A practical data-driven method for applying amplitude inverse Q that preserves amplitude variations with offset

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Summary

For many years inverse Q has been applied to poststack data as a means of enhancing the temporal resolution of a dataset thus improving its interpretability. Typically, the problem encountered is that the high-frequency noise tends to be boosted too much. The amount of gain (boosting) applied can be limited to keep the signal-to-noise ratio within acceptable limits for a given frequency range. Many applications of inverse Q have parameters such a reference frequency for gain control and gain limit to restrict the boosting done at the higher frequencies. More recently, inverse Q has been applied to gathers after prestack-time migration and these gathers have been used to produce full-fold and angle stacks with the aim of doing amplitude versus offset (or angle) work on these datasets. By means of a simple synthetic event it is shown here that when a gain limit is used within the inverse Q then the amplitude variation with offset is distorted. The Q application method described here prevents such distortion.

Introduction

Q, or the quality factor, is a measure of the loss of energy as the seismic wave moves through the absorptive medium of the earth. A seismic wave travelling through the earth experiences two effects, absorption and dispersion. Both of these effects are frequency dependent: higher frequencies travel slightly faster than lower frequencies, whilst they lose their strength more rapidly. Together, the attenuation and dispersion of the seismic wave travelling through a subsurface medium can be expressed in terms of a dimensionless parameter known as Q, the quality factor of the medium. Therefore, a larger Q corresponds to less absorption and less dispersion. Effective Q is an inverse sum of intrinsic Q and apparent Q. Intrinsic absorption may be described by the conversion of seismic energy into heat, mainly due to a wave-induced fluid-flow mechanism, and partly due to the friction at the grain corners. Apparent Q is related to frequency-dependent scattering. The Q effect modifies both the amplitude and the phase of the wavelet, but it is the amplitude effects with which we will concern ourselves. Amplitude inverse Q is an attempt to recover the time and frequency varying amplitude loss.

Theory and/or Method

For many years inverse Q has been applied to poststack data as a means of enhancing the temporal resolution of a dataset thus improving its interpretability. Typically, the problem encountered is that the high-frequency noise tends to be boosted too much. The amount of gain (boosting) applied can be limited to keep the signal-to-noise ratio within acceptable limits for a given frequency range. Many applications of inverse Q have parameters such a reference frequency for gain control and gain limit to restrict the boosting done at the higher frequencies (see Figure 1).

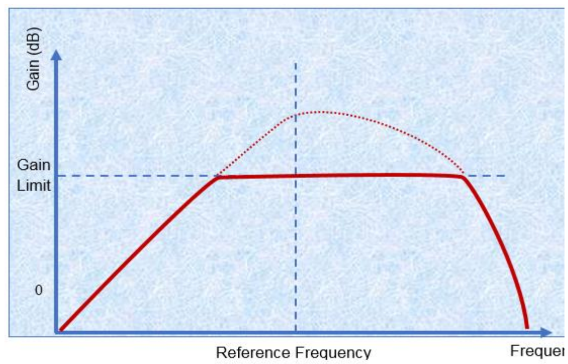

Figure 1 Either or both ‘Gain Limit’ and ‘Reference Frequency’ parameters can be used to define a desired gain spectrum.

More recently, inverse Q has been applied to gathers after prestack-time migration and these gathers have been used to produce full-fold and angle stacks with the aim of doing amplitude versus offset (or angle) work on these datasets. Again, the aim of the inverse Q is to improve the temporal resolution of the data, but often not enough attention has been paid to the preservation of the relative amplitude properties. The success of the inverse Q filtering is usually judged on the resolution of the data, the signal-to-noise and also the flatness of the amplitude spectrum within bandwidth of the data. Some synthetic traces demonstrate what we often see.

Figure 2a shows a synthetic event which has been produced with a single high-cut filter, NMO applied, amplitude-only forward Q applied. (Our Q software runs on NMO corrected data). A Q value of 100 was used. Frequency spectra have then been taken in five different offset windows across the gather. This represents the signal in a dataset before the application of inverse Q.

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Figure 2b shows the effect of applying inverse Q to this data without any gain or frequency limiting. We will get back to a set of spectra that just show the effect of the NMO stretch with offset.

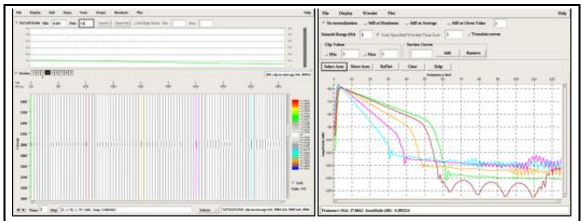

Figure 2a Synthetic event with forward Q.

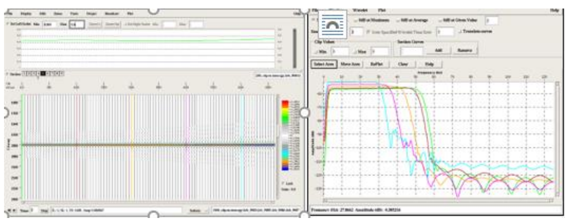

Figure 2b Same synthetic event with inverse Q applied (unlimited gain).

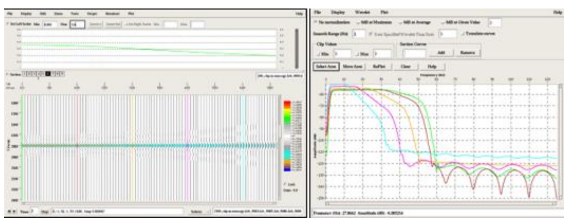

Figure 2c Same synthetic event with inverse Q (gain limited to a maximum of 24 dB).

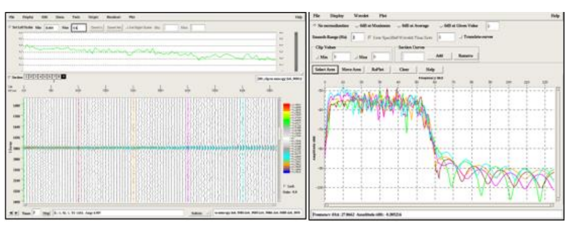

Figure 2d Synthetic event with added noise showing flat amplitude spectra.

Figure 2c shows the effect of applying inverse Q to this data with a gain limit of 20 dB and a reference frequency of 40 Hz. Here we plainly see that the higher frequencies have been progressively attenuated as we move to higher offsets. Clearly the amplitudes have not been preserved across offsets.

Figure 2d shows a synthetic with additive white noise prior to the inverse Q which more realistically represents what we see on data. The spectra look consistent with each other and flat within the bandwidth of the data, but we know that Figure 2c shows the effect of inverse Q on the signal. This clearly shows that a flat spectrum is not a sufficient check for the maintenance of relative amplitude across a gather following inverse Q.

Our approach is to estimate a set of time and space varying Q values by comparing the amplitude spectra of pairs of consecutive windows on a stack data volume (Hardwick, Woods, Masoomzadeh, Clarke 2017). These Q values may be smoothed within layers if necessary. A second volume is produced that contains time and space variant frequency limits where the frequency is the peak frequency for that window of data. This frequency field can also be smoothed in a similar manner to the Q field. The programme doing the application of amplitude inverse Q on CMP gathers then uses both the Q field and the frequency field. The inverse Q is applied up to the frequency value without any limit set to the gain value. The data with inverse Q applied is high-cut filtered at this frequency limit. The data after inverse Q can then be regarded as amplitude preserving up to that time and space-varying frequency limit. The angle stacks and full-fold stacks produced from the gathers with Q applied can then be more reliably used for AVO or AVA analysis.

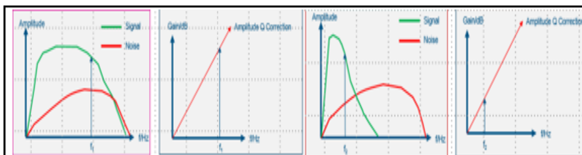

Figure 3: A shallow and deep time-window example sketch of a signal-to-noise plot and the resulting frequency limit.

It should be noted that the stacks and gathers produced by this inverse Q method will be band-limited dependent on the value of the signal-to-noise ratio at any given time and as such they may not have the resolution required for all purposes. Figure 3 shows a cartoon that demonstrates this effect. The improvement in resolution achieved by the application of inverse Q can be increased by better noise attenuation. If the aim is to have as high a resolution processed stack as possible then the best option will be to apply the inverse Q to the stacked data without the use of the band-limiting filter.

Example gather and stack data can be seen in figure 4 showing the application of inverse Q.

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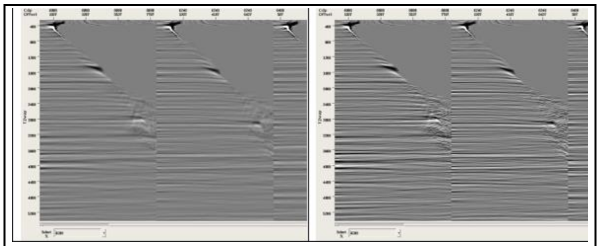

Figure 4a CMP gather data before (left) and after (right) inverse Q

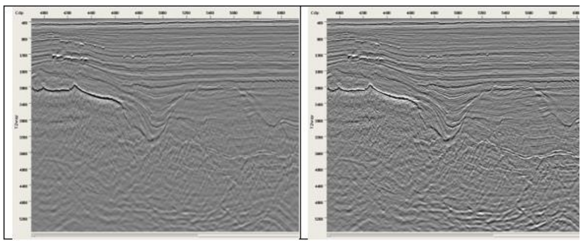

Figure 4b Stack data before (left) and after (right) inverse Q

The frequency-limit volume also provides a rapid method of checking the stack and gather volume quality since it can be overlaid on the seismic.

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Conclusions

We have outlined the limitations of applying prestack inverse amplitude Q and the effects it can have on the AVO of events. This has been demonstrated on synthetic data. Rather than by limiting the frequency-dependent gain of the inverse Q but by limiting the maximum usable frequency of the data any amplitude variations with offset can be preserved.

Acknowledgments (Optional)

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Hardwick, A. J., D. Woods, H. Masoomzadeh, and R. Clark, 2017, Improved Q estimation and application in the time domain with broadband seismic data from the North Sea: 79th Annual International Conference and Exhibition, EAGE, Extended Abstracts, WE A2 09, doi: 10.3997/2214-4609.201701150.