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# Estimation of Scattering Attenuation from Zero-offset VSP Data: CO2CRC Otway Project Case Study

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## SUMMARY

Seismic attenuation consists of anelastic absorption and scattering loss. Due to the dominance of stratification, the scattering attenuation in the sedimentary crust is dominated by 1-D scattering. In this study we applied an integrated workflow for estimation of attenuation from ZVSP and log data to a comprehensive dataset acquired at Otway basin. Both 1D reflectivity modeling and application of generalized O'Doherty-Anstey theory to the Otway log data shows that the 1-D scattering component of attenuation gives Q of over 200. At the same time, average Q estimated from field VSP data value is close to 60. Hence we conclude that scattering plays a relatively minor role in the study area. Further research is required to understand whether this conclusion holds in other areas. In particular, scattering attenuation might be larger in environments with larger variability of elastic properties between layers, such as in areas with laminated coal layers.

## Introduction

Reservoir characterization using seismic reflection data is most often based on the analysis of seismic amplitudes, which provide information on reflection coefficients and hence on the reservoir properties. However seismic amplitudes are also significantly affected by wave attenuation in the overburden, and their lateral variations. These variations can cause amplitude anomalies which can be mistaken for anomalies caused by variations of reservoir properties. Thus reflection amplitudes need to be corrected for attenuation effects before they are used for reservoir characterization. To this end, a detailed understanding of attenuation and its lateral variation is required.

A number of papers (Menke 1983, Schoenberger and Levin 1974, Schoenberger and Levin 1978, O'Doherty and Anstey 1971, Shapiro et al., 1994) show that the estimated attenuation that comes from the actual data (also known as apparent attenuation) is a combination of intrinsic attenuation (transfer of the wave's energy into heat) and scattering.

The CO2CRC Otway Project is Australia's first demonstration of the deep geological storage or geosequestration of carbon dioxide ($CO_2$). A significant amount of borehole seismic data and wireline logging data were acquired as a part of reservoir characterization and $CO_2$ injection monitoring program. This includes ZVSP in three closely spaced wells.

The purpose of this study is to estimate apparent attenuation from these VSP data and quantify contribution of intrinsic and scattering components of attenuation using both mathematical modeling and generalized O'Doherty-Anstey theory. Having significant redundancy in the VSP data we also aim to evaluate reliability of our estimates.

## Scattering component of attenuation from well log data: modeling

Analysis of the relative effects of geometrical spreading, anelastic absorption, scattering attenuation, transmission loss and elastic anisotropy requires accurate numerical simulation of seismic data. For zero-offset VSP data in sedimentary environments, the scattering and transmission losses occur mainly due to transmission and reflection effects caused by layering (Shapiro and Hubral 1999). Thus, for this analysis, modeling the wave propagation in a 1-D earth is adequate. We use OASES (MIT; Schmidt, 2004) code to generate synthetic seismograms. In order to quantify contribution of scattering attenuation we generate synthetic seismograms from thin layered elastic models constructed from the sonic and density log data using Backus averaging.

The CRC-1 well was logged from 150 to 2400m depth. This gives a model with approximately 13000 layers (assuming that every single well log reading can be treated as a separate layer), which we Backus average down to 1000 and 100 layers. These different scales allow us to investigate not only the difference in computation time for different numbers of layers, but also what effect upscaling of the model has on the synthetic seismograms produced. The result for the 1000 layer model is practically identical to the result for the original 13000 layer model. The synthetic for 100 layers is noticeably different from that for 1000 layers. Thus layering with the scale below 2 m has negligible effect on the scattering. We use the same level of upscaling to generate synthetic seismograms for the CRC-2 borehole.

For both boreholes the observed centroid frequency shift is below 1-1.5 Hz per 1 km which corresponds to scattering $Q^{-1} < 0.002$. Amplitude decay rate caused by scattering attenuation and transmission losses is on average less than 3 dB/km. This clearly indicates that in the study area, 1D scattering is not a major contributor to apparent attenuation observed in ZVSP data.

## Scattering component of attenuation from well log data: generalized O'Doherty-Anstey theory

In order to gain further insight into the nature of attenuation, we estimate the amount of scattering attenuation using the generalized O'Doherty-Anstey theory. We follow the approach published by Shapiro et al, 1994. CRC-1 velocity and density model is used to scattering attenuation. In order to compute scattering attenuation estimates based on the formulas given in Shapiro et al. (1994) we need to estimate the standard deviations, the shape of the autocorrelation functions as well as the correlation length of the residual fluctuations of both shear and compressional velocities and density.

In order to reveal the statistical properties of this stack of layers, we first need to define a background medium. It is here chosen by polynomial fitting such that the residual fluctuations have a mean value close to zero. Once this background trend is subtracted we can estimate the scattering Q (Figure 1).

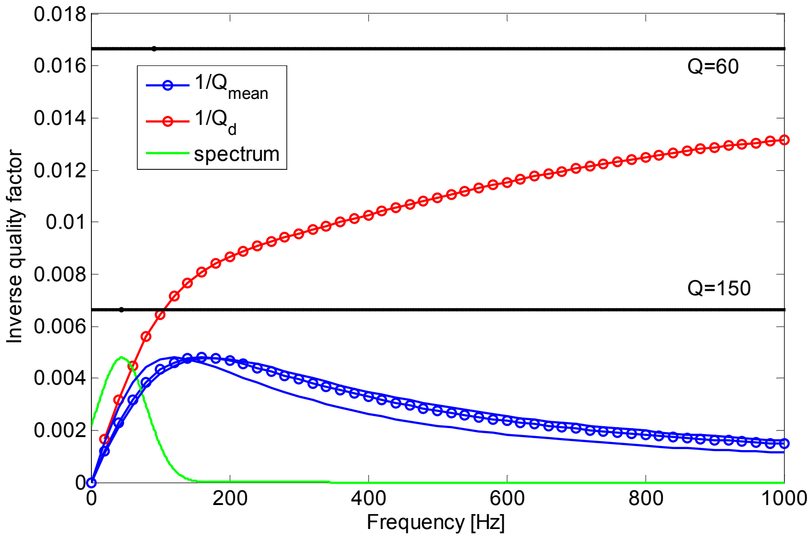


***Figure 1*** *Scattering attenuation prediction on the basis of the well log statistics using the generalized O'Doherty-Anstey theory.*

The blue curve labeled '1/Q_mean' corresponds to the scattering Q using the mean values as given above. As a reference we also plot the amplitude spectrum of the downgoing P-wave with a dominant frequency of 45 Hz (green curve). For frequencies below 100 Hz scattering attenuation results in a quality factor higher than 200 (see also black lines for reference) and is therefore considered to be a minor contributor to the observed (estimated) attenuation. Scattering attenuation reaches the maximum at a frequency of 150 Hz and results in Q values of approximately 200. Thus, in the frequency range of interest, say less than 100 Hz, scattering attenuation becomes negligibly small for practical purposes.

## Conclusions

In this study we applied an integrated workflow for estimation of attenuation from ZVSP and log data to a comprehensive dataset acquired at Otway basin. Both 1D reflectivity modeling and application of generalized O'Doherty-Anstey to the Otway log data shows that 1-D scattering component of attenuation gives Q of over 200. At the same time, average $Q^{-1}$ estimated from field VSP data value is close to 60. Hence we conclude that scattering plays a relatively minor role in the study area. Further research is required to understand whether this conclusion holds in other areas. In particular, scattering attenuation might be larger in environments with larger variability of elastic properties between layers, such as in areas with laminated coal layers. Another significant factor that requires further study is transmission loss. Although transmission loss has similar nature to scattering attenuation, it is governed by slightly different equations as the assumption of constant Q is not valid for transmission loss. It would be important to investigate if transmission loss can be modelled by the generalized ODA theory with experimentally measured autocorrelation function.

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