Preface: Special Topics on Ultra-deep Oil and Gas Exploration

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The term 'ultra-deep layers' refers to those sedimentary formations which are currently, or have been, buried at depths exceeding 6000 m. China has continuously achieved major oil and gas breakthroughs in marine ultra-deep exploration, significantly promoting the strategic level of ultra-deep oil and gas resources over recent years. The ultra-deep formations of the cratonic basins in China are predominantly constrained to Precambrian to lower Paleozoic marine stratigraphy. These layers are demonstrably of ancient strata that have experienced high degrees of thermal evolution, as indicated by complex oil and gas generation and accumulation processes. Consequently, the exploration difficulties of these areas are huge. To explore the oil and gas resources enriched in the ultra-deep layers of the Tarim and Sichuan basins in China, as well as to uncover their entangled growth processes and multiple controlling factors, it is urgently required that comprehensive research from the perspectives of hydrocarbon generation, migration and accumulation be conducted. This will be of great importance in providing scientific guidance for future oil and gas exploration in ultra-deep layers.

On the occasion of the 100th anniversary of the Acta Geologica Sinica, the Acta Geologica Sinica (English Edition) organized and published the issue on 'Ultra-deep Oil and Gas Exploration', aiming to focus on the innovative accomplishments of geological basic research into ultra-deep oil and gas in China. Nearly 100 researchers have contributed to this issue through collaborating on 15 papers, which cover comprehensive geological evolution, laboratory simulation analyses and geological case studies. These papers systematically discussed the formations of hydrocarbon source rocks, carbonate reservoir rocks, structural faults and traps in the ultra-deep layers of the Tarim and Sichuan basins, presenting constructive advice and direction for ultra-deep oil and gas research and exploration.

The lower Cambrian source rocks are among the most important source rocks in the Tarim and Sichuan basins. The genetic mechanism of these rocks is of great significance for ultra-deep oil and gas exploration. Zhang Shuichang et al. (2022, this issue) re-establishes the depositional patterns of the Cambrian-Ordovician source rocks in the Tarim Basin, proposing the middle and lower Cambrian salt-related assemblages, dolomite inner reservoirs, in addition to the Middle and Lower Ordovician oil-bearing karst as three of the most favorable targets of ultra-deep oil and gas in this basin. Wang et al. (2022, this issue) introduce a Cambrian stratigraphical division scheme based on organic-inorganic carbon isotope records, arguing that the formation of the Cambrian source rocks in the eastern part of the basin might be associated with a change in the size of a dissolved organic carbon reservoir in the ocean depths. Through the use of multi-scaled mineralogical and geochemical studies of the silica-phosphatic nodules and hosted black shales from the Yanjiahe Formation in the Three Gorges Area of South China, Qiu et al. (2022, this issue) assert that the periodic variations of continental input might regulate the formation of silica-phosphatic nodules and black shales.

In the process of source rock burial into ultra-deep layers of the basin, the high-temperature environment and complex fluid conditions in the depths of the basin leads to complex and diverse oil and gas genesis. Chang et al. (2022, this issue) summarize and contrast present-day with paleo heat flow, geothermal gradient and deep formation temperatures of the Tarim and Sichuan basins, clarifying that different thermal evolution histories are the most important reasons for the differences between the ultra-deep oil and gas phases in these two basins. Based on the measured geothermal data and thermophysical properties of the rocks, Zhu et al. (2022, this issue) studied the thermal lithospheric thickness of the Sichuan Basin, and provided thermal support for detailed understanding of the evolutionary scenario of the basin-mountain system and the enrichment mechanism of oil and gas in this basin. Zhao et al. (2022, this issue) carried out laboratory experiments through Fischer-Tropsch synthesis and confirmed the practical feasibility of abiotic hydrocarbon generation through a variety of processes and with varying products under high temperature and hydrothermal conditions in the ultra-deep basins. Meng et al. (2022, this issue) studied the effects of igneous intrusions on hydrocarbon generation and pore generation in source rocks, finding that thermal energy input of intrusions can result in rapid maturation of organic matter up to several meters in

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thickness, advocating for the development of organic matter pores and micro-rupture of the rock matrix.

In the scenario where the capacity of ultra-deep hydrocarbon generation continues to break through traditional understanding, the development of large-scale storage reservoirs has become a key factor in the formation of large ultra-deep oil and gas fields. Discoveries of deep high-quality carbonate reservoirs also challenge general understanding of the evolution of porosity decreasing with depth. Li et al. (2022, this issue) studied the mechanisms of pore generation and preservation of different dolomite reservoirs in the deep realm, suggesting that seal and source rocks not only play important roles in hydrocarbon accumulation, but also have a general control over the deep fluid-rock interactions and porosity evolution in the deep burial realm. Tang et al. (2022, this issue) divided the Upper Ediacaran microbial carbonate rocks in the Tarim Basin into four types, finding that the pore types and porosities were related to the initial microbial structure. The most important reservoir spaces are contributed by vugs and dissolution-enlarged pores, which are likely to have been associated with the widespread uplift of the Aksu area in the terminal Ediacaran. For the dolomites in the Fengjiawan Formation of the Jixian System in the Ordos Basin, Zhang J et al. (2022, this issue) demonstrate that the formation and dissolution of dolomites were both highly autochthonous, while being controlled by a favorable microenvironment under the influence of microbial biological activities and related biochemical reactions.

The formation and maintenance of ultra-deep reservoirs are closely related to the tectonic structures and physical and chemical effects in the deep basins. According to the geological characteristics of high temperature, high pressure and high in-situ stress in the ultra-deep basins, as well as the existence of hydrocarbon phase state transformation, hydrocarbon-water-rock interaction and rock mechanical property transition at those depths, Yuan et al. (2022, this issue) propose three physical leakage evaluation indexes and two thermochemical oxidation of hydrocarbon indexes to evaluate the oil and gas preservation in ultra-deep basins. Chen et al. (2022, this issue) summarize the impacting factors on fault sealing and propose a method for evaluating ultra-deep fault sealing, which was applied in the Shunbei 5 strike-slip fault analysis in the Shunbei area in the Tarim Basin and achieved a high consistency with the practical eexperience gained from exploration. Based on drilling and high-precision three-dimensional seismic data, Tian F L et al. (2022, this issue) analyzed the geometric and kinematic characteristics of strike-slip fault zones in the Shunbei area, proposing that the vertical differential structural deformation controls the ultra-deep hydrocarbon accumulation processes in the entire Shunbei area. After interpreting 38 2-D seismic profiles in the Changning anticline in the Sichuan Basin, Yang et al. (2022, this issue) establish a 3-D geometric and quantitative kinematic model, arguing that the basement fault controlled the formation of the Changning anticline. Tian X W et al. (2022, this issue) analyzed the unconformable development and fault characteristics of the key tectonic transitioning periods of the northern slope of the Central paleo-uplift in the Sichuan Basin, proposing that the multi-stage inheritance activities of the slip fault both improved the physical properties of the reservoir and acted as a channel for oil and gas migration. They further infer that this system creates a favorable exploration target of multi-layer gas enrichment in the Penglai Gas Field.

Although the scale of ultra-deep oil and gas resources has exceeded previous knowledge to a remarkable extent, the complexity is greatly beyond the current level of understanding. Hopefully, the launch of this special issue will provide a milestone for the development of geological theory and the exploration of ultra-deep oil and gas, establishing a new ‘starting point’ for subsequent research. We look forward to seeing that the great discoveries of ultra-deep oil and gas can profoundly influence the energy pattern of China and even worldwide, while also anticipating another revolution in oil and gas resources following unconventional oil and gas exploration.