Q Factor Estimation by Numerical and Physical Modeling to Improvement the High Frequency Content of the Seismic...

Conference Paper · June 2015

DOI: 10.3997/2214-4609.201413066

3 authors:

Roseane Missagia
Universidade Estadual do Norte Fluminense
71 PUBLICATIONS **53** CITATIONS

Adalto Oliveira da Silva
Universidade Estácio de Sá
5 PUBLICATIONS **1** CITATION

Marco Ceia
Universidade Estadual do Norte Fluminense
65 PUBLICATIONS **32** CITATIONS

Introduction

The estimate of the Q factor has been studied by various researchers (Guerra & Leaney, 2006; Blias, 2012) due to its importance as a tool for reservoir characterization. It can restore the high frequency range of seismic reflection data aiming to improve the resolution of seismic data (Raji & Rietbrock, 2011), identifying important attributes and interpreting small-scale seismic features, besides work as a direct indicator of hydrocarbons. Mu and Cao (2003) used the seismic physical modeling and Biot theory to demonstrate that through of the absorption coefficient is possible to detect regions of gas and oil. Yin et al (2010) performed experiments using ultrasonic P waves on a physical model composed by solid Plexiglas material filled with spherical inclusions of silicone rubber and different sizes and obtained Q factor by spectral ratio method for determining the P wave attenuation in a fracture medium. The calibration of surface data by seismic well has an important advantage, since it allows including the inelastic absorption effect. Tonn (1991) compared several methods to estimate the Q factor through VSP (Vertical Seismic Profile) data and argues that their performance is directly related to the preservation of amplitude and noise level of the seismic data.

This paper proposes an inverse Q_{ef} filter (Q effective) aimed at increasing the amplitude and restoring the frequency of the surface seismic signal, using for this the interface Q_{ef} factor. This proposal includes replacing the constant Q factor for a Q_{ef} factor that represents accurately the amplitude attenuation associated to effects of the geometry and type of saturation in each layer of a reservoir model, making it possible to test the effectiveness of the Q_{ef} inverse filter.

Theory and Method

The seismic pulse loses energy during the propagation through the Earth interior, due to the effects of absorption, scattering and spherical divergence. The estimate of the absorption coefficient using seismic data reveals useful information, such as: lithology, degree of saturation of the rock and presence of fluids in the pores, porosity, permeability (Carcione & Picotti, 2006), indicating porosity and saturation heterogeneity as the most severe mechanism of decaying amplitude. That justifies the importance of incorporating the attenuation effects in the evaluation of reflection coefficients to improve the resolution of images and minimize the impact on the amplitude variation along the reflector. The Q factor is a parameter used to characterize the attenuation in an inelastic medium, which is defined as the ratio between the energy of the seismic signal and the energy lost in each cycle. The attenuation may be approximated linearly to frequency, and then the attenuated signal may be considered as a linear combination of the attenuated components. Thence, the higher frequency components of the signal suffer more the attenuation effects than the lower frequency components, resulting in loss of resolution of the seismograms. The sensitivity of the attenuation to changing signal frequency, phase and amplitude makes the VSP data more accurate to estimate the Q factor.

The spectral ratio method is based on the estimation of the amplitude spectra of two reference waves recorded at different depths and frequency band of interest selected on the interval of linearity between the amplitude and frequency spectrums, thus the logarithm of the ratio spectral between the amplitudes observed and Q factor can be calculated. Considering that the decay time $\tau = t - t_0$ is known, the Q factor can be written as:

$$\frac{1}{Q} = -\frac{\ln(A/A_0)}{\pi f (t - t_0)}, \tag{1}$$

The use of the inverse Q filter for improving the seismic resolution requires reliable estimative of the Q factor of the layers at any point of a interface. In inverse Q filtering the goal is to eliminate the non-stationary seismic signal characteristics generated by the attenuation effect of seismic amplitude during wave propagation through the inelastic medium, such as: reduced amplitude, changed waveform due to the absorption of high frequency content, and phase delay. Da Silva (2012) deduced an inverse Q filter (Eq. 5) to recover the higher frequency components of the seismic signal after quantifying Q_{ef} (Eq. 2), the attenuated amplitude spectrum (Eq. 3), and applying the stability function of the inverse Q Filter for a cutoff frequency (4).

$$Q_{ef}(x) = \frac{(y_1 - y_0)x}{(x_1 - x_0)} + \frac{(y_0 x_1 - y_1 x_0)}{(x_1 - x_0)} \tag{2}$$

$$A(\tau, f) = A_0(t_0, f)e^{-(\pi f \tau)\frac{1}{Q^{ef}}} \tag{3}$$

$$B_c(\tau, f) = A_c(\tau, f)\, A(\tau, f). \tag{4}$$

$$a(t) = \frac{1}{\pi}\int B_e(\tau, f)\, e^{-i f t} df \tag{5}$$

Physical and Numerical Modeling

To implement and validate the proposed methodology, two seismic datasets were carried out by numerical and ultrasonic simulations of the P wave conducted with the model immersed in a water tank. Figure 1, (left) represents a scaled model wedge reservoir composed of a Plexiglas block with a wedge cavity filled by oil, and (right) a numerical version of model, both show a value to P wave velocity on the solid part of the block - 2777 m/s and oil (fluid content) -1690 m/s. The 2D constant offset (CO) experimental data acquisition consisted of 1 line of 300 mm along the wedge reservoir, spaced of 28 mm between transducers. The 2D VSP zero offset numerical survey was implemented according the following parameters: source - located on the surface; receptors - located at 200, 250, 1110, 1150, 1490, 1510 m depth in the well. More details about experimental set-up, data acquisition and data processing can be found in Da Silva (2012), Da Silva et al., (2013).

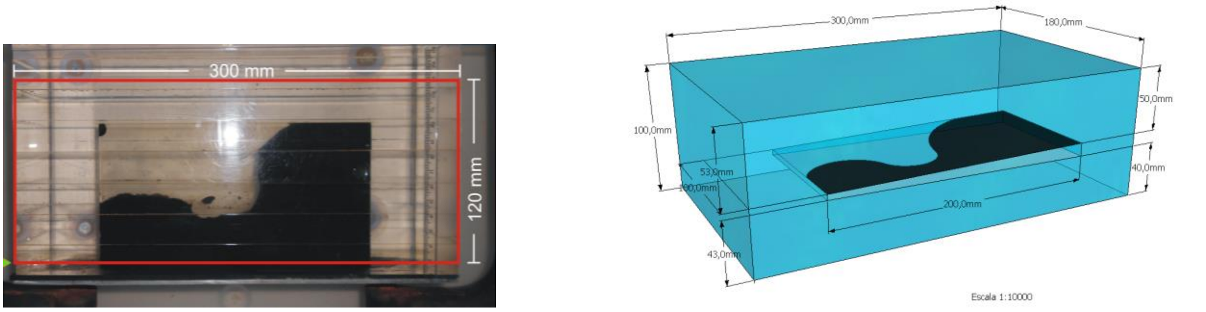

Figure 1. Wedge Reservoir Model illustration – (left) Physical, (right) Numerical.

Results

The results from seismic numerical and physical modeling reflect the proposed methodology, which the Q and Q_{ef} factors that enable the proposition of the inverse Q_{ef} filter are defined by the VSP numerical data e CO ultrasonic data, and in the next step are applied to surface seismic data to restore the frequency content of the seismic signal and amplitude attenuation. Figures 2, 3 and 5 show the results of inverse Q_{ef} filtering obtained from Q_{ef} factor estimated for oil saturated model that allow visualizing the impact of fluid saturation on the waveform and amplitude attenuation seismic. Despite this it and of strong noises disseminate through of seismogram (Figure 2), probably caused by the tuning effects from thin layer and transducers, it was possible to find the linearity required between the spectral ratios of amplitudes over the range of frequencies, contributing to the accuracy of the Q_{ef} factor estimated for each trace for top and bottom inclined interfaces. The result of applying this filter to the seismograms shown that the effect of the stabilization function promoted further improvement of the amplitudes at the base of the reservoir. In Figures 4-6, the plots for frequency spectrum vs. time obtained by Gabor transform and spectrum amplitude versus time for base interface displays the restoration of frequency content around the dominant frequency in the filtered data.

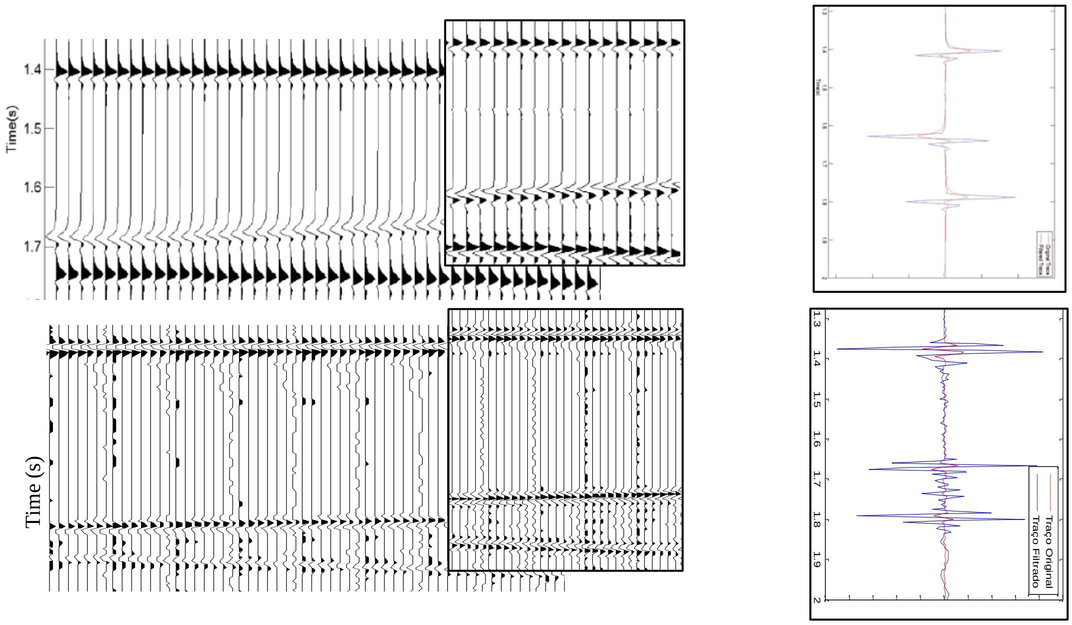

Figure 2 – Traces before and after applying inverse Q filtering – (Top) Numerical and Physical Modeling (bottom)

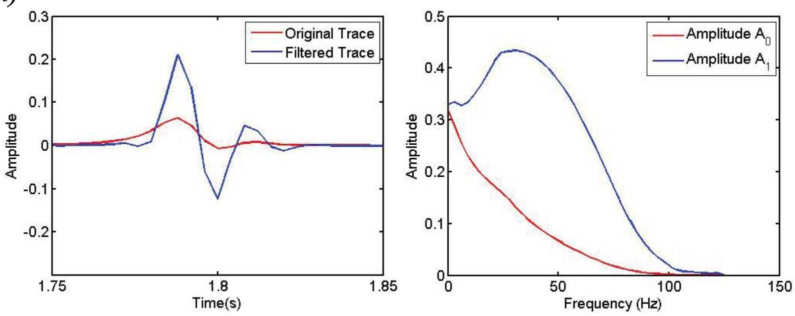

Figure 3 – Inverse Q_{ef} Filtering – Individual analysis of the base of reservoir (Numerical Modeling)

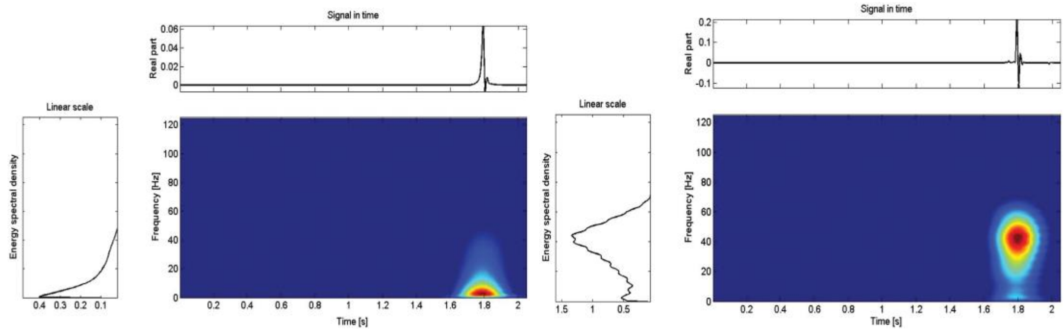

Figure 4 – Spectrogram – Base of the reservoir (Numerical Modeling): original (left) and filtered (right).

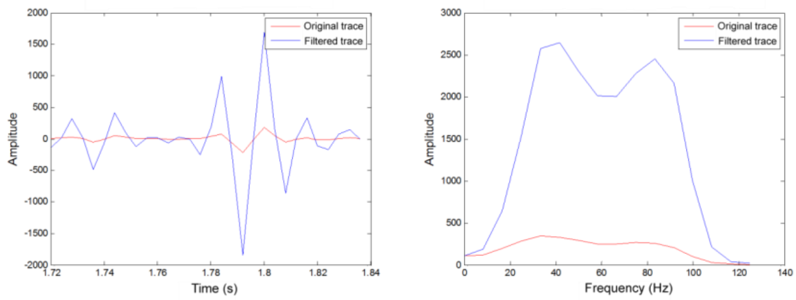

Figure 5 – Inverse Q_{ef} Filtering – Individual analysis of base of reservoir (Physical Modeling)

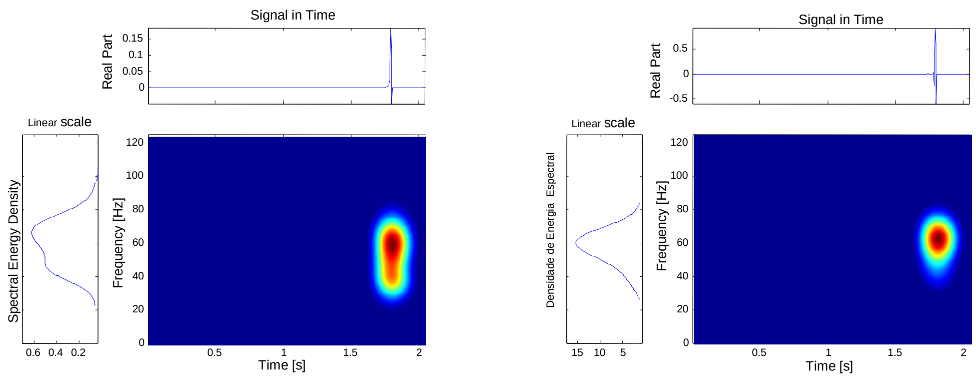

Figure 6 – Spectrogram – Base of reservoir (Physical Modeling): original (left) and filtered (right).

Conclusions

Currently, several studies are using the seismic modeling to analyze the sensitivity of the seismic response in different geological settings. This work purposed a technique to restore the frequency content of the seismic signal, achieving satisfactory results while simulated subsurface structures, parameters and saturation mode. The application of this procedure in both modelling allowed an analysis of the wedge structures, representatives of top and base structural features present in oil reservoirs, and addressed an important contribution of VSP data for calculation of the Q factor of the layer, in addition to demonstrate the effectiveness of applying the spectral ratio method. The inverse Q_{ef} filtering proposed contributed to a significant recovery of the frequency content of signal. The Wang (2002) function provided high stability of the inverse Q_{ef} filtering. The methodology outlined here may be effective to enhance the theoretical knowledge and increase the reliability of procedures to estimate seismic attributes as attenuation and Q factor, contributing to real data analysis from well log and seismic data.

References

Blias E. 2012. Accurate Interval Q-Factor Estimation from VSP Data. Geophysics, Vol. 77, No. 3. May-June 2012; P. WA 149-WA 156.

Carcione J & Picotti S. 2006. P-Wave Seismic Attenuation by Slow-Wave Diffusion: Effects of Inhomogeneous Rock Properties. Geophysics, 71(3): 1–8.

Da Silva, A.O. Missagia R.M. & De Ceia, M.A.R. 2013. Q Factor Estimation from Surface and VSP Data: A Numerical Modeling Study. Brazilian Journal of Geophysics (RBGF), 31(4): 683-697.

Da Silva, A.O., 2012. Melhoramento da frequência de dados sísmicos através das modelagens numérica e experimental. PhD Thesis. LENEP/UENF University. Brazil, *(in Portuguese.)*

Guerra R & Leaney S. 2006. Q(z) Model Building Using Walkaway VSP Data. Geophysics, 71(5): V127–V132.

Mu Y. G. and Cao S., 2004. Seismic physical modeling and sandstone reservoir detection using absorption coefficients of seismic reflections. Journal Petroleum Science and Engineering 41(1), Elsivier, pp. http://dx.doi.org/10.1016/S0920-4105(03)00150-5159-167.

Raji Wo & Rietbrocka A. 2011. Enhanced Seismic Q compensation. SEG Annual Meeting. San Antonio.

Tonn R. 1991. Determination of the seismic quality factor Q data: a comparison of different computational methods. Geophysical Prospecting, 39: 1–27.

Wang Y. 2002. A stable and efficient approach of inverse Q filtering. Geophysics, 67: 657–663.

Yin Z., Wei J., Di B. Li X.2010. Efects of structure scale on P wave attenuation: a Physical Modelling Study. SEG Denver 2010.Annual meeting.