frontiers | Frontiers in Earth Science

TYPE Editorial
PUBLISHED 22 April 2025
DOI 10.3389/feart.2025.1602806

Check for updates

OPEN ACCESS

EDITED AND REVIEWED BY:
David R. Lentz,
University of New Brunswick
Fredericton, Canada

*CORRESPONDENCE
Hu Li,
lihu860628@126.com,
lihu@suse.edu.cn

RECEIVED 30 March 2025
ACCEPTED 10 April 2025
PUBLISHED 22 April 2025

CITATION
Li H, Tan P, Radwan AE and Wang H (2025) Editorial: Differences in shale oil and gas reservoirs across various sedimentary environments: theories and applications, volume II.
Front. Earth Sci. 13:1602806.
doi: 10.3389/feart.2025.1602806

Editorial: Differences in shale oil and gas reservoirs across various sedimentary environments: theories and applications, volume II

Hu Li[1,2]*, Peng Tan[3], Ahmed E. Radwan[4] and Haijun Wang[1,2]

[1]School of Economics, Sichuan University of Science and Engineering, Yibin, China, [2]Sichuan Key Provincial Research Base of Intelligent Tourism, Sichuan University of Science and Engineering, Yibin, China, [3]CNPC Engineering Technology R & D Company Limited, Beijing, China, [4]Faculty of Geography and Geology, Institute of Geological Sciences, Jagiellonian University, Kraków, Poland

KEYWORDS

shale oil and gas, pore structure, multi-scale fracture, sedimentary environment, diagenesis

Editorial on the Research Topic
Editorial: Differences in shale oil and gas reservoirs across various sedimentary environments: theories and applications, volume II

1 Introduction

The success of the North American shale revolution has not only reshaped the global energy landscape but also driven a systematic paradigm shift in unconventional hydrocarbon exploration (Fan et al., 2020). As a major shale gas resource country, China has achieved commercial development in marine shale systems (such as the Ordovician Wufeng Formation and Silurian Longmaxi Formation), and in 2022, their shale gas production surpassed 24 billion cubic meters (Li, 2023; Li H. et al., 2024; Li et al., 2024b; Li et al., 2025a; He et al., 2025). Currently, exploration and development efforts are underway in new marine shale intervals (e.g., the Qiongzhusi and Wujiaping formations), continental shale intervals (e.g., the Qingshankou Formation in the Songliao Basin), and marine–continental transitional shales (e.g., the Shanxi Formation in the Ordos Basin) (Zhai et al., 2019; Chen et al., 2019; 2023; Feng et al., 2023; Yan et al., 2024). Breakthroughs in the exploration of continental shale in India's Cambay Basin and Jurassic marine–continental transitional shale in Saudi Arabia's Jafurah Basin further validate the resource potential of shale oil and gas in different depositional settings (Singh and Chakraborty, 2023; Madukwe et al., 2023). With the application of technologies such as pre-stack 3D seismic inversion, nano-CT pore characterization, and multi-stage fracturing in horizontal wells, research focus has shifted from macroscopic reservoir description to advanced topics including organic matter enrichment dynamics, evolution of nanometer-scale pore throats, and multiscale reservoir heterogeneity (Guo et al., 2019; Chen et al., 2022; Dang et al., 2022). Notably, shales deposited in different depositional facies exhibit systematic differences in organic matter type, diagenetic processes, and preservation conditions, which directly affect the accuracy of sweet spot prediction models.

This research topic is organized precisely against this backdrop, aiming to compile the latest research findings and insights in this field, and comprises nine papers covering a wide range of themes and diverse depositional environments, with study areas including representative Chinese basins such as the Ordos, Bohai Bay, Sichuan, and Beibuwan basins. The following sections review each paper's research content, methodology, principal conclusions, and significance.

2 Paper reviews

2.1 Multiscale fracture patterns in tight sandstones and their impact on natural gas accumulation

In tight sandstones, the connectivity of multiscale natural fractures is critical for forming high-quality reservoirs and achieving sustained high hydrocarbon production. This study (Manuscript ID: 1,448,238), taking the Upper Paleozoic tight sandstones of the Ordos Basin as an example, quantitatively characterized fracture parameters across various scales and innovatively proposed a classification of four fracture network patterns: (i) high-density, multi-orientations (multi-scale fracture); (ii) moderate-high density and dual orientations (multi-scale fracture); (iii) moderate density and dual orientations (small-scale fracture); and (iv) low density and single orientation (small-scale fracture). The results show that fracture length, density, porosity, and connectivity exhibit clear regularities, and different network patterns have distinct effects on gas accumulation (Li et al., 2025a; Li et al., 2025b). In particular, high-density, multi-orientations fractures tend to compromise caprock integrity, while moderate-density, dual orientations small-scale fractures are more favorable for gas accumulation. This multiscale perspective deepens our understanding of the coupling between fracture systems and hydrocarbon enrichment, thereby providing a scientific basis for sweet spot selection and production enhancement in tight gas reservoirs (Liu et al., 2024a; Yin et al., 2024).

2.2 The influence of CO_2 on sandstone reservoirs under different fluid regimes

Mantle-derived CO_2, an important component of hydrothermal fluids, has traditionally been studied in open systems where its role in mineral dissolution is believed to improve reservoir properties. However, its adverse effects *via* carbonate cementation have often been overlooked. This study (Manuscript ID: 1,436,573), using a mantle-derived CO_2 gas reservoir in the Dongying Sag of the Bohai Bay Basin as a case, systematically investigates the mechanisms by which CO_2 affects sandstone reservoirs in both open and closed fluid environments. The results demonstrate that CO_2-enriched hydrothermal fluids actively participate in water-rock interactions, significantly influencing diagenetic evolution. In open environments, mantle-derived CO_2 promotes the dissolution of feldspar and carbonate minerals, facilitates the timely removal of dissolution products (e.g., clays), and inhibits new carbonate cementation, thereby enhancing porosity and permeability. In contrast, in closed systems, as depth increases and CO_2 concentration decreases, the dissolution effect weakens while carbonate cementation intensifies, resulting in reduced porosity and permeability. This study corrects the one-sided view derived solely from open-system experiments and emphasizes the dual (both positive and negative) impact of CO_2 on reservoir properties. The findings enrich our theoretical understanding of CO_2–rock diagenetic interactions in sedimentary basins and provide practical guidance for evaluating reservoirs in CO_2-active areas, facilitating the identification of sweet spots with favorable properties.

2.3 Enrichment characteristics and genesis of key elements in coals

The discovery of co-associated valuable metals in coal and their genetic mechanisms represents a cutting-edge topic in sedimentary environmental research. This study conducted mineralogical and geochemical tests on coal samples from seven typical mines in the Late Permian coalfields of northeastern Guizhou (Manuscript ID: 1,520,502). It reveals the anomalous enrichment and mineralization mechanisms of key elements such as niobium (Nb), tantalum (Ta), zirconium (Zr), hafnium (Hf), rare earth elements (REE), and yttrium (Y). The results show significant variations in elemental composition and abundance among different mines and coal seams, with key elements preferentially concentrated in the clay-rich layers interbedded with coal. The enrichment types and abundance differences are mainly controlled by terrigenous detrital input, depositional conditions, seawater influence, and hydrothermal fluid activity. This study not only elucidates the enrichment patterns and genesis of key rare metals in coal-bearing strata, but also provides valuable insights for the comprehensive recovery of strategic metals from coal and the expansion of unconventional mineral resources.

2.4 Machine learning-driven lithology identification in complex reservoirs

Accurate lithology identification is crucial for selecting exploration targets, evaluating reservoirs, and optimizing development strategies in complex reservoirs. However, the limited availability of core data introduces uncertainties when relying solely on conventional well logs. Recently, machine learning techniques have been introduced to enhance lithology prediction accuracy. This study (Manuscript ID: 1,491,334), using the Niuxintuo block in the Liaohe Oilfield as an example, evaluated the applicability of five algorithms, which are Bayesian discriminant analysis, Random Forest (RF), Support Vector Machine (SVM), Back-Propagation Neural Network (BPNN), and Convolutional Neural Network (CNN), for lithology identification in complex reservoirs. The results indicate that all models, except the Bayesian classifier, achieved prediction accuracies above 85%, with the SVM model performing exceptionally well, attaining an accuracy of 93%. Moreover, the optimized SVM model was successfully applied to predict lithology in blind wells, demonstrating its strong generalizability. These findings confirm that machine learning approaches based on well log data can significantly enhance lithology identification accuracy, providing new tools for reservoir characterization and modeling, predicting residual oil distribution, and guiding further exploration (Liu Z. D. et al., 2024).

2.5 Characteristics and main controlling factors of mudstone reservoirs

This study examines the mudstone reservoir of the first Member of the Maokou Formation in the southeastern Sichuan Basin (Manuscript ID: 1,494,518). By integrating outcrop observations, core descriptions, thin-section analysis, scanning electron microscopy (SEM), X-ray diffraction (XRD) testing, total organic carbon (TOC) measurements, low-temperature nitrogen adsorption and well log data, the research comprehensively analyzes the reservoir characteristics and controlling factors of the mudstones. The results indicate that mudstones with high TOC content and superior porosity represent the best reservoir rock type, and their formation is jointly promoted by organic enrichment and clay diagenesis. This work not only deepens our geological understanding of tight mudstone reservoirs in southeastern Sichuan, but also enriches diagenetic models for marine carbonate unconventional reservoirs (Shan et al., 2022).

2.6 A fine interpretation method for tight reservoirs based on core analysis and imaging well logs

Addressing the limitations of conventional well log interpretation, which often fails to accurately delineate productive intervals in tight carbonate reservoirs (with porosities of only 2%–6% and permeabilities less than 2 mD) in Lower Paleozoic Ordovician marine carbonates at the eastern margin of the Ordos Basin. This study proposes an integrated method combining core experimental analysis with imaging well logs (Manuscript ID: 1,534,598). The methodology involves: (i) detailed lithofacies classification using XRD analysis of core samples; (ii) comprehensive evaluation of pore types and permeability using electrical imaging logs and multi-array sonic logs; and (iii) calculation of gas saturation using a modified Archie equation with a variable cementation exponent. This approach significantly overcomes the limitations of conventional well log interpretation in tight reservoirs, improves the accuracy of fluid identification, and offers a new pathway for the quantitative evaluation of complex unconventional reservoirs. Practically, it aids in identifying sweet spot intervals and increasing drilling success rates.

2.7 Controls of sedimentation, diagenesis, and geochemistry on lacustrine shale reservoir characteristics

Taking the Qianfoya Formation in the Langzhong–Yuanba area of the northeastern Sichuan Basin as a case study, this study employs comprehensive sedimentological, geochemical, and rock-physical analyses of core samples to identify three main depositional facies, and each corresponding to different depositional energy environments (Manuscript ID: 1,499,533). The findings reveal that the laminated, clay-rich shales in a semi-deep lacustrine setting exhibit the best reservoir properties, characterized by high TOC and a pore structure dominated by silt intergranular pores, clay interlayer pores, intra-pyrite pores, and microfractures; in contrast, the organic pores typical of marine shales are not the primary storage space in this lacustrine system. The primary controlling factors include the synergistic interaction between organic matter and clay minerals, the depositional environment, and diagenetic processes. This study systematically elucidates the formation mechanisms of lacustrine shale reservoirs, highlighting significant differences in reservoir quality between lacustrine and marine shales, and offers important insights for the exploration of similar continental shale gas plays worldwide.

2.8 Formation processes and controlling factors of tight buried-basement hill reservoirs

In stable cratonic basins, hydrocarbon reservoirs hosted in buried basement hills typically form after the basement structure is established and before overlying sediments are deposited. This study (Manuscript ID: 1,552,826), using a buried hill in the Weixinan Depression of the northern Beibu Gulf Basin as a case, employs balanced section restoration and paleo stress field analysis to reconstruct the tectonic evolution and burial history of the hill, and to analyze the main factors controlling reservoir development. In carbonate basement hills, the combined effect of multistage tectonic stresses and karstification forms a tight reservoir system dominated by dissolution pores and tectonic fractures, primarily distributed along lateral underflow zones on the hill flanks; in contrast, in granite or metamorphic basement hills, tectonic stresses and karstification remain the primary controls, with pore–fracture reservoirs mainly developing in weathered, leached zones at the hilltops. This study clarifies the entire process from tectonic evolution to reservoir formation in buried basement hills, deepening our understanding of unconventional hydrocarbon accumulation in cratonic basins, and provides strong guidance for seismic interpretation and sweet spot selection in similar deep target areas.

2.9 Characterization and exploration implications of marine shale reservoirs

Taking the Upper Permian Wujiaping Formation marine shales in the Longmen–Wushankan area of the eastern Sichuan Basin as an example, this study comprehensively characterizes the key reservoir properties by integrating well rock electrical properties, TOC, porosity, brittle mineral content, and sedimentary-structural analyses (Manuscript ID: 1,453,098). The results indicate that the high natural gas productivity in the Wujiaping shales is primarily attributed to favorable depositional environments, excellent pore conditions, an optimal combination of cap and floor rocks, and a robust fracturing response. However, compared with the Wufeng–Longmaxi shales, the Wujiaping shales exhibit

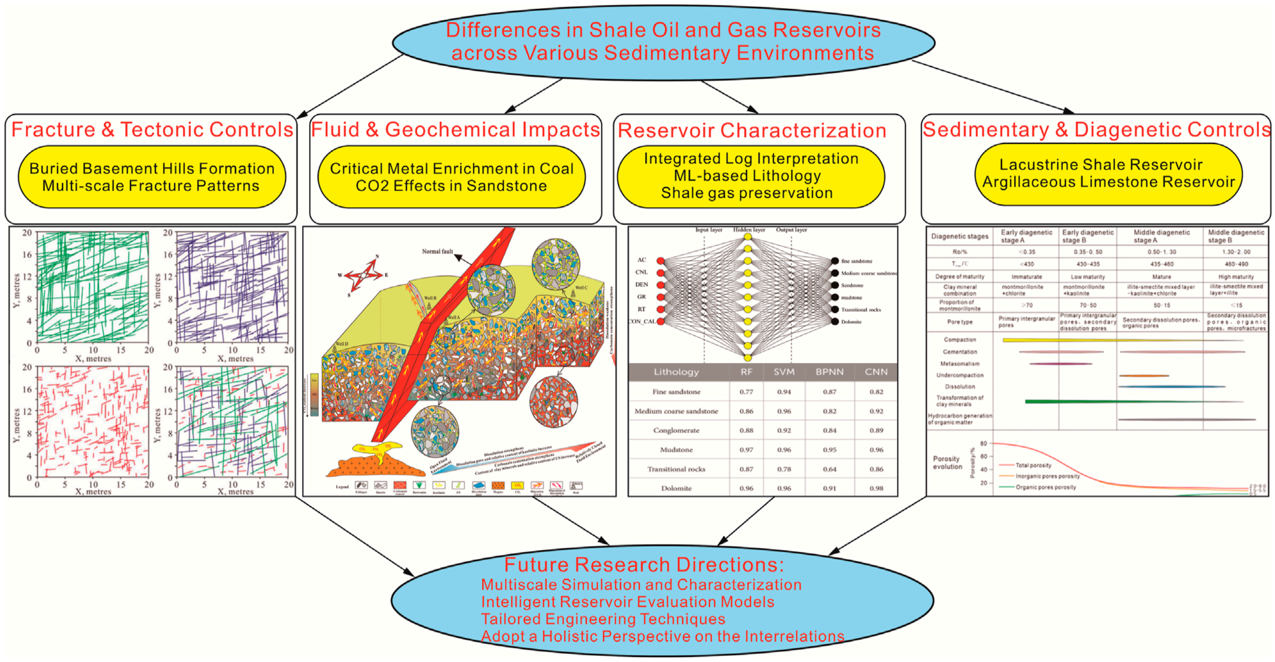

FIGURE 1
The main content of the papers published in this rsearch topic.

lower porosity, thinner single shale intervals, and greater burial depths, which pose additional challenges for development. Based on a multi-parameter evaluation, the study establishes a set of criteria for assessing Wujiaping shale gas potential and identifies four favorable exploration zones within the study area. These findings provide both theoretical and practical guidance for future marine shale gas development, contributing to more rational development strategies and optimized well placement.

3 Conclusions and outlook

The majority of the papers in this Research Topic have demonstrated the latest advances in understanding the geological characteristics and accumulation mechanisms of unconventional hydrocarbon reservoirs formed in diverse depositional environments. Overall, these studies reveal several common insights (Figure 1).

3.1 Multiscale geological controls on reservoir characteristics

Whether through pore–fracture structures, diagenetic environments, sedimentary sequences, or tectonic evolution, geological factors across different scales collectively influence hydrocarbon accumulation and preservation (Li et al., 2022a; Liu et al., 2025). Hence, research on unconventional reservoirs should adopt a multi-scale, integrated approach to fully reveal their accumulation mechanisms.

3.2 Depositional environment variability shapes reservoir diversity

Reservoirs formed in marine, continental, and transitional settings exhibit systematic differences in organic matter type, mineral composition, pore structure, and fluid occurrence. For example, lacustrine shales differ markedly from marine shales in their primary storage spaces, and the evolution pathways of reservoir porosity in open *versus* closed systems are distinct. Therefore, it is crucial to consider depositional environment characteristics when devising effective exploration and development strategies.

3.3 Advanced technologies support unconventional reservoir evaluation

Faced with the limitations of conventional methods for characterizing complex reservoirs, an increasing number of studies have introduced innovative techniques, such as machine learning for well log lithology identification, integrated analysis of geological and geophysical data, and geochemical tracers for microscale diagenetic process investigation, that significantly enhance our understanding and predictive accuracy, providing robust tools for quantitative reservoir evaluation.

3.4 Importance of reservoir identification and quantitative control factors

Several studies have quantitatively delineated the controlling factors of reservoirs, for example, the impact of fracture network patterns on productivity, the enrichment conditions of key metals in coals, diagenetic influences on carbonate reservoir quality, and tectonic–karst controls on buried hill reservoirs. These efforts provide a scientific basis for predicting favorable reservoir zones and guiding engineering improvements, which are key to increasing exploration success rates.

Looking ahead, although significant progress has been made in unconventional oil and gas, particularly in shale gas, many scientific challenges remain. Firstly, it is essential to strengthen multiscale simulation and characterization studies from nanoscale pore throats to basin-scale structures, and to develop integrated modeling techniques to elucidate the coupling among pore evolution, fracture propagation, and hydrocarbon migration (Li et al., 2022b; Xu et al., 2025). Secondly, with the widespread application of machine learning and big data in geosciences, constructing robust and universally applicable intelligent reservoir evaluation models resilient to complex geological scenarios has become an inevitable trend; this requires the integration of various data types (e.g., 3D seismic, production dynamics) and the optimization of algorithm integration. Thirdly, in terms of unconventional reservoir stimulation and enhanced recovery, future efforts should focus on developing tailored engineering techniques and enhanced oil recovery (EOR) methods that address the microscale differences among various reservoir types (e.g., tight sandstones, mudstones, shales, coalbed methane, basement reservoirs). Finally, against the backdrop of the global energy transition, coordinated assessments of unconventional oil and gas alongside other resources, such as critical metals, geothermal energy, and carbon storage potential, may emerge as new research hotspots, requiring geoscientists to adopt a holistic perspective on the interrelations among various resources within sedimentary basins.

In summary, comparing the formation and differences of hydrocarbon reservoirs across various depositional environments not only deepens our overall understanding of unconventional hydrocarbon accumulation but also provides valuable lessons for global exploration. The research outcomes in this Research Topic demonstrate the latest progress and diversified exploration approaches in this field, and we look forward to more interdisciplinary, multiscale studies that continuously refine shale oil and gas geological theories and drive efficient development and sustained innovation of unconventional resources.

Author contributions

HL: Conceptualization, Formal Analysis, Funding acquisition, Project administration, Writing – original draft, Writing – review and editing. PT: Data curation, Formal Analysis, Investigation, Methodology, Writing – review and editing. AR: Conceptualization, Formal Analysis, Methodology, Writing – review and editing. HW: Formal Analysis, Funding acquisition, Methodology, Writing – review and editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This study was financially supported by the Sichuan Key Provincial Research Base of Intelligent Tourism, Sichuan University of Science and Engineering (No. ZHYR24-05), the Open Fund of the National Key Laboratory of Oil and Gas Reservoir Geology and Exploitation (Southwest Petroleum University) (No. PLN 2023-31), the Open Funds of the Shale Gas Evaluation and Exploitation Key Laboratory of Sichuan Province (No. YSK2023001).

Conflict of interest

Author PT was employed by CNPC Engineering Technology R & D Company Limited.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

References

Chen, Y., Yang, K., Wu, W., Yang, Y., Yang, X., and Ma, K. (2023). Favorable lithofacies and pore characteristics of the Permian Longtan formation shale in the southern Sichuan Basin. *Energy Geosci.* 4 (3), 100193. doi:10.1016/j.engeos.2023.100193

Chen, Y. H., Zhu, Z. W., and Zhang, L. (2019). Control actions of sedimentary environments and sedimentation rates on lacustrine oil shale distribution, an example of the oil shale in the Upper Triassic Yanchang Formation, southeastern Ordos Basin (NW China). *Mar. Petrol. Geol.* 102, 508–520. doi:10.1016/j.marpetgeo.2019.01.006

Chen, Z. P., Liao, Y., Li, L., Chen, L., Wang, P., Zuo, Y., et al. (2022). Implication of alkane carbon and hydrogen isotopes for genesis and accumulation of over-mature shale gas: a case study of Longmaxi Formation shale gas in Upper Yangtze area. *Front. Earth Sci.* 10, 901989. doi:10.3389/feart.2022.901989

Dang, W., Nie, H. K., Zhang, J. C., Tang, X., Jiang, S., Wei, X., et al. (2022). Pore-scale mechanisms and characterization of light oil storage in shale nanopores: new method and insights. *Geosci. Front.* 13 (5), 101424. doi:10.1016/j.gsf.2022.101424

Fan, C. H., Li, H., Qin, Q. R., He, S., and Zhong, C. (2020). Geological conditions and exploration potential of shale gas reservoir in Wufeng and Longmaxi Formation of southeastern Sichuan Basin, China. *J. Petrol. Sci. Eng.*, 191, 107138. doi:10.1016/j.petrol.2020.107138

Feng, W., Li, R., Zhao, Z., Yu, Q., Liu, W., and Cao, J. (2023). Geological characterization and exploration potential of shale gas in the Carboniferous Jiusi Formation, northern Guizhou and Yunnan provinces, SW China. *Energy Geosci.* 4 (3), 100177. doi:10.1016/j.engeos.2023.100177

Guo, X. B., Huang, Z. L., Zhao, L. B., Han, W., Ding, C., Sun, X., et al. (2019). Pore structure and multi-fractal analysis of tight sandstone using MIP, NMR and NMRC methods: a case study from the Kuqa depression, China. *J. Petrol. Sci. Eng.* 178, 544–558. doi:10.1016/j.petrol.2019.03.069

He, S., Tan, W. C., Li, H., Li, H., Wang, Y., Niu, P. F., et al. (2025). Mineralogical and lithofacies controls on gas storage mechanisms in organic-rich marine shales. *Energy Fuel* 39 (8), 3846–3858. doi:10.1021/acs.energyfuels.4c05685

Li, H. (2023). Advancing "Carbon Peak" and "Carbon Neutrality" in China: a comprehensive review of current global research on carbon capture, utilization, and storage technology and its implications. *ACS Omega* 8 (45), 42086–42101. doi:10.1021/acsomega.3c06422

Li, H., Duan, H. T., Qin, Q. R., Zhao, T. B., Fan, C. H., and Luo, J. (2025b). Characteristics and distribution of tectonic fracture networks in low permeability conglomerate reservoirs. *Sci. Rep.* 15, 5914. doi:10.1038/s41598-025-90458-6

Li, H., He, S., Radwand, A. E., Xie, J. T., and Qin, Q. R. (2024a). Quantitative analysis of pore complexity in lacustrine organic-rich shale and comparison to marine shale: insights from experimental tests and fractal theory. *Energy Fuel* 38 (17), 16171–16188. doi:10.1021/acs.energyfuels.4c03095

Li, J., Li, H., Jiang, W., Cai, M. L., He, J., Wang, Q., et al. (2024b). Shale pore characteristics and their impact on the gas-bearing properties of the Longmaxi Formation in the Luzhou area. *Sci. Rep.* 14, 16896. doi:10.1038/s41598-024-66759-7

Li, J., Li, H., Xu, J. L., Wu, Y. J., and Gao, Z. (2022a). Effects of fracture formation stage on shale gas preservation conditions and enrichment in complex structural areas in the southern Sichuan Basin, China. *Front. Earth Sci.* 10, 921988. doi:10.3389/feart.2022.921988

Li, J., Qin, Q. R., Li, H., and Wan, Y. F. (2022b). Numerical simulation of the stress field and faultsealing of complex fault combinations in Changningarea, Southern Sichuan Basin, China. *Energy Sci. Eng.* 10, 278–291. doi:10.1002/ese3.1044

Li, J., Zhang, Q., Jiang, W., Li, H., Li, L., Xue, T. F., et al. (2025a). Lithological controls on pore structure and their implications for deep shale gas reservoir quality in the Longmaxi Formation, Luzhou area, Southern Sichuan Basin, China. *Energy Fuel* 39 (3), 1541–1558. doi:10.1021/acs.energyfuels.4c05247

Liu, J. F., He, X., Xue, F. J., Dai, J. J., Yang, J. X., Huang, H. Y., et al. (2024a). The influence of natural fractures of multi-feature combination on seepage behavior in shale reservoirs. *J. Min. Strata Control Eng.* 6 (1), 131–140. doi:10.13532/j.jmsce.cn10-1638/td.20240018.001

Liu, J. F., Zhao, C. X., Dai, H. Y., Wei, J. B., and Yang, J. X. (2025). Experimental study on shale fault instability and reactivation induced by fluid injection. *J. Min. Strata Control Eng.* 7 (1), 53–66. doi:10.13532/j.jmsce.cn10-1638/td.2024-1387

Liu, Z. D., Yang, B. R., Tang, X. Y., Wang, W., Ji, L., and Jiang, Z. H. (2024b). Evaluating the fracture resistance and drainage difficulty of coal reservoirs using log data. *Appl. Geophys.* 21 (2), 265–278. doi:10.1007/s11770-021-0961-8

Madukwe, H. Y., Adegoke, A. K., Adeleye, M. A., and Aturamu, A. O. (2023). Paleo-productivity and petroleum source evaluation of the Nkporo and Awgu shales, lower Benue trough, Nigeria: insight from inorganic geochemistry. *Energy Geosci.* 4 (3), 100161. doi:10.1016/j.engeos.2023.100161

Shan, C., Ye, C., Zhang, Z., Zou, C., He, F., Zhang, H., et al. (2022). Reservoir characteristics and resource potential analysis of transitional shale gas in Southern Sichuan Basin. *Front. Earth Sci.* 10, 909469. doi:10.3389/feart.2022.909469

Singh, A. K., and Chakraborty, P. P. (2023). Geochemistry and hydrocarbon source rock potential of shales from the Palaeo-Mesoproterozoic Vindhyan Supergroup, central India. *Energy Geosci.* 4 (3), 100073. doi:10.1016/j.engeos.2021.10.007

Xu, X. Y., Hu, B., Dong, C. W., Zhang, H. J., and Li, H. Y. (2025). Fractional-order creep model of carbonaceous shale considering age damage. *J. Min. Strata Control Eng.* 7 (1), 145–156. doi:10.13532/j.jmsce.cn10-1638/td.2024-1233

Yan, W., Wang, C., Yin, S., Wen, Z., Zheng, J., Fu, X., et al. (2024). A log-based method for fine-scale evaluation of lithofacies and its applications to the Gulong shale in the Songliao Basin, Northeast China. *Energy Geosci.* 5 (3), 100291. doi:10.1016/j.engeos.2024.100291

Yin, S., Radwan, A. E., Xiao, F., Xie, G. C., and Lai, P. F. (2024). Developmental characteristics of vertical natural fracture in low-permeability oil sandstones and its influence on hydraulic fracture propagation. *Geomech. Geophys. Geo-Energy Geo-Res.* 10 (1), 165. doi:10.1007/s40948-024-00889-0

Zhai, G. Y., Li, J., Jiao, Y., Wang, Y., Liu, G., Xu, Q., et al. (2019). Applications of chemostratigraphy in a characterization of shale gas sedimentary microfacies and predictions of sweet spots -taking the Cambrian black shales in Western Hubei as an example. *Mar. Petrol. Geol.* 109, 547–560. doi:10.1016/j.marpetgeo.2019.06.045