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Research Article

Accumulation characteristics and exploration strategies of coal measure gas in China☆,☆☆

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Abstract

Coal measure gas is broadly defined as all natural gas occurring in coal measure strata while narrowly defined as the coalbed methane (CBM) in coal beds and the natural gas in the adjacent tight sandstone reservoirs. In this paper, the accumulation characteristics and control factors of narrowly defined coal measure gas in China were analyzed from the aspects of source rock distribution, coal–sandstone combination type, sedimentary facies and closed system to improve CBM development benefit. And the following research results were obtained. First, there are various coal–sandstone combination relationships in coal measure strata of coal bearing basins in China. Second, the widely-distributed source rocks provide sufficient gas sources for the enrichment of coal measure gas. Third, sedimentary facies dominate the combination relationships of source–reservoir–caprock assemblages of coal measure gas, so the inborn material base of coal measure gas accumulation is formed. The sedimentary systems of fluvial facies and delta facies are the most favorable sedimentary facies for the paragenesis and accumulation of coal measure gas for their coal beds and sandstones are developed. Fourth, the closed system controls the whole process of generation, enrichment and accumulation of CBM (coal measure gas). Three types of coal measure gas reservoirs are identified: self-source and self-reservoir CBM reservoirs, paragenetic CBM–sandstone gas reservoirs, coal-derived sandstone gas reservoirs, among which the first type is currently the main target of CBM exploration and development. Finally, the next exploration direction of coal measure gas was pointed out as follows. First, the exploration and evaluation of coal measure gas shall be focused on the giant basins with abundant coal measure gas, such as Qinshui, Ordos, Junggar, Hailar and Jixi. Second, coal measure gas reservoirs shall be explored specifically based on different types. It is necessary to carry out CBM exploration in the self-source and self-reservoir CBM enriched zones in the shallow layers, integrated exploration of CBM and sandstone gas in the paragenetic CBM–sandstone gas reservoirs in the deep layers, and sandstone gas exploration in coal-derived sandstone gas reservoirs.

Keywords: China; Coal measure gas; Coalbed methane (CBM); Tight sandstone gas; Accumulation characteristic; Control factor; Closed system; Integrated exploration and development

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The exploration and development of coalbed methane (CBM) began in the early 1990s in China. After nearly three decades of development, two major CBM bases, i.e. Qinshui and Eastern Ordos, have been built, and appropriate CBM development technologies have been also preliminarily formed [1–4]. As a whole, restricted by poor resource grade, large investment, long return period, low output and low price [5,6], there is still a big gap between the present situation of CBM industry and the national target under the 12th Five-Year Plan. The development of the CBM industry is thus restricted. As an unconventional natural gas resource with great potential, coal measure gas has gradually become the hotspot of research and the realistic choice of exploration and development [7–10].

Coal measure gas is broadly defined as all natural gas generated from the evolution of source rock parent materials in the whole coal measures during the biochemical, physicochemical and coalification processes and occurs in the coal measure strata, including the shale gas from coal measure mud/shale, coalbed methane and tight sandstone gas [11,12]. From the perspective of improving the CBM development effect, the coal measure gas is narrowly defined as the CBM occurs in coal beds and the natural gas in adjacent tight sandstone reservoirs. It is of great significance in promoting the exploration and development of unconventional natural gas to study the accumulation characteristics and analyze the exploration prospect of coal measure gas. In this paper, the narrowly defined coal measure gas was discussed, its accumulation characteristics and control factors were analyzed from the aspects of source rock distribution, coal–sandstone combination type, sedimentary facies and closed system, and the exploration strategies were proposed.

1. Accumulation characteristics of coal measure gas

1.1. Widely distributed source rocks provide sufficient gas sources

Coal measure source rocks are mainly composed of coal, dark mudstone and limestone. Coal is an important gas source rock. Different types of source rocks are alternated and superposed, with the common characteristics of stable distribution, large thickness and wide coverage, which constitute a good material basis for the accumulation of coal measure gas.

Taking the Upper Paleozoic coal measure strata in the Ordos Basin for example, gas source rocks mainly consist of coal bed, dark mudstone and argilliferous biolithite [13]. The distribution area of coal measure gas source rocks exceeds 24×10^4 km^2, and that of source rocks entering a substantive gas generation phase exceeds 18×10^4 km^2, exhibiting a characteristic of wide hydrocarbon generation (Fig. 1). The present gas generation intensity is universally higher than 12×10^8 m^3/km^2 in total in the basin, and reaches 42×10^8 m^3/km^2 in the eastern region [14]. Obviously, the effective hydrocarbon generation range of Upper Paleozoic source rocks almost covers the whole basin, showing a characteristic of extensive hydrocarbon generation.

1.2. There is a diverse coal–sandstone combination relationship

Coal measure gas is mainly stored in coal beds and adjacent sandstones; a coal and sandstone interbed can be uniformly taken as a target layer for an integrated evaluation, so as to vertically expand the exploration and development space and significantly increase resource abundance [3]. However, different coal–sandstone combination relationships determine the types and development modes of coal measure gas reservoirs. In this paper, four combination types were introduced based on the combination relationships of coal beds and adjacent sandstones (Fig. 2).

Type I combination: multilayer coals + multilayer sandstones. Type I combination reflects the cyclic evolution of coal accumulation environment, where multiple sets of coals and sandstones are superposed each other in a cyclic mode vertically. The coal beds can act as both gas source rocks and CBM reservoirs. The gaseous hydrocarbon generated from coals is directly stored in the adjacent sandstones. With a good regional seal, a source–reservoir interactive coal measure gas play is formed (Fig. 2-a).

Type II combination: multilayer coals + few layers or no sandstone. In Type II combination, coals are developed, sandstones are underdeveloped or undeveloped, reflecting a *long*-term swamping sedimentary environment, where terrigenous detritus supply is insufficient, mudstones are usually relatively developed, and good sealing conditions exist, which is favorable for the CBM preservation (Fig. 2-b).

Type III combination: monolayer or few layer coal beds + multilayer sandstones. In Type III combination, there are a few layers of coal beds, but many sets of sandstones are developed above and below them, reflecting a sufficient supply of terrigenous detritus. Coal bed distribution is restricted. Gaseous hydrocarbon generated from coal can be directly stored in adjacent sandstones. Due to the development of sand bodies, the presence of a good regional seal in the coal measures determines the enrichment and accumulation of coal measure gas in the region (Fig. 2-c).

Type IV combination: monolayer, few layers or no coal beds + few layers or no sandstone. Type IV combination generally reflects a deep water sedimentary environment, where sealing conditions are good, but sandstones are undeveloped. If there is a coal bed, it is favorable for forming a simplex CBM reservoir. If there is no coal bed or the coal bed is relatively thin, it is unfavorable for the CBM enrichment. If shale is developed, a shale gas reservoir can be formed (Fig. 2-d).

2. Controlling factors for coal measure gas accumulation

2.1. Sedimentary facies controls the source–reservoir–caprock assemblage

The sedimentary systems developed in coal measure strata in China mainly consist of neritic-barrier coast, neritic-barrier free coast, alluvial fan, stream, delta and lake [15]. Obvious sedimentary differentiation exists spatially and multiphasic