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Original research paper

The Late Paleozoic relative gas fields of coal measure in China and their significances on the natural gas industry☆

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Abstract

The coal measure gas sources of coal-derived gas fields in the Late Paleozoic China are the Lower Carboniferous Dishuiquan Formation, the Upper Carboniferous Batamayineishan Formation and Benxi Formation, the Lower Permian Taiyuan Formation and Shanxi Formation, and the Upper Permian Longtan Formation. The coal-derived gas accumulates in Ordovician, Carboniferous, Permian, and Paleocene reservoirs and are distributed in Ordos Basin, Bohai Bay Basin, Junggar Basin, and Sichuan Basin. There are 16 gas fields and 12 of them are large gas fields such as the Sulige large gas field which is China's largest reserve with the highest annual output. According to component and alkane carbon isotope data of 99 gas samples, they are distinguished to be coal-derived gas from coal-derived gas with $\delta^{13}C_2 > -28.5‰$ and $\delta^{13}C_1$ -$\delta^{13}C_2$ -$\delta^{13}C_3$ identification chart. The Late Paleozoic relative gas fields of coal measure are significant for the Chinese natural gas industry: proven natural gas geological reserves and annual output of them account for 1/3 in China, and the gas source of three significant large gas fields is coal-derived, which of five significant large gas fields supporting China to be a great gas producing country. The average reserves of the gas fields and the large gas fields formed from the late Paleozoic coal measure are 5.3 and 1.7 times that of the gas fields and the large gas fields in China.

Keywords: China; The Late Paleozoic; Coal-derived gas; Natural gas industry

1. Introduction

Coal is mainly composed of humic coal and sapropelic coal. Sapropelic coal is formed from shallow sea algae, mainly in the lower organisms. The Cambrian, Ordovician, and Silurian had coal measures appeared. At present, the coal in China are anthracite in places where the proportion of coal is very small and the geographical distribution was limited. Humic coal is formed from swamps and onshore higher plants and is a major component of coal measures. The earliest known terrestrial flora in the world evolved in the Late Silurian to Early Devonian period. On such flora in Altay in Xinjiang, Shanglin in Guangxi, Fengkai in Guangdong, Luquan in Yunnan formed Early and Middle Devonian coal line or thin coal seam. Early Devonian flora has begun to appear on the earth, but the distribution is sparse and have not discovered valuable coal seam yet [1]. Due to the early Paleozoic sapropel and Devonian system's humic coal restricted distribution area's inability to form scale coal measures, so far it has not been found in the world of coal-derived gas field.

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2. The coal measures associated with coal-derived gas in the Late Paleozoic

There are eight main coal accumulating periods in China from Early Cambrian to Tertiary. The Late Paleozoic, the Late Carboniferous to the Early Permian, and Late Permian to coal accumulating period, are two of China's four biggest coal accumulating effect phase [1]. The Late Paleozoic coal-bearing strata is distributed widely in China and developed as well. Associated with the currently known coal-derived gas field of coal-bearing strata, it is mainly distributed in the Upper Carboniferous Benxi Formation, the Lower Permian Taiyuan Formation and Shanxi Formation of the Eastern North and Northwest of China, the Lower Carboniferous Dishuiquan Formation and the Upper Carboniferous Batamayineishan Formation in Junggar Basin of Xinjiang, and the Upper Permian Longtan Formation of south China.

2.1. The coal measures associated with coal-derived gas in north China coal basin

Late Paleozoic coal accumulating basin of North China, or North China coal basin, is an important coal-bearing area in China. The original scope of the coal basin, north from south of Yinshan Mountain, south to north of Qinling Mountain and Dabie Mountain, west to the east of Helan Mountain, east facing Japan sea, an area of 120×10^4 km^2, is a very large coal-bearing basin. Basin, in the main part of the formation from bottom to top are: Hutian Formation (Tielvyan Formation), Benxi Formation, Taiyuan Formation, Shanxi Formation, Shihezi Formation, and Shiqianfeng Formation [2]. The Benxi Formation, Taiyuan Formation and Shanxi Formation are coal-bearing strata in the north. The Shihezi Formation in southern basin, the south of the north latitude 35° of Pingdingshan and Huainan regions, has coal and buried shallow. It is now an important coal mining area, in addition to the coal bed methane, not found coal-derived gas field.

North China coal basins, which are suffering the influence of the Cenozoic tectonic movement, have significant changes. It formed an uplift tectonic belt of the NNE trend Taihang Mountain−Lvliang Mountain in the middle. The rise of the late Paleozoic coal, with shallow buried depth, becomes China's major coal-producing area. And Qinshui area in its south became the coal bed of gas production areas in China. However, coal-derived gas field in the uplift belt haven't been found so far. In the Bohai Bay Basin of the eastern uplift belt, Mesozoic−Cenozoic tectonic is strongly active, it fractures more and is becoming a rift type. It makes many areas in the original coal continuous distribution by denudation because of the rising, just to be saved in deep sag coal measures, and found the relevant coal-derived gas field. In the west of Taihang Mountain−Lvliang Mountain uplift belt area mainly is Ordos Basin and is a craton-type structure region [3], the continuous Late Paleozoic coal measures preserved well in the interior.

2.1.1. The accumulation conditions of Late Paleozoic coal into gas in Ordos Basin

Ordos Basin is the earliest basin (in 1907) in mainland China to use mechanic well drilling (Well Yan 1) to explore oil and gas. But since then, because of the traditional industry think coal measures is not hydrocarbon source rock, it doesn't put the Carboniferous-Permian coal as exploration targets. Until 1978 it has no progress for natural gas exploration. In 1979, after the birth of the theory of coal-derived gas [4], many scholars have pointed out that coal-bearing strata of Benxi Formation, Taiyuan Formation, and Shanxi Formation in the basin are good gas source rocks since 1980, and should strengthen the coal-derived gas exploration [5−10].

Coal and mudstone of late Paleozoic in Ordos Basin are all kerogen III. Coal seams are mainly distributed in Taiyuan Formation and Shanxi Formation, the thickness 2−20 m in general, dark mudstone in the western basin generally 140−150 m, 70−140 m for east, and 20−50 m for north and

Table 1
Geochemical parameters of Upper Paleozoic source rocks in Ordos Basin [12,13].

Type		Organic carbon /%	Chloroform bitumen A/%	Total hydrocarbon /ppm	Maceral/%		
					Vitrinite	Fusinoid	Inertinite
		Maximum/minimum Average					
Shanxi Formation	Coal	*89.17/49.28* 73.6	*2.45/0.1* 0.8	*6699.93/519.9* 2539.8	*90.2/43.8* 73.6	*54/6.3* 24	*12.3/0* 4.6
	Mudstone	*19.29/0.07* 2.25	*0.5/0.0024* 0.04	*524.96/519.85* 163.8	*47/8* 20.5	*87/51.8* 72	*20.3/0* 7.4
Taiyuan Formation	Coal	*83.2/3.83* 74.7	*1.96/0.03* 0.61	*4463/222* 1757.1	*98.8/21.2* 64.2	*63.7/1.3* 32.1	*15.1/0* 3.7
	Mudstone	*23.38/0.1* 3.33	*2.95/0.003* 0.12	*1904.64/15* 361.6	*82/8.3* 38	*89.3/15.3* 53.3	*34.5/0.3* 8.4
	Limestone	*6.29/0.11* 1.41	*0.43/0.0026* 0.08	*2194.53/88.92* 493.2			
Benxi Formation	Coal	*80.26/55.38* 70.8	*0.97/0.41* 0.77		*93.3/72* 87.2	*25.2/6.7* 16	*2.8/0* 1.4
	Mudstone	*11.71/0.05* 2.54	*0.44/0.0024* 0.065	*1466.34/12.51* 322.73	*47.8/12.3* 24.5	*59.8/12.3* 44	*39.5/0.3* 18.2

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