Reservoir seismic inversion method and Key problems and Countermeasures in application

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Abstract. Although reservoir seismic inversion technology has achieved some results in reservoir prediction and description, but due to the complex seismic geological conditions and the lack of in-depth and systematic research on the application conditions of the technology, to a certain extent, it has affected the wide application of the technology. Based on the classification and description of the current inversion methods, through the theoretical model and the inversion processing practice of a large number of data, this paper studies and summarizes the applicable conditions of several inversion methods, expounds some key problems existing in the application of inversion technology, and puts forward corresponding solutions.

Key words: reservoir, prediction and description, seismic inversion, classification, application conditions, problems and Countermeasures

With the deepening of exploration and the lack of structural traps, it is more and more important to search for subtle reservoirs purposefully, but it is very difficult to predict and describe subtle reservoirs. In recent years, the reservoir seismic inversion technology developed and put into application can better combine the vertical resolution of well logging and drilling data with the characteristics of high horizontal sparsity, rough vertical and dense horizontal of seismic data, so as to accurately describe the thickness and geometry of the reservoir, and then estimate the physical changes of the reservoir, greatly improve High drilling success rate [1]. However, due to the complex geological conditions for the formation of subtle oil and gas reservoirs, large lateral changes in the reservoir, complex changes in the internal and physical properties of the reservoir, low quality and resolution of conventional post stack seismic data, ill posed inversion technology and lack of in-depth study on application conditions, etc., to a certain extent, this technology has affected its wide application. According to the inherent characteristics of seismic and logging data and the current application and development status of inversion technology, through the processing practice of a large number of inversion data, we study and summarize the key problems in the application of reservoir seismic inversion technology, and propose corresponding solutions, hoping to play an important role...
in the exploration and development of oil and gas fields [2].

1. Reservoir seismic inversion method

Seismic inversion refers to a special seismic processing and interpretation technology which uses seismic data to invert the impedance (or velocity) of formation wave. Compared with the common statistical methods such as seismic pattern recognition or neural network prediction of formation parameters, it has clear physical significance and is a more deterministic method for reservoir prediction.

Seismic inversion can be divided into pre stack and post stack inversion. Prestack inversion is still in the stage of research and test, while post stack seismic inversion has developed rapidly in the past 20 years, forming a variety of technologies [3]. There are two methods to realize seismic inversion: wave equation inversion based on wave theory and inversion based on Robinson convolution model. The latter is the most commonly used technology, such as recursive inversion (trace integration, block inversion, band limited inversion and pivt), sparse pulse inversion and mode based inversion.

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Wang Yanguang, male, born in 1963, senior engineer, Ph.D., has been engaged in the research of geophysical methods and comprehensive application of seismogeology. Type. The following is a brief introduction of several representative inversion methods and their application limitations.

1.1. Relative wave impedance inversion (trace integration)

Trace integral is a direct inversion method based on seismic data, that is to calculate the relative wave impedance (velocity) of the formation by using the integral calculation of post stack seismic data

$$\text{Pu} = \exp [2 \frac{\text{Xi}}{\text{f}}]$$ (1)

The calculation is simple and fast, and the recursive cumulative error is small, which has clear physical significance. This method does not need drilling control. It is one of the simple and effective tools for reservoir lateral prediction and reservoir description in the early stage of exploration.

The application of trace integration method is limited: ① limited by the inherent frequency width of earthquake and low resolution, it is difficult to meet the needs of thin layer interpretation; ② unable to obtain the absolute wave impedance and absolute velocity of the formation, which can not be used for quantitative description of the reservoir; ③ unable to use geological or logging data for constraint control in the calculation process, so the accuracy is relatively low.

1.2 Recursive inversion

Recursive inversion is a seismic inversion method based on the recursive calculation of the reflection coefficient to calculate the wave impedance (velocity) of the formation. The expression is

$$Z_i^j + 1 = Z_{i+1}$$ (2)

In formula i117, R is the reflection coefficient obtained from seismic records by wavelet deconvolution, and B is the initial wave impedance, which is the j + 1 formation wave impedance.

It can be seen that the key lies in how to correctly estimate the reflection coefficient of the formation according to the seismic records. Well logging data is mainly used for calibration and quality control, so recursive inversion is also called direct inversion or well logging controlled seismic inversion. Typical inversion methods are based on stratum deconvolution, sparse pulse deconvolution, frequency domain deconvolution and phase correction [4]. Sparse pulse inversion is one of the most commonly used methods in production. It is based on sparse pulse deconvolution and can be realized by MLD, II module deconvolution and med. This method is aimed at the underdetermination of seismic records. It is assumed that the reflection coefficient sequence model corresponding to the
wave impedance model of the underground strata is sparse, which is composed of the main (strong) reflection coefficient sequence and the weak reflection coefficient sequence with Gaussian background. Under these conditions, different methods are used to estimate the "strong" reflection coefficient and seismic wavelet, and the impedance model of the underground wave represented by the sparse pulse model is obtained through gradual screening and optimization [5]. In the process of iteration, geological structure frame model and three-dimensional multi well model can also be introduced to participate in inversion constraints, which can not only limit the multiple solutions of the results, but also retain the characteristics of amplitude, frequency and phase of seismic data. This technology is widely used in all stages of exploration and development, and it can be applied in case of more or less or even no logging data. The following Figure 1 seismic response of several thin sandstones with different wavelet frequencies (Sun Jiazhen et al., 1997)

![Wavelet Frequencies](image)

Figure 1. Different wavelet frequencies of thin sandstones

The recursive inversion method based on the frequency domain deconvolution and phase correction is an ideal inversion method, which mainly includes: frequency domain deconvolution to recover the amplitude spectrum of the reflection coefficient of the formation, phase correction to make the well side inversion trace and the well logging best match, and low-frequency model technology to reflect the change trend of the formation wave impedance. Because the method avoids the underdetermination of wavelet or reflection coefficient calculation, the basic criterion of parameter optimization is the degree of coincidence between the inversion result by the well side and the actual logging curve, which can ensure the reliability and interpretability of the inversion result.

The application of recursive inversion is limited: because the method is completely dependent on the quality of seismic data itself, the seismic noise is sensitive to the inversion results and has a large impact; the narrow seismic bandwidth leads to a relatively low resolution, which is difficult to meet the requirements of thin reservoir description.

1.3 Model based seismic inversion

In fact, the seismic inversion technology based on the model is to realize the best matching process between the measured seismic response and the seismic forward simulation response by applying the appropriate generalized linear or non-linear optimization algorithm through repeated calculation iterations, that is, starting from the geological model, adopting the iterative disturbance algorithm of model optimization, and constantly modifying and updating the model, so that the model can forward synthesize the seismic data. The final model data is the inversion result. It can be seen that the inversion result depends not only on the selection of forward model, but also on the selection of the
appropriate principle of minimizing error. The implementation methods include generalized linear inversion (GLI) (Cooke, 1983), seismic lithology simulation (SLIM) (Gelfand, 1984), robust velocity inversion (rovim) (Fabre, 1989), broadband constrained inversion (BCD (Martinez, 1988), genetic algorithm with global optimization characteristics, simulated annealing (Smith et al., 1992; Sen and stoffa, 1995), Monte Carlo search (Cary and Chapman, 1988), and human Industrial neural network method (calderron Macias et al., 1998), etc. At present, log constrained seismic inversion is a model-based seismic inversion technique with strong ability of reservoir characterization. This method avoids the direct inversion of seismic data, that is to say, the problem of fast propagation of accumulated error caused by converted wave impedance after the calculation of reflection coefficient is avoided. Instead, through the addition of abundant high-frequency information and complete low-frequency components of logging data, the shortage of seismic data bandwidth is overcome.

By directly inversion of wave impedance with non-linear method, the inversion result can be higher Resolving power. The stochastic simulated seismic inversion technology developed in recent years can realize the organic combination of seismic inversion (simulated annealing method, etc.) and geostatistical simulation technology (co Kriging, Gauss algorithm, etc.), make the best use of all the data of seismic, geological and logging, so as to make the inversion result fully consistent with the known conditions. The results are not only in accordance with the characteristics of seismic reflection data, but also controlled by the three-dimensional spatial statistical simulation results of geological structure framework model and well point known data. The results are in good agreement with the actual drilling in many areas, and the reservoir resolution is strong.

The inherent characteristic of model-based seismic inversion technology is multi solution. The actual seismic data will always be disturbed by noise. It can be predicted that within the given measurement error range, there will be more than one underground model to meet the observed data. In other words, inversion is not the only way. Academician Li Qingzhong and Cooke also produced seismic wavelet, and analyzed the problem that band limited wavelet will inevitably cause multiple solutions in inversion. However, due to the constraints of seismic logging and geological data, it is often possible to minimize the multiplicity of solutions.

2. Key problems and Countermeasures in application

At present, the commonly used reservoir seismic inversion method based on Robinson convolution model takes logging constrained seismic inversion as an example. Although the low and high frequency information of the result comes from logging data, the structure, reservoir characteristics and intermediate frequency section depend on post stack seismic data. In view of the characteristics of the implementation algorithm, the following key problems must be considered and solved in the specific application.

2.1 Analysis of reservoir geophysical characteristics

The analysis of reservoir geophysical characteristics is an important basic work. It is necessary to make full use of all logging and geological data in the area, and study the characteristics of the reservoir through various statistical analysis methods, including sand mud content, acoustic wave and density, electrical property and physical property of the reservoir, and then make well seismic connection to study the geophysical characteristics of the reservoir, so as to lay a foundation for inversion processing.

2.2 Applicability of seismic and logging data

There are two main functions of seismic data in log constrained seismic inversion. The first is to provide the information of strata and faults to guide the interpolation and extrapolation of logging data and establish the initial model; the second is to constrain the geological model of effective seismic frequency band to converge in the right direction. The higher the resolution of seismic data is, the finer the horizon interpretation is possible. The initial model is close to the actual situation, and the multi
solution area is correspondingly reduced. Therefore, it is an important way to improve the resolution of seismic data. In addition, the factors of high fidelity, high signal-to-noise ratio, surface consistency processing and zero phasing of seismic data are equally important. Therefore, in the process of data processing, band limited filtering, hour window and single channel transformation should be avoided as much as possible. When processing the data collected under different construction conditions in different years and years, it is necessary to do a good job in the processing of spectrum phase consistency. If conditions permit, prestack time migration processing should be done for the inversion data.

Inversion requires well logging data, especially acoustic and density data, to objectively reflect the characteristics of the reservoir. Therefore, it is necessary to do a good job in the standardization of environmental correction and baseline drift correction, so as to eliminate the errors caused by borehole collapse and mud immersion, as well as the problems of inconsistent calibration caused by different logging instruments, logging time and well structure. At the same time of using the measured acoustic data for inversion, we can also consider using the conversion formula to make joint correction for the acoustic curve from the logging curve (such as gamma, resistivity curve, etc.) with less error factors. Refer to figure 2.

![Figure 2. (a) 20 Hz pulse; (b) 50 Hz pulse](image)

2.3 Extraction of seismic wavelet and well seismic calibration

Wavelet is the key factor in inversion based on Robinson convolution model, and well seismic calibration is an extremely important and time-consuming work in inversion, both of which have a great impact on inversion results. In order to get seismic wavelet suitable for different inversion algorithms, we must consider many factors. For example, the influence of the length of seismic wavelet, the influence of wavelet error, the influence of the DC component of wavelet far away from zero value, the influence of wavelet change in space and so on. Well seismic calibration is to calibrate the reservoir in the well in the depth domain. The technology can solve the problem well;

3. Conclusions and suggestions

Reservoir seismic inversion technology is one of the effective tools for reservoir prediction and
description at present, but due to its inherent multiple solutions, blind application without in-depth analysis is risky. In order to improve the reliability of post stack inversion to the greatest extent, it is necessary to carefully study the geophysical characteristics of the reservoir in the exploration area, the applicability of logging and seismic data, the establishment of structural and sedimentary facies models, the extraction of seismic wavelet, the calibration accuracy of well seismic, the selection of inversion algorithm, density, seismic resolution and other factors. At present, the post stack seismic data used in inversion is difficult to achieve "three highs", which can not meet the inversion requirements in theory. It is suggested to increase the research efforts of full waveform inversion and pre stack elastic inversion to reduce the multiplicity of post stack inversion and directly serve the prediction and description of oil and gas reservoirs.

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