

Exploration and Development of Unconventional Oil and Gas Resources: Latest Advances and Prospects: 3rd Edition

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Against the backdrop of the ongoing transition of the global energy system toward cleaner, lower-carbon, and more diversified development, unconventional oil and gas resources remain essential for ensuring energy security and supporting energy-structure transformation [1–3]. Shale gas, tight sandstone gas, coalbed methane, tight carbonate oil and gas reservoirs, heavy oil, and other resource types have become major targets for oil and gas exploration and development [2,4–6]. Compared with conventional reservoirs, unconventional oil and gas resources are generally characterized by strong reservoir heterogeneity, complex pore–fracture structures, and a high dependence on development technologies [1,7]. Their effective development is commonly controlled by the level of reservoir characterization, the delineation of sweet spot areas, and the degree of matching between geological conditions and engineering measures [7–9].

The enrichment, occurrence, and production of unconventional oil and gas are controlled by multiple geological and fluid-related factors, including sedimentary environment, lithofacies differentiation, diagenetic alteration, tectonic activity, pressure systems, and fluid properties [10,11]. The effectiveness of tight sandstone gas and tight carbonate reservoirs is mainly governed by pore–throat structure, fracture connectivity, and the development of favorable lithofacies [12–14]. Resource evaluation and favorable area optimization for shale gas and coal-measure gas require integrated consideration of hydrocarbon source conditions, source–reservoir configuration, gas-bearing properties, and stratigraphic heterogeneity [15]. Heavy oil development, CO₂-enhanced oil recovery, and coal mine gas control also involve multiphase seepage and displacement processes, CO₂ sequestration effects, gas drainage efficiency, and the compatibility between engineering technologies and geological conditions [16–18].

In recent years, the increasing application of micro- to nanoscale characterization, integrated geological and geochemical analysis, numerical simulation, and machine learning has advanced the characterization of reservoir pore structures, the analysis of hydrocarbon enrichment mechanisms, and the prediction of development performance [12,19–23]. This Special Issue includes 10 research papers covering three main aspects: reservoir characterization and evaluation; hydrocarbon enrichment and geological control mechanisms; and development technology optimization and enhanced oil recovery [24]. The following sections provide an overview organized by research topic.

The first group of studies focuses on reservoir characterization and evaluation technologies. With the continued expansion of unconventional oil and gas exploration targets, reservoir effectiveness identification, pore-structure evaluation, and intelligent prediction methods have become increasingly important [25,26]. Jiang et al. [27] investigated the tight sandstone gas reservoirs in the second member of the Xujiache Formation in the Anyue area, Sichuan Basin. Using core observations, thin-section analysis, scanning electron



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microscopy, mercury injection, nuclear magnetic resonance, and physical property test data, they classified reservoir types, analyzed their formation mechanisms, determined the lower limits of effective reservoir physical properties for the second member of the Xujiahe Formation, and divided the reservoirs into four types. They further indicated that sedimentation, diagenesis, and tectonism jointly control differences in reservoir development. Wang et al. [28] used thin-section analysis, X-ray diffraction, mercury injection, and reservoir heterogeneity parameters to examine the differential development mechanisms of tight sandstone reservoirs in the Shaximiao Formation, southwestern Sichuan, and their influence on gas-bearing properties. Their results indicate that variations in provenance supply and diagenetic alteration control differences in reservoir development. Carbonate cementation and clay mineral filling reduce reservoir quality, whereas chlorite films contribute to the preservation of primary pores. In addition, areal heterogeneity, interlayer heterogeneity, sandbody thickness, and reservoir connectivity jointly control variations in gas content. Taking the carboniferous tight bioclastic limestone in the Shiqiantan Sag, Junggar Basin, as the study object, Wang et al. [29] analyzed the pore system and reservoir effectiveness of different lithofacies types by integrating core observations, thin-section analysis, scanning electron microscopy, X-ray diffraction, high-pressure mercury intrusion, nitrogen adsorption, and nuclear magnetic resonance data. They identified three lithofacies types: bioclastic dolomitic limestone, micritic bioclastic limestone, and grainstone bioclastic limestone. Among these, grainstone bioclastic limestone is characterized by a relatively well-developed pore system and favorable pore–throat connectivity, making it a more favorable reservoir type in the study area. Sedimentary microfacies, paleogeomorphology, structural fractures, and dissolution-related alteration jointly influence the development of high-quality reservoirs. Using the Dongpu Sag in the Bohai Bay Basin as an example, Yang et al. [30] constructed oil and gas resource potential prediction models based on BP neural networks, BP-bagging, BP-AdaBoost, and other methods, incorporating parameters related to hydrocarbon source rocks, reservoirs, traps, migration, and accumulation. Model comparison indicates that BP AdaBoost achieves the best prediction performance, and that trap area and sandstone thickness exert relatively strong controls on oil and gas resource abundance.

The second group of studies focuses on hydrocarbon enrichment and its geological control mechanisms. For tight sandstone gas, shale gas, coal-measure gas, and other resource types, the delineation of gas-bearing systems, source–reservoir–caprock assemblages, sedimentary environment, pressure systems, and reservoir heterogeneity are key issues that need to be clarified for resource evaluation and favorable area selection [31–33]. Chen et al. [34] investigated Carboniferous–Permian tight sandstone gas in the Daning–Jixian Block on the eastern margin of the Ordos Basin. By integrating geochemical characteristics, reservoir pressure coefficients, and sequence stratigraphic analysis, they identified the gas-bearing systems and productivity differences in multilayer tight sandstone reservoirs. Tight sandstone gas in this area can be divided into upper and lower gas-bearing systems, and the upper gas-bearing system can be further subdivided into four relatively independent subsystems. Differences in sedimentary environment control rock composition, pore–throat structure, and reservoir physical properties at different intervals, thereby influencing productivity performance under single-layer production and multilayer commingled production conditions. For the thinly interbedded coal-measure gas system of the Chengzihe Formation in the Jixi Basin, Guo et al. [35] discussed the geological conditions for hydrocarbon enrichment and resource evaluation methods based on integrated analysis of drilling data, geological data, and source–reservoir–caprock conditions. The study indicates that the gas-supply capacity of high-quality source rocks, the development of tight thinly interbedded reservoirs, and the sealing capacity of effective caprocks constitute the fun-

damental conditions for coal-measure gas enrichment. Sedimentary microfacies, tectonic evolution, magmatic activity, and hydrogeological conditions jointly influence resource distribution and interlayer differences. Rao et al. [36] investigated the shale gas reservoirs in the Jiaoshiba Block of the Fuling Gas Field. They established a shale gas productivity potential evaluation model based on the analytic hierarchy process and fuzzy mathematics, integrating parameters such as gas content, brittleness index, total organic carbon content, reservoir physical properties, and formation pressure. Field application shows that the evaluation results are in good agreement with the absolute open flow capacity of gas wells.

The third group of studies focuses on development technology optimization and enhanced oil recovery [37]. In relation to heavy oil development and gas control in coal mines, these studies mainly address CO₂-enhanced oil recovery, nanoparticle-assisted displacement, gas geological unit division, and gas drainage technology evaluation [38–40]. Li et al. [41] analyzed the effects of water flooding and nanoparticle flooding on CO₂ cyclic solvent injection (CO₂-CSI) for heavy oil recovery and CO₂ storage using sand-pack model experiments and numerical simulation. Their results show that water flooding can improve the recovery performance of subsequent CO₂-CSI and extend the production cycle, whereas nanoparticle flooding can enhance sweep efficiency and displacement performance by stabilizing CO₂ foam. Taking the No. 8 coal seam in the Baode Coal Mine as the study object, He et al. [42] established a multiparameter fusion classification method for gas geological units and applied it to the optimization of large-scale gas drainage. Gas content and gas pressure in the coal seam generally increase with increasing burial depth, whereas local structures and hydrogeological conditions may cause abnormal gas occurrence and affect regional drainage performance. Luo et al. [43] combined gas geological unit division with the analytic hierarchy process (AHP) to construct an evaluation framework for gas drainage technology optimization. They evaluated the applicability of downhole long boreholes, ultra-long directional boreholes, staged hydraulic fracturing, and surface fractured horizontal wells, and suggested that drainage technology selection should comprehensively consider risk control, cost constraints, and the matching between geological conditions and engineering technologies.

In summary, this Special Issue focuses on reservoir characterization and evaluation, hydrocarbon enrichment and geological control mechanisms, development technology optimization, and enhanced oil recovery in the exploration and development of unconventional oil and gas resources. The resource types covered include tight sandstone gas, shale gas, coal-measure gas, tight carbonate oil and gas reservoirs, heavy oil, and coal mine gas. The included papers advance the understanding of pore structure, reservoir effectiveness, hydrocarbon enrichment mechanisms, resource potential, and development performance in complex unconventional oil and gas reservoirs, thereby supporting resource evaluation, favorable target selection, and the efficient development of unconventional oil and gas resources.

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