

# Analysis of Seismic Response Characteristics of Coal-Bearing Strata in Pinghu Formation of Xihu Depression

Pan Yang<sup>1,2</sup> 

<sup>1</sup>School of Earth Science and Engineering, Xi'an Shiyou University, Xi'an, China

<sup>2</sup>Shaanxi Key Laboratory of Petroleum Accumulation Geology, Xi'an Shiyou University, Xi'an, China

Email: y1458651011@foxmail.com

**How to cite this paper:** Yang, P. (2025). Analysis of Seismic Response Characteristics of Coal-Bearing Strata in Pinghu Formation of Xihu Depression. *Journal of Geoscience and Environment Protection*, 13, 156-167.

<https://doi.org/10.4236/gep.2025.133009>

**Received:** February 7, 2025

**Accepted:** March 14, 2025

**Published:** March 17, 2025

Copyright © 2025 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

**Objectives:** Pinghu formation is the main target layers for oil and gas exploration in the western slope of Xihu Depression as well as a coal bearing transition between land and sea. The main characteristics of its coal seams are thin single layer and multiple layers, which make seismic waves susceptible to interference during propagation. **Methods:** Based on these characteristics in the research area, 4 theoretical geological models have been established for the Pinghu Formation of the Paleogene in the Xihu Depression, and forward simulation of these models was carried out using the wave equation. The influence of the thickness of coal seams in sandstone and the relative position between coal seams and sandstone on seismic reflection characteristics was studied, providing a theoretical basis for reservoir prediction. **Results and Conclusions:** The following three points of understanding have been achieved: 1) In the combination form of “sand coal sand”, when the thickness of the coal seam increases within the range of 0 - 5 m, the reflection characteristics of the coal seam to the top and bottom interface of sand and mud are reflected as amplitude enhancement, and the polarity reversal of the reflection amplitude does not occur. 2) In the combination form of “sand coal interbed”, when the thickness of the coal seam increases within the range of 0 - 5 m, the influence of the coal seam on the reflection characteristics of the sand and mud roof and bottom increases with the increase of the thickness of the coal seam, and the polarity reversal of multiple reflection amplitude occurs. 3) When the thickness of the coal seam is constant, the influence of the coal seam on sandstone decreases with the increase of its relative distance. When the relative distance is within 10 - 20 m, the polarity reversal of the sand and mud interface occurs.

---

## Keywords

Forward Simulation, Coal Seam, Seismic Reflection Characteristics, Pinghu Formation, Xihu Depression

---

## 1. Introduction

Seismic forward modeling is an essential part of seismic reservoir prediction research. It helps to better understand the geophysical characteristics and geological significance of complex propagation media in strata. [Fu et al. \(2010\)](#) used wave equation forward numerical simulation to study the seismic reflection structure characteristics of bioherms. [Liu \(2014\)](#) conducted forward modeling to study the influence of coal seam thickness on reflection wave energy and frequency, laying a theoretical foundation for interpreting coal thickness changes using seismic attribute technology. [Li et al. \(2018\)](#) established models based on drilling data for different types of sand-mudstone combinations and conducted forward modeling to study the internal seismic facies structure characteristics of deep-water fans, matching them with actual seismic facies identification. [Niu et al. \(2022\)](#) used pre-stack reflection low-value anomalies of sand bodies and post-stack reflection low-value anomalies of coal-mud interbeds to identify lithologic traps in coal-bearing strata in the Pingbei area of the Xihu Depression. [Zhang et al. \(2024\)](#) used seismic forward modeling to study the relationship between sand thickness and seismic attributes in tight sandstone reservoirs. [Wang et al. \(2017\)](#) used seismic forward and inverse modeling combined with petrophysical analysis to study tight reservoirs in the Loess Plateau region. [Mirkamali et al. \(2023\)](#) used seismic forward modeling combined with seismic petrophysics, geological model construction, and 2D finite-difference elastic modeling to investigate and interpret thin layers in carbonate reservoirs in southwestern Iran. [Johansen](#) conducted seismic forward modeling of the Kvalhovden outcrop in Spitsbergen, Norway, exploring the resolution gap between outcrop, reservoir, and seismic scale observations ([Johansen et al., 2023](#)). [Zhang et al. \(2020\)](#) conducted detailed seismic forward modeling analysis of coastal oilfields, exploring the relationship between seismic wave penetration and branching.

In the study of seismic reflection configuration characteristics, there is limited research on the influence of coal seams on the seismic reflection configuration of sand bodies. The coal-bearing strata of the Pinghu Formation in the Pingbei area of the Xihu Depression are the main source rocks in the Xihu Depression. Due to the widespread distribution of coal-bearing strata, the large number of coal seams, thin single-layer thickness, and the significant influence of coal seams on the identification of sedimentary microfacies in seismic profiles, there are many controversies regarding the sedimentary facies of the Pinghu Formation. [Xiong et al. \(2007\)](#) believe that the spatial distribution of coal seams in the Pinghu Formation is characterized by being numerous, scattered, thin, widespread, and uniform.

Zhang & Xu (2012) conducted detailed research on the sequence stratigraphy and sedimentary facies of the Pinghu Formation in the Xihu Depression, concluding that one of the lithological characteristics of the Pinghu Formation is the presence of numerous thin and scattered coal seams in both mudstone and sandstone. Zhou et al. (2016) believe that the tidal flat and tide-controlled delta environments in the Pinghu Formation of the Xihu Depression have better coal accumulation effects than the braided river delta, and the main factors influencing the matching relationship between the regional sedimentary system and the coal-rich zone are the coal accumulation environment and mode. Shen (2018) believes that the main coal accumulation units in the Pinghu Formation are the supratidal and intertidal zones, with coal seams characterized by thin single-layer thickness and large cumulative thickness. He also points out that the uneven distribution of coal seams in the Pinghu Formation is due to changes in accommodation space during different tectonic evolution stages. Wang et al. (2021) believes that the coal seams in the Pinghu Formation of the Xihu Depression developed in tide-controlled delta and river-controlled delta peat swamp environments, characterized by multiple layers and thin thickness.

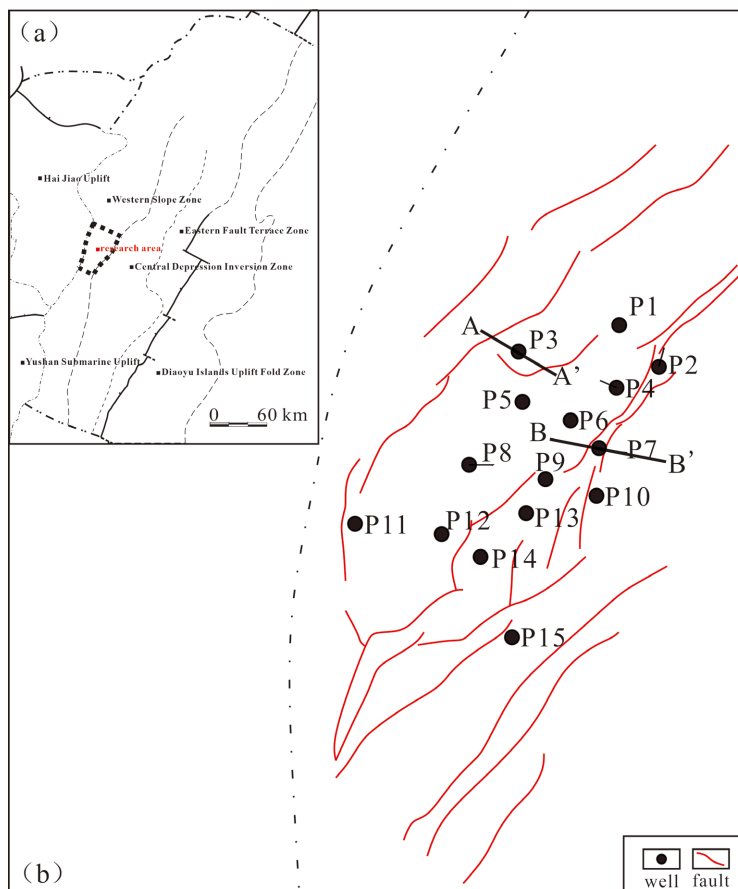
Through previous research, it has been found that the coal accumulation environment of the Paleogene Pinghu Formation in the Xihu Depression is mainly tidal flats and tide-controlled delta plain peat swamps (Zhou et al., 2016). Based on well logging data and Tesseral software, this paper constructs theoretical geological models for the coal-bearing strata of the Paleogene Pinghu Formation in the Xihu Depression. Through seismic forward modeling, the influence of coal seam thickness and spatial distribution on the seismic reflection characteristics of sand bodies is analyzed. Variables such as the distance between sand and coal layers as well as coal seam thickness are integrated into the model. The results are then compared and analyzed with actual seismic profiles and lithological data. Ultimately, conclusions are drawn, providing a basis for the study of regional sedimentary systems and the configuration of typical seismic profiles.

## 2. Regional Geological Background and Coal Accumulation Environment Characteristics

### 2.1. Regional Geological Background

The Xihu Depression is one of the most oil- and gas-rich depressions in China's offshore areas with significant exploration potential. It is located in the northeastern part of the East China Sea Basin, belonging to the eastern depression belt of the East China Sea Shelf Basin, with a water depth of about 100 m and an area of  $4.27 \times 10^4$  km<sup>2</sup> (Xu et al., 2020). To the east is the Diaoyu Islands Fold Belt, and to the west is the Central Uplift (Figure 1) (Zhang et al., 2011). The Xihu Depression began to deposit in the late Cretaceous, with obvious east-fault and west-overlap characteristics, forming a half-graben basin. It includes three main structural units from east to west: the western slope zone, the central sag-reversal zone, and the eastern fault-step zone. The strata of the Xihu Depression, from bottom to top,

include the Paleocene, Eocene Pinghu Formation, Oligocene Huagang Formation, Miocene Longjing Formation, Yuquan Formation, and Liulang Formation, Pliocene Santan Formation, and Quaternary Donghai Group. The Pinghu Formation is the main target layer for oil and gas exploration (Zhang et al., 2012).



**Figure 1.** Location of research area and brief table of stratigraphic sequence.

## 2.2. Coal Accumulation Environment Characteristics

The main coal-bearing strata in the Xihu Depression are distributed in the Pinghu Formation. The main coal accumulation environments of the Pinghu Formation are:

1) Braided river delta plain peat swamp: The braided river delta plain is a terrestrial deposit with well-developed distributary channels, which strongly erode muddy deposits, making peat accumulation difficult and significantly affecting coal accumulation. The lower delta plain is an underwater deposit, where underwater distributary bays are similar to tide-controlled delta distributary bays, easily developing swamp environments conducive to coal seam formation (Figure 2(a)).

2) Tidal flat peat swamp: Tidal flat peat swamps develop in the supratidal and intertidal zones. Due to the periodic nature of tides, parts of the intertidal and supratidal zones periodically emerge above water, and under suitable climatic conditions, these areas easily develop peat swamps and form coal seams. Due to

the periodic influence, the coal seams formed in this environment are characterized by thin single-layer thickness and multiple layers (Li et al., 2013) (Figure 2(b)).

3) Tide-controlled delta plain peat swamp: Due to coastline advancement, tide-controlled delta plain distributary bays are easily filled with sediments and become shallower. Under these conditions, plants and peat accumulation easily develop into swamp environments (Guo et al., 1998). Tide-controlled delta distributary bays, after being filled with sediments and becoming shallower, are suitable for peat swamp development and coal seam formation. Abandoned tidal sandbars and abandoned distributary channels in the tide-controlled delta plain are also important coal accumulation environments (Figure 2(c)).

In general, the coal accumulation environment characteristics of the Pinghu Formation in the Xihu Depression are: stable structure, suitable water depth, stable water body, stable climate, conducive to plant growth and peat accumulation, and easy development of peat swamps.

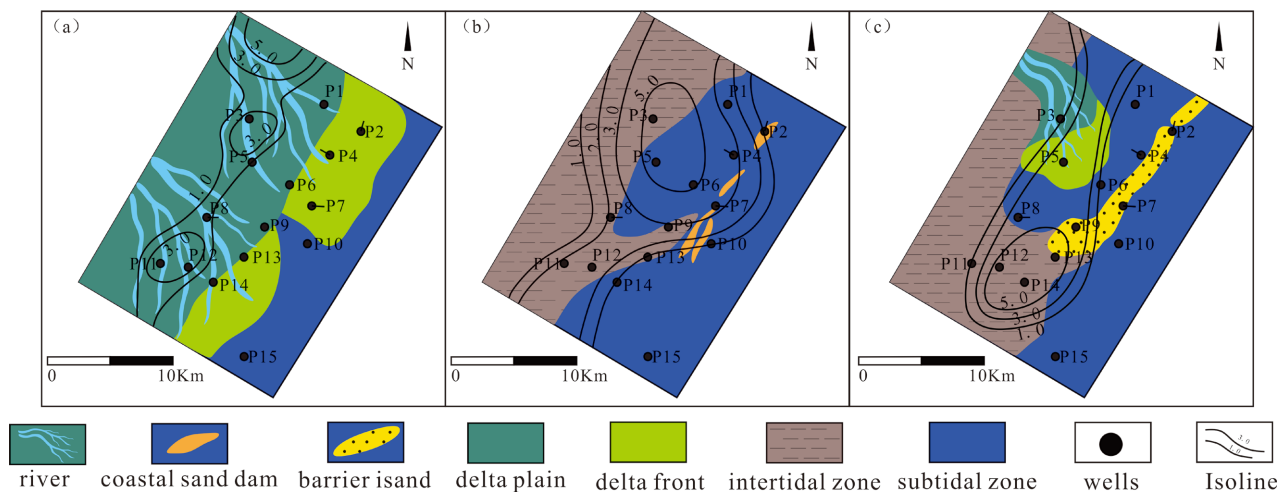


Figure 2. Contour map of coal series thickness in the research area.

### 3. Basic Principles of Acoustic Forward Modeling

Seismic forward modeling, or seismic wavefield simulation, simulates seismic wave signals in real geological structures based on the geophysical properties (velocity, density, etc.) of different lithologies in well logging data, obtaining seismic records close to real ones. This forward model is based on the Tesseral-2D velocity-depth model, which effectively simulates the 2D wave propagation effects of seismic energy in real situations, without considering the hardness of solid media, representing an ideal fluid medium situation. By summarizing velocity and density parameters from well logging data and assigning them to corresponding lithological bodies in the 2D model, the numerical solution of the wave equation is used to synthesize seismic records, accurately reflecting seismic attributes such as amplitude, phase, and frequency during seismic wave propagation.

The wave equation in seismic forward modeling mainly considers the dynamic properties of seismic waves. The propagation law of seismic waves in underground media can be approximately represented by the following acoustic wave equation (Xie et al., 2015):

$$\frac{\partial^2 u}{\partial t^2} - S(t) = v^2 \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial z^2} \right) \quad (1)$$

$$\frac{\partial^2 u}{\partial t^2} = \frac{u_{i,j}^{k+1} - 2u_{i,j}^k + u_{i,j}^{k-1}}{\Delta t^2} \quad (2)$$

$$\frac{\partial^2 u}{\partial x^2} = \frac{u_{i+1,j}^k - 2u_{i,j}^k + u_{i-1,j}^k}{\Delta l^2} \quad (3)$$

$$\frac{\partial^2 u}{\partial z^2} = \frac{u_{i,j+1}^k - 2u_{i,j}^k + u_{i,j-1}^k}{\Delta l^2} \quad (4)$$

( $u$ : wavefield value;  $v$ : wave velocity at point ( $x, y$ );  $S(t)$ : source function;  $l$ : grid interval distance;  $\Delta t$ : unit sampling step).

By combining Equations (1)-(4), the following is obtained:

$$U_{i,j}^{k+1} = \left( v * \frac{\Delta t}{\Delta l} \right)^2 * (U_{i+1,j}^k + U_{i-1,j}^k + U_{i,j+1}^k + U_{i,j-1}^k) + \left( \frac{2\Delta l^2 - 4v^2 \Delta t^2}{\Delta l^2} \right) U_{i,j}^k - U_{i,j}^{k-1} + S(k) * \delta(i - i_0) * \delta(j - j_0) \quad (5)$$

When the source function, grid interval distance, unit sampling step, and wave velocity are determined, Equation (5) can be used to recursively calculate the wavefield value at any sampling point at any time in the established 2D geological model. After processing, the final synthetic seismic forward record can be obtained.

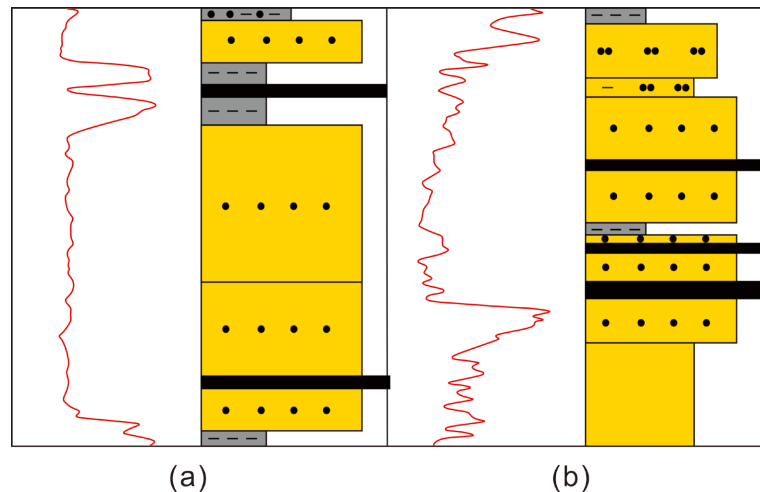
## 4. Forward Model Establishment and Result Analysis

### 4.1. Forward Model Parameter Selection

Based on well logging data from the study area, two combinations of “sand-coal-sand” and “sand-coal interbed” were summarized for sand, coal, and mud in the study area (Figure 3). By statistically analyzing data from 15 wells in the study area, combined with the high-velocity coal seam characteristics of the study area, the P-wave velocity, density, and wave impedance of sandstone, mudstone, and coal seams in the Pinghu Formation were obtained, laying the foundation for the establishment of seismic forward geological models (Table 1).

**Table 1.** Statistical table of geophysical parameters.

Lithology	Velocity (m/s)	Density (g/cm <sup>3</sup> )	Acoustic Impedance (10 <sup>7</sup> m/s·kg/m <sup>3</sup> )
Sandstone	3907	2.373	9273
Mudstone	3628	2.654	9630
Coal Seam	4118	2.608	10,742

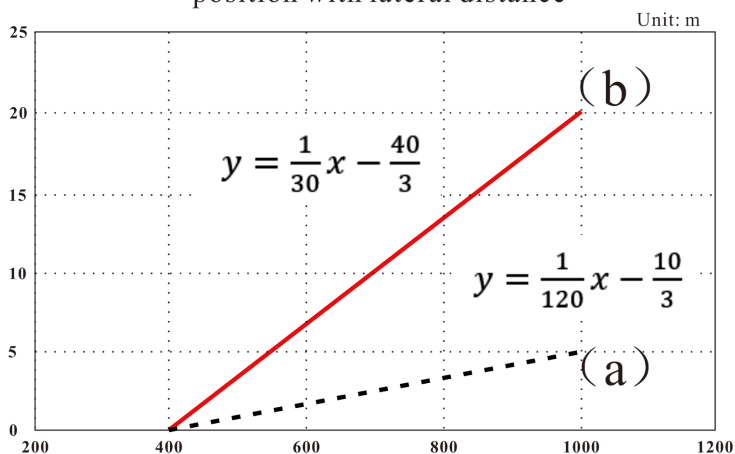


**Figure 3.** Combination form of sand and coal. (a) Sand-coal-sand; (b) Sand coal interlayer.

#### 4.2. Forward Model Establishment

Based on the above geophysical parameter statistics, well logging facies lithology configuration, sand-coal distance, and sand, coal, and mud combination types, four theoretical forward models were established. The horizontal width of the models is 1000 m. To explore the influence of coal seams on seismic reflection characteristics in different combination types, Model 1 (**Figure 5(a)**) was established with lithology settings from bottom to top as follows: first layer mudstone, second layer sandstone, third layer coal seam (thickness gradually increasing from 0 - 5 m), fourth layer sandstone, fifth layer mudstone; the horizontal 0 - 400 m is set as no coal seam, and the horizontal 400 - 1000 m is set as the “sand-coal-sand” combination (**Figure 3(a)**). Model 2 (**Figure 5(b)**) was established with lithology settings from bottom to top as follows: first layer mudstone, second layer sandstone, third layer coal seam (thickness gradually increasing from 0 - 5 m), fourth layer sandstone, fifth layer coal seam (thickness gradually increasing from 0 - 5 m), sixth layer sandstone, seventh layer mudstone; the horizontal 0 - 400 m is set as no coal seam, and the horizontal 400 - 1000 m is set as the “sand-coal interbed” combination (**Figure 3(b)**). To explore the influence of the distance between the underlying coal seam and sandstone on seismic reflection characteristics in different combination types, Model 3 (**Figure 5(c)**) was established with lithology settings from bottom to top as follows: first layer mudstone, second layer sandstone, third layer mudstone, fourth layer coal seam with a thickness of 5 m and a distance from the overlying sandstone gradually increasing from 0 - 20 m, fifth layer mudstone. Model 4 (**Figure 5(d)**) was established with lithology settings as follows: first layer mudstone, second layer coal seam with a thickness of 5 m and a distance from the underlying sandstone gradually increasing from 0 - 20 m, third layer mudstone, fourth layer sandstone, fifth layer mudstone. The relationship between coal seam thickness and horizontal distance in the four models (**Figure 4(a)**), and the relationship between coal seam distance to overlying sandstone and horizontal distance in Model 3 and Model 4 (**Figure 4(b)**) are as follows.

Relationship between coal seam thickness and coal seam position with lateral distance



**Figure 4.** The relationship between coal seam thickness, coal seam position, and lateral distance.

### 4.3. Forward Simulation Analysis

Seismic forward simulations were conducted using zero-phase Ricker wavelets with main frequencies of 30 Hz, 40 Hz, 50 Hz, 60 Hz, and 70 Hz. After setting the source parameters, spatial range parameters, and time sampling interval parameters, forward simulations were performed using the acoustic wave equation. After velocity analysis and Kirchhoff pre-stack migration processing, the final depth-domain synthetic seismic profiles based on Model 1, Model 2, and Model 3 were obtained. **Figure 5(a)** shows the seismic forward profile based on Model 1 with a wavelet main frequency of 60 Hz, **Figure 5(b)** shows the seismic forward profile based on Model 2 with a wavelet main frequency of 50 Hz, **Figure 5(c)** shows the seismic forward profile based on Model 3 with a wavelet main frequency of 60 Hz, and **Figure 5(d)** shows the seismic forward profile based on Model 4 with a wavelet main frequency of 50 Hz. In **Figure 7**, AA' and BB' correspond to the reflection characteristics of the forward simulation results of Model 1 and Model 2 in the original seismic profile, with their geographical locations shown in **Figure 1**. Model 3 and Model 4 aim to study the influence of the relative distance between coal seams and overlying or underlying sandstone on seismic configuration characteristics.

#### Influence of Coal Seam Thickness on Seismic Reflection Configuration

Analyzing coal seam thickness variations based on different models. For Model 1 (**Figure 5(a)**), the sandstone-coal combination is “sandstone-coal-sandstone”. When the coal seam thickness is 0 - 1 m, sandstone-coal interface reflection characteristics emerge, with minimal enhancement in seismic reflection amplitude. As the coal seam thickness increases, strong amplitudes appear in the sandstone-coal interface seismic reflections, but no phase inversion of the seismic signal occurs. The top surface of the coal seam reflects as a wave crest, while the bottom surface reflects as a wave trough. Throughout this process, the reflection characteristics

of the top and bottom interfaces of the sandstone-mudstone remain unchanged (Figure 6(a)), and its true seismic reflection characteristics correspond to Profile AA' (Figure 7).

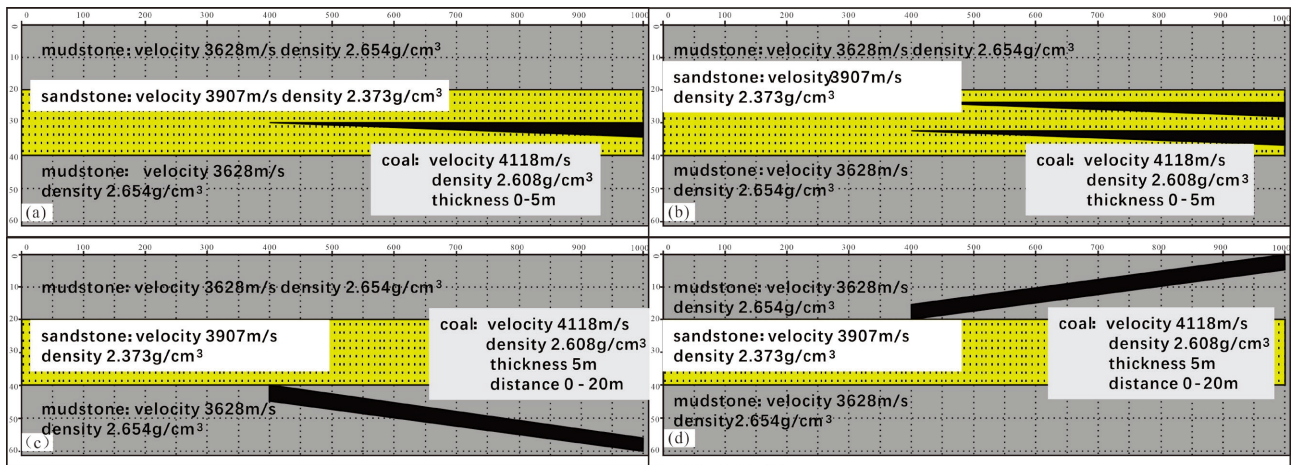


Figure 5. Theoretical forward model.

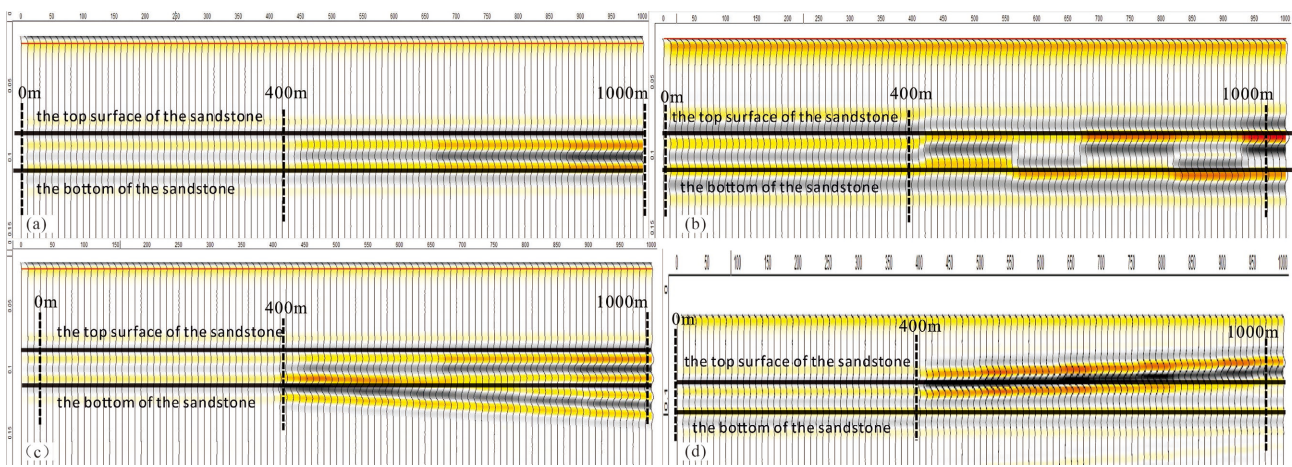


Figure 6. Forward modeling results.

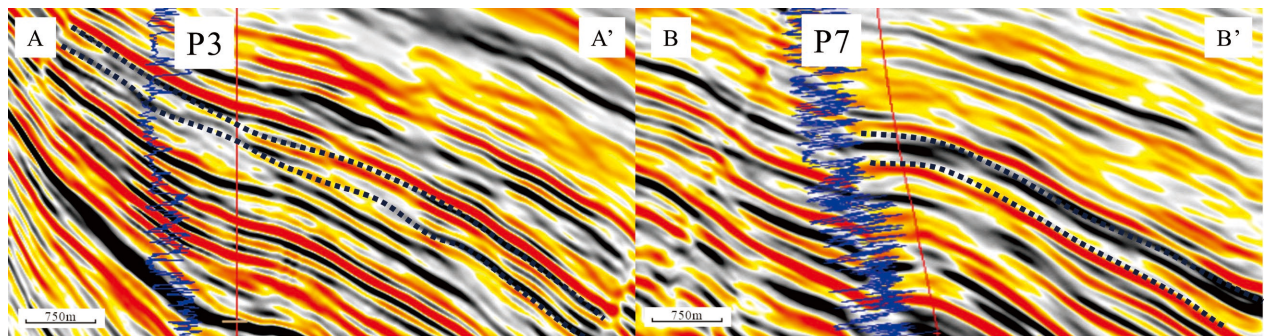


Figure 7. Original seismic profile.

For Model 2 (Figure 5(b)), the sandstone-coal combination is “interbedded sandstone and coal”. Within the horizontal range of 400 - 570 m, corresponding

to a coal seam thickness of 0 - 1.4 m, sandstone-coal interface reflection characteristics appear, with minimal enhancement in seismic reflection amplitude. The amplitude at the interface between the upper coal seam and sandstone exhibits a wave crest, while the lower one exhibits a wave trough. The reflection amplitudes of both the top and bottom interfaces of the sandstone-mudstone change from wave crests to wave troughs, with a slight enhancement in amplitude. Within the horizontal range of 570 - 670 m, corresponding to a coal seam thickness of 1.4 - 2.25 m, due to the thin coal seams and the interference between upper and lower coal seams, the sandstone between coal seams exhibits no reflection characteristics. Meanwhile, the reflection characteristics of the upper coal seam are also affected by the wave reflection of the lower coal seam, resulting in weakened amplitude. The sandstone-coal reflection interface still exhibits a wave crest, while the reflection characteristic of the sandstone-coal bottom interface changes from a wave crest to a wave trough. Both the amplitudes of the top and bottom interfaces of the sandstone-mudstone exhibit wave troughs. Within the horizontal range of 670 - 830 m, corresponding to a coal seam thickness of 2.25 - 3.6 m, the amplitude at the reflection interface between the upper coal seam and sandstone increases and exhibits wave crest reflection. The amplitude of the top interface of the sandstone-mudstone increases, while the amplitude of the bottom interface decreases, with both top and bottom interface amplitudes exhibiting wave troughs. Within the horizontal range of 830 - 930 m, corresponding to a coal seam thickness of 3.6 - 4.4 m, the amplitudes of the top and bottom interfaces of the upper sandstone-coal decrease, while the reflection amplitude intensity at the top and bottom interfaces of the lower sandstone-coal shows no significant change. The amplitude of the top interface of the sandstone-coal changes from a wave trough to a wave crest, and the lower one changes from a wave crest to a wave trough. Within the horizontal range of 930 - 1000 m, corresponding to a coal seam thickness of 4.4 - 5 m, the amplitudes of the top and bottom interfaces of the upper sandstone-coal increase. The amplitude intensity of the top interface of the lower sandstone-coal shows no significant change, exhibiting a change from a wave crest to a wave trough, while the amplitude intensity of the bottom interface decreases. The amplitude intensities of both the top and bottom interfaces of the sandstone-mudstone increase (**Figure 6(b)**), and its true seismic reflection characteristics correspond to Profile BB' (**Figure 7**).

## 5. Conclusion and Insights

Based on the geological features of coal measures in the Pinghu Formation of Pingbei, Xihu Sag, four forward models were built and analyzed using acoustic wave equations. The following insights were obtained:

- 1) In the “sandstone-coal-sandstone” combination, as coal seam thickness increases, the reflection amplitude intensity of sandstone-mudstone interfaces augments without polarity reversal.
- 2) In the “interbedded sandstone and coal” scenario, increasing coal seam

thickness boosts reflection amplitude intensity at sandstone-mudstone interfaces. Multiple polarity reversals occur when coal thickness ranges from 0 - 5 m, attributed to interference from multiple coal seams.

3) The influence of coal seams on sandstone reflections diminishes as their distance increases. Between 0 - 10 m, reflection amplitude at sandstone-mudstone interfaces intensifies without polarity reversal. Between 10 - 20 m, amplitude decreases and polarity reversal occurs.

## Acknowledgements

Thanks to the school and colleagues for their help, as well as the strong support for me.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

## References

- Fu, W. B., Xiong, X. J., & Li, Y. (2010). Research on Seismic Reflection Characteristics of Biological Reefs Based on Wave Equation Numerical Simulation. *Journal of Changjiang University (Natural Science Edition) Science and Technology*, 7, 165-166.
- Guo, Y. H., Liu, H. J., & Jia, J. H. (1998). The Tidal Delta-Fluvial Sedimentation and Coal Accumulation of the Shanxi Formation in Pinggou Mining Area, Southwestern Edge of Inner Mongolia. *Coal Geology & Exploration*, 5, 11-14.
- Johansen, S. E., Arntsen, B., Raknes, E. B., Omosanya, K. O. L., Harishidayat, D., & Henningsen, T. (2023). Seismic Forward Modelling of the Kvalhovden Outcrop, Spitsbergen, Norway. *Marine and Petroleum Geology*, 147, Article ID: 106000. <https://doi.org/10.1016/j.marpetgeo.2022.106000>
- Li, D. M., Yuan, G. H., Feng, C. J. et al. (2018). Seismic Forward Modeling Research on the Deep-Water Fan Reservoir of the Sanya Formation in the Changchang Depression of the Qiongdongnan Basin. *Inner Mongolia Petrochemical Industry*, 44, 7-13.
- Li, Z. X., Zhou, J., Lv, D. W. et al. (2013). Coal-Bearing Distribution Characteristics of the Yacheng Formation in the Qiongdongnan Basin. *Journal of Shandong University of Science and Technology (Natural Science)*, 32, 1-8.
- Liu, W. (2014). Forward Modeling and Application of Coal Thickness. *Journal of Henan Polytechnic University (Natural Science Edition)*, 7, 165-166.
- Mirkamali, M. S., Javaherian, A., Hassani, H., Saberi, M. R., & Sarallah-Zabihi, S. (2023). Seismic Forward Modeling for Investigating and Interpreting Thin Beds in a Carbonate Reservoir in SW Iran. *Exploration Geophysics*, 54, 601-624. <https://doi.org/10.1080/08123985.2023.2212697>
- Niu, H. W., Liu, M., Jiang, C. et al. (2022). Identification of Lithologic Trap in Coal-Bearing Stratum of Pingbei Area, Xihu Sag, East China Sea Shelf Basin. *Petroleum Geology & Experiment*, 44, 7-13.
- Shen, W. C. (2018). *The Coal Accumulation Model and Sedimentary Organic Facies of Paleogene Coal in the Xihu Depression*. China University of Mining & Technology.
- Wang, D., Zhang, M., Yang, W., Cai, K., Gao, L., & Zhu, J. (2017). Seismic Forward and Inverse Simulation in a Tight Reservoir Model of Loess Plateau Region. *Petroleum Exploration and Development*, 44, 265-273.

[https://doi.org/10.1016/s1876-3804\(17\)30029-0](https://doi.org/10.1016/s1876-3804(17)30029-0)

- Wang, H. Y., Zhou, X. L., Hu, W. et al. (2021). Prediction of Coal-Bearing Strata Reservoir in the Pingbei Slope Zone of the Xihu Depression. *Geophysical Prospecting for Petroleum*, *60*, 595-603.
- Xie, L. L., Jiang, F. Y., & Chang, W. K. (2015). Tesseral 2D-Based Earthquake Forward Simulation of under Sand Strata. *Journal of Hohai University (Natural Sciences)*, *43*, 351-355.
- Xiong, B. H., Wang, C. H., Zhang, J. W. et al. (2007). The Distribution and Exploration of Coal Beds of the Pinghu Formation, Paleogene in Xihu Sag. *Offshore Oil*, *3*, 27-33+40.
- Xu, G. S., Cui, H. Y., Liu, Y. et al. (2020). Relationship between Sandstone Reservoirs Den-sification and Hydrocarbon Charging in the Paleogene Huagang Formation of Xihu De-pression, East China Sea Basin. *Bulletin of Geological Science and Technology*, *39*, 20-29.
- Zhang, J., Xu, F., Zhong, T., Zhang, T., & Yu, Y. (2012). Sequence Stratigraphic Models and Sedimentary Evolution of Pinghu and Huagang Formations in Xihu Trough. *Marine Ge-ology & Quaternary Geology*, *32*, 35-42. <https://doi.org/10.3724/sp.j.1140.2012.01035>
- Zhang, M., Li, Z., Liu, Q., Zhao, Z., & Liu, S. (2020). Forward Modeling of Fine Seismic Wave Velocity Model in Coastal Oilfields. *Journal of Coastal Research*, *95*, 320-324. <https://doi.org/10.2112/si95-062.1>
- Zhang, M., Xu, F., Zhang, J., & Zhang, T. (2011). Structural Pattern during the Rifting Stage of the Xihu Sag and Its Control of Sediment Infilling. *Marine Geology & Quaternary Geology*, *31*, 67-72. <https://doi.org/10.3724/sp.j.1140.2011.05067>
- Zhang, X. L., & Xu, Q. (2012). Sequence and Sedimentary Facies of the Pinghu Formation in the Xihu Depression of the East China Sea Shelf Basin. In The Professional Committee of Lithology and Paleogeography of the Chinese Society of Mineral and Rock Geo-chemistry (Eds.), *Collection of Abstracts from the 12th National Conference on Paleo-geography and Sedimentology* (pp. 71-72). CNOOC Research Institute.
- Zhang, Y., Xu, S. L., & Dan, L. L. (2024). Seismic Forward Modeling of Tight Sandstone Reservoir. *Unconventional Oil & Gas*, *11*, 29-35.
- Zhou, Q. Y., Shen, W. C. et al. (2016). The Coal-Accumulating Environments Characteris-tics and Coal-Forming Pattern of the Pinghu Formation (Paleogene) in Xihu Depression. *Journal of Hebei University of Engineering (Natural Science Edition)*, *33*, 105-107+112.