Application of tomographic static correction technology constrained by micro logging in 3D splicing processing

Introduction

Sulige gas field is the key block of Changqing gas field development in recent years. In order to cooperate with the well location deployment of the gas field, two pieces of 3D seismic data collected in 2014 and 2015 are used for splicing processing and interpretation to improve the success rate of reservoir prediction.

The surface conditions of the study area are complex and changeable, and the terrain fluctuates greatly. In the northern desert and grassland area, the terrain is relatively flat, with an altitude of 1200m-1350m; The Southern Loess Plateau is characterized by crisscross gullies and crisscross ridges, with an altitude of 1060-1400m. The near surface structure of the study area is complex. The low velocity layer is quaternary mobile sand dunes and modern river deposits. The thickness is 1-130m, the depth of phreatic surface is 2m-80m, the velocity of low velocity layer is 200-900m/s, and the velocity of low velocity layer is 1000-2000m/s. Complex seismic geological conditions restrict the improvement of data quality, become the technical bottleneck of this 3D splicing processing.

Processing idea of tomographic inversion static correction constrained by micro logging

Different static correction calculation methods and parameters of 3D seismic data collected at different times lead to serious static correction closure error between 3D blocks at the junction of work areas, which directly affects the structural morphology. If we can’t solve the problem of seismic data splicing between work areas, we can’t carry out fine structural interpretation and reservoir inversion, let alone the identification and evaluation of lithostratigraphic traps. Therefore, the closure error between the blocks of the two 3D seismic data can be eliminated through the unified calculation of the static correction, thus a good foundation for the subsequent processing is provided.

In order to obtain the accurate near surface velocity model and static correction, the micro logging constrained tomographic static correction method is used in this splicing processing. In order to reduce the multiplicity of inversion, the prior constraint condition is added and the tomographic inversion is constrained by the surface structure model information of micro logging.

In the first break tomography forward modeling, the high-precision fast stepping algorithm based on wave equation is used to calculate the travel time and ray path of the first break wave, so as to improve the calculation accuracy of ray tracing, and meet the severe undulating terrain conditions and lateral velocity changes in the complex areas of desert and Loess Plateau. The accuracy of the inversion is further improved by using wavelet transform in the inversion of the tomographic. The method can solve the problem of 3D static correction and improve the quality of seismic imaging.

Principle of constrained tomographic inversion method

The tomographic static correction method takes the first break information of seismic records (including direct wave, refraction wave, gyration wave, etc.) as the inversion target. Through the combination of the three waves and the adaptability of the tomographic method to the lateral variation of the medium, the matrix equation (1) is solved iteratively. According to the error between the forward first break time and the actual travel time, the velocity model is modified to achieve the required error accuracy.

\[
A\Delta S = \Delta T
\]  

In this equation, \(A = (a_{ij})_{M \times N}\) is the ray path set matrix, \(T = (t_1, t_2, \ldots, t_M)\) is the travel time matrix stands for the first break time picked up, \(\Delta S = (\Delta s_1, \Delta s_2, \ldots, \Delta s_N)\) is the matrix of correction value of underground medium’s slowness. Tomographic inversion is a non-linear problem. The small disturbance during travel is linearly related to the small change of slowness (velocity) model. In order to obtain stable inversion results and fast convergence, the interpretation results of micro logging are used to constrain the initial velocity model, and the nonlinear inversion method is adopted. After iterative correction of tomographic inversion, the correct velocity model is gradually approximated. \(\tilde{S} = (\tilde{s}_1, \tilde{s}_2, \ldots, \tilde{s}_L)\) stands for some known approximate velocities obtained from micro logging, the constraint equations established by \(L\) constraints are as follows:
\[ \Delta S = F \]  \hspace{1cm} (2)

In this equation, \( C = (c_{ij})_{L \times N} \) is a Jacobi matrix with \( L \) known constraints, \( c_{ij} = \begin{cases} 1 & i = j \\ 0 & i \neq j \end{cases} \) and the velocity inversion residual error is \( F = (f_1, f_2, \ldots, f_L)^T \), then formula (2) can be simplified as:

\[ \Delta S_i = f_i = \xi_i - s_i, \quad i = 1, 2, \ldots, L \] \hspace{1cm} (3)

In this equation, \( \xi_i \) is known, \( s_i \) is the slowness value of the last iteration of the unit \( i \). \( \Delta T = (\Delta t_1, t_2, \ldots, \Delta t_N)^T \) is the travel time residual matrix. If (1) is constrained by (2), the objective function of regularization inversion is as follows:

\[ e = e_1 + \lambda e_2 \rightarrow \min \] \hspace{1cm} (4)

In this equation, \( e \) is the general goal, \( e_1 = (A \Delta S - \Delta T)^T (A \Delta S - \Delta T) \) is the objective function of observation data, \( e_2 = (C \Delta S - \Delta F)^T (C \Delta S - \Delta F) \) is the objective function of prior constraints, \( \lambda \) is the weight factor.

When the total objective function \( e \) is minimum, the calculated result \( \Delta S \) is the optimal solution. The formula \( \lambda = 0 \) is equivalent to unconstrained. The larger \( \lambda \) is, the greater the weight of constraint information of micro logging in the total objective function. \( \lambda \) reflects the similarity between the inversion results and the known information. Weight factor \( \lambda \) needs to be determined according to the test results to obtain the best inversion results.

**Application of well constrained tomographic inversion**

**Establishing initial velocity model based on micro logging**

Small refraction and micro logging are the main methods to investigate the near surface structure in the field. The results show that the near surface structure and parameters obtained by micro logging are more accurate, especially for the surface structure with thick low velocity drop layer and large velocity variation, its calculation accuracy is better than other near surface structure investigation methods. However, the sparsity of the survey points is difficult to control the lateral change of the surface structure in the study area. According to the investigation and analysis, there are 160 historical surface points in the 3D splicing data with a full coverage area of 420 km². For individual contradictory surface survey data in the work area, the relatively new micro logging data are selected, and the mutation points are eliminated, and the relatively gentle change points are retained. As shown in (a) and (b), the surface velocity and thickness models before and after adjustment are respectively presented, and the influence of abrupt change point is eliminated. In order to improve the stability of inversion model to a certain extent, micro logging data from two 3D work areas are interpolated to establish surface model.

![Figure 1](https://via.placeholder.com/150)

*Figure 1* Comparison of surface model before (a) and after (b) adjustment in 3D splicing area

**Constrained tomographic inversion of micro logging**

The tomographic inversion assumes that the near surface velocity is composed of velocity units, and a small rectangular grid model is used to adapt to the severe terrain fluctuation or lateral velocity change, so as to improve the inversion accuracy. The grid size of the study area is consistent with the panel size, and the longitudinal step size is one fourth of the track spacing of 10m.

Take the micro logging velocity and thickness information adjusted in Fig. 1b as the initial model for the first break tomography inversion. In the process of micro logging constraint, the reasonable weight factor \( \lambda \) is determined by analyzing the data of low velocity zone in splicing area. The wavelet
transform is applied to the decomposition and reconstruction of velocity model, which not only meets the requirements of imaging resolution, but also takes into account the reliability of inversion. Figure 2 shows the comparison of near surface model before (a) and after (b) micro logging constrained in the study area. The accuracy of constrained model is significantly higher than that of unconstrained first break tomographic inversion. The shallow velocity model is closer to the real surface condition, more consistent with micro logging, more precise description of model details, and more stable bottom boundary of low deceleration zone, which is conducive to improving the effect of constrained static correction.

Figure 2: Comparison of near surface model before (a) and after (b) micro logging constrained.

Figure 3: Plane attribute analysis of 3D splicing area, (a) is elevation, (b) is the static correction of unconstrained tomographic inversion, (c) is the static correction of constrained tomographic inversion of micro logging.

From the inversion of near surface velocity model, pick up the top interface of high-velocity and smooth it, determine the datum and replacement velocity, then calculate and apply the static correction. Figure 3 shows the plane attribute analysis of 3D splicing area, (a) is elevation, (b) is the static correction of unconstrained tomographic inversion, (c) is the static correction of tomographic inversion constrained by micro logging. From the plane attribute analysis, the static correction of tomographic inversion constrained by micro logging has higher correlation with surface elevation. Figure 4 shows the static correction stack effect analysis before and after splicing of overlapping parts. (a) is the initial stack without applying static correction after splicing, and (b) is the stack after applying static correction before splicing. It can be seen that there is closure error at splicing. (c)
shows the static correction stack of unconstrained tomographic inversion after splicing, and the static correction closure problem is eliminated at the splicing after processing. (d) shows the static correction stack of tomographic inversion constrained by micro logging after splicing. After splicing, the problem of closure error is eliminated, the continuity of in-phase axis is better, the detail imaging accuracy is higher, the signal-to-noise ratio of the section is also significantly improved.

Figure 4 Stack effect analysis of static correction before and after splicing overlapping parts, (a) is the initial stack without applying static correction after splicing, (b) is the stack after applying static correction before splicing, (c) is the static correction stack of unconstrained tomographic inversion after splicing. (d) is the static correction stack of tomographic inversion constrained by micro logging after splicing.

Conclusions

Based on the difficulties of static correction processing of 3D splicing data in Sulige area, the author puts forward the idea of static correction processing of constrained tomographic inversion by micro logging. The surface structure information of micro logging is used as the initial model to constrain the tomographic inversion of first break. At the same time, the wavelet transform is applied to tomographic inversion, which greatly improves the accuracy and reliability of inversion. Static correction method of constrained tomographic inversion in micro logging has good fidelity for large amount of 3D splicing processing, which lays a good data foundation for subsequent processing. The processing results meet the needs of pre stack reservoir prediction and fracture distribution research in 3D contiguous area.

References