

# Application of Horizontal Well Seismic Geo-Steering Technology in XX Block Development

Xuecheng Jia<sup>1</sup>, Xiaoyi Cheng<sup>2</sup>, Hui Ma<sup>1</sup>, Shilei Lu<sup>3</sup>, Xin Yang<sup>1</sup>, Shuo Wang<sup>1</sup>, Xiang Li<sup>1</sup>

<sup>1</sup>BGP Geological Research Center Inc., CNPC, Zhuozhou, China

<sup>2</sup>No.6 Oil Production Company, Petro China Changqing Oilfield Company, CNPC, Xi'an, China

<sup>3</sup>Pipe China Group Beijing Pipe Co. Ltd., Beijing, China

Email: jiaxuecheng@cnpc.com.cn

**How to cite this paper:** Jia, X.C., Cheng, X.Y., Ma, H., Lu, S.L., Yang, X., Wang, S. and Li, X. (2024) Application of Horizontal Well Seismic Geo-Steering Technology in XX Block Development. *Open Journal of Yangtze Gas and Oil*, 8, 65-74.  
<https://doi.org/10.4236/ojogas.2024.93004>

**Received:** June 7, 2024

**Accepted:** July 26, 2024

**Published:** July 29, 2024

Copyright © 2024 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).  
<http://creativecommons.org/licenses/by/4.0/>



Open Access

## Abstract

During the development phase horizontal wells are very efficient way to improve the production in the deep coal bed methane. The 8# coal seam in the XX block on the eastern edge of the Ordos Basin has challenges such as deep burial depth (>2000 m), thin coal sweet spot (3 m), and significant short-distance structural fluctuations. The challenges caused a high risk of missing targets and running out of the target layers, as well as difficulties in cementing and completion due to uneven well trajectories. To address these challenges, this paper focuses on solving the issues through detailed precise geological modeling, optimized trajectory design, and accurate seismic geology Steerable Drilling. 1) Based on reasonable velocity field construction and Time-Depth transformation, a precise directional model is constructed using the layer-by-layer approximation principle with reference to marker layers, improving the accuracy of the target spot and avoiding premature or delayed entry into the target; 2) Based on a precise geological model, the dip angle of the strata ahead and the development of sweet spots are clearly defined, enabling optimized trajectory design for horizontal wells; 3) Using “1 + N” dynamic modeling to update the geological model in real-time during the drilling process, and actively guide the drill bit through the horizontal segment smoothly by using multi-information judgment of the drill bit position. The actual drilling of 80 completed horizontal wells in this area show: That this approach effectively ensures the smooth trajectory and high-quality drilling rate of the horizontal well in the coal seam, providing a basis for subsequent hydraulic fracturing and increasing single-well production. At the same time, it has certain potential value and significance for similar coalbed methane developments under similar geological conditions.

---

## Keywords

Seismic Geosteerable, Horizontal Wells, Coalbed Methane, Marker Layers

---

### 1. Foreword

According to the 4th resource assessment, the coal bed methane resources at a depth of 1,500 - 2,000 meters nationwide are  $11.93 \times 10^{12} \text{ m}^3$ , and those at a depth of 2,000 - 3,000 meters are  $18.47 \times 10^{12} \text{ m}^3$ . Deep coal bed methane will become an important replacement field for China's next step in coal bed methane exploration and development [1] [2]. The Hancheng, Daning-Jixian, and Sanjiao blocks in the eastern margin of the Ordos Basin have abundant coal bed methane resources, with high-quality coal beds mainly in the 8# & 9# coal beds of the Taiyuan Formation. After a breakthrough in deep coal bed methane exploration at a depth greater than 2000 m in the XX block in 2019, the curtain was opened on the exploration and development of deep coal bed methane [3] [4]. Increasing drilling practices have shown that the quality of the horizontal section is the key to obtaining high-yield wells and forming scale benefits. Therefore, the Geosteerable Drilling of coal bed methane wells is crucial.

Currently, Geosteerable Drilling mainly relies on measuring and recording well logs, structural maps, etc., to establish an initial geological model before drilling horizontally and perform real-time correction during actual directional drilling. However, in areas where minor structures are relatively developed, there is a large difference between the initial geological orientation model and the actual drilling, which presents great challenges for real-time Geosteerable. Currently, the solution to the problems encountered by real-time guidance is to use real-time control point refined construction maps near the wellbore to obtain a plane geological orientation model in a timely manner. However, this single-point correction method has limitations in extrapolation trend prediction and low model accuracy [5] [6]. In addition, seismic-based directional drilling, which uses seismic data and new data obtained during drilling to re-predict the front of the wellbore, can also provide the scientific basis for real-time drilling decisions, but has not been further studied for real-time tracking of horizontal wells for deep coal bed methane.

In order to improve the target accuracy and drilling rate of horizontal Wells, In this paper, a new idea of horizontal well accurate seismic geology steerable drilling, including "precise geological modeling, optimized trajectory design, and accurate seismic geology Steerable Drilling", is proposed to solve the problem. Taking the 8# coalbed methane horizontal wells in the XX block on the eastern edge of the Ordos Basin as an example, 80 drilled horizontal wells show that the seismic steerable drilling technology for horizontal wells oriented towards development and engineering needs effectively guarantees the drilling encounter rate and trajectory smoothness of high-quality coal and rock in the horizontal

section, laying the foundation for subsequent fracturing construction and increasing single-well production.

## 2. The Problems Faced by Geosteerable Drilling

The XX block is a wide and gentle westward dipping monocline with no developed faults, and the dip angle of the strata is generally less than 2, and there are many complex minor structures developed on the slope. The strata from old to new are the Majiagou Formation of the Middle Ordovician, the Benxi Formation of the Upper Carboniferous, the Taiyuan Formation of the Upper Carboniferous-Lower Permian, and the Shanxi Formation of the Lower Permian. The 8# coal seam of the Taiyuan Formation is the main development layer [7] [8] [9]. A large amount of drilling data confirms that 2 - 3 sets of limestone are developed in the roof of the 8# coal seam, and the thickness of the direct roof limestone is 4 - 15 m; the floor mainly develops mudstone, and the thickness of the direct floor mudstone is 0 - 14 m. The thickness of the coal seam is 4 - 12 m, and the sweet spot section of the 8# coal seam is the optimal target for horizontal drilling for coal bed methane, with a relatively thin thickness averaging around 3 m (Figure 1).

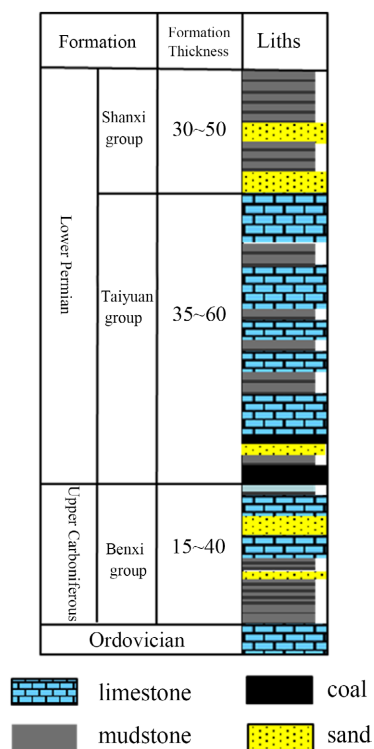
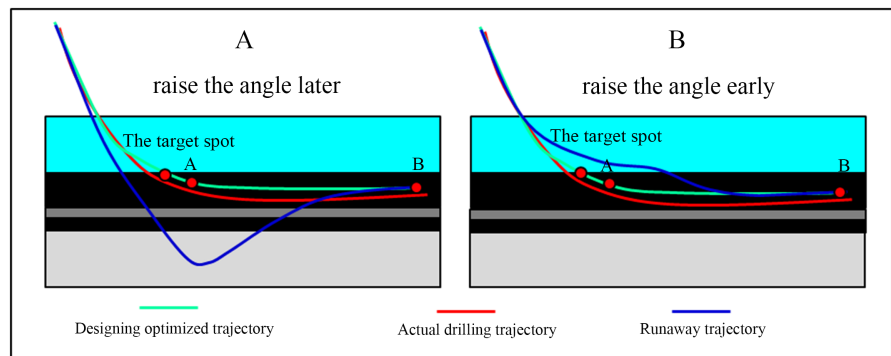


Figure 1. Comprehensive column chart of the study area.

For horizontal drilling of deep coal bed methane wells, there are high requirements for geosteerable drilling technology to ensure engineering quality and efficient production during extreme fracturing. The accuracy of entering the target, the smoothness of the wellbore in the horizontal section, and a high

drilling encounter rate for the coal seam target are all important. The Taiyuan Formation limestone developed in the roof of the 8# coal seam can serve as a marker bed, but it is a sedimentary deposit of a lagoon-barrier island, with unstable thickness development. At the same time, the minor structures in this area are developed, and the sweet spot thickness of the coal seam is thin. It is difficult to accurately hit the target relying on real-time gamma measurements, and delayed inclination increase can easily lead to drilling through the coal seam, while premature inclination increase can cause delayed entry into the target (Figure 2A), and increase ineffective drilling footage in the horizontal section (Figure 2B). Due to factors such as the quality of real-time data, instrument measurement blind spots, etc., when there are significant changes in short-distance structural undulations, adjustments to the trajectory during the horizontal drilling process often lag behind, resulting in an uneven trajectory in the horizontal section, a low drilling encounter rate, and even the risk of off-target drilling.



**Figure 2.** Different types of horizontal well hit the target modes.

### 3. Seismic Geosteerable Drilling Technology

#### 3.1. Technical Approach

In order to improve the drilling encounter rate of coal bed methane horizontal wells, this paper proposes a strategy of “1 + N” (1: reasonable initial speed; N: N speed points added during drilling) iterative variable speed field construction to quickly process the target block centered on the drilling platform for depth processing. The real-time updating of the geological directional model predicts changes in the dip angle of the strata during the drilling process and ensures a smooth well trajectory, actively guiding the drill bit to accurately traverse the horizontal section. The specific approach includes three important steps: precise geological modeling, optimized trajectory design, and accurate seismic geology Steerable Drilling. 1) Based on reasonable velocity field construction and Time-Depth transformation, a precise directional model is constructed using the layer-by-layer approximation principle with reference to marker layers, improving the accuracy of the target spot and avoiding premature or delayed entry into the target.; 2) Based on a precise geological model, the dip angle of the strata ahead and the development of sweet spots are clearly defined, enabling optimized tra-

jectory design for horizontal wells.; 3) Using “1 + N” dynamic modeling to update the geological model in real-time during the drilling process, and actively guide the drill bit through the horizontal segment smoothly by using multi-information judgment of the drill bit position.

## **3.2. Seismic Geosteerable Drilling**

### **3.2.1. Precise Geological Modeling**

The construction of a precise structural directional model is key to the success of horizontal wells, especially in areas with developed minor structures and thin layers of sweet spots. The process mainly includes three parts: the construction of a basic velocity field, velocity field correction, and layer-by-layer verification during drilling. 1) Layer-controlled and well-controlled velocity field construction is adopted in this paper. Based on the drill wave travel time curve, under the constraint of the geologic stratification corresponding to the seismic interpretation results, the velocity of each layer segment is obtained by weighted averaging, and interpolation smoothing is performed with lateral trend constraints of the stacked velocity field to establish a layer velocity field through spatial gridding in each layer segment. 2) Velocity field correction includes two aspects: first, matching the velocity control layer depth of known well points; second, ensuring that the velocity changes reasonably away from the control point position without distortion. 3) Verification of layer-by-layer drilling in real-time. Before entering the horizontal section, verification is conducted based on the real drilling depth of the marker layer, and if it is consistent, it indicates that the construction of the velocity field for depth-domain data-body transformation is accurate and can be continuously tracked and analyzed. If it is not consistent, real-time drilling information is immediately incorporated, and the above method is repeated to update the velocity field layer by layer to ensure accurate entry into the target.

### **3.2.2. Optimized Trajectory Design**

A well-designed horizontal well trajectory is the foundation for achieving good steerable drilling in the horizontal section. There are mainly two steps:

1) Establishment of a precise geological model. Through the layer-by-layer real-time adjustment strategy, updating the velocity field to ensure accurate entry into the target, and establishing an accurate structural directional model. Then, a deep 8# coal seam reservoir model prediction is conducted. This paper mainly uses high-resolution waveform indication simulation seismic inversion methods for sweet spot prediction in the coal seam segment. This method combines well logging and seismic data, follows the trend of seismic data, and involves logging information to improve vertical resolution and basically meets the needs of sweet spot prediction in the coal seam segment [10] [11]. Combining the structural directional model with the reservoir model, a more accurate geological directional model is constructed.

2) Trajectory design of the horizontal section. Based on this geological directional model, a point-by-point horizontal section trajectory design is conducted at intervals of 50 m while ensuring a smooth trajectory and drilling encounter

rate in the sweet spot of the coal seam. The elevation, dip angle, azimuth, and other information of each interval point are predicted, providing decision-making references for later guidance (Figure 3).

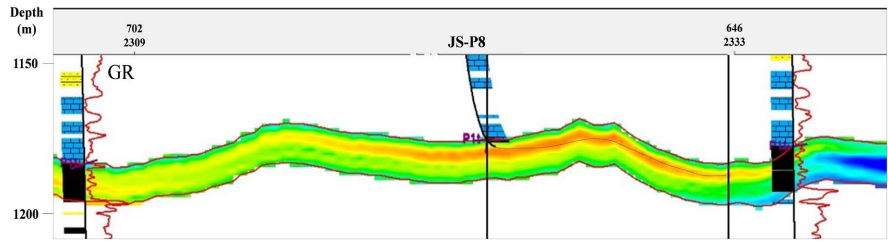


Figure 3. Optimized horizontal well trajectory design.

### 3.2.3. Accurate Seismic Geosteerable

As is well known, the real-time positioning judgment of the drill bit and the trend of the dip angle of the strata in front of the horizontal section are two core aspects of precise directional drilling. Based on a large amount of drilling data through the coal seam and combining the subdivision of small layers and the lithological characteristics of the top and bottom plates in the 8# coal seam, this paper summarizes nine different rock combination relationships including lime-coal-mud, lime-coal-sand, and lime-coal-lime (Figure 4) [12]. During the drilling process, the real-time position of the drill bit is comprehensively judged based on multiple information sources such as carbonate content, drilling time and size, GR during drilling, and gas measurement values.

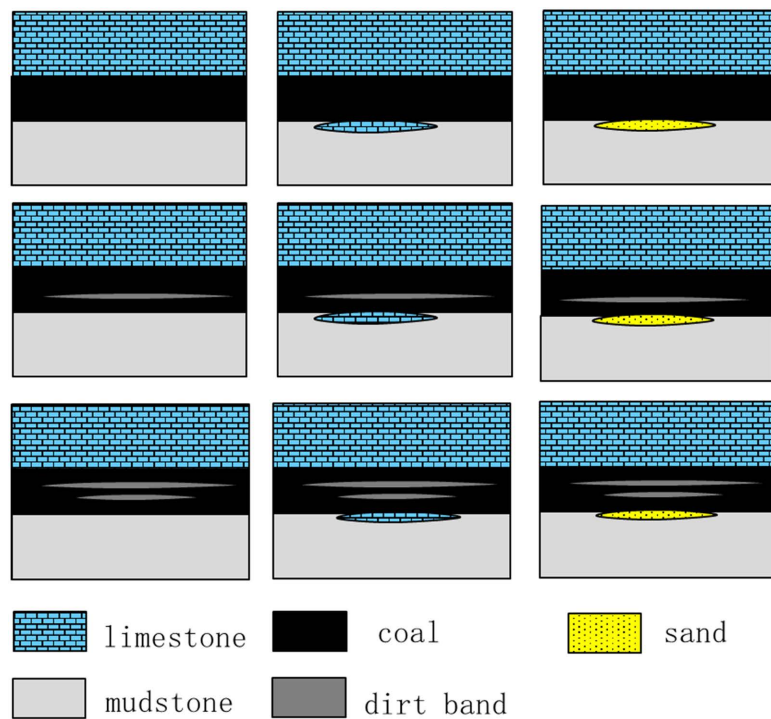
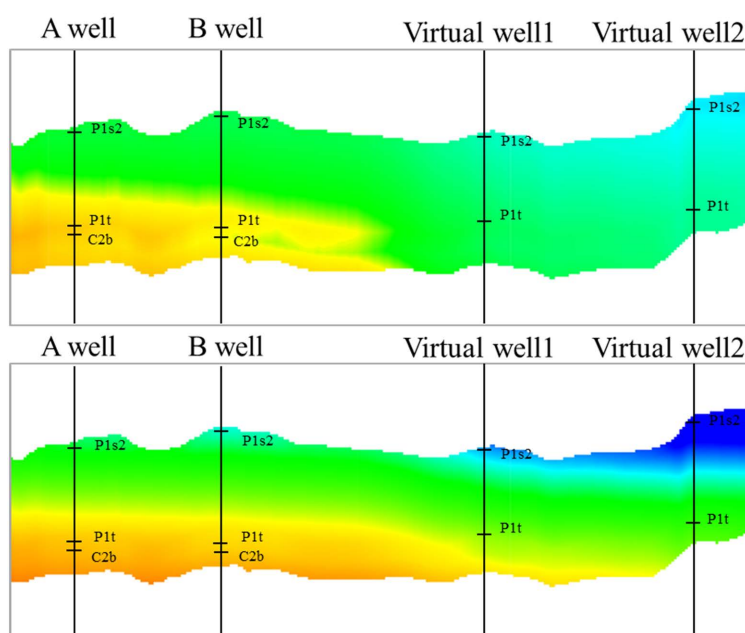


Figure 4. Different lithology combinations of coal seam and roof/floor Strata in Block XX.

When the comprehensive judgment of the drill bit position based on multiple information sources does not match the design trajectory, that is, there are clear top or bottom layer-out points, these points can be used as “winning data” for well-seismic identification to conduct real-time depth-domain data-body transformation and obtain a more accurate geological model to guide the directional drilling [13]. This paper updates the geological directional model in real-time using the “1 + N” iterative variable speed field construction method, with the initial velocity field as the object “1” and continuously increasing real-time top-out and bottom-out points as “N”. Using the curves of adjacent wells and the elevation of the top-out and bottom-out points added in real-time during horizontal drilling, a virtual depth domain is constructed, and based on the added virtual well depth, the initial velocity field is reconstructed to achieve spatial variable velocity field correction under the control of the stratigraphic framework (Figure 5). By increasing the virtual well depths of multiple wells, the defect of uncontrollable velocity in non-well areas is compensated, the initial velocity field is corrected, and the accuracy of the variable velocity field is improved, thereby obtaining a high-precision real-time geological directional model.



**Figure 5.** Initial velocity model (Top) and real-time updated velocity model (Bottom).

#### 4. Application Examples

As shown in Figure 6 during the implementation of well JS-P10 in the XX block, it was found during drilling that the depth of the velocity control layer of the overlying strata did not match the predicted depth by the seismic survey before entering the target. After quickly updating the velocity field to ensure that the depth of the control layer matched, the depth of the target point was re-predicted

using the updated velocity field to ensure that the drill bit successfully entered the target.

The absolute error is reduced from 3.2 m to 2.1 m, and the relative error is reduced from 2.7 ‰ to 1.8‰.

As the drilling depth of the horizontal section increases, there may be differences between the drilled geological model and the dip angle of the strata

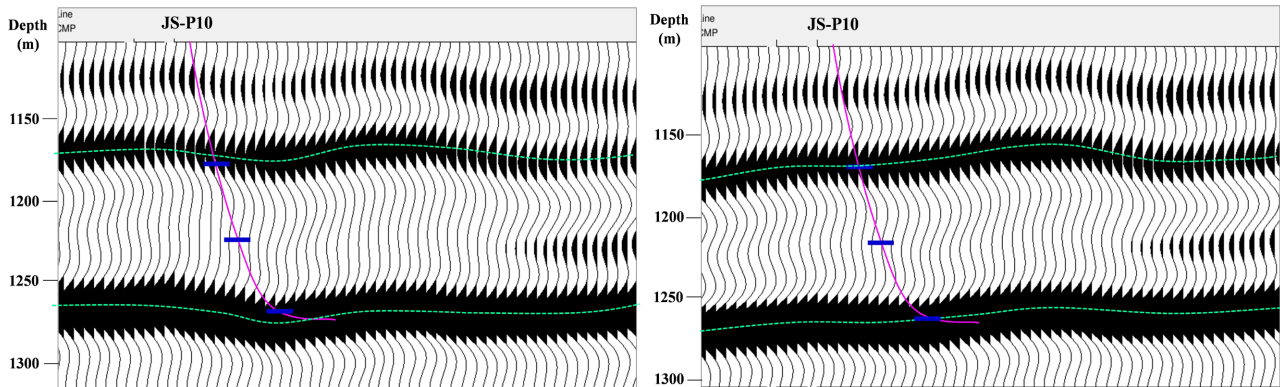


Figure 6. Initial velocity depth profile (left) and update depth profile (right) to ensure accurate entry into the target.

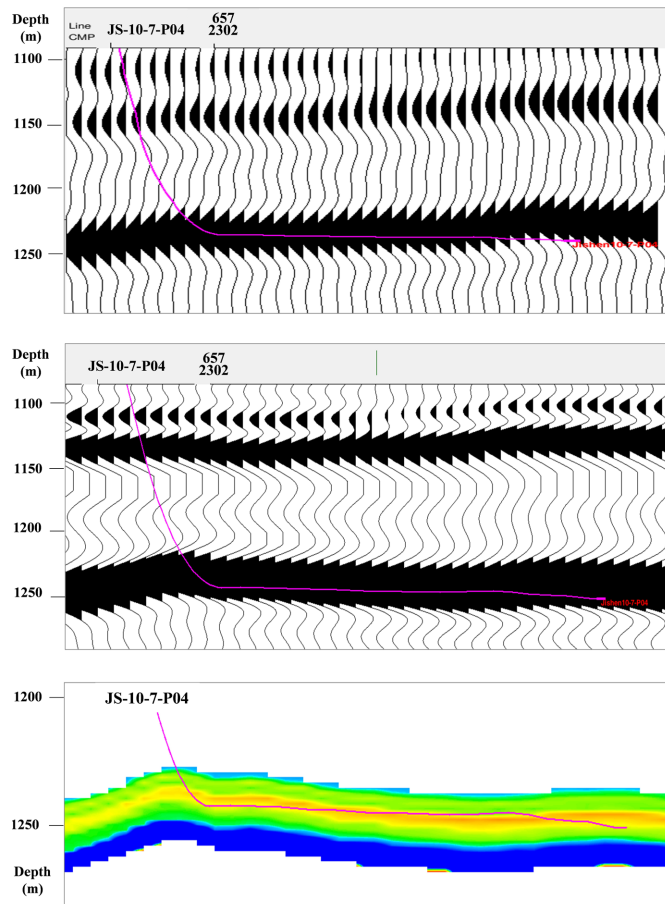


Figure 7. Pre and post “1 + N” updated depth seismic profile in real-time.

predicted by the seismic profile. Through the “1 + N” iterative variable speed field construction method, the depth seismic profile is updated in real-time, and a real-time geological directional model that matches the drilling results is obtained, effectively guiding the next adjustment of the horizontal section. By using seismic steerable technology during drilling, the average drilling encounter rate of 80 horizontal wells in this area has reached more than 97% (Figure 7).

## 5. Conclusions

Based on seismic data, the new method including “precise geological modeling, optimized trajectory design, and accurate seismic geology Steerable Drilling” greatly improves the target accuracy of horizontal wells and the drilling rate of horizontal reservoirs:

1) By drilling data, superposition velocity field, VSP velocity and other data, the method of reasonable foundation velocity field construction, velocity field correction and layer-by-layer verification of real drilling is carried out, which greatly eliminates the shortcomings of traditional modeling theory in the process of model establishment and correction, improves the accuracy of guidance model prediction of landing point, and ensures smooth wellbore trajectory into the target.

2) The combined application of seismic data and drilling logging data realizes “microscopic” precise positioning of the drill bit in the formation during the directional drilling process for horizontal wells. Combined with the “1 + N” iterative variable speed field construction technology, the directional model is updated in real-time to accurately predict the characteristics of the strata changes ahead and proactively guide the drill bit to precisely traverse the horizontal section, effectively ensuring the drilling encounter rate of high-quality reservoirs in the horizontal section and smooth trajectory.

## Conflicts of Interest

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

## References

- [1] Xu, F.Y., Wang, C.W., Xiong, X.Y., *et al.* (2022) Deep (Layer) Coalbed Methane Reservoir Forming Modes and Key Technical Countermeasures-Taking the Eastern Margin of Ordos Basin as an Example. *China Offshore Oil and Gas*, **34**, 30-42.
- [2] Yan, X., Xu, F.Y., Zhang, L., *et al.* (2022) Reservoir-Controlling Mechanism and Production-Controlling Patterns of Microstructure to Coalbed Methane. *Journal of China Coal Society*, **47**, 893-905.
- [3] Yan, X., Xu, F.Y., Nie, Z.H., *et al.* (2021) Microstructure Characteristics of Daji Area in East Ordos Basin and Its Control over the High-Yield Desert of CBM. *Journal of China Coal Society*, **46**, 2426-2439.
- [4] Xu, F.Y., Yan, X., Li, S.G., *et al.* (2022) Difficulties and Countermeasures in Theory and Technology of Deep CBM Exploration and Development in the Eastern Edge of

- Ordos Basin. *Coal Geology & Exploration*, 1-17.
- [5] Li, S.G., Wang, C.W., Wang, H.N., *et al.* (2022) Reservoir Forming Characteristics and Favorable Area Evaluation of Deep Coalbed Methane in Daning-Jixian Block. *Coal Geology & Exploration*, **50**, 59-67.
  - [6] Zhang, F., Zhang, M., Li, W., *et al.* (2021) Identification of Low Sequence Faults and Microstructures in Tight Reservoirs. 2021 *SPG*, Rome, 19 October 2021, 1305-1307.
  - [7] Sun, Q.P. and Wang, S.W. (2006) The Deposit Environment Analysis of the Coal-Bearing Strata and Its Significance to the Coalbed Methane Development in Daning-Jixian Region. *Natural Gas Geoscience*, **17**, 874-879.
  - [8] Sun, X.W., Zhang, F., Zhang, B.Q., *et al.* (2022) Seismic Prediction Method for Tight Gas Thin Reservoir in Coal Measure Strata: Taking Daning-Jixian Block in Ordos Basin as an Example. *Natural Gas Geoscience*, **33**, 1165-1174.
  - [9] Zhang, F., Jia, X.C., Zhang, X.M., *et al.* (2022) Application of Thin Reservoir Prediction Technology Based on Facies-Controlled Inversion at Eastern Margin of Ordos Basin. *OGP*, **57**, 215-220.
  - [10] Diao, W., Tong, J.N., Zhang, B.Q., *et al.* (2022) Facies-Controlled Inversion Prediction for Tight Thin Sand Layers Distribution. *OGP*, **57**, 172-176.
  - [11] Jia, X.C., Zhang, F., Li, X.G., *et al.* (2022) Prediction Technique of Thin Sandstone Reservoir Affected by Dual Coal Seam. *Open Journal of Yangtze Gas and Oil*, **7**, 231-239. <https://doi.org/10.4236/ojogas.2022.74013>
  - [12] Xu, F.Y., Yan, X., Lin, Z.P., *et al.* (2022) Research Progress and Development Direction of Key Technologies for Efficient Coalbed Methane Development in China. *Coal Geology & Exploration*, **50**, 1-14.
  - [13] Zhang, X.M., Zhang, F., Hu, X.D., *et al.* (2022) Fine Interpretation Method and Quality Control of Sand Formation in Fuyu Reservoir, Qian'an Oilfield, Songliao Basin. 2022 *SPG*, Rome, 24 October 2022, 1112-1114.