Q Inversion in a Heavy Oil Sand

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Summary

In this work we implement a method to invert a *Q* profile from zero offset VSP in a heavy oil reservoir. The method is published in the literature and is based in the spectral ratio technique. We attempt to solve the problem using damped least squares. The inversion results agree with results obtained from the traditional trace to trace comparison method. Both methods are consistent with a nonphysical but apparent negative attenuation area in the shallow part, at depths between 70 and 90 m that could be related to a constructive scattering area associated to shale and siltstone cycles. The heavy oil reservoir shows a shallow area between depth 120 and 140 m with lower values of Q up to 20, and a deeper area from 140 to 160 m with values around 50.

Introduction

The heavy oils are an important source of hydrocarbons. In some cases, as in Canada, the viscosity of these heavy oils is so high that it is almost solid state. The recovery process in these cases involves steam injection to reduce the viscosity and induce oil to flow into production wells, the process is called SAGD (Steam Assisted Gravity Drainage). In this process, the steam injection increases the temperature of the reservoir. Batztle and Hoffman (2006) have discussed many of the effects of this heating on the seismic properties of the heavy oil. Among others, a drastic change in the viscosity of the material implies an important change in seismic attenuation, and as consequence velocity dispersion. Seismic attenuation is the measure of the loss of energy per cycle, and is commonly represented by its proportionally inverse, the dimensionless quality factor, Q. This measurement of attenuation has been proposed to monitor steam flood (i.e. Hedlin et al., 2002), which is one of the principals goals in the SAGD process. However, heavy oil, as any other material, is not homogeneous, nor vertically, nor laterally; in fact, one can expect to see viscosity variations before the steam injection. Therefore, an appropriate identification of any possible differentiation before steam injection could be crucial for later monitoring of steam flow.

In this work, we show that algorithms for Q inversion can be used to estimate detailed profiles, that can work as background for further monitoring of steam flow. We also show that the velocity discrepancy between seismic and well log, can be associated to variations in Q. The data we use is a zero offset VSP that corresponds to a heavy oil sandstone in the Athabasca region of Alberta, Canada. In this data, Schmitt (1999) observed variation between seismic and log velocity at heavy oil level. Batzle and Hofman (2006) argue that this dispersion is highly possible in a heavy oil sand. Solano and Schmitt (2004) computed Q for the same data using the spectral ratio technique at the level of the heavy oil sand, and got a value around 20. Here we compute the Q profile for the whole data set using spectral ratio technique (see i.e. Tonn, 1991) and a implementation of this technique in a inversion algorithm proposed by Rickett (2006).

Theory

The spectral ratio technique consists in trace to trace computation of the amplitude spectra ratio, the equation is as follows:

$$\ln\left|\frac{A_n(f)}{A_l(f)}\right| = \ln\left|\frac{R_n G_n}{R_l G_n}\right| + \pi f\left(\frac{t_n}{Q_n} - \frac{t_l}{Q_l}\right), \tag{1}$$

where A is the amplitude spectrum, f is the frequency, R and G are respectively the reflection coefficient and the geometrical spreading. The quality factor is Q and the travel time is t. Sub-indexes n and l indicate two different travel paths with the same source. If the medium is stratified and the propagation is vertical or close to, we have that:

$$\ln\left|\frac{A_n(f)}{A_l(f)}\right| = B_n + \pi f \sum_{\zeta} \frac{\pi f \Delta t_\zeta}{Q_\zeta}, \tag{2}$$

where B_n is a term that catches all the terms independent of frequency, Δt_ζ is the time difference at layer ζ and ζ -1, and sub-index ζ goes from layer at depth l to layer at depth n. Equation (2) can be solved using damped least squares or any other inversion technique (Rickett, 2006). To apply this method we interpolate the time difference Δt_ζ from the first break picks.

Example

The data is a zero offset VSP with a 0.1 ms sampling. The geophones were placed every 2.5 m starting at a depth of 30 m below the surface and ending at 270 m (Figure 1a). Standard processing was applied to obtain the downgoing wavefield (see e.g. Hinds et al. 1996 for details). The first breaks (Figure 1b) were used to compute a velocity profile and compared to the velocity log (Figure 1c). As stated by Schmitt (1999) there is an important deviation between both velocities between 122 and 146 m depth. The McMurray Formation, which is the oilsand extends from 122 m to 160 m depth.

We compute Q using the amplitude spectra of the downgoing wavefield, on a frequency range from 20 to 120 Hz. In order to avoid ringing efects in the amplitude spectra we use a Blackman-Harris filer. For the traditional spectral ratio technique we keep one trace as the source at a fixed depth and compare with deeper traces up to a 25 m interval. The value computed is assigned at depth in the middle. Then we shift to the next trace in depth to the one used as source and to a deeper and repeat the procedure for the next traces. This method allows us to compute more than one Q for a given depth interval, the general trend is in Figure 2a.

To compute the inversion, we use a damped least square algorithm. We did several runs to deteminate the appropriate parameters, we chosed the results shown in Figure 2b. In general, all of the runnings gave the same trend, excepting the areas with negative values that were eliminated with large trade off parameters. However, we decided to keep these negative values because they are consistent not just with the traditional spectral ratio technique, but also with the real behavior we observe in the amplitude spectra (see Figure 3).

To show how the quality factor varies at the different depths we extracted amplitudes spectra at three different levels (see Figure 3). Figure 3a shows the amplitude spectra for traces between 70 and 85 m depth, look at the gain of energy at some frequencies. Figure 3b and 3c show respectively the amplitude spectra at the upper and bottom part of the McMurray formation, observe that loss of energy is larger in the shallow level.

Conclusions

Results from the trace to trace comparison of *Q* and the inversion are comparable each other. The overall *Q* value for the inversion is about 70, and is slightly lower in the trace to trace comparison. Both profiles show a consistent area between depth of 70 to 90 m that coincides with the deeper part of the Clear Water formation. It can bee seen an alternation of high velocities in that area in the well log. The high decrease of attenuation can be due to a combination of scattering due to shale siltstone cycles in this formation, and to the presence of clay as has been shown in laboratory measurements (Best et al., 1994). Modeling of scattering has to be done to be sure.

There is an small decrease of Q at the beginning of the reservoir's depth (around 120 m), and a small increase of this value between 140 m and 160 m, this two areas are in the MacMurray formation and coincide with previous discussion about velocity dispersion at that depth (Schmitt, 1999). Velocity dispersion estimation is needed in this area to justify results. A change in the viscosity of the heavy oil sand could be related to Q variations. The average apparent Q is 50

The high resolution of the data allows us to make direct comparison between the two methods. That would not be possible for large sampling because the traditional spectral ratio method would lost layers smaller that the vertical sampling.

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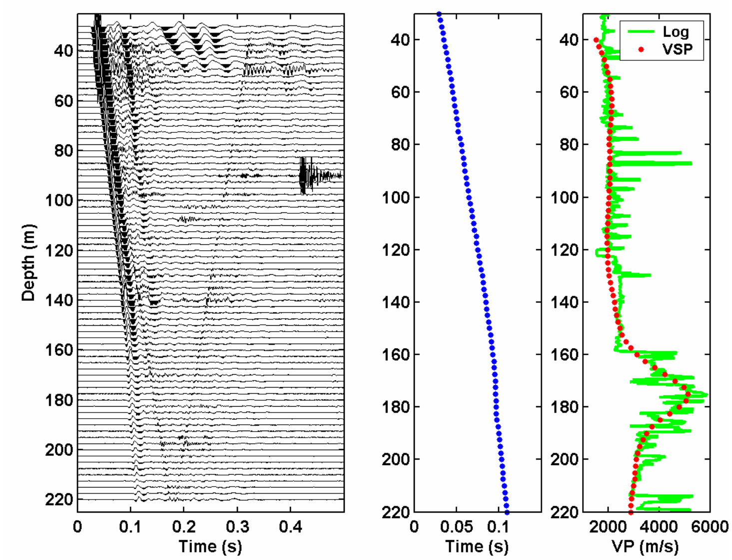

Figure1: a) raw VSP, b) First Break picks, c) velocity log (green) with velocity from first break picks (red).

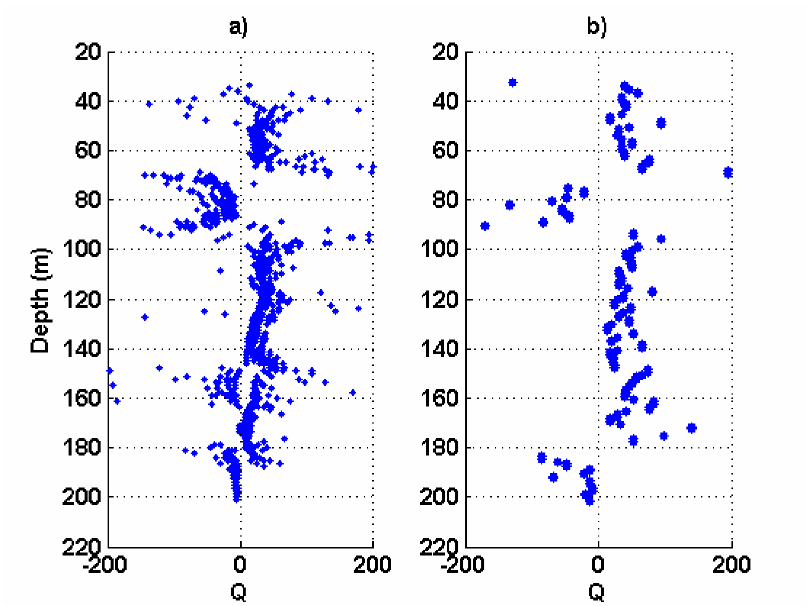

Figure2: Comparison of Q estimation with a) the traditional spectral ratio technique, and b) the inversion algorithm.

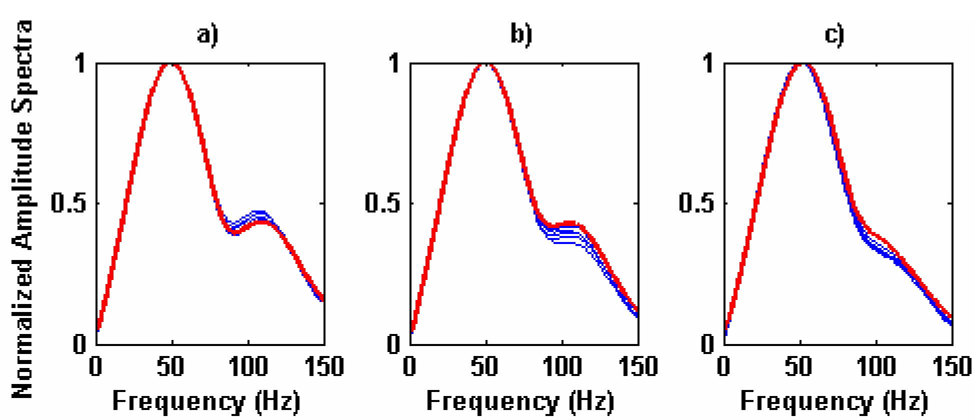

Figure3: Amplitude spectra of the downgoing wavefield between a) 70-85 m, b) 130-145, c) 170-185. The red line is corresponds to the shallower trace