VSP study of attenuation in oil sands

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Introduction:
Attenuation estimates are important as they provide lithology or fluid content information (e.g Rapoport & Ryjkov, 1994; Martin et al, 1998). More recently, it has been proposed to use attenuation estimates from VSP in frequency restorations to improve surface seismic images. In order to get reliable Q estimates it is crucial to evaluate the effects of applying different processing techniques to the dataset.
Vertical Seismic Profiles are best suited for attenuation studies as they allow one to sample the downgoing wavefield at different well known depths. In a perfect homogeneous halfspace, determination of attenuation is straightforward via tracking of the frequency dependent decay rate. However, in VSP the geophones are placed in the earth where reflections are produced; consequently the recorded pulse is contaminated by reflections coming from immediately below. This effect has been much studied before by O'Doherty and Anstey (1971) and more recently by Ateeva (2002).
Median filters, FK filters, or tau-p filters are commonly used for separate the downgoing wavefield in conventional VSP processing. This paper is intended to evaluate the effect on applying those techniques on the attenuation estimates on seismic data from the McMurray Formation in Northern Alberta.

Method: Seismic wave attenuation can be modeled as the solution for a damped oscillating system (Lay and Wallace, 1995) as:

$$A(x,f) = B \cdot A(x_0,f) \cdot e^{-\frac{\pi f}{Qv}x} \quad (1)$$

$A(x,f)$ is the amplitude at frequency f and depth x, v is the wave phase velocity, Q is the quality factor which describes the attenuation, and B is a factor that accounts for amplitude processing. Based on equation (1), a logarithm can be computed for the amplitude ratio to calculate Q for a set of amplitudes at different depths. This is known as the spectral ratio method (e.g., Hauge, 1981; Stainsby and Worthington,1985; Pujol and Smithson, 1991). Following from equation (1):

$$\ln\frac{A(x,f)}{A(x_o,f)} = -\frac{\pi x}{Qv} f + C \quad (2)$$

For constant Q, equation (2) describes a line of slope $-\pi x/Qv$ and intercept C. The advantage of this technique is all of the spreading, transmission loss and local impedance effects are contained in the intersect and can be ignored if Q is to be fund.
Equation (2) is applied to the VSP dataset in the frequency domain which had been sampled at different x depths.

Data processing: The VSP data used was acquired by the University of Alberta in a 225m deep wellbore drilled through the Athabasca reservoir Northeastern Alberta using a 3 component wall locking geophone (Grech, 1998). It consists of 77 traces sampled at 0.1msec from 30m to 220m depth. The seismic source consisted of a Betsy Gun fired into a mud pit, this provides a highly repeatable source signature necessary for our current attenuation analysis. Figure 1 depicts the VSP data with spherical divergence restoration (Grech, 1998) against the corresponding sonic log. Note strong reflections from the Wabiskaw sand at 122 m and the Paleozoic unconformity underneath the oil sand at 156 m. The McMurray Formation corresponds to the interval 122-156 m. The effect of local impedance is evident by the substantial loss of amplitude within the high velocity-density carbonates below 156 m depth. A close-up to the last traces in oil sand shows strong contamination for the down-going pulse from the reflection coming from the unconformity.

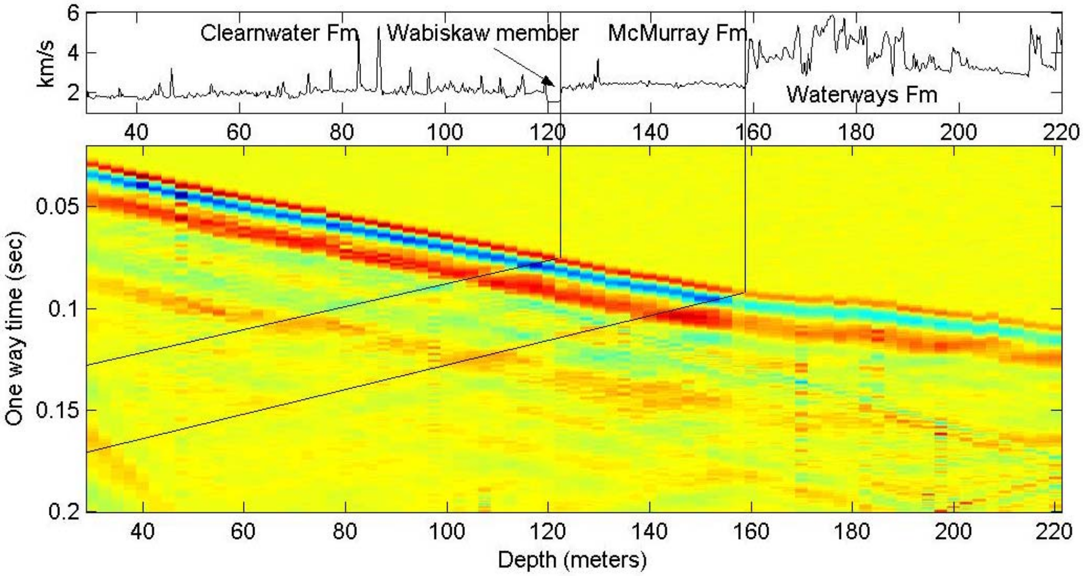

Figure 1. Sonic log and raw VSP data in study.

The first step in processing was to apply a first break time shift to all the traces to flatten the onset peaks to 100ms (fig. 2a). This procedure is necessary to carry out separation of the up-going and down-going wavefields. Three different separation methods were applied: a 6-point median filter, fk and a tau-p filter. Figure 2 displays the resulting down-going wave-field.

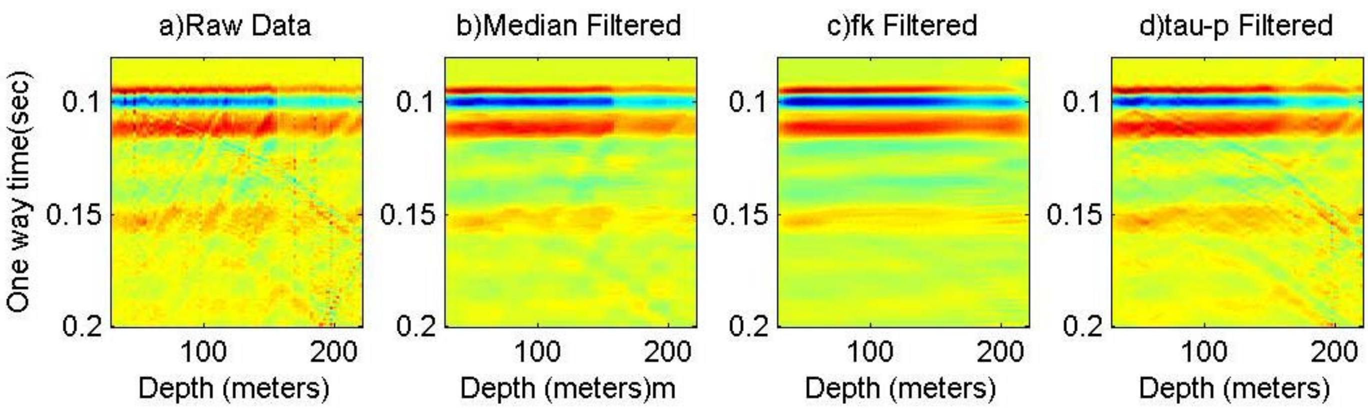

Figure 2. a) Raw VSP data. b) 6 point median filtered data. c) FK filtered data d) t-p filtered data.

Next, the separated primary down-going pulses were isolated from later multiples using a 80ms Blackman-Harris type window centered on 0.1sec (Pujol and Smithson, 1991). To apply equation (2) in finding Q, the FFT for the 13 traces within the McMurray Formation were calulated. The shallowest of these was taken as reference to compute the ratios for the frequency band from 20 to 80 Hz. The wave velocity was computed from the VSP first break under the as yet unproven assumption that the compressional wave speed is not dispersive over this band.

Results:

Figure 3 shows the values of Q estimated for different separations between the traces using the unseparated raw wave-field traces (figure 2a) and those for the isolated down-going pulse of figures 2b-d. The average Q estimates for the three methods fall between values of Q = 9 to 22.

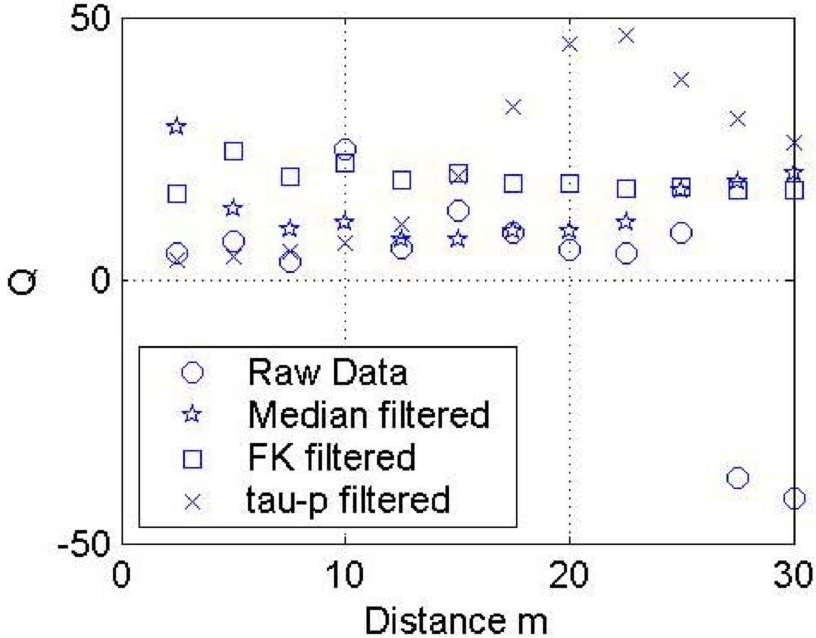

Figure 3. Q estimates for the McMurray Formation for dataset obtained from different wavefield separation methods.

For the raw data Q estimates, two nonphysical negative values are observed for the bottommost two traces. This is not unexpected as those traces are contaminated by the bottom reflection. Ignoring these two outlier points yields an average Q = 9 for the raw data. This value should be suspect as the raw data contains substantial contamination by the up-going wave-field. Still this includes the effect of other weaker reflections from the formation.

The Q estimates for the median and FK datasets are relatively constant Q averages of 13 and 19, respectively. However, the Q values for the tau-p dataset give an average substantially greater than the others, especially for traces separated by more than 15 m, with average Q values ranging from 3 to 46. This high variance in the values suggests that this last method do not work well for Q estimation. On the other hand, the values of Q provided by the other techniques are relatively stable.

Despite the differences in the estimated values, the results suggest that the oil sands are relatively attenuating over the frequency band studied with an average Q value of 13 from the FK and median filtered separated data. Future work will focus on understanding the effects on different factors such as frequency band, windowing and receiver pairing. As well we will attempt to investigate the physical mechanisms causing such attenuation.

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