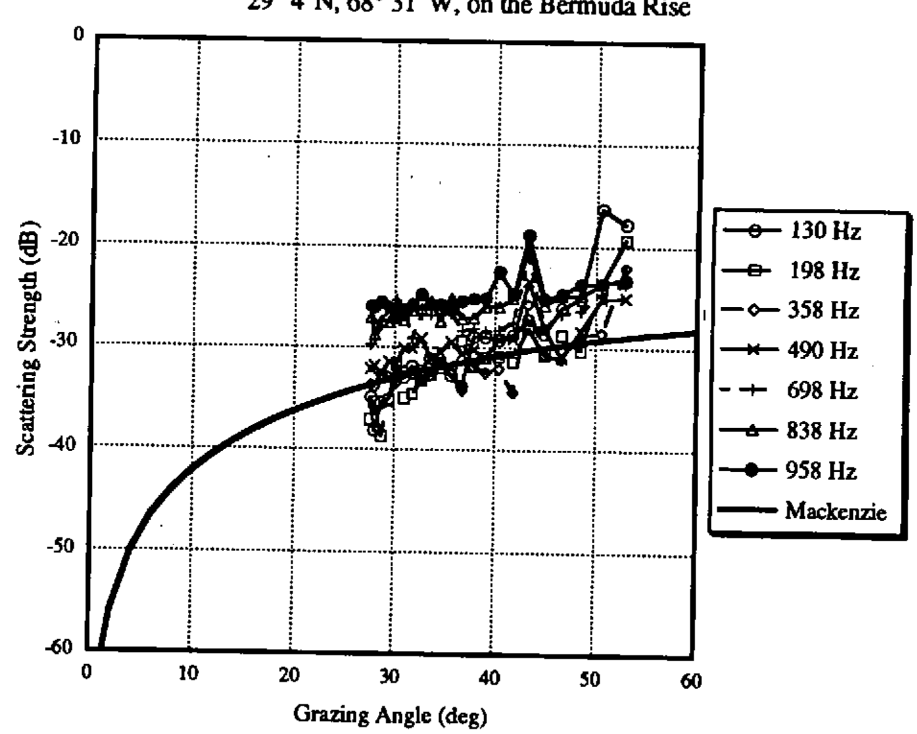

Fig. 4—Bottom scattering strengths taken at 28° 21' N, 70° 3' W, on the Hatteras Abyssal Plain

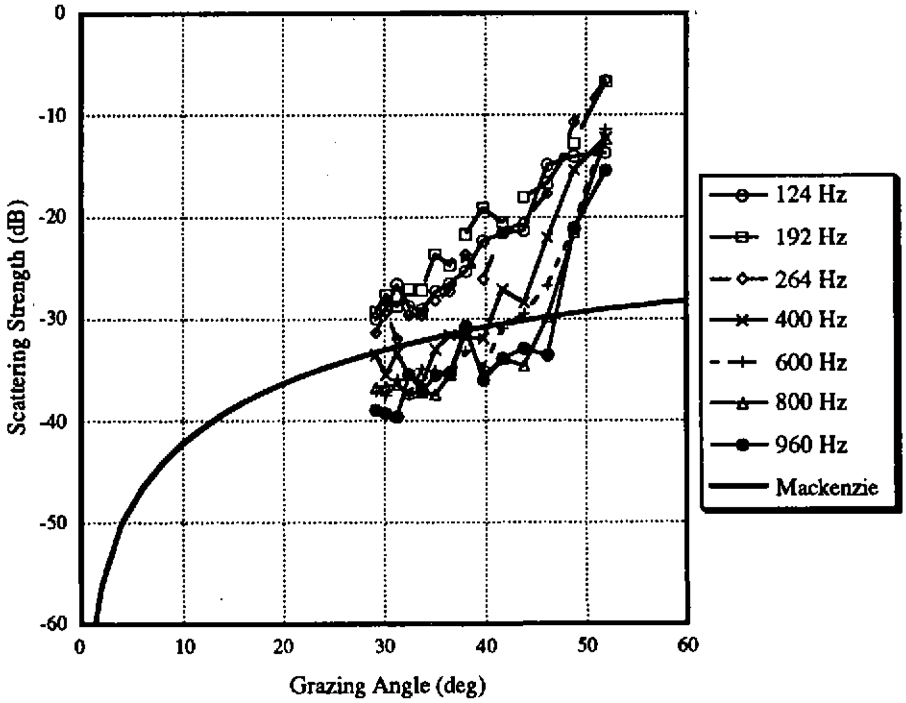

Fig. 5—Bottom scattering strengths taken at 67° 52' N, 3° 39' W, in the Norway Basin

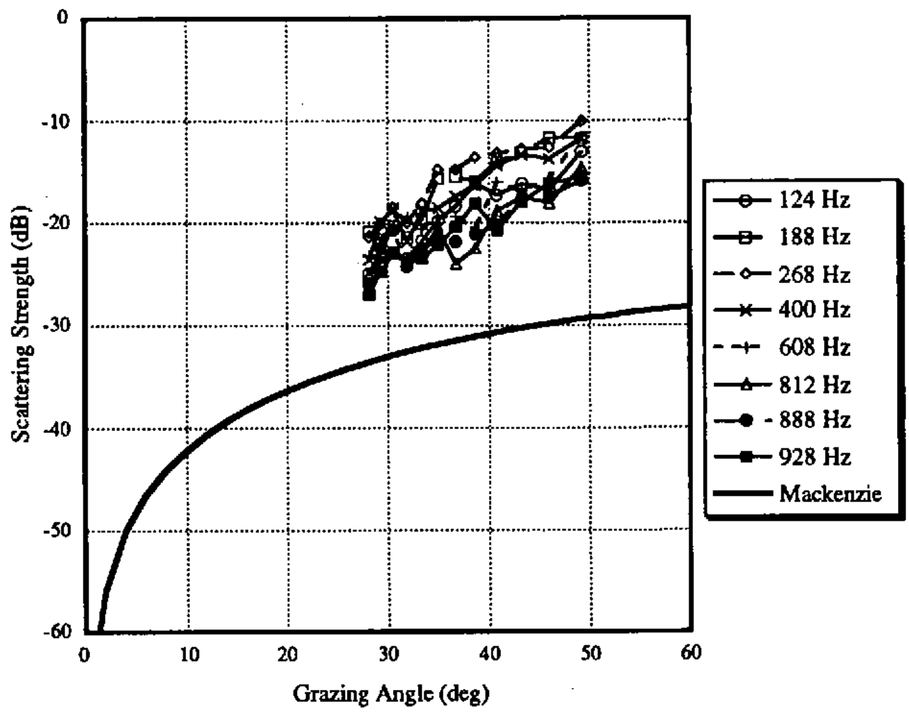

Fig. 6—Bottom scattering strengths taken at 67° 36' N, 4° 6' W, over the Aegir Ridge

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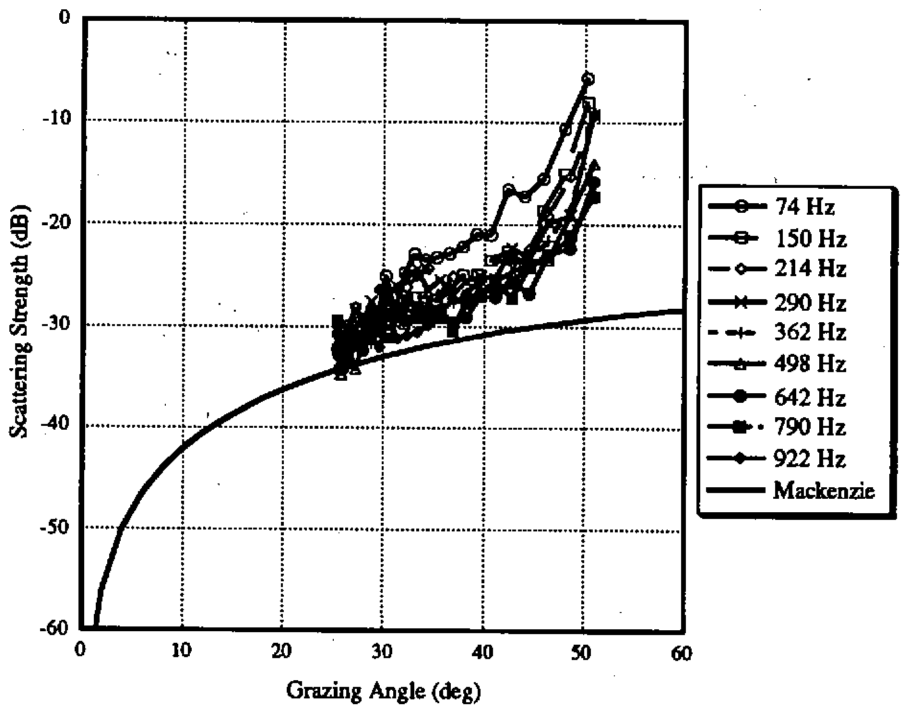

Fig. 7—Bottom scattering strengths taken at 50° 8' N, 160° 3' W, on the Aleutian Abyssal Plain

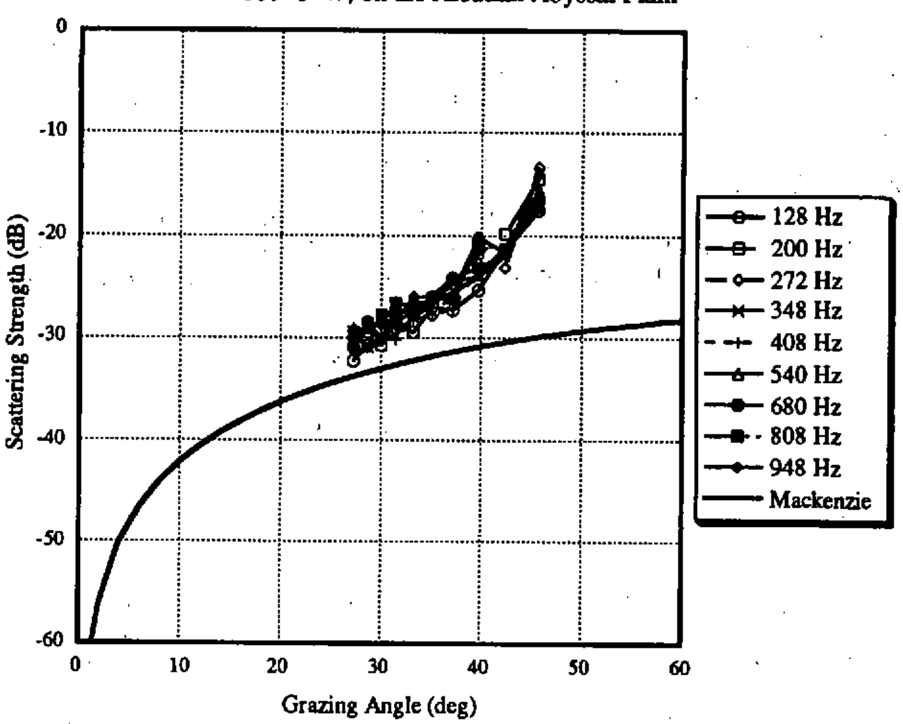

Fig. 8—Bottom scattering strengths taken at 59° 46' N, 17° 51' W, in the Icelandic Basin

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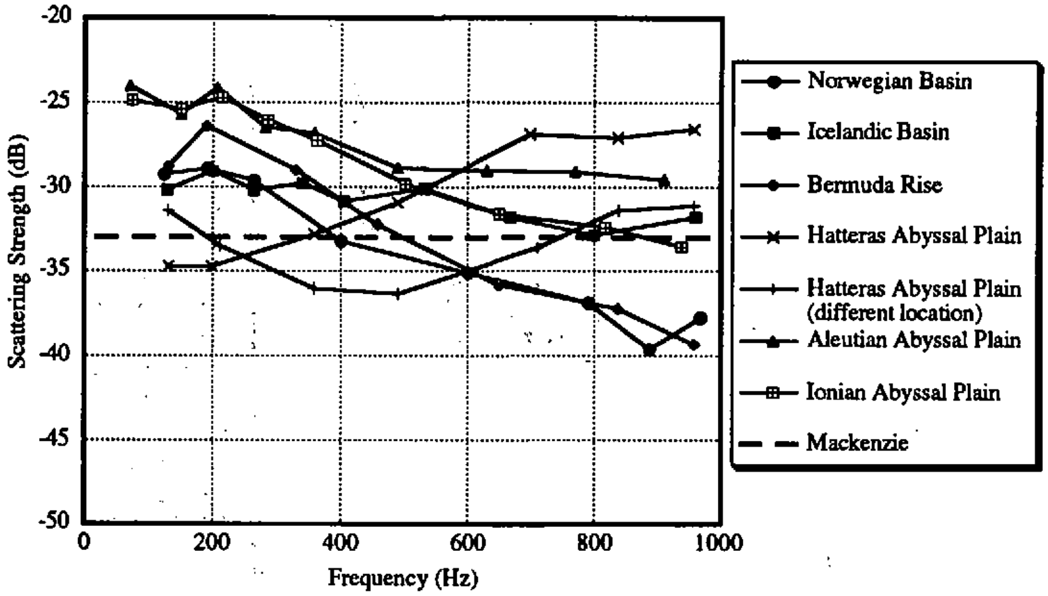

Fig. 9—Summary of bottom scattering strengths at 30 deg grazing angle for representative data sets from the areas shown

4. SUMMARY AND CONCLUSIONS

We have presented a sample of the bottom backscatter data we have collected at a number of deep-water sites around the world using broadband SUS charges as sources. The data were collected between about 70 and 950 Hz and for grazing angles of approximately 27 to 55 deg. The principal conclusions are as follows.

- For almost all of the sites surveyed, the scattering strengths decreased or stayed roughly constant as frequency increased.
- Subbottom effects were important at most sites for the grazing angles measured, with the lower frequencies being most affected. The importance of the effects was very site-dependent.
- Considerable variations in scattering strength levels are seen between the various sites surveyed.

5. REFERENCES

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[3] E P LAINE, J E DAMUTH, & R JACOBI, "Surficial sedimentary processes revealed by echo-character mapping in the western North Atlantic Ocean," in *The Geology of North America, Vol. M: The Western North Atlantic Region,* P VOGT & B TUCHOLKE, eds., Geol. Soc. of Amer. (1986)

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