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EDITED AND REVIEWED BY
Derek Keir,
University of Southampton,
United Kingdom

*CORRESPONDENCE
Hu Li,
lihu860628@126.com

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Editorial: Quantitative characterization and engineering application of pores and fractures of different scales in unconventional reservoirs, volume III

Hu Li[1,2]*, Shuai Yin[3] and Wenlong Ding[4]

[1]Shale Gas Evaluation and Exploitation Key Laboratory of Sichuan Province, Chengdu, China, [2]School of Geoscience and Technology, Southwest Petroleum University, Chengdu, China, [3]School of Earth Science and Engineering, Xi'an Shiyou University, Xi'an, China, [4]School of Energy Resources, China University of Geosciences, Beijing, China

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Editorial on the Research Topic
Quantitative characterization and engineering application of pores and fractures of different scales in unconventional reservoirs, volume III

1 Introduction

Unconventional oil and gas resources have emerged as a pivotal area in the global petroleum industry, representing a significant shift from conventional hydrocarbon exploration and production. These unconventional resources, which encompass reservoirs like shale, tight sandstones, tight carbonates, and volcanic rocks, pose distinct challenges due to their intricate pore-fracture systems and the unconventional mechanisms governing fluid flow and accumulation (Gao and Li, 2016; Li et al., 2019; Li et al., 2020; Radwan et al., 2021; Li, 2023). Notably, each type of unconventional reservoir exhibits unique characteristics, necessitating a comprehensive and precise quantification of their pore and fracture attributes. This quantification is pivotal to advancing the exploration and production strategies for unconventional oil and gas reservoirs.

In recent years, there has been a remarkable surge in technological advancements and their practical application in reservoir characterization. These innovations span various disciplines, including high-resolution CT scanning, nuclear magnetic resonance (NMR), field-emission scanning electron microscopy (FE-SEM), atomic force microscopy (AFM), and gas adsorption techniques (Fan et al., 2020a; Li et al., 2022a; Li, 2022; Zhu et al., 2023). These cutting-edge technologies have collectively enabled researchers and industry professionals to undertake quantitative assessments of the intricate three-dimensional pore structures and the behavior of mobile fluids within tight reservoirs.

The significance of this Research Topic, volume III within the series '*Quantitative characterization and engineering application of pores and fractures of different scales in unconventional reservoirs*' is underscored by its compilation of 36 exceptional contributions from esteemed scholars worldwide. Among these submissions, 14 have been selected for publication, reflecting the rigorous standards upheld. Notably, including these research papers marks a pivotal milestone in further advancing the field, providing fresh and innovative perspectives for the quantitative characterization of multiscale pore-fracture systems, focusing on tight carbonate and shale reservoirs. This Research Topic serves as a valuable resource for researchers, professionals, and organizations engaged in exploring and producing unconventional oil and gas resources, facilitating more effective decision-making and enhancing the industry's sustainability.

2 Quantitative characterization of multi-scale pores and fractures in unconventional reservoirs

2.1 Tight carbonate reservoir

Compared to the previous two research topics, this focuses on the recent advancements in the characterization of tight carbonate reservoirs. Carbonate reservoirs account for over half of the total oil and gas reserves, making them paramount in the world's hydrocarbon resources. Among carbonate reservoirs, tight carbonate reservoirs are a significant subset. However, these reservoirs often exhibit poor petrophysical properties high heterogeneity, and pose challenges in development (Li et al., 2021; Shan et al., 2021). The quantitative characterization of the pore-fracture system within such reservoirs is crucial for effectively exploring and producing oil and gas resources.

In recent years, with the fine exploration of carbonate reservoirs in the Qixia Formation of the central Sichuan Basin, researchers have made important oil and gas discoveries in the dolomite reservoirs. The petrology, pore structures, physical properties, and geochemical characteristics of the dolomite reservoirs have been systematically studied based on a large number of cores, thin sections, physical properties, and geochemical tests, and the genesis and main controlling factors of dolomite reservoirs are clarified Tan et al. Liu et al. also take the Qixia Formation of the Gaomo block as an example, and they have studied distribution characteristics of sedimentary microfacies of a system tract under a high-resolution sequence framework. In this study, the vertical fourth-order sequence is divided using the high vertical resolutions of gamma-ray (GR), uranium (U), thorium (Th), and potassium (K) curves in the logging curves, and the sequence is divided in the depth system is then accurately superimposed on the seismic profile through one-dimensional forward modeling. Different lithofacies' origin and pore-throat structure are key issues in the exploration and development of tight oolitic reservoirs. Ren et al. first classify the lithofacies of oolitic reservoirs according to the macro–micro petrological characteristics. Then, different lithofacies' pore type, throat type, and petrophysical properties are discussed using 3D CT scanning, low-field nuclear magnetic resonance (NMR), MICP, and scanning electron microscopy (SEM). Finally, based on cathodoluminescence (CL), stable isotope, and rare Earth element (REE) data, factors controlling the origin of different lithofacies are studied, and a sedimentary-diagenetic evolution model is established. The heterogeneity of deep carbonate reservoirs is strong, it is significant for exploration and development to clarify the key stages of oil and gas accumulation. Zhang et al. have systematically investigated the key stage and model of hydrocarbon accumulation using the data of the cores, thin sections, cathode luminescence tests, laser ablation U-Pb isotope geochronometry, bitumen reflectance, and fluid inclusion tests, and seismic interpretation in the Gucheng area of Tarim Basin. Then, the favorable zones for hydrocarbon exploration in the Gucheng area were determined.

2.2 Shale reservoirs

The characteristics of source-rock gas reservoirs, which combine gas source and storage in one, have made reservoir characterization and evaluation essential for area assessment, sweet spot prediction, and development plan design and implementation (Abolghasemi and Andersen, 2021; Li et al., 2022b; Fan et al., 2022; Wood, 2022; Li et al., 2023a). This Research Topic continues to report on various aspects related to the characterization of pores and fractures in shale reservoirs. The Jurassic Lianggaoshan Formation lacustrine shale oil is Southwest China's most potential exploration target for unconventional hydrocarbon resources. To accurately characterize the pore structure characteristics of shale reservoir, Lai et al. use Nuclear magnetic resonance (NMR), scanning electron microscopy (SEM), low-temperature N_2 adsorption (LTNA), and high-pressure mercury intrusion mercury injection capillary pressure to reveal pore structure and its controlling factors of Lianggaoshan Formation lacustrine shale reservoir. The enrichment of organic matter has little effect on the development of micropores and does not affect the mesopore and macropore development. Quartz particles in Lianggaoshan lacustrine shale do not facilitate the development of micropore and mesopore-macropore. Intraparticle pore in feldspar clast is an important component of mesopore and macropore. Clay minerals have no positive effect on the formation of micropores and mesopore-macropores. Hu et al. have analyzed high-quality shale logging response characteristics and drilling logging, seismic, and analytical test data in the WY area to establish a rock physical model of seismic attribute parameters and shale reservoir quality parameters. Seismic elastic parameters are converted into indicators that directly reflect shale reservoir quality and predict the quality parameters. Taking the typical block of the Longmaxi shale reservoir in southern Sichuan as the engineering background, Feng et al. use the finite element method to develop a numerical model of a two-dimensional fracture closure variation subjected to the non-hydrostatic stress field. It explores the influence of different fracture occurrences and rock mechanical parameters on stress sensitivity. The theoretical model verifies the numerical simulation results to reveal the stress sensitivity mechanism of the fractured reservoir. In addition, Yu et al. studied the main controlling factors of natural fractures in tight reservoirs of the Lucaogou Formation in the Jimsar Sag of Xinjiang. There are mainly

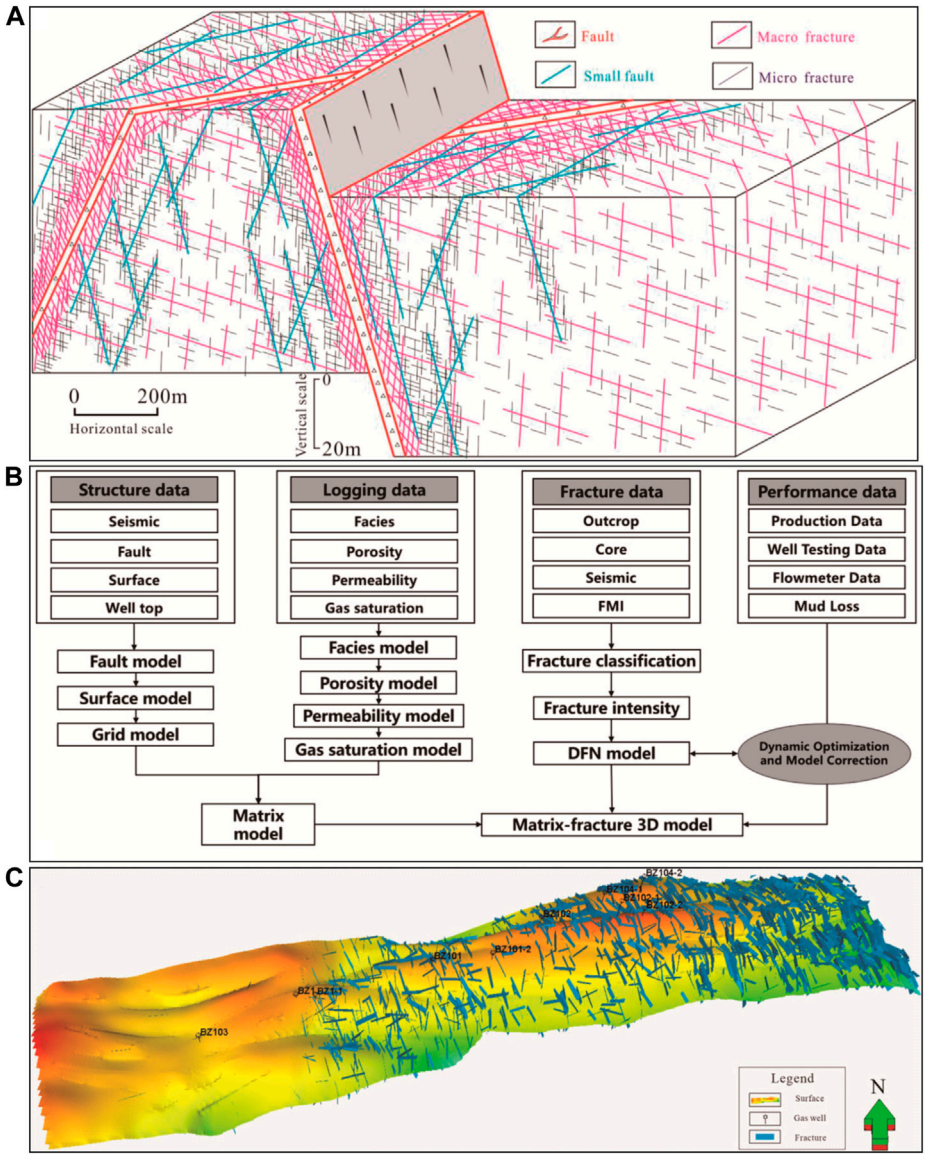

FIGURE 1
The main fracture modeling techniques in the Research Topic. **(A)**. The typical structure model of fracture networks under various configurations (Mi et al.); **(B, C)**. A generalizable of the flow chart of multi-scale fracture-matrix-performance 3D geological modeling and the modeling results (Liu et al.).

three types of natural fractures: tectonic, diagenetic, and abnormal overpressure-induced fractures. Large tectonic stress, smaller bed thickness, and higher total organic carbon are favorable for developing tectonic fractures and bedding seams.

2.3 Volcanic reservoirs

Volcanic rock oil and gas reservoirs are widely distributed in more than 40 basins across 13 countries worldwide, constituting a significant oil and gas exploration domain. Research on volcanic rock oil and gas reservoirs includes reservoir characteristics, distribution patterns, formation mechanisms, and controlling factors (Fan et al., 2020b; Tang et al., 2020; Wang and Wang, 2021). These reservoirs possess distinct features, such as the development of primary pores and fractures, high soluble component content under acidic conditions conducive to secondary porosity formation, modification due to pre-burial weathering and leaching processes, and even the presence of volcanic material components in sedimentary rocks, which help prevent intergranular pores from being filled with silica and promote pore preservation.

Identifying the characteristics and main factors controlling high-quality volcanic reservoirs is the key to increasing oil and gas reserves and production in the Shixi area of the Junggar Basin. Through core observations, thin section identification, physical property, and pore structure analyses, combined with production data, the main controlling factors and development modes of high-quality reservoirs are analyzed by Yiming et al. Lithology and lithofacies, weathering and corrosion, and fractures are the main

factors controlling the development of high-quality volcanic reservoirs. Intermediate mafic lava is a special oil and gas reservoir. Yue et al. have evaluated the intermediate mafic lava flows of the Yingcheng Formation in the Dongling area of Songliao Basin by analyzing drilling cores, corresponding thin sections, and scanning electron microscope (SEM) images, as well as well-logging and seismic attributes. We also performed helium gas experiments and high-pressure mercury intrusion (HPMI) analysis to assess the reservoir's physical properties and pore structure, respectively. The reservoir quality is best in the Crater-proximal facies (CF-PF). Metamorphic rocks are often associated with volcanic activity, Mi et al. take the Bozhong 19–6 metamorphic buried hill as an example, and they use image logs, core samples, thin sections, scanning electron microscope, *etc.*, to characterize genesis and distribution of multi-scale fractures, clarify fracture distribution modes and their contributions to storage capacity, establish structure model of fracture networks under various configurations, and discuss development characteristics and their impact on productivity (Figure 1A). In addition, Liu et al. have established the 3D geological modeling of a deep fractured low porosity sandstone gas reservoir in the Kuqa Depression of Tarim Basin. This method includes four key techniques: 1) Structural modeling using well-to-seismic ties, 2) facies modeling utilizing stochastic objects, 3) reservoir petrophysical modeling under facies constraints, and 4) fracture modeling under multiple-condition constraints and static-performance data combination (Figures 1B,C).

3 Summary

In summary, the 14 high-quality papers featured in this Research Topic significantly advance our understanding of the quantitative characterization and engineering application of pores and fractures in unconventional reservoirs. As we alluded to in the previous Research Topic, the current edition emphasizes the quantitative characterization and predictive research progress of fractures within tight reservoirs (Wang et al., 2022; Li et al., 2023b). This Research Topic provides a valuable platform for scholars and experts to delve into the intricacies of these critical reservoir features.

We are genuinely grateful for the opportunity to present this dynamic Research Topic, and we trust that our readers will find immense value in the breadth and depth of the research contributions. Moreover, we are excited to announce the involvement of Professor Ahmed E. Radwan in another Research Topic titled "Differences in Shale Oil and Gas Reservoirs across Various Sedimentary Environments: Theories and Applications." We eagerly anticipate the active participation of more scholars in this research theme, as it promises to foster insightful discussions about the distinctions inherent in shale oil and gas reservoirs. Through collaborative efforts, we aspire to unravel further complexities and drive innovation in unconventional reservoir studies.

Author contributions

HL: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Project administration, Supervision, Validation, Writing–original draft, Writing–review and editing. SY: Investigation, Methodology, Resources, Software, Writing–original draft, Writing–review and editing. WD: Investigation, Validation, Visualization, Writing–original draft, Writing–review and editing.

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Conflict of interest

The 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.

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