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Application of Multiple Wells -Constrained Sparse Pulse Inversion Technology in Coalfield 3D Seismic Prospecting

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Abstract

The paper used logging data combined with 3D seismic data and interpretation results to carry out multiple well-constrained sparse-spike inversion .Layer of wave impedance corresponding to coal seam is determined by calibrating horizon, and then the thickness of the layer of wave impedance is derived and fitted to the coal seam thickness intersected by drilling, finally the distribution regularities of coal seam in 3-D seismic survey area is found out. Practices have verified that the method produces ideal effect..

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Keywords: impedance; seismic inverse; thickness of coal seam

1. Introduction

At present three-dimensional seismic exploration has become the indispensable approach for coal exploration, largely replaced the traditional geological exploration method. 3D seismic data in horizontal direction have densely covering degree and good reservoir-distinguishing ability, but because of the influence of earth filtering and seismic wavelet composite as well as noises on acquisition of seismic data, the vertical resolution is limited, so seismic data can not be used directly to calculate seam thickness. Borehole data have extremely high vertical resolution, but are sparse and uneven in horizontal distribution, so borehole interpolation method is often inaccurate in calculation of coal reserves, influencing reserve prediction. Seismic wave impedance inversion technology has been used to predict coal thickness by

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combining seismic data and logging data and there are some application cases in coalfield [1]. In an area of Inner Mongolia, coal seams are numerous and thin, it is difficult to correlate seams and to calculate coal thickness. We havecarried out sparse pulse inversion and further deepened study on interpretation, actual drilling verified that the error was very small.

2. The basic principle of sparse pulse inversion

At present sparse pulse inversion method is a kind of more important seismic wave impedance inversion method. In the maximum likelihood the convolution and L1 norm deconvolution based on the study of deposition, formed sparse pulse wave impedance inversion method.

At present JASON seismic inversion software system, established sparse pulse inversion function type on seismic convolution and the expression of the transcendental material constraint relation in inversion equation is as follows:

$$F=L_p(r)+\lambda L_q(s-d)+\alpha^{-1} L_1(\Delta Z)+\beta_{in} L_1(\Delta z-\Delta Z_{in})+\beta_x L_1(\Delta z-\Delta Z_x)$$

Where: $d = w * r$; r — reflection coefficient; d — seismic records; w — wavelet; s — synthetic record; λ —weights factor not matching data; z —wave impedance; p —reflection coefficient module q —not matching module of earthquake; α、β_{in}、β_x —relative uncertainties; in、x —vertical, horizontal line number; $\Delta z = z - Z_{trena}$; $L_p(r)$ —not matching of reflection coefficient ; $L_q(s-d)$ —not matched seismic; $L_1(\Delta z-\Delta Z_{in})+L_1(\Delta z-\Delta Z_x)$ —soft space constraints.

3. Key technique and steps of sparse pulse inversion

In an area of Inner Mongolia, seismic data have relative high SNR, density and speed of logging data were reliable, wave impedance inversion was used to calibrate coal seam and to predict coal thickness.

3.1. Logging data preprocessing

Because logging had been conducted by 4 companies, before inversion, logging curves needed to be standardized. Logging curve standardization mainly included two steps. The first step is to check original data, eliminating abnormal point of target interval on logging diagrams of each well. The second step was to conduct balance correction, on the basis of ensured quality of original data, the basic value of different logging diagrams were normalized according to unified target intervals. Concretely, a suitable standard layer, i.e. layer with evident lithological and electrical properties, stable distribution an certain thickness was selected, and according to geological tasks, target intervals were selected.

3.2.Seismic wavelet extraction and production of synthetic record

Wavelet extraction is the basis of wave impedance inversion, it can determine corresponding relation about the geological interface and seismic reflection, in the same time it is the key for knowing the characteristics of wave set of seismic data of the surveyed area. It mainly includes wavelet phase, frequency and amplitude. The polarity and the phase of seismic wavelet are directly related to the calibration of synthetic of record and influence the variation of wave impedance for inversion.

When extracting wavelet by combination of seismic channels beside wells and wells, attention should be paid to the following points:

Time interval with seismic data of good quality and higher SNR within the studied target interval is selected as time widow for wavelet extraction, generally the length of the time window

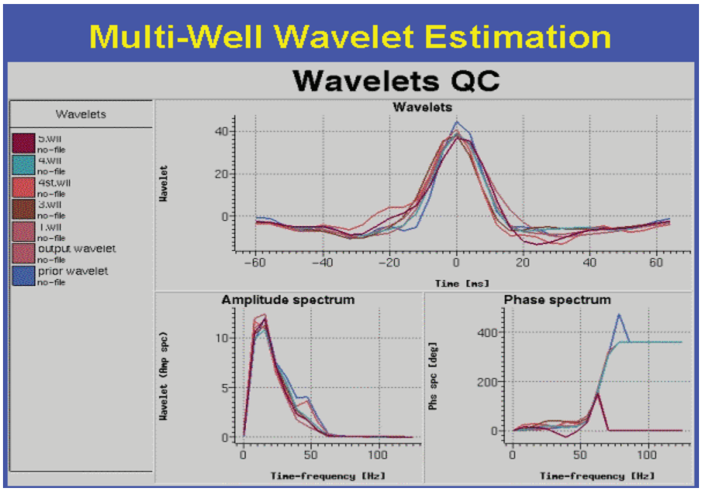

Fig 1. Sketch of seismic wavelet extraction

is three times longer than that of wavelet, if the time window is too small, stable wavelet can not be obtained.

The wavelet length must be appropriately selected (usually 100ms), in shallow layer, seismic frequency band is wider, wavelet may be shorter; in deep layer, seismic frequency band is narrower, wavelet may be slightly longer.

The quality of extracted wavelet must be judged from waveform, amplitude and phase spectra, stable waveform, smooth single peak of frequency, stable phase within effective frequency band are required. The extracted wavelet from multiple wells in a working area should be that shown in Fig.1.Finally, the integrated wavelet used in inversion is determined..

Figure 2 is the result of calibration in well zkkj9-30 in a coalfield of Inner Mongolia. From the figure, it can be seen that the synthetic record corresponds well to seismic channels nearby well, the base of coal seam corresponds to a strong wave peak and has good continuity .With aid of high resolution inversion profile, identification of the horizontal thickness of coal seam can be carried out.

3.3 .The build-up of low frequency model

The low-frequency constraint model is an important link in the process of constraint inversion, interpolation and extrapolation of the constraint information from structural horizons, faults and wells are realized through initial constraint model, influencing directly the results of inversion.

Vertically logging data constitute basic constraint, horizontally geological horizons as basic constraint for setting up sedimentary model and contact relation of strata. the concrete methods to do this are as follows:

① To build up a table of sedimentary sequence of strata at upward order;

② When there is a fault, to build up firstly the lower block the upper block;

③Horizon can be truncated by definition to cut off the other layers

④Fault can be defined by the basal serial numbers and cut off by underlying layers or underlying fault.

⑤ To combine faults in a mining district, to build up the trend surface of fault to control spatial extrapolation of fault;

⑥ Internal structure of strata can be changed by defining trend surface;

⑦Local fault or horizon are controlled by defining the second fitting surface.

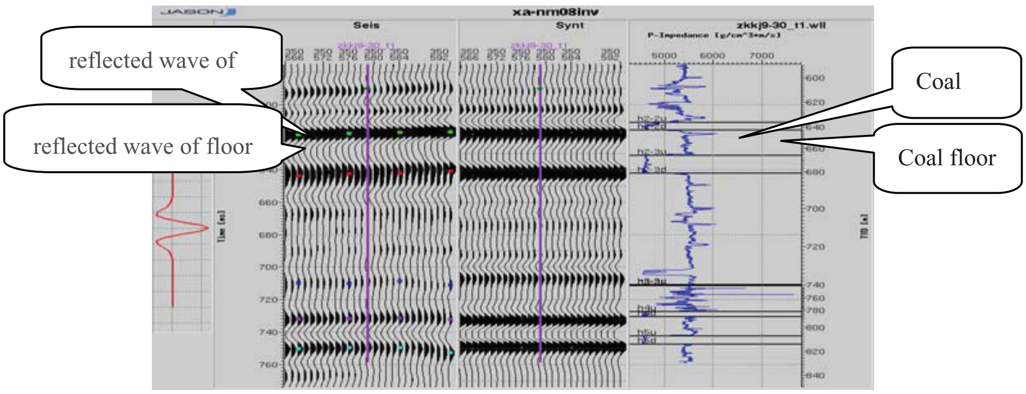

Fig 2.Sinthetic record of well zkkj 9-30

3.4. inversion

Figure 3 shows the experimental selection of the parameters for sparse pulse seismic wave impedance inversion, several parameters shown here are equations with Lambda as variable. The most important ones are signal-to-noise ratio (the top left corner), and the correlation of well curve (top-middle) and normalized standard deviation of well diagram (top-right). Others show sparse value (left lower) and merger error term (right lower). It reflects seismic matching degree of synthetic seismic channels produced by acoustic impedance model value and wavelet convolution with actual seismic channels, low value emphasizes the minimum sum of reflection coefficient, can cause less details in inversion profile, low resolution small, big residual error, but too big value emphasizes too much minimum residual error to make the synthetic record coincide to original seismic channels, can make seismic noise added into to the inversion result profile, and in the same time sparse reflection coefficient, i.e. the low-frequency components of wave impedance, so, and it is important to conduct analysis and testing of its sensibility, to find out a suitable value, to not loss low frequency background while keeping details in inversion profile. In the coal fields, usually 0 ~ 20 is taken.

4. Application

4.1. Improve vertical resolution of coal reflection wave

In a mining area of Inner Mongolia, the major mineable seams are seam 2-2 , 2-3, 3-3, 4 and 5 . Figure 4 is conventional seismic time profile which has high SNR and good continuity of seismic wave event but with dominant frequency of only 60Hz. It could not define the position of seam roof and floor. Figure 5 is the corresponding wave impedance profile, where dominant frequency

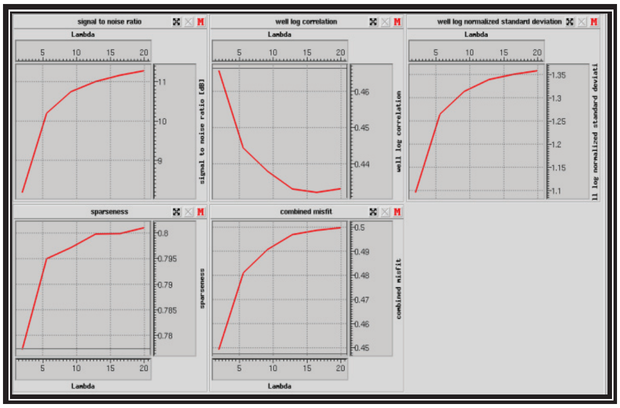

Fig 3. Experimental selection of parameters for sparse pulse wave impedance inversion

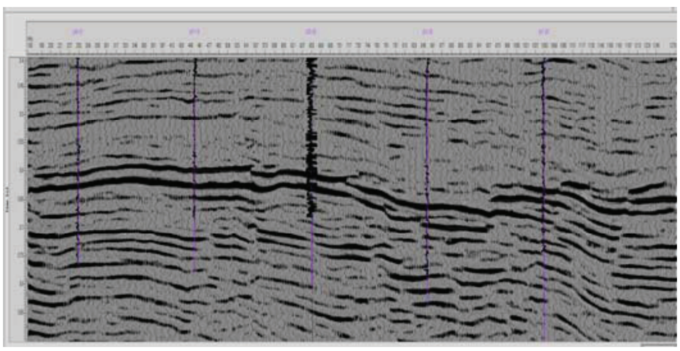

Fig. 4. Crossline 680 conventional seismic time profile

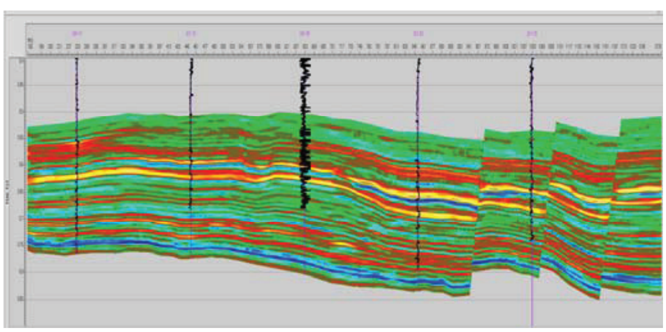

Fig.5. Crossline 680 wave impedance profile

increased significantly, the position of seam roof and floor is clearly visible. From the inversion profile, it can be seen that seam2-2 thickened gradually from the left to the sight, seam2-3 thinned gradually from the lift to the right.

4.2. Forecasting of coal thickness

In a coalfield of Inner Mongolia, there are 5 mineable seams, the thickness of seams ranges from1.85m to15.81m, the variation of coal seam thickness could not be discerned in conventional seismic profile. While the wave impedance profile reflected the variation of wave impedance of strata, the characteristics of coal seams was obvious in coal bearing measures. There was big contrast of wave impedance between coal seams and surrounding rocks, so the variation of seam thickness could be accurately discerned.

The method of determination of seam thickness by wave impedance inversion is as follows:

①To make statistics of the range of wave impedance of coal seams in all wells, to classify wave impedance of wells lithologicall..

② To classify inversion data by using statistical range of wave impedance of coal seams, what falls in the range is coal, marked as 1, what is outside the rang is not coal, marked as 0.So, lithological classification of wave impedance of the whole area is obtained.

③ The second step is to give a time window to the seam to calculate, to make statistics of sampling points to calculate the thickness of coal seams according to boreholes.

Table 1 shows that 9 boreholes were pre-remained before conducting inversion in a coalfield of Inner Mongolia to verify the precision of prediction of seam thickness and interpretation of seam floor. From the table, it can be seen that the predicted seam thickness coincided well with actual seam thickness, the error was within 1.5%. the coal seam thickness was predicted by this method allover the area, Fig. 6 shows the results of prediction.

Table 1. 2-3 coal the actual thickness and predict thickness contrast table

Well number	2-3 coal			
	drill thickness	3d exploration thickness	relative error	error
ZKKJ0-30	11.05	10.4	-5.88235	-0.65
ZKX0-20	13.35	11.5	-13.8577	-1.85
ZKP0-18	12.66	11.5	-9.16272	-1.16
ZKX0-40	1.6	2.2	37.5	0.6
ZKKJ1-23	1.92	2.2	14.58333	0.28
ZKKJ5-30	11.62	10.2	-12.2203	-1.42
ZKX5-27	12.14	11.2	-7.743	-0.94
ZKKJ9-30	14.66	13	-11.3233	-1.66
ZKX9-29	16.23	15.1	-6.96242	-1.13

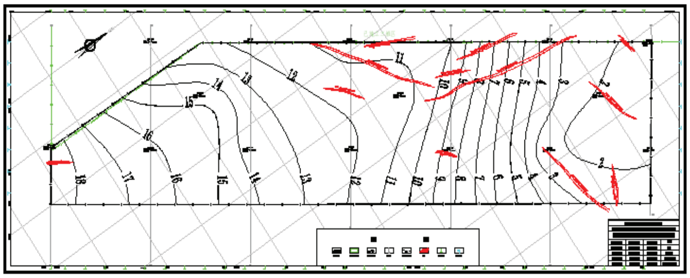

Fig.6. Sketch of prediction of thickness variation of seam 2-3 prediction schemes

5. Conclusion

Seismic inversion transforms seismic data into wave impedance data which can reflect lithological features of strata. Integrated interpretation by combining seismic wave impedance data and conventional seismic data can more accurately determine seam thickness the range seam splitting and mergence. During inversion, attention should be paid to matching wavelet extraction with seismic data. Inversion has strict requirements on horizon and fault, either of them can influence the result of inversion.

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