Finite-difference modelling of the seismic wave attenuation in the Athabasca Basin

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Introduction

The regional geology of the Athabasca Basin is characterized by an undeformed clastic sequence that overlies highly deformed and metamorphosed rocks. The deformations and metamorphism of basement rocks present within the Athabasca Basin is a product of continent-continent collision of the Trans-Hudson Orogen (Jefferson et. al, 2003). From this geological formation, uranium deposits are observed through the unconformities between sedimentary sequence and metamorphic basement rocks. Due to the complexity involving sedimentary and crystalline rocks of the current area, uranium deposits were able to form within fracture zones of the basin by the different stages of silicification and argilization (Hoeve and Sibbald, 1978). This process creates high alteration zones of the formation sequence and fracture zones leading to different compositional layers which, yet favorable in the mineralization of uranium, becomes problematic when interpreting seismic geophysical data. The area pertinent to this study resides within a thrust fault located near McArthur River mine.

From a previous comprehensive research conducted by EXTECH IV Athabasca Multidisciplinary Uranium Studies Project, geophysical, mineralogical, and stratigraphic knowledge of this region have originated. The results observed by Mwenifumbo et al. (2007) from downhole geophysical logs concludes that there are large variations of in situ density and acoustic impedance within the Athabasca sandstone formation which correlates with resistivity variations. The gradual variance in resistivity, density and seismic velocity (V_p) leads to the conclusion that these data corresponds to the change in porosity, thus to the desilicification and fracturing of the surrounding rocks (C.J. Mwenifumbo et al., 2007). Furthermore, the fracturing and silicification are associated with acoustic impedance and reflection coefficients: Strong vertical variations of acoustic impedance leads to blatant seismic reflections (D.J. White, 2007). Hence, the compressional-wave velocity is directly related to reflectivity coefficients of the rock structure.

From the collected borehole data and high resolution 2-D profiles by EXTECH IV, Hajnal et. al (2010) have found that internal reflectivity of sandstone is directly dependent on porosity variations and, therefore, the reflectivity at the surface was found to be relatively weak due to low surface pressure. Yet, the reflectivity within the internal structure near the unconformity presents different results. As a principal, the sandstone-basement contact should generate very strong seismic reflectivity due to the alternation zone. Yet, due to the suspected fracturing and desilicification of the sandstone bed and the unconformity zone, the reflectivity strength is drastically reduced. Furthermore, the extensive fracturing at the base of the sandstone will result in a low-velocity zone (D.J. White, 2007). Thus, these variations in geophysical properties lead to suspect that the strong attenuations resulting in decreasing V_p may potentially be an outcome of either the surface overburden or from the highly contrasting seismic velocities found in the overall region of the unconformity and within the alteration zones.

Theory and/or Method

In this research, both of these conditions will be modelled through a two-dimensional seismic modelling software SOFI2D (Bohlen, 2002). By using two-dimensional viscoelastic models, these different

attenuation zones will be assigned to each model and will be simulated in order to reveal the nature of the strong variation in V_p values. Yet, before doing so, an elastic model will be simulated in order to determine the values of the compressional- and shear-wave velocities within this local area.

This geological model (Fig. 1) consists of the different velocity zones within the unconformity structure with each different density, compressional- and shear-wave velocity values. The Athabasca sandstone which is in direct contact with the basement rocks has a varying compressional- and shear-wave velocity where lower values can be observed near the surface and higher values near the basement rock contact. This leads to a lower contrast zone within the transition between the sandstone and basement rocks. Within the alteration, the mineralized zone is shown as part of the structure of the thrust fault holds different physical properties than its surrounding. For the elastic seismic model using SOFI2D software, the parameters used to do the simulation is shown in Table 1.
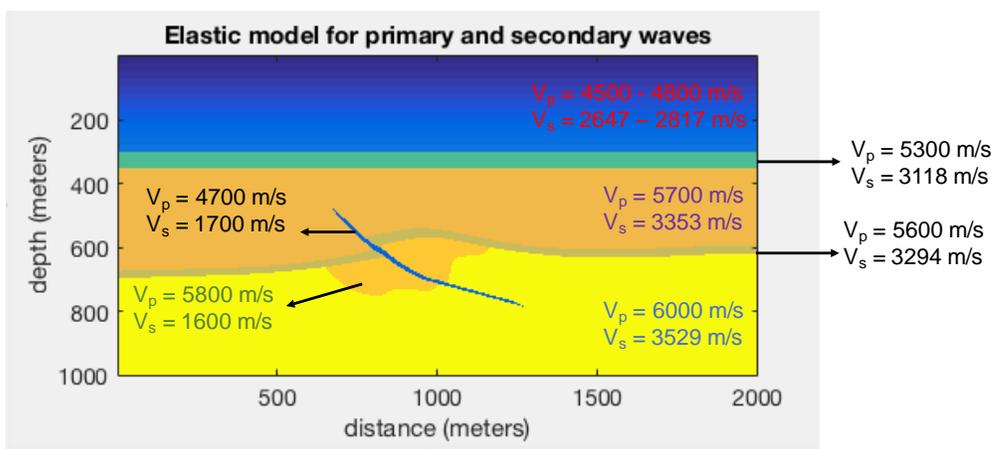

Figure 1 Elastic geological model of the unconformity zone of P2 fault within McArthur River. (Shi, 2014)

Parameters	Value	Parameters	Value
NX	2000 m	Absorbing frame width	50 m
NY	1000 m	Damping	8
Grid size	1.0 m	Initial Receiver	100 m
Total time	0.8 s	Final Receiver	1900 m
dt	1.0e-05 s	Receiver depth	5 m
Source type	Explosive	Receiver spacing	10 m
Source frequency	50 Hz	Sampling rate	100

Table 1 Parameters used for SOFI2D simulation for elastic model

The first viscoelastic model (Model A) consists of defining the uranium unconformity structure as a high attenuation zone, therefore modelling the low reflectivity of the fractured and desilicified sandstone and sandstone-base. This model will justify to what extent the fracturing and desilicification found within the basement rock and at the base of the sandstone will affect the reflectivity coefficient of V_p. For the second viscoelastic model (Model B), the high attenuation zone was defined by the overburden. Hence, the low confining pressure and mobilized fluids have been identified as being the cause of the loss of energy of the sound wave and will therefore be simulated in order to understand how this affects the seismic results and perhaps explain the loss of image in seismic profiling.

The attenuation values have been predetermined for each sound wave and used for both viscoelastic models. The attenuation coefficient value for the compressional wave (Q_p) has been evaluated to be 7 within the high attenuation area and 70 outside of this zone. For the shear-wave velocity, the attenuation

coefficient value (Q_s) has been evaluated to be 4 within the high attenuation zone and 40 for the rest of the model (as shown in Figure 2). As for the parameters used to the viscoelastic model, these are the same as for the elastic model.
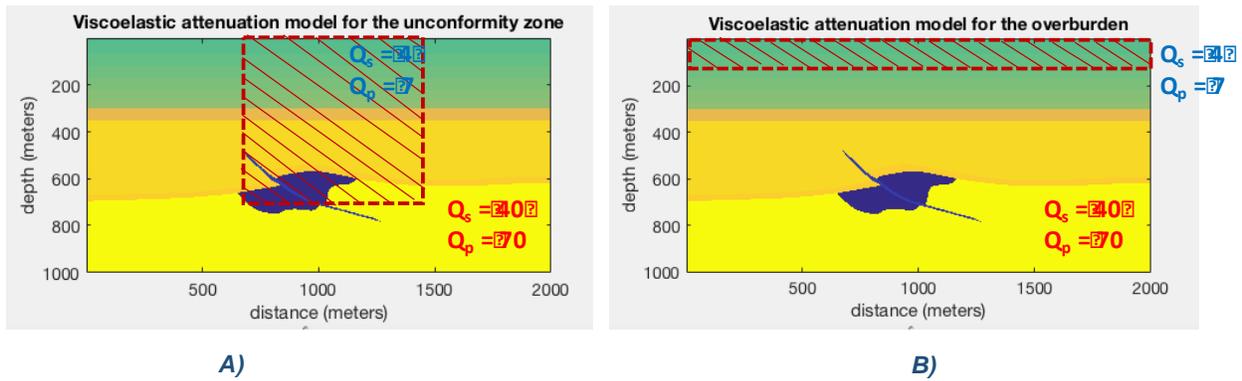

A)   B)

Figure 2 A) Viscoelastic model with high attenuation of the unconformity zone (hatched zone). B) Viscoelastic model with high attenuation of the overburden (hatched zone). Model derived from Shi (2014).
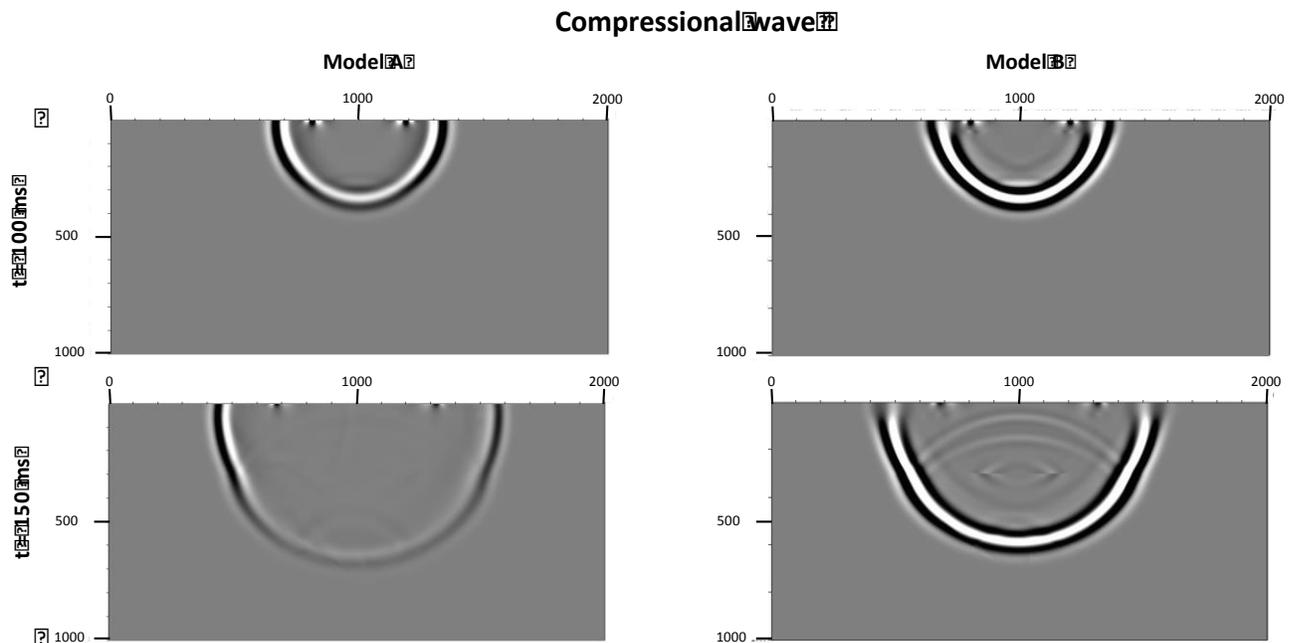
Examples

Figure 3 Modelling results from SOFI2D software of both Model A and Model B involving shear wave
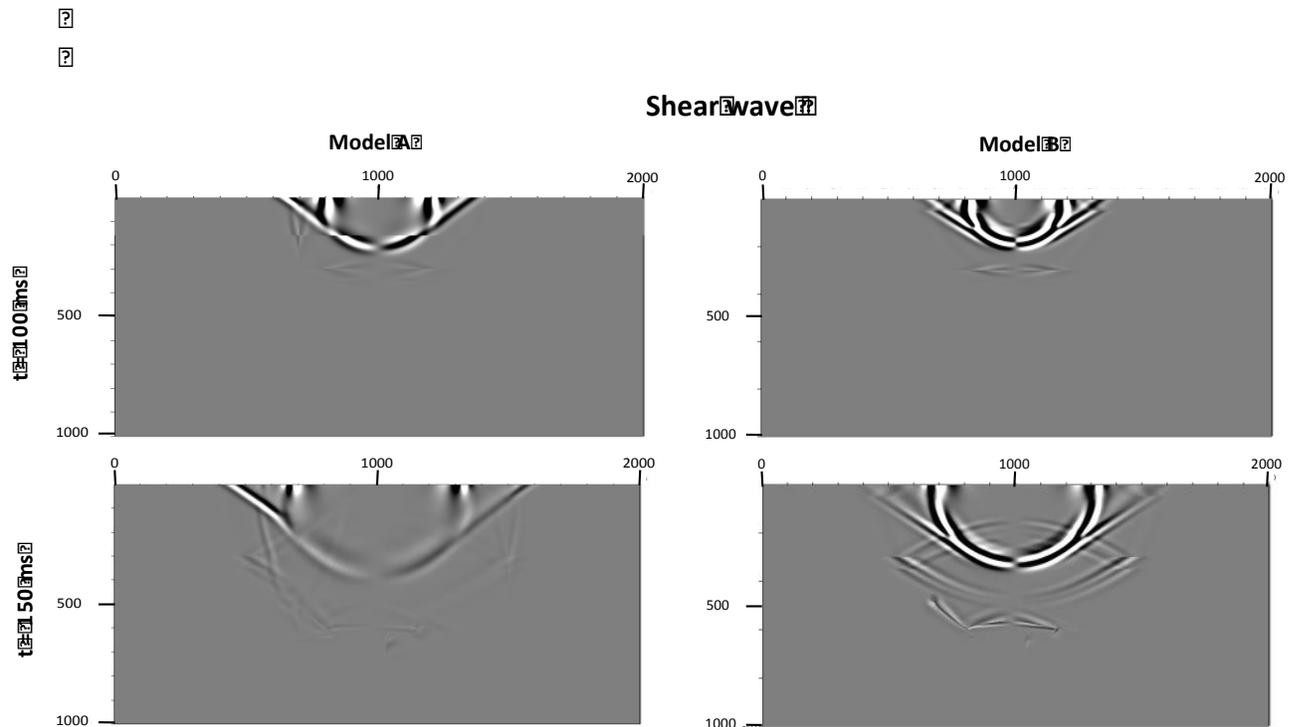
Shear wave

Figure 4 Modelling results from SOFI2D software of both Model A and Model B involving shear wave

Conclusions

The results shown from the previous figures (Fig. 3 and 4) are snapshots of the seismic wave which consists of the compressional wave (p-wave) and the shear wave (s-wave). The dispersion of these waves can be observed through time via modelling. When comparing the models, the influence of the location of the high attenuation zone on seismic waves can be investigated. Thus far, the model in which the high attenuation zone is located within the unconformity zone (Model A) has shown lower reflectivity since the compressional and shear wave dissipate within the region.

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