1542384 Prestack Data Prediction for Fluvial Reservoirs

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Summary

Based on the fluvial lithologic reservoir predication through prestack inversion and by analyzing the petrophysical properties obtained from well logs, the correlation between lithologic parameters and elastic parameters is established. Then, with the seismic data at different incident angles, together with the logging data like P-wave, S-wave and density, multiple elastic parameters related to lithology and hydrocarbon potential are determined, so as to synthetically discriminate the reservoir properties and hydrocarbon potential.

1. Introduction

China has stepped into the exploration and development of litholgoic oil and gas fields. However, challenges are encountered in poststack prediction, especially for the Neogene fluvial reservoirs, which are hard to predict with poststack technique when the sand-shale velocity does not change obviously. In this circumstance, the prestack inversion is increasingly dominant in fluid prediction. The seismic attributes are usually known as time, amplitude, frequency, phase and etc. But, they are just based on poststack seismic data, leaving incident angle out of consideration. Actually, the amplitude changes to some extent with the incident angle, which is defined as the AVO phenomenon. Therefore, the impact of incident angle should be included in the study of seismic attributes. The prestack inversion has become a key technique of hydrocarbon detection at present, and extensively used in quite a lot of oilfields.

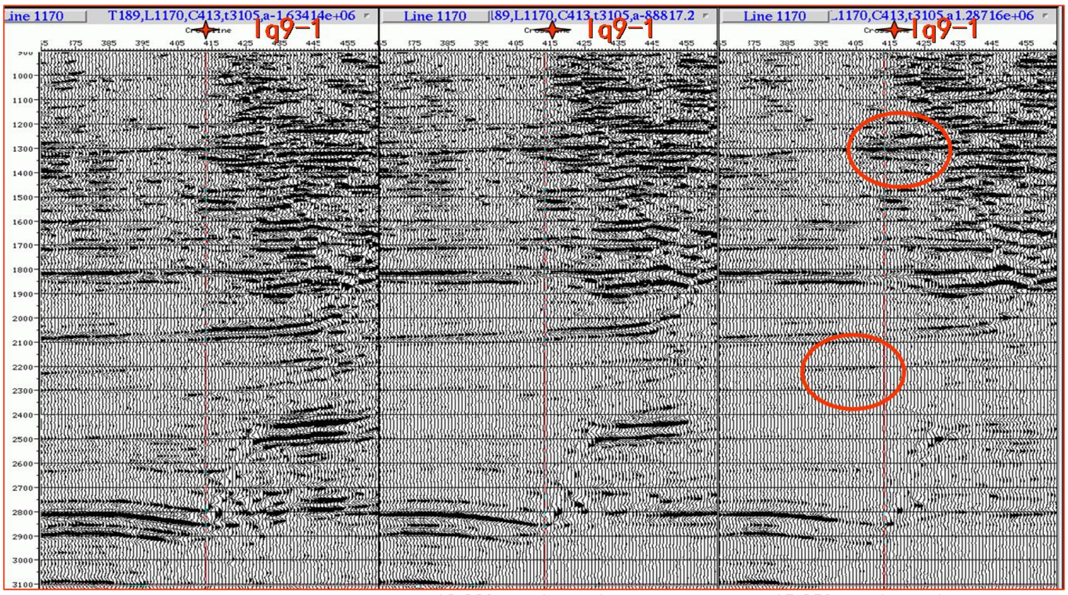
The essence of AVO technique is to analyze the variation of seismic reflection amplitude with the incident angle and its relation with the stratum lithology. As is well known, in actual seismic survey, the seismic ray incides onto the rock interface at nonzero angle, and the reflectance is related to P-wave velocity, S-wave velocity and density. Therefore, accurate determination of the reflectance characteristics requires an exact formula of reflectance strictly based on wave theory. Generally, when a P-wave is incident onto the interface of 2 media, 4 waves will be generated, i.e., reflected P-wave, reflected converted S-wave, transmitted P-wave and transmitted converted S-wave. According to the wave theory, with the displacement and stress continuity of planar incident P-wave in the direction of normal and tangent lines of the rock interface, the correlation of amplitudes of these waves with incident angle, P-wave velocity and S-wave velocity can be derived, which is referred to as Zoeppritz equation.

Because the Zoeppritz equation set is a multivariable super-underdetermined equation set, and its analytic expression is extremely complicated, it is impossible to directly conclude that the correlation of amplitude and incident angle can be used to predict the hydrocarbon potential. Therefore, the solution to the formula is simplified, to expound the impacts of lithologic parameters, P/S-wave velocity, density and Poisson's ratio on the reflection amplitude from different aspects, making AVO significant for actual production.

2. Preserved amplitude seismic processing

The excellent prestack data processing provides basic data for prestack seismic inversion. Therefore, prior to the inversion, the impacts of factors in seismic wave shooting, propagation, receiving and processing on the wave’s reflection amplitude must be considered thoroughly; moreover, the amplitude must be compensated and calibrated in the course of acquisition and processing if possible, so that the variation of amplitude with the geophone offset resulted from non-hydrocarbon or lithology factors can be minimized. In this way, high SNR, high resolution and hi-fi prestack seismic data are obtained, benefiting the successful prestack seismic inversion.

To preserve the AVO information, it is essential to restore and maintain the relative amplitude relation of each trace in the CRP gather, improve the resolution of prestack seismic data at higher SNR, and correctly reflect the location of reflecting interface. Key techniques hereof include fine spherical diffusion compensation, fine absorptive attenuation compensation, surface consistent amplitude compensation, surface consistent deconvolution, and surface consistent static correction. In addition, it is a prerequisite in prestack seismic inversion and attribute analysis to enhance the SNR and resolution. In the preprocessing of AVO, based on the specific data and requirements, the optimal denoising method should be used, so that the relative relation of usable reflection amplitude will not damaged seriously while the SNR is improved. As for the lower SNR seismic data, the SNR is enhanced by stacking of partial angle gather data, when the relative relation of original amplitude is generally not changed (Figure.1). The data resolution to be enhanced can be divided into vertical resolution and lateral



5-15° angle stack 10-20° angle stack 15-25° angle stack

Figure 1 Separated angle stack data for preserved amplitude seismic processing

resolution. As for AVO study, the vertical resolution can be enhanced with the surface consistent deconvolution method, while the lateral resolution can be enhanced with the prestack time migration method.

Under the processing and interpretation integration mode, the processing personnel develop the preserved amplitude processing flow, and the interpreters trace the processing progress and strictly control the quality, so as to maximize the fidelity of seismic data while guaranteeing the resolution and SNR. In this way, the inversion is conducted effectively.

3. Petrophysical simulation

Petrophysical simulation is a bridge to connect logging and seismic data. Therefore, the accurate analysis of log data is the foundation for the whole inversion process. As for the raw log data, preprocessing is done first, including environmental correction and data standardization. The environmental correction targets the sonic curve. At the location where the borehole is distorted, the log value of DT may bring forth obvious ambiguity, so correction is required through mean filtration and manual compilation to make it in a rational range of variation. The essence of log data standardization is to use the distribution similarity, i.e., the similar geologic-geophysical properties in identical interval in one oilfield or region, to conduct bulk analysis on the log data of each well in the oilfield, and correct the inaccurate scale, so as to realize the standardization of log data of the whole oilfield.

Before prestack seismic inversion, the P-wave velocity, S-wave velocity and density should be known. Generally, there is abundant log data of P-wave velocity and density, but the S-wave velocity data are seldom available in practices. In this case, we will figure out the variation of S-wave velocity and accurately fit and forecast it. There are 2 approaches for predicting the S-wave velocity: empirical formula, and petrophysical principle.

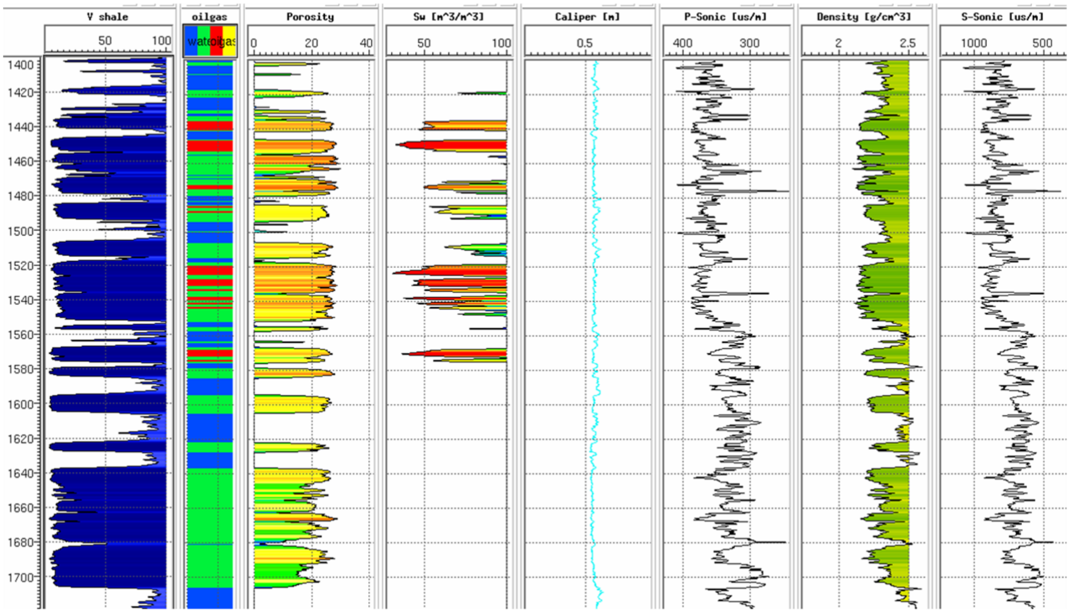


Figure 2 Petrophysical analysis

Based on the research and analysis on well A in Gangdong area (Figure 2), the simplified Zoeppritz equation is used to simulate the P/S-wave velocity and density. The log data are correlated to investigate its variation; at the location where hydrocarbon is ascertained by fluid characteristics, the fluid replacement method is used to get the relatively true simulation curve, which can basically interpret the characteristics of lithology and fluid. Based on the analysis, a conclusion is drawn that the oil-bearing sandstones of Nm-III Member in well A feature low P/S-wave velocity and low density.

4. AVO forward analysis

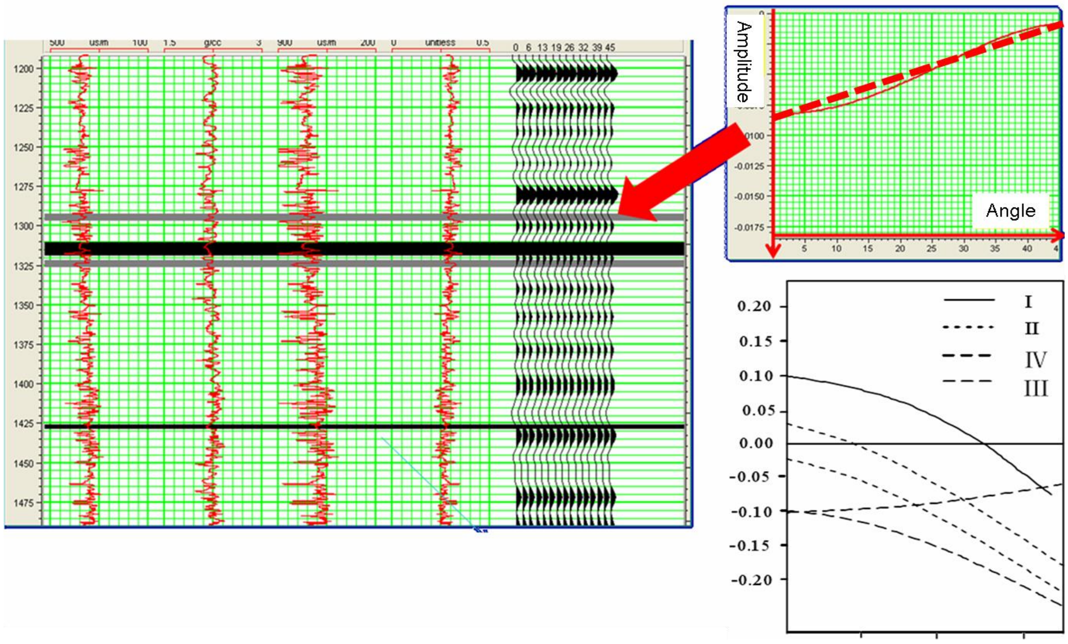


Figure 3 AVO forward analysis

The AVO forward modeling is critical in the exploration and development. It is helpful to establish the pattern and attributes of AVO curve of strata sets and typical hydrocarbon-bearing reservoirs in the local area. It also benefits AVO data interpretation by reducing the ambiguity and enhancing the precision of reservoir prediction. With the model forward and inversion analysis, the variation of elastic parameters (e.g. P-wave attribute, S-wave attribute, gradient attribute and Poisson's ratio) with the lithology, physical property and gas potential of reservoir is studied, which can help us get a more accurate and quantitative understanding on the real data.

Based on the AVO forward analysis on well A in Gangdong area (Figure 3), the seismic reflectance of the oil-bearing sandstones of Nm-III Member changes from the negative maximum to (but never over) zero, but the changing rate is small. It can be classified as the Class IV anomaly, and its variation amplitude is not so evident, which is analyzed as resulting from oil-bearing fluid, and the S-wave variation is not very obvious.

5. Simultaneous inversion of prestack parameters

5.1. Principles of simultaneous inversion of prestack parameters

The simultaneous inversion of prestack seismic data is an important technique used in prestack inversion now. It can provide P/S-wave impedance and density data volume simultaneously, and accordingly, the petroelastic parameters like P-wave to S-wave velocity ratio, Poisson's ratio, Lame's coefficient and shear modulus can be derived.

The simultaneous inversion is realized in following steps: (1) set a group of angle gathers and seismic wavelet corresponding to each gather; (2) best fit *k* and *m* values by using the log data; (3) give the initial solution; (4) use the Conjugate Gradient (CG) method to solve the equation; (5) conduct inversion to obtain the P-wave impedance, S-wave impedance and density.

When the incident angle equals to 30°, the elastic impedance can be approximately expressed as the function of acoustic wave impedance and incident angle; when the incident angle is zero, the elastic impedance can be expressed as the acoustic wave impedance. For the sake of connecting the elastic impedance with the seismic data, the convolution model is used (supposing there is no noise). As for the data related to angle, the convolution model becomes: $S(\theta)=R(\theta)*W(\theta)$, in which, $S(\theta)$ is the angle seismic trace, $R(\theta)$ is the angle reflectance, which can be approximated by Zoeppritz equation with P-wave velocity, S-wave velocity and density obtained from well logs, and $W(\theta)$ is the angle wavelet, which is obtained from the reflectance and angle gather data. The acoustic impedance is obtained by integrating the reflectance R; similarly, the elastic impedance can be calculated by the angle reflectance. The elastic impedance is a parameter not obtained through physical measurement, but through derivation and for seismic data interpretation. Currently, it can be calculated with multiple software. For inversion, the elastic impedance is superior to poststack acoustic as follows:

1) The computing formula of elastic impedance is more coincident with the elastic properties of rocks underground;

2) The prestack gather can more truly reflect the actual observation in the field and the fluctuations of actual subsurface amplitude;

3) The log data used in prestack inversion are more abundant, and the judgment of lithology and oiliness is more accurate at more adequate evidences; and

4) The parameter is more sensitive to hydrocarbons than acoustic impedance.

5.2 Basic flow for simultaneous inversion of prestack elastic parameters

The basic flow for simultaneous inversion of prestack elastic parameters is shown in Figure 4:

1) Seismic data processing: seismic data dynamic/static correction, conversion from CMP data to CRP data, and extraction of partial stack data at separated angles;

2) Well data processing: S-wave velocity prediction and K value estimation with multiple methods, zonation based on several logs, calculation and analysis of multi-angle EI curve of each well, well intervening and well location correction, correlation and correspondence of well curve and seismic data, etc.;

3) Angle wavelet extraction: extraction of optimal wavelet corresponding to each angle gather

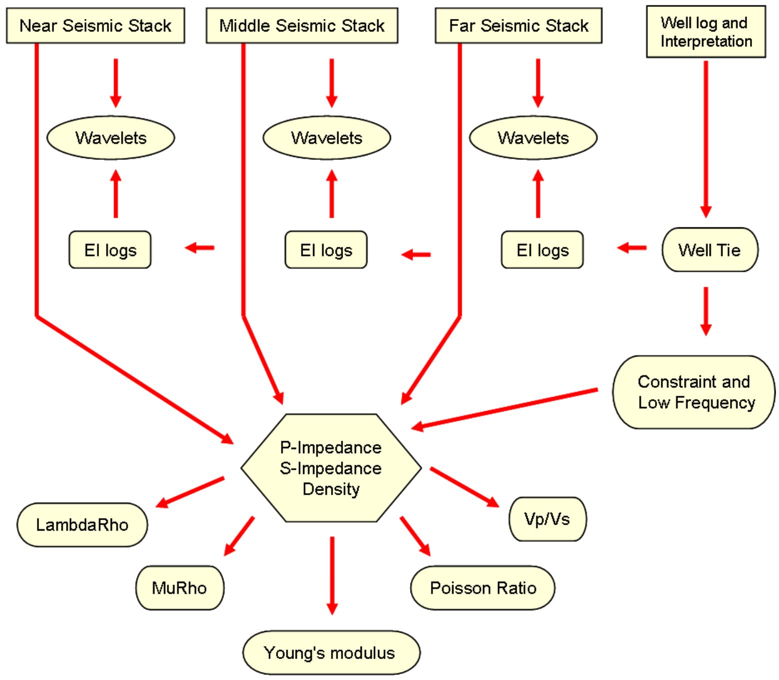


Figure 4 Flow of simultaneous inversion of prestack parameters

with the seismic statistics method based on well wavelet data;

4) Elastic impedance inversion model construction: using numerous constraints, and regulating each relevant parameter, to build the most reasonable model;

5) Simultaneous inversion of prestack parameters: using different angle data to simultaneously calculate the P/S-wave impedance and density.

Like the poststack wave impedance inversion, the data obtained in simultaneous inversion also needs to be supplemented by the low frequency components; exceptionally the low frequency model used in simultaneous inversion is not built using the wave impedance logs and traditional poststack data, but using P-wave impedance, S-wave impedance and density. The low frequency components among wells can be calculated at weighted distance, and extrapolated from the interpreted seismic horizon. Then, the parameters in the model are

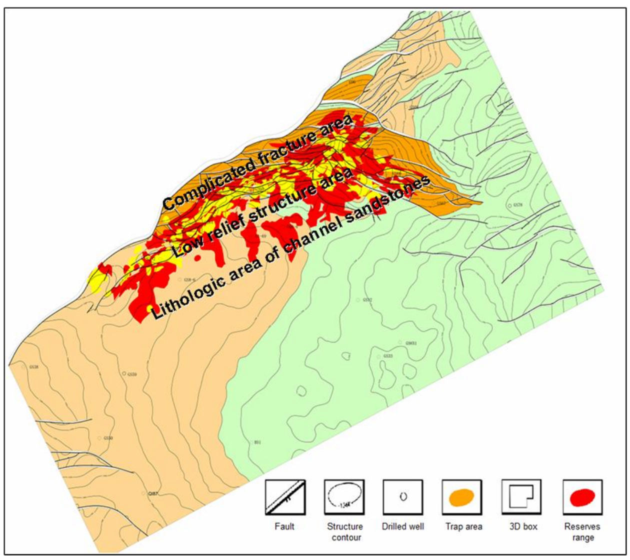


Figure 5 Bottom structural map of Nm-III Member in Gadong area

adjusted, to build a precise inversion model of the entire data volume at any angle.

6. Case study of Gangdong region

The Gangdong region is located at north side of Qikou sag and the middle east section of north Dagang structural zone. This oilfield was discovered in 1965, producing beneficially at lower Minghuazhen Formation and Guantao Formation, Neocene (Figure 5). After exploration and development for more than 30 years, this oilfield enters the high watercut stage. However, in recent years, further researches have revealed more oil and gas reserves, making the oilfield remain as one of the major oil producing areas in the Dagang Oilfield. The development has covered the complicated fracture zone of Gangdong fault and is advancing gradually towards the lithologic areas. On the basis of prestack data predication, and combining with the integrated study results, numerous targets for rolling development are ascertained (Figure 6).

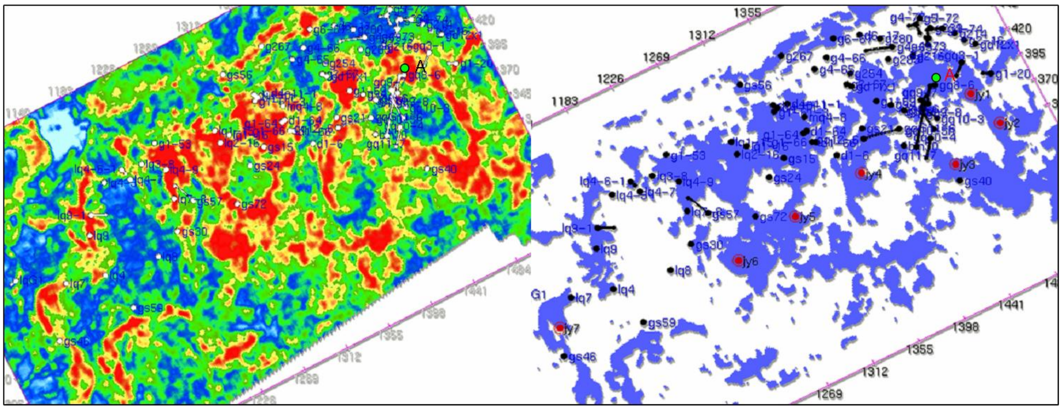


Figure 6 Planar prediction of S-wave impedance and oil-bearing sandstone of Nm-III Member in Gangdong area

In the developed blocks, such as wellblock G34, Nm-III and Nm-IV oil group are the major pay zones, with thickness of 2~8m in individual well. According to the distribution of hydrocarbons in channel sandstones of Nm-III pay zone and the reported reserves and production reality, it is found that the discovered oil reservoirs mainly distribute at both sides of this wellblock, and the development wells are deployed by stages from north to south, among which, wellblock A at east side was put into development at earlier time, with many wells deployed. Three sets of oil-yielding strata (5.8m thick) distribute in Nm-III Member in well A, with initial production of 30.18t in test, and additional probable reserves of 135×10^4t. Further well test was conducted in Nm-III pay zone, with 21.38t/d oil and no water produced initially, and 18.3t/d and 2.3m^3/d water now. The analysis of petrophysical properties of oil-bearing sandstone reveals low P-wave impedance, low S-wave impedance, and Vp/Vs less than 1.4. Based on analysis of prestack inversion data volume, the oil-bearing sandstones distribute roughly in SN trend (narrow south and wide north). Many rolling development wells and appraisal wells have been deployed at the south, with oil and gas shows; the oil-bearing sandstones in the wells at north and east are thin and drilled at the boundary of the predicted sand bodies, potential for future well deployment.

Wellblock LQ9 at the west of the Gangdong region runs from the south boundary of the study area northward to the upthrow of Mapengkou fault, with an area about 9km^2. There are totally 16 exploration wells and 5 development wells. Nm-III and Nm-IV pay zones in the northeast of the wellblock located in the reserves area, and commercial oil flow was obtained from Nm-III pay zone in many wells. Wellblock LQ9 is generally situated in the southwest of the Gangdong region and the upthrow of Mapengkou fault. Fault is not developed in this wellblock, but channel sand bodies are well developed in Nm-III pay zone, as a typical lithologic area. The prestack attribute analysis reveals a near SN fluvial channel extending from the north of the wellblock, presenting as typical meandering stream, which is quite different from well G34. Based on the prestack inversion, this wellblock is determined as a lithologic reservoir development area, providing prospects for next rolling development.

7. Conclusions

The progressiveness and practicability of prestack inversion technique is verified by application in the Gangdong region. It is extremely superior to poststack prediction technique, either in theoretical method or in practical application. The devotion to exploration of lithologic reservoirs will increase in the future. However, the identification of lithologic reservoir will be more difficult, and it will result in greater risk only using the poststack data to predict the fluid. Therefore, a space is left for the widespread use of prestack attribute prediction technique.

In addition to recognitions obtained through researches, some problems are discovered as follows.

1) The prestack inversion requires stringent amplitude preserving of seismic data. Accordingly, any problems should be addressed and the integrated processing and interpretation mode be used in prestack inversion technique study, to enhance the entire technical level.

2) There are diversified AVO attributes and multiple simplified Zeoppritz equations. Not all of them can be used in actual production. Instead, the research shall be conducted after various assumptions for parameters and simplified modes are understood.

3) Many default parameters are used in the petrophysical simulation, mostly from one area. However, it is difficult to get the accurate data of pure rocks in the area, mainly S-wave data, impacting the certainty and accuracy of petrophysical simulation. Therefore, a model suitable to the work area shall be selected in practical application.

4) It is not a simple linear relation between elastic parameter and fluid parameter. It is difficult to directly determine the accurate fluid parameter. Therefore, the data of target zone acquired shall be used to define the value that is relatively close to the linear relation.

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