Well Log Analysis and Seismic Attenuation in a Heavy Oilfield: Ross Lake, Saskatchewan

Zimin Zhang*
University of Calgary, Calgary, AB
zzhan@ucalgary.ca

and

Robert Stewart
University of Calgary, Calgary, AB, Canada

Summary

We analyze the relationship between seismic data attenuation and rock properties in well 11-25-13-17W3 from the Ross Lake heavy oilfield, Saskatchewan. Well log analysis indicates that the main lithologies in this well are shale and shaly sandstone. Interval Q values for the P wave and shear wave were estimated by applying the spectral ratio method on near-offset VSP data (which used both vertical and horizontal vibrators). The Q values are most reliable from 400m to 1050m for the P wave and from 225m to 1050m for the shear wave. The Q values correlate interestingly with petrophysical variables. Qp values increase with P- and S-velocities and decrease with Vp/Vs and porosity. Shaly sandstone shows more attenuation than pure shale and sandstone. The crossplot between Qp and clay-bound water indicates more attenuation in shaly sandstone possibly caused by the interaction between mobile water and clay-bound water. Q values for S-waves also display a similar relationship.

Introduction

Attenuation is one of the basic seismic attributes of waves propagating in the earth. Understanding the causes of attenuation and the relationship between seismic attenuation and rock properties is important in the acquisition, processing and interpretation of seismic data. In this study, well log data and VSP data will be used for analyzing the relationship between rock properties and attenuation. Based on this study, attenuation of seismic data is expected to provide helpful information for seismic interpretation and reservoir characterization. The well selected for this study is the well 11-25-13-17W3 from Ross Lake, Saskatchewan. The producing reservoir in this well is a Cretaceous-age channel sand in the Cantuar formation of the Mannville Group. The produced oil is heavy, about 13° API (from Xu and Stewart, 2003). A multi-offset VSP survey was conducted in June 2003. The zero-offset VSP survey used both vertical and horizontal vibrators as sources, which are favorable for estimation P- and S-wave attenuation. Density and neutron porosity, dipole sonic and resistivity logs were also available in this well.

Well Log Analysis and Q Estimation

Figure 1 displays well log curves with formation tops of well 11-25-13-17W3. There are two clean sand intervals with good permeability at 1148m-1160m and 1164m-1180m respectively, which are interpreted to be sand channels in the Cantuar formation. There is about 12m of oil pay of the upper sand, while the lower sand is wet. Clay content in the rock was estimated from the gamma-ray curve by linear scaling between its minimum and maximum values. The total porosity was calculated from the average of density-porosity and neutron-porosity logs. Effective porosity was estimated from the average of the shale-corrected density-porosity and neutron-porosity. The porosity of the channel sand is quite high, about 30%. According to the neutron-density porosity difference and regional geology in southwest Saskatchewan, the lithologies in this well are mostly shale, shaly sandstone and sandstone.

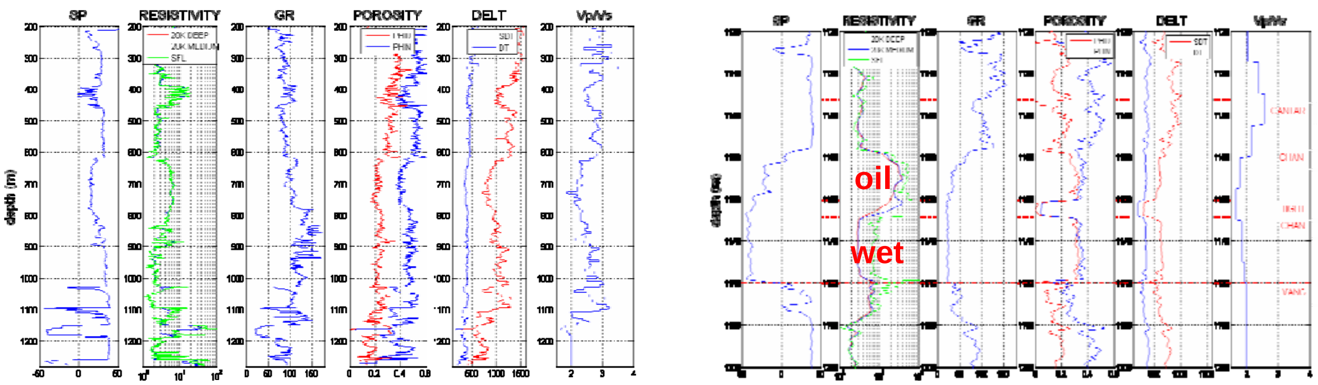

Figure1: Left, well log curves for the Well 11-25-13-17W3. From left to right - spontaneous potential (SP); resistivity (deep measurement in red, medium measurement in blue and shallow tools in green); gamma-ray (GR); density porosity (red, sandstone-scale) and neutron porosity (blue, sandstone-scale); DELT (shear wave in blue, and P wave in red); and Vp/Vs. The right is same as the left focusing on the channel sand portion of the well.

The spectral ratio method (Toksöz and Johnson, 1981) was used for the average Q value (Qave) estimation from VSP data. The interval Q values for a layered medium are then calculated from Qave (Bale et al., 2002),

$$\frac{T(n)}{Q_{ave}(n)} = \frac{T(n+1)}{Q_{ave}(n+1)} - \frac{T(n+1)-T(n)}{Q_{ave}(n+1)} \quad , \; n=1,2, \ldots, N-1$$

The amplitude spectra for all the levels were calculated using a 500ms window on down-going P- and down-going shear-waves respectively. Considering the signal-to-noise ratio, frequency bands from 20Hz to 120 Hz for P-wave and 20Hz to 40 Hz for shear wave were chosen to build the cumulative attenuation curves for Q value estimation (Figure 2). To avoid unreasonable Q values, the cumulative attenuation curves were smoothed using a 7-point smoothing window before calculating average Q values from the surface to each depth. Interval Q-depth structures for P-wave and shear wave were determined from smoothed average Q values. The Qp values are from 20 to 120, and Qs values range from 10 to 80. All of them are in reasonable value range. They are also comparable to average Q values by Haase and Stewart (2004), which are 67 for the P-wave and 23 for the shear-wave over an interval of 200m to 1200m.

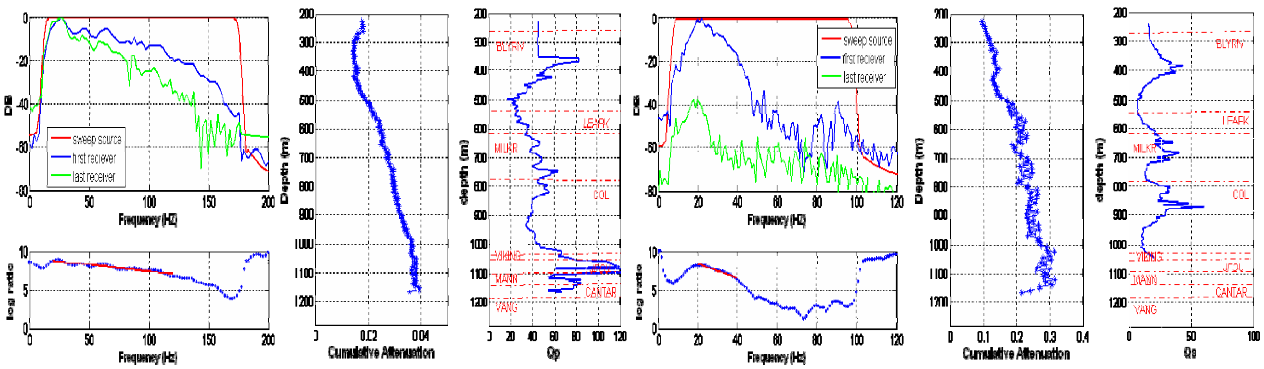

Figure 2: left, - amplitude spectrum and spectral ratio (sweep source in red, the first depth level in blue and the bottom receiver in green); cumulative attenuation calculated from the spectral ratio method; and estimated interval Q values of P wave. The right plots are for the shear wave.

Q Value and Rock Properties

From the cumulative attenuation curve in Figure 2, we see that the values gradually increase with depth from 400m to 1050m. The Q values for P wave are considered reliable for this interval. For shear waves, since the frequency bandwidth for Q estimation was narrow, the accumulative attenuation at each depth level was a little dispersed. And a decreasing accumulative attenuation was found over some local parts and the bottom part of the well, which means the interval Q value will be negative (not physically reasonable). Therefore, the following analysis will be focus on the depth intervals with reliable Q values.

Figure 3 displays Q values for P- and shear-wave and rock properties from well log analysis. Some correlations between Q values and rock properties can be seen from these curves. Generally high attenuation corresponds to low velocity, high porosity and high Vp/Vs, and vice versa.

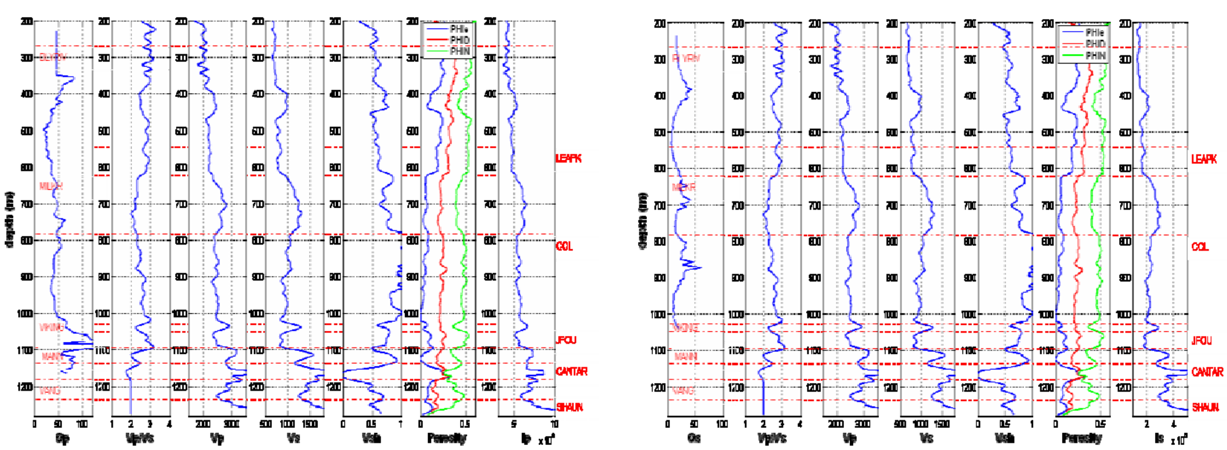

Figure 3: Left – Qp, Vp/Vs, Vp, Vs, shale volume, porosity (effective porosity in blue, density porosity in red and neutron density in green), and P-wave impedance. The right plots are for the S wave (the right frame is shear-wave impedance). Well log data were smoothed using a 15m window.

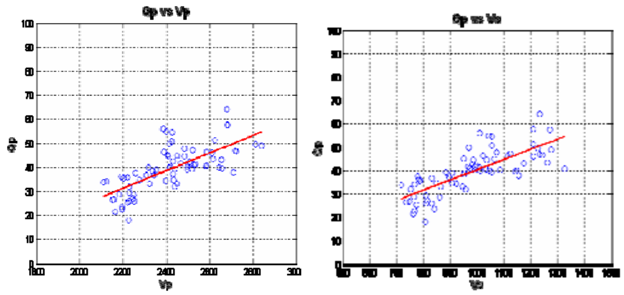

Figure 5: Crossplot between Qp and P velocity (left) and Qp vs. shear velocity (right).

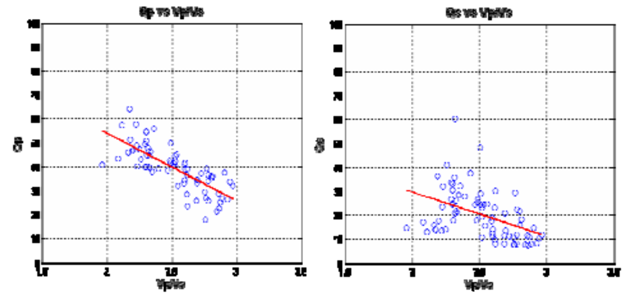

Figure 6: Crossplot between Qp and Vp/Vs (left) and Qs vs. Vp/Vs (right).

From the crossplot between Qp values and P- and shear-velocities (Figure 5), we see that Qp values increase linearly with P and shear velocities. A similar variation is also observed for Qs values and velocities, although the correlation is not as. Similar relationships are found between Q values and Vp/Vs (Figure 6).

From the crossplot between Q value and shale volume (Figure 7), the maximum P-wave attenuation was found in shaly sandstones. The attenuation of the P wave was lower in clean sand and shale. However, it is generally observed that Vp/Vs increases with shale volume. This is not obvious in our current case. The Q vs. Vp/Vs relationship and the Q vs. shale volume relationship seem to be contradictive with this idea. According to the relationship between attenuation and fluid, it is possible that the interaction between mobile water in the pores and clay-bound water generates large attenuation of P wave. To investigate this idea, a crossplot between Q values and clay-bound water were also created (Figure 8). Neutron porosity responds to the total water volume in the rock, which includes clay-bound water and free water. Thus, the clay-bound water volume was estimated from the difference between neutron porosity and effective porosity and normalized by neutron porosity. When the water is 100% bound to clay, the attenuation seems small. When part of the water is free and the other is bound to clay, a larger attenuation seems to be measured. For the shear wave, a similar relation can also be observed, although less distinct. Perhaps, the S-wave does not mobilize the free water as much.

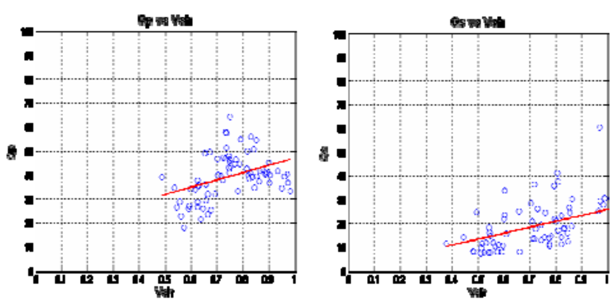

Figure 7: Crossplot between Qp and shale volume (left), and Qs vs. shale volume (right).

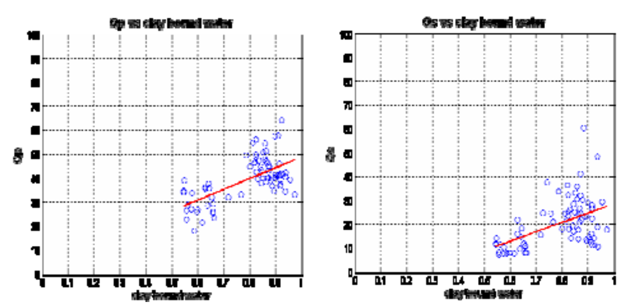

Figure 8: Crossplot between Qp and clay-bound water (left), and Qs vs. clay-bound water (right).

Conclusions

Well 11-25-13-17W3 from Ross Lake was selected for the analysis of relationship between seismic data attenuation and rock properties. Well log analysis indicates the studied depth interval is mainly shale and shaly sandstone. An interesting correlation between the Q values and rock properties was found over a reliable Q estimation interval. Generally, increasing P- and S-velocities accompany a decreasing attenuation of P- and S-waves. Greater pore space in the rock and higher Vp/Vs coincide with low Qp and Qs values. Interestingly, attenuation was found to be decreasing with clay content for clay-rich sandstone. Clean sand in this well shows less attenuation than shaly sandstone. The crossplot between Qp and clay bound water indicates more attenuation of shaly sandstone. Perhaps, this is related to the interaction between mobile water and clay-bound water.

Since attenuation of reservoir and wet sand in this well were not obtained in this study, the effect of different pore fluid on attenuation was not seen. If reliable attenuation can be acquired from surface seismic data, the rule of attenuation variation with different pore fluid is possibly acquired. Thus, we might be able to use the attenuation characteristics of seismic data to differentiate hydrocarbons from water in the reservoir.

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