HAIJIAO FU
DAZHEN TANG
LINLIN WANG
SHIDA CHEN
TAO ZHANG
and
HAIYONG WU

Geological controls on CBM enrichment and its exploration target optimization in the southeast Junggar basin, China

To date, coalbed methane (CBM) explorationhas only achieved a big breakthrough in Fukang-Dahuangshan regions, while CBM exploratory wells in the other regions of the southeast Junggar basin exhibit poor exploration effects. The analysis suggests that three unclear factors, including CBM accumulation process, geological controlling factors and distribution principle of favourable areas, cause the mismatch between CBM exploratory well deployment and practical geological regularity. In this study, the systematic research about three unclear factors has been carried out for the first time. The research shows that the well-developed extruding thrust faults are beneficial to CBM enrichment and preservation in the study area. Sandy roof not only can form tight-sandstone gas reservoir, but also serve as the cap rock for underlying coalbed gases. Liuhuanggou-Fukang regions in the southern Junggar basin and depression regions in the eastern Junggar basin are all hydrodynamic stagnation areas beneficial to CBM enrichment. Seven typical CBM enrichment models are summarized in this study, and they have different development degrees and various controlling mechanism of CBM enrichment. Finally, a suitable mathematical evaluation model for CBM exploration potential is established, and seven prospective targets (e.g. Fukan, Liuhuanggou and Qigu areas, etc.) are selected to be the preferred areas for CBM exploration, and both of them are ordered on the basis of their Ui values. The findings provide the geological basis for future CBM exploration and deployment.

Keywords: *Coalbed methane; controlling factor; enrichment model; prospective targets; Junggar basin.*

Messrs. Haijiao Fu, Dazhen Tang, Shida Chen, Tao Zhang and Haiyong Wu, School of Energy Resources, China University of Geosciences (Beijing), Beijing 100 08 and Linlin Wang, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100 037, China. Email:wanglinlin2003@sina.cn

1. Introduction

In the past 20 years, CBM practitioners have done a lot of work about medium-high rank CBM resources in China, and have achieved a key breakthrough in Qishui and Ordos basins, where several demonstrative bases about CBM exploratin and development already have been established [1],[2]. However, low-rank CBM resources have achieved a big breakthrough in Power River basin, which can provide new ideas for the development of CBM industry in China[3], [4]. As a typical low-rank coal-bearing basin in China, Junggar basin contains abundant coal resources, which can satisfy the geological needs of forming large-scale CBM reservoir, due to suitable buried depth, large thickness and great gas content [5]. At present, the Xinjiang Geological Mine Bureau has drilled 56 CBM development wells in Fukang-Baiyanghe mining area, with gas production of $3\times10^4 m^3/d$, and has established the first CBM demonstrative base in Xinjiang [6]. Moreover, the Xinjiang cleanseed new-energy limited liability company also has achieved a key breakthrough in Fukang-Sigonghe areas, with the highest single-well daily gas-production of $1.73\times10^4 m^3/d$. Except for Fukang area, more than 10 CBM exploration wells were deployed in Liuhuanggou, Hutubi, Manasi and Shazhang areas. However, both of them achieved poor exploration effects, due to big work area, complex structural feature and unclear distribution principle of CBM resources [7],[8].

In this paper, the Jurassic coal seam in the southeast Junggar basin has been taken as an object of study. Firstly, regular recognitions about CBM enrichment are done from three aspects (i.e., sturcture, sedimentation and hydrogeology). Secondly, combined with the practical geological situation and CBM exploration progress, some typical CBM enrichment models are established. Finally, a suitable mathematical evaluation model for CBM exploration potential is established on basis of fuzzy mathematics and analytical hierarchy, and seven favourable exploration areas are selected to provide the geological basis for future CBM exploratory well deployment.

2. Regional geology

The Junggar basin belonging to large-scale superimposed basin, has underwent multiphase tectonic movements from late palaeozoic to quaternaey [9]. Both North tianshan piedmont fault fold belt and uplift region in the east are first-order tectonic units of the Junggar basin with different tectonic evolution process, which have an obvious impact on coal enrichment in the southeast Junggar basin[10]. The southeast Junggar basin covers an area of 30000km^2, which is east to Laojunmuiao, south to Bogeda Mountain, and north to Kelameili Mountain (Fig.1). Zhunnan coalfield is attached to secondary structures of North Tianshan piedmont fault fold belt in structure (e.g., Qigu fault-fold belt and Fukang fault zone), which is closely related to formation and evolution of piedmont foreland basin of North Tianshan and Bogeda mountains [11]. Among them, anticline and syncline are the major fold types, and both of them should be treated as the main targets for CBM exploration in the study area. Moreover, zhundong coalfield is attached to the east uplift region of the Junggar basin, while its basement depth shows a increasing trend from east to west [12]. Nowadays, there are several secondary tectonic unlts (e.g., salient and depression) in the eastern Junggar basin,showing a checkboard type structural framework.

The earth surface of the southern Junggar basin is mainly covered by the quaternary strata, and the Jurassic strata are exposed partly at the same time. The main strata containing coal seams are Badaowan formation and Xishanyao formation, and the Sangonghe formation developed between them, contains only a small amount of coal streak or nothing [11]. Controlled by tectonic and sedimentary environments, the coal-rich center of Badaowan formation mostly located in Fukang regions, with better CBM exploration values. Overall, thick seams are mainly developed in the Xishanyao period, which is beneificial to CBM exploration and development, due to thick coal seam, more numbers of coal seam, and suitable burial depth.

3. Main controls on CBM enrichment

Research suggests that the geological factors that influence the accumulation of CBM mainly include structure, sedimentation and hydrogeology[13]. Among them, structure is the most important and direct factor during the process of CBM enrichment, while coal-forming environment mainly affects the gas generation potential, roof lithology, reservoir properties and permeability. Moreover, hydrogeology controls the generation, migration and accumulation of biogenic gas, as well as the effusion and preservation of thermogenic gas.

3.1 Structural geology

Structure is the most important and direct gas controlling factors, which not only controls the distribution, migration and accumulation of CBM, but also leads to the destructive or constructive reformation of previously formed coal reservoirs[14], [15]. In the period of coal accumulation, the structure controls the potential of source-reservoir-cap of CBM. After that, structural feature and its evolution process not only affect the source-reservoir-seal assemblage, but also directly control the transport, accumulation and conservation of CBM, which determines the development potential of CBM resources in certain areas [16],[17]. The research shows that the southern and eastern margin of Junggar basin belongs to different geological tectonic units, which has an obviously different impact on CBM enrichment.

The southern Junggar basin is mainly located in the north wing of North Tianshan and Bogda Mountains. Under the control of multi-period tectonic movements (i.e.,Yanshan movement and Himalayan movement),a series of synclines and anticlines were subsequently developed from south to north along with reversed faults[18], which are favourable to the formation of stress sealing of CBM in the adjacent areas (Fig.2). Research shows that neutral plane of fold located in the Jurassic Sangonghe formation, while the Xishanyao coals and the Badaowan coals developed in the syncline and anticline, respectively. The strong tectonic stress is beneficial to enhance the adsorption capacity (CH_4) of coal reservoir, which is favourable for CBM enrichment (Fig.3). Moreover, the fault types in the southern Junggar basin are composed of compressional thrust faults with good sealing performance, which is

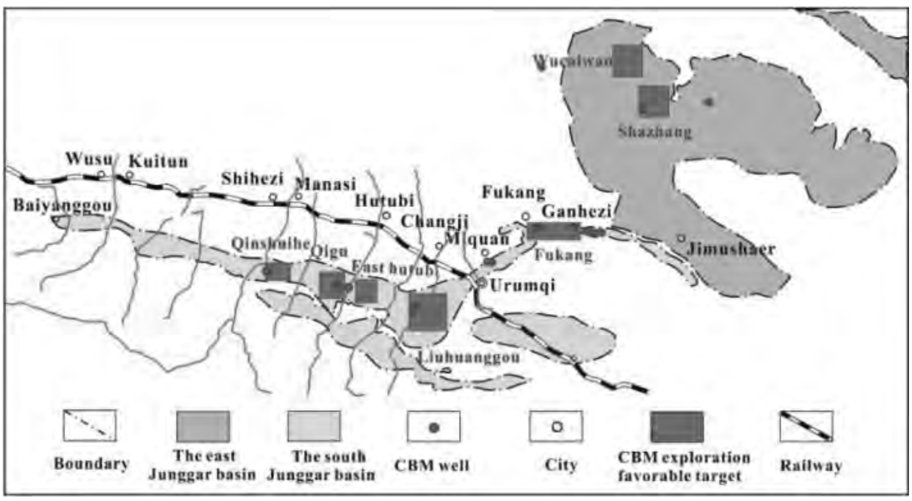

Fig.1 Traffic location map and CBM favorable area distribution in the southeast Junggar basin

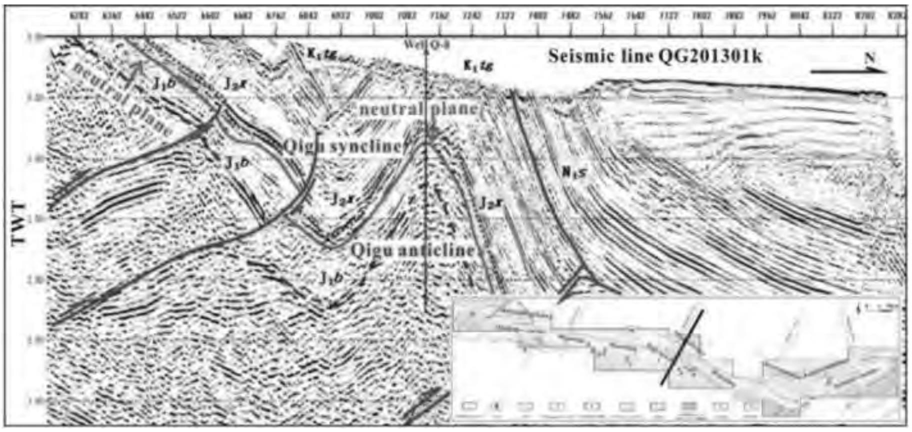

Fig.2 The distribution map of structural traps in the southern Junggar basin

Fig.3 The distribution map of neutral plane of fold in the southern Junggar basin

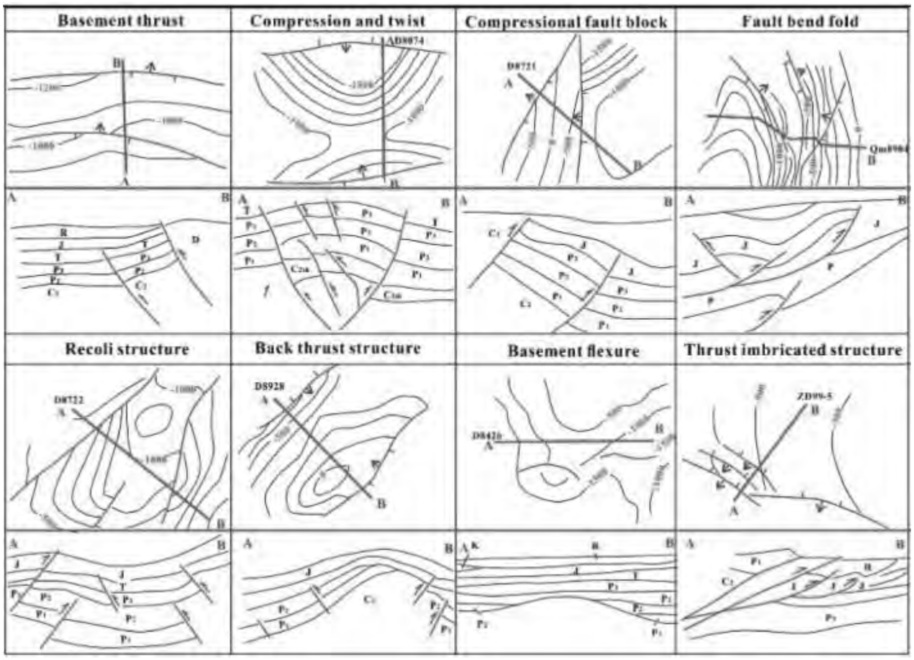

Fig.4 The sketch map of structural styles in the eastern Junggar basin [20]

beneficial to CBM enrichment.

Under the action of compressional stress from Kelameili and Bogda mountains, the tectonic types are very complex along with well-developed faults, showing as the chess board structure in the eastern Junggar basin (Fig.4). According to tectonic and thermal evolution history, it can be seen that the control of the uplift of Southern Bogda mountain at the end of Cretaceous on basin sedimentary structures is obviously higher than that of Kelameili mountain[19]. The uplift and erosion of strata in the northeast side of the eastern Junggar basin, lead to the shallower of buried depth of coal seam, which are not conducive to CBM accumulation and preservation. Research shows that the fault types in this area are mainly consist of compressional faults, and the fault plane is mostly confined tectonic stress concentration zone. This kind of fault can improve the adsorption quantity of gas content due to the increase of reservoir pressure. Moreover, it is also conducive to the preservation of CBM because methane gas is not easy to escape through the fault plane.

Overall, the structural complexity of the Jurassic straum in the eastern Junggar basin is obviously larger than that of the southern regions, and the former develops several tectonic types (e.g., basement thrust, compression-twist, compression fault block and fault bend fold, etc), which has more complicated geological significances for CBM enrichment.

3.2 Sedimentary geology

By controlling the composition of coal reservoir, the thickness/ distribution of coal seam and the contact relationship of lithology, coal-forming environment can affect the gas generation potential, reservoir properties, preservation conditions and permeability of coal reservoirs, and can further control the process of CBM accumulation[21],[22].

3.2.1 Material composition of coal petrography

It was widely accepted that there were obvious differences about coal types, maceral and ash composition of the coal seams from different coal-forming environments. In

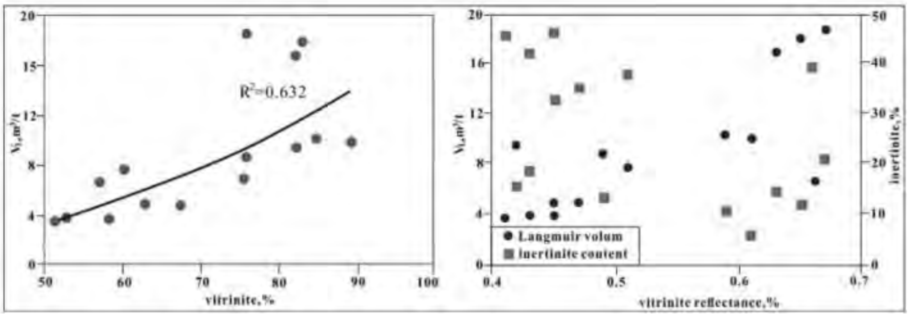

Fig.5 Langmuir volume VS the content of vitrinite and inertinite

general, the exinite has poorer methane adsorption capacity compared to vitrinite and inertinite[23],[24]. The content of vitrinite (humic group) is the highest in the eastern Junggar basin (51.7 to79%, mean 67.1%), followed by inertinite (15.1 to 45.5%, mean 29.28%) and exinite (0 to 10.6%, mean 3.12%). Seen from Fig.5, methane adsorption capacity of coal petrography has a significant positive correlation with vitrinite, while its relationship with inertinite is not obvious. Therefore, the higher the vitrinite content is in the area, the more favourable for enrichment of CBM.

In addition, the vitrinite content in the southern Junggar basin is 45.6 to 66.4% (mean 55.6%), and the inertinite content is 29.7-55.7% with the average of 42.8%, while the exinite is almost not developed (0.5-4.7%, mean 1.7%). The comparison shows that the vitrinite content in the eastern Junggar basin is significantly higher than that in the southern Junggar basin, indicating that adsorption capacity of coal in the eastern Junggar basin is relative higher.

3.2.2 Roof lithologic character of coal seam

The sedimentary environment not only can control material composition, generation potential and reservoir conditions of coal petrography, but also controls the lithology and thickness of its surrounding rock, which can influence preservation conditions of CBM[25]. In general, mudstone, limestone and tight sandstone all can provide effective sealing conditions for CBM enrichment, and the higher the mud content, the better the sealing performance [26]. Roof lithology of coal seam in the southern Junggar basin is obviously controlled by sedimentary environment. It is dominant bycoarse-grained sandstone (e.g., Wusu, Hutubi, Manasi and Shazhang regions), and followed by fine-grained mudstone (e.g., Liuhuanggou and Fukang regions). Sealing condition of coal roof has been preliminary thought to be moderate. However, compared to the relation between roof lithology and gas content of coal seam, we find both sandy and muddy cap rock can form an effective plugging to coal-bed gases.The gas content of coal seam sealed by sandstone roof also can reach 6m^3/t (Fig.6). Analysis shows that burial depth of coal seam is higher in well c-1 and well c-2 (more than 1000m). The strong compaction caused sandstone reservoir cementation and compaction-continuously, and low permeability can form an effective plugging. Therefore, sandy roof in the southeast Junggar basin can effectively plug the lower coal seam besides forming a tight sand secondary gas reservoir.

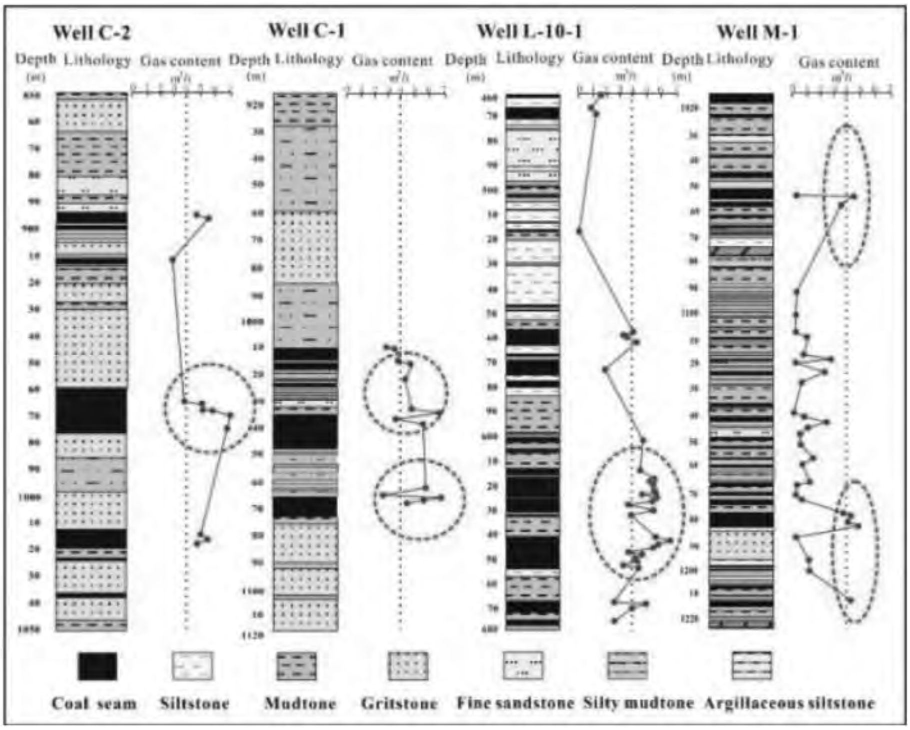

Fig.6 The comparison diagram between lithologic section and the gas content in the southeast Junggar basin

3.3 Hydrogeology

Hydrogeology in the southeast Junggar basin is relatively simple, which belongs to a typical temperate continental arid climate. Meanwhile, evaporation is much larger than precipitation in this area, and therefore glacier snowmelt is the most important water supply source for coal formation water[27],[28]. The specific yield of the coal measure strata ranges from 0.00067 to 0.7055 L/(S.m), and the permeability coefficient K is 0.001-0.522 m/d, showing the confined water

TABLE 1: WATER TYPES AND THE TDS VALUES IN THE SOUTHEAST JUNGGAR BASIN

Tectonic division	Hydrological unit	Water type	TDS (mgL^{-1})
South Junggar basin	Wusu-Hutubi	$HCO_3 \cdot SO_4$-Na, $SO_4 \cdot Cl \cdot HCO_3$-Na	601~3398
	Liuhuanggou-Fukang	$Cl \cdot SO_4$-Na, $HCO_3 \cdot SO_4$-Na	1750~30509
	Jimushaer	$SO_4 \cdot HCO_3$-Na·Ca	1300
	Houxia	$HCO_3 \cdot SO_4$-Ca·Na, $SO_4 \cdot HCO_3$-Ca·Na	536~2035
East Junggar basin	Depression	$Cl \cdot SO_4$-Na	1540~70066

with poor water-abundance. The total dissolved solids (TDS) of coal-bed water in the southeast Junggar basin is about 536-70066 mg/L, and the water type is mainly composed of $HCO_3 \cdot SO_4$-Na, $SO_4 \cdot Cl \cdot$HCO3-Na and $Cl \cdot SO_4$-Na. Among them, $Cl \cdot SO_4$-Na type represent the retention environment, and $HCO_3 \cdot SO_4$-Na type represent opening weak alternation environment, while $SO_4 \cdot Cl \cdot HCO_3$-Na represent closed weak alternating environment[29]. Comprehensive analysis shows that Liuhuanggou-Fukang regions in the southern Junggar basin and depression regions in the eastern Junggar basin are located in water retention area,which is good for CBM accumulation and preservation (Table 1).

4. Typical CBM enrichment models

4.1 CBM MODELS IN THE SOUTHERN JUNGGAR BASIN

4.1.1 Broad fold enrichment model

Broad fold enrichment model is mainly developed in the structural traps of Qingshui-River, Hutubi-River and Changji regions, which is mainly composed of anticline and syncline structures. Anticlinal core of this structure is easy to form sealing reverse faults due to structural compression, which can prevent CBM from escaping. Moreover, the south part of the syncline structure is subjected to the recharge of glacier melt-water. Synclinal core is the groundwater retention area, which is favourable area for CBM enrichment, with large burial depth and high degree of coalification (Fig.7).

4.1.2 Northward monocline enrichment model

Successful development of biogenic methane gas in the margin of Power River basin provided a reference for CBM enrichment and accumulation of northward monocline in the southern Junggar basin [4]. Influenced by many glaciations and North Tianshan snowmelt, shallow coal seam is easy to form low-salinity and low-salinity formation water, which is beneficial to the propagation of methanogens and the formation of secondary biogenetic gas. Owing to the continuous water supplement, coal-bed water carrying biogenetic gas tends to migrate towards deep monocline and form CBM reservoir. Overall, CBM accumulation is mainly controlled by

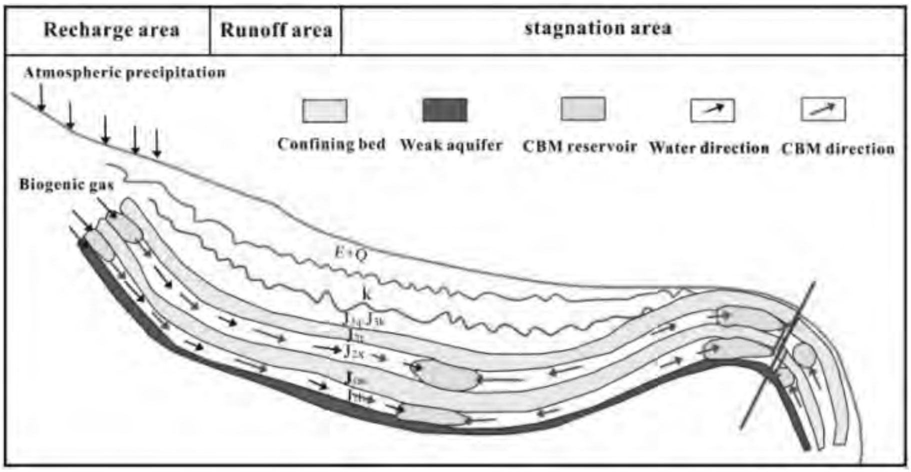

Fig.7 Broad fold enrichment model in the southern Junggar basin

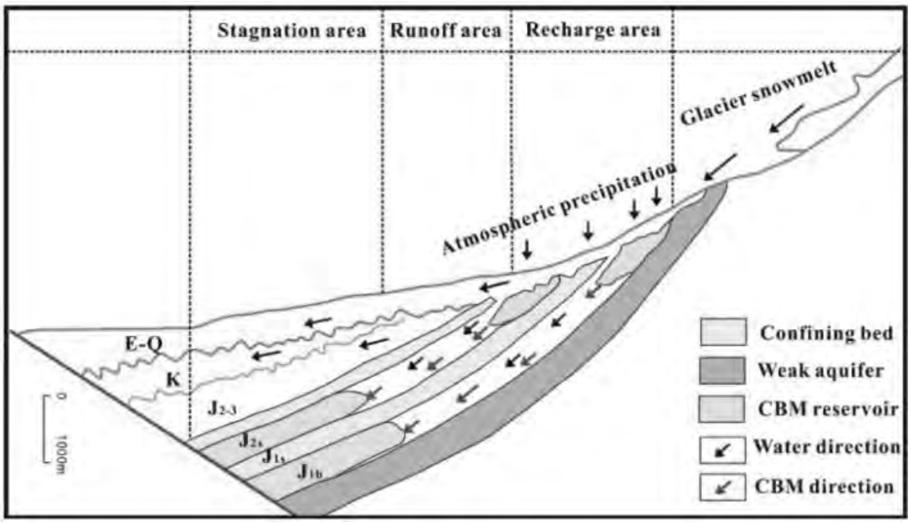

Fig.8 Northward monocline enrichment model in the southern Junggar basin

hydrodynamic conditions, and the south wing of monocline receives the water supply from surface water and snowmelt (Fig.8). Given this, hydrodynamic conditions of the monocline is divided into the recharge area, runoff area and stagnation area, and its stagnation area is good for CBM enrichment, with large TDS values and poor water mobility.

4.1.3 Overlying composite fold enrichment model

Composite anticline-syncline structure is mainly developed in Xishan region, whose structural framework is obviously affected by the Urumqi-Miquan strike-slip fault. The early tectonic pattern has been destroyed by the Himalayan movement, and this overlying composite began to form with multi-set anticlines and synclines (Fig.9). Researches show that multiple south-trend thrust faults are developed within the north wing of the structure, whose syncline core is beneficial to CBM preservation, due to strong tectonic stress and methane adsorption capacity.

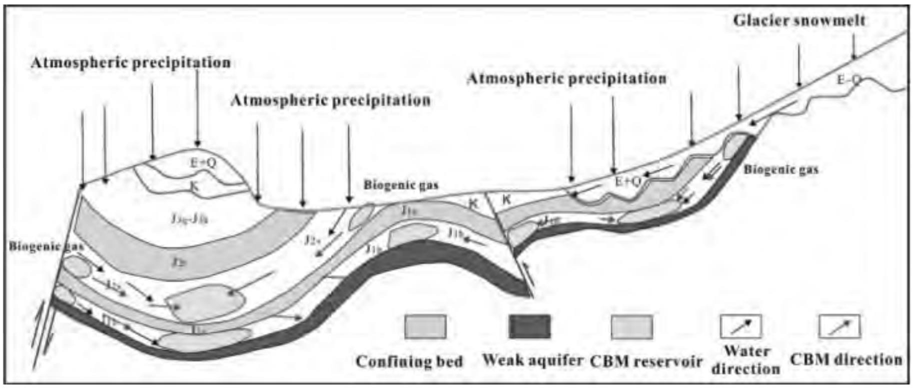

Fig.9 Overlying composite enrichment model in the southern Junggar basin

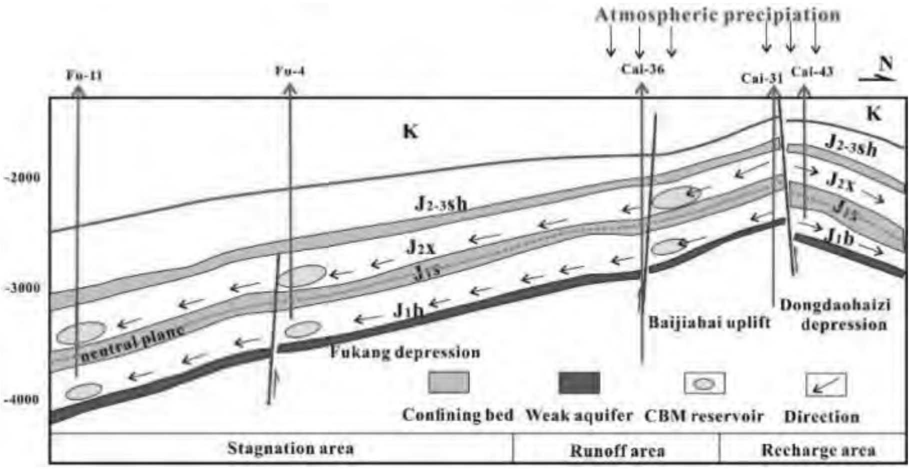

Fig.10 Sag-uplift transitional zone enrichment model in the eastern Junggar basin

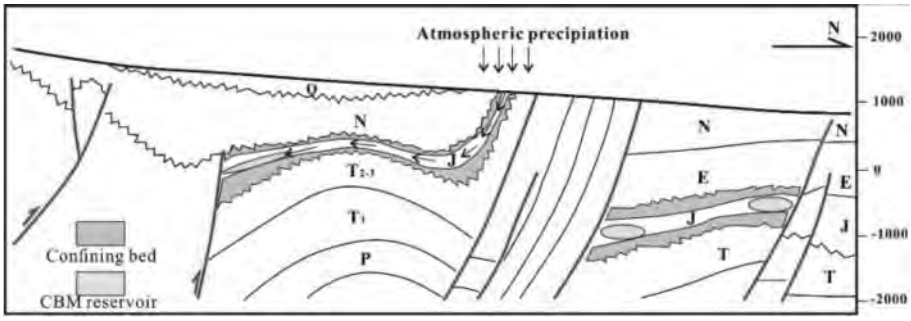

Fig.11 Fault depression enrichment model in the eastern Junggar basin

4.2 CBM Models in the eastern Junggar basin

4.2.1 Sag-uplift transitional zone enrichment model

The Jurassic coal-bearing strata existed in the uplift-depression tectonic pattern (i.e., chessboard type) in the eastern Junggar basin, and thick coal seams are mainly developed in depression areas, with few layers of coal seam and large single layer thickness. Hydrodynamic conditions are relative complex in the study area, while the TDS values increases obviously from uplift to depression, and methane content significantly increases too. Researches show that neutral plane of fold is located in the Sangonghe formation, which has an important controlling function for CBM enrichment. The Xishanyao formation locating in the upper part of neutral plane is obviously influenced by stretching stress, associated with a series of open faults. Consequently, surface water tends to migrate into deep depression, where CBM exploration are favourable areas, due to the joint sealing of hydrodynamic conditions and faults (Fig.10).

4.2.2 Fault depression enrichment model

Under the “chessboard type” tectonic pattern, several fault-folding tectonic zones are developed in the sub-mountain regions (e.g., Fukang and Shazhang fault-fold belts). The sealing faults develop well in these areas, which is good for CBM enrichment. Moreover, the outcrops of the Jurassic strata are easy to receive atmospheric precipitation, and hydrological units are also divided into the recharge area, runoff area and stagnation area. A deeper tectonic position is beneficial to form CBM reservoir under the joint sealing of hydrodynamic conditions and faults (Fig.11).

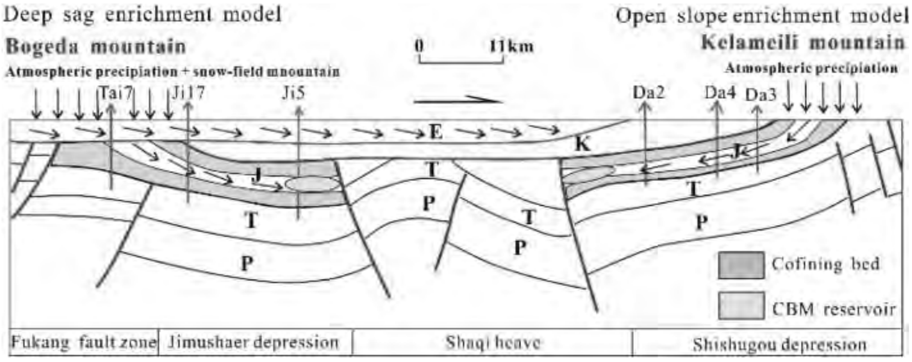

Fig.12 Deep sag and open slope enrichment models in the eastern Junggar basin

4.2.3 Deep sag enrichment model

Rift structure with strong tectonic deformation is widely developed in the west side of the Fukang fault zone of the Bogda piedmont, whose deep sag is good for CBM enrichment because of the hydrodynamic sealing effect (Fig.12).

4.2.4 Open slope enrichment model

Tectonic movement is so strong in the piedmont area of Kelameili mountain that the Jurassic stratum has been uplifted and disintegrated. Most of the Jurassic coals are exposed directly, and the shallow coal-bed gases are easy to escape from coal reservoirs. Moreover, coal-bed water is mainly supplied by intermittent atmospheric precipitation, which only forms temporary hydrodynamic sealing effects. Overall, open slope is not good for CBM accumulation, showing as low CBM content and deep methane weathering zone (Fig.12).

Comprehensive analysis of structural types, coal development and hydrogeology, indicates that the key factors controlling CBM enrichment are fault sealing and hydrodynamic sealing in the southeast Junggar basin. The Xishanyao coal developed in synclinal structure is the most beneficial to CBM enrichment in the southern Junggar basin, due to suitable development of coal seam and hydrological condition. Moreover, the transition regions from uplift to depression is easy to form a united sealing to CBM resources within hydrodynamic force and fault development, and beneficial to CBM enrichment in the eastern Junggar basin.

5. Evaluation result and distribution of CBM favourable areas

5.1 Establishment of mathematical evaluation model

The geological factors influencing on enrichment conditions of CBM are extremely complex, and the simple evaluation model cannot reflect practical situation of CBM production potential[11]. Therefore, multi-level mathematical models were often used to carry out quantitative evaluation of CBM exploration potential [30], [31]. Combined with the fuzzy mathematics method, a three-level evaluation model suitable to CBM potential evaluation of the southeast Junggar basin is established and discussed as follows.

5.1.1 Optimization of the evaluation parameters and their weight calculation

Based on the analysis of CBM enrichment conditions of the southeast Junggar basin, CBM high-production condition is treated as the ultimate goal. Resource, occurrence and development conditions are thought to be secondary evaluation indicators. Moreover, 9 geological parameters are chosen as the three-degree evaluation indexes, e.g., gas content, coal thickness, vitrinite content and coal rank, etc. After the determination of geological parameters, their weights are calculated using judgment matrix (Table 2).

5.1.2 The membership calculation

This paper learns from the past member accessor methods about CBM fuzzy evaluation, and provides a new member computing scheme that is suitable to the southeast Junggar basin (Table 3). Among them, the evaluation parameters are divided into good, medium and poor, according to their influences on CBM enrichment and accumulation.

5.1.3 Mathematical model establishment

In order to precisely difine to CBM exploration potential of the southeast Junggar basin, we have established the multi-level mathematical model in this paper. CBM enrichment and high- production index U_i (0-1.0) can be calculated using this model, and the higher value of U_i indicates more favourable

TABLE 2: THE EVALUATION PARAMETERS AND THEIR WEIGHT IN THE SOUTHEAST MARGIN OF THE JUNGGAR BASIN

Secondary indicator and its weight	Evaluation parameters	Weight
Resource conditions (A_1) 0.36	Gas content (A_{11})	0.34
	Coal thickness (A_{12})	0.28
	Vitrinite content (A_{13})	0.16
	Coal rank (A_{14})	0.22
Occurrence conditions (A_2) 0.30	Langmuir volume (A_{21})	0.33
	Langmuir pressure (A_{22})	0.17
	Porosity (A_{23})	0.23
	Permeability (A_{24})	0.27
Development conditions (A_3) 0.34	Burial depth (A_{31})	0.35
	Roof lithology (A_{32})	0.26
	Hydrology (A_{33})	0.17
	Structure condition (A_{34})	0.22

Table 3: The member standards of the evaluation parameter in the southeast Junggar Basin

Secondary indicator	Parameter	Weight	Good ($0.7 \le A_{ij} \le 1.0$)	Medium ($0.3 < A_{ij} < 0.7$)	Poor ($0 \le A_{ij} \le 0.3$)
Resource conditions	Gas content (m^3t^{-1})	0.1224	≥5	2~5	≤2
	Coal thickness/m	0.1008	≥40	20~40	≤20
	Vitrinite content/%	0.0576	≥70	40~70	≤40
	Coal rank/%	0.0792	≥0.7	0.4~0.7	≤0.4
Occurrence conditions	Langmuir volume (m^3t^{-1})	0.0990	≥20	8~20	≤8
	Langmuir pressure/MPa	0.0510	≥4.5	3~4.5	≤3
	Porosity/%	0.0690	≥10	3~10	≤3
	Permeability/$10^{-3}mm^2$	0.0810	≥5	1~5	≤1
Development conditions	Burial depth/m	0.1190	1500~2000	1000~1500	≤1000
	Roof lithology	0.0884	Mudstone	Sandy mudstone	Sandstone
	Hydrology	0.0578	Weak hydrodynamic	General hydrodynamic	Strong hydrodynamic
	Structure condition	0.0748	Less fault	More fault	Very many fault

CBM exploration potential.

$$U_i = \sum_{i=1}^{3} \sum_{j=1}^{4} A_{ij} \cdot X_{ij} \quad \text{... (1)}$$

where, U_i is CBM enrichment and high- production index; A_{ij} is the weight of evaluation parameter; X_{ij} is the membership of evaluation parameter.

5.2 Optimization of CBM exploration targets

The statistics about gas content, coal thickness, vitrinite content and coal rank collected from each block of the southeast Junggar basin, was plugged into Eq(1), and seven CBM prospective targets had been optimized in this paper (Fig.1). Moreover, exploration potentials of these seven favourable areas were ordered following the value of U_i, i.e., Fukang region (0.8663)> Liuhuanggou region (0.8483)>Qigu region (0.7800)> East-hutubi region (0.7325)>Qinshuihe region (0.7223)>Shazhang region (0.6818).

Overall, CBM exploration potentials of the southern Junggar basin are better than the eastern Junggar basin, and Liuhuanggou and Qigu favourable areas should be the key replacing areas for CBM exploration in the Junggar basin.

6. Conclusions

(1) The structural complexity of the Jurassic stratum in the eastern Junggar basin is obviously greater than that of the southern regions, where several tectonic types have more complex tectonic controlling effects. Roof lithologic characters of coal seam are greatly affected by depositional environments in the southeast Junggar basin, which are mainly composed of coarse-grained sandstone (e.g., Wusu. Hutubi , Manasi and Shazhang regions), and followed by fine-grained mudstone (e.g., Liuhuanggou and Fukang regions). The relations between gas content and its roof litholoy indicate that sandy roof is not only beneficial to creat tight gas reservoir, but also can form a effective sealing to its underlying seam. This study shows that the hydrodynamic stagnation areas of Liuhuanggou-Fukang regions in the southern Junggar basin and depression regions in the eastern Junggar basin are beneficial to CBM enichment and preservation.

(2) CBM enrichment models can be divided into seven types in the southeast Junggar basin, i.e., broad fold, northward monocline and overlying composite fold models in the south regions, and sag-uplift transitional zone, fault depression, deep sag andopen slope models in the east regions, respectively. These models have different developmet degree and various controlling mechanism of CBM enrichment in the study area. Among them, the Xishanyao coal developed in synclinal structure is the most beneficial to CBM enrichment in the south regions, due to sutiable development of coal seam and hydrological condtion. Moreover, the transition region from uplift to depression is easy to form a united sealing for CBM resources within hydrodynamic force and fault development, and is beneficial to CBM enrichment in the east regions.

(3) Combined with the fuzzy mathematics method, three-level evaluation parameters suitable to the southeast Junggar basin are selected to establish CBM enrichment and high-production mathematical model in this study. Then, seven CBM prospective targets have been optimized (i.e., five in the south regions and two in the east regions). Contrastive analysis of CBM enrichment and high-production index U_i indicates that Liuhuanggou and Qigu favourable areas should be the key replacing areas for CBM exploration in the Junggar basin.

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