THE EFFECT OF THIN BEDS ON ATTENUATION ESTIMATES FOR SHALLOW SUBBOTTOM CLASSIFICATION

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Acoustic seabed classification from sonar data has generally focussed on attributes of the return echo from the seafloor. For many engineering applications such as the dredging and monitoring of navigable waters, building of major structures such as bridges, pipelines, and dams requiring the support of the subbottom, and research into regional tectonic activity, a detailed knowledge of the subbottom is also required. The development of high-resolution seismic systems such as chirp sonars (1) and the IKB SEISTEC^{TM} system (2) this decade has allowed the mapping of the subsurface in shallow water to become cost-effective, and provides the potential for rapid, subbottom classification.

These shallow-water high-resolution seismic profilers operate in water depths of 10-15 metres with bandwidths up to 1-12 kHz. Subsurface penetration in excess of 10 metres can be achieved. Often, in cases where seismic reflectors appear to be well resolved, it is inviting to assume a frequency-dependent loss of amplitude between seafloor and subbottom reflectors. Methods, such as the spectral-ratio technique, that can utilize the wide bandwidth of these profilers, can be then used to estimate attenuation coefficients between successive reflectors. These estimates in turn could be then used to classify subbottom sediment types.

In many cases, however, an apparently well-resolved reflector may be the result of the constructive interference between reflected energy (including multiples) from closely spaced interfaces. This paper will present the results of a model study investigating the effects on apparent attenuation due to thin bed interaction.

ACOUSTIC ATTENUATION IN SEDIMENTS

When an acoustic signal passes through sediments, attenuation typically causes the amplitude of the signal to decrease with the distance traveled. Hamilton (3) demonstrated from a large database of field measurements that compresssional attenuation varies linearly with frequency. Therefore, we can write the average attenuation between two consecutive reflectors as (4):

$$A_2(f) = G \times A_1(f) \times \exp\left(\frac{-\beta \times (t_2 - t_1) \times f}{20 \times \log_{10}(\exp(1))}\right) \qquad (1)$$

where $A_1(f)$ and $A_2(f)$ are the amplitude spectra of the shallower and deeper reflector signals, f is the frequency, t_2-t_1 is the traveltime between the two reflectors, β is the attenuation coefficient in dB/wavelength (dB/λ), and G is a frequency independent term dependent on the reflection coefficients at the interfaces associated with the two reflectors. A least squares fit of the logarithm of the ratio of the amplitude spectra versus frequency over the source bandwidth results in a line with a slope related to the attenuation coefficient and intercept related to approximately the ratio of the reflection coefficients (for a small upper reflection coefficient).

There are a few studies in which the values of attenuation coefficients in near surface sediments have been published. Schock (1) summarizes the results of these few studies, and the attenuation coefficient ranges typically from 0.05 to 0.35 dB/λ, and is well resolved (approximately 0.05 dB/λ) for the sediment types of interest, suggesting that this property is useful for classification purposes.

However, in many cases, interference from overlapping subbottom reflectors creates a "hole" in the spectrum of the subbottom arrival in the useful source band (see (6)), and consequently degrades the fit of the least-squares relationship described above. At the expense of classifying less of the subbottom, rejecting estimates where the correlation coefficient of the least-squares fit falls below the 95% confidence level can overcome potential misclassification. The effectiveness of this criterion in the following model study will also be examined.

MODELING PROCEDURE

To test the effect of thin beds on attenuation coefficient estimates, the impulse response of a series of acoustic models containing a near-surface thin bed (depicted in Figure 1) was calculated at a sample rate of 50 KHz by varying the attenuation coefficient (α), the thin bed reflection coefficient (z_{tb}), the thin bed thickness (Δx), and the thickness of the bed below the thin bed (x-Δx) over the ranges shown in Figure 1, while holding the surface and subsurface reflection coefficient constant (0.20 and 0.05 respectively. A synthetic seismogram for each case was created by convolving a ~2-8 KHz source wavelet with the impulse response. 64 point FFT's of the apparent seafloor and subsurface reflectors (as shown in Figure 2) were calculated (the thin bed reflector was eliminated and the data zero-padded if it was well-resolved from the seafloor reflector). The attenuation coefficient and reflection coefficient ratio between the reflectors were then estimated by fitting a straight line between the log of the amplitude spectra ratio versus frequency over the source of range 2-8 KHz.

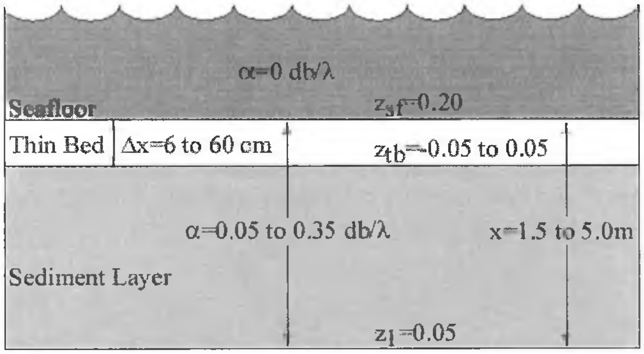

Fig. 1. Geoacoustic model used for this study. The parameters varied are the attenuation of the sediment layer (α), the reflection coefficient of the thin bed-sediment layer interface (z_{tb}), the thin bed thickness (Δx), and the overall thickness of sediment (x).

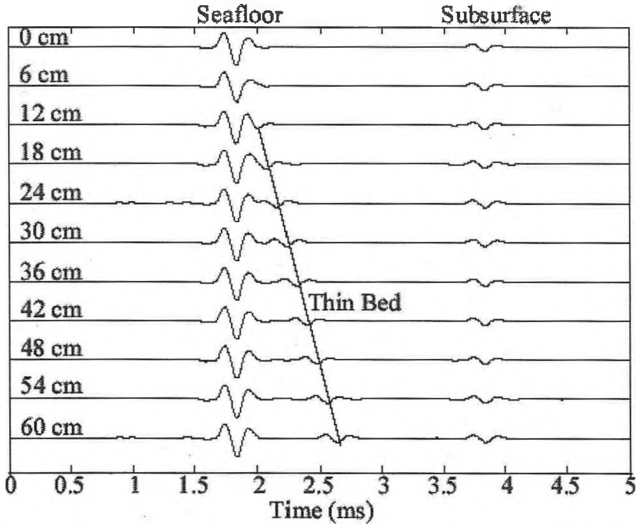

Fig. 2. Arrivals resulting from a geoacoustic model with α=0.05 dB/λ, x=1.5m, z_{tb}=0.04, for various thin bed thicknesses Δx. Note for very thin beds, an arrival from a single interface is nearly indistinguishable from one resulting from the interaction of two interfaces.

RESULTS

To attempt to isolate the sensitive parameters influencing attenuation estimates, histograms of the estimated attenuation coefficients and reflection coefficient ratios were generated with the value of one model variable held constant, while letting the other variables span their entire tested range. Figure 3, as an example, shows the histograms of the estimated attenuation coefficient by holding the attenuation coefficient constant (for various values of a), while letting ztb, x, and Dx vary. Also shown (in solid) are the histograms of estimates that were generated from a least-squares line with a goodness-of-fit significant at the 95% confidence level.

From all these histograms, some general patterns can be observed concerning the attenuation coefficient estimates.

1. The attenuation coefficient has little effect on the accuracy of the estimated values, except that the number of estimates that pass the 95% confidence level increases as the attenuation increases. This is not surprising, as the influence of the thin-bed will be increasingly suppressed as attenuation increases.
2. The reflection coefficient of the thin bed, ztb, has a strong influence on the accuracy of the estimation. For |ztb|<0.2, the estimates form histograms that are not widely dispersed (<0.03 dB/l) from the true value. As the value of |ztb| increases, the histograms about each of the true attenuation coefficients have wider tails and lower peaks, and develop bimodal distributions for |ztb|=0.03 and higher.
3. The total thickness of the sediments, x, has little effect on the shape of the histograms about the true attenuation coefficients when considering all the estimates. For the histograms generated from estimates from least-square fits with a 95% confidence, the dispersion about the true values decreases for thinner sediment thickness and lower attenuation coefficients, but the number of estimates satisfying that criteria also decreases.
4. The estimated attenuation coefficient is very sensitive to thin bed thickness, but the relationship is not simple. For thin bed thickness of 18 cm., and 30 cm. and greater, the histograms about the true attenuation coefficient are narrow, indicating accurate estimates regardless of the value of the other parameters. For a bed thicknesses of 24cm., the histograms are bimodal and have a width of .10 dB/l on either side of the true value. For bed thickness of 6 and 12 cm., the width of the histograms is even wider. Again the histograms generated from estimates from least-square fits with a 95% confidence are narrower for lower attenuation coefficients, though the number of estimates satisfying that criteria also decreases. This is undoubtedly the result of zeros in the amplitude spectra of the apparent surface reflector for thin bed thicknesses of 6 and 12 cm. The result for a 24 cm. thin bed is curious.
5. This study shows that a difference in the attenuation coefficient of 5 dB/l between two sediment layers can be distinguished with some confidence, especially if a goodness of fit criterion is used to limit problems that can be caused by thin bed interaction.

ACKNOWLEDGEMENTS

S.F. Bloomer and N.R. Chapman wish to acknowledge support for this study by NSERC through the Industrial Chair in Ocean Acoustics, and for Dave Hannay for supplying the program used to generate the impulse response from a geoacoustic model.

REFERENCES

1. Schock, S.G., "The Chirp Sonar - A High Resolution, Quantitative Subbottom Profiler", PhD Thesis, University of Rhode Island. (1989).
2. Toth, T. and Simpkin, P., Leading Edge, pp. 1691-1695 (1997).
3. Hamilton, E.L., Journal of the Acoustical Society of America, 68, 1313-1340 (1980).
4. Maroni, C.S. and Quinquis, A., "Estimation of chirp sonar signal attenuation for classification of marine sediments: Improved Spectral Ratio Method", in Proceedings of the Conference on High Frequency Acoustics in Shallow Water, NATO SACLANTCEN, pp. 347-354, 1997.

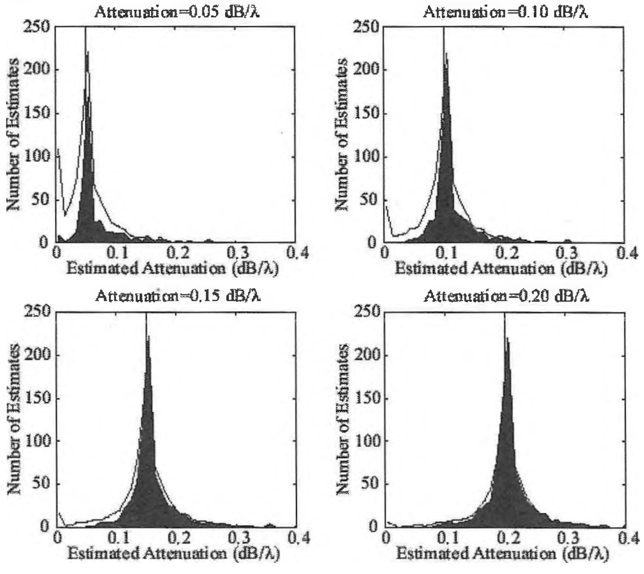

Fig. 3. Plot of histograms of the estimated attenuation for all the model runs with the attenuation equal to 0.05 (upper left), 0.10 (upper righ), 0.15 (lower left), and 0.20 dB/l (lower right). The dark shaded histograms are those that the goodness-of-fit is significant at the 95% confidence level.