

# OCEAN BOTTOM REFLECTION LOSS FROM ELASTIC SOLID MATERIALS: REFLECTIONS ON REFLECTIVITY

N. Ross Chapman<sup>1</sup> and Hefeng Dong<sup>2</sup>

<sup>1</sup>Earth and Ocean Sciences, University of Victoria, Victoria, BC, Canada, V8P5C2; chapman@uvic.ca

<sup>2</sup>Norwegian University of Science and Technology, NO-7491 Trondheim, Norway; hefeng@iet.ntnu.no

## 1. INTRODUCTION

In large regions of the Pacific Ocean the ocean bottom is characterized by a thin layer of sediment over an elastic solid crust. The presence of the solid basement close to the sea floor generates additional losses that affect long range acoustic propagation. This paper describes geoacoustic inversion of reflection loss versus angle data at very low frequencies (~16 Hz) to obtain estimates of the compressional (p) and shear (s) wave velocities in uppermost oceanic crust, Layer 2A. The data were obtained in experiments using small explosive charges and a horizontal line array. The measurements were made at thin sediment sites located at increasing distance from the spreading centre at the Endeavour segment of the Juan de Fuca Ridge of the west coast of British Columbia to determine the effect of crustal age of the basalt on the seismic velocities.

The results for very low frequency data are sensitive to the thickness of the sediment layer, which increases with distance from the spreading ridge, resonances caused by interference of p- and converted shear waves, and possibly Stoneley waves excited at the sediment/basalt interface.

## 2. EXPERIMENTS

The reflection loss experiments were carried out at three sites along a transect west of the Endeavour segment of the Juan de Fuca Ridge. The ridge axis is aligned approximately 023°, and the general topography to the west consists of a series of valleys and ridges aligned parallel to the axis. The entire region is very thinly sedimented, less than 25 m out to distances of 35-40 km from the spreading centre. The sites were located in the valleys between the ridges: site A in the first valley 3 km west of the ridge crest at a depth of 2250 m; site B in the next valley approximately 18 km west of the crest at a depth of 2440 m; and site C in the third valley approximately 32 km west of the crest at a depth of 2640 m.

The reflectivity measurements were made using two ships according to a broadside experimental geometry, in which the shooting ship opened range on a course of 65° with respect to the array ship's course. For this geometry, the measurement provided an average of the crustal velocity over a distance of ~25 km in the direction of the track. The acoustic paths were perpendicular to the ridge axis.

One ship towed a 40-channel, 1500-m horizontal line array at a depth of 250 m, and the other ship deployed small explosive charges as the vessels opened range along the tracks. The shot spacing was designed to provide data for angles from 10° to 80° at 2° intervals, and the shot depth was ~200 m. Ship-to-ship ranges were measured using a GPS navigation system. The data were processed in a 1/3-octave frequency band at 16 Hz, and spatially filtered using a time-delay beamformer to measure the array response at the specular angle for the first bottom reflection path. The specular beam data were time-windowed to extract the bottom reflected signal. Significant scattering in non-specular paths was observed at higher frequencies at each site, but the impact of this effect was considerably reduced by processing the specular beam for the 16-Hz data.

The bottom reflection loss, BL (in dB), was determined from measurements of the acoustic propagation loss for the signal in the specular beam according to

$$BL(\theta) = (H_m(\theta) - H_c + 6)/n, \quad (1)$$

where  $H_m$  is the measured loss in dB for the  $n$ th bottom reflection,  $H_c$  is the calculated spreading loss,  $\theta$  is the angle of incidence and 6 dB accounts for the four acoustic paths in each order of bottom reflection. The propagation loss was determined from the received energy level, RL, in the specular beam, using known values of the source levels, SL, of the explosive charge [1].

$$H_m(\theta) = SL - RL(\theta) \text{ (in dB)}. \quad (2)$$

The incidence angles at the bottom were determined from the experimental geometry using ray theory and a measured water velocity profile.

## 3. GEOACOSUTIC INVERSIONS

An example of the averaged reflection coefficient versus angle data for the 16-Hz band is shown in Figure 1 for site A. The maximum around 38° is associated with the p-wave critical angle in layer 2A, and the low reflectivity at higher angles is related to losses due to s-wave propagation in the sediment and upper crust. The relatively low reflectivity at very low angles (> 75°) suggests that there is no shear wave critical angle in the upper crust.

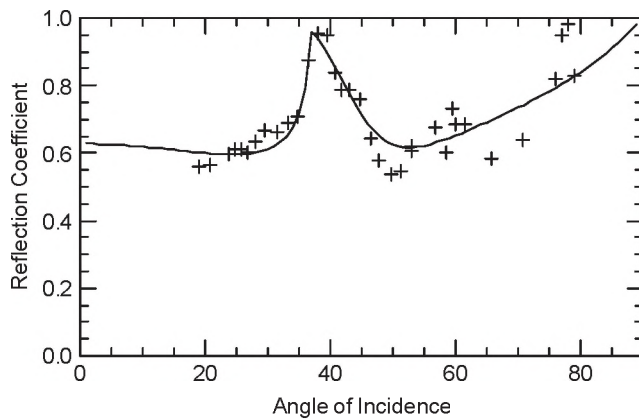


Fig. 1. Reflection coefficient versus angle for site A (~0.1 Ma.). The p-wave critical angle corresponds to the peak at about 38°.

The sound reflected from the ocean bottom carries information about the interaction with a system of interfaces, including the basalt crust and the overlying thin sediment layer. It would be expected that the presence of a thick sediment layer would have to be taken into account for interpreting the acoustic reflectivity, but a thin layer can also cause significant modifications to a simple half-space interpretation of the reflection process. Hovem [2] has shown that the sediment layer generates Stoneley waves at the sediment/basalt interface for certain frequencies and high incidence angles. Also for sufficiently thin elastic solid sediment layers, a resonant condition occurs due to the conversion of p- to s- waves at the sediment-basalt interface [3]. This effect has been shown to cause variations of several decibels in the reflection loss at long ranges or high incidence angles. These resonance effects complicate the interpretation of the experimental data, and it is important to account for them in modeling the reflection loss in the inversion.

Accordingly we use a geoacoustic model consisting of a simple thin sediment layer over an elastic solid basalt half-space. The model was parameterized by the compressional and shear wave velocities,  $v_{p,s}$ , and attenuations,  $\alpha_{p,s}$ , the densities,  $\rho$  of the sediment and basalt, and the thickness of the sediment layer,  $H$ . The parameter values are typical of clayey silt or silty clay. The water layer was given a sound speed of 1500 m/s and density of 1.03 g/cm<sup>3</sup>.

In this work, the reflection coefficient versus angle data are inverted using a Bayesian approach to estimate the posterior probability distribution for the parameters of a specific geoacoustic model. In the Bayesian approach, the complete solution of the inverse problem is given in terms of an *a posteriori* probability distribution that specifies the probability of each possible model within the *a priori* limiting values for each model parameter.

The most sensitive parameters in the inversions were the p- and s-wave velocities of the basalt, and the sediment layer

thickness. The shear wave speed in the sediment was also sensitive, indicating that the resonance due to converted shear waves was a significant factor in the reflections. The estimated seismic velocities for the uppermost portion of layer 2A and the sediment thickness are listed in Table I for the young crustal sites. The uncertainties are derived from the 1-D marginal distributions for each parameter that were obtained in the inversion. An example of the reflection coefficient calculated using the estimated properties from the inversion is shown in Figure 1 by the solid curve.

Table I. Estimated values of basalt velocities and the thickness of the sediment layer for very young crust.

Site	H (m)	$V_p$ (m/s)	$V_s$ (m/s)
A	$6.9 \pm 3.8$	$2547 \pm 30$	$725 \pm 178$
B	$26 \pm 3.0$	$2626 \pm 20$	$1014 \pm 35$
C	$17 \pm 2.0$	$2710 \pm 18$	$1320 \pm 46$

The relatively low values for the p-wave velocity out to 1.5 Ma suggest that the western portion of the Endeavour segment is open to hydrothermal circulation, and the aging process is continuing at all sites. In contrast to the gradual change in p-wave velocity, there is a significant change in the s-wave velocity over the span of crustal ages observed in this experiment. These results provide new constraints for modeling the porosity in the crustal low velocity layer. The very large value of Poisson's ratio at the youngest site suggests that thin cracks mostly remain open. At the older sites where the sediment cover is thicker, the decrease in Poisson's ratio suggests that the thin cracks are being filled, but the thicker cracks remain open.

## REFERENCES

- [1] Chapman, N.R. "Source levels of shallow explosive charges", *J. Acoust. Soc. Am.*, 84, 697-702, (1988)
- [2] Hovem, J.M., and Åge Kristensen, "Reflection loss at a bottom with a fluid sediment layer over a hard solid half-space," *J. Acoust. Soc. Am.*, 92 (1), 335-340 (1992)
- [3] S.J. Hughes, D.M.F. Chapman and N.R. Chapman, "The Effect of shear wave attenuation on acoustic bottom loss resonance in marine sediments," *Shear Waves in Marine Sediments* (J. Hovem, ed.), 439-446, Kluwer Academic Publishers, Dordrecht (1991)