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Prediction Technique of Thin Sandstone Reservoir Affected by Dual Coal Seam

Xuecheng Jia[1], Feng Zhang[1], Xiaogang Li[2], Xin Yang[1], Baoquan Zhang[1], Hongyu Jiang[1], Xiaomin Zhang[1]

[1]Geophysical Research Institue, BGP, Zhuozhou, China
[2]Exploration, Development and Construction Branch Company of Coalbed Methane Co., Ltd., Xi'an, China
Email: jiaxuecheng@cnpc.com.cn

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Abstract

The reservoir thickness of S_2^3 sub-member of Lower Permain in the south of the eastern margin of Ordos Basin is thin and large variable i laterally. And the seismic response characteristics of sandstone reservoir are doubly interfered by the strong reflection sidelobes of overlying 5# coal seam and underlying 8# coal seam. In view of this situation, in order to better eliminate the influence of upper and lower coal seams and improve the accuracy of reservoir prediction, the strategy of de-strong seismic reflection and de-logging (curve) interference is adopted to carry out the matching of logging and seismic, and on this basis, uses the seismic waveform indication inversion to predict the thin sandstone. The steps are as follows: firstly, by using wavelet decomposition and reconstruction technology, select the seismic wavelet component that can better characterize the reservoir or oil & gas to reasonablely reconstruct seismic data, weaken the influence of the strong reflection from overlying 5# coal seam and underlying 8# coal seam, and highlight the response of weak seismic reflection of tight sandstone in Shan 2^3 sub-member; Then, the acoustic value of coal seam is corrected to that of mudstone on the logging curve to maintain the consistency of log-seismic data. This method realizes the effective identification of sandstone reservoir in Shan 2^3 sub-member, and greatly improves the target-penetrated rate and sandstone-penetrated rate of horizontal wells.

Keywords

Coal, Tight Sandstone, Strong Reflection, Inversion

1. Introduction

Daning-Jixian (the study area) is located in the southeast of Ordos Basin. The sandstone of Taiyuan Formation-Shihezi formation of Permian is the main reservoir, and the main coal-bearing strata are Carboniferous Benxi formation and Permian Shanxi formation. Among them, the lower sandstone of Shan 2^3 sub-member between the 5# coal seam of Shanxi formation and the 8# coal seam of Benxi formation is the main producing interval of tight gas in this area [1] [2]. It is the subaqueous distributary channel deposition with the characteristics of thin single-layer sand and large lateral change, and it is difficult to identify sandstone by using the seismic data with the dominant frequency of 35 Hz. At the same time, there are a few sets of coal seams above and below the lower sandstone of Shan 2^3 sub-member. The coal seam is characterized by the electrical characteristics of low p-wave velocity and low density, and generally forms a large acoustic impedance difference between adjacent strata and causes a strong reflection on seismic response, which interferes with the seismic response of sandstone reservoir near coal seam and makes it difficult to accurately predict sandstone. Considering the complex geological characteristics and the difficulties of reservoir prediction in the study area, the designed methodology includes: weakening the interference of strong seismic reflection from coal seams, eliminating the distortion of the logging curve affected by coal seams, conducting log-seismic matching, and then predicting the thin sandstone by seismic waveform indication inversion. The specific implementation steps are: 1) Decomposing the traces of original seismic data into a number of seismic wavelet components with different shapes and different dominant frequencies; combining the analysis of drilling and logging data, optimizing the reservoir sensitive components to refactor new traces; and eliminating the coal strong reflection to weaken the influence of the overlying and underlying double coal seams, so as to highlight the effective response of sandstone reservoir. 2) Modifying the coal acoustic value to mudstone acoustic value on logging curve to maintain the consistency of logging and seismic data. 3) Using the refactoring seismic traces and modifying logging curve as basic data input and conducting the prediction of sandstone reservoir by Seismic Meme Inversion. This idea provides a new choice for identifying the thin sand layer.

2. Eliminating Coal Strong Seismic Reflection

Wavelet decomposition and reconstruction is generally employed to remove coal strong seismic reflection. This technology was proposed by Mallat and Zhang in the 1990s. At present, it has been widely used in improving seismic resolution and complex reservoir identification, and has played an important role in reservoir prediction. The low-frequency and strong reflection of coal seam reduces the vertical and horizontal resolution of seismic reflection, shields the seismic response of the geological characteristics of the reservoir, and seriously interferes with the effective reservoir prediction. Wang Ya *et al.* [3] [4] [5] applied the wavelet decomposition and reconstruction technology to the oil & gas detection of coal-bearing sandstone reservoir, which effectively eliminated the interference of the low-frequency from coal seam and achieved the good results of oil-gas prediction. She Gang *et al.* [6] applied this technique to the prediction of gas-bearing sandstone reservoirs in Daniudi gas field, northern Ordos Basin, and also achieved good results.

In the traditional seismic data processing and interpretation, the basic seismic trace model is usually assumed to be formed by the convolution of single seismic wavelet and formation reflection coefficient. However, the frequency of seismic wave will be decreased with increasing depth of layer in actual production. The response characteristic, shape, frequency etc. of the seismic signals on different types of reservoir, non-reservoir, oil-gas bearing layers, non-oil-bearing layers are different. There are some differences between the traditional seismic track model and the actual situation. The multi seismic wavelet model can relatively improves the accuracy, that is, assuming a multi wavelet seismic trace model, the shape and frequency of seismic wavelet in the model will change with each reflection, and the seismic trace is formed by the stack of all these reflections. Based on the multi-wavelet seismic trace model, the seismic data is decomposed into multiple seismic wavelet components with different dominant frequencies and different shapes, and then, combined with the analysis of drilling and logging data, the relationship between the wavelet component seismic data with different types and frequency and reservoir characteristics or oil and gas response is correlated. The seismic wavelet component with the response of good reservoir or oil and gas characterization is selected to reconstruct the new seismic data, then the strong seismic reflection of coal seam can be removed from the original seismic data.

The seismic response of the lower sandstone of Shan 2^3 sub-member is near the peak reflection between the strong reflection of the 5# coal seam of Shanxi Formation and the 8# coal seam of Benxi Formation. The change of the sandstone seismic reflection is little laterally, and has no significant response to the thickness of sandstone. It is difficult to charactrize the sandstone reservoir by using original seismic data [7] [8] [9]. Generally, the velocity and density of P-wave and S-wave of coal seam are smaller than that of sand and mudstone. It is easy to form a strong wave impedance interface between the two, which causes a reflection loss of downward seismic wave and shields underlying reservoir response. In this paper, through forward modeling analysis, multiple wavelets with large amplitude differences can be reconstracted by decomposition, at different lithologic interfaces (**Figure 1**). The wavelets decomposed at the top of 5# coal seam and 8# coal seam can form strong main peak and side lobe (the top of 5# coal seam is brown wavelet, and the top of 8# coal seam is blue wavelet). The seismic reflection (pink wavelet) of the lower sandstone of Shan 2^3 sub-member is not only affected by the shielding of overlying coal 5#, and also by the underlying coal 8#. That is, the seismic response of the lower sandstone of Shan 2^3 sub-member is interfered by the strong reflection of overlying and underlying coal seam.

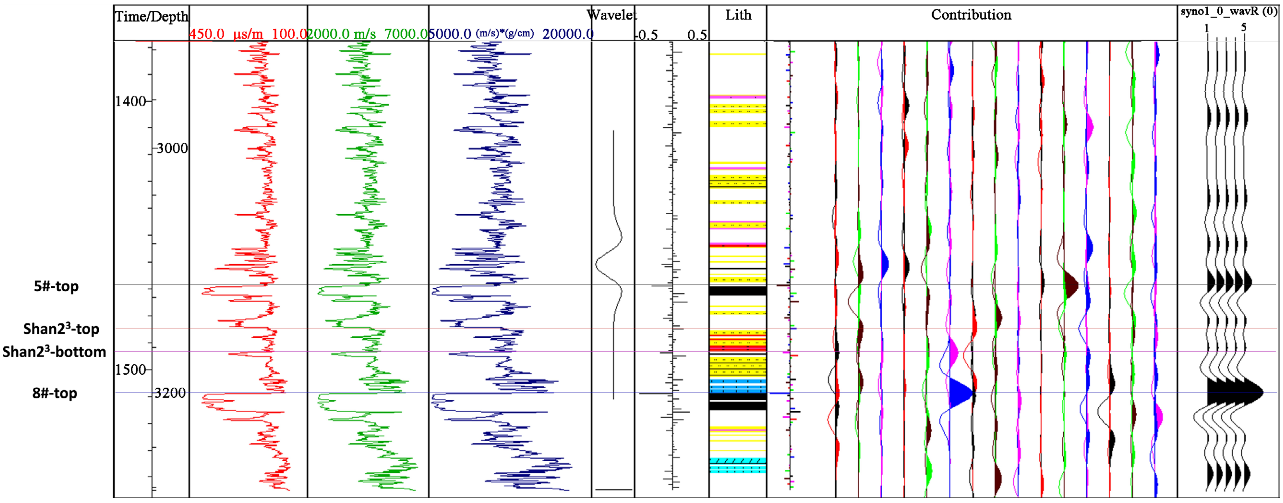

Figure 1. One dimensional forward modeling of D2 well.

The selection of appropriate time window is the basis for wavelet decomposition and reconstruction. The time window of 100 ms upward from 5# coal top (strong peak reflection) and 60 ms downward from 8# coal top (strong peak) reflection are selected to ensure that the seismic waveform reflection characteristics of 5# coal seam and 8# coal seam are fully included in these time windows. Then, Geocyber software is used to automatically decompose the original seismic data into 199 seismic components with different waveform and dominant frequency. The range of seismic dominant frequency of coal seam reflection in this area is 15 - 22 Hz. The analysis shows that the first and second seismic wavelet components can basically characterize the low-frequency strong reflection characteristics of 5# and 8# coal seam. After removing the first and second components, the other seismic wavelet components are reconstructed, and the reconstructed seismic data can better reflect the seismic characteristics of sandstone in the drilled well. For example, the sandstone in the Shan 2^3 sub-member in well D1 is thin and shows weak amplitude seismic reflection. The lower sandstones of the Shan 2^3 sub-member of D2 well are well developed and show strong amplitude reflection characteristics. The penetrated rate of the sandstone of Shan 2^3 sub-member in the 1000 m horizontal section of well D-P1 is more than 95%, showing strong amplitude seismic reflection (**Figure 2**).

Compared with the root mean square (RMS) amplitude plane properties of the original and removed coal strong reflection seismic data, there are great differences in the predicted distribution of Shan 2^3 sub-member sandstone. the seismic attributes of removing coal strong reflection can more clearly reveal the North-South channel, which is consistent with the geological understanding and the drilling situation in the area (**Figure 3**).

3. Correction of Sensitive Logging Curve

There are many methods for logging curve reconstruction to improve the accuracy of lithology identification and reservoir prediction, such as curve correction,

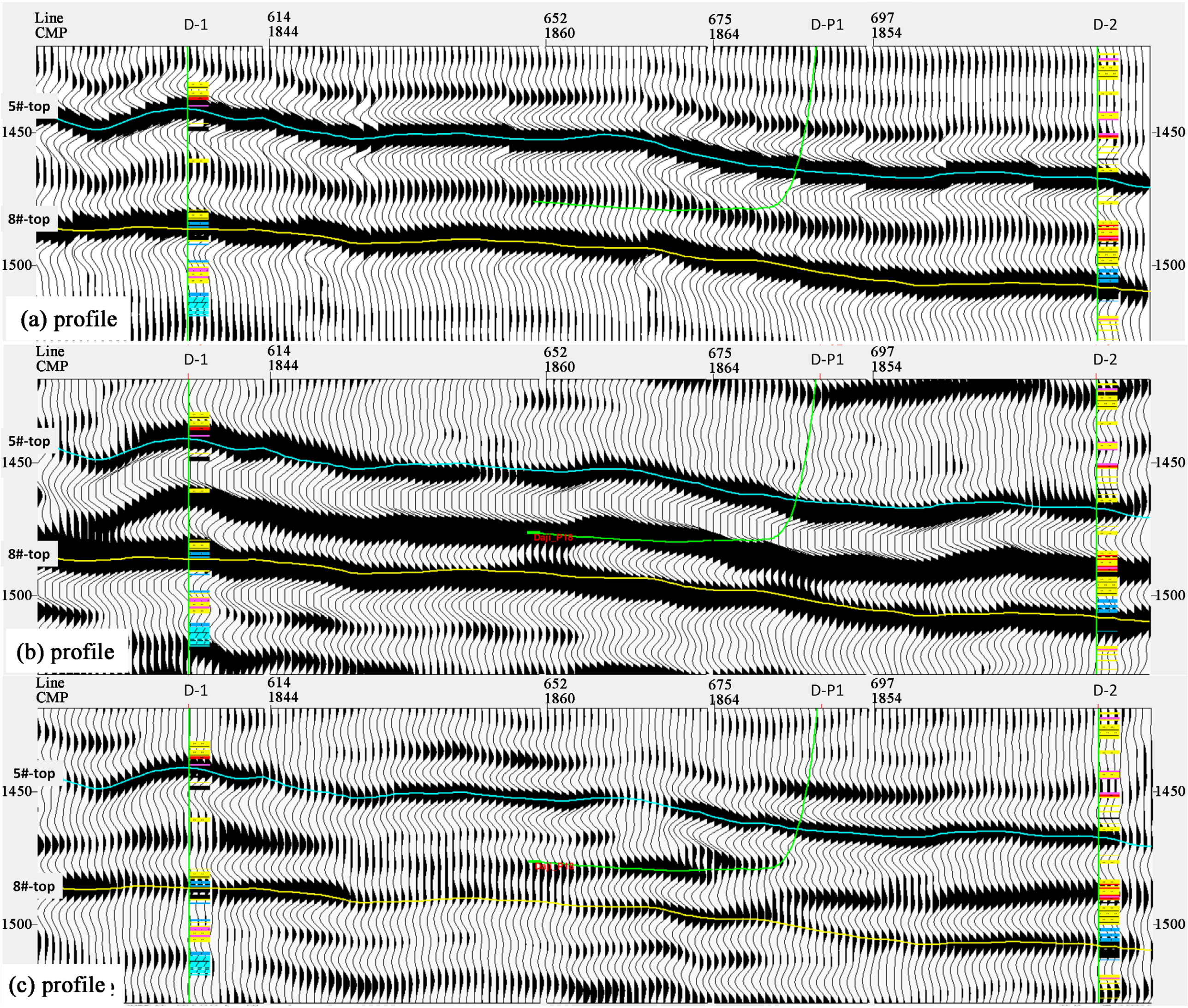

Figure 2. First and second seismic wavelet components profile (a) Original seismic profile (b) and reconstructed seismic profile (c).

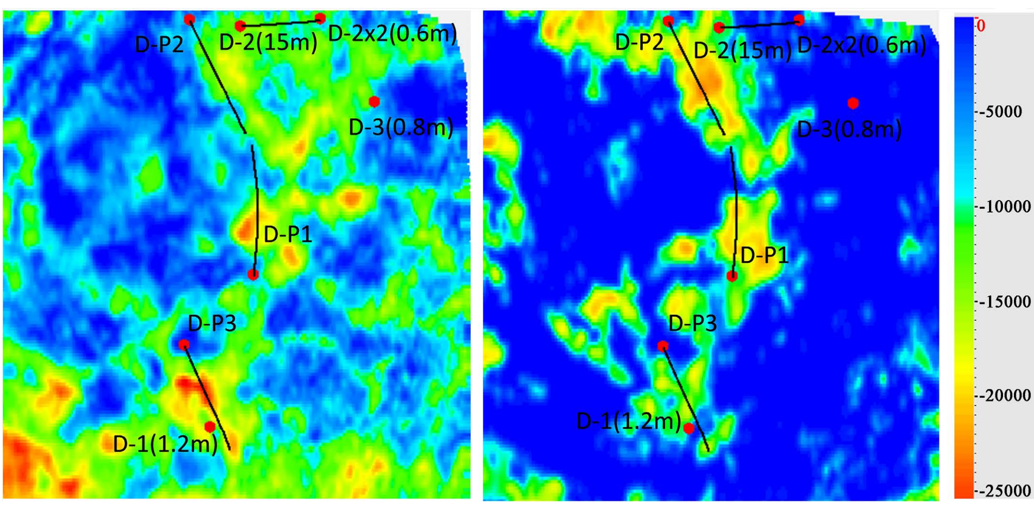

Figure 3. RMS plan of original (lift) and reconstructed (right) seismic data of Shan 2^3 sub-member.

empirical formula statistical fitting, wavelet transform reconstruction, multi curve reconstruction and so on [10]. In the study, the seismic data used in the seismic inversion of reservoir prediction is the reconstructed seismic data. Considering the consistency of well-seismic data, this paper attempts to correct the acoustic value of coal seam to the acoustic value of mudstone on the logging curve. Through calibrating, it is confirmed that the seismic strong reflection of coal seam is removed, the logging curve is also corrected accordingly, and the consistency of the characteristics of well-seismic synthetic seismogram is better.

The lithology is complex in the area. Through the analysis of the drilled wells, limestone and coal can be distinguished on the acoustic curve, mudstone and sandstone cannot be effectively distinguished. Mudstone and sandstone can be distinguished on natural gamma ray curve, but limestone and coal cannot be effectively distinguished. In the study, only tight sandstone is taken as the reservoir for prediction, and tries to reconstruct sandstone sensitive lithology curve by eliminating the interference of coal seam and limestone on logging curve.

The idea is to merge the interference layer and highlight the reservoir, as shown in Figure 4(a). Step ①: count the GR values of mudstone section in the study area; step ②: modify the GR values of limestone and coal seam into mudstone GR values. The reconstructed GR curve not only eliminates the interference of limestone and coal, but also retains the discrimination of sand and mud by the original GR curve (Figure 4(b), Figure 4(c)).

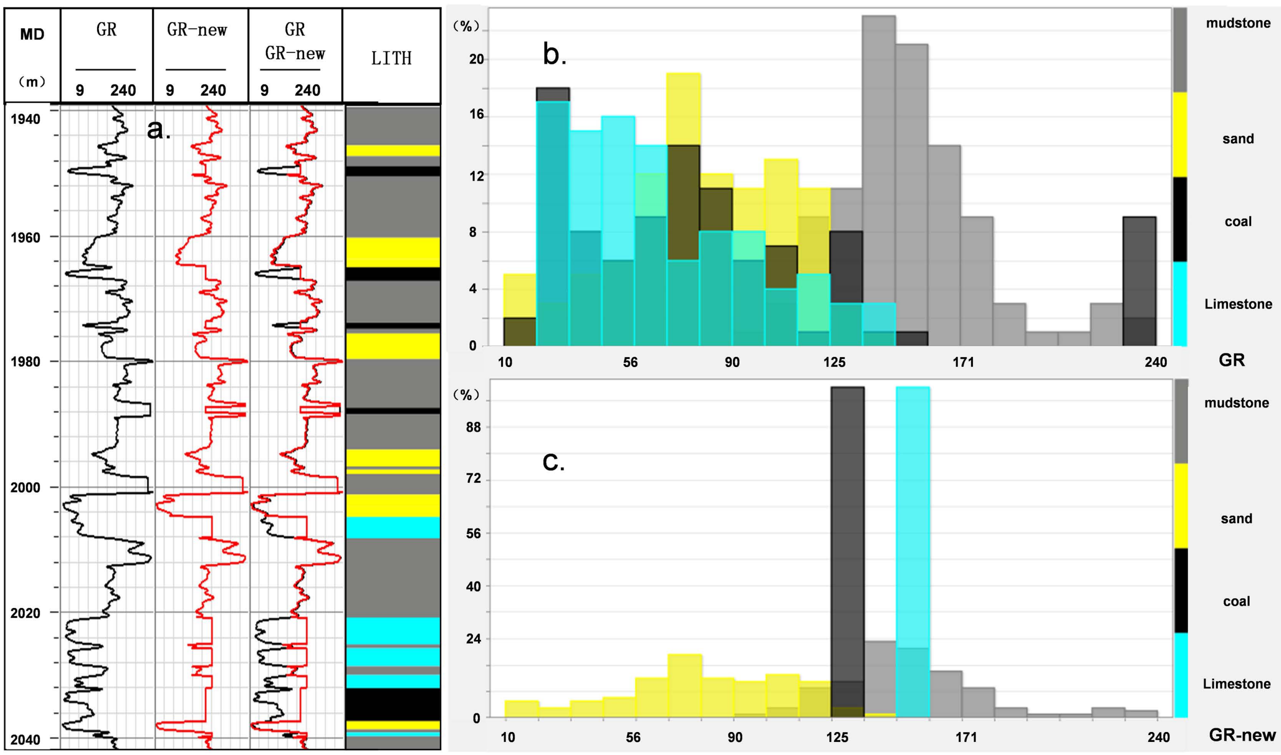

Figure 4. GR-reconstruction curve, (a), the histogram of lithology of Shan2^3 sub-member before GR-reconstruction (b), the histogram of lithology of the Shan2^3 sub-member after GR-reconstruction (c).

4. Thin Reservoir Prediction and Effect

Based on the reconstructed seismic data and the modified logging curve, the seismic waveform indication inversion under the constraint of sedimentary facies is carried out to predict the thin sandstone reservoir. Seismic meme inversion (SMI) is a new high-precision inversion method developed on the basis of traditional geo-statistical inversion [11]. The principle of this method is that the seismic waveform reflects the spatial change of sedimentary environment and lithologic combination, represents the tuning pattern of vertical lithologic combination, and its lateral change reflects the spatial characteristics of sedimentary facies [12] [13] [14] [15]. Therefore, according to the change of seismic waveform, the spatial variability of reservoir can be reflected macroscopically. The seismic waveform indication inversion does not strictly require the uniform distribution of wells, which also greatly improves the applicability of reservoir inversion.

In order to evaluate the applicability of seismic waveform indication inversion technology and the reliability of inversion results, there are three ways to do quality control. One is the forward modeling of inversion results is compared with the actual seismic data to determine whether the selection of inversion parameters is reasonable, the other is the horizontal wells not involved in inversion in the study area are selected as the post test wells for verification. The third is to compare whether there is a certain correlation between the waveform boundary of seismic inversion section and the one of waveform section. From the high-resolution profile of seismic waveform indication inversion, it has a high coincidence rate with the drilling results, effectively reflects more than 1 m sandstone, and the body of sandstone has proper shape and clear boundary on the inversion section, the inversion results is reasonable and reliable (**Figure 5**). This achievement is beneficial to support the deployment of evaluation and development wells in the study area.

5. Conclusions

For the prediction of tight and thin sandstone reservoir with upper and lower coal seams, the method of removing coal's strong reflection can effectively

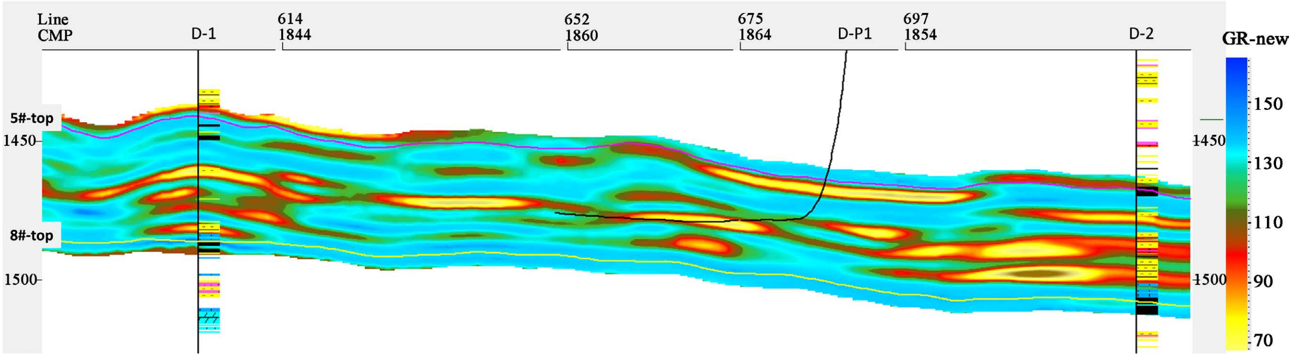

Figure 5. Seismic inversion profile through wells.

eliminate the interference of coal seams, highlight the seismic response of thin sandstone reservoir, and provide effective seismic data for the seismic attribute analysis and seismic inversion for reservoir prediction.

The recognizability of sandstone can be improved by eliminating the interference of coal seam and limestone on the logging curve and reconstructing the sensitive lithology curve of sandstone. The calibration confirms that the better the consistency of well-seismic data, the greater the correlation between the seismic characteristics and the synthetic seismogram. Therefore, the interference of seismic data and the distortion of logging curve from coal seam should be eliminated.

Based on the idea of removing the interference of strong seismic reflection from coal seam and correcting the distortion of coal logging value, the logging data and seismic data are matched. On this basis, the seismic waveform indication inversion is used for predicting the thin sandstone, which realizes the effective identification of sandstone reservoir in Shan 2^3 sub-member, and greatly improves the penetrated rate of targets and sandstone in horizontal development wells. This method provides a new choice for identifying the seismic response of thin sandstone interfered by the strong seismic reflection of double coal seams in the study area and even in the eastern of Ordos Basin.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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