A Synthetic Test of Q Tomography for Multi-Source VSP data

Dong Shi, Bernd Milkereit[1]
Department of Earth Sciences University of Toronto

Summary

Previous work observed an extremely strong seismic attenuation (i.e. low quality factor, Q) in the Athabasca Basin, Saskatchewan, Canada. Q measured from VSP datasets through various methods confirmed it can be as low as 7.8 at McArthur River, and 24 at Millennium. Such condition is one of the key factors affecting the 3D seismic image quality. The observation also suggests the strong attenuation is highly localized, and tends to associate with sandstone alterations (i.e. argillic and/or silicic). The high contrast Q in the Athabasca Basin provides a special case allowing the imaging of the mineral (i.e. uranium) alteration zone though a tomographic inversion of multi-offset VSP data. To accomplish this task, seismic velocity and Q models based on known Athabasca Basin geological and geophysical observations are utilized to generate synthetic Multi-offset VSP datasets through full waveform viscoelastic modelling using Finite-Difference (FD) software package SOFI3D (Bohlen, 2002). The Q tomography result from the synthetic datasets provides reference to verify the future attenuation image of the field 3D multi-offset VSP data from the Athabasca Basin.

Introduction

Strong seismic wave attenuation is often reported from marine exploration area where presents partially saturated gas clouds or curtains within a porous rock. The gas associated low Q ranges from 10 to 30 (e.g. Zhou et al., 2014; Liu et al., 2014; Shen et al., 2015). In such environment, the amplitude dimming effect is a key factor influencing the seismic data signal-to-noise ratio (SNR). This is rarely observed on-land for a typical fresh sandstone exhibits almost elastic property (Q>100). A special case exists in the Athabasca Basin where both a 2D and 3D seismic section becomes problematic to image a sandstone-granite unconformity close to the uranium ore zone (Hajnal et al., 2010; Wood et al., 2012; Shi et al., 2014). The image loss is caused by the extremely strong attenuation. We (Shi et al., 2016) measure the Q from borehole seismic datasets through various methods, and the result show local Q value can be even lower than that reported from marine gas zones. This abnormally strong attenuation occurs not only on the surface but also to the bottom of the Athabasca sandstone sequence. Thus, the hypothesis of the highly localized and deep low Q relates to the fault zone and the fault-associated sandstone alteration. This unique attenuation condition provides chance of performing Q tomographic inversion for imaging the mineral alteration zone.

Multi-offset VSPs are suitable datasets for Q tomography in a strong attenuation area. As reflected wave energy is significantly absorbed by the media, analysis of transmitted wave (i.e. first arrivals) amplitude is easier to accomplish. Brzostowski and McMechan (1992) perform the first test of the 3D tomographic inversion on a 3D surface seismic data from Oklahoma, USA. The surface data behaves well in resolute lateral variations of Q, while it only covers shallow depth. Reine et al. (2012) review the existing methods for Q measurement and inversion from surface seismic datasets. Quan and Harris (1997) test the Q tomography scheme on a 1D synthetic offset VSP and 2D synthetic cross-well seismic data. The inversed Q model demonstrates the advantage of the downhole geometry on Q imaging. Plessix (2006) and Blias (2012) show a few examples of similar attenuation studies from downhole geometries. Focusing on multi-offset VSP data, Guerra and Leaney (2002) inverted for a 1D Q(z) model using a synthetic walkaway VSP from a 2D layered model. The method implemented into field data delivers good results for amplitude compensation and enhancement. Such tomographic inversion has not been tested on 3D datasets before.

In the Athabasca Basin, the entire 3D 3-component surface seismic survey at the Millennium mine site (Wood et. al., 2012) is simultaneously recorded in a borehole 3-component receiver line forming the multi-offset VSP dataset. To provide reference for the Q tomography performed on the multi-offset VSP data at Millennium, we test the inversion method on synthetic multi-offset VSP datasets created through waveform modelling based on the borehole geology and velocity logs.

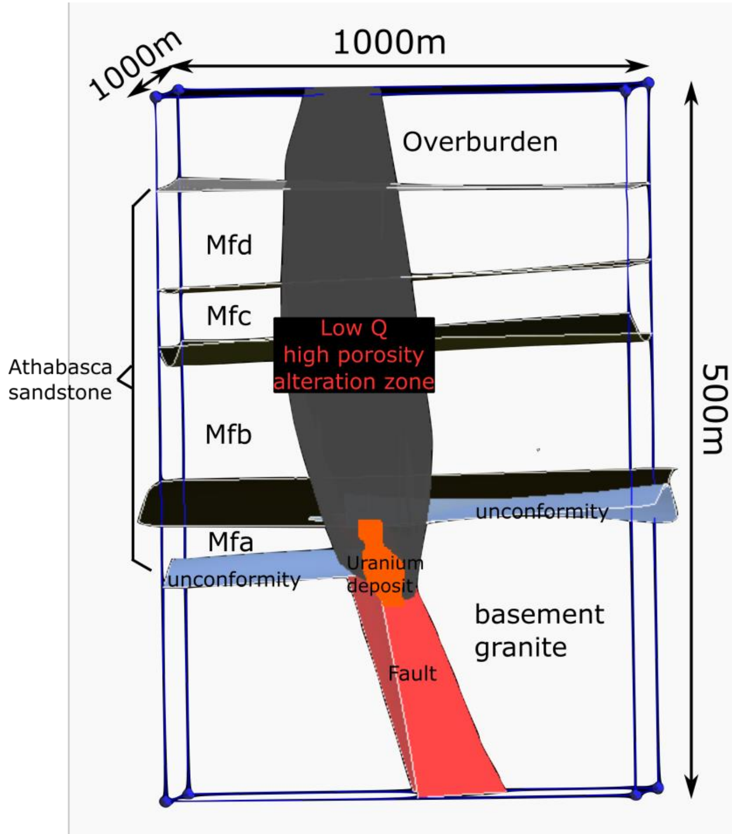

Figure 1. The 3D geological model of the Athabasca Basin with alteration extending to the surface. The alteration can potentially increase the sandstone porosity, thus significantly affecting seismic wave attenuation.

Theory and methods

The forward model is based on the typical geology of the Athabasca basin (Figure 1). The high grade uranium deposit is controlled by the unconformity between Mesoproterozoic Athabasca sedimentary sequence and Paleoproterozoic metamorphosed granitic basement. The sandstone group is subdivided into four sequences: Mfa, Mfb, Mfc and Mfd with little velocity variation. The sandstone alteration type (i.e. argillic and silicic) and degree significantly affect porosity, cementation and clay content, thus are the key factors influencing seismic velocity and attenuation. However, the extent and degree of the sandstone alteration in the Athabasca Basin is not yet well studied. The model structure is extracted from the Athabasca GoCAD® geologic model. The p- and s-wave velocities input into SOFI3D (Bohlen, 2002) utilize the observation from borehole geophysical logs, and Qp and Qs values are based on the previous measurements (Shi et al., 2016).

Figure 2 shows the 4 models created to generate the synthetic dataset for testing the Q tomography results: a constant velocity model with no attenuation (i.e. elastic), a heterogeneous model based on the Athabasca Basin typical geology with no attenuation, an identical velocity model with a global constant attenuation and an identical velocity model with a vertical low-Q zone. Although the field multi-offset VSP has surface sources and borehole receivers, the forward model has a source located in the center and receiver lines on the surface. This configuration is chosen to save the computing storage, at the same time, its raypath coverage is similar with the field multi-offset VSP survey.

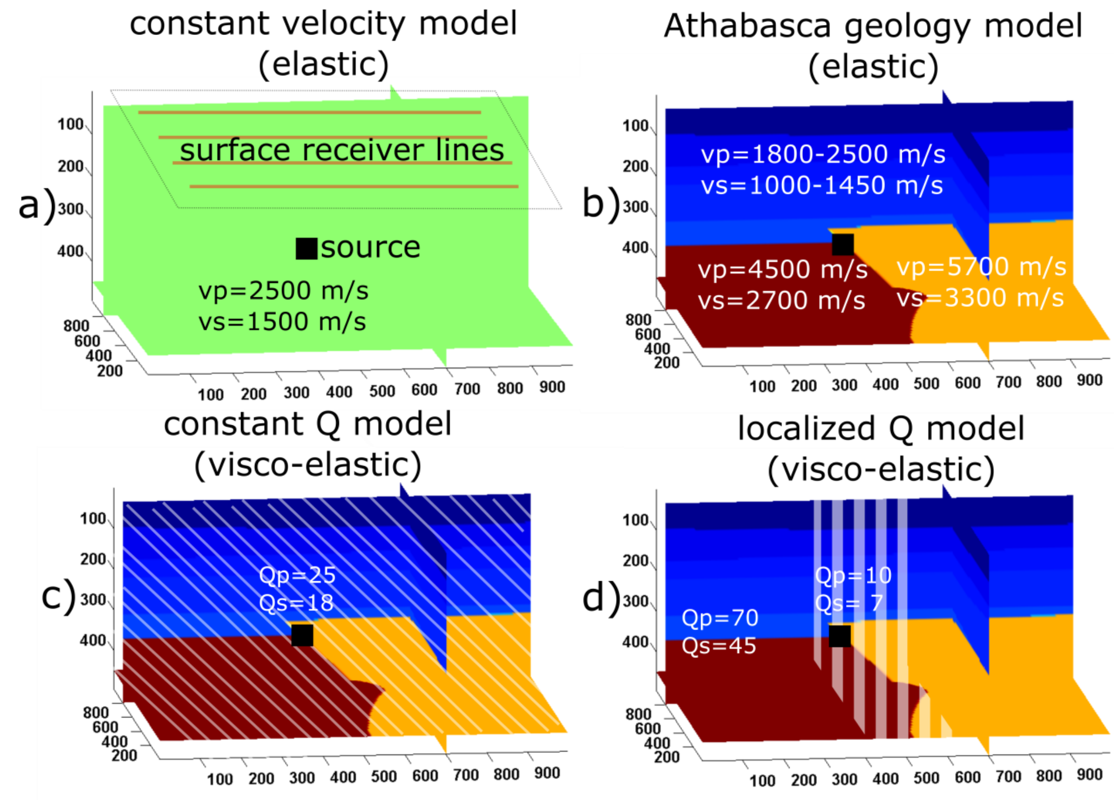

Figure 2. The four models used to generate synthetic data for testing 3D Q tomography: a) a constant velocity model with no attenuation (i.e. elastic) b) an elastic model with the typical sandstone-basement geology of the Athabasca Basin c) the geology model with a globally constant Qp and Qs d) the same model with a local vertical low Q zone. Each model has source at (500 m, 500 m, 420 m) and receiver lines on the surface.

Examples

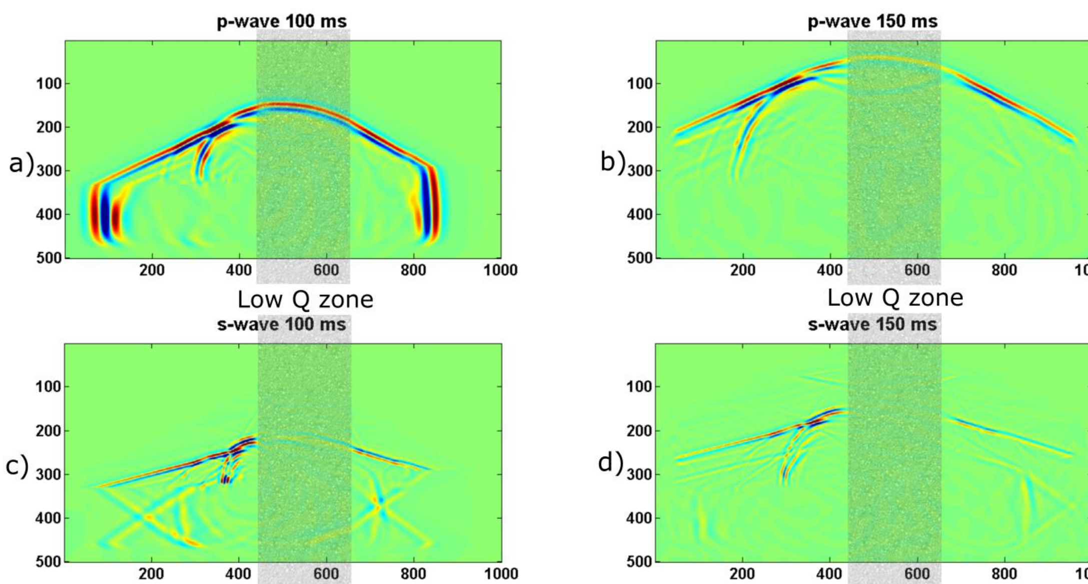

Figure 3. Y=500 m plane snapshots of p- and s-wave wavefield snapshots at 100 ms and 150 ms from Figure2.d) model. Darkly shaded are low Qp and Qs zones.

Figure 3 shows one 2D slice of the waveform snapshot from the vertical low-Q zone model. Although the seismic source is located in the strong attenuation zone, the wavefront outside is still clear. The s-wave is more attenuated than the p-wave, because 1) Qs is lower than Qp 2) s-wave velocity is slower, thus spends more time traveling within the low-Q zone.

Conclusions

In the Athabasca Basin, the Q inversion is beneficial for two reasons: 1) to compensate for the amplitude loss of the field surface 3D seismic data and 2) to image the Q associated alteration zone. This study will later test the t* Q tomography (Cavalca et al, 2011) on the synthetic 3D seismic data. With feasible results, the tomography will be applied to the field multi-offset VSP data from the Athabasca Basin.

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