Can we use frequency shift due to attenuation for fizz water discrimination?

Carlos Cobos and De-hua Han; University of Houston.*

Summary

In this abstract, we explore the viability of discriminating fizz water (low saturated gas sandstones) from commercial gas reservoirs based on the frequency shift (FS) caused by attenuation. Data from one well were used to build a simple geological model. Forward modeling of CDP gathers and normal incidence sections were carried out and their amplitude spectra were evaluated.

For this study, we analyzed the FS in two different domains:

1. We tested the attenuation effect on the peak amplitude versus offset for the same seismic interface.
2. The peak frequency decay due to the presence of a high attenuating thin layer on normal incidence data.

Introduction

Small amount of gas dissolved in the formation water dramatically drops the P-wave velocity of the rock (Domenico, 1976.) This phenomenon makes it virtually impossible to discriminate between fizz water and commercial gas reservoirs based on P-wave seismic amplitudes. However, fizz water displays a quality factor (Q) several times smaller than commercial gas reservoir (Kumar et. al., 2003.) Consequently, attenuation might be used as a rock property for fluid characterization.

In this study, we explored the effect of high attenuating thin layer on the seismic signature. We generated a simple geological model with a thin layer that simulates a gas and fizz gas reservoirs whose Q=30 and 5 respectively.

Background

When a seismic wave propagates through an attenuating media its amplitude spectrum is affected. Figure 1 shows a schematic representation of how the attenuation filter reduces the amplitude and shifts the peak frequency to lower values. These effects are described in the well known expression:

$$A_1 = A_0 e^{-\frac{\pi f \Delta t}{Q}} \qquad (1)$$

Where A_o and A_1 are the amplitude spectra of the original and attenuated wave respectively, Δt is the travel time and Q the quality factor. From equation (1) it can be seen that the attenuation effect is controlled by travel-time (which depend on layer thickness and velocity) and Q.

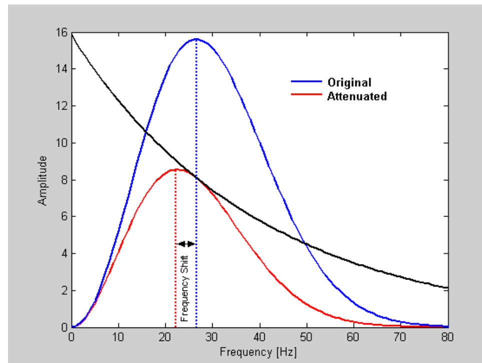

Figure 1: Schematic representation of original and attenuated wave.

A time-frequency attribute called Peak Frequency Trace was defined to help analyze the frequency shift. The peak frequency trace was defined as:

$$PF(t_0) = f_p(t_0) \qquad (2)$$

and,

$$f_p(t_0) = f \left| G(f_p, t_0) = \max[G(f, t_0)] \right. \qquad (3)$$

where *PF* is the peak frequency trace, f_p is the peak frequency and $G(f,t_o)$ is the time-frequency gather at $t=t_o$. Figure 2 shows a time-frequency gather of corresponding peak frequency trace.

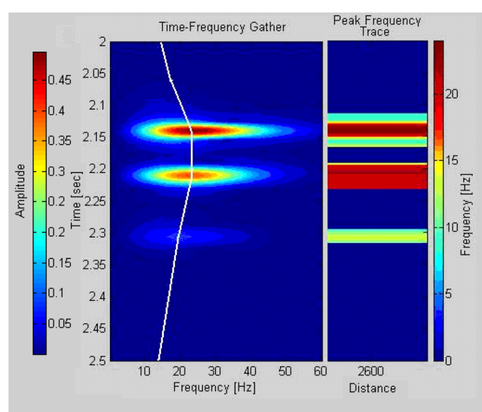

Figure 2: Time-Frequency gather and its corresponding peak frequency trace.

Synthetic model

We tested the feasibility of discriminating between fizz water and commercial gas reservoir in a multilayer model based on well log data. The model used to generate the prestack synthetic seismograms consist of 5 homogeneous and isotropic layers with Vp, Vs, density and Q shown in Table 1. Q values were taken from Kumar, Batzle and Hofmann (2003.) Velocity and density were kept constant for the target layer (layer 3,) and only Q was varied. Layers 1, 2 and 4 were assigned high quality factors close to 100.

Layer	Vp [m/s]	Vs [m/sec]	ρ [Kg/m^3]	Q	Thickness [m]
1	2000	1020	2100	90	1700
2	3100	1500	2430	100	200
3	2400	1600	2150	30/5	25
4	3100	1500	2430	100	200
5	3500	1600	2280	N/A	N/A

Table 1: Model parameters

Peak Frequency vs. Offset Analysis

Ray path differences between near and far offset trace causes a decrease of peak frequency with offset increase, for the same seismic interface. Figure 3 shows a prestack synthetic response for a simple attenuating layer with Q=50 and ΔT=640 ms. The frequency shift between the near and far trace caused by the differential travel-time is easily observed in the time frequency domain. For this model and incident wave with dominant frequency of 35 Hz the frequency shift between near and far offset is approximately 5 Hz.

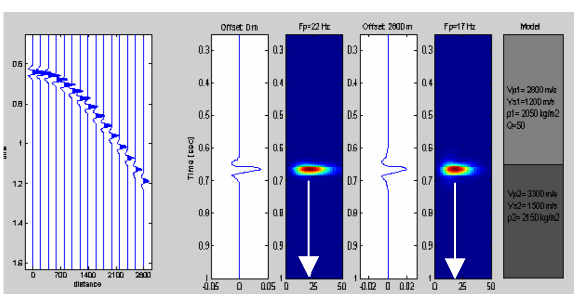

Figure 3: Example of Q estimation based on time-frequency analysis. The frequency shift between the near and far offset is approximately 5 Hz.

Figure 4 shows a comparison of the seismic response for the model with Q_3=30 (Figure 3a) and 5 (Figure 3b). Because the top of the layer 4 is affected by tuning, we choose the top of the layer 5 for the frequency-offset analysis. To avoid any amplitude spectrum distortion due to NMO stretch, we applied NMO static shifting (Figure 5) to the prestack synthetic seismograms.

For the frequency analysis we generated the peak frequency gathers from the prestack shifted seismograms (Figure 6.) Figure 7 shows that the frequency shift is very small for both gathers, 4.0 and 4.32 Hz for Q=30 and 5 respectively. It means that this method cannot distinguish between thin fizz water and commercial gas reservoirs for the proposed model.

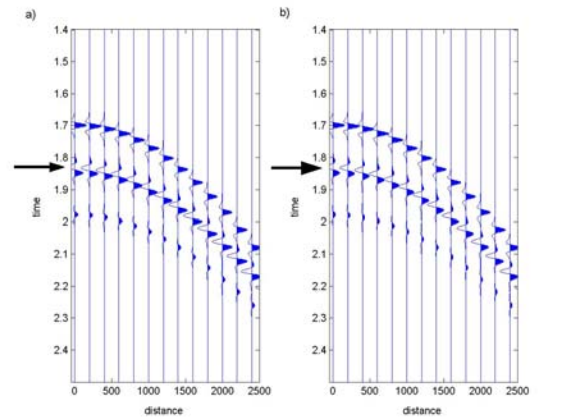

Figure 4: Prestack synthetic seismograms for Q_3=50 (a) and Q_3=10 (b) for the layer 3. The arrows indicate the top of layer 3.

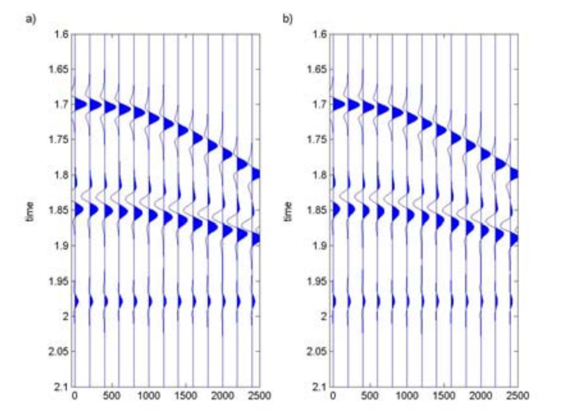

Figure 5: Prestack synthetic seismograms NMO shifted to the top of layer 5.

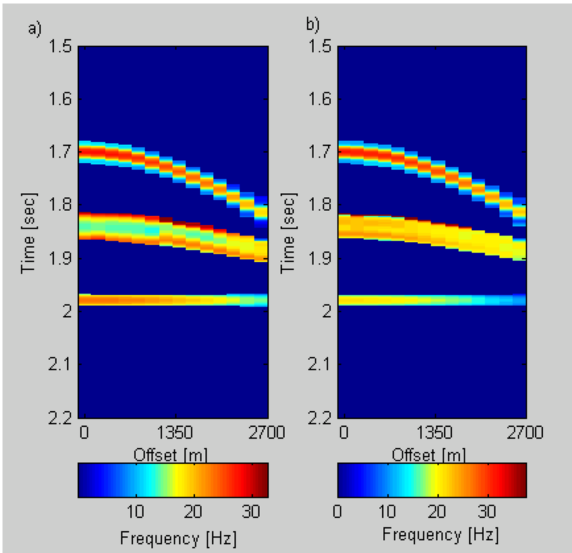

Figure 6: Peak frequency gathers generated from the prestack shifted seismograms, Q=30 (a) and Q=5 (b).

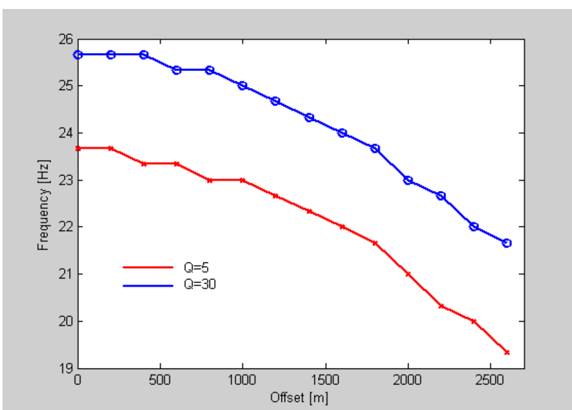

Figure 7: Peak frequency vs. offset at top of layer 5.

We increased the reservoir thickness to test the behavior of the frequency shift. Figure 8 shows the effect of layer thickness on the frequency shift. We can see that the fizz water layer shows frequency shifts higher than gas sand. However, the differences are small and we believe that they are not significant enough to be observed in surface seismic data.

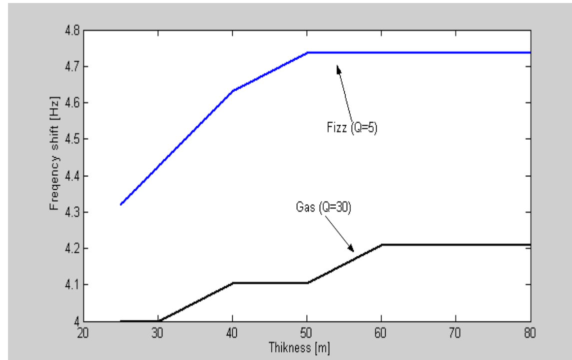

Figure 8: Frequency shift versus thickness.

Normal incidence frequency shift

Finally, we studied the peak frequency translation on normal incident data. We generated a wedge model where the thickness of the layer 3 was varied from 25 (original model) to 100 meters, the peak frequency sections are displayed on Figure 9. The frequency values from top of layer 2 and top of the layer 3 were picked and their deference is displayed on Figure 10. We can see that the frequency shift difference between both saturations start to be significant at thickness higher than 50 meters. Consequently, this method is suitable for fizz gas discrimination of thick reservoirs.

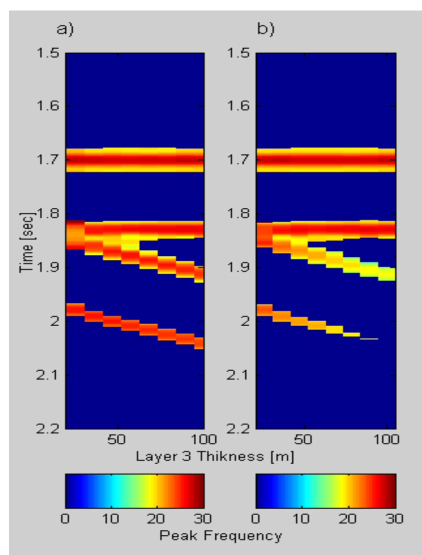

Figure 9: Peak amplitude wedge sections for Q=30 (a) and Q=5 (b).

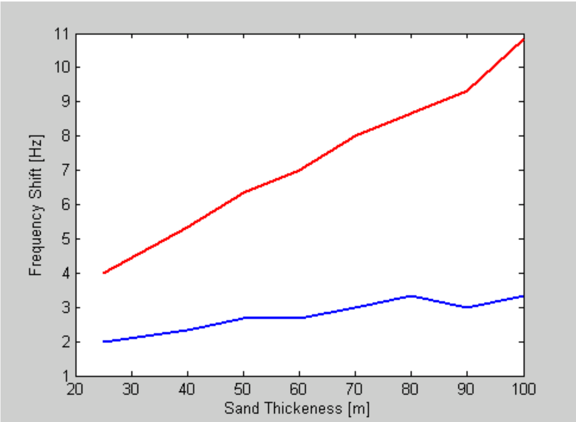

Figure 10: Peak frequency shift vs. offset.

Conclusions

Although, significant thickness and Q difference were used for the synthetic seismograms, it was impossible to discriminate between fizz water and commercial gas reservoirs on peak frequency vs. offset domain. The normal incidence analysis is a suitable method that can be useful for thick reservoirs. Finally, the peak amplitude proved to be a useful attribute to visualize the effect of attenuation on seismic signature.

Acknowledgements

We would like thank Mr. Mritunjay Kumar for his helpful comments. This work was sponsored by the U. H. Rock Physics Lab.

References

Domenico, S. N., 1976, Effect of brine-gas mixture on velocity in an unconsolidated sand reservoir: Geophysics, Soc. of Expl. Geophys., 41, 882-894.

Kumar, G., Batzle, M. and Hofmann, R., 2003, Effect of fluids on attenuation of elastic waves, 73rd Ann. Internat. Mtg.: Soc. of Expl. Geophys., 1592-1595.

Mavko, G., Mukerji, T. and Dvorkin, J.,1998. The Rock Physics Handbook: Tools for Seismic Analysis in Porous Media. New York: Cambridge University Press.

Zang, C. and Ulrych, T. J., 2002 Estimation of quality factor from CMP records. Geophysics, 67, 1542-1547. Tulsa: SEG.