ESTIMATING GEOACOUSTIC PARAMETERS OF GASSY SEDIMENT USING LOW-FREQUENCY SOUND IN ST. MARGARET'S BAY, NOVA SCOTIA.

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1. INTRODUCTION

The geoacoustic properties of gassy sediment not only differ greatly from that of gas-free sediment, but present a strong frequency dependence. These properties are normally measured *in situ* using acoustic sensors embedded in the seabed, or in laboratory by examining pressurized core samples through CT scans, for example (Anderson *et al*., 1989; Tuffin, 2001). The first objective of this study was to assess the possible use of a Bayesian inversion algorithm to remotely (and cheaply) estimate the geoacoustic parameters of a gassy seabed at frequencies below 500 Hz. The effectiveness of the studied algorithm has already been proven for various environments including shallow-water, multi-layered seabeds. However, its use for gassy sediment is complicated by the frequency-dependence of the geoacoustic parameters and its effectiveness needed to be assessed in this particular environment. This assessment was done through simulations, focusing on environments similar to the central basin of St. Margaret's Bay. The results from these simulations provided basic guidelines describing some limiting factors for which the inversion of gassy geoacoustic parameters may be possible. The main objective of this study was to evaluate the geoacoustic profile of the deep central basin of St. Margaret's Bay, using the inversion algorithm and field data.

2. METHOD

In May 2006, Defence R&D Canada conducted sea trials using a vertical line array of hydrophones in the deep central basin of St. Margaret's Bay, Nova Scotia, Canada. The array, deployed in 63 m of water, comprised 11 hydrophones unevenly spaced in the bottom two thirds of the water column. During one experiment, an acoustic source emitting a signal composed of five tonals below 500 Hz was towed at approximately 26-m depth and horizontal distances from the array of less than 1000 m. The field data used in this project were composed of the acoustic pressure fields recorded by the 11 hydrophones.

The inversion algorithm used in this study is the Adaptive Simplex Simulated Annealing (ASSA) algorithm, developed by *Dosso and Wilmut* (2000). It encompasses a hybrid optimization technique, which was proven very effective in estimating geoacoustic parameters of acoustically complex shallow-water environments (*Dosso*, 2000; *Dosso and Wilmut*, 2000; *Gillard et al.*, 2003). The uncertainties associated with the geoacoustics inversion solution were then estimated using the Fast Gibbs Sampler (FGS) algorithm developed by *Dosso* (2002). The two algorithms were paired with a parabolic equation (PE) propagation model called PE04, and the *implicit* energy function, E_{imp}, based on the Bartlett correlator, $B_f(\mathbf{m})$ (Bartlett, 1947; Tolstoy, 1993):

$$E_{imp}(\mathbf{m}) = N_D \sum_{f=1}^{F} \ln[B_f(\mathbf{m}) \mid \mathbf{D}_f^{obs} \mid^2], \quad (1)$$

where, $$B_f(\mathbf{m}) = 1 - \frac{\left|\mathbf{p}_f^{\dagger}(\mathbf{m})\mathbf{D}_f^{obs}\right|^2}{\left|\mathbf{p}_f^{\dagger}(\mathbf{m})\right|^2 \left|\mathbf{D}_f^{obs}\right|^2}, \quad (2)$$

$\mathbf{m}$ is the series of parameters to be inverted, $\mathbf{p}_f(\mathbf{m})$ is the predicted sound field, $\mathbf{D}_f^{obs}(\mathbf{m})$ is the measured field, F is the number of frequencies, N_D is the number of data point, and † represents the conjugate transpose of a matrix.

3. RESULTS

Through the use of simulated data, the effectiveness of the algorithm for a gassy sediment layer was assessed by comparing results in four types of environment: a gassy and a gas-free version of a 2-layer and a 3-layer geoacoustic model. Then, field data were inverted, assuming a 2-layer and a 3-layer environment, in order to estimate the thickness, density, compressional-wave speed and attenuation of each sediment layer found in St. Margaret's Bay.

3.1 Inversion of simulated data

The inversion of the simulated data sets showed that, in a gassy environment, the number of unknown parameters in the inversion problem must be reduced to a minimum in order to achieve convergence of the parameter estimates. Following this limitation, the algorithm distinguished between the gas-free and gassy environments by reproducing the low sound velocity and high attenuation that characterizes the gassy layer. Results also showed that the low sound velocity in gassy sediment causes an important increase in the uncertainty level of the estimated density in the layer. Consequently, in both cases, *i.e.* for the 2-layer and the 3-layer gassy environments, the density of the gassy sediment was irresolvable.

3.2 Inversion of field data

Following the limitations in the number of resolvable parameter, the unknown parameter set was reduced to include the thickness of each layer and the geoacoustic properties of the gassy layer (*i.e.*, the top layer in the 2-layer model; the second layer in the 3-layer model).

Results indicated that the 3-layer geoacoustic profile better simulates the deep central basin seabed than the 2-layer profile. The presence of a thin layer of highly porous clay over the gassy sediment allowed the algorithm to better estimate the low sound velocity and high attenuation expected in the gassy layer. The technique estimated the sound velocity to be up to 1.75 times lower than that of gas-free LaHave Clay, and the attenuation to be up to 350 times that in gas-free Lahave Clay. These values are consistent with the effect predicted by the Anderson and Hampton theory (Anderson and Hampton, 1980a, b).

In addition, the estimated average thickness of this highly porous layer corresponds to the depth at which *in situ* measurements indicated an important decrease in sound velocity (Kepkay, 1977). However, the density and the thickness of the second and third layers were undetermined. It is believed that the use of more accurate values for the density, sound velocity and attenuation in the top and third sediment layers would allow the technique to better determine all parameter values.

4. DISCUSSION

Although many geological parameter describing St. Margaret's Bay sediment properties were unknown, an attempt was made in comparing the estimated sound velocity and attenuation *vs.* frequency to the *Anderson and Hampton* (1980a; 1980b) theory on the acoustic of gassy sediment. This comparison led to an estimated bubble frequency of resonance less than 117 Hz, and an estimated bubble radius between 15 and 25 cm – compared to an averaged maximum observed radius of 10 mm (Tuffin, 2001). Preliminary investigation showed that the effects from bubble size distribution and bubble asphericity does not fully account for this incredibly large bubble size. However, it is possible that as for accumulation of gas bubbles in the water column, at low frequencies (less than 1 kHz), the acoustic effect on gassy sediment may be driven by the resonance of bubble clouds or plumes, instead of the resonance from individual bubbles, via a process in which bubbles pulsate in a collective mode of oscillation (Carey and Browning, 1988; Prosperetti, 1988).

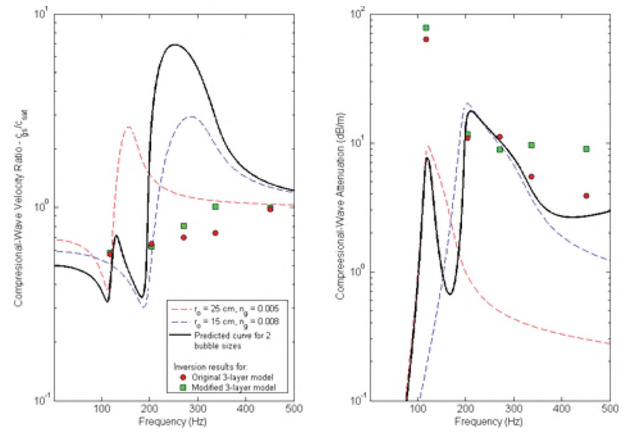

Fig. 1. Example of comparison of theoretical curves and inversion results for the sound velocity and attenuation of gassy sediment in St. Margaret's Bay, NS.

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AUTHOR NOTES

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