New Progress of China Natural Gas Exploration Practice and New Recognition on Resources Potential

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Key words: China natural gas; new exploration progress; new knowledge on geological theory; resources potential; new field for future exploration

1. Research background

Natural gas accounts for a large proportion in the consumption pattern of primary energy, but the average consumption level of natural gas in China is lower than the world average level. It is an urgent task to change the energy consumption pattern of China. In recent years, the output of natural gas in China in growing rapidly and predicted to reach 130 billion cubic meters by 2020. Regardless of the fast increase of natural gas demand domestically, the overall output can not still satisfy the domestic demand and the nation has to highly depend on foreign countries. With the gradual improvement of the exploration degree and the deeper understanding on geology, low-permeability-dense sandstone lithology, marine carbonate, deep layer of thrust belt of foreland basin, volcanic gas reservoir in large area and other fields are becoming the main fields of natural gas exploration in China. Therefore, it is urgent to strengthen the research on gas hydrate reservoir accumulation and exploration technology of key gas fields in China, which is significant for implementing the natural gas potential of China and defining the exploration direction of gas field. Meanwhile, the coal seam gas, shale gas and other unconventional natural gas resources are abundant in China but remain in the initial development period. With the gradual improvement of exploration technology and deeper understanding on geology, the exploration field will be expanded gradually and new breakthrough will be made in the new area with low awareness, new field and series of strata which will be developed alternatively.

2.Research purpose

The fast development of China natural gas industry and low-carbon economy poses a higher demand on strengthening the exploration of domestic natural gas resources. In recent years, dramatic results on China natural gas exploration have been achieved gradually and new breakthrough and discoveries are obtained on low-permeability sandstone, marine carbonate, volcanic rock, biogas in large area and other fields. Three large gas fields in one trillion cubic meters including Sulige, Chuanzhong Xujiahe and Kuga depression have been formed at present with fast development trend. New challenges exist at the same time: ① with the improvement on exploration and understanding, great changes have taken place in the natural gas resources in some key exploration fields and the natural gas resources potential needs assessing again. ② dense gas sand, carbonate gas, volcanic rock gas and biogas have become the main object for natural gas exploration in China. Some vital geological problems such as the accumulation mechanism of continuous gas reservoir are to be resolved. ③ By the exploration practice in Sichuan, Ordos Basin and other key gas fields, the

accumulation rule of gas field needs recognizing again so as to guide the implementation of more beneficial exploration targets. Therefore, new progress obtained in China natural gas exploration practice needs summarizing systematically, the resources potential of China natural gas needs recognizing again and the exploration field and direction of gas field in the future need defining, so as to increase the reservoir and production. It plays a significant role in the continuous, fast and favorable development of China natural gas industry and strengthening the capacity of natural gas supply guarantee.

3.Research ideas

By developing theoretical research on the natural gas geology, the main control factors and accumulation rules for the formation of gas field are summarized on the basis of analyzing the gas formation mechanism of coal formed gas, crude oil cracked gas and biogas, assessment of resources potential, formation and distribution prediction of high quality reservoir of large gas field and various types of gas fields, so as to deepen understanding, develop and improve the geological theory of China natural gas, implement the resources potential of China natural gas and assess and select the superior one to seek for the favorable exploration area and target of gas fields in the future.

Resources strategy was highlighted in CNPC since 2006 and a series of major measures have been taken to strengthen oil gas exploration from all dimensions particularly accelerating the steps of natural gas exploration, resulting in the new progresses in natural gas exploration and entering an unprecedented fast development period. Many major results with strategic significance and a batch of high quality reservoirs in large batch have been obtained to realize the sustainable and fast growth of natural gas reserves.

On the basis of analyzing the development trend of China natural gas, the article has summarized the new progress and results for the exploration of China petroleum and gas in 2006-2010. As the comprehensive analysis shows, the main exploration direction for the discovery of large gas fields in China in future is the new field of sandstone rock reservoir, marine carbonate, gas reservoir in deep structure of thrust belt of foreland basin, volcanic rock gas reservoir, coal seam gas, shale gas and other unconventional natural gas.

4.Research results

New results and progresses have been obtained in natural gas exploration of CNPC and the increase of natural gas reservoir enters fast development period. A batch of target areas in scale reservoir has been discovered and explored and six main exploration areas for natural gas exploration have been formed. The sandstone lithology, marine carbonate, foreland basin, volcanic gas reservoir in large area in Ordos Basin, Sichuan Basin, Tarim Basin, Qaidam Basin, Songliao Basin and Junggar Basin and other exploration fields have become the main fields for the discovery of gas field for CNPC in future while biogas and unconventional gas are the important alternate field for the discovery of gas for CNPC in future.

4.1 New progress on natural gas exploration of CNPC

4.1.1 The increase of natural gas reservoir enters new period for fast development

The geological reserves of the newly explored natural gas of CNPC remain in fast increase in 2006-2010 continuously (Figure 1) with the accumulative reserves of 2.14 trillion cubic meters.

The geologic reserve of the newly explored natural gas is 0.42trillion cubic meters annually and it is the period for the fastest increase of the explored natural gas reserves along the history of CNPC. The newly-increased reserves area of natural gas is mainly distributed in four exploration fields including sandstone lithology, marine carbonate, foreland basin, volcanic gas reservoir in large area.

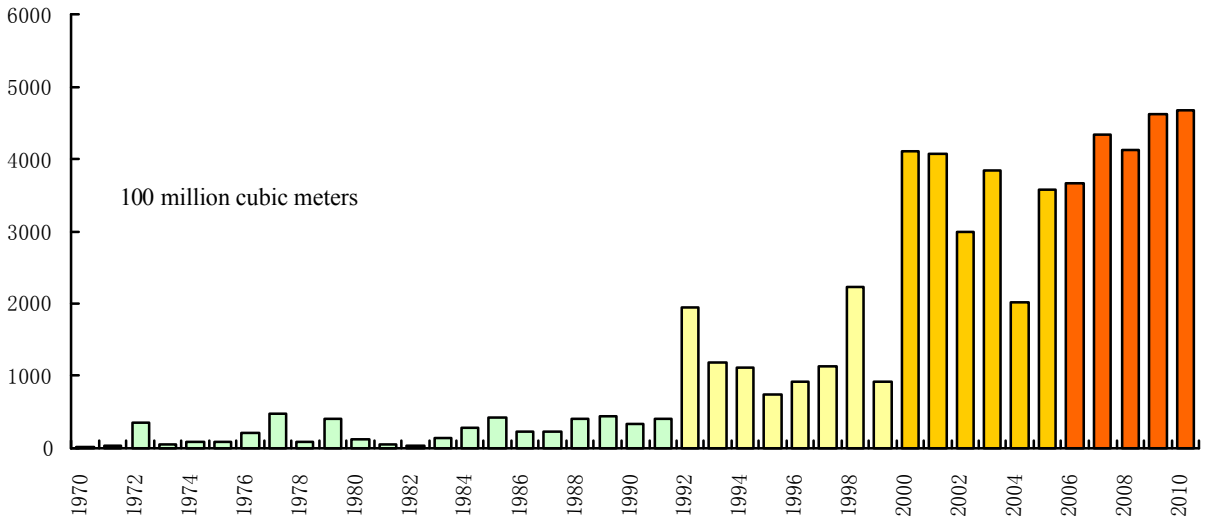

Fig.1 Time Diagram of Natural Gas Reserves Increase of CNPC

4.1.2 A batch of target areas in scale reserves has been discovered and explored

CNPC made major discoveries in natural gas exploration in Ordos, Sichuan, Tarim, Songliao and Junggar Basin and discovered and explored three reserves areas in one trillion cubic meters in Sulige, Kuqa and Chuanzhong Xujiahe as well as four reserve areas in 100 million cubic meters including Songliao deep layer, Tarim Tazhong, the east of Ordos and Ludong~Wucaiwan (3000~5000) in 2006-2010. Also, it formed reserves in certain quantity is Longgang area of Sichuan Basin.

Sulige Gas Field---the largest domestic gas field was explored in Ordos Sulige Basin before 2004 and over 0.6trillion cubic meters of geological reserves of natural gas have been explored accumulatively. CNPC effectively developed Sulige Gas Field since 2005, started exploration in large scale in the surroundings of gas field in 2006, and focused on No. 1 area in the east and west of Sulige respectively in 2007~2010 and strengthened the exploration of No. 2 areas in the east and west of Sulige instead of the southern part of Sulige. The Grade 3 geological reserves of newly-added natural gas are more than 2.8 trillion. Great discovery has been achieved in exploration and 3 trillion cubic meters of atmospheric zone has been formed.

In Kuche area of Tarim basin, Kela 2 gas field was discovered in 1989; high yield was obtained in Dabei 1 well in 1999 and Dabei 1 gas field was discovered; high yield was obtained in Dina 2 well in 2001 and Dina gas field was discovered; since 2006, CNPC strengthens to tackle key problems on broadened line and large combined seismic acquisition and handling of depth migration before stack for bottleneck technology which restrains exploration in this area, the quality of seismic data is improved obviously and implemented “five-story building” structural patterns in Kelasu structural belt; high yield was obtained in Dabei 3 well in 2007 and Dabei 3 gas reserve was discovered; high yield was obtained in Keshen 2 well in 2008 and important breakthrough was made in exploration of Keshen

structure; from 2009 to 2010, new progress was made in evaluation and exploration of Dabei gas field, and new breakthrough was made in exploration of Keshen structure. From 2006 to 2010, cumulative new grade III geologic reserve of natural gas is nearly 800 billion cubic meters and it is hopeful to form reserve area with scale of trillions of cubic meters.

Wide distribution of sand in Xujiahe formation in central Sichuan basin has favorable conditions to form large area of lithologic gas reservoir. After breakthrough of Guang'an 2 well in 2005, CNPC found its feet in Sichuan to discover large gas field and speed up exploration appropriately. Since 2006, Guang'an, Hechuan, Tongnan, Anyue gas fields and Yingshan, Shehong - Renshou and other favorable gas bearing areas are discovered successively, important achievements are obtained in exploration, the new grade III reserve is nearly 900 billion cubic meters, which displays good exploration prospect in Xujiahe formation of the basin and it is hopeful to form reserve area with scale of trillions of cubic meters.

The condensate gas reservoir in 62 Langlitage Formation of Tazhong was proved in Tazhong area in 2005; breakthrough was made in karstic reservoir bed of lower Ordovician Yingshan formation of slope at north of Tazhong in well 83 in 2006; for overall evaluation of Tazhong slope break belt I since 2006, cumulative newly proved geologic reserve of natural gas for karstic reservoir bed in upper Ordovician Langlitage formation is about 100 billion cubic meters; cumulative newly proved geologic reserve of natural gas for karstic reservoir bed in lower Ordovician Langlitage formation is about 300 billion cubic meters. "From 2006 to 2010, cumulative newly proved geologic reserve of natural gas is nearly 400 billion cubic meters and it is hopeful to form reserve area with scale of 500 billion cubic meters."

After breakthrough of volcanic rock in Xunshen well 1 in Xujiaweizi fault depression in northern Songliao Basin in 2002, CNPC speeds up exploration and development of deep natural gas and realizes leapfrog development of deep natural gas in north of Songliao basin; in 2005, high output of volcanic rock was obtained in deep well 1 of Changling fault depression and this began the deep natural gas exploration in southern Songliao basin. In 2008, high output of Longshen well 101 and 2 in Yingtai fault depression further proved good exploration potential of deep zone of southern Songliao basin. The exploration of volcanic rock made breakthrough and new discovery is made in glutenite exploration in deep zone. High-yield gas flow was obtained from deep horizontal well 32 of Xujiaweizi fault depression in 2009, and industrial gas flow was obtained in deep well 10 at east slope of Changling fault depression in 2010. From 2006 to 2010, total newly grade III reserve is 500 billion cubic meters and basically forms reserve area with scale of 500 billion cubic meters.

In 2007, new progress was made in Taiyuan formation exploration of Shuang 3 and Shen 15 well in Shenmu area of east of Ordos basin, Shenmu gas filed with reserve of thousands of billions of gas was found and proved, and total grade III reserve exceeds 200 billion cubic meters; in 2007, new progress was made in exploration of section 2 of mountain for Mi 16 and Shuang 25 well field in Yuxingzhuang area and total grade III reserve exceeds 100 billion cubic meters. From 2006 to 2010, cumulative newly proved geologic reserve of natural gas is nearly 300 billion cubic meters and it is hopeful to form reserve area with scale of 300~500 billion cubic meters.

In Ludong - Wucaiwan area of Junggar basin, high yield hydrocarbon flow was obtained in Carboniferous system in Dixi 10 well in 2004 and Dixi gas field was discovered. From 2005 and 2008, CNPC changed its thought with Carboniferous volcanic rock as key target to

strengthen exploration. In 2006, high output was obtained in Carboniferous system in Dixi 14 well in 2006. From 2007 to 2008, daily high-yield gas flow was obtained in Carboniferous system of five wells and Kelameili gas field was discovered and proved. From 2006 to 2010, cumulative newly proved grade III reserve is nearly 200 billion cubic meters and it is hopeful to form reserve area with scale of 300 billion cubic meters.

In 2006, two pore reservoir beds of Permian Changxing formation reef and oolitic beach reservoir of Permian feixianguan formation were found in Longgang well 1 in Longgang area. High yield gas flow was obtained through testing and this shows primarily the characteristics of large area, high abundance and lithologic gas reservoir. CNPC carried out large scale exploration. From 2006 to 2010, many wells in main part of Longgang area have industrial gas flow; and meanwhile industrial gas flow was obtained in Changxing formation reef of Jianmen 1, Longgang 61 and Longgang 62 well of West Jianmen – Jiulong Mountain area of Longgang , and industrial gas flow was obtained in Feixianguan formation of Long 16 well. Great achievement is obtained in overall exploration of Longgang area and forms a certain scale reserve.

4.1.3 Six main exploration areas for natural gas

Mining right area of CNPC has geologic resources amount of natural gas 30.3 trillion cubic meters. By the end of 2010, the cumulative identified natural gas geologic reserve is 5.7 trillion cubic meters, proved rate is only 18.8%, and the natural gas exploration is still in early exploration stage.

In recent years, CNPC has formed gradually six main exploration areas for natural gas in Ordos basin, Tarim basin, Sichuan basin, Qaidam basin, Songliao basin, Junggar basin. By the end of 2010, cumulative proved natural gas geologic reserve is 5.5 trillion cubic meters, accounting for 96% of total cumulative proved reserve of CNPC; in 2010, natural gas annual output of CNPC is 72.2 billion cubic meters, of which the annual output of six main exploration areas is 68.6 cubic meters, accounting for 95% of natural gas annual output of CNPC.

4.2 New knowledge on geological theory of natural gas in China

From 2006 to 2010, natural gas exploration of CNPC has such great achievements, mainly because of new knowledge on geological theory of natural gas in China and progress of exploration technology. In particular, the breakthrough new knowledge on geological theory guides effectively exploration of large gas fields of main gas bearing basin.

4.2.1 The high temperature hot pressing simulated test proves that coal and carbargilite still can produce another 20% natural gas in post mature stage to increase resource potential of natural gas for highly mature coal-measure source rock

The past maximum analog temperature for hydrocarbon generation is 600℃ (Ro approximately 2.5%) and it is believed that the gas generation capacity is depleted at such temperature. It can be seen from the evolutionary trend of coal kerabitumen and atomic ratio H/C that gas generation process of coal does not end and shall have great gas generation potential.

模拟温度	Stimulated temperature
产气率	Gas production rate
岩石	Rock
鄂尔多斯盆地太原组	Taiyuan formation of Ordos basin
准噶尔盆地侏罗系	Jurassic system of Junggar basin

鄂尔多斯盆地山西组	Shanxi formation of Ordos basin

The coal measure strata of coal and carbargilite are mainly the gas source rock. Simulated test is performed by selecting sore sample of Jurassic coal and Carboniferous carbargilite in Junggar basin and outcropping rock sample of Permian coal and carbargilite in Ordos basin. They are heated from temperature of 300 with temperature interval of 100 until 800 . The results show that the main gas generation stage of source rock is below 600 . This may be the main cause to set maximum test temperature of Rock pyrologger at 600 . However, the coal and carbargilite from two basins can produce large quantity of natural gas from 600 to 800 . This was not discovered or neglected before. To be specific, the coal from Ordos basin and Junggar basin may produce another 28.44%, 24.57% and 27.87% of natural gas in this stage (Figure 2) and the carbargilite from the two basins may produce another 25.38% and 34.39% of natural gas in this stage (Figure 3), and gas generation amount of coal and carbargilite in this stage accounts for 20%~35% of total gas generation amount. It can be seen from vitrinite reflectance corresponding to stimulated temperature (Figure 4) that the underground source rock with Ro=2.5%～5.0% still can generate over 20% of natural gas in total gas generation. This discovery may further increase resource potential of natural gas for coal measure stratum in high thermal evolution area and provide resources foundation for deep exploration.

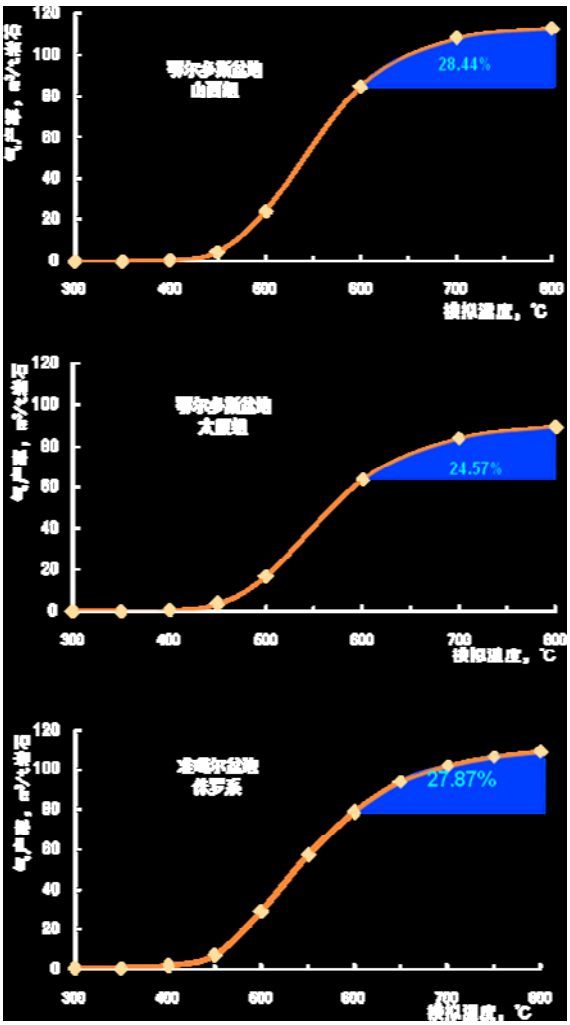

Figure 2 Stimulated Gas Production Rate Curve of Coal from Oerhtossu and Junggar Basin

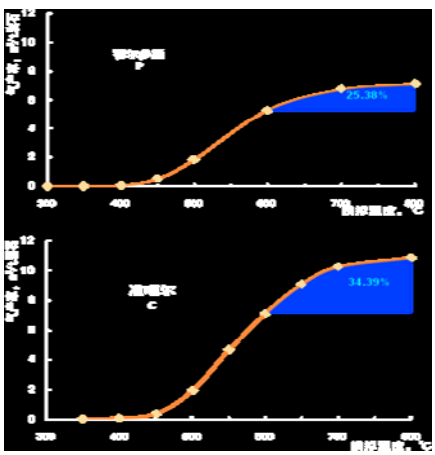

Fig.3 Stimulated Gas Production Rate Curve of Coal from Ordos Basin and Junggar Basin

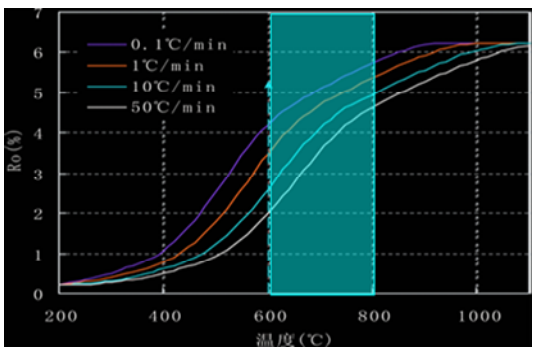

Fig. 4 Relation Diagram between Thermal Stimulated Temperature and Ro

模拟温度	Stimulated temperature
产气率	Gas production rate
岩石	Rock
鄂尔多斯	Ordos
准噶尔	Junggar
温度	Temperature

4.2.2 The research on reservoir mechanism of rapid burial, deep fluid corrosion, reservoir overpressure and structural fracture broke through the lower limit of deep clastic reservoir and extended the depth of exploration

It was believed in the past that Carbonate rock and volcanic rock reservoirs were less limited by the depth. In recent years, the research on the mechanism of deep clastic reservoir in China shows that clastic rock can also develop natural gas reservoir in the deep (Fig.5). The research provided the following four new results. (1) Rapid burial shows relatively weak diagenesis, and a part of primary pores are preserved; (2) In deep fluid solution, acidic fluid high temperature often dissolve particles to form secondary pores; (3) Reservoir overpressure is helpful for retaining original pores; (4) In structural fracture, multiphase tectonic often cause mesh pores.

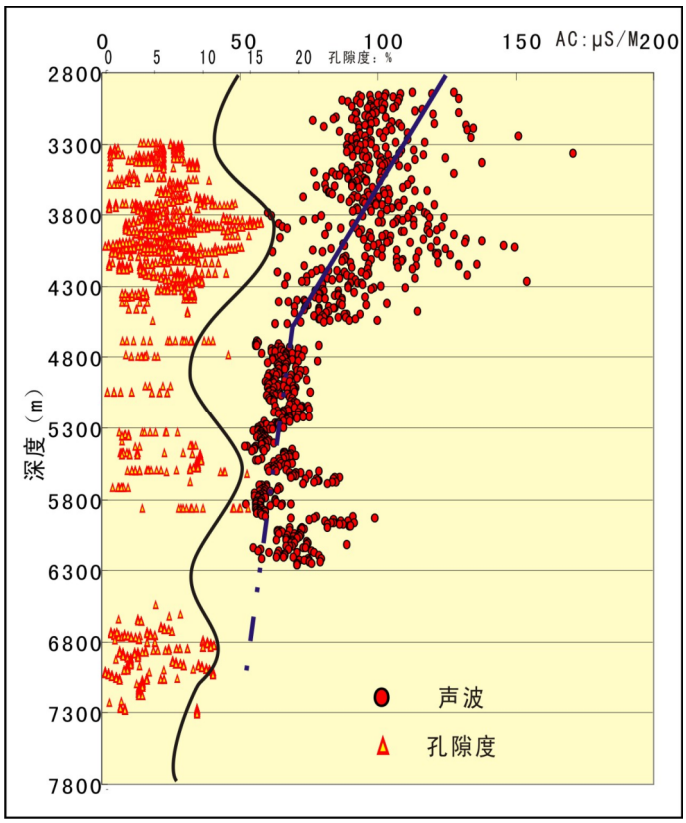

Fig.5 The relationship between Cretaceous porosity and acoustic wave in Kuche region

Deep clastic rocks in foreland basins in central and western China can form overpressure-fractured sandstone reservoirs (Table 1) due to rapid burial, reservoir overpressure and structural fracture. Based on this study, the depth of exploration in foreland basins in central and western China was increased by 1000-2500m, which directly led to the new discoveries of deep natural gas reservoirs in Kuche Depression of Tarim Basin, Turpan-Hami Basin and Sichuan Basin.

Deep clastic rocks in faulted basins in eastern China can form reservoirs of dissolved pore and fractured corrosion type (Table 1) due to highland temperature gradients and multiphase fluid corrosion. Based on this study, the depth of exploration in foreland basins in eastern China was increased by 1000-1500m, which effectively drove the new discoveries of deep and deep depression natural gas reservoirs in Qikou, Songliao Basin.

Table 1 Characteristics of deep clastic reservoirs in China

Deep areas	Previous exploration depth	Current exploration depth	Reservoir types
Cretaceous, Kuche region	5500-6000m	8000m	Over pressured fracture
Jurassic, Turpan-Hami	3500m	4500m	Over pressured fracture
Foredeep belt, Southwest Sichuan	4000m	5000m	Fractured corrosion
Deep layer, Songliao	4000m	5000m	Dissolved pore
Qikou Binhai region	3500-4000m	5000m	Fractured Corrosion

4.2.3 The dissection of typical gas reservoirs like Kela 2, Sulige, Wubaiti and Xushen shows that hydrocarbon source and sealing conditions are the main control factors on gas accumulation in large gas fields in China

Traditionally, the formation of natural gas reservoir follows the “source control theory” that only gas generation center and its periphery can gather natural gas reservoirs; in the areas far away from the center, as the loss rate of natural gas is much higher than that of oil, large-scale accumulation of natural gas needs enough gas supply volume and high gas supply rate which can ensure that the accumulation of natural gas is far more than loss in certain periods, so as to preserve and form large and medium-sized gas fields. But, according to the dissection of some typical gas reservoirs like Sulige, widely spread hydrocarbon generation of coal-bearing source rocks and low permeability-tight sandstone can form large gas fields by overlay each other, so large gas fields can also be formed in the periphery of the center, which further extend the “source control theory”.

Regional caprocks strictly control the formation and distribution of various types of large gas field. The significance of caprock in the accumulation and reservation of oil and gas has been widely recognized by geologists. After the in-depth research on different sedimentary basins and regional caprocks, many geologists have recognized that the thick and stably distributed regional caprocks widely spread in the entire Petroliferous basins or the primary formation significantly control the distribution of large gas fields. But in recent years, as the large area of tight sandstone gas was discovered, many experts tended to believe that tight sandstone could form a good cap. Further research found that the tight sandstone overlying on the large area of low-permeability sandstone could form effective caprock since it was controlled by the mudstone extensively developed on the near overlying formation. For example, the mudstone with thickness of 40-140m distributed on the Upper Paleozoic gas fields and their top areas in Sulige, Ordos Basin have close relationship. As shown in Fig.6, the depth of the overlying mudstone has been more than 3000 meters since gas filling period in Early Cretaceous, and it has shown strong accumulation effect and good capping capacity for the natural gas injected on the overpressure, so a large number of natural gas has been retained and accumulated. In general, the distribution of gas fields is strictly controlled by regional caprocks.

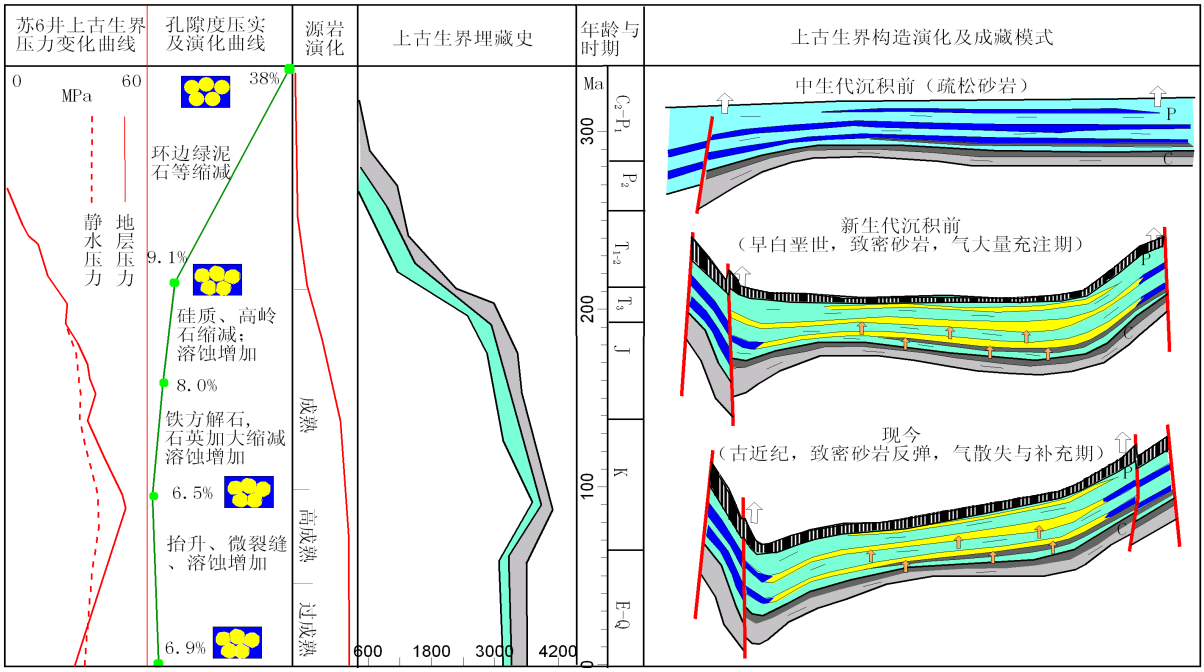

Fig.6 Distribution of regional caprocks and natural gas in large gas fields in China

4.3 Re-evaluation of the potential resources of oil and natural gas in China

New understanding of geological theories has effectively guided natural gas exploration in China, in turn, the great achievements made in natural gas exploration in recent years in China caused that the existing natural gas resources in main gas-bearing basins could not meet the need of exploration, so we had to re-evaluate potential natural gas resources.

4.3.1 The potential natural gas resources in main gas-bearing basins in China such as Sichuan, Songliao, Ordos and Tarim were re-evaluated, which resulted that the volume of the resources increased by 70％ comparing to the third resource evaluation

Based on the new understanding of geological theories, the deep structure gas reservoirs in Kuqa depression in Tarim Basin, the Upper Permian - Lower Triassic reef gas reservoirs in Sichuan basin, the lithologic gas reservoirs in Xujiahe, the Upper Paleozoic large area lithologic gas reservoirs in Ordos basin, the deep volcanic rock and Conglomerate gas reservoirs in Songliao basin and other potential natural gas resources were re-evaluated. The oil and gas resources after the re-evaluation increased by 12 trillion m^3(Table 2), 70％ more than the results of the third oil and gas evaluation in 2005.

Table 2 Comparison of the resource evaluation results in major natural gas exploration fields of CNPC

Basins	Exploration field	The third evaluation （$10^{12}m^3$）	Latest evluation （$10^{12}m^3$）	Increase （$10^{12}m^3$）
Sichuan basin	Upper Permian - Lower Triassic reef gas reservoirs	2.1	2.9	0.8
	lithologic gas reservoirs in Xujiahe	0.9	5.6	4.7
Songliao basin	Volcanic rock and Conglomerate gas reservoirs	2.0	3.9	1.9

Ordos basin	Upper Paleozoic large area lithologic gas reservoirs	8.8	12.2	3.4
Tarim	Deep structure gas reservoirs in Kuqa depression	3.2	4.4	1.2
Total		17.0	29.0	12.0

（1）Upper Permian - Lower Triassic reef gas reservoir field in Sichuan basin

The volume of natural gas resources is calculated in two ways. The gas reservoir calculated by scope sequence method is 2.95 trillion m^3, while calculated by basin simulation method is 2.89 trillion m^3. The analysis by Monte Carlo method shows that the natural gas resources with probability value of 95%, 50% and 5% are 2.25 trillion m^3, 2.92 trillion m^3 and 3.8 trillion m^3 respectively. The natural gas resources in the Upper Permian - Lower Triassic in Sichuan basin are 2.92 trillion m^3.

The gas generation evaluated this time in the Upper Permian - Lower Triassic in Sichuan basin increased by 139.88 trillion m^3 from about 323.69 trillion m^3 in the third evaluation to about 463.57 trillion m^3 this time. The volume of resources increased by about 0.8 trillion m^3 from about 2.09 trillion m^3 in the third evaluation to about 2.89 trillion m^3 this time.

（2）Lithologic gas reservoirs in Xujiahe, Sichuan basin

It is calculated that total gas generation from Xujiahe Upper Triassic Hydrocarbon generation rocks in Sichuan basin is 406 trillion m^3, among them the gas generation from mudstone is 262 trillion m^3, accounting for 65% of total generation, while the gas generation from coalbed is 144.3 trillion m^3, accounting for 35％of total generation. In all Hydrocarbon generation rocks, the gas generation from Xu 2, Xu 4 and Xu 6 segment Hydrocarbon generation rocks mainly consisting of sandstone reservoirs is 122 trillion m^3, accounting for 30％ of total generation, so the Xu 2, 4, and 6 segment Hydrocarbon generation rocks have great potential of gas generation, and should not be ignored in exploration of natrual gas in Xujiahe region.

According to a conservative calculation using migration and accumulation factor of 2%, the volume of natural gas resources in Xu 2, 4 and 6 segments is about 2.8 trillion m^3, while the volume in Xujiahe region, Sichuan basin is about 5.6 trillion m^3.

（3）Upper Paleozoic large area lithologic gas reservoir field in Ordos basin

According to basin simulation calculation, the total gas generation from Upper Paleozoic hydrocarbon generation rock in Ordos basin is 563 trillion m^3, mainly distributed in Yishaan slope, accounting for 56% of total generation; followed by Jinxi flexure, accounting for 15% of total generation; the remaining four formations account for only 29% of total gas generation.

Migration and accumulation factor is based on the dissection results of Sulige and Yulin scale zones. The natural gas with the probability of 95%, 50% and 5% is 9.89, 12.20 and 16.05 trillion m^3 respectively. Taking the probability of 50% as the typical, the volume of Upper Paleozoic natural gas resources in Ordos basin is 12.20 trillion m^3.

（4）The Mesozoic volcanic rock and Conglomerate gas reservoir field in Songliao basin

Due to the limit of data, the dissection and basin simulation calculation of gas generation from coal and rock is made only taking Xujiaweizi depression as scale zone. The calculation result shows that the gas generation from Shahezi coal and rock group in Xujiaweizi is 11.72 trillion m^3. According to the calculation results based on the analog of Xujiaweizi scale zone and the fovorable prediction areas oubside Xujiaweizi depression, the total gas generation from deep

argillaceous source rock in Shahezi group in Songliao basin is about 158.56 trillion m^3, then the volume of natural gas resources in different depressions in Shahezi group is further calculated according to the migration and accumulation factor generated from Xujiaweizi. The calculation result shows that the total volume of deep natural gas resources in Songliao basin is about 3.08-4.91 trillion m^3, averagely 3.92 trillion m^3, increased by 1.9 trillion m^3 comparing to the third evaluation result.

（5）Deep structure gas reservoir field in Kuqa depression

The gas generation from 6 sets of Triassic - Jurassic hydrocarbon generation rocks in Kuche depression is calculated using basin simulation method. The calculation result shows that the gas generation from the Triassic - Jurassic hydrocarbon generation rocks is 195.1 trillion m^3. According to the research on the evolution history of Triassic - Jurassic hydrocarbon generation rocks in Kuche depression, the gas generation from the Triassic - Jurassic hydrocarbon generation rocks in Kangcun period and Kuche period accounts for 40.86％ and 34.26％ of total gas generation respectively. According to the calculation based on the migration and accumulation factor from dissection of scale zone, the total natural gas with the probability of 95%, 50% and 5% in Kuche depression is 3.69 trillion m^3, 4.38 trillion m^3 and 5.99 trillion m^3 respectively. Taking the probability of 50% as the typical, the total natural gas in Kuche depression is 4.38 trillion m^3.

The gas generation evaluated this time in the Kuqa depression increased by 46.4 trillion m^3 from 148.7 trillion m^3 in the third evaluation to 195.1 trillion m^3 this time. The total volume of natural gas resources increased by 1.23 trillion m^3 from about 3.15 trillion m^3 in the third evaluation to about 4.38 trillion m^3 this time.

4.3.2 Foreland thrust belt, large area of low-permeability sandstone, Carbonate rock and volcanic rock, with 10 potential natural gas exploration targets and 10.23 trillion m^3 of resources, were selected after evaluation

Exploration targets in main gas-bearing zones are evaluated and selected on the basis of zone evaluation. Based on careful analysis of forming geological conditions of exploration zones in each exploration area, we established evaluation parameter system for target geologies and defined evaluation parameter system, then evaluated the geologies, data reliability and economy of targets, and calculated volume of resources. Finally, we made comprehensive evaluation of the targets, and selected the favorable drilling targets.

Foreland thrust belt, large area of low-permeability sandstone, Carbonate rock and volcanic rock, with 10 potential natural gas exploration targets covering an area of 141.6 thousand m^2 and the resource volume of 10.23 trillion m^3 were selected after evaluation. It has laid a foundation for the development oil and natural gas industry in China.

Table 3 Evaluation results of oil and gas exploration zones in China

Fields	No.	Basins	Favorable zones	Area （10 thousand km^2）	Volume （Trillion m^3）
Large area of low-permeability sandstone	1	Ordos	East of Sulige	2.50	2.50
	2	Ordos	Gaoqiao	0.62	1.00
	3	Sichuan	Guang'an - Yingshan	1.10	0.30
Marine carbonate	4	Sichuan	Longgang Platform Margin	2.50	0.5-1
	5	Tarim	Tazhong North Slope	0.20	0.80
	6	Ordos	Weathering crust	1.20	0.75

			around Qiantai, Jingbian		
Volcanic rock	7	Songliao	Xujiaweizi Fault	0.54	0.68
	8	Songliao	Changling Fault	0.70	1.10
Foreland thrust belt	9	Tarim	Kuche	2.80	2.00
	10	Tarim	Taxinan thrust belt	2.00	1.10
Total				14.16	10.23

5. Conclusion

China has made many significant achievements in gas and natural gas exploration from 2006 to 2010, which have driven the innovative development of geological theories of natural gas in China, and brought lots of new understanding. Under the guidance of the new understanding on the geological theories, all natural gas resources in major gas-bearing basins in China were re-evaluated. The estimated natural gas resources from the evaluation were substantially more than the results from the third national evaluation of oil and gas resources. The comprehensive evaluation selected favorable exploration targets in the main focus exploration fields of the major gas-bearing basins in China, which will play an important role in driving the development of natural gas and easing the supply-demand relationship of natural gas in China.