Research and Application of Viscoelastic Q Pre-stack Depth Migration Technology in Deep Thin Reservoir Imaging

Introduction

During the propagation of seismic waves, because the underground medium is not completely elastic, viscous absorption attenuation occurs. The amplitude attenuation of different frequency components is different. The higher the frequency, the more severe the absorption, and the propagation of different frequency components at different seismic speeds directly leads to the dispersion of seismic wavelets. The deeper the reflection layer, the more serious the dispersion. Therefore, the dominant frequency and frequency band of conventional deep seismic data in China's Songliao Basin are relatively narrow, and it is difficult to meet the demand for fine exploration of thin reservoirs.

At present, the technology with near-surface Q compensation as the core has achieved good results in medium and shallow near-surface absorption compensation, but the effect of compensation for deep or ultra-deep layers is not obvious. When the velocity has lateral changes or the formation is non-horizontal, Pre-stack time migration cannot solve the problem of the misalignment of the imaging point and the underground diffraction point. The imaging accuracy and resolution of deep thin reservoirs is low. Conventional pre-stack depth migration treats the earth medium as a completely elastic medium and does not consider the influence of absorption. Therefore, the deep imaging quality is poor and the resolution is low.

Based on the acquisition and processing of broadband seismic data, this paper uses viscoelastic Q pre-stack depth migration to effectively compensate the attenuation of high-frequency seismic waves caused by the viscosity of the earth's medium and thin-layer scattering. At the same time, amplitude compensation and phase correction are performed to restore the attenuation. The attenuated high frequency components are recovered, and high resolution migration imaging results are obtained. Practical data application shows that this method effectively broadens the seismic data frequency band, obtains migration imaging results with higher resolution than conventional pre-stack depth migration, and provides high-quality results for fine structure interpretation and reservoir prediction of deep thin reservoirs. The results effectively supported the well site deployment and reserve submission in the area.

Method and/or Theory

Viscoelastic Q pre-stack depth migration

Viscoelastic Q pre-stack depth migration is an improvement of the conventional pre-stack depth migration method. If the seismic trace is regarded as a shot seismic record of the receiving trace, in the viscoelastic absorbing medium, the upward wave field $P^U(x, y, \omega, z)$ of migration can be expressed as

$$P^U(x, y, \omega, z) = F(\omega) \frac{\omega}{2\pi} \exp\left(-j \frac{\omega}{2} \frac{r_g}{r_g^2} \right) \exp\left[j \omega \tau_g \left[ 1 - \frac{1}{\pi Q_g} \ln\left(\frac{\omega}{\omega_0} \right) \right] \right) \exp\left[\frac{-\omega \tau_g}{2Q_g} \right)]$$  \hspace{1cm} (1)

Where: $x, y, z$ are the three-dimensional space coordinates of the underground imaging point, $F(\omega)$ is the seismic data in the frequency domain, $\tau_g$ is the travel time of the imaging point along the ray path to the detection point, $r_g$ is the linear distance from the imaging point to the detection point, $\omega$ is the frequency of the seismic data, $\omega_0$ is the seismic reference frequency, $j$ is the imaginary unit, the subscript $g$ represents the location of the detection point, and $Q_g$ is the equivalent value related to the ray path at the detection point, the formula is as follows

$$\frac{1}{Q_g} = \frac{1}{r_g} \sum_{i=1}^{n} \Delta t_i Q_i$$  \hspace{1cm} (2)
Where: $\Delta t_i$ is the one-way travel time used by the $i$ layer of the ray propagation path, $Q_i$ is the layer $Q$ value of the $i$ layer of the ray propagation path, and $n$ is the total number of layers of the ray propagation path.

The formula for the downward wave field $P^D(x, y, \omega, z)$ of the shot migration from the shot domain is

$$P^D(x, y, \omega, z) = S(\omega) \frac{\omega}{2\pi} \exp\left(\frac{\omega}{2} \frac{\tau_s r_s}{r_s^3}\right) \exp\left(-j\omega \tau_t \left[1 - \frac{1}{\pi Q_s} \ln\left(\frac{\omega}{\omega_0}\right)\right]\exp\left[\frac{\omega}{2} \frac{\tau_s r_s}{Q_s r_s^3}\right]\right)$$

(3)

Where: $S(\omega)$ is the Fourier transform of the source signal, $\tau_s$ is the travel time of the shot point along the ray path to the imaging point, $r_s$ is the linear distance from the shot point to the imaging point, the subscript $s$ represents the shot point position, and $Q_s$ is the equivalent $Q$ value related to the ray path at the shot point. The formula is as follows

$$\frac{1}{Q_s} = \frac{1}{\tau_s} \sum_{i=1}^{n} \Delta t_i$$

(4)

Assuming that the deconvolution processing in the conventional processing eliminates the influence of source wavelet, the imaging result of single trace data can be obtained by applying the deconvolution imaging condition of amplitude preserving

$$I(x, y, z) = \frac{\tau_s r_s^3}{\tau_s r_g^3} \int F_u(\omega) \omega \exp\left(-j\frac{\pi}{2}\right) \exp\left[j\omega(\tau_s + \tau_g)\right] \left(\frac{\tau_s + \tau_g}{Q_s + Q_g}\right) \ln\left(\frac{\omega}{\omega_0}\right) \exp\left[\frac{\omega}{2} \frac{\tau_s + \tau_g}{Q_s + Q_g}\right] d\omega$$

(5)

Where, $\tau_g r_s^3 / \tau_g r_g^3$ is the imaging weighting coefficient, which is used to compensate the spherical diffusion compensation effect of seismic wave. The imaging results of all seismic traces are sorted and accumulated according to shot-receiver distance, that is, the migration imaging results of 3D imaging space are obtained.

**An improved method for obtaining high precision layer Q**

In view of the difficulty in estimating the Q value of the middle and deep layers, and its accuracy directly affects the imaging effect of viscoelastic Q pre-stack depth migration, this paper develops an improved high-precision layer Q method based on actual seismic data and VSP data, which is mainly divided into the following two steps:

(I) Q-value scanning and interactive picking based on pre-stack seismic data

This method is implemented on pre-stack migration CRP gathers. By comparing the local sections with different Q values and the frequency spectrum in the corresponding time window, especially the protection of low frequency and the expansion of high frequency in multi-time windows, the reasonableness of each time window and each spatial location is determined Q value. It follows ray theory and wave field extension theory to realize space variant absorption compensation processing. It is convenient for geological target block and high-resolution demand. It is stable, efficient and easy to realize.

(II) Q value calculation based on VSP data

At the same point, the Q value calculated by the VSP is used as a constraint, and the Q value based on the pre-stack seismic data driven scan is calibrated. Based on the difference between them, the ratio $M$ between the two is established, that is:

$$M = \frac{Q_{exp}}{Q_{scan}}$$

(6)

which $Q_{exp}$ is the is the $Q$ value calculated by VSP data, $Q_{scan}$ is the is the $Q$ value obtained by scanning pre-stack CRP gathers.
According to the above process, a more accurate layer Q value can be obtained, which provides a basis for viscoelastic Q pre-stack depth migration high-resolution imaging.

Examples (Optional)

The surface of the research area is mainly farmland and cultivated land, as shown in the figure; the terrain is relatively flat, and it is generally raised from west to east, with an altitude of 148-167m, as shown in Figure 1.

![Figure 1](image1.jpg)

*Figure 1 (a)* shows the elevation map of this area; *b* shows the satellite photo of this area.

Figure 2 is the conventional pre-stack depth migration and viscoelastic Q pre-stack depth migration profile comparison diagram. It can be seen that through viscoelastic Q pre-stack depth migration, the resolution of seismic profile has been significantly improved, the bandwidth has been widened, the description of small faults and sections is clearer, and the imaging of thin reservoirs is clearer.

![Figure 2](image2.jpg)

*Figure 2* (a) is the pre-stack depth migration profile of conventional, and (b) is the viscoelastic Q pre-stack depth migration profile.

Figure 3 is the spectrum comparison chart of conventional pre-stack depth migration and viscoelastic Q pre-stack depth migration profile. It can be seen that the main frequency of viscoelastic Q pre-stack...
depth migration is significantly improved, from 28 Hz to 40 Hz, and the high frequency is increased by about 17 Hz, which provides high resolution seismic data for fine interpretation and reservoir prediction of deep thin reservoirs.

Figure 3 (a) is the spectrum of conventional pre-stack depth migration and (b) is the spectrum of viscoelastic Q pre-stack depth migration.

Conclusions

The “2W1H” data processing results in the Songliao Basin confirm that viscoelastic Q pre-stack depth migration effectively improves the vertical resolution of seismic data, which is an effective method for high-resolution imaging of deep thin reservoirs and small faults. Not only obtained higher-resolution imaging results than conventional migration, but also achieved clear imaging of small faults, effectively supporting the exploration, deployment and development of horizontal wells for tight oil and gas in this area, and can be carried out in other deep high-resolution processing areas promote applications.

Acknowledgements (Optional)

We thank Daqing Oilfield Company of CNPC for permitting the publication of this abstract. Thanks to the support of the National Natural Science Foundation project "Data-driven inverse scattering series interbed suppression method" (41974116) and China National Petroleum Corporation fund project "Identification of interbed and suppression method based on Marchenko self-focusing Research "(2019D-500803).

References

Kjartansson, E., [1979], Constant Q wave propagation and attenuation: Journal of Geophysical Research, 84, 4737–4748.
Huahui Zeng, [2019], Application of Viscoelastic Pre-stack Time Migration in Thin Sand Reservoir Imaging, 81st EAGE.