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Multi-scale Pore Structure Characteristics of Deep Marine Shale and Its Controlling on Gas Transport Mode: Silurian Longmaxi Formation in Southern Sichuan, China

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The attributes of shale pore structure govern the accumulation, presence, and dissipation of gas. Deep marine shale undergo intricate geological evolution, with pore development at the nanoscale. Consequently, quantifying the impact of deep shale pore structure on gas is challenging. In this paper, the microscopic storage space structure of deep shale is quantified, and the correlation between pore structure and mode of gas transport is established. The study focused on the Silurian Longmaxi Formation shale, utilizing techniques such as SEM, CO2 and N2 adsorption, HPMI, and the Frenkel-Halsey-Hill method approach to quantify the development characteristics and controlling factors of pores at multiscale. Based on the pore structure, fractal, and molecular dynamics of methane, the numerical correlation linking pore structure and gas transportation mechanisms was established. The results indicate that the deep marine shale formations are predominantly composed of ORSS and ORMS. The evolution of pores is impacted by the TOC content and mineral composition. Based on the governing function of pore structure in gas transport mechanisms, the pores can be classified into three categories: ultramicro adsorption pore, nano-diffusion pore, and micro-nano flow-diffusion pore. Correspondingly, there are five types of gas transport modes: surface adsorption diffusion, Knudsen diffusion, Fick diffusion, slip flow, and continuously flow. These diverse modes collectively form a complex gas transport network. Deep shale exhibits a greater abundance of micropores and mesopores compared to shallow shale. The contribution of micro-fractures to shallow shale gas transport is crucial, and the contribution to deep shale decreases significantly. In conclusion, the favorable exploration lies in targeting ORSS formations with low D1 (fractal dimension) and high D2 (fractal dimension), as well as ORMS segments with high D1 and high D2. Specifically, within hydrocarbon-rich basins located below 3500 m, it is recommended to search for overpressure regions with weak structural deformation. These areas hold potential for successful gas exploration. This research establishes a basis for the exploration, development, and geological principles of deep shale gas.

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