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The Classification and Model of Coalbed Methane Reservoirs

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Abstract Coalbed methane has been explored in many basins worldwide for 30 years, and has been developed commercially in some of the basins. Many researchers have described the characteristics of coalbed methane geology and technology systematically. According to these investigations, a coalbed methane reservoir can be defined: "a coal seam that contains some coalbed methane and is isolated from other fluid units is called a coalbed methane reservoir". On the basis of anatomization, analysis, and comparison of the typical coalbed methane reservoirs, coalbed methane reservoirs can be divided into two classes: the hydrodynamic sealing coalbed methane reservoirs and the self-sealing coalbed methane reservoirs. The former can be further divided into two sub-classes: the hydrodynamic capping coalbed methane reservoirs, which can be divided into five types and the hydrodynamic driving coalbed methane reservoirs, which can be divided into three types. The latter can be divided into three types. Currently, hydrodynamic sealing reservoirs are the main target for coalbed methane exploration and development; self-sealing reservoirs are unsuitable for coalbed methane exploration and development, but they are closely related with coal mine gas hazards. Finally, a model for hydrodynamic sealing coalbed methane reservoirs is established.

Key words: coalbed methane reservoir, classification, reservoir model, hydrodynamics, reservoir boundary

1 Introduction

Coalbed methane, a kind of unconventional natural gas, is different from conventional natural gas in evolving mechanism of gas reservoirs. Therefore, it is unreasonable to apply the concept of natural gas reservoirs to coalbed methane reservoirs (CBMR). In the past 30 years, coalbed methane has been explored in many basins worldwide, and has been developed commercially in some basins. The coalbed methane geological theory has been systematically discussed according to the information from exploration and development, based on which coalbed methane geology, a new discipline, comes into being. Up to now, there has not been a universal definition and classification for coalbed methane.

There is hardly the concept of coalbed methane reservoirs in overseas documents. In China, some researchers tried to define and classify coalbed methane reservoirs in terms of pressure (Liang et al., 1996; Yuan, 1997; Wang et al., 1999), tectonics (Zhang et al., 2000), a combination of pressure and tectonics (Qian et al., 1996; Zhao et al., 1997; Qin et al., 2001), the structure of coal seams (Su and Zhang, 2002) and gas saturation (Yu, 1995). On the basis of these investigations, as well as anatomization, analysis and correlation of the typical coalbed methane reservoirs both in China and abroad, this paper presents a definition and classification of coalbed methane reservoirs, and a model of coalbed methane reservoirs that is helpful to the development of coalbed methane.

2 Definition of Coalbed Methane Reservoirs

The coalbed methane reservoirs can be defined as follows "coal seams that contain some coalbed methane and are isolated from other fluid units are called coalbed methane reservoirs. Coalbed methane reservoirs that can been commercially developed with the current technology are called commercial coalbed methane reservoirs; otherwise, they are called subcommercial coalbed methane reservoirs". The commercial and subcommercial coalbed methane reservoirs are relative conceptions, which depend on the national resource abundance, the economic policy and the technological progress.

3 Classification of Coalbed Methane Reservoirs

Coalbed methane that is mainly adsorbed in coal seams is mainly controlled by temperature, pressure and properties of coal. The temperature depends on the geothermal gradient; coal properties are the results of geologic processes. These two controlling factors are basically changeless. Only pressure is constantly changing along with the recharge, migration, and drainage of groundwater. Therefore, according to the pressure

Table 1 Classification of coalbed methane reservoirs

Class	Sub-class	Type	Typical coalbed methane reservoir
Hydrodynamic sealing CBMR	Hydrodynamic capping CBMR	Permeability-hydrodynamic capping CBMR	San Juan basin
		Fault-hydrodynamic capping CBMR	Sand Wash basin
		Monocline-hydrodynamic capping CBMR	Ordos basin
		Syncline-hydrodynamic capping CBMR	Qinshui basin
		Pinch out-hydrodynamic capping CBMR	Powder basin
	Hydrodynamic driving CBMR	Anticline-hydrodynamic driving CBMR	Powder basin, San Juan basin, Qinshui basin
		Anticline-truncation-hydrodynamic driving CBMR	
		Fault-anticline-hydrodynamic driving CBMR	
Self-sealing coal-bed CBMR		Abnormally high pressured fluid compartment CBMR	Washakie basin
		Low permeability self-sealing CBMR	Limin colliery and multitudinous outburst coal seams
		Isolated (lenticular) CBMR	Common in many basins

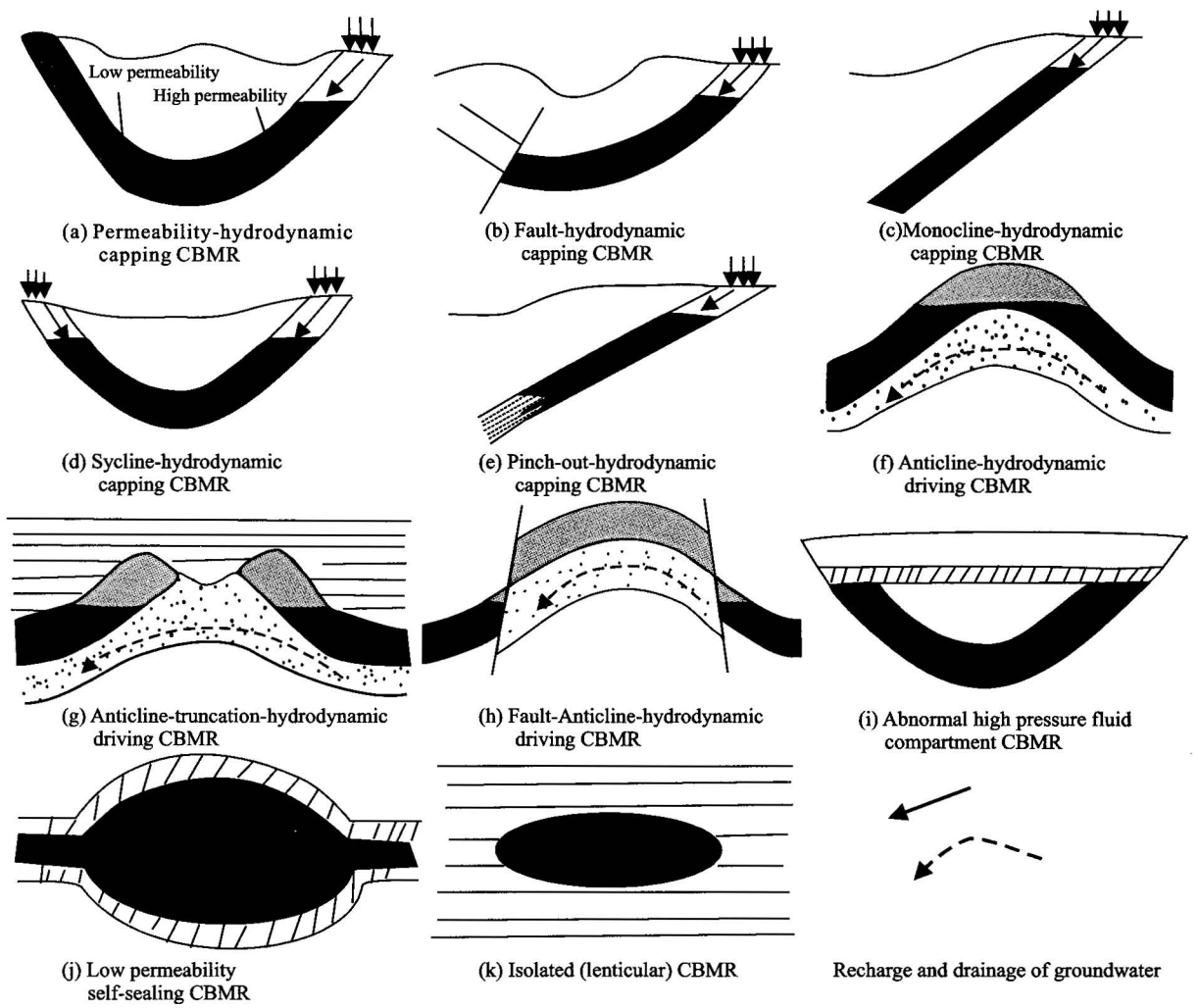

Fig. 1. Schematic diagrams showing classification of coalbed methane reservoirs.

mechanism, coalbed methane reservoirs can be classified (Table 1, Fig. 1).

Firstly, according to the mechanism of pressure formation, coalbed methane reservoirs can be divided two classes: the hydrodynamic sealing coalbed methane reservoirs and the self-sealing coalbed methane reservoirs. The former can be further divided into two sub-classes: the hydrodynamic capping coalbed methane reservoirs, which can be divided into five types by boundary and the hydrodynamic driving coalbed methane reservoirs, which can bed divided into three types by structure. The latter can bed divided into three types.

3.1 Hydrodynamic sealing coalbed methane reservoirs

Hydrodynamic sealing coalbed methane reservoirs are those in which the migration and accumulation of coalbed methane are sealed by groundwater as well as other geological boundaries. That is to say, the hydrodynamic sealing coalbed methane reservoirs are closely related to the recharge, migration, stagnation and drainage of groundwater.

Precipitation or groundwater migrates from the recharge area to the deep part of the basin along coal seams whose permeability is high. Therefore, the reservoir pressure will increase and coalbed methane will accumulate in the groundwater detention area. Consequently, hydrodynamic sealing coalbed methane reservoirs are formed. This "inversion" of gas-water is similar to the deep basin gas (Jiang et al., 2000). The hydrodynamic sealing boundary is the groundwater table near the outcrop area. The hydrostatic pressure caused by the groundwater table should ensure that the lowest gas content is sealed in coal seams. The hydrostatic pressure can be calculated by the lowest gas content and Langmuir's equation or measured in the field. There are many boundary types in the detention area, base on which the coalbed methane reservoirs can be farther divided into sub-classes and types.

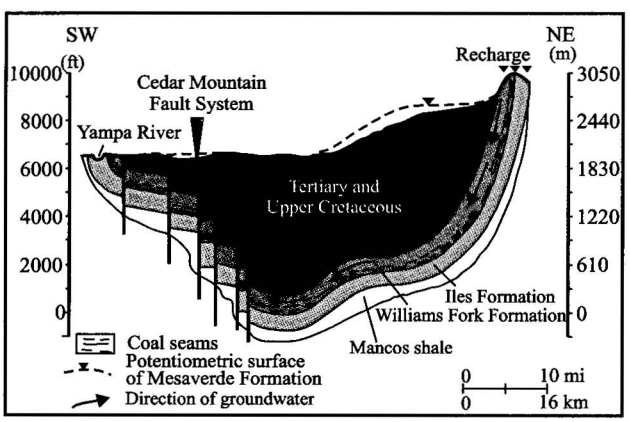

Fig. 2. Hydrological section of the Williams Fork Formation in the Sand Wash Basin (modified from Tyler et al., 1997).

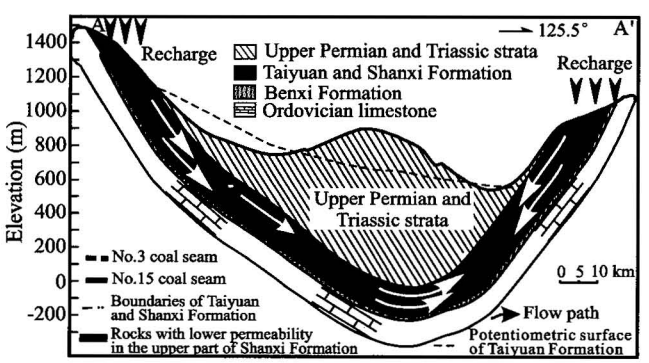

Fig. 3. Hydrological section of the Taiyuan Formation in the Qinshui Basin.

For example, the boundary of the coalbed methane reservoir of the Fruitland Formation in the San Juan basin (U.S.A.) is a low-permeability reservoir (Ayers, 2002); that of the Williams Fort Formation in the Sand Wash basin (U. S.A.) is bounded by faults (Fig. 2); the Qinshui basin is sealed by groundwater along both wings of the syncline (Fig. 3); the Hedong coalfield on the eastern margin of the Ordos basin is a monocline, where groundwater migrates to the detention area without an obvious boundary (Su et al., 2003) (Fig. 4); and pinch-out of coal seams exists in many coal-bearing basins.

Hydrodynamic driving coalbed methane reservoirs refer to those in which the migration of groundwater not only causes the migration of coalbed methane, but also results in accumulation of coalbed methane in the tectonic high. This is similar to the mechanism of conventional oil and gas. Hydrodynamic driving coalbed methane reservoirs are common in the Powder basin. According to the tectonic features, hydrodynamic driving coalbed methane reservoirs can be divided into three types: anticline-hydrodynamic driving coalbed methane reservoirs (Fig. 5), anticline-truncation-hydrodynamic driving coalbed methane reservoirs and fault-anticline-hydrodynamic driving coalbed methane reservoirs.

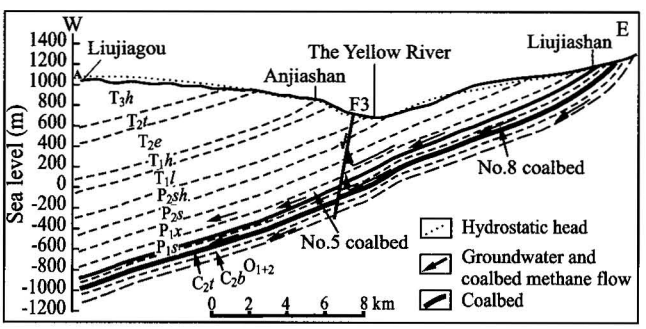

Fig. 4. Hydrogeological section in the Liulin district (modified from Su et al., 2003).

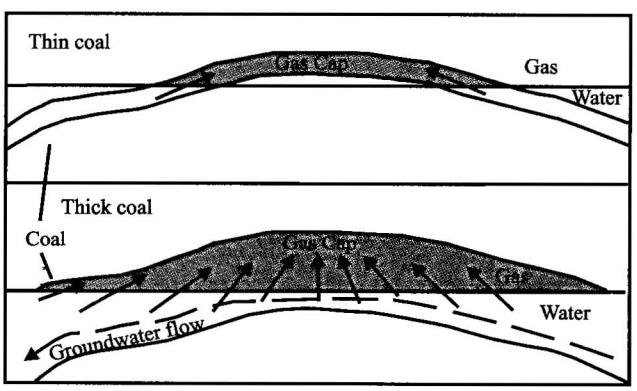

Fig. 5. Hydrogeological section of the Powder River basin (modified from Ayers, 2002).

3.2 Self-sealing coalbed methane reservoirs

Self-sealing coalbed methane reservoirs are similar to conventional petroleum abnormally pressured fluid compartments. The formation of self-sealing coalbed methane reservoirs is related to coal deformation under tectonic stresses, in addition to temperature, hydrocarbon generation and tectonic stresses (including uplift and erosion). This kind of reservoirs can be divided into three types. The first is abnormally pressured fluid compartment coalbed methane reservoirs. There is a tight seam that is related to the generation of hydrocarbon and lithification at the burial depth of about 3000 m. Below the tight seam, the coalbed methane reservoir is a fluid compartment with isolated pressure system (Fig. 6). The reservoirs cannot be developed commercially because of the deep burial depth of coal seams and the gas content is low. The second is low-permeability self-sealing coalbed methane reservoirs. Under strong tectonic stresses (or other forces such as gravity), coal seams can be deformed severely and become mylonitic coal (Fig. 7). The permeability of mylonitic coal that commonly contains high coalbed methane is very low. Gas hazards often happen in the coal seams. They are unsuitable for coalbed methane development because the permeability is low. The third is lenticular coalbed methane reservoirs. The coal seams are discontinuous and lenticular. These reservoirs exist in many coal-bearing basins. If the reservoir is large enough and seals with low-permeability rocks, the coalbed methane can be developed commercially.

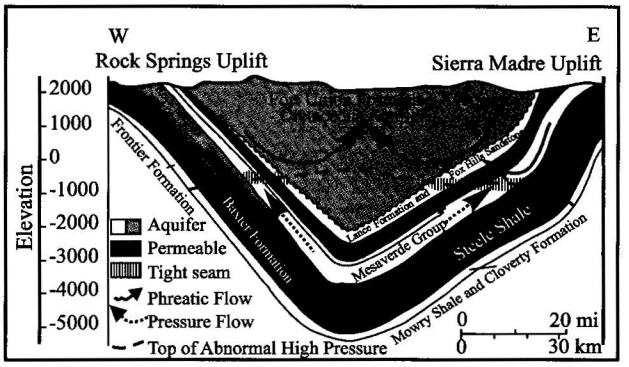

Fig. 6. Hydrogeological section of the Washakie basin (modified from Wang et. al., 1998)

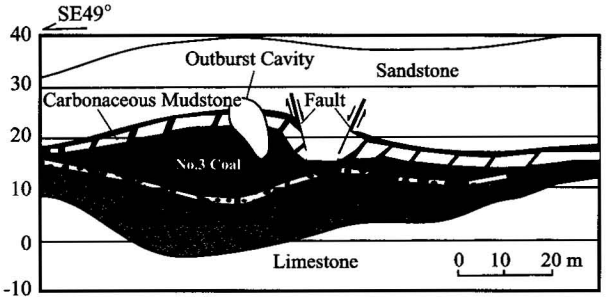

Fig. 7. Geological section of the Limin Colliery (modified from Wang et. al., 2002).

4 The Model of Hydrodynamic Sealing Coalbed Methane Reservoirs

Based on the above anatomization and classification, we have established a model of hydrodynamic sealing coalbed methane reservoirs (Fig. 8). This model illustrates the coalbed methane reservoirs that have been proved to be suitable for commercial development.

A hydrodynamic capping coalbed methane reservoir is shown on the left side of Fig. 8, where precipitation is recharged from an outcrop and migrates to the deep part of the basin along coal seams which are highly permeable, and is detained when it comes to boundaries such the pinch-out of coal seams, permeable layers or closed faults. During the process of migration, groundwater carries coalbed methane in shallow coal seams to the detention area, where coalbed methane accumulates, thereby forming commercial gas

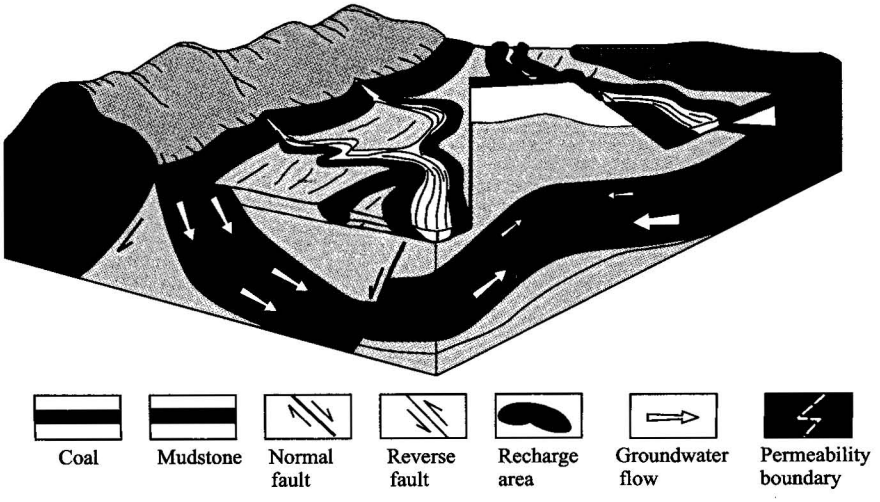

Fig. 8. The model of a hydrodynamic sealing coalbed methane reservoir.

reservoirs. In low coal rank reservoirs biogenic gas is dominant; to middle coal rank reservoirs, secondary biogenic gas may probably generate besides thermogenic methane; and for high coal rank reservoirs, thermogenic gas predominates. A hydrodynamic driving coalbed methane reservoir is shown on the right of Fig. 8, where a conventional trap exists. This kind of reservoirs are similar to hydrodynamic capping coalbed methane reservoirs in the migration and accumulation of groundwater and coalbed methane. A conventional trap can be regarded as a coalbed methane "fairway" ("sweet spot") and is most favorable for coalbed methane development.

5 Conclusion

By anatomizing the typical coalbed methane reservoirs, coalbed methane reservoirs are strictly defined and systematically classified, and a model of hydrodynamic sealing coalbed methane reservoirs is established. This classification is put forward on the basis of typical coalbed methane reservoirs that have been presently discovered, and along with their exploration and development, this classification needs to be complemented and consummated. Self-sealing coalbed methane reservoirs are unsuitable for coalbed methane exploration and development, and are not well investigated. Therefore, the model for self-sealing coalbed methane reservoirs is not established in this paper.

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