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OPTIMIZING RESOURCES

Seismic Imaging In A Low Q Environment

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Summary

Seismic data quality can be reduced significantly in a strong attenuation environment with low Q values. The very strong attenuation of seismic waves in the Athabasca Basin, Saskatchewan, was previously assumed to occur because of the presence of unconsolidated near surface materials (i.e. the overburden). However, we observe an extremely low Q over the entire extent (i.e. from 50 to 450m) of the vertical seismic profiling (VSP) data acquired in 2007. Various measuring techniques performed on the near-offset dataset confirm that locally Q can be lower than 10. Q estimation methods used are time-domain amplitude decay, frequency-domain spectrum ratio and forward viscoelastic waveform modelling. The Q is lower than values obtained from marine and land seismic exploration datasets associated with either gas anomalies or volcanic chambers. Meanwhile, high Q (i.e. >>100) observed from the offset VSP data (i.e. source located 300 m away from the near-offset one, and likely to be away from local alteration) indicates the attenuation condition can be correlated with sandstone alteration. Thus, a vertically occurring low-Q body (e.g. an attenuating plume) is a more realistic model to explain the strong attenuation rather than the overburden-only model. Such environments are challenging for seismic imaging as the signal-to-noise ratio (SNR) is strongly reduced by loss of wave energy. We therefore expect to achieve an attribute model through Q tomography, and this will be utilized for compensation of the energy loss in the future processing of surface seismic data in the Athabasca Basin.

Introduction

Modern exploration seismic methods evolved from on-land reservior imaging generally neglect the effect of attenuation, as the Q value in these environments are high (i.e. Q> or >> 100). Challenges emerge in some marine exploration projects with presences of shallow gas anomalies (i.e. as cloudes and curtains). The attenuation is intensified by the absorption property of the partial saturated gas within the porous media. This situation is observed globally (e.g. Zhou et al., 2011, 2014; Liu et al., 2014; Shen et al., 2015). The lowest Q value reported for these types of gas anomalies are within the range from 10 to 20.

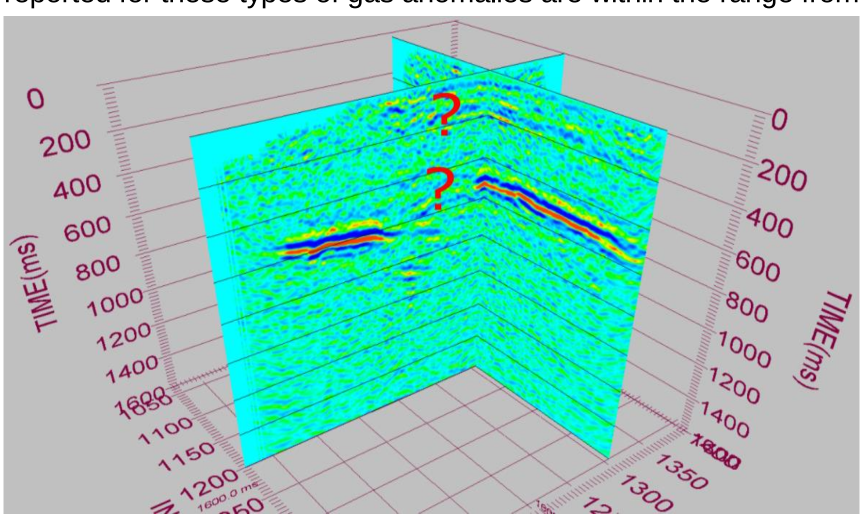

Figure 1. A 3D seismic cube from the Athabsca Basin, Saskachewan. Question marks denotes areas with significant attenuation of seismic waves. (Wood et al, 2012)

Hardrock (i.e. highly metamorphosed and igneous) environment can attenuate seismic waves more significantlly. Although Malehmir et al. (2012) concludes higher Q values in hardrock seismic exploration due to the fact that scattering prevails intrinsic effect, the authors neglect the significance of erosion at near surface and the abundance of fractures at depth. Our observations from the Athabasca Basin provide evidences that the Q value can be lower than 10. This condition causes the loss of seismic image within the alteration zone (simutanously, mineralization zone; Figure 1).

Measurements

The seismic attenuation quality factor Q is defined:

$$Q = \frac{\textit{energy of the seismic wave}}{\textit{energy loss per cycle of oscillation}} = \frac{2\pi E}{\Delta E} \quad (1)$$

where E is the energy of the seismic wave, and ΔE is the loss of energy per cycle. Thus, Amplitude of the seismic wave can be written as:

$$\frac{A}{A_0} = Ce^{\frac{-\pi f t}{Q}} \quad (2)$$

where A is the amplitude of the seismic wave as a function of both travel time and frequency. A_0 is the amplitude of non-attenuated seismic wave. C is a constant incorporates geometric spreading effect. f represents the frequency of the wave. t is the group traveltime to transverse the media. Equation (2) denotes that the effects of attenuation include amplitude decaying, temporal broadening and band narrowing (Figure 2).

The relationship can be written as:

$$\ln\frac{A}{A_0} = -\frac{\pi t f}{Q} + C \quad (3)$$

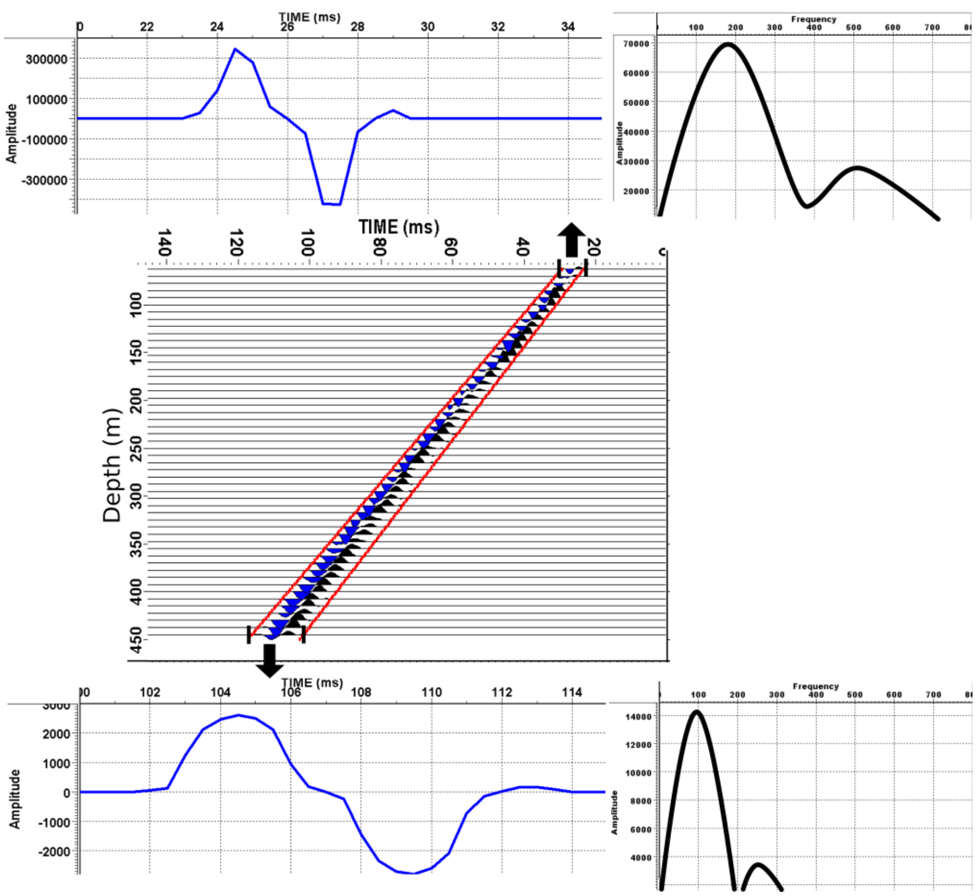

Figure 2. First arrivals extracted form the near-offset VSP data from the Athabasca Basin. A comparison of the nearest trace and the farthest trace is given on the top and the bottom. The strong attenuation broadens the wavelet in time, and narrows the frequency band, and amplitude scales changes significantly.

This leads to various methods determining Q from a VSP dataset (Tonn, 1991). With an over-all amplitude ratio and a dominant frequency, the time-domain amplitude decay method provides one Q estimation over the entire extend (Figure 3 left). From the uncorrelated VSP record, the amplitude ratio in equation (3) can be seen as a function of the frequency. Frequency-domain methods thus provide Q measurements at each receiver depth (Figure 3 right). We successfully performed two frequency-domain Q estimations (i.e. spectrum ratio and dispersion method) on the VSP dataset, while trails on the dispersion method in sedimentary environments often fail as the result of Q not being low enough to cause measurable dispersions.

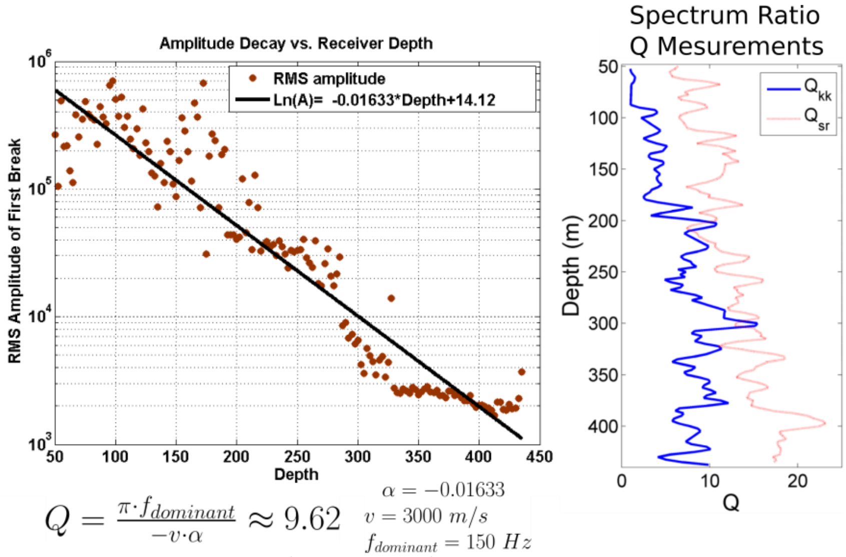

Figure 3. Left: the time-domain amplitude decay measurement of the over-all Q from the Athabasca Basin VSP dataset. Right: Spectrum ratio and dispersion measurements of Q values at each receiver depth from uncorrelated VSP data. Q_{kk}: calculated from the linear dispersion of the ray-path-average V_P in the 30 to 150 Hz band. Q_{sr}: calculated from the spectral ratio of the first break in the 120 to 290 Hz band.

Waveform Modelling

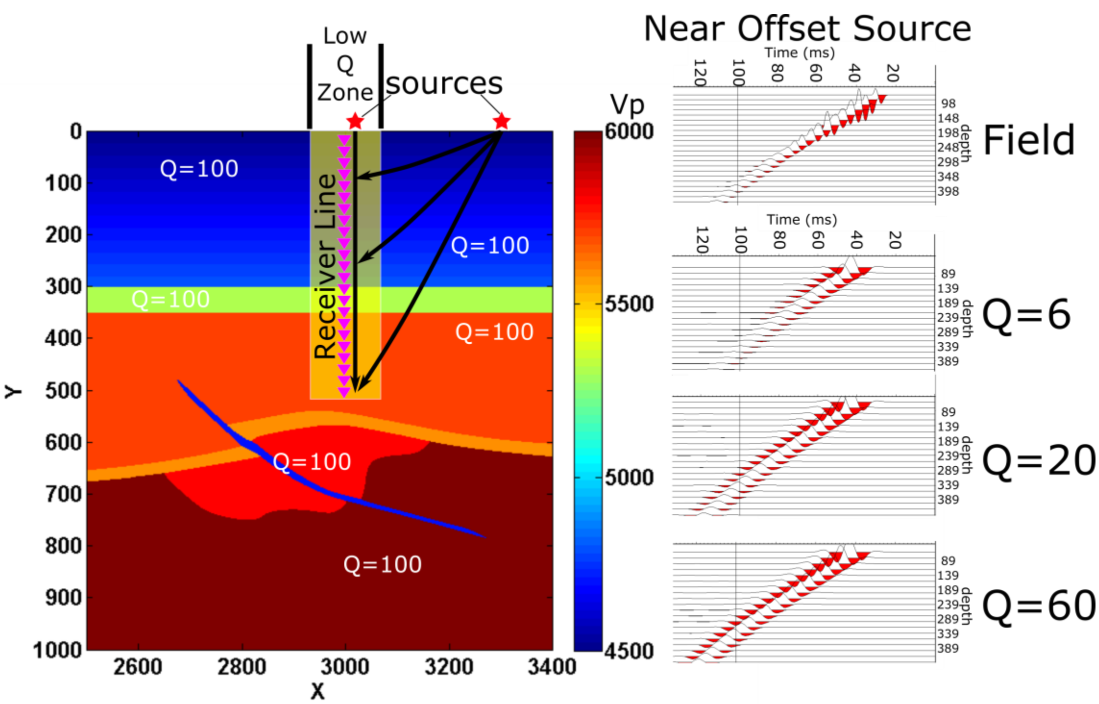

Figure 4. Left: the velocity model for the finite-difference visco-elastic waveform modelling. The yellow zone represents a strong attenuative body with low Q value compared to the environment. The raypaths of the near offset source stays within the Low-Q body. However, only a small portion of the offset source's raypaths lies within the Low-Q body. Right: synthetic VSP first arrivals compared to the field observations with various Q values.

For the Q estimation methods described above are all based on planar wavefront assumption, the extremly low values can become invalid. Waveform modelling results provide decent estimating of the visco properties of the model. Based on the vertical low-Q body model (Figure 4 left), synthetic VSP first arricals (Figure 4 right) show that the in-situ observed Q is between 6 and 20 (determined by the apparent amplitude decay rate compared to the synthetic record). The model reasonably predicts the strong decaying of the first arrivals of the Near offset VSP dataset (Figure 5 top), and the bare energy loss of the offset one.

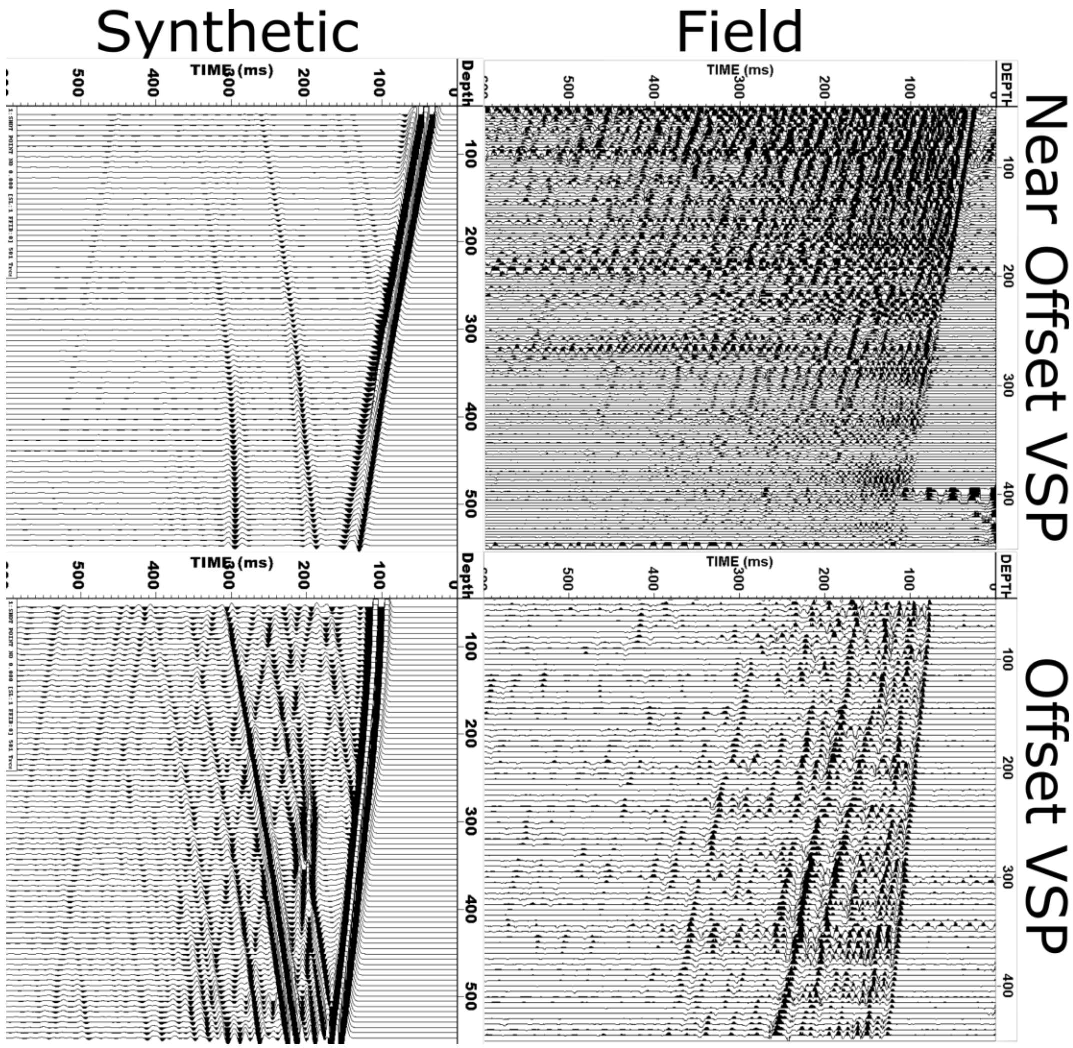

Figure 5. Comparisons of synthetic (from model shown in Figure 4) and field (Athabasca Basin) VSP datasets for both of the near and offset surveys. At this stage, the simulation used lower frequency wavelet than the field for the consideration of computation efficiency.

Conclusions

Measurements with the viscoelastic waveform modelling result denote a extremely low Q value for the seismic data in the Athabasca Basin. The Q can be lower than 10 in some areas. Current synthetic results suggest such strong attenuation tends to occur within small local zones. Future Q tomographic inversions from the VSP data can provide a detailed model for the compensation of energy loss of the surface seismic data.

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