Seismic Attenuation Analysis for Reservoir Description

Changjun Zhang*
Sensor Geophysical Ltd, Calgary, AB
changjun_zhang@sensorgeo.com

Summary

In reservoir description, seismic attenuation property, Q, is ideally expected at all prospective layers defined by acoustic impedances. The proposed technique is based on the idea that Q values can be calculated from the peak frequency variation of a seismic wavelet. It first estimates peak frequencies at a CMP location, then correlates the peak frequency with sparsely distributed reflectivities, and at last calculates a Q curve from the peak frequencies at the locations of reflectivities. The peak frequency is estimated from the prestack CMP gather using peak frequency variation with offset analysis (PFVO), which is similar to AVO analysis to reduce the stacking effect on the waveform. The estimated Q section has the same layer boundaries defined by reflectivity, so that it is easy to be interpreted for reservoir description.

Introduction

There are mainly three categories of techniques to investigate seismic attenuation properties for hydrocarbon reservoir description. They are iso-frequency analysis (Castagna, et al, 2003), direct Q estimation (Taner and Treitel, 2003; Dvorkin and Mavko, 2006; Parra, 2006) and attenuation tomography (Quan and Harris, 1997; Pratt et al., 2003).

In seismic exploration, seismic data carries information of the interface of rock layers along the propagating wave-path. Generally we deduce layer information from the interface information. Acoustic impedance inversion and AVO inversion are two instances of this strategy to find rock properties. Attenuation property is an intrinsic rock property, i.e., attenuation property must be associated with other layer properties for meaningful interpretation. The layer boundaries defined by reflectivity is also the layer boundaries of attenuation property. The technique presented here uses the peak frequency variation at layer boundaries to estimate the attenuation properties of layers.

Theory

If a medium is absorptive, high frequencies of seismic waves traveling through it will be attenuated. Attenuation properties can be determined from the frequency variation along offset quantitatively.

There are two main issues in Q estimation from the frequency variation with offset: one is how to determine the peak frequency at each time sample; another is how to determine Q from the peak frequency variation. For the first issue, one general and maybe reliable way is to use spectral decomposition, i.e. to do time-frequency analysis on each trace, and from instantaneous amplitude spectrum to determine a peak frequency. For the second issue, I try to fit the peak frequencies of an

event at different times by a formula like the equation introduced in Zhang and Ulrych (2002) depending on the spectrum shape of a seismic wavelet.

Seismic peak frequencies at a zero offset can be estimated from prestack CMP gathers using peak frequency variation along offset (PFVO) analysis. This multichannel analysis makes the estimation algorithm more robust to random noise and the crossing events in a CMP gather. PFVO analysis follows a similar implementation procedure as AVO. It fits the peak frequency along offset with a straight line. PFVO operates on a CMP gather without NMO, because NMO stretch at far offset distorts the spectrum of reflections.

For a Ricker shape spectrum, the peak frequency varies with time (Zhang and Ulrych, 2002)

$$f_p = f_{p_0} \left[\sqrt{\left(\frac{f_m \pi \Delta t}{4Q} \right)^2 + 1} - \frac{f_m \pi \Delta t}{4Q} \right] \tag{1}$$

The square root in Equation 1 can be expanded into the first order of Taylor series to obtain

$$f_p = P_f - G_f \Delta t \tag{2}$$

Where $P_f = f_{p_0}$, $G_f = \dfrac{\pi f_{p_0} f_m}{8Q}$ and Δt is the NMO shift at an offset for an event starting from two-way traveltime t_0 at zero-offset. Δt is a function of t_0, RMS velocity and offset, i.e. $\Delta t = \Delta t(t_0, v_{rms}, offset)$. Equation 2 shows that for a seismic wavelet with a Ricker like amplitude spectrum, its peak frequency decays linearly with arrival time in absorptive media. If peak frequencies at different offsets are picked, based on Equation 2, the peak frequencies along offset can be linearly fitted. The intercept P_f of the straight line is the peak frequency at a zero offset, and the gradient G_f is related to seismic attenuation.

The technique is implemented mainly in six steps as outlined in the following:

1. build a CMP super-gather to suppress the effect of random noise. This is the same as AVO super gather. The CMP gather used for Q estimation needs to be without NMO stretch, so that if normal moveout is applied when forming a CMP super-gather. Reverse NMO needs to be applied afterwards.

2. do time-frequency analysis on each trace using the continuous wavelet transform or the short window Fourier transform.

3. compute instantaneous amplitude envelope using Hilbert transform to get a smooth amplitude spectrum.

4. examine for the highest amplitude among frequencies at interface locations. The peak frequency is the frequency corresponding to the maximum amplitude.

5. fit peak frequencies with offset (the traveltime at an offset) linearly using L_1 norm to get P_f and G_f, and edit P_f by removing the values corresponding to negative or very small G_f's.

6. calculate Q from the effective P_f values.

Theoretically, peak frequencies at two offset locations can fully define the trend of peak frequency variation of a reflection. By using multi-channel information along offset, the algorithm is robust to random noises and the effects of cross events. Forming super-gathers, spectral decomposition and L_1 linear fitting are the main parts of the whole PFVO computation.

Examples

Figure 1(a) shows a synthetic CMP gather. From the CMP gather, P_f and G_f are extracted, and P_f and G_f/P_f which are displayed in Figure 1(b) and Figure 1(c) respectively. The reason to display G_f/P_f instead of G_f is that the value of G_f/P_f alls in a relatively narrow range. G_f/P_f is called relative gradient. The low frequency caused by tuning events at $time = .6s$ is excluded from the calculation because it does not decay with offset. The estimated Q curve is shown in Figure 1(d).
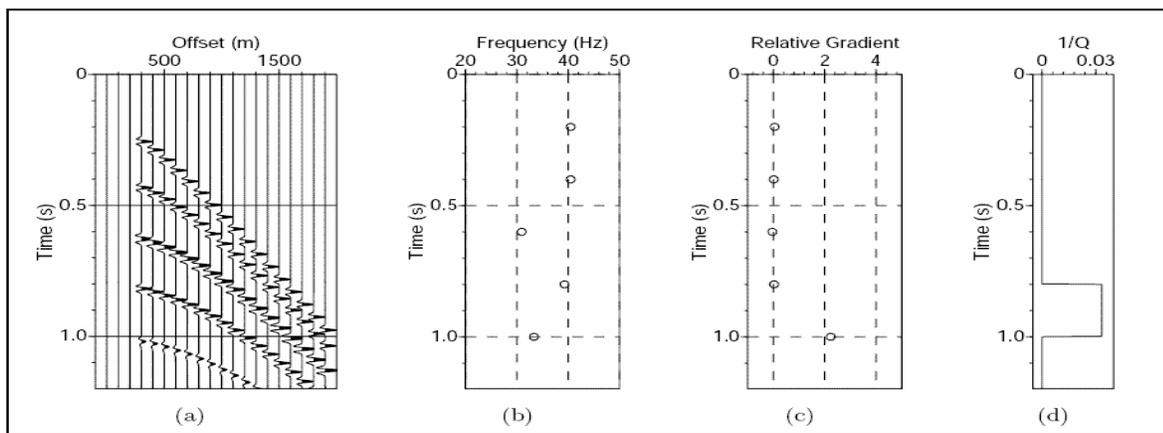
Figure 1: Attenuation estimation from peak frequency variation.

The technique is also tested on an unnamed real 2D dataset. The calculated peak frequencies at each CMP location are shown in Figure 2 and the estimated attenuation section is shown in Figure 3. The attenuation section displays the values of $1/Q$. The inverse of Q is used since it lies in the range of $(0,1)$ and is ideal for the display purpose. The blue background indicates small inverse Q values, which means less absorption than the red areas.

Conclusions

Reflectivity guided seismic attenuation analysis uses post-stack sparse reflectivity (the interfaces defined by acoustic impedance) to help to pick the layer boundaries on prestack CMP gathers. The peak frequencies at interface locations are selected to calculate Q values. The obtained Q section can have the same resolution as other attribute sections. Peak frequency estimation at zero offset is implemented through PFVO analysis. The accuracy of the method depends on the accuracy of time-frequency analysis, the equation used to calculate Q , and also depend on the accuracy of the interface information.

Acknowledgements

The work presented here was carried during Zhang's PHD program at the University of British Columbia under the supervision of Prof. Tad Ulrych and Prof. Michael Bostok.

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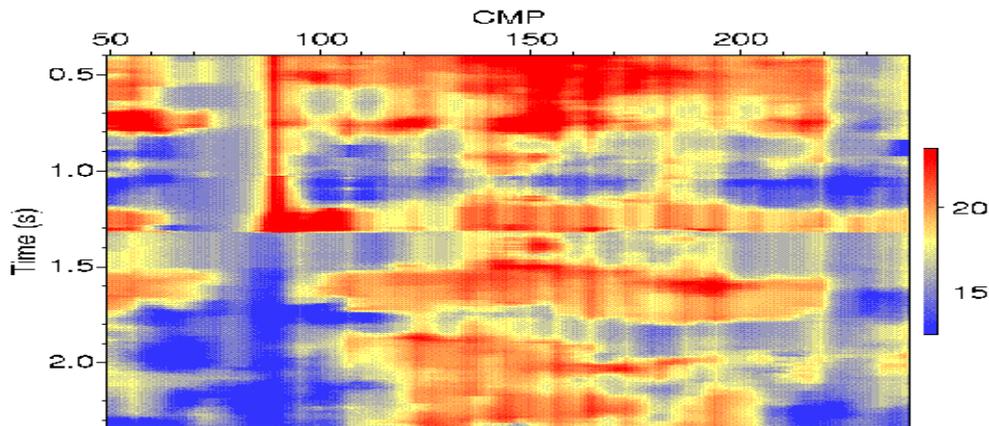
Figure 2: Peak frequency Section.
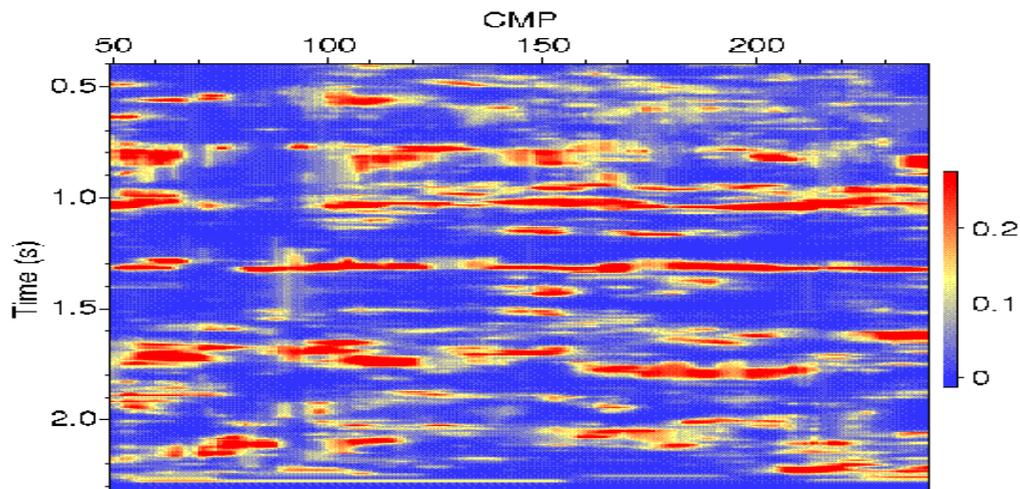
Figure 3: Attenuation section.