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Application of Multi-parameter Lithological Seismic Inversion to Identify Limestone Aquifer

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Abstract L4 limestone in YQ Mine is a confined aquifer in which karst fissure develops heterogeneously. Its spatial distribution and thickness cannot be identified by drilling results and conventional seismic interpretation ways. In this paper, different types of log curves were analyzed and merged, and then multi-parameter lithological seismic inversion, restrained by the curves, was completed. Finally, pseudo-impedance volume was obtained. In this pseudo-impedance volume, the spatial distribution and thickness variation of L4 limestone were interpreted, and the inversion result was consistent with the underground verification, providing an important hydrogeological basis for mine water control.
Keywords mine water control, limestone aquifer, log curve merging, multi-parameter lithological seismic inversion

Introduction

Limestone in Taiyuan Formation, as one of main aquifers in North China type coal field, has high water level and abundant water quantity. Furthermore, it is easy for the limestone aquifer to form karst caves or conduct other geological structures such as collapse column, threatening coal mining seriously (Cui 2009). L4 limestone in YQ Mine, a thick limestone aquifer in Taiyuan Formation, exists between No.7 coal and No.17 coal and develops collapse columns that connect Ordovician limestone aquifers. As a result, in order to mine safely, before mining, it is important to identify the spatial distribution and thickness of L4 limestone.

Because limestone isn’t good reflection interfaces, the information of L4 limestone cannot be acquired by conventional seismic data. Seismic inversion technology, an important means of lithological seismic exploration, uses logs of high vertical resolution to constrain seismic data of good lateral continuity, and after inversion calculation, the resulting data volume can indicate information of formation and lithology (Yang 2003). Application basis of conventional seismic inversion depends on impedance difference between the target layer and surrounding rock. In many cases, little difference of them makes it difficult for horizons correlation. Hardly can geological problems be solved only by little impedance difference. Analysis finds that some logs such as apparent resistivity log, natural gamma log are sensitive to distinguish lithology. Then with seismic data and multiple logs information, multi-parameter lithological seismic inversion can be achieved, which can predict more information about formation and lithology than before (Zhang 2008, Zhang 2009).

Characteristics of log curves

Generally speaking, geophysical logs in coal field include apparent resistivity log, density log, natural gamma log and spontaneous potential log. In coal measure strata, the main lithologies of coal or limestone’s roof and floor are mudstone and sandstone. Limestone, mudstone and sandstone have features of high density and high velocity, while coal has low density and low velocity. Therefore, it can identify coal, but not limestone, by using density curve and acoustic curve. Analysis shows that the resistivity of limestone is far greater than mudstone and sandstone, so apparent resistivity log curve can distinguish limestone and surrounding rock, shown in fig. 1. So log curves which have limestone and coal's anomalies respectively can be merged to get pseudo-density curve, reflecting limestone aquifer and coal in the meantime.

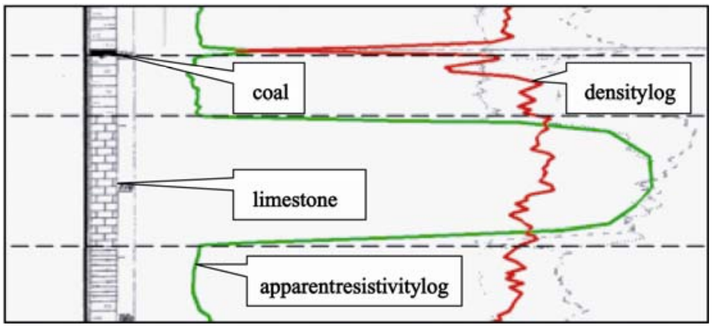

***Fig. 1** log characteristics of limestone*

Log curve merging

Log curve normalization

Because both log curves have different dimension, different normal formulas are needed. Extreme normalization method is utilized here (Wang 2005).For the apparent resistivity curve *R*, limestone shows higher anomaly than others, so it is normalized by formula (1)

$$R_i = \frac{R_i - R_{\min}}{R_{\max} - R_{\min}} \tag{1}$$

Where R_i is a resistivity value at the curve, $R_{\max}$ is the maximum resistivity, and $R_{\min}$ is the minimum resistivity.
For the density curve ρ, coal has relatively low density, so it is normalized by formula (2)

$$\rho_i = \frac{\rho_{\max} - \rho_i}{\rho_{\max} - \rho_{\min}} \tag{2}$$

Where R_i is a density value at the curve, $R_{\max}$ is the maximum density, and $R_{\min}$ is the minimum density.

Log curve merging

Normalized apparent resistivity curve *R* and density curve ρ, are given different weighted factors *a*, *b*, and then merged to get new curve *X*.

$$X = aR + b\rho \tag{3}$$

Where $a + b = 1$

Pseudo-density curve forming

Curve *X* is normalized by formula (1). After linear transformation that makes it close to the range of coal measure strata, pseudo-density curve ρ^* is obtained.

$$\rho^* = mX + n \tag{4}$$

Where *m* is zoom factor, *n* is offset factor, and the value of ρ^* is [*n*, *m*+*n*].

Model based seismic inversion

The foundation of seismic inversion based on model is seismogram convolution. In essence, starting from log information, an initial impedance model is established according to well data and time-depth relationship. Based on this model, synthetic seismic profile is compared with the actual profile, and then the model is constantly revised, so that the final synthesis can be the best approximation of the actual profile and the final geological model is closest to the real geological situation.

Application of multi-parameter lithological seismic inversion

Because L4 limestone has an obvious anomaly on the apparent resistivity curve, pseudo-density curve was obtained by using log merging method, which can reflect both coal and L4 limestone at the same time. Obvious anomaly is useful for multi-parameter lithological seismic inversion.

Following the pseudo-density curves acquired, with inversion parameters in Table 1, constrained inversion was carried out by applying the method of inversion based on model to obtain inversion data volume. Fig. 2 described the pseudo-impedance profile across Well No.22. In fig. 2, the impedance value of coal No.7 was low, about 4500~5400 $g/cm^3 \cdot m/s$, shown as green in the impedance profile, while the impedance value of L4 limestone was high, about 11500~14000 $g/cm^3 \cdot m/s$, shown as purple in the impedance profile. With different colors reflected by L4 limestone and surrounding rock, the roof and floor of L4 can be tracked continuously, so that L4 limestone's distribution feature can be predicted.

Table1 *Inversion parameters*

Inversion type	Impedance inversion
Seismic data	post-stack migration data
Curves used	ρ^*, V_P
Inversion method	model based
Constraint condition	hard condition: ±25%
Wavelet type	statistical; length:100 ms
Number of iterations	50

Spatial distribution prediction of L4 limestone

Velocity information of the whole survey was got by interpolation method, combined with well data and floor horizon time of L4 limestone, which was acquired from impedance profile. After time-depth conversion, time information on the seismic profile was converted into geological depth information that generated the floor contour map, showing L4 limestone's spatial distribution.

Thickness variation of L4 limestone prediction

Time difference of roof and floor horizon of L4 limestone was calculated by their travel time information. As L4 limestone' thickness in the wells of this survey was known, with time difference of roof and floor of L4, interval velocity of L4 limestone in the wells was calculated. Thickness contour map of L4 limestone was drew by using two-way time difference and velocity information.

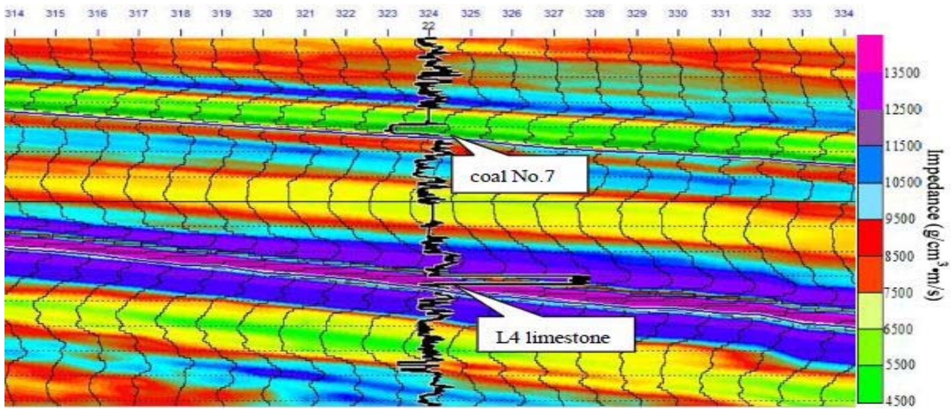

Fig. 2 *multi-parameter lithological inversion profile across Well No.22*

Verification of L4 limestone's spatial distribution and thickness variation

The elevation of L4 limestone is -772.05 m and its thickness is about 8.2 m in Well E21 that didn't participate in multi-parameter inversion. From the prediction, the results are -774.5 m and 9.1 m, which are very close to the actual situation.

Conclusions

(1) Application base of multi-parameter lithological seismic inversion is kinds of physical difference, such as apparent resistivity, spontaneous potential and natural gamma. Through analyzing log curve response of different lithologies in the survey, apparent resistivity curve and density curve can be merged into pseudo-density curve, reflecting both coal and limestone aquifer.

(2) Compared with conventional seismic inversion, multi-parameter lithological seismic inversion is more efficient in dealing with specific lithology problems. From the inversion profiles, L4 limestone horizon information is identified clearly and the spatial distribution and thickness of L4 limestone is obtained finally, which gives an important guiding significance for mine water control.

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