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Bottom Backscattering Measured Off the Southwest Coast of Florida During the Littoral Warfare Advanced Development 99-1 Experiment

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Measurements of ocean bottom backscattering were performed in a shallow water environment off the southwest coast of Florida as part of the Littoral Warfare Advanced Development 99-1 Experiment. Scattering strengths were obtained at 1 to 4.5 kHz as a function of grazing angle. Scattering strengths were in the –35 to –45 dB range. The grazing angle dependence could be fit adequately by assuming a dependence of scattering strength on the sine of the grazing angle.

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BOTTOM BACKSCATTERING MEASURED OFF THE SOUTHWEST COAST OF FLORIDA DURING THE LITTORAL WARFARE ADVANCED DEVELOPMENT 99-1 EXPERIMENT

INTRODUCTION

The Littoral Warfare Advanced Development (LWAD) 99-1 experiment was conducted in the Gulf of Mexico 130 nm west-northwest of Key West in February 1999. Bottom reverberation is a potential source of clutter for active sonar systems operating in this littoral area. Bottom backscattering strength (BSS) in the 1 to 4.5 kHz band was calculated using direct path measurements.

The bottom interaction problem can involve multiple physical processes, all of which may contribute to the measured scattering strength: scattering from the water/sediment interface, scattering in the sediment volume itself, or scattering from the basement or a subsurface layer with a significant impedance mismatch. The frequency and grazing-angle dependence can reflect an enhancement of one mechanism over another, and given the variability of the littoral environment in sediment thickness, composition, and frequency-dependent attenuation, correct physical interpretation of bottom scattering strengths usually requires significant knowledge of the geoacoustic properties and structure of the subbottom. For regions where sand cover tends to be significant and results depend on specific characteristics such as sand layer thickness and homogeneity, there is greater potential for variability in frequency and site dependence.

Bottom scattering strength can be calculated by solving the sonar equation in the following form:

$$BSS = RL - SL + TL_s + TL_r - 10 \log A \tag{1}$$

where BSS is the scattering strength in dB, RL is the measured reverberation level in dB *re* $(1\mu\text{Pa})^2/\text{Hz}$, SL is the source level in dB *re* $(1\mu\text{Pa})^2/\text{Hz}$ at 1 m, TL_s is the transmission loss from the source to the ensonified patch on the bottom in dB, TL_r is the transmission loss from the ensonified patch on the bottom to the receiver in dB, and A is the area of the ensonified patch in square meters.

Bottom backscattering measurements have been performed during five previous LWAD experiments: Focused Technology Experiment 96-2 (FTE 96-2), Focused Technology Experiment 97-2 (FTE 97-2), System Concept Validation 97 (SCV-97), LWAD Experiment 98-2 (LWAD 98-2) and LWAD Experiment 98-4 (LWAD 98-4). The FTE 96-2, SCV-97 and LWAD 98-4 backscattering measurements appear in [1,2,3]. FTE 97-2 data were collected at a site 16 nm southwest of Key West, Florida and the results are reported in [4]. LWAD 98-2 data were collected near the LWAD 99-1 site and the results are reported in [5].

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Table 1 — LWAD 99-1 Bottom Scattering Runs

Run #	Date (Z)	Time (Z)
1	7 Feb 1999	0441-0452
2	7 Feb 1999	1732-1741
3	9 Feb 1999	1945-1951
4	10 Feb 1999	0603-0612

During LWAD 99-1, data were obtained at eight frequencies (1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 kHz) covering grazing angles of 3 to 30 degrees during four scattering runs. Table 1 shows the date and time in Zulu for the scattering runs. The BSS data were collected at one site shown as the solid circle in Figure 1. The location of the LWAD 99-1 anchor site is 25.620 N 84.184 W and the water depth is 160 m. The site is close to LWAD 98-2 scattering runs 1 and 2. The location of the LWAD 98-2 scattering runs are depicted as the two lines showing the (drifting) ship tracks.

LWAD BSS measurements have shown a strong dependence in scattering strength level on the presence or absence of a significant sand layer (> 20 m). Data taken with a significant sandy sediment thickness can be fit well by assuming a scattering strength proportional to the sine of the grazing angle, with proportionality constants of -25 dB to -30 dB. However, when the sediment is negligible and the underlying limestone is the scatterer, BSS values are 15-20 dB higher [5]. This report compares the LWAD 99-1 results with the LWAD 98-2 data collected at a nearby site.

EXPERIMENT GEOMETRY AND DATA ANALYSIS

The bottom scattering tests were conducted from the research vessel *Edwin Link* during LWAD 99-1. A 28-hydrophone vertical line array (VLA) and a source were deployed on a single cable, with the source at a depth of approximately 72 m, 5 m above the center of the VLA receiving aperture. This produces a nearly monostatic measurement geometry.

The source was a ring-shaped transducer (USRD G81) that gave maximum (over the range of launch angles) root-mean-square source levels ranging from 177 dB (1000 Hz) to 197 dB (2500 Hz). The source beam pattern features a null in the upward direction and some flattening in the downward direction. This beam pattern gave maximum source level for all of the launch directions used to calculate scattering strength, so the deviations from the omnidirectional pattern did not affect the BSS calculation. However, the source directionality does help to mitigate sidelobe interference for very high grazing-angle returns, such as the initial acoustic interactions with the ocean surface and bottom. This allows extension of data validity to lower grazing angles. The waveforms were 50 ms gated continuous wave (GCW) signals. Two sets of 20 identical wavetrains consisting of four adjacent signals were transmitted. The signals were separated by 15 s. One set consisted of signals in the sequence 1, 2, 1.5, and 2.5 kHz. The second set consisted of signals in the sequence 3, 4, 3.5, and 4.5 kHz.

The bottom reverberation from the 50 ms pulses was received on the 28-hydrophone VLA. The hydrophones were spaced at 15.24 cm (6 in) which corresponds to half-wavelength spacings of 4920 Hz. Seventeen beams with cosine-spaced main response axes were formed from the 16-phone aperture at the center of the array, with most of the returns coming from downward-looking beams closest to broadside.

After beamforming, power spectra were obtained by performing 50 ms Fourier transforms with 50 percent overlap over the length of the reverberation time series. A frequency band representing the total energy about the zero-Doppler peak was selected, and a time series including only the energy in this band was created for each ping. The direct arrivals for the pings were then temporally aligned and the various pings were averaged to produce a single reverberation curve for each beam and frequency bin. Integration over the roughly zero-Doppler spectral peak produced the total returned power as a function of time and beam. By calculating geometric spreading loss along each ray path, the transmission loss terms to and from the scattering patch were obtained. Finally, the computed beam pattern and raytrace were used to calculate the scattering patch area. From these inputs, BSS was calculated using Eq. (1) as a function of beam, frequency, and grazing angle. The standard deviations due to ping-to-ping variability within the sets of identical transmissions were $\pm$ 2 to 3 dB. The system calibration was computed to within 1 dB accuracy.

BOTTOM SCATTERING RESULTS

The LWAD 99-1 scattering site is to the east of Howell Hook reef which is a Pleistocene coral reef that acts as a sediment trap. The scattering site is in an area consisting of a deep layer of foraminiferal sand. The sediment is composed of muddy calcareous sand [6]. At the anchor site, chirp sonar appeared to reveal a subbasement reflector at approximately 3 m which may indicate a transition from muddy to coarser calcareous sand.

Figure 2 shows the BSS values from the four LWAD 99-1 scattering runs at 1 kHz as a function of grazing angle. The grazing angles for the source-to-scatterer and scatterer-to-receiver are similar (i.e., within tenths of a degree), so only one angle needs to be considered in the analysis. The average of the two grazing angles is the quantity plotted on the x-axis. The scattering measurements are averaged over a set of 20 pings from downward directed beams. The beam angles span 60 to 83 degrees relative to bottom endfire. The circles are scattering measurements from the four scattering runs. The bold curve is the scattering strength averaged over the measurements. The bottom bold curve in the figures is the Mackenzie curve $-27+10\log(\sin^2\theta)$, a reference curve showing Lambert's law with a coefficient of -27 dB. This curve is the standard input to Navy performance models, with the selection of the -27 dB value originating in the work of Mackenzie [7].

Figures 3-9 presents the results for the remaining seven frequencies (2, 2.5, 3, 3.5, 4 and 4.5 kHz.) Figure 10 shows the bottom backscattering strength as a function of grazing angle for all eight frequencies. (The curves shown in figure 10 are the averaged curves presented in figures 3-9.) The scattering strength measurements are in the -35 to -45 dB range covering grazing angles of 3 to 30 degrees. The grazing angle dependence can be fit adequately by assuming a dependence of scattering strength on the sine of the grazing angle. The dashed lines represent $\mu+10\log(\sin\theta)$ for μ = -30,-35, and -40.

Figure 11 presents bottom backscattering strength as a function of grazing angle for 2, 2.5, 3 and 3.5 kHz at two nearby LWAD 99-1 and LWAD 98-2 experimental sites. The sites are separated by approximately 1 nm. (The results from this particular LWAD 98-2 site is not presented in [5].) The average LWAD 98-2 BSS value from this site is approximately -35 dB. The average LWAD 99-1 BSS value is approximately -40 dB or 5 dB lower.

SUMMARY

During LWAD 99-1, ocean bottom backscattering strengths were measured at a site off the southwest coast of Florida. The water depth at this site is 160 m. Scattering strength measurements for 1 to 4.5 kHz covering grazing angles of 3 to 30 degrees were obtained during four scattering runs. Scattering strengths were in the -35 to -45 dB range. The grazing angle dependence could be fit adequately by assuming a dependence of scattering strength on the sine of the grazing angle. The LWAD 99-1 scattering strength measurements were compared with LWAD 98-2 measurements taken approximately 1 nm away. The LWAD 99-1 scattering strength level is approximately 5 dB lower.

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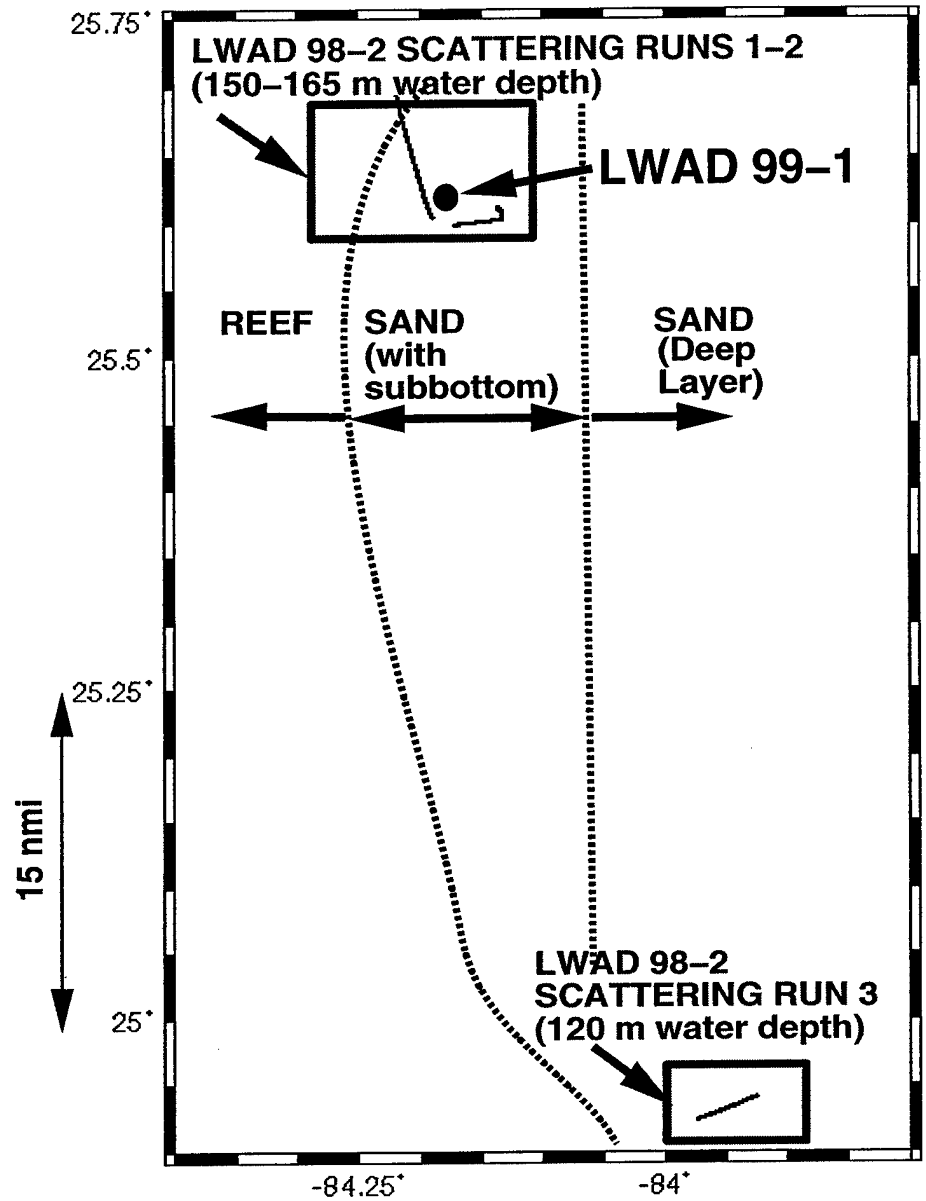

Fig. 1 — LWAD 99-1 bottom scattering site. The anchor site is near the location of LWAD 98-2 scattering runs 1 and 2. The (drifting) ship tracks of LWAD 98-2 are depicted as the two lines in the box.

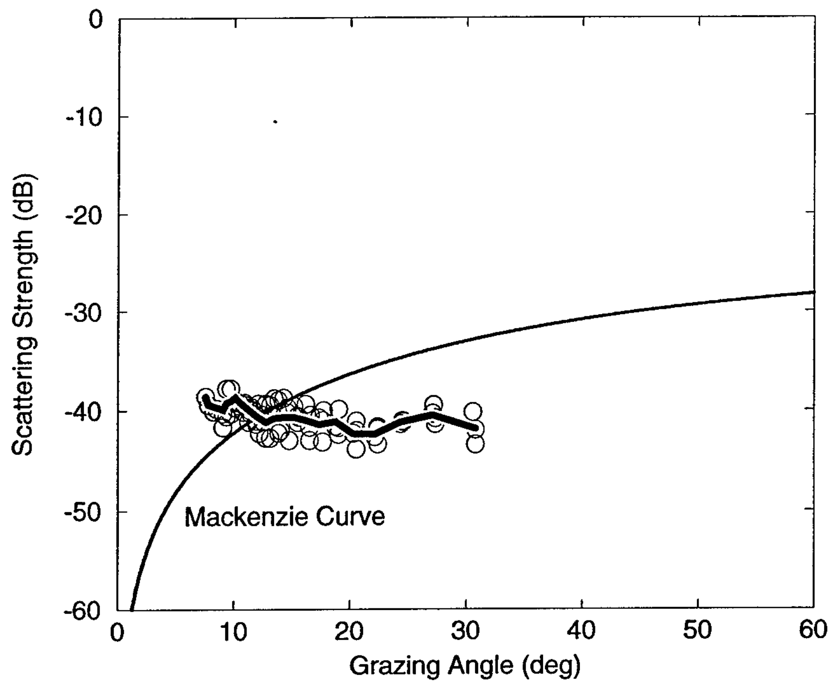

Fig. 2 — Bottom backscattering strength as a function of grazing angle for 1 kHz. The circles are scattering measurements during the four runs. The bold curve is the scattering strength averaged over the measurements. The Mackenzie curve is also shown.

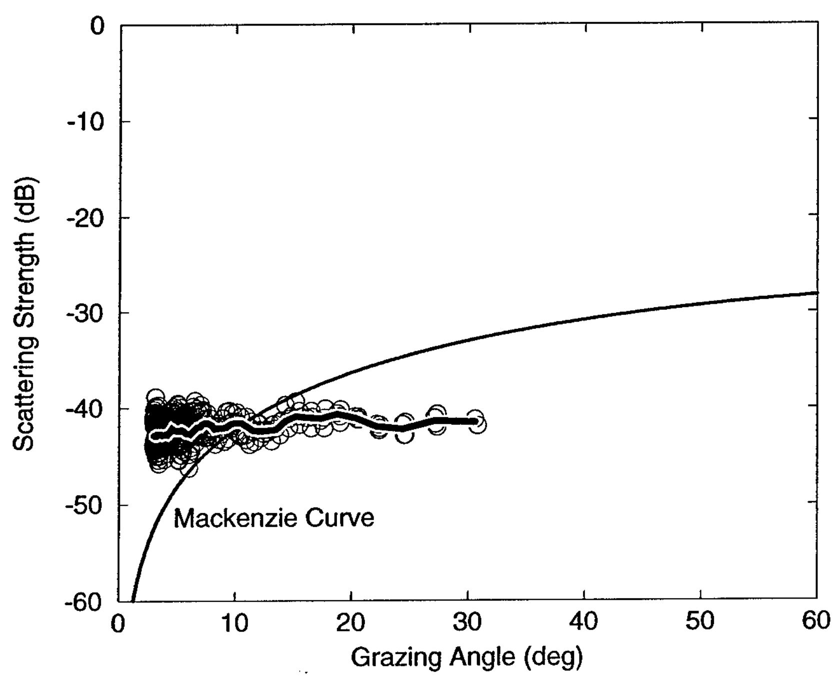

Fig. 3 — Bottom backscattering strength as a function of grazing angle for 1.5 kHz. The circles are scattering measurements during the four runs. The bold curve is the scattering strength averaged over the measurements. The Mackenzie curve is also shown.

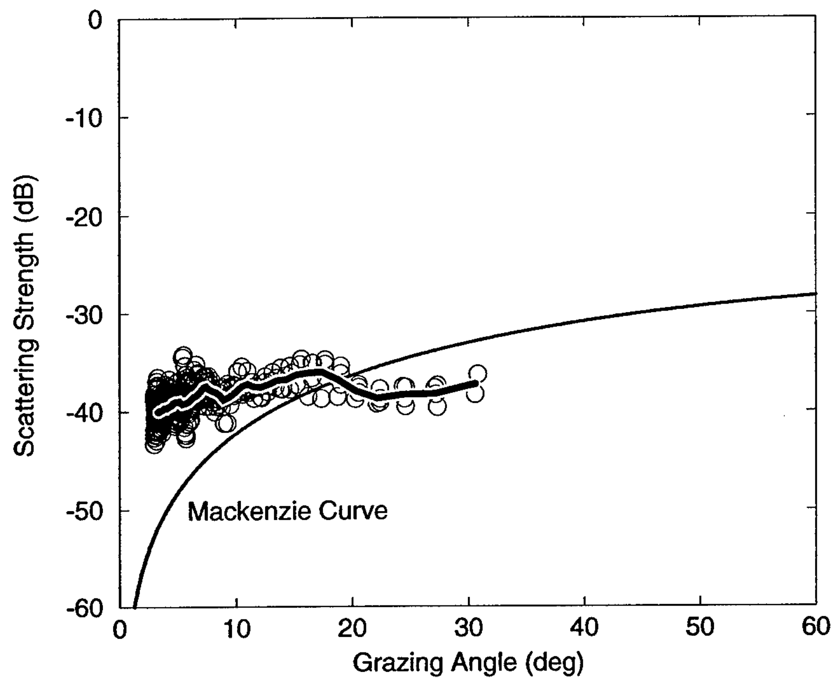

Fig. 4 — Bottom backscattering strength as a function of grazing angle for 2 kHz.

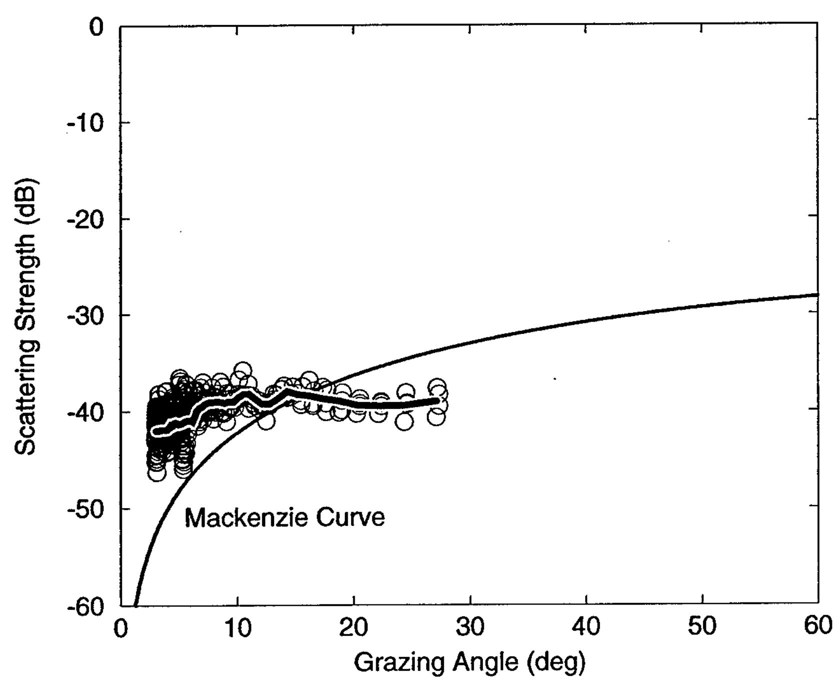

Fig. 5 — Bottom backscattering strength as a function of grazing angle for 2.5 kHz.

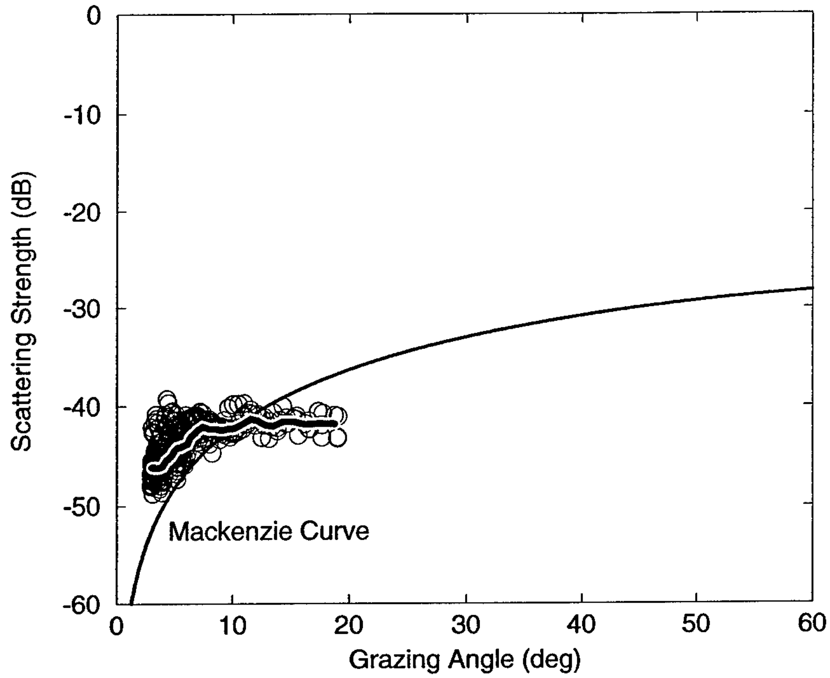

Fig. 6 — Bottom backscattering strength as a function of grazing angle for 3 kHz.

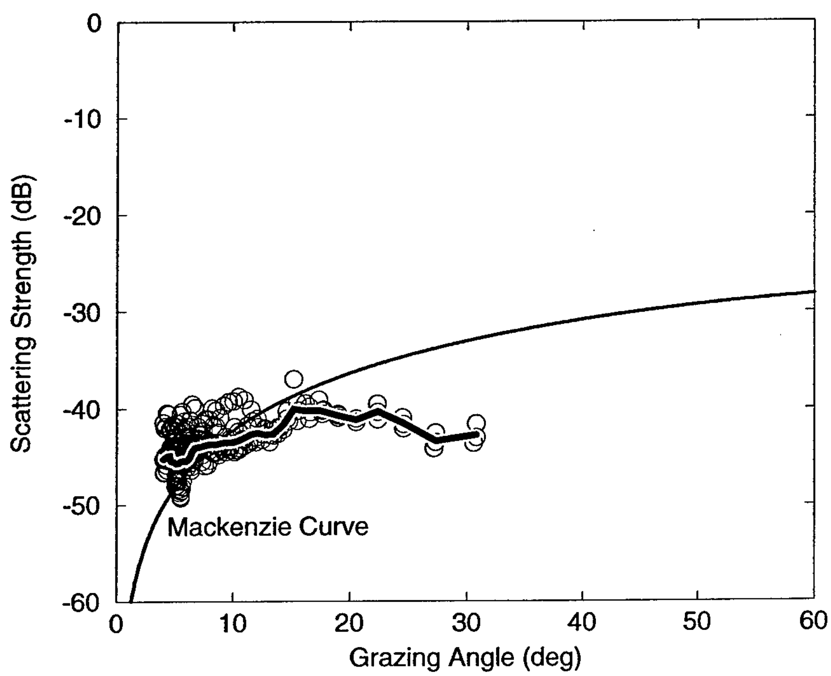

Fig. 7 — Bottom backscattering strength as a function of grazing angle for 3.5 kHz.

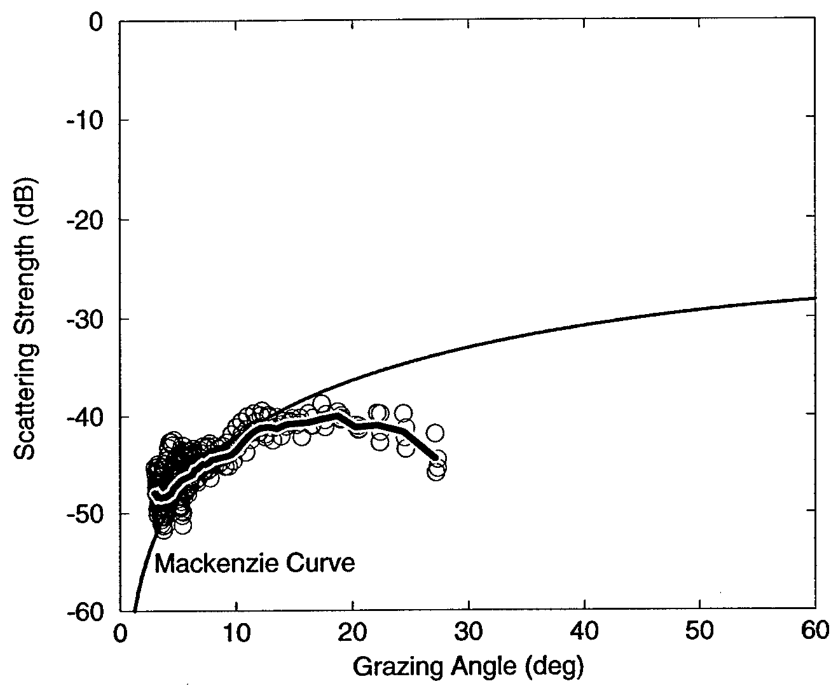

Fig. 8 — Bottom backscattering strength as a function of grazing angle for 4 kHz.

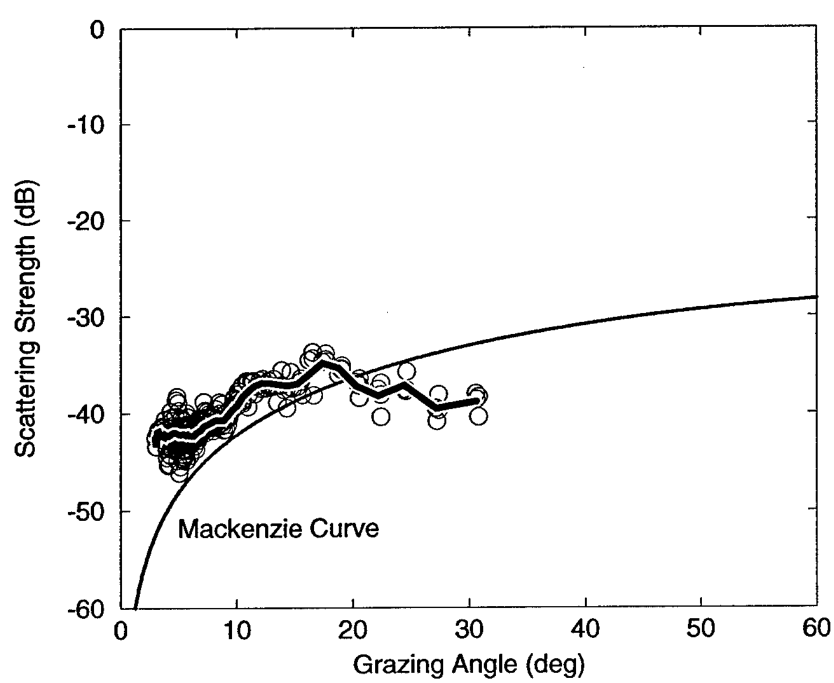

Fig. 9 — Bottom backscattering strength as a function of grazing angle for 4.5 kHz.

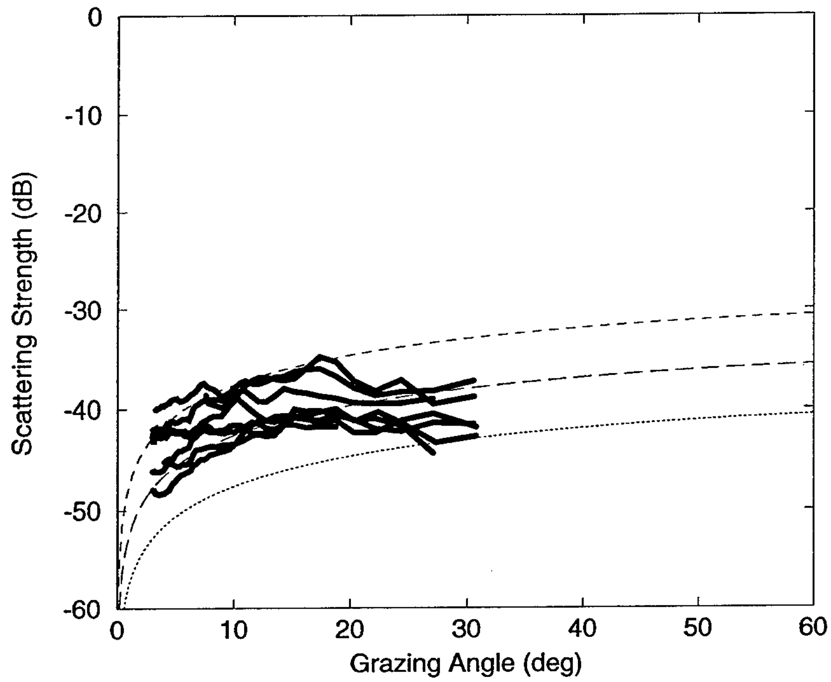

Fig. 10 — Bottom backscattering strength as a function of grazing angle for all eight frequencies (1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 kHz.) The dashed lines represent $\mu + 10\log(\sin\theta)$ for μ = -30,-35 and -40.

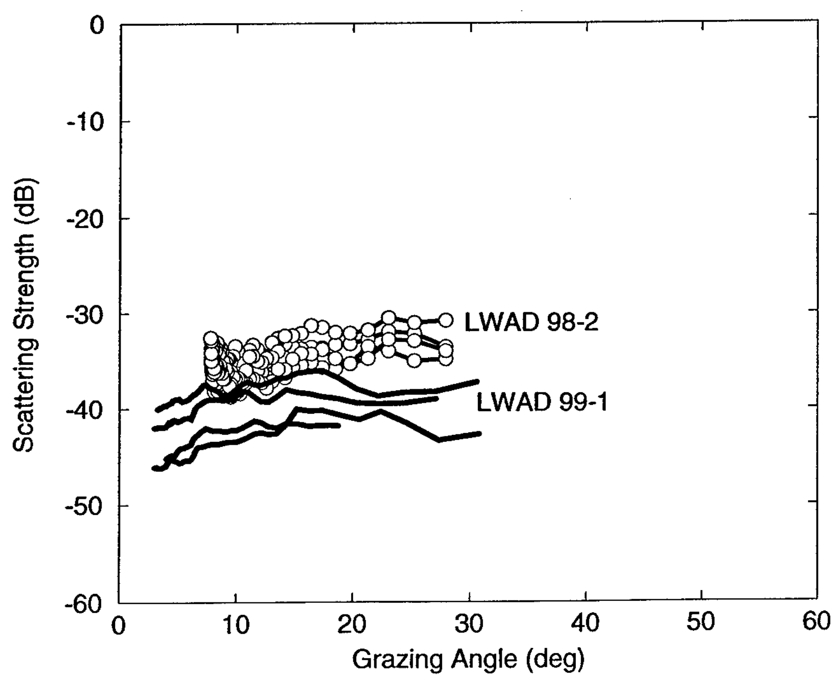

Fig. 11 — Bottom backscattering strength as a function of grazing angle for 2, 2.5, 3 and 3.5 kHz at two nearby LWAD 99-1 and LWAD 98-2 experimental sites.