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Review article

The research on method of interlayer modeling based on seismic inversion and petrophysical facies

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ABSTRACT

Currently, the three-dimensional distribution of interlayer is realized by stochastic modeling. Traditionally, the three-dimensional geological modeling controlled by sedimentary facies models is built on the basis of logging interpretation parameters and geophysical information. Because of shallow gas-cap, the quality of three-dimensional seismic data vertical resolution in research area cannot meet the interlayer research that is below ten meters. Moreover, sedimentary facies cannot commendably reveal interlayer distribution and the well density is very sparse in research area. So, it is difficult for conventional technology to finely describe interlayers. In this document, it uses L_1-L_2 combined norm constrained inversion to enhance the recognition capability of interlayer in seismic profile and improve the signal to noise ratio, the wave group characteristics and the vertical resolution of three-dimensional data and classifies petrophysical facies of interlayer based on core, sedimentary facies and logging interpretation. The interlayer model which is based on seismic inversion model and petrophysical facies can precisely simulate the distribution of reservoir and interlayer. The results show that the simulation results of this new methodology are consistent with the dynamic production perfectly which provide a better basis for producing and mining remaining oil and a new interlayer modeling method for sparse well density.

1. Introduction

In the late period of oilfield development, remaining oil has become more and more important for deep tapping. It is also a current research focus on interlayer. Its distribution and pattern has evident effect on oil group development and production. A fine interlayer model can better deal with its distribution. So, based on seismic inversion model and petrophysical facies, this document set up a new interlayer method. In order to detect sparse reflection coefficient sequences and estimate the amplitude values of reflection coefficients, the L_1-L_2 combined norm constrained inversion gets sparse reflection coefficient sequences by the latest interior point algorithm and improves vertical resolution by seismic wavelet filtering elimination and

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the high-frequency components of seismic data recover. The interlayer distribution is mainly controlled by sedimentary environment and late diagenesis, the petrophysical facies based on cores and well logging interpretation can finely identify all kinds of interlayer and precisely determine the reservoir and interlayer distribution.

2. Geology

Basically, the structure is a low-amplitude anticline, faults develop and the reservoir is fault-controlled. The sparse well density is less than 20 wells including exploration wells, pilot wells, production wells and adjusting wells at oil area of 20 km^2. Because of shallow gas and faults, the seismic data quality is not so good that the wave energy and signal-to-noise ratio is low, images are blur and events seriously drop, which have a certain influence on the results of structural interpretation and reservoir inversion. At target stratum, the frequency is about 45 Hz, the layer velocity is approximately between 2600 m/s and 3400 m/s, the vertical resolution is approximately between 16 m and 22 m. Sedimentary facies is mainly offshore facies, subfacies are foreshore facies and shoreface facies, microfacies are beach bar, beach sand and sea mud. The lithologies are mainly terrigenous-bioclastic limestone, some feldspar-quartz sandstone and quartz sandstone. The formation is related to meteoric water and bioclastic corrosion, the main diagenesis is carbonate cementation. Shoreface beach sand is affected by wave washing, widely distributing in the plane of sandstone sediments. It has the characteristics of loose cement, good sorting and common bioturbation. There are some shale strips locally, developing wavy bedding. As sea level rose, the water deepened and water power weakened, there formed widely distributed sea mud, a set of fine-grained sediments. The lithology is mainly mudstone, silty mudstone. The bioturbation is common [1].

According to the characteristics of macroscopic and microscopic geological causes, genetic types and sealing ability, the interlayer is divided into three types that are muddy interlayer, calcareous interlayer and petrophysical interlayer. Vertically, the main group in study area forms sets of interlayer and the reservoir heterogeneities is very strong. Actual production shows that the interlayer plays an important role in blocking bottom water and the interbeds are restraining barriers but cannot completely block, which affect the remaining oil distribution and partly restrict the research of improving liquid production and adjusting wells and so on. The calcareous interlayer is emphasis and difficulty, which have an important influence on the study of tapping remaining oil. Affected by sedimentary environment and diagenetic conditions, there are three sets of calcareous interlayers, the top set, the middle set and the bottom set. The top and bottom sets are interlayer which develop continuously and have large thickness, stable distribution. The scattered interbeds are the middle set, which are thin and unstable. The muddy interlayer and petrophysical interlayer heterogeneously distribute. Both are thin.

3. L_1-L_2 combined norm constrained inversion

3.1. The basic principle

Due to the limited resolution of seismic data, it is very difficult to predict thin calcareous and muddy interlayer, largely uncertain to meticulously describe interlayer. The processing seismic data with L_1-L_2 combined norm constrained inverse can improve the vertical resolution and precision.

The constrained sparse spike inversion (CSSI) actually uses deconvolution principle to calculate the amplitude and time of reflection coefficient with characteristics of sparse distribution from seismic channel with noise. On the assumption that the reflection coefficient is sparse, and the seismic record is the convolution of wavelet and reflection coefficient plus noise. The mathematical expression follows [2–4]:

$$s(t) = w(t)*r(t) + n(t) \tag{1}$$

Where, *s (t)* is seismic records; *w (t)* is seismic wavelet, *n (t)* is linear noise.

The reflection coefficient sequence that is estimated by band-limited seismic traces and wavelet can have infinitely many solutions. These solutions can be tally with seismic traces. To solve a multi-solution problem, it is necessary to find a unique and best solution which should meet the following conditions:

(1) .Matching with seismic trace
(2). Meeting the conditions
(3). Most likely to be correct

The most common approach is to give a priori assumption of probable solutions. The priori assumption of constrained sparse spike inversion is reflection coefficient, which is composed of sparse pulse sequence.

L1-L2 combined norm constrained inverse applies the clogarithmic barrier algorithm based on interior point methods to transform nonlinear optimization problem into linear optimization problem. Then solve the reflection coefficient by using linear programming algorithm. The objective function is:

$$\|w(t) \times r(t) - s(t)\|_2 + \alpha\|r(t)\|_1 \tag{2}$$

where, α is an adjusting parameter in formula 2.

The front half part of objective function is restrained by L_2 norm, which can ensure the synthetic seismogram generating from convolution is Similar with the practical seismic. The L_1 norm is applied to restraint reflection coefficient at the second part to make it sparse. Because of the noise seismic data and the changing seismic wavelet in different space, the synthetic seismogram cannot be fully consistent with actual data in the actual calculation. By adjusting the parameter a, not only the reflection coefficient r is sparse, but also the synthetic seismic data is consistent with real seismic data possibly. The residuals between the synthetic and real seismic data are considered noise.

It can solve the mathematical programming problem by disturbing clogarithmic barrier algorithm based on interior point methods, and calculate the reflection coefficient sequence and get the inversion results on the basis.

3.2. Comparison between logging data and seismic data

On the basis of precisely demarcating time–depth relationships, a conclusion is shown in Fig. 1, the comparison chart of logging data, synthetic seismogram, pure wave seismic data and inversion results, the top surface cannot be separated from the bottom in sandstone and mudstone at objective intervals (3–6), stratigraphic details basic lose because the pure wave profile is affected by tuning effects of seismic wavelet. At reflection coefficient profile, the influence of seismic wavelet factors is eliminated; the vertical resolution of seismic data is improved. Compared to logging curve, the reflection coefficients coincide with the top and bottom of sand and shale.