Seismo-acoustic measurements using an ocean bottom seismometer in the high Arctic

S. E. Dosso, G. H. Brooke and D. G. Baade

Defence Research Establishment Pacific

FMO Victoria B.C., Canada V0S 1B0

INTRODUCTION

Geoacoustic properties of the upper tens of metres of ocean bottom sediments can significantly influence low-frequency acoustic propagation in the ocean. Therefore, knowledge of these properties is required for reliable propagation modelling and matched-field processing. To date, however, few measurements of geoacoustic properties have been reported for the high Arctic at sufficient resolution for underwater acoustic applications. This paper describes a high-resolution seismic experiment designed to measure ocean-bottom compressional and shear properties on the continental shelf of the Lincoln Sea, north of Ellesmere Island, Canada.

EXPERIMENT

The seismic experiment was carried out at a research camp located on a multi-year ice floe in the polar ice pack. The geometry of the experiment is shown in Fig. 1. A specially-designed three-component ocean bottom seismometer (OBS) was deployed by melting a hole through the sea ice with a hot-water drill, and lowering the unit by cable to the sea floor. The OBS signals were transmitted to the surface via the cable and recorded on a multi-channel digital seismograph at a sampling rate of 4 kHz. Sources consisted of explosive charges detonated on the sea-floor. A total of 17 sources of a variety of sizes (0.5–27 kg) were deployed through nine holes in the ice at ranges of 35 to 900 m from the OBS. Fig. 1 also shows the acoustic and seismic waves of principal interest: the direct and reflected waterborne waves, the head wave (refracted compressional wave), and seismic interface (Scholte) wave.

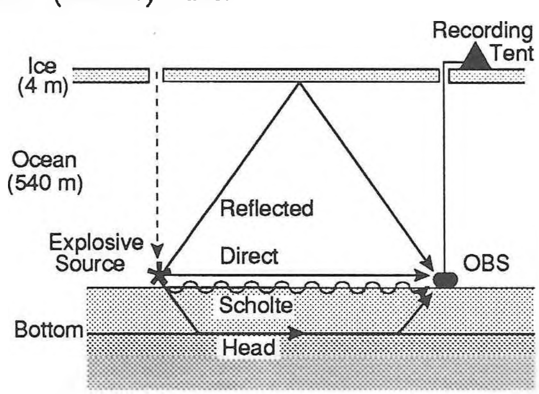

Fig. 1. Experiment geometry.

ANALYSIS

Fig. 2 shows the recorded vertical-component seismograms plotted in the format of a seismic section. Refracted, direct, and first and second surface-reflected arrivals are evident on all seismograms (labelled P, D, R and RR respectively), and good examples of Scholte waves appear as the low-frequency arrivals on seismograms recorded for ranges less than 400 m. First-break arrival time picks were made for all seismograms. These fell on two well-defined line segments indicating that the refracted arrivals can be interpreted as head waves, and that the data set is well suited to interpretation by the classical slope-intercept method [1]. Fig. 3 shows the two-layer compressional-speed model determined by this analysis, with the envelope of the model parameter uncertainties indicated by dotted lines.

Shear properties of ocean sediments are perhaps most readily determined from the propagation characteristics of Scholte waves [2, 3]. The Scholte-wave speed is closely related to the shear speed over a depth of one to two wavelengths into the sea-bed, but is relatively insensitive to the compressional properties. Since long-wavelength components of the Scholte wave penetrate a greater depth into the bottom than short wavelengths, the dispersion characteristics of this wave provide information about the shear-speed profile of the upper sediments. Fig. 4 illustrates the dispersion of vertical and horizontal seismograms for a source at 82-m range in terms of Gabor diagrams, which show contours of energy, in arbitrary decibels (maximum level: 99 dB), as a function of

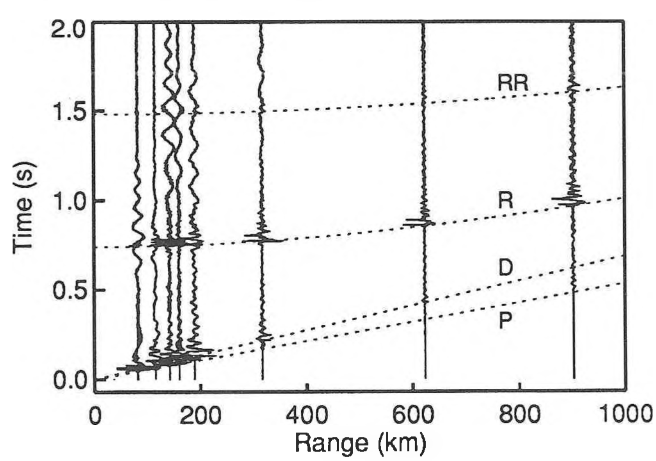

Fig. 2. Seismic section.

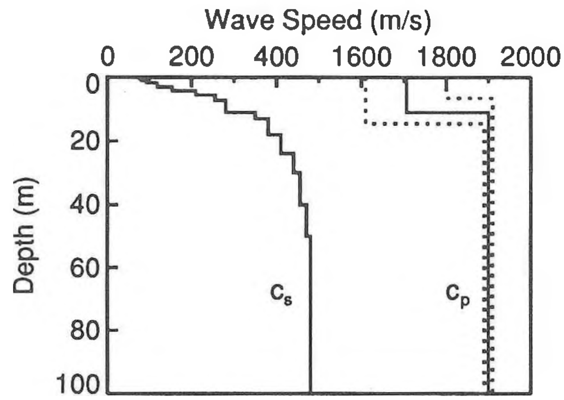

Fig. 3. Shear (c_s) and compressional (c_p) speed models (note the 1000-m/s discontinuity in the wave-speed axis at 500 m/s).

group speed and frequency. The dispersion properties shown in these diagrams are representative of all the recorded seismograms. The Gabor diagram for the horizontal (y) seismogram indicates that the energy is propagating in three discrete modes: M_0, the fundamental (Scholte) mode, and M_1 and M_2, the first and second shear modes. Shear modes appeared most strongly on the horizontal seismograms and were evident only for short-range shots (< 140 m). The z-component Gabor diagram shows only M_0 and M_1. At all ranges it was found that the Scholte mode was more clearly defined for z than y.

A shear-speed model for the bottom sediments was constructed by matching the observed dispersion characteristics of the Scholte and shear modes [2, 3]. The solid white lines superimposed on the energy contours in Fig. 4 represent modal dispersion curves computed for

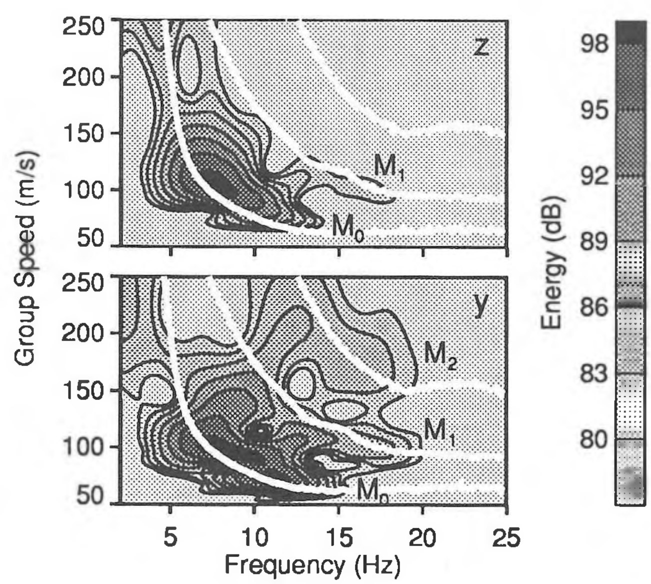

Fig. 4. Gabor diagrams for vertical (z) and horizontal (y) seismograms recorded for a source at 82-m range.

the shear-speed profile shown in Fig. 3 using the full-wave numerical propagation model SAFARI [4]. This profile was determined by systematically varying the parameters of a layered model until good agreement was achieved between the computed dispersion curves and the measured Gabor diagrams. Considerable care was taken to ensure that the shear-speed model correctly reproduced the dispersion characteristics of the seismograms recorded at all ranges.

The (volume-average) attenuation of bottom sediments was estimated from an analysis of the exponential decay of signal amplitude A with range r:

$$A(r) = A(0)\, S(r)\, \exp[-\alpha\, r], \tag{1}$$

where α is the attenuation coefficient and $S(r)$ represents the geometrical spreading appropriate to the particular wave type. According to (1), the attenuation coefficient can be determined as the slope of a plot of $\log_e[A(r)/S(r)]$ as a function of r; by transforming to the frequency domain, this procedure can be carried out at a number of frequencies to investigate the frequency dependence of the attenuation. This procedure was used to estimate frequency-dependent compressional and shear attenuation coefficients, $\alpha_p = 0.1$ dB/km/Hz and $\alpha_s = 5$ dB/km/Hz, using head-wave and Scholte-wave arrivals respectively

SUMMARY

A high-resolution seismic experiment was carried out in the Canadian high Arctic to measure ocean-bottom geoacoustic properties. Compressional- and shear-speed models and (frequency-dependent) compressional and shear attenuation coefficients were determined. All of the geoacoustic parameters are in good agreement with accepted values [5].

REFERENCES

[1] W. M. Telford, L. P. Geldart, R. E. Sheriff, and D. A. Keys. *Applied Geophysics*, Cambridge University Press, Cambridge, 1976.

[2] F. B. Jensen and H. Schmidt. Shear properties of ocean sediments determined from numerical modeling of Scholte wave data, in *Ocean Seismo-acoustics*, T. Akal and J. M. Berkson, Eds., Plenum, New York, pp. 683–692, 1985.

[3] A. B. Hassan and L. D. Bibee. The influence of sediment layering and geoacoustics on the propagation of Scholte interface waves, *Proc. Oceans 93, IEEE*, pp. 114–118, 1993.

[4] H. Schmidt and F. B. Jensen. Efficient numerical solution technique for wave propagation in horizontally stratified ocean environments, *Rep. SM-173*, SACLANT ASW Research Centre, La Spezia, Italy, 1984.

[5] E. L. Hamilton. Geoacoustic modeling of the sea floor, *J. Acoust. Soc. Am.*, Vol. 68, 1313–1340, 1980.