BOTTOM LOSS IN AREAS WITH ICE-RAFTED SEDIMENTS

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ABSTRACT

Bottom loss vs grazing angle data was obtained for a location in Baffin Bay. The analysis showed bottom losses decreasing with frequency, for frequencies from 20 to 630 Hz. This feature fits the hypothesis of the presence of ice-rafted sediments, which could be modelled by adding a thin layer of high-impedance material at the sediment surface. Other areas of the North Atlantic Ocean have shown similar features in their bottom loss curves and sediment configuration. The thin-layer approximation appears to be valid for areas where ice-rafting is dominant. Turbidity currents may possibly create the same phenomenon.

SOMMAIRE

Des analyses de pertes acoustiques en fonction de l'angle d'incidence rasante ont été produites pour une région dans la baie de Baffin. L'analyse a démontré que les pertes acoustiques dues au fond marin diminuent avec la fréquence, pour des fréquences allant de 20 Hz à 630 Hz. Cette caractéristique soutient l'hypothèse de la présence de sédiments déposés par les glaciers (floes), ce qui peut être modelé en ajoutant une mince couche de matériel de grande impédance à la surface des sédiments. D'autres régions de l'océan Atlantique Nord ont montré des caractéristiques semblables dans leurs courbes de pertes acoustiques dues au fond marin et dans leur configuration de sédiments. L'approximation faite avec la couche mince semble être valide pour les régions où les floes sont dominants. Les courants de turbidité peuvent vraisemblablement créer le même phénomène.

1. INTRODUCTION

Sound propagation in Arctic regions has recently taken on a new importance, and an effort has been made over the past few years to collect and analyze acoustic data from several Northern areas. DREA produced an analysis of bottom losses vs grazing angle for one station in Baffin Bay which presents an interesting case of what could be a thin layering at the sediment surface. The hypothesis was made that the particular sediment configuration was due to ice-rafted sediments, which are a main characteristic of this northern area.

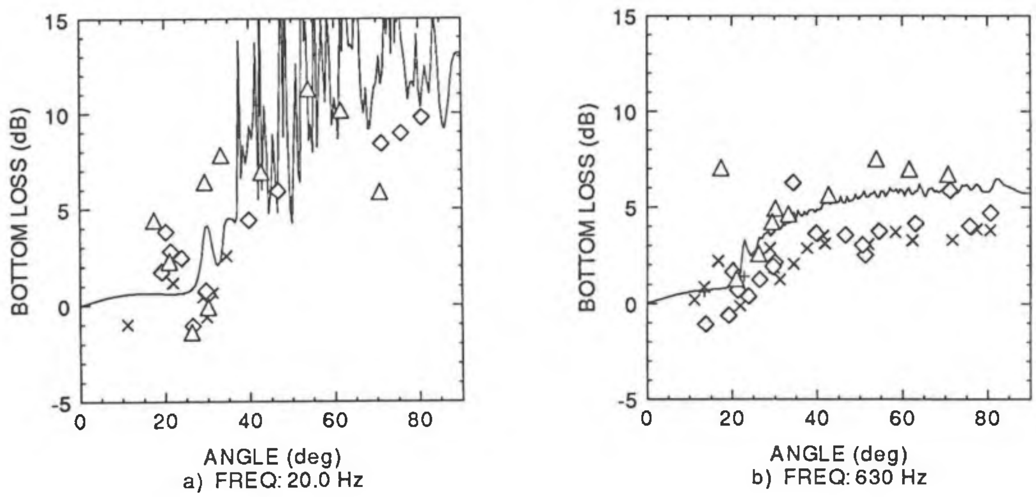
The experiment is described and the bottom loss vs grazing angle data are presented. Extensive modelling was done to support the thin layer hypothesis. This hypothesis seems to be valid for areas where either ice-rafting and/or turbidity currents are the main sediment transportation agents.

2. EXPERIMENT AND DATA ANALYSIS

The experiment was conducted by DREA at an unspecified site in Baffin Bay (the site will be referred to as station 1). The research vessel CFAV QUEST deployed and monitored an experimental dipole array of hydrophones (EDA), and HMCS CORMORANT dropped charges along two radial tracks approximately 70 km long, each ending at the station (with approximately 60° between the tracks). 1.8 lb explosive sound sources were used, with a detonation depth around 200 m. The omnidirectional hydrophone depths were set at approximately 300 m. The water depth was relatively constant along the two tracks.

The analysis of the data was done using a set of shot analysis programs available at DREA (Desharnais and Peters, 1989). The programs divide the transients into their diverse components (according to the number of bottom interactions for each component). The energy levels of each component are calculated for several frequency bands of one-third of an octave. Six centre frequencies were chosen, from 20 to 630 Hz. The results, ie. data points of bottom loss vs grazing angle, are shown in Figures 1a and b for 20 and 630 Hz respectively. The grazing angle is the angle between an acoustic propagation vector and the seabed.

The symbols indicate the different number of bottom interactions. The reader is reminded that the lower the number, the more reliable are the data. The data with higher



Figures 1a,b. Bottom loss vs grazing angle, for 20 and 630 Hz, data and SAFARI modelling.
Symbols: ▲ = 1 bottom bounce; ◆ = 2 bb; ✕ = 3 bb; + = 4 bb; —— = SAFARI.

orders of bottom bounces are consistently lower than the one bottom bounce data at high grazing angles. This problem occurs when the different energy arrivals are too close in time to accurately estimate independently the separate energy levels. The bottom loss is not well defined at very low grazing angles, for any frequency. This problem is due to the low number of charges at long distances. At higher grazing angles, we observe bottom losses decreasing with increasing frequency. Effectively, the bottom losses cluster around 10 dB for the low frequencies (20, 40 Hz), and gradually decrease for higher frequencies (315, 630 Hz), where the values reach 5-6 dB (one bottom bounce data.

3. DATA MODELLING

The model used was SAFARI (Seismo-Acoustic Fast field Algorithm for Range-Independent environments; see Schmidt, **1988**). This normal-mode based model can include shear waves for a multi-layered stratified medium. It has the capability to calculate plane-wave reflection coefficients, from which the reflection losses are obtained. In this case, due to the particular geometry of the experiment, these reflection losses are taken to be a good approximation of the observed bottom losses. The geology of the site and the modelling parameters that we used are presented next, followed by the modelling results.

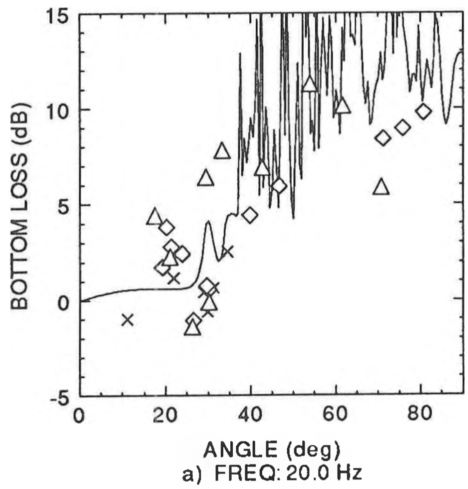
3.1 Geology

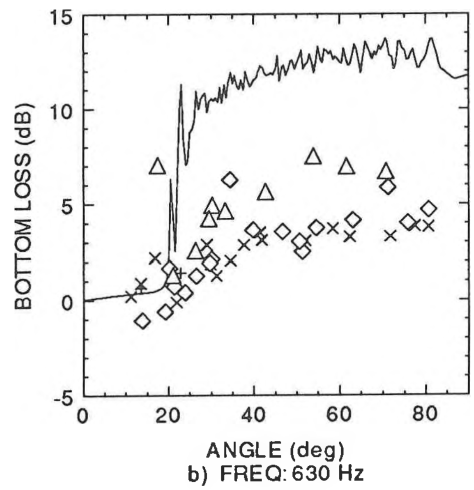
Jackson, Keen and Barrett (**1977**) as well as Keen and Barrett (**1972**) published seismic refraction and reflection measurements taken in Baffin Bay. These two references thus supply compressional sound speeds and densities for the main bottom layers, down to the mantle. Because of the nature of these measurements, the layers are crudely defined and do not provide a sufficiently refined description of the surface layer.

Several authors though reported core analysis for the area of Baffin Bay where ice-rafting prevails [Aksu and Hiscott (**1989**), Aksu and Piper (**1979**), A. Grant (**1971**) and J. Marlowe (**1968**)]. The first few centimetres are predominantly composed of a yellow-brown to brown gravelly, sandy mud. Scattered pebbles and gravel are present, because of the ice-rafting. Mud aggregates beds (from submarine slumping, and further transportation by suspended flows) were also found in thin layers, in the first few meters. These aggregates might contain as much as 80% of sand-size grains.

A compressional sound speed profile associated with the above bottom description is insufficient to model the data realistically. Even though it represents well the high losses at low frequencies, an additional feature, like the presence of a thin reflector near the surface, is required to explain the low losses at higher frequencies (630 Hz). A high-impedance thin layer would reflect the high frequency energy, but would be transparent to longer wavelengths, ie lower frequencies, which would be absorbed by the soft material underneath the reflector.

Such a thin layer in fact is not unusual since it has been reported in many other areas of the North Atlantic Ocean where core analyses are available. It has been observed in certain areas of Labrador Sea (Gallagher, **1973**), Hatteras Abyssal Plains (Tucholke, **1980**), Sohm Abyssal Plains (Horn et al., **1969**), etc.





Figures 2a,b. As figures 1a,b without the thin layer at the sediment surface.
Symbols: ▲ = 1 bottom bounce; ○ = 2 bb; × = 3 bb; + = 4 bb; —— = SAFARI.

A thin layer was therefore added to the bottom parameters to obtain a better modelling of the data. An improvement was indeed observed. The best fit was obtained with the addition of a high-impedance layer slightly below the sediment-water interface, between the depths of approximately 0.1 and 0.75 m. The compressional sound speed varies from 1600 to 1830 m/s within the layer, and the density is from 1.6 to 2 g/cm^3. The final compressional sound speed profile used to model the sediment and bottom is shown in Figure 3; the top 11 m of sediment is detailled on the inset of Figure 3. Other parameters necessary to model the data, and not found in the previously mentioned literature, were derived from Hamilton (**1987**).

3.2 Modelling Results

Figures 1a and b show, along with the data, the modelling results averaged in one-third octave bands (solid curves), using realistic geo-acoustic parameters (including the thin high-impedance layer at the sediment-water interface). For a comparison, the modelling results obtained with the same parameters, but without the surficial thin layer, are shown in Figures 2a and b, also with the data. The addition of the thin layer yields highly improved results at higher frequencies, as seen at 630 Hz. The oscillations produced by the model at low frequencies are due to the multiple interactions between the acoustic energy and the different bottom layers (resonance effect). The effect is less obvious at high frequencies since the wavelengths are much shorter. At all frequencies, the agreement is within 2-3 dB (except for a few data points) between the modelled and the experimental results, and the difference is even less if we consider only the one-bottom-bounce data points. This good agreement seems to indicate that the geo-acoustical parameters used to model the station 1 data are realistic if the thin layer is included. The small amount of data at low grazing angles makes it hard to conclude anything about the validity of the model at these angles, and on the real shear speeds for station 1. The negative bottom losses seem to indicate that a fair amount of energy is refracted within the sediments. Since SAFARI produces reflection loss data, and not bottom loss data, it cannot effectively model the negative bottom losses due to this phenomenon, even though it handles bottom-refracted waves very well.

There is also some scatter in the data arising from different numbers of bottom interactions. This could be due partly to the lower reliability of the data for higher bottom bounce arrivals, since at this point the signal to noise ratios can be fairly low. Discrepancies at angles above 30° can also be related to the time spreading of the signal. As explained by Vidmar and Oakley (**1987**), the energy of the first bottom bounce arrival can persist into the two-bottom bounce arrival and so on. This overlapping was found to be negligible for the first bottom bounce arrival, though it could lower the bottom loss of the two and three bottom bounce arrivals by 2-3 dB, as we can observe in Figure 1b. Vidmar and Oakley correlated these discrepancies with scattering from the sea surface; this effect would be mainly observed at wind speeds above 10 kt. Winds of 10 kt and over were effectively recorded for one of our runs, and such a phenomenon could therefore have affected about half the data points.

4. DISCUSSION

The bottom-loss data have been successfully modelled using geophysical parameters that are realistic for the area, and the

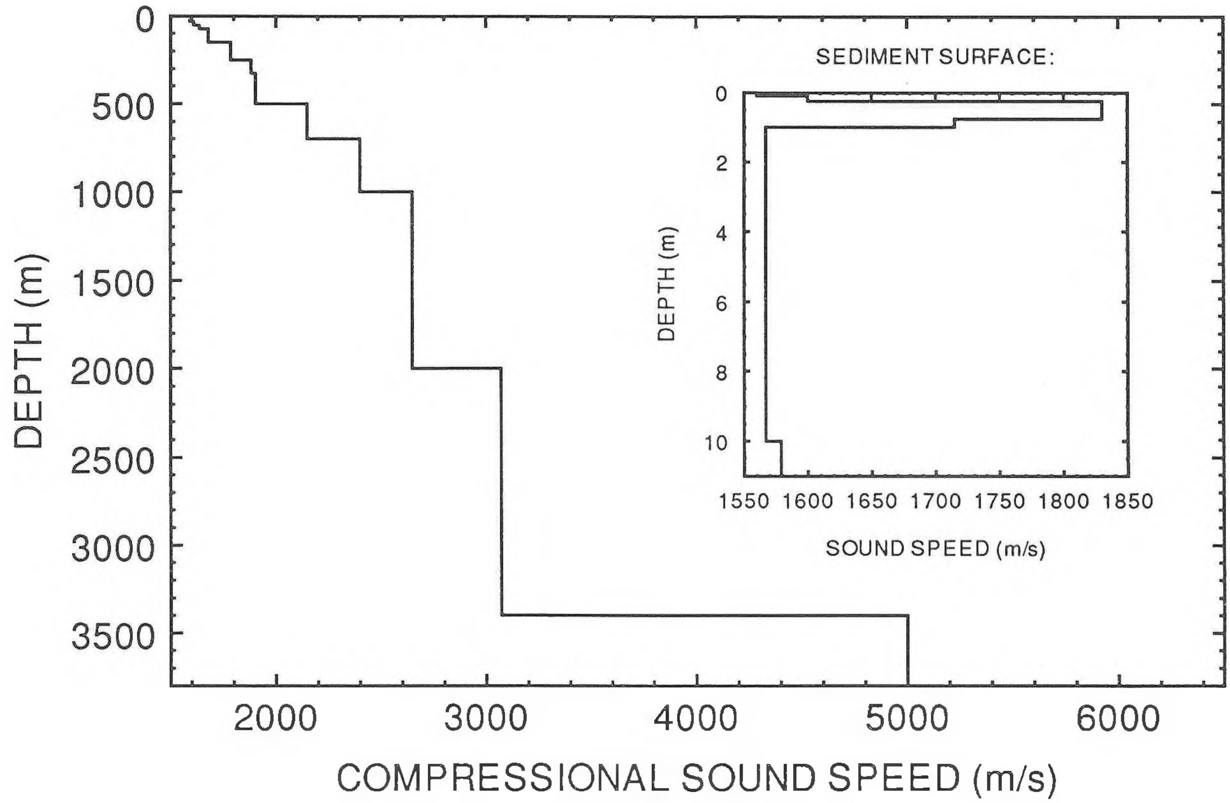


Figure 3. Compressional sound speed profile of the sediments and bottom, used to produce the results of Figure 1. Depth 0 is the water-sediment interface.

addition to the model of a thin layer with a high impedance near the sediment-water interface. Gallagher (1973) has presented the following hypothesis to explain a similar thin layer found at one site in the Labrador Sea. For this particular location, the thin layer has two components: one upper section composed of coarse material overlying a lower section of finer material. Turbidity currents and, to a lesser extent, ice-rafting, are to be held accountable for the presence of coarse material at the sediment surface (upper section of the thin layer), since the material is of the same type as the adjacent continental shelf and land masses. This coarse material is of higher density and sound speed than the sediments that would otherwise be found in the Labrador Sea. The underlying fine material has a higher percent clay size component than other typical cores of the North Atlantic, and it has a lower water content and a higher strength than the coarse layer. The overburden load caused by the coarse layer would have decreased the water content of the underlying material, and increased its sound speed and density. This mechanism would account for the high impedance of the lower section of the thin layer. Care must be taken, however, when considering this mechanism, since it was observed that the fine, high-speed material of the thin layer contained a high percentage of sand. The measurements performed on the core samples to determine water content may therefore be unreliable, since there is a possibility that water escaped during the core sampling, and that the high impedance of the layer was solely due to the high sand content within the layer, and not to the low water content.

It is possible that a similar "coarse layer overload" could explain the data collected at station 1. Ice-rafting is the main sediment transportation agent for at least the first several metres of sediments, in addition to the less important effect of turbidity currents and debris-flow deposits (which could be more important for different layers of the bottom, or different areas). Because of the ice-rafting, there are mud aggregates with high percentages of sand, and a certain amount of sand-mud mixtures, with a high variability in the porosity.

The sediment type at station 1 therefore appears to have a different origin than that shown in Gallagher's data, though both areas present sandy types of material close to the surface, and coarse material right at the sediment surface. On a first analysis, the same arguments could be used to explain the similar sound speed profiles at the sediment surface for these two areas. Unfortunately, these mixtures are not pure sand, and may not justify an impedance for the thin layer as high as found necessary to model the data. One explanation for this problem might be some water drainage from the sand layers interbedded with the mud layers. This drainage would explain the porosity reduction and the high impedance of the layer. It should also be added that it is possible that the thin layer that was added to the model could also be found at greater depths. Since the high-frequency energy is reflected mostly by the first thin layer, deeper layers cannot be acoustically seen. The model as it stands is still valid, however, since it fits the data very well.

Other processes could also explain the presence of a thin layer at the sediment surface at station 1. The theory of a permafrost layer could possibly explain this peculiar layer. It may also be that the layer is some type of crust due to evaporation of chemicals, although the core analysis did not indicate the presence of any such consolidated material right at the surface. Neither is erosion a satisfactory answer, since it would not explain the thinness of the layer. However, gas hydrates have a similarly high impedance (Max, **1990**), and it is possible that they could appear at a relatively small depth within the sediment, although why solid hydrates would form near the sediment surface only could not be explained.

It can therefore be concluded that the most satisfactory explanation for the observed bottom loss phenomenon is that a singular sediment configuration appears when ice-rafting or turbidity currents are mainly responsible for sediment transportation. This type of sediment seems to incorporate a near surface layer probably consisting of coarse grains and low water content; this structure has the effect of increasing the speed and thus the impedance of that layer.

There are methods to determine the sound speed and the thickness of a thin layer using relative arrival time differences from separate energy arrivals (see for example Herstein, Dullea and Santaniello, **1979**). Such a method will be tested in the near future as an attempt to confirm the presence of a thin layer at the sediment surface of station 1.

Assuming that we confirm the presence of the layer, it would be interesting to analyze other North Atlantic Ocean sites, and see if the presence of a thin layer is a fairly common phenomenon, extended to more areas where we can have either ice-rafting and/or turbidity currents.

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