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A Comprehensive Review on the Geological Uniqueness and Enrichment Regularity of Shale Gas Reservoirs in China

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ABSTRACT

This paper reviews the geological uniqueness and enrichment regularity of shale gas reservoirs in China, analyzes the patterns of shale gas formation under different geological backgrounds, discusses the main controlling factors affecting the enrichment of shale gas, and proposes potential directions for future exploration and development of shale gas. The study shows that the patterns of shale gas formation in China are diverse and are jointly controlled by multiple factors such as sedimentary environment, diagenesis, and later tectonic movements.

KEYWORDS

Shale Gas; Formation Patterns; Geological Uniqueness; Enrichment Regularity; Main Controlling Factors.

1. INTRODUCTION

With the transformation of the global energy structure and the increasing awareness of environmental protection, the development and utilization of unconventional natural gas resources have attracted more and more attention. Shale gas, as an important part of unconventional natural gas, has become a hot topic in the field of energy research due to its huge resource potential and clean environmental protection characteristics. China has abundant shale gas resources, and their exploration and development are of great significance for ensuring national energy security, optimizing the energy structure, and promoting sustainable economic development. In recent years, China has made significant progress in the geological theory and exploration and development of shale gas, especially in commercial development in areas such as the Sichuan Basin. However, compared with North America and other regions, the development of shale gas in China is still in its infancy, and there is still a lack of understanding of the geological uniqueness and enrichment regularity of shale gas. The process of shale gas formation is complex and affected by various geological factors, including sedimentary environment, organic matter abundance, thermal evolution, and tectonic movements. In-depth research on these geological factors and their controlling effects on the formation of shale gas is of great theoretical and practical value for guiding the exploration and development of shale gas. At present, one of the main challenges faced by shale gas exploration and development in China is the complexity and uniqueness of geological conditions (Sun D.S. et al., 2021). China has a vast territory, and the sedimentary environment, tectonic background, and geological history of different regions vary significantly, which together determine the patterns and regularity of shale gas formation. In addition, the exploration and development of shale gas in China are also constrained by various factors such as technology, economy, and policy. Therefore, systematically summarizing the geological characteristics of shale gas formation in China and exploring its formation laws are of

great significance for promoting the healthy development of China's shale gas industry (Ran B. et al., 2014). This paper will review the geological uniqueness and enrichment regularity of shale gas formation in China, analyze the patterns of shale gas formation under different geological backgrounds, discuss the main controlling factors affecting the enrichment of shale gas, and propose potential directions for future exploration and development of shale gas.

2. CURRENT RESEARCH STATUS

The geological uniqueness and enrichment regularity of shale gas reservoirs in China are key factors in the development of the natural gas industry. According to the research by Zhang Jinchuan et al. (2022), the study results on the patterns of shale gas reservoirs in China indicate that the pre-Mesozoic continental margin marine and marine-terrestrial transitional sediments, as well as the Mesozoic and Cenozoic basin-type terrestrial sediments, have developed a diversity of organic-rich shales. The formation and preservation conditions of these shales, along with their evolution during different geological periods, constitute the rich and varied patterns of shale gas reservoirs in China.

Shale gas reservoir patterns can be categorized into two main types: tectonic and stratigraphic. The tectonic type is primarily related to the structural morphology, while the stratigraphic type is mainly associated with lithological and stratigraphic variations. The development of shale and variations in gas content are influenced and controlled by various geological factors, including sedimentation, diagenesis, and subsequent tectonic movements. Favorable sedimentary environments, appropriate thermal evolution levels, and good sealing and structural preservation conditions are essential prerequisites for the enrichment of shale gas. Sedimentary processes provide the material basis for the formation of shale and shale gas, while diagenesis controls the generation of hydrocarbons from organic matter and the evolution of the reservoir. The sealing of the caprock and structural modifications determine the gas content of the shale strata. These factors work in concert to affect the enrichment and distribution of shale gas.

In summary, the geological uniqueness and enrichment regularity of shale gas reservoirs in China are the result of a combination of various geological factors. A thorough understanding of these geological characteristics is of significant theoretical and practical importance for improving the success rate and efficiency of shale gas exploration and development.

3. DISCUSSION

3.1. Discussion on the Enrichment Law of Shale Gas

The factors influencing the enrichment of shale gas can be discussed from the following aspects:

Sedimentary Action: The sedimentary environment is the material basis for the formation of shale gas, determining the thickness, distribution range, mineral composition, initial physical properties, organic matter content, and type of shale. Marine environments typically form thick and widely distributed shales, while terrestrial environments produce shales with high clay content that may contain higher proportions of sand, silt, calcium, and dolomite. Special geological events during the sedimentary period, such as volcanic activity and hydrothermal action, are significant for the formation of organic-rich shales (Qiao S.H. et al., 2020).

Diagenetic Action: Diagenetic processes affect the hydrocarbon generation potential and reservoir properties of organic matter. Compaction, cementation, dissolution, and recrystallization lead to mineral transformation, changes in physical properties, and organic matter maturation, thereby influencing the content and state of shale gas. When the maturity of organic matter reaches a certain level, the gas generation capacity of shale decreases, while the capacity to generate nitrogen and carbon dioxide gas relatively increases.

Seal Integrity: A good seal is key to the preservation of shale gas. Continuous overlying strata, appropriate sealing of the top and bottom plates, sufficient seal thickness, and dense porosity and permeability provide the necessary enclosure for shale gas. Later tectonic movements, such as stratal uplift and subsidence, folding and faulting, and magmatic intrusion, can affect the seal integrity of shale strata (Jiang L. et al., 2019).

Structural Modification: Tectonic movements affect the gas content of shale strata through processes such as uplift, deformation, and erosion. Areas with good structural stability are conducive to the preservation of shale gas, while areas with intense tectonic activity may adversely affect the enrichment of shale gas. Faults and related fractures can provide spaces for the enrichment of shale gas (Zhang X.L. et al., 2015).

Lateral Thermal Evolution: The degree of thermal evolution of organic matter is crucial for the enrichment of shale gas. Shales with a moderate degree of thermal evolution are conducive to the formation and preservation of gas, while excessively high or low thermal evolution degrees may reduce the enrichment level of shale gas (Mou Z.H. et al., 2017).

Formation Pressure and Temperature: Formation pressure and temperature significantly affect the state of shale gas. High-temperature and high-pressure environments in deep layers are conducive to the preservation and enrichment of shale gas.

3.2. Future Prospects

The potential directions for future shale gas exploration and development mainly focus on the following aspects:

Deep Shale Gas Exploration and Development: With the advancement of technology and the gradual development of existing resources, deep shale gas resources are set to become a significant area for future exploration and development. Deep shale gas typically refers to resources buried more than 3500 meters deep, and the development of these resources requires higher technical levels and more complex engineering techniques. For instance, Zou Nengcai (2021) have pointed out that by accelerating the development of shale gas resources at depths of 3500 to 4000 meters, the national annual shale gas production could reach 30 billion cubic meters by 2025; and by 2030, the expected annual production of shale gas could be between 35 billion and 40 billion cubic meters.

Exploration of New Areas and Fields: Beyond existing production areas, exploring new shale gas resource regions, such as the marine-terrestrial transitional and terrestrial shale gas in the Ordos Basin and the Sichuan Basin, could provide new support points for the growth of shale gas production.

International Cooperation and Technology Introduction: Through international cooperation, the introduction of advanced shale gas exploration and development technologies, and strengthening cooperation with international energy companies, can accelerate the development of the domestic shale gas industry.

Development of the Shale Gas Industry Chain: Promoting the development of the entire shale gas industry chain, including exploration, development, production, storage, transportation, and utilization, can increase the added value of shale gas and promote industrial upgrading and structural optimization.

These directions highlight the strategic importance of technological innovation, exploration of new resource areas, international collaboration, and the comprehensive development of the shale gas industry to ensure sustainable growth and competitiveness in the global energy market.

4. SUMMARY

Integrating various geological factors such as sedimentary action, diagenesis, and later tectonic movements, research on the control of shale gas reservoirs in China should focus on the following areas:

Enhance the Study of Sedimentary Environment Constraints: Strengthen the research on the restrictive effects of sedimentary environments on the formation of shale gas reservoirs. Understanding the specific conditions of sedimentary environments that favor the formation and preservation of shale gas is crucial.

Deepen the Understanding of Diagenetic Effects: Further investigate the mechanisms by which diagenesis affects the evolution of shale reservoir properties. This includes how compaction, cementation, and other diagenetic processes alter the porosity and permeability of the shale, affecting its ability to store and transmit gas.

Clarify the Role of Later Tectonic Movements: Define the transformative effects of later tectonic movements on the preservation conditions of shale gas. This involves studying how uplift, subsidence, faulting, and other tectonic activities can create or destroy the necessary conditions for shale gas to accumulate and be retained within the reservoir.

Through these research efforts, theoretical support and guidance can be provided for the effective exploration and development of shale gas in China. It is essential to consider these multifaceted geological factors to optimize exploration strategies, improve drilling techniques, and enhance the overall efficiency of shale gas extraction.

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