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Characterization of Compact Carbonate Pore-Throat Network Systems using NMR and Nano-CT Techniques: Case Study from Xiagou Formation (K1g) in Qingxi Sag, Jiuquan Basin, China

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The Xiagou Formation (K_1g) in Qingxi Sag, Jiuquan basin, is mainly composed of compact carbonate reservoirs. In the reservoir, micrometer- and nanometer-scale pore-throat systems are widely developed, and pore throats have complex inter connections. These interconnected pore-throat systems constitute the main reservoir spaces of the compact carbonate reservoirs. To completely and finely characterize the microscopic pore-throat network systems of the compact reservoirs, 56 pieces of compact core samples collected from wells 104, Q_{2-4}, Liu 4, Liu 102, Liu 5, and so on in the study area were investigated using nuclear magnetic resonance (NMR) and nano-computed tomography (CT) techniques. NMR T2 spectrum can better reflect the pore-throat structure of a reservoir. This spectrum was transformed into a pore-throat size distribution spectrum to obtain distribution curves of mainly unimodal and bimodal shapes. The main pore size of the unimodal shape was 0.01–0.69mm, and the main peak of the average pore-throat size distribution was 0.03–0.07mm.The main pore sizes of the bimodal shape were0.01–0.22mm and 0.69–4mm, and the average pore-throat-size peak values of the first and second peaks ranged between 0.03 and 0.07mm and1 and 2mm,respectively. Overall, nanometer-scale pore throats accounted for the majority. Many samples with diameters of 2mm and 65μmwere prepared for high-resolution micro-and nano-CT scanning, respectively, to obtain a three-dimensional (3D) pore-throat stereogram. At the micrometer scale, pore throats were different in size, and they had shelf-like, banded, and spheroidal shapes with diameters of 4.12–2.24μm. At the nanometer scale, micro-pores measured 0.208–0.562μm in size, and a greater number of nanometer-scale micro-pores were observed. These pores were shelf-like and spheroidal and distributed inside or at the mineral grain (crystal) surface. Nanometer-scale spheroidal micro-pores showed poor connectivity and were isolated in terms of 3D space; most of them were merely used as reservoir spaces. However, nanometer-scale short-shelf-like micro-pores showed certain connectivity. They were connected with micron-grade shelf-like micro-pores and adjacent isolated spheroidal nanometer-scale micro-pores to a certain degree, and they acted as both pore throats and pores. Samples from the numerical calculation test site had porosities of 1.34%–7.52% and an average permeability of 0.52×10^{-3}. Experimental analysis proved that NMR and micrometer- and nanometer-CT can provide accurate characterization and evaluation of the pore-throat network system of a compact reservoir. This technique is significant for the exploration and development of compact reservoirs.