Application of Seismic Waveform Inversion in Prediction of Tight Sandstone Conglomerate Reservoir in Surenuoer Oilfield

Li Liu *
Hulunbeier subsidiary of Daqing oilfield Co., ltd, Inner Mongolia, China

*Corresponding author e-mail: liu34li@126.com

Abstract. The reservoir of Tongluomiao Temple in Surenuoer Oilfield is dominated by glutenite. The sand body is dense, the buried depth is shallow, the heterogeneity is strong, and the oil-water relationship is complex. The favorable reservoir sand body prediction has always plagued the block exploration and development. Therefore, based on the seismic waveform indication inversion principle, process and key parameter settings, based on the petrophysical analysis in the study area, the reservoir inversion technique is studied, and the well interpolation model and the waveform indication inversion model are proposed. The method generates the inversion prediction model of the study area. On this basis, the threshold value of the layer is used to extract the thickness distribution of the sand body plane, and then the favorable target area is predicted. The actual drilling results show that the thickness of the sand body predicted by the method and the actual drilling results are in good agreement and the oil and gas shows good, providing a reliable technical method for reservoir prediction.

1. Foreword
The Surenuoer oilfield is located in the northern part of the Wuexun depression in the Hailaer Basin. The Lower Cretaceous Tongyumiao Formation was in the early stage of rifting, and the basin began to settle. The climate is relatively dry, with less debris and shallow water. It is a slope/steep slope fan delta. In the sedimentary system, the lithology is dominated by grayish and variegated glutenite, which is marked on logging and earthquakes. The seismic profile reflects a set of strong reflective interfaces, which are overlying the overlying strata, which is an obvious unconformity interface. Well electrical characteristics are characterized by high resistivity and high gamma. The seismic waveform indication inversion technique is developed on the basis of the traditional wave impedance inversion technology. It breaks through the disconnection between the well and the seismic data in the traditional statistical inversion, ignores the change information of the seismic waveform, and utilizes the seismic waveform. The lateral change information replaces the variogram, drives the simulation of the interwell reservoir, and realizes the high-resolution reservoir characterization technique of well-seismic synergy. The seismic inversion predictor plane law is consistent with the geological law. Taking the Surenuoer oilfield as an example, this paper predicts the distribution range of favorable reservoirs of glutenite through seismic waveform indication inversion and attribute slicing technology, and then guides the design and operation of drilling wells and achieves better results.
2. Seismic waveform indication inversion principle and process

2.1. Inversion principle
Seismic waveforms contain sedimentary cycle information of the rock formation, and lateral changes are related to the sedimentary environment. According to the idea of seismic stratigraphy, a waveform continuously changes in the lateral direction, which actually represents a period of reservoir structure that does not change. It is the effect of sedimentation, that is, the lateral variation of the waveform is related to the sedimentary environment of the formation. Therefore, similar sedimentary environments have similar curve-return characteristics (combined structures), and similar composite structures will produce similar seismic waveforms. The lateral variation of seismic waveforms can indicate the classification of reservoir structures, and the reservoirs represented by similar waveforms. The structure is analogous. Using well logs from multiple wells with similar waveforms, deterministic frequency components can be detected over a wider frequency range than earthquakes.

2.2. Inversion process

The main ideas and processes of the algorithm are as follows (Figure 1):

First, the seismic waveform similarity feature is utilized, and an effective sample well is preferred; The second is to optimize the relationship between the sample statistical waveform and the reservoir combination structure. Multi-scale analysis of the sample well curve in the wavelet domain, determine the common structure in the statistical sample as the initial model, and analyze the cyclic structural features of the curve as the conditional probability distribution; The third is to simulate the high-frequency components of the initial model under the Bayesian framework (Markov chain-Monte Carlo); the simulation results are consistent with the seismic IF impedance and well curve structure characteristics (conditional distribution probability).

![Figure 1. Inversion process](image-url)
The advantage of this method is that it can simultaneously improve the vertical and horizontal prediction accuracy, and has phase-control thinking. It can simulate a variety of reservoir parameters without limitation and impedance, from completely random to stepwise determination. The frequency component of the inversion is less than 30Hz, which is directly determined by the well and the earthquake. The intermediate frequency part is obtained by using the seismic data waveform classification to obtain the wave impedance gradually, and the high frequency component is obtained by the interwell interpolation simulation.

3. Application of seismic waveform indication inversion

3.1. Geological overview

The Hailar Basin is a large fault basin developed on the Paleozoic fold base and is part of the Central Asian-Mongolian trough. In the middle and late Jurassic-Early Cretaceous period, due to the thunderstorming of the mantle, the Hailar Basin stretched and formed a fault basin. The Wuerxun depression is a negative secondary structural unit of the Hailaer Basin. The Surenuoer Oilfield is located in the northern part of the Wuerxun Depression (Figure 2). The geographical location is located in the Xinbaerhuzuo Banner, Hulunbeier City, Inner Mongolia Autonomous Region, with an average elevation of 570m. The sedimentary strata are divided from the bottom to the top: the base Budate group, the Lower Cretaceous Tongluo Temple Formation, the Nantun Formation, the Damoguaihe Formation, the Yimin Formation, the Upper Cretaceous Qingyuangang Formation, and the Tertiary System. Mountain group, Quaternary. During the sedimentary period of the Tongyumiao Formation, the fault depression activity is the strongest, the sedimentation rate and sedimentation rate are relatively large, and the fault depression is in a strong tensile period [1-2].

3.2. Reservoir types and characteristics

It is seen from the scanning electron microscopy data that the pore type of the reservoir of the Tongluo Temple Formation is mainly the primary intergranular pores, followed by the feldspar and the internal pores of the cuttings, which shrink the intergranular pores. See also a small amount of intergranular, intragranular microfissures, cementation. The type is dominated by pore cementation. The porosity varies from 7.2% to 13.0% and the average porosity is 9.3%. The permeability range is from 1.73 to 2.23 mD and the average permeability is 1.98 mD. It belongs to ultra-low porosity and ultra-low permeability reservoir.

From the pore structure characteristics of mercury intrusion data analysis, the average pore radius of the Tongluo Temple group is generally between 0.06 and 1.30 μm, with an average of 0.52 μm; the
The median radius is generally between 0.004 and 0.704 μm, with an average of 0.235 μm. The sorting coefficient is a characteristic parameter reflecting the pore size and uniformity of distribution. The composition coefficient of Tongluo Temple is 2.65. The displacement pressure reflects the physical properties of the reservoir. The displacement pressure of Tongluomiao Group is 0.58MPa. It reflects that the oil layer of the Tongluo Temple Formation is poorly sorted, the discharge pressure is high, and the structural coefficient is large (Table 1).

### Table 1. Pore structure characteristic parameter table of Surenuoer Oilfield

| classification | Porosity (%) | Permeability (mD) | Pore radius (μm) | sorting coefficient | Twist radius (μm) | Structural coefficient | Maximum mercury saturation (%) | Maximum retreat Efficiency (%) | Excavation pressure (MPa) |
|----------------|--------------|-------------------|------------------|---------------------|-------------------|------------------------|-------------------------------|-----------------------------|--------------------------|
| Max            | 15.7         | 14.2              | 5.32 1.30 0.704 | 3.58 0.57 1.26     | 7.65              | 97.60                  | 38.53                         | 2.83                        |
| Min            | 6.6          | 1.8               | 0.26 0.062 0.004 | 1.84 -0.85 0.04   | 0.18              | 40.50                  | 21.35                         | 0.14                        |
| Average        | 0.9          | 8.4               | 2.21 0.52 0.235 | 2.65 0.25 0.41    | 3.63              | 85.00                  | 31.49                         | 0.58                        |

### 3.3. Reservoir rock physical analysis

Firstly, the pre-processing of the logging data in the target area is carried out, mainly for the deviation of the logging data due to the inconsistency between the instrument and the logging series. Through the geological study of the logging data and the area, it is found that the upper part of the upper part of the block temple The zero oil group is a set of stable mudstone sections in the whole area. The layer is preferably a marker layer, and the logging curve of the target area is standardized. Then calculate the wave impedance value of the study area. Based on the synthetic record calibration, the wave impedance of sandstone and mudstone is analyzed. The wave impedance of sandstone is 9810-15375 m/s g/cm³, and the wave resistance of mudstone is 7930-11638 m/s g/cm³ can better distinguish between reservoirs and non-reservoirs (Fig 3).

### Figure 3. Sand-mudstone wave impedance statistical histogram

### 3.4. Inversion parameter determination

The main steps of seismic waveform indication inversion are as follows: data loading and inspection, logging curve normalization processing, synthetic recording calibration, reservoir parameter calculation and logging curve sensitivity analysis, and seismic waveform indication inversion. Among them, after the synthetic record calibration, it is possible to check whether the synthetic record calibration is reliable.
by model interpolation. The key parameters of the waveform indication inversion include smooth radius, effective sample number, optimal cutoff frequency and target volume sampling rate [3-14].

1. The number of valid samples

The “effective sample number” is the result of the number of well samples and seismic correlation statistics, which mainly characterizes the spatial variation of seismic waveforms. A large number of samples indicates that the reservoir is laterally stable, whereas the lateral change is fast and the heterogeneity is strong.

2. The best cutoff frequency

If the bias is more biased towards the certainty of the inversion, the parameter should not be set too high. Conversely, if the resolution is more biased and the random result can be accepted, a higher cutoff frequency can be set.

3. Smooth radius

The larger the smoothing radius, the more the number of tracks participating in the smoothing, the better the lateral continuity of the obtained inversion data body, and the smoother the inversion profile.

4. The target sampling rate

The smaller the target volume is, the higher the resolution of the inversion result, but the more computational time and storage space. In this paper, through data analysis and research, it is finally determined that the effective number of blocks is 5, the optimal cutoff frequency is 150Hz, the smoothing radius is 1, and the target sampling rate is 0.5, and the waveform indication inversion is performed.

According to the analysis, the upper part of the reservoir of Tongluo Temple in Surenuoer Oilfield is a relatively stable development of mudstone, low density, high acoustic wave, high density of low-lying Tongying Temple reservoir, low acoustic wave, and the wave impedance value is significantly higher than that of the upper stratum. This provides an accessible geological condition for the inversion. Figure 4 shows the wave impedance inversion seismic profile of the S1 well. The wave impedance of the upper glutenite reservoir in Tongluomiao is analyzed by the wave impedance calculated by the well and the inversion wave impedance well. The inversion wave impedance is found. The well wave impedance is high.

According to the threshold value on the histogram, the effective sand body thickness of the study section of the Tonglu Temple is extracted, and the flatness distribution trend of the sand body thickness is formed. Under the control of this trend surface, the plane thickness distribution of the sand body is produced by using the thickness of the sandstone drilled by the actual drilling (Fig. 5).

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Figure 4. Wave impedance inversion profile of S1 well
Based on the inversion prediction results, combined with the geological law, in 2019, the wells of the wells 2 and S3 and S4 were deployed in the northern part of the block. Currently, the wells have been drilled and the S4 wells have been drilled. The high-resistance reservoir section of the glutenite in the temple is 66.9m, the oil spot on the well is 32m, the oil is immersed 8m, the thickness of the sand body in the S3 is 69.9m, the oil spot on the well is 38m, and the oil immersion is 4m. And 2 oil wells are put into operation in the block. At present, the daily production of single well is 3.5t and the water content is 4.4%. It has good production capacity. It is estimated that 10 development wells can be deployed in the block, and 1 evaluation well can be used. Store 1.5 million tons.

4. Conclusion
(1) Seismic waveform indication inversion Under the guidance of the principle of seismic sedimentology, the lateral variation of the waveform is used to reflect the change of reservoir space, which fully reflects the idea of phased reservoir prediction. The key parameters of the inversion are the key parameters including smooth radius, effective sample number, optimal cutoff frequency and target volume sampling rate. Reasonable inversion parameters are obtained through data analysis.

(2) The author uses the wave impedance model inversion in the study area using the crosswell impedance interpolation model and the waveform indication inversion, and finally merges the frequency domain to form the inversion wave impedance model, further improving the longitudinal and lateral resolution of the inversion model.

(3) Using the threshold value on the histogram to extract the layer property of the inversion wave impedance body, obtain the trend of the thickness of the reservoir plane, predict the favorable distribution area of the reservoir, and guide the deployment of the design well position 2, the actual encounter The reservoir section is 68.4m, and 3 favorable target areas are predicted, which can increase 1.5 million tons.

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