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Q Inversion and Comparison of Influential Factors among Three Methods: CFS, SR, and AA

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Abstract. The goals of this study were to examine factors influencing Q inversion and to provide references for practical application. Three different methods for inverting Q values with VSP data were explored, including centroid frequency shift (CFS), spectral ratio (SR), and amplitude attenuation (AA). Comparison between the CFS and the other two methods was conducted on frequency band widths and low attenuation, wavefield components, interface interference, and thin layers. Results from several sets of VSP modeling data indicated that the CFS method is more stable and accurate for dealing with thin and high Q layers. Frequency band width, especially the presence of high frequencies, influences the inversion effect of all three methods. The wider the band, the better the results. Q inversion from downgoing wavefield was very similar to that of the upgoing wavefield. The CFS method had fewer outliers or skip values from the full wavefield than the other two methods. Moreover, the applications to Q inversion for the set of field VSP data demonstrated that the Q curves from the CFS method coincided with the geological interpretations better than the Q curves of the other methods. Meanwhile, inverse Q filtering shifted the frequency component from 25 Hz to 35 Hz. The results demonstrated that the Q curve is more sensitive to geological horizons than velocity.

AMS subject classifications: 74J25, 86A15, 86A22, 86A60

Key words: Q inversion, centroid frequency shift, amplitude attenuation, spectral ratio, zero-offset VSP data.

1 Introduction

Inherent energy attenuation, resulting in high frequency absorption and waveform alteration, reflects the non-elastic property of seismic waves propagating through a medium

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[1], and is one of the key factors to seismic prospecting resolution. Experiments have proven that attenuation is sensitive to the porosity, permeability, and fluid properties of the reservoir stratum [2]. Based on the attenuation of different wave types, the quality factor (Q) can be used for the high-precision interpretation of multi-wave and multi-component data. As a filtering factor, inverse Q filtering can recover the energy loss caused by formation attenuation and enhance the energy of seismic data [3].

A large variety of algorithms have been created and a great amount of research has been done on the process and characteristics of energy attenuation. Changes in amplitude, frequency, phase, and so forth can be used to calculate the inverse Q value in different domains. Rainer [4] contrasted ten methods based on vertical seismic profile (VSP) data. Tommy [3] carried out a comparative study of up to eight attenuation patterns. Specifically, measurements were conducted at the very beginning of the time domain. Since the most noteworthy manifestation of seismic attenuation is the change of amplitude, the first method taken into consideration was the amplitude attenuation method (AA). Ward and Yong [5], Brzostowski and McMechan [6], and Leggett et al. [7] utilized this traditional method in the modification of seismic wave amplitude from observational data when studying attenuation imaging. However, many factors can interfere with the amplitude of seismic waves, including geometric diffusion, scattering, focal types and detector response. It is believed that the estimated values are not reliable.

The spectrum ratio (SR) method is the most commonly used of the techniques involving the frequency domain that are based on changes of the amplitude spectrum. Many seismologists [8–10] have adopted or improved this approach. Dasgupta and Clark [11] used ground seismic data to calculate the Q value. They hypothesized that the SR method would perform very well when it was applied after normal moveout (NMO), and they also found that a linear relationship between frequency and the amount of attenuation could not be established. Chen et al. [12] took advantage of the SR method in the time-frequency domain to prospect a tight gas sandstone reservoir. Zhang et al. [13] calculated spectral ratios of different periods based on the adaptive wavelet technique, with inverted Q values used for inverse Q filtering. This method, however, depends on a number of artificial factors, such as the length and shape of the time window, the slope of the start-stop frequency, and so forth. The SR method is not considered to be very stable and has a high demand for original seismic data [4, 14, 15].

The centroid frequency shift (CFS) method was proposed by Quan and Harris in 1997 [16]. It is generally regarded to be the realization form of the rise time principle in the frequency domain. Since the centroid frequency of a waveform (or pulse broadening) is not affected by far wavefield geometry diffusion or the transmission/reflection effect, more reliable results can be obtained from centroid frequency shift. Yan et al. [17] used this method on the joint tomography of Q values and velocities in a cross-well; Wang et al. [18] expanded upon this for use one of the main methods for cross-well seismic attenuation imaging. Zhu et al. [19] and Wu [20, 21] applied and analyzed influential factors using zero-offset VSP models. Meanwhile, Zhu et al. [19] noted that, due to the sensitivity of absorption characteristics to frequency, this method would yield high resolution for