New understanding of tight sandstone gas resource and the future development potential In China

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Abstract: In recent years, tight sand gas has become one of the focuses of world's natural gas exploration. With the in-depth exploration, the accumulation theory was constantly improved. But because of the geological complexity and various reservoir types, it is still difficult to interpret the accumulation mechanism of tight sand gas systematically. Combined with the analysis of basin evolution, tectonic and sedimentary evolution and simulation experiment etc. it is thought that there are three main accumulation mechanisms, including the Large Area Tight Sandstone Gas in Cratons, tight Sandstone Gas in Rift Basins and foreland Basin Tight Sandstone Gas. Their similarities are the tight sands contacting closely with source rocks, the sand being very tight and the sweet spot being very enrichment; their differences are shown in the conducting conditions, capping mechanism, migration and accumulation characteristics etc. The characteristics of large-scale tight sandstone are near distance seam hole mesh conducting, reservoir and seal double block and large scale gathered; the latter two are with fracture aperture conducting, high quality seal cover, block or anticline tectonic control play. China's tight sandstone gas favorable exploration area is about 560,000 square kilometers, with geological resource of 37.8 trillion cubic meters. The study of the theory, exploration and development technology of large-scale of tight sandstone gas are more mature, with geological resource of 30.4 trillion cubic meters. It has the basis and potential for accelerating development. Sichuan Xujiahe formation and upper palaeozoic of Ordos basin are the realistic key exploration zones; Jurassic of Kuqa northern section, TuhaTaipei and the south of Junggar basin are the next favorable exploration zones.

Key Words: Tight sandstone; Accumulation theory; New Progress; Favorable zones.

1 Concept and Development Profile of Tight Sandstone Gas

China attaches high importance to tight gas exploration & development and PetroChina is the leader in the tight sandstone gas field. An industry standard on the geological assessment method is established for tight sandstone gas in 2011. Tight sand gas is matrix permeability under overburden pressure less than or equal to 0.1mD of sandstone gas layers. Generally there is no natural productive capacity or the natural productive capacity is less than the lower limit of industrial gas flow for single wells, however natural gas can be obtained under certain economic conditions and technical measures. Typically, these measures include fracturing, horizontal wells, multi- lateral wells , etc.

The tight sandstone gas reserves and production in China account for around 30% of the total. By the end of 2012, the proved geological reserves of gas in gas layers was 9.01 trillion m^3, including 33.1% tight sandstone gas and the production of gas in gas layers was 97.81 billion m^3, including 27.17% tight sandstone gas. the two major gas provinces of the Upper Paleozoic of Ordos Basin and Xujiahe Formation of Middle Sichuan in Sichuan Basin are formed.

2 New Progress in the Theory of Tight Sandstone Gas Accumulation

Through exploration and development in recent years, it is concluded that China's tight sand stone gas can be divided into three types, namely large area tight sandstone in craton basin, deep layers in rift basins and deep layers in foreland thrust fault belts.

2.1 Large Area Tight Sandstone Gas in Cratons

Large area tight sandstone gas formation mechanism are source and reservoir mutual superposition, overpressure dynamic filling, Fracture-pore meshwork texture transporting and reservoir tight sweet spot enrichment (Table1). The basic geological conditions are that sources and tight reservoirs mutually or closely superposed make the gas supply sufficient. So the characteristic of large area tight sandstone gas is reservoirs tight before accumulation. Overpressure dynamic filling and micro fractures–pore connecting ensure mass gas into the dense reservoir. Dense reservoir damping effect limits the natural gas migration and lost. Reservoir property is good and sweet spot is very enrichment. The sweet pot property better block is rich gas zones with high productivity.

Table 1 Large Area Tight Sandstone Gas in Cratons geological features

Factors	Theoretical Meaning	Characteristics
Geological Settings	Source and reservoir mutual superposition	Coal-bearing source rocks are all over the basin with sand bodies distributed in large areas, sources and reservoirs mutually or closely superposed.

Transporting Conditions	Fracture-pore meshwork texture transporting	Filling mainly with hydrocarbon generation overpressure as the power and diffusion pattern; faults, fractures and pores form a fracture-pore meshwork transporting system
Seal Mechanism	Reservoir and caprock dual blocking	Getting tight first and then accumulating, spreading and migrating in non-linear flows, reservoir capillary force participating in blocking and large area accumulation
Migration and Accumulation Characteristics	Hydrodynamic trap accumulation	The range of overpressure power filling, pressure gradient control accumulation
Enrichment Conditions	Near source high-efficiency enrichment	Short distance gathering and accumulation with high migration and accumulation coefficients
Exploration Ideas	Searching for high-efficient reservoirs in large scale	Changing from structural gas reservoirs to lithological gas reservoirs in large area
		Changing from searching for sand bodies to searching for dominant areas in large scale (dominant factor superposition such as sources, reservoirs, local structures and fractures etc.)

Typical gas reservoirs- Upper Paleozoic in Ordos Basin. Large-scale delta sand bodies and coal-bearing source rocks are mutually superposed, laying a foundation for the formation of major gas fields with large areas(Fig1).The coal-bearing hydrocarbon source rocks of the Upper Paleozoic are all over the basin. Large scale gentle slope type braided stream deltaic deposit sand bodies are developed with a distribution area of 210,000 km ^{2}.

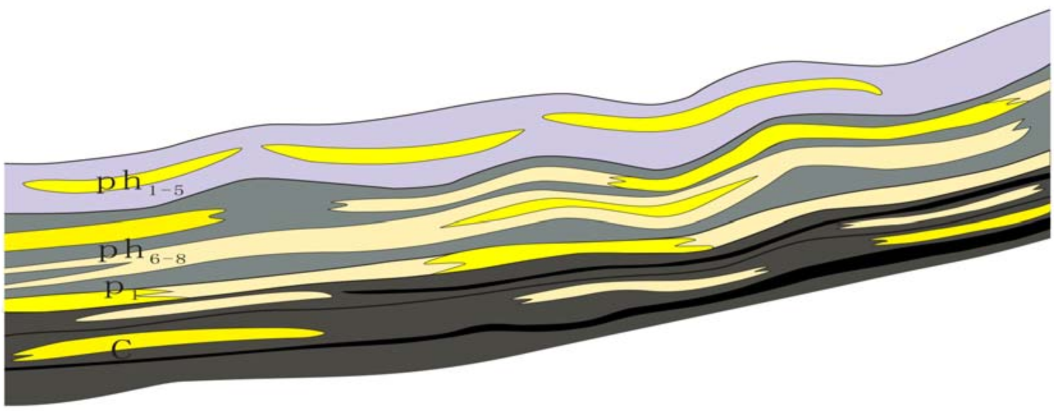

Fig. 1Craton Large Area Tight Sandstone Gas Accumulation Mode , Upper Paleozoic in Ordos Basin

The fracture-pore meshwork type transporting system has provided a predominate passage for large area gas accumulation in tight sandstone(fig.2). According to field outcrop, core, thin section and seismic data interpretation, it is considered that the interlayer fractures of mudstone cooperated with pores and fractures of sandstone effectively to form the favorable meshwork type transporting system.

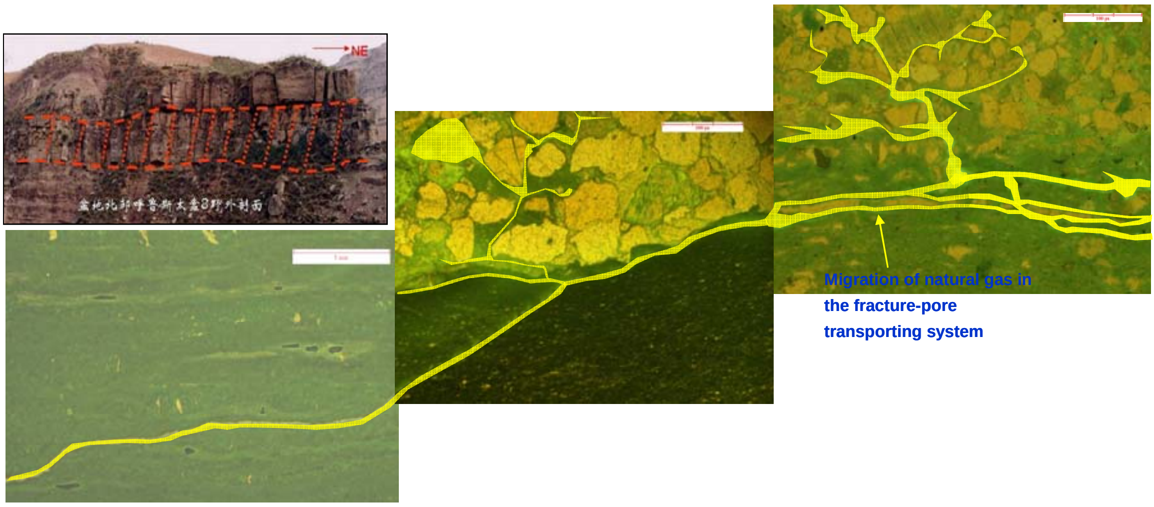

Fig.2 Migration of Natural Gas in the Fracture-pore Meshwork Type Transporting System

The palaeo overpressure was mainly formed by hydrocarbon generation, and the overpressure for hydrocarbon generation was an important power for gas filling tight sandstone. Jurassic-Cretaceous was an important period during which the hydrocarbon source rocks of the Upper Paleozoic in Ordos Basin got into the high mature to post-mature stage and also an important period when the overpressure was formed.

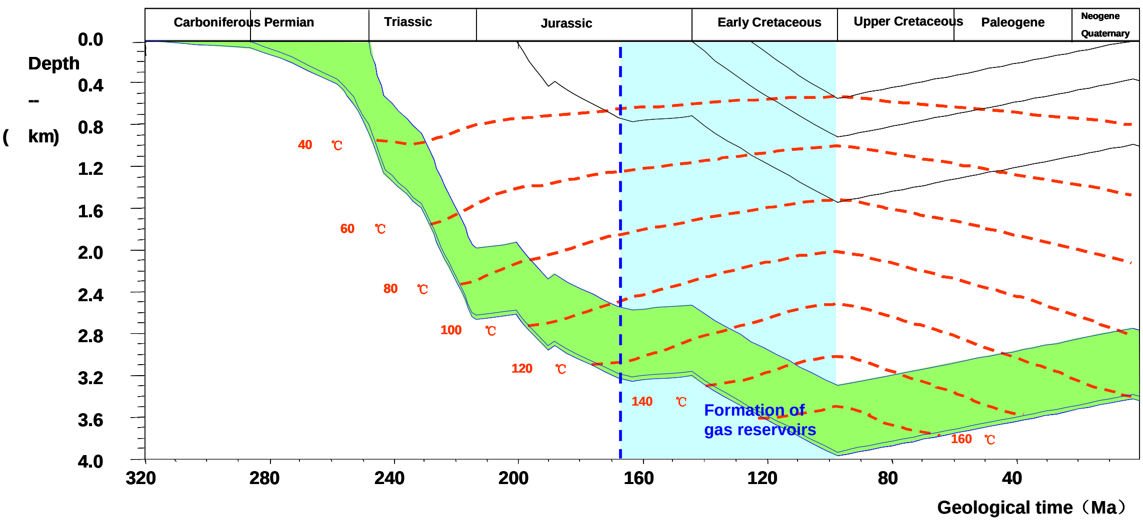

Fig2 鄂尔多斯盆地埋藏演化史图

Fig.3 Single well burial thermal evolutionary history chart of the Upper Paleozoic in Ordos Basin

The understanding on accumulation has played an important guiding role in the fast development of Sugeli gas field industrialization. Accumulative proved reserves in Sugeli gas field is 1.3 trillion m^3 and accumulative Proved, Probable and Possible Reserves exceed 4 trillion m^3. 17 billion m^3 tight gas was produced in Sugeli, accounting for 17.3% output in China, in 2012. In addition, satisfactory exploration results were obtained in the southeast and the southwest of the basin with good exploration prospects.

2.2. Tight Sandstone Gas in Rift Basins

Comparing with the tight gas in craton basins, they have major differences on transporting, sealing, migration and accumulation etc (Table2).

Table2 Tight Sandstone Gas in Rift Basins geological features and comparison

Key Factors	Craton gentle background tight sandstone gas reservoir	Rift basin deep layer tight sandstone gas reservoir
Geological Settings	Source and reservoir mutual superposition	Source and reservoir adjacent contact
Transporting Conditions	Fracture-pore meshwork texture transporting	Fault fracture-pore transporting
Seal Mechanism	Reservoir and caprock dual blocking	Mudstone interlayer sealing
Migration and Accumulation Characteristics	Hydrodynamic trap accumulation	Fault & lithology reservoir control
Enrichment Conditions	Near source high-efficiency enrichment	Fault high-efficiency enrichment
Regularities of Distribution	Near source large scale tight sandstone	Ring & groove tight glutenite bodies

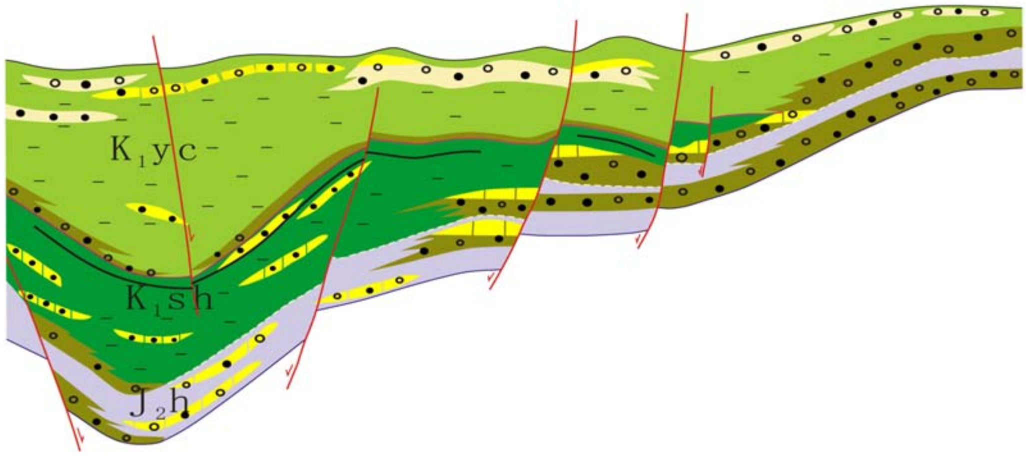

Fig. 4 Rift basins tight sandstone gas accumulation mode, Songliao Basin

Typical deep layer gas reservoir in Songliao Basin(fig.4). The deep layer glutenite reservoirs are tight, but their compression resistance and developed fractures provided important reservoir space. The glutenite bodies have large thickness and they are distributed around the periphery of the sags. The reservoir space is dissolution pores, fractures close to grains and intergranular pores. The main glutenite bodies are distributed below 3000m. They are tight but their physical properties are distributed widely. There are still good reservoirs near 5000m. Faults and fractures are predominate transporting passages. Faults and lithological traps are important gathering locations. Exploration target screening and well site selection were guided for deep layer glutenite in Songliao Basin under this mode, and new discoveries were gotten. Deep layer glutenite gas fields such as Changshen, Xushen and Yingtai etc. were discovered with proved reserves of 100 billion m^3.

2.3. Foreland Basin Tight Sandstone Gas

Tectonic activities were strong and stratigraphic dips were large in foreland basins, where faults, structures and fractures were developed (Table 3).It has high requirements on preservation conditions and trap conditions.

Table3 Foreland Basin Tight Sandstone Gas geological features and comparison

Key Factors	Craton gentle background tight sandstone gas reservoir	Rift basin deep layer tight sandstone gas reservoir	Foreland thrust fault belt deep layer tight sandstone gas reservoir
Geological Settings	Source and reservoir mutual superposition	Source and reservoir adjacent contact	Source and reservoir adjacent contact
Transporting Conditions	Fracture-pore meshwork texture transporting	Fault fracture-pore transporting	Fault & fracture transporting
Seal Mechanism	Reservoir and caprock dual blocking	Mudstone interlayer sealing	Gypsum and mudstone interlayer sealing
Migration and Accumulation Characteristics	Hydrodynamic trap migration & accumulation	Fault & lithology reservoir control	Structure & lithology reservoir control
Enrichment Conditions	Near source high-efficiency enrichment	Fault high-efficiency enrichment	Anticline high-efficiency accumulation
Regularities of Distribution	Near source large scale tight sandstone	Ring & groove tight glutenite bodies	Relative high-position tight sandstone

Typical gas reservoir-Jurassic system in Kuche Basin(fig.5). With the fractures forming in reservoir after getting tight, tight gas quickly accumulated. The reservoir were strongly controled by the actions of structures, faults and fractures in late stage. The gypsum rocks and mudstone without faults became important ensurance for natural gas preservation and tectonic lithological traps were favorable gathering locations. The accumulation of tight sandstone gas in foreland basins is reflected by the characteristics of fault and fracture transporting, structural reservoir control and anticlinal zone enrichment.

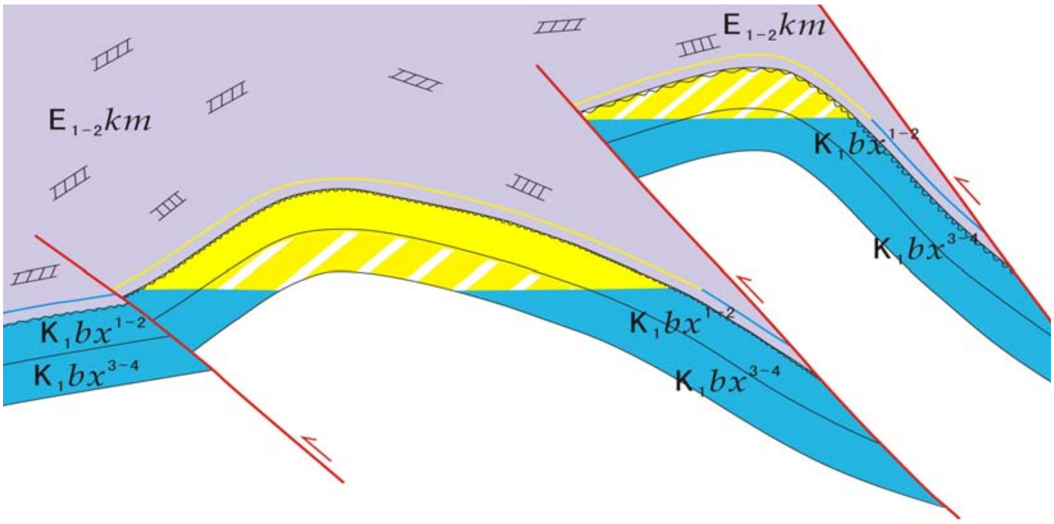

Fig. 5 Foreland basin tight sandstone gas accumulation mode, Kuche basin

4 Tight Sandstone Gas Exploration Potential and Field

Tight gas resources in key field are estimated to be 32.44 trillion m^3 by calibration area method or by migration & accumulation coefficient method. So we think it’s very promising for exploration and development.

Table 4 Tight sandstone gas resource assessment of key field

Basin	Basin Area (10000 km^2)	Exploration Area	series of strata	Gas-generating quantity	Migration & accumulation	Amount of geological resources		
		(10000 km^2)		(trillion m^3)	coefficient	(trillion m^3)		
						5%	95%	50%
Ordos	25	10	C-P	563	2-5%	9.01	22.52	15.76
Sichuan	18	8	T3x	406	2-3%	6.5	9.74	8.12
Songliao	26	3	K1	233.8	2-3%	2.34	3.51	2.92
Tuha	5.5	2	J	16	2-5%	0.32	0.81	0.57
Tarim	56	3.5	J	195	2-3%	3.95	7.73	4.72
Total	148.5	36				22.4	43.73	32.44

Conclusion

A boom period for natural gas industry is coming. Because of the exploration targets increasingly getting more and more complex, tight gas has become one of the major resources for natural gas development. Great achievements have been made in craton basins for tight gas exploration & development, but in rift basins and foreland basins it is still in the early stage. So strengthening researches on theoretical study and attaching importance to exploration & development technical for tight gas are still important tasks in recently.