Application of Density Curve Reconstruction Technology in Seismic Inversion

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Abstract: Density curve is one of the indispensable data for impedance inversion. However, the limitation of density logging often results in the loss of density curve. The common solution is to use empirical formulas, such as Gardner formula, to reconstruct the density curve, but the effect is often not ideal. In order to solve this problem, the authors propose to reconstruct the missing density log curve by means of multiple linear regression, and then carry out geostatistical inversion by using the curves with high correlation between natural potential, gamma, resistivity and density curve. Finally, by comparing the inversion results of the two parameters, the inversion results of the former have a significant improvement in the coincidence rate of the posterior wells and the horizontal distribution of sandstone, which proves that the method has a significant application effect in reservoir prediction and lithologic sensitivity.

Key words: multiple linear regression; curve reconstruction; geostatistics inversion; reservoir prediction.

1. Introduction
Geostatistical inversion technology combines geological, logging and three-dimensional seismic data with dual advantages of high vertical resolution of logging data and high lateral resolution of seismic data, which can effectively identify thin reservoirs[1]. Reservoir prediction using wave impedance inversion results generally requires that the reservoir's wave impedance can effectively distinguish reservoirs from surrounding rocks. Equation (1) is the general formula for wave impedance inversion:

\[ S(t) = R(t) * W(t) + N(t) \]  

(1)

Where \( S(t) \) is the seismic record, \( R(t) \) is the reflection coefficient of the subsurface interface, \( W(t) \) is the given seismic wavelet, and \( N(t) \) is the noise [2].

Seismic reflection occurs only at interfaces with different velocities and densities (i.e. different impedance). which is a necessary condition for seismic reflection: if the velocity \( v \) and the density \( \rho \) are known, the reflection coefficient at the i-th interface \( R_i \) is:

\[ R_i = \frac{(\rho_{i+1} v_{i+1} - \rho_i v_i)}{(\rho_{i+1} v_{i+1} + \rho_i v_i)} \]  

(2)

However, in some areas, due to complex reservoir space and logging curve acquisition conditions, a large number of density curves are missing or even if there is a density curve, there are too many influencing factors in the acquisition process, and the density curve is on the reservoir characteristics,
the reflection is not obvious. Therefore, reconstruction of the density curve is required for this part of the density curve (missing or poor quality).

Density curve reconstruction methods include conventional collapse correction method, Gardner formula method and curve double scale method. The Gardner formula is a widely used formula for obtaining density using sonic curves [3]:

\[ \rho = av^b \]  

\(a, b\): Undetermined coefficient; \(\rho\): density; \(v\): velocity.

2. Principle of multiple linear regression density reconstruction technology

2.1. Mathematical Principles

Multivariate linear regression is a statistical method to establish linear or non-linear mathematical relationships among multiple variables, which reflects the law that the number of a phenomenon or thing changes accordingly with the number of many phenomena or things. Suppose a dependent variable \(y\) is affected by \(k\) independent variables \(x_1, x_2, \ldots, x_k\), and the observed values of \(n\) groups are \((y_{\alpha}, x_{1\alpha}, x_{2\alpha}, \ldots, x_{k\alpha})\), \(\alpha = 1, 2, \ldots, n\). Then, the structural form of the multiple linear regression model is:

\[ y_{\alpha} = b_1x_{1\alpha} + b_2x_{2\alpha} + \ldots + b_kx_{k\alpha} + \varepsilon_{\alpha} \]  

\(b_1, b_2, \ldots, b_k\): pending parameter; \(\varepsilon_{\alpha}\): random variable [5-9].

In this study, the “multivariate” in the above formula is a variety of logging curves, and the response equations of various logging curves and density curves are established by multiple linear regression. The response between the density curve and other well logs can be represented by a variety of models, including linear, exponential, logarithmic, exponential, and polynomial models. According to the specific conditions of the study area, the reservoir characteristics parameters are selected through experiments to reconstruct the required well logs and the most ideal model [10-14].

3. Application Examples

3.1. Density Curve Reconstruction

Fig. 1 is the sensitivity analysis chart of logging curves in the study area. The analysis results show that the sonic time difference curve has poor ability to distinguish sand and mudstone, and that sand and mudstone can be distinguished in areas with good density, natural potential and resistivity.

![Fig. 1 Curve sensitivity analysis diagram]
3.2. Density Curve Reconstruction

Taking well 5G33-45 as an example, Fig. 2 is the intersection diagram of the well density curve and other curves. The density curve has a good relationship with resistivity, spontaneous potential and natural gamma ray curve, and the correlation coefficient is above 0.8, while the correlation coefficient between acoustic time difference and density curve is poor, and the correlation coefficient is less than 0.3.

Through the analysis and attempt of logging data, the density curve is reconstructed by resistivity, spontaneous potential and gamma ray, logarithm of resistivity, spontaneous potential and gamma log data are taken as independent variables, density log data as dependent variables, and multivariate linear fitting is carried out by SPSS software to obtain the reconstructed characteristic curve. The correlation between reconstructed curve and original density curve is analyzed, and the well data with good correlation is selected to re-fit. Finally, the fitting formula of reconstructed density by multiple linear regression in this work area is obtained:

\[
\text{DEN}\_\text{CHG}=1.066-0.068\ln(\text{RLLD})+0.014\text{GR}+0.009\text{SP}
\]  

(5)

Fig. 3 is the effect analysis of reconstruction curve. The correlation between the reconstruction density curve and the original curve is good. The sensitivity of sand and mud is better than the quasi-density curve calculated by Gardner formula. The reconstruction density curve can reflect the reservoir characteristics.
Fig. 3 Comparison of reconstructed curves

(a) Inversion attribute plane map obtained by Gardner reconstruction method
4. Conclusion

(1). The resistivity and spontaneous potential optimized by multiple linear regression density reconstruction technology can effectively reflect the reservoir characteristics when logging curves are reconstructed by adding more abundant geological information, so that reconstructed density curves are more in line with the actual geological conditions.

(2). Multivariate linear regression density reconstruction technology improves the inversion accuracy of geostatistics in this work area and is more conducive to reservoir prediction.

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