

Study on Sedimentary Facies of Ledong Formation in Yinggehai Basin Based on Seismic Facies Analysis

Hao Li¹, Pan Yang²

¹CNOOC China Ltd., Hainan, Haikou, China

²Optical Science and Technology (Chengdu) Ltd., Chengdu, China

Email: y1458651011@foxmail.com

How to cite this paper: Li, H., & Yang, P. (2025). Study on Sedimentary Facies of Ledong Formation in Yinggehai Basin Based on Seismic Facies Analysis. *Journal of Geoscience and Environment Protection*, 13, 137-146.

<https://doi.org/10.4236/gep.2025.137008>

Received: June 6, 2025

Accepted: July 15, 2025

Published: July 18, 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: The sedimentary distribution of Ledong formation in Yinggehai basin is not clear. The combination of seismic data and seismic forward modeling can clarify the sedimentary distribution in this area. **Methods:** The seismic facies boundary is characterized by seismic configuration, and the seismic subfacies boundary is characterized by seismic attribute structure. The sand body thickness of Ledong formation is characterized by seismic forward modeling and well logging sand body statistics of relevant well sections. Finally, the plane distribution of sedimentary facies is summarized. **Results and conclusions:** (1) The overall seismic attributes of the Ledong Formation in the Yinggehai Basin are favorable, characterized primarily by moderate to strong reflections on both sides. However, the middle section is severely disrupted by faults, exhibiting weak reflection characteristics. (2) The Ledong Formation represents a shallow marine beach-dam depositional environment, with extensive sand body development. A significant beach-dam complex is developed in the central part of the study area. The core of the sand bodies is relatively pure in texture and possesses excellent physical properties, making it a promising reservoir for oil and gas. (3) Based on seismic facies, two gas-water models are summarized: sheet sand bodies and multiple sets of sand bodies.

Keywords

Yinggehai Basin, Ledong Formation, Seismic Attributes, Sedimentary Distribution Patterns

1. Introduction

The Ledong Formation in Yinggehai Basin is a key area for natural gas explora-

tion, and its sedimentary facies research has direct guiding significance for reservoir prediction and exploration target selection. Luo et al. (2025) determined the sequence and chronostratigraphic framework of the Ledong Formation through the analysis of lithological cycle characteristics, microfossil biological events, seismic reflection characteristics, and shelf slope folding and migration patterns, as well as the comparison of global glacial and oceanic oxygen isotope stages. Li et al. (2024) established a high-precision sequence stratigraphic framework for the Ledong Formation using three-dimensional seismic and drilling data, combined with regional sea level changes, and explored the evolution and distribution patterns of sedimentary systems. Fang et al. (2022) identified the composite sequence boundary of the Ledong Formation based on typical seismic contact relationships, and divided and determined 6 sets of third-order sequences in the lower section and 8 sets of third-order sequences in the upper section of the Ledong Formation. They further identified the initial flooding surface, maximum flooding surface, and maximum regression surface within the third-order sequences, providing an accurate sequence framework for the identification of sedimentary facies and the study of sedimentary evolution in the Ledong Formation. Xu et al. (2021) conducted systematic research on source rocks, reservoir cap rock combinations, reservoir dynamics, migration pathways, etc., and clarified the formation conditions and natural gas accumulation mode of the Ledong Formation ultra-high temperature and high pressure gas field. Li et al. (2021) dissected and discussed the mechanism of overpressure formation in the Ledong Formation structural reservoir based on overpressure logging response, numerical simulation, and natural gas reservoir conditions, and analyzed the relationship between reservoir strong overpressure formation and natural gas reservoir formation. Li et al. (2013) explored the relationship between the pore structure and natural gas enrichment in this area based on the spatial configuration relationship between the pore structure and natural gas, combined with research methods such as hydrocarbon generation dynamics and carbon isotope dynamics. In 2020, he systematically conducted research on the basin forming structures and deep-water sandstone sedimentation processes in the Yinggehai Basin by integrating seismic, logging, logging, testing and other data. He established deep-water sandstone sedimentation models and distribution prediction methods such as basin center submarine fans and axial channels. It can be seen that research on the Ledong Formation in the Yinggehai Basin mainly focuses on the sequence stratigraphy and reservoir formation mechanism under high temperature and pressure environments, with few studies on seismic sedimentation of the Ledong Formation starting from seismic facies. This paper aims to comprehensively study the seismic data of the region, and summarize the sedimentary facies of the Ledong Formation in the Yinggehai Basin from the perspective of seismic facies by combining seismic profiles and plane facies with seismic attribute relationships. It also conducts a comprehensive analysis of the reservoir formation patterns in the study area through seismic forward modeling.

2. Regional Geological Overview

The Yinggehai Basin is a large strike slip extensional basin in the northern South China Sea during the Cenozoic era, with an area of approximately $11.3 \times 10^4 \text{ km}^2$ and a maximum sedimentary thickness of over 17 km. The strata in the basin generally exhibit high temperature and high pressure characteristics, and multiple oil and gas bearing structures have developed (Zhao, 2023). The basin consists of five secondary structural units: the Central Depression, the Hanoi Depression, the Lingao Uplift, the Yingxi Slope, and the Yingdong Slope. Controlled by late stage strike slip faulting, the central depression developed a series of herringbone like basal structures. The Cenozoic in the basin includes the Yanqing Formation and Lingshui Formation of the Oligocene, the Sanya Formation, Meishan Formation, and Huangliu Formation of the Miocene, the Yinggehai Formation of the Upper Neogene, and the Ledong Formation of the Quaternary from bottom to top. The Yacheng Formation and Lingshui Formation were only partially revealed by drilling in the Lingao uplift and slope zone. The Ledong Diaphragm Area is located in the southeastern part of the Central Depression, adjacent to the southern part of the Yingdong Slope. It is mainly composed of nearshore shallow sea to semi deep sea mudstone developed in the Neogene Miocene Sanya Formation and Meishan Formation, with the Miocene Huangliu Formation, Upper Miocene Yinggehai Formation, and Pleistocene Ledong Formation as the main exploration layers (Figure 1) (Cao et al., 2022; Fan et al., 2021; Yang & Huang, 2019).

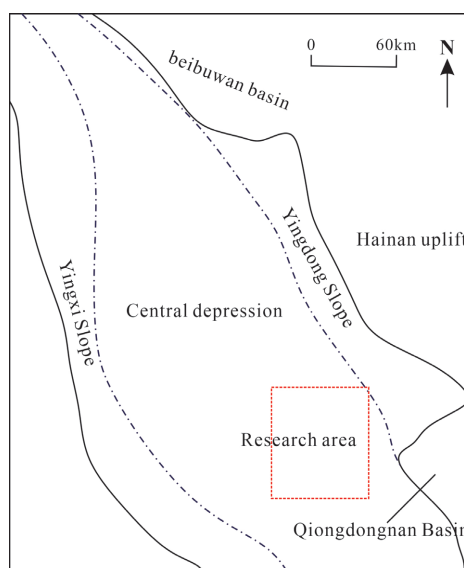


Figure 1. Location of Ledong Formation in Yinggehai Basin.

3. Research on Seismic and Sedimentary Facies

3.1. Seismic Facies Research

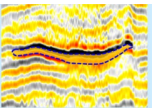
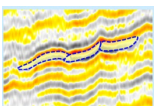
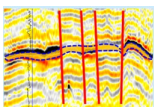
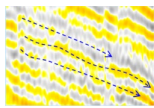
Seismic facies analysis refers to the seismic interpretation technique that uses the geological significance represented by seismic facies parameters (such as reflec-

tion structure, continuity, external geometric shape, amplitude, frequency, layer velocity, etc.) to explain sedimentary facies of geological strata. It is one of the important methods for studying sedimentary facies, especially for determining sedimentary facies in offshore areas with few or no wells. Due to the lack of drilling core data and electrical logging curves for well logging facies calibration, seismic data is almost the only effective research method, and seismic facies research is undoubtedly the most important link. Guo et al. (2010) conducted seismic facies analysis on the shallow layers of the Yinggehai Basin using seismic data, and proposed new exploration targets with different rock types, physical properties, and sedimentary environments compared to those already drilled. Pei et al. (2015) classified the seismic facies types of gas bearing reservoirs in Yinggehai Basin into three categories based on zero phase positive polarity seismic data. Based on this, they conducted in-depth analysis of the genesis of these three types of seismic facies from the aspects of lithological combination, rock physical characteristics, and sand body coupling. They classified 15 seismic facies styles and analyzed their transition relationships, improving the universal and promotable seismic facies identification technology for gas bearing reservoirs. Pan et al. (2012) analyzed a new seismic facies pattern in the Yinggehai Basin waterway: one is a set of weak amplitude and weak continuity in-phase axes sandwiched between two strong amplitude and strong continuity in-phase axes; The second is the inverted seismic phase of the waterway bulge. The former can be included in the research scope of waterways mainly containing sandstone, while the latter is caused by differential compaction of sandstone and mudstone. By identifying and classifying stratigraphic units with similar shapes or parameters within the same seismic sequence, the planar distribution of seismic facies can be obtained, and then seismic facies sedimentary facies conversion can be carried out to analyze sedimentary facies.

The Ledong Formation mainly develops the following four typical seismic facies: ① Seismic facies with strong amplitude and high continuity exhibit a strip-shaped appearance, generally being thin on both sides and thick in a lens-shaped configuration in the middle. Sedimentary interpretation identifies these as coastal sand dams. ② Seismic facies characterized by medium to strong amplitude and medium to high frequency display a leaf-like shape with a low, flat, convex, and hilly configuration. They are typically composed of multiple interconnected small parts and are interpreted as shallow-sea beach dam complexes in sedimentary terms. ③ Seismic facies with strong amplitude but low continuity show a strip-shaped and hilly morphology, generally similar to ①, yet severely disrupted by internal faulting, and are interpreted as sand dams influenced by faults. ④ Seismic facies with weak amplitude to medium-high continuity exhibit a sheet-like shape with parallel or sub-parallel configurations, interpreted as shallow marine mudstone sedimentation. The typical planar distribution of seismic facies in the Ledong Formation is relatively simple. Among them, the seismic facies ② with a hilly configuration have the widest distribution range of strong amplitude to medium-high frequency seismic facies, followed by the seismic facies ④ with parallel

and sub-parallel configurations of weak amplitude to medium-high continuity seismic facies, which are distributed alternately. Faults are relatively well-developed in the central part of the study area, and there exists a certain range of fault-affected zones (Table 1).

Table 1. Seismic facies analysis of Ledong Formation in Yinggehai Basin.

Typical seismic facies				
describe	Lens shaped strong amplitude high continuity	Hill shaped medium to strong amplitude with high continuity	Lens shaped strong amplitude low continuity	Sub parallel weak amplitude with high continuity
sedimentary facies	Sand dam	Beach dam complex	Sand dam affected by faults	Continental shelf mud

3.2. Sedimentary Facies Research

Seismic attribute analysis plays an extremely important role in sedimentary facies analysis. Through planar seismic attribute analysis, the geometric shape, lithological distribution, and sedimentary environment of sedimentary bodies in the study area can be revealed, providing key basis for oil and gas exploration and reservoir prediction. On the basis of seismic facies analysis, combined with RMS attributes and wave impedance inversion seismic attributes, comprehensive research is carried out to characterize sedimentary microfacies. Typical seismic configuration analysis is used to characterize the boundaries of sedimentary units, and multiple seismic attributes are used to characterize the internal details of sedimentary units, completing fine sedimentary microfacies characterization.

The seismic attribute characteristics of the Ledong Formation are as follows: ① The overall seismic attribute is relatively good, with strong reflection areas mainly concentrated in the central part of the study area, and the two sides are mainly characterized by medium strong reflection features. The medium strong reflection areas and weak reflection areas are mostly distributed alternately; ② In the central part of the research area, between well-3 and well-8 wells, there is severe damage caused by fault cutting, exhibiting relatively weak reflection characteristics (Figure 2).

Through the analysis of seismic attribute characteristics and typical seismic phases, it can be concluded that the main seismic phases with large areas of medium to strong amplitude and high frequency in the central part of the study area are mainly revealed as beach dam. Above the beach dam, there are spindle shaped sand dam with strong amplitude and high frequency in a north-south direction. Among them, between Well 3 and Well 8, a sand dam is severely cut and damaged by faults, dividing one sand dam into two smaller sand dam. The blank area between the two sand dam is affected by faults. From the perspective of sedimentary

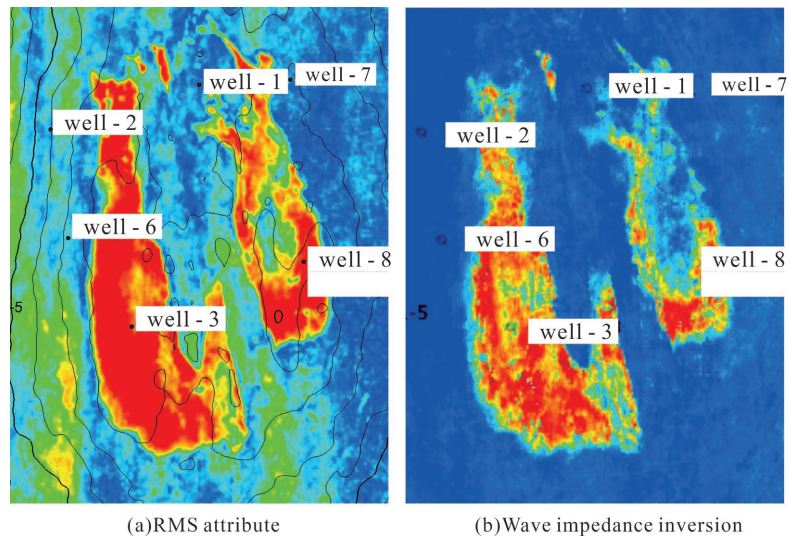


Figure 2. Seismic attributes of Ledong Formation in Yinggehai Basin.

facies, the study area is located in the distal part of the turbidity current sedimentary system, with relatively fine grain size and poor physical properties. The sandstone lithology is mainly composed of mudstone and siltstone. In the early stage of sedimentation, the transport speed of fine-grained sedimentary bodies is relatively fast, but the sedimentation scale is small. In the middle stage of sedimentation, the turbidity current energy is relatively strong and more stable, and thick sandstone deposits begin to appear. The source material is relatively coarse at the proximal end and fine at the distal end; At the end of sedimentation, the turbidity current energy decreases, and thin sheet-like mudstone deposits are more developed at the distant source end, with an increase in mudstone content (Figure 3, Figure 4).

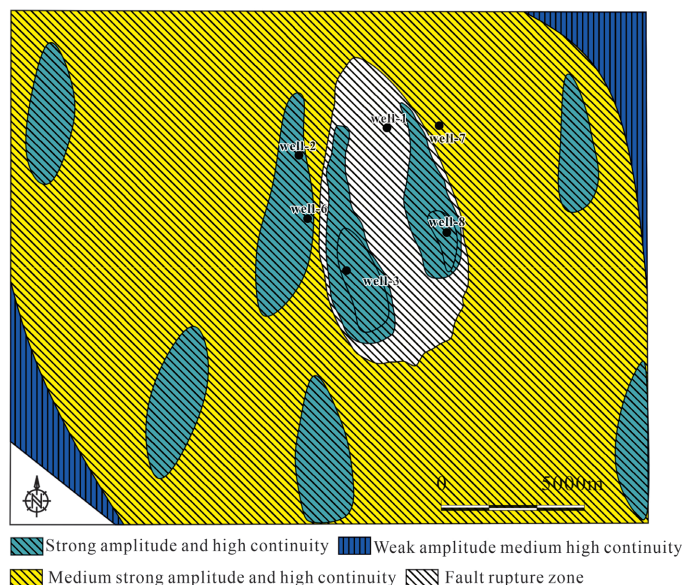


Figure 3. Seismic facies of Ledong Formation in Yinggehai Basin.

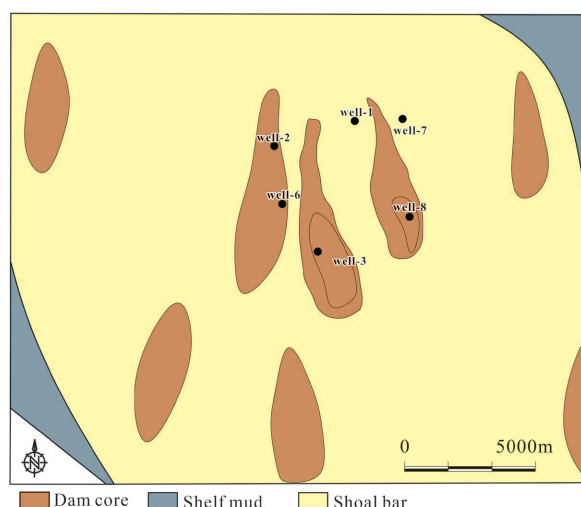


Figure 4. Sedimentary facies of Ledong Formation in Yinggehai Basin.

4. Seismic Forward Simulation and Sand Gas Water Model

Seismic forward modeling (i.e. seismic wavefield simulation) constructs geological models and simulates their seismic responses based on different lithological and physical parameters (such as velocity and density) obtained from logging data, in order to generate seismic records that are close to the real situation. The conventional seismic wavefield forward modeling methods mainly include geometric ray method and wave equation method. The former can accurately calculate the kinematic characteristics such as the ray path and travel time of seismic waves, but it is prone to blind spots for some complex geological structures and lithological information; The wave equation simulation method focuses on the dynamic properties of seismic waves, which can more realistically simulate the seismic wave field characteristics of complex strata (Wang et al., 2012; Xie et al., 2015). This simulation uses Tesseral-2D software to establish a velocity depth model, which can effectively simulate the wave effect of seismic energy propagation in two-dimensional space. The model is based on the assumption of an ideal fluid medium and does not take into account the influence of solid medium hardness. The specific process is to assign the velocity and density parameters obtained from logging statistics to the corresponding lithological bodies in the two-dimensional model, and then solve the numerical solution of the acoustic wave equation to synthesize seismic records, accurately reflecting the amplitude, phase, frequency and other attribute characteristics of seismic wave propagation (Table 2).

Table 2. Statistical table of geophysical parameters.

Lithology	Velocity (m/s)
Gas bearing sandstone (m/s)	2760
Water bearing sandstone (m/s)	2840

Based on the joint analysis of sedimentary facies research and seismic forward simulation, and by comparing with typical seismic profiles, two types of gas bearing sand body models, namely, in-situ sand dam and multiple sets of sand dam, are summarized:

(1) Seat shaped sand dam gas bearing mode: The forward model has a clear vertical three part structure (bottom mudstone → middle water bearing sandstone → top gas bearing sandstone), and the simulation results reveal that the top of the sand body shows strong amplitude continuous bright spot reflection, which is highly consistent with the response characteristics of the beach dam sand body in actual seismic profiles (**Figure 5(a)**);

(2) Multiple sets of sand dam gas bearing models: The model consists of three sets of adjacent sand dam, with the gas bearing layer in the middle sand dam dominating the fluid response. The forward modeling results show that there is a structural discontinuity zone between the sand dam (corresponding to the Well-3 to Well-8 well areas), and the seismic phase exhibits strong amplitude difference continuity reflection, which is consistent with the amplitude mutation characteristics caused by the cutting of the fault layer in the actual profile (**Figure 5(b)**).

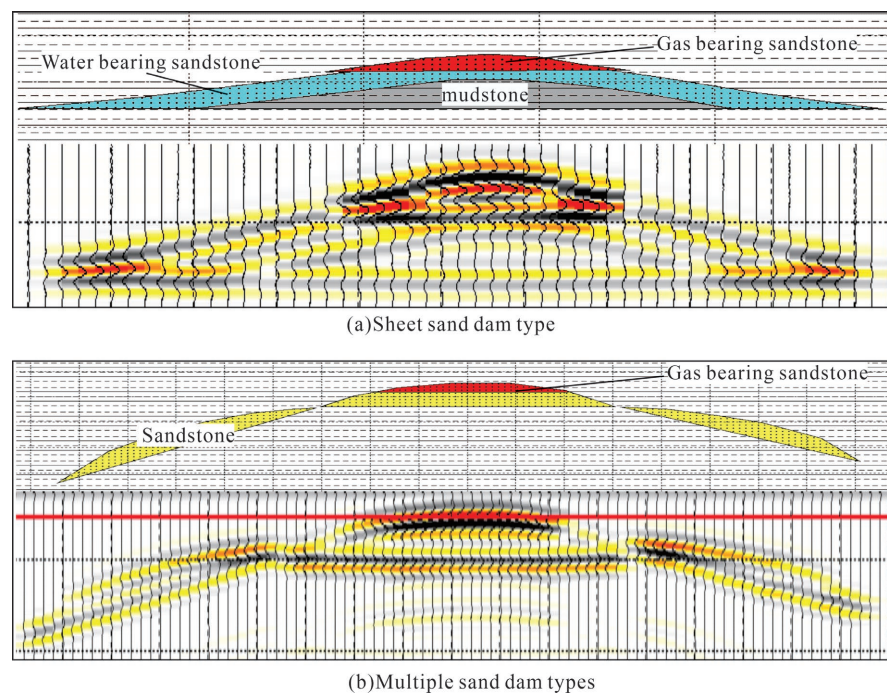


Figure 5. Sand body air-water model and forward simulation.

5. Conclusions and Insights

(1) Using seismic configuration analysis to delineate seismic phase boundaries, and combining attribute structure analysis (amplitude/coherence attributes) to finely delineate seismic subfacies. Research has shown that the Ledong Formation exhibits moderate to strong amplitude continuous reflection as a whole, but the reflection structure in the middle is disordered due to the alteration of the fault

zone (weak reflection phase zone).

(2) Through seismic attribute fusion (RMS amplitude and spectral decomposition), a large beach dam complex in the central region was identified. The sand body in the core has low mud content (lithological indication attribute) and high porosity (wave impedance inversion), forming a high-quality reservoir.

(3) The sheet sand gas water model and multi sand body gas water model were summarized through the coupling analysis of seismic facies sedimentary facies seismic forward modeling.

Conflicts of Interest

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

References

- Cao, J. J., Luo, J. L., & Fan, C. W. (2022). Deep Thermal Fluid Activity and Its Influence on the Diagenesis and Pore Evolution of Reservoirs: A Case Study from the Miocene Huangliu Formation Reservoir in the LDX Area, Yinggehai Basin, Northern South China Sea. *Earth Science Frontiers*, *29*, 412-429.
- Fan, C. W., Cao, J. J., & Luo, J. L. (2021). Heterogeneity and Influencing Factors of Marine Gravity Flow Tight Sandstone under Abnormally High Pressure: A Case Study from the Miocene Huangliu Formation Reservoirs in LD10 Area, Yinggehai Basin, South China Sea. *Petroleum Exploration and Development*, *48*, 903-915.
- Fang, X. Y., Yao, Z., & Liao, J. (2022). Sequence Stratigraphic Architecture of the Quaternary Ledong Formation in the Deep-Water Area of the Qiongdongnan Basin and Its Significance to Gas Hydrate Exploration. *Marine Geology Frontiers*, *38*, 51-60.
- Guo, A. H., Zhou, J. X., & Fan, C. W. (2010). The Application of Seismic Facies Analysis in Yinggehai Basin Mid-Depth Exploration. *Inner Mongolia Petrochemical Industry*, *36*, 204-207.
- Li, C., Luo, X. R., & Fan, C. W. (2021). Generation Mechanism of Overpressure and Its Implication for Natural Gas Accumulation in Miocene Reservoir in Ledong—A Structure, Ledong Slope, Yinggehai Basin. *Chinese Journal of Geology*, *56*, 1034-1051.
- Li, W. L., Mao, X. L., & Liu, P. (2024). Evolution On Sedimentary System of the Quaternary Ledong Formation, Qiongdongnan Basin. *Natural Gas Exploration and Development*, *47*, 1-7.
- Li, X. S., Pei, J. X., & Li, Y. L. (2013). Gas Play Conditions and Accumulation Patterns of the Ledong Gas Fields, Yinggehai Basin. *Natural Gas Industry*, *33*, 16-21.
- Luo, W., Pei, J. X., & Wang, Y. H. (2025). High-Resolution Sequence and Chronostratigraphic Framework of Ultra-Shallow Ledong Formation in Qiongdongnan Basin. *Journal of Stratigraphy*, *49*, 31-41.
- Pan, G. C., Han, G. M., & Song, R. Y. (2012). New Seismic Facies Style of Channels in Yinggehai Basin and Gas-Bearing Prediction. *Petroleum Geophysical Exploration*, *47*, 984-989+1024+843.
- Pei, J. X., Pan, G. C., & Wang, Y. (2015). Improvement and Application of Seismic Facies Identification Technology for Gas-Bearing Reservoir in Yinggehai Basin. *China Offshore Oil and Gas*, *27*, 30-36.
- Wang, X. W., Qin, G. S., & Zhao, W. F. (2012). The Application of Forward Modeling Technique in Seismic Acquisition Design. *Progress in Geophysics*, *27*, 642-650.

- Xie, L. L., Jiang, F. Y., & Chang, W. K. (2015). Tesseral 2D-Based Earthquake Forward Simulation of Underwater Sand Strat. *Journal of Hohai University (Natural Sciences)*, *43*, 351-355.
- Xu, M. G., Fan, C. W., & Zhang, D. (2021). Formation Condition and Hydrocarbon Accumulation Model in Ledong 01 Gas Reservoir of Super High Temperature and High Pressure in the Yinggehai Basin. *Natural Gas Industry*, *41*, 43-53.
- Yang, J. H., & Huang, B. J. (2019). Origin and Migration Model of Natural Gas in L Gas Field, Eastern Slope of Yinggehai Sag, China. *Petroleum Exploration and Development*, *46*, 450-460.
- Zhao, J. (2023). *High Temperature and High-Pressure Fluid Activities and Natural Gas Accumulation Mechanism in the Ledong Area of the Yinggehai Basin*. China University of Petroleum (Beijing).