THE EFFECT OF SEDIMENT LAYERING ON OCEAN BOTTOM REFLECTION LOSS

Francine Desharnais
Defence Research Establishment Atlantic, P.O. Box 1012, Dartmouth, N.S., B2Y 3Z7

1. Introduction

DREA has produced several analyses of acoustic data for northern ocean areas, in particular analyses of acoustic bottom reflection loss vs grazing angle. The data from one station in Baffin Bay presented some interesting features that were discussed by Desharnais (1990): the data showed that, at high grazing angles, bottom loss at high frequencies (630 Hz) was several dB lower than bottom loss at lower frequencies (20 Hz). The low-loss interval was concentrated in a broad band centred around 600 Hz. The data was successfully modelled using normal geo-acoustic parameters for the ocean sediments of that area, with the addition of a thin high impedance layer near the sediment-water interface. The layer structure is thought to be associated with periodic sediment deposition influenced by ice-rafting and turbidity currents.

Other authors presented bottom loss data with similar low-loss bands at high frequencies. Among others, Holthusen and Vidmar (1982) analyzed sites in the western Nares Abyssal Plain (North Atlantic Ocean), and Hastrup (1969) analyzed a site in the Small Tyrrhenian Abyssal Plain (Mediterranean Sea). Both references estimated the low-loss frequency band to be somewhere between 1400 and 1600 Hz. Core samples were available for these two areas, and the presence of turbidity currents was verified. A semi-periodic layered sediment structure is characteristic of turbidity currents, and these authors used such a layering to explain the behaviour of their data at high frequencies. It is known (Brekhovskikh,1980) that constructive interference can occur between the acoustic reflections from each layer of a periodic system, and that reflection loss can be greatly reduced in specific frequency bands. These low-loss frequency bands are closely related to the periodic structure.

Comparison of the data from different areas shows that the centre frequency of the low-loss frequency band can differ greatly between areas. If a semi-periodic layered structure produces an increase in bottom reflectivity for a particular frequency band, it should be possible to associate the centre frequency to the structure, and to the geological area.

This paper discusses how core samples can be easily analyzed to estimate the centre frequency of those low-loss bands. Modelling trials will be presented to emphasize the layer parameters that are closely related to low-loss frequency bands, and how the low-loss frequency bands could possibly be associated to different geological areas.

2. Theory of the half-wavelength layer

For a periodic system consisting of 2 alternating layers of different acoustic impedance (see Figure 1), it can be shown that the reflection coefficient of the system at normal incidence will be minimum at an acoustic wavelength (λ) equal to twice the thickness of the two basic layers (D). The reader is referred to Hastrup (1969) for the derivation of the basic equations. For a system such as shown in Figure 1, the reflection loss will have a minimum at:

$$f = \bar{c} / \lambda = \bar{c} / 2D \qquad (1)$$

where $\bar{c}$ is the average sound speed through the layer.

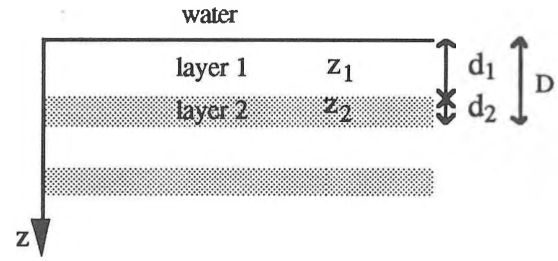

Figure 1. *Layers of alternating impedance.*

Figure 2 shows the density profile from a real core sample that will be used as a test case for the discussion that follows. An average sound speed of 1600 m/s was used to convert the density profile to an impedance profile. This approximation does not affect the conclusions presented below.

Modelling of the reflection loss vs frequency for a bottom of this type can be done with an acoustic propagation model like SAFARI (Seismo-Acoustic Fast field Algorithm for Range-Independent environments; Schmidt, 1988). Figure 3 shows a plot of smoothed reflection loss as a function of frequency for the SAFARI model using the density profile given in Figure 2, for a near-vertical grazing angle of 88°. A five-point moving average (corresponding to a moving window of 25 Hz) was applied to smooth the modelled data.

A decrease of reflection loss is noticeable at approximately 1535 Hz. The low-loss band is defined as that where the reflection loss is within 2 dB of the minimum value.

For a sediment structure of undefined periodicity as the core shown in Figure 2, a Fourier transform analysis can be done on the impedance profile (after subtracting the average impedance) to determine the main periodicity of the first few meters of sediments. The input series to the Fourier transform is a series of impedance values vs depth, and the spectrum obtained is therefore a function of the spatial periodicity of the impedance.

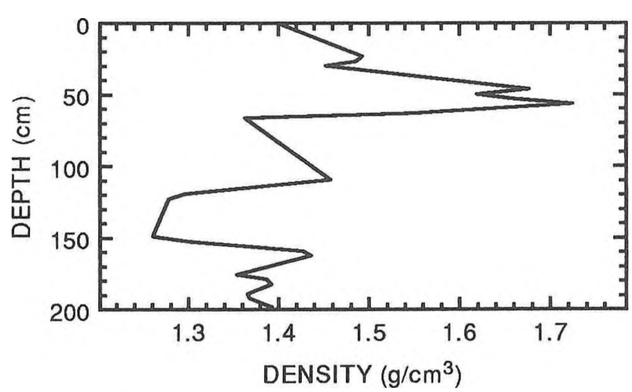

Figure 2. *Density vs depth of a core sample (Hastrup, 1969).*

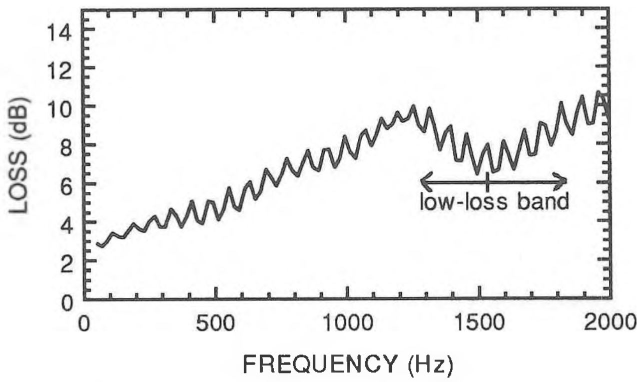

Figure 3. *Calculated reflection loss vs frequency, from SAFARI, showing centre frequency and bandwidth of the low-loss band.*

The spectrum of the test case is shown in Figure 4. The associated frequencies, as defined by equation (1), are noted on the upper axis of the spectrum. It is observed that the main periodicity of the core is approximately 55 cm, which is associated to a low-loss frequency band centred at 1460 Hz (the error bar drawn in Figure 4 defines the area where the amplitude is within 2 dB of the maximum value). The centre frequency of 1460 Hz agrees with the frequency of 1535 Hz indicated by SAFARI, as shown by the overlapping error bars (Figures 3 and 4).

3. Modelling of periodic structure

The analysis presented in the previous section allowed us to estimate the centre frequency of the low-loss band (if any) of a particular area for which core samples are available. The low-loss centre frequency can therefore be estimated without a complete bottom loss analysis.

To analyze the effect of the sediment layering on the low-loss centre frequency, modelling of different types of sediment layering was investigated. A Fourier transform was done on the impedance profile to find out the periodicity of the system, and reflection loss modelling with SAFARI was done to see the effect on the low-loss frequency band . The main results are here summarized:
For a periodic system of two layers of identical thicknesses, the centre frequency of the reflected band is proportional to the average sound speed of the two layers; the amplitude at the peak period of the spectrum is directly proportional to the impedance contrast between the two layers. A high amplitude in the spectrum indicates a broader reflected frequency band. If the thicknesses are identical, the peak amplitude is independent of $\bar{c}$. If the two layers are semi-periodic, meaning periodic with a gaussian variability in thicknesses, the results will be the same as above.

The system seems to require a minimum of 4 double layers in order to show the low-loss frequency band, or else the peak associated with the low-loss band will be lost in the background features of the spectrum. The frequency band also diminishes if the layers are covered by several wavelengths of regular sediment of constant impedance.

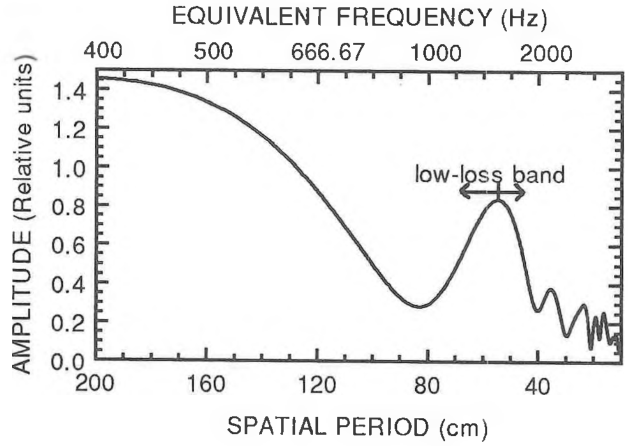

Figure 4. *Spatial frequency spectrum of the impedance profile.*

Therefore, the most important factors affecting the low-loss frequency band are the impedance contrast between the layers, and the average sound speed of the layers.

4. Conclusions

Various sets of bottom loss data from areas with turbidity currents indicate high acoustic reflectivity at a certain frequency band. The centre frequency of the band varies with the geographical location.

Different sedimentation processes affect the average speed of the sediments at a particular site and the vertical distribution of the layers. Turbidity currents, contour currents and ice-rafting all can create an alternation of layers of different impedances by the sediment-water interface. If the impedance contrast is large between the different layers, the bottom loss decrease at high frequencies will be more manifest.

It was shown that core samples could potentially be used to estimate the centre frequency of the low bottom loss frequency band. Statistics of core properties of different areas with known sedimentation could improve the knowledge of bottom losses for remote areas.

5. References

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