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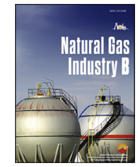

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Research article

Breakthrough and prospect of shale gas exploration and development in China☆

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Abstract

In the past five years, shale gas exploration and development has grown in a leaping-forward way in China. Following USA and Canada, China is now the third country where industrial shale gas production is realized, with the cumulative production exceeding 60×10^8 m^3 until the end of 2015. In this paper, the main achievements of shale gas exploration and development in China in recent years were reviewed and the future development prospect was analyzed. It is pointed out that shale gas exploration and development in China is, on the whole, still at its early stage. Especially, marine shale gas in the Sichuan Basin has dominated the recent exploration and development. For the realization of shale gas scale development in China, one key point lies in the breakthrough and industrial production of transitional facies and continental facies shale gas. Low–moderate yield of shale gas wells is the normal in China, so it is crucial to develop key exploration and development technologies. Especially, strictly controlling single well investment and significantly reducing cost are the important means to increase shale gas exploration and development benefits. And finally, suggestions were proposed in five aspects. First, continuously strengthen theoretical and technical researches, actively carry out appraisal on shale gas "sweet spots", and gradually accumulate development basis. Second, stress on primary evaluation of exploration and development, highlight the effective implementation of shale gas resources, and control the rhythm of appraisal drilling and productivity construction. Third, highlight fine description and evaluation of shale gas reservoirs and increase the overall development level. Fourth, intensify the research on exploration and development technologies in order to stand out simple and practical technologies with low costs. And fifth, summarize the experiences in fast growth of shale gas exploration and development, highlight the demonstration and evaluation of key indicators, and try to achieve more breakthroughs and replacement in new areas, new domains and new strata.
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Keywords: Shale gas field; Super-large gas province; New progress; Effective resource; Development prospect; Enlightenment; South China

1. Main achievements in shale gas exploration and development in China

1.1. Marine shale gas exploration & development breakthrough in Wufeng–Longmaxi Fms in the Sichuan Basin and massive proven geologic reserves

After the first shale gas exploration and evaluation well, W201, obtained the industrial gas in marine shale of Upper

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Ordovician Wufeng Fm−Lower Silurian Longmaxi Fm in 2010, with reference to the successful experiences of the North America in shale gas exploration and development and focusing on marine shale of Lower Paleozoic Wufeng−Longmaxi Fm and Qiongzhusi Fm (and the corresponding stratum) in the south, China has carried out comprehensive geological evaluation, exploration evaluation and development pilot test of shale gas, and successively explored the shale gas in Wufeng−Longmaxi Fms in the Sichuan Basin, eastern Chongqing and western Hubei, northern Yunnan and Guizhou, western Hunan, etc. (Fig. 1); and also industrial shale gas production has been made in Weiyuan, Changning (Changning−Zhaotong), Fushun−Yongchuan, Fuling and other regions of Sichuan Basin

Fig. 1. Shale gas exploration and development in China.

(Fig. 2). So far, it generally shows that Wufeng–Longmaxi Fms are very rich in shale gas resources, featuring wide gas distribution and high production in a large area. Wells with high yield in industrial shale gas are mainly located in conventional natural gas enrichment regions of Sichuan Basin. It is preliminarily determined that Wufeng–Longmaxi Fms in Southern Sichuan–Eastern Sichuan–NE Sichuan area have trillions of cubic meters of marine shale gas; Fuling, Weiyuan, Changning and other areas have hundreds of billions of cubic meters of shale gas (Table 1) [1], as well as other gas-producing areas such as Fushun–Yongchuan, Pengshui and Nanchuan–Dingshan. In 2014, the proven shale gas bearing area in JY1–JY3 well block of Fuling shale gas field was 106.45 km^2 and the proven geologic reserves of shale gas was 1067.5×10^8 m^3, which achieved zero breakthrough in shale gas reserves in China. In 2015, the proven shale gas reserves in China realized a great breakthrough, for example, Well W202 in Weiyuan shale gas field, Well N201 and YS108 Well Block in Changning shale gas field and Well JY4–JY5 in Fuling shale gas field had been respectively proven with the shale gas-bearing area of 48.23 km^2, 159.64 km^2 and 277.09 km^2, and the proven geologic reserves of shale gas are respectively 273.51×10^8 m^3, 1361.80×10^8 m^3 and 2738.48×10^8 m^3. Accumulative proven geologic reserves of shale gas is 5441.29×10^8 m^3, with the proven recoverable reserves of 1360.33×10^8 m^3, which laid a good foundation for the rapid production of shale gas in China.

1.2. Rapid increase of shale gas production in the Sichuan Basin makes China the third country in the world to realize shale gas industrial production

China's shale gas production began at Well W201 in 2010. With the discovery and operation of a series of high-level wells in 2011–2012 such as N201-H1 and Y202-H1, China's shale gas production exceeded 1.0×10^8 m^3 in 2012; with the discovery of Fuling shale gas field in 2013, China's shale gas production in the same year exceeded 2.0×10^8 m^3. With the rapid production of Weiyuan, Changning and Fuling shale gas fields, in 2014, China's shale gas production made a leap to

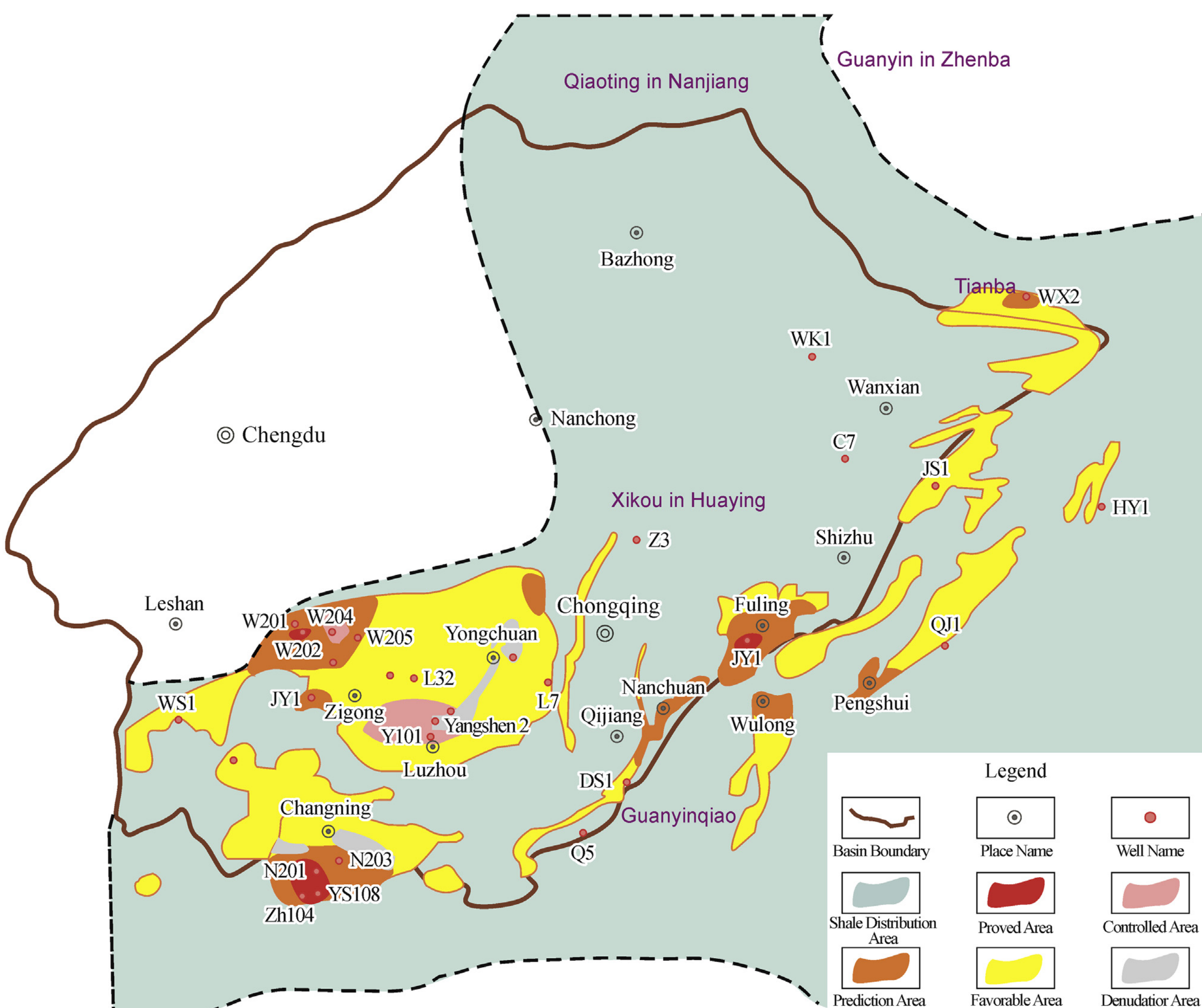


Fig. 2. Shale gas fields distribution in the Sichuan Basin.

Table 1
Statistics of proven reserves and production of shale gas fields discovered in the Sichuan Basin.

Gas field	Year	Area/km^2	Technical recoverable resources volume/10^8 m^3	Proven shale gas area/km^2	Proven geologic reserves/recoverable reserves/10^8 m^3	Depth of pay zones/m	Sedimentary environment	Accumulative production/10^{8}m^3
Fuling	2012	2304	4046	383.54	3805.98/951.5	2100−3500	Cratonic platform deep continental shelf facies	43.26
Weiyuan	2010	4216	4512	48.23	273.51/68.38	1530−3500	Cratonic platform deep continental shelf facies	4.50
Changning (Changning−Zhaotong)	2011	3980	4807	159.64	1361.80/340.45	2300−4000	Cratonic platform deep continental shelf facies	10.65
Fushun−Yongchuan	2011	6670	8514	/	/	3000−4500	Cratonic platform deep continental shelf facies	2.00
Wuxi	2014	1660	1533	/	/	1500−3200	Cratonic platform deep continental shelf facies	/
West Chongqing	2015	2180	2058	/	/	3000−4500	Cratonic platform deep continental shelf facies	/
Pengshui	2012	3586	3764	/	/	1000−2500	Cratonic platform deep continental shelf facies	0.14
Nanchuan−Dingshan	2014	3796	2852	/	/	3500−4800	Cratonic platform deep continental shelf facies	/
Total	2010−2015	28392	32086	591.41	5441.29/1360.33			60.55

12.5 × 10^8 m^3, and annual production in 2015 exceeded 40 × 10^8 m^3; the accumulative shale gas production was more than 60 × 10^8 m^3, based on which the massive production of shale gas has been basically achieved and China becomes the world's third largest producer of shale gas (Table 2) [2,3]. Studies suggested that the Wufeng−Longmaxi reservoirs is a large continuous accumulative type of shale gas reservoir, in continuous distribution and with a large area and the average burial depth of 2100−3000 m; they are moderate−deep gas reservoirs with high formation pressure and moderate−high yield of single well (3.4 × 10^8−54.7 × 10^8 m^3/d) (Fig. 3); the test mining effect is good, with the methane content of more than 98%, which is a quality shale gas field containing no hydrogen sulfide.

1.3. Further evaluation is needed for a breakthrough in shale gas due to the multi-strata gas-bearing shale reservoirs in South China

In addition to the Wufeng−Longmaxi Fms, organic-rich shale strata in the South also include Sinian Doushantuo Fm, Lower Cambrian Qiongzhusi Fm, Middle Devonian Yingtang Fm−Luofu Fm, and Upper Carboniferous Datang Fm−Jiusi Fm. Some of these shale formations are distributed throughout the southern area and other formations are only partly distributed, but they have common features such as high *TOC* value, great thickness, high maturity, high brittleness index and containing a certain volume of gas; it was found that many places have shale gas and industrial shale gas; Sinian shale gas was found in the Three Gorges area and Devonian shale gas was found in Liuzhou of Guangxi Province (daily gas production about 2.0 × 10^4 m^3); the Carboniferous shale gas was found in Liupanshui of Guizhou Province (daily gas production about 5.0 × 10^4 m^3); all these findings will provide important basis for further shale gas geological comprehensive evaluation, selection of target areas and exploration breakthrough in the southern area. It is worth emphasizing that the shale gas of Cambrian Qiongzhusi Fm was widely distributed in the southern area; similar to the Wufeng−Longmaxi Fms, shale gas was discovered in the whole middle−upper Yangtze region, including Sichuan Basin, SE−NE Chongqing, Guizhou, Hubei and Hunan, but

Table 2
Statistics of shale gas reserves and production of major shale gas producers in the world.

Country	Year to start shale gas exploration and development	Shale gas volume[a]/10^{12} m^3	Number of wells drilled[b]	Proven reserves[c]/10^8 m^3	Annual production/10^8 m^3
USA	1821	17.64	*c.*100 000	56543.95	3807
Canada	2006	16.23	3000		320
China	2005	31.57	700	5441.29	45
Argentina	2012	22.71	300		0.065 × 10^8 m^3/d

[a] The data is from EIA, 2015-09-24; the update date of US data is April 2015, while those of Canada, China and Argentina is May 2013.
[b] Number of wells is from different sources, with incomplete statistics and only an approximate value.
[c] 2015-12-06, http://www.eia.gov/dnav/ng/ng_enr_shalegas_a_epg0_r5301_bcf_a.htm, China's reserves from the National Commission of Mineral Reserves, 2015-12-05, http://www.nrcan.gc.ca/energy/sources/shale-tight-resources/17677, China's production from CNPC and Sinopec.

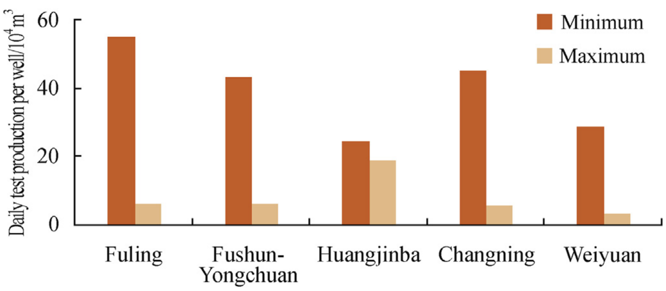


Fig. 3. Statistics of test production of single shale gas well in the Sichuan Basin.

the difference is that Qiongzhusi Fm had low content of gas or gas free, with high content only in some areas. According to incomplete statistics, the number of Qiongzhusi shale gas wells in the middle–upper Yangtze region is no fewer than 40, but only 4 wells of Weiyuan–Qianwei block in the Sichuan Basin obtained industrial gas flow; some of the other wells had no gas, some contained nitrogen, some had a little volume of gas and some had low yield. Preliminary studies suggest that Qiongzhusi Fm had high degree of thermal evolution, with the R_o generally greater than 3.0%, which made its organic matters carbonized and the gas-producing capacity close to failure, and which resulted in the embrittlement of organic matters, so organic matter pores are easy to collapse and the number of nano-pores decrease; also the chlorite became the main content of the clay minerals and the number of pores between the clay mineral crystals reduced to decrease the shale pore space, which would lower the gas content.

Statistics show that shale reservoir porosity of Qiongzhusi Fm ranges from 1.5% to 4.2% with an average of 2.4%, which is 1/2–1/3 that of Wufeng–Longmaxi Fms, so the shale gas content of Qiongzhusi Fm is usually only 1/2–1/3 that of Wufeng-Longmaxi Fms, with the gas content of 0.5–4.0 m^3/t and an average of 1.29 m^3/t (Table 3). In addition, the formation of shale of in Qiongzhusi Fm (dating back to about 570 Ma) is 122–132 million years [1] earlier than that of Wufeng–Longmaxi Fms (dating back to 448 to 438 Ma), so Qiongzhusi Fm has more structure changes and high degree of reconstruction and higher requirements for the preservation conditions of shale gas. Therefore, most parts of Qiongzhusi Fm have risk, and only some parts with low degree of evolution and good preservation conditions may be rich in gas and have exploration potential.

1.4. There were findings in the exploration and development of marine–continental transitional shale gas, but the prospect is uncertain

Statistics show that China's marine–continental transitional shale has a large distribution area, early gas formation time and long duration; in the conventional gas reserves discovered in China, the gas source rock of more than 50% is marine–continental transitional facies shale. But studies found that the marine–continental transitional facies high-quality shale has large accumulative thickness but small single-layer thickness (usually between 5 and 15 m), and there is fast variation in both longitudinal and lateral directions; total gas content is low and adsorption gas content is high; organic nano-pores are fewer; shale layers and tight sandstone or coal beds are associated with each other, resulting in complex water–gas relationship. In view of this, the exploration and development of marine–continental transitional shale gas is generally in the stage of comprehensive geological evaluation, straight well exploration evaluation and selection of favorable zones. Drilling results show that there is a certain exploration prospect [4], for example, three drilled wells in Permian System in the Ordos Basin obtained a certain volume of shale gas after fracturing: Well Eye 1 of Taiyuan Formation has a daily gas production of 1.95 × 10^4 m^3; Well Yunyeping 1 of Shanxi Formation has a daily gas production of 2.0 × 10^4 m^3, Well Shenmu SM0-5 of Taiyuan Formation has a daily gas production of 6695 m^3. Two wells drilled in the south of North China Basin showed good signs in the Carboniferous System–Permian System; it was proven that Well Weican 1 has quality organic-rich shale (accumulative thickness of 465 m), and the field core gas content reaches 4.5 m^3/t; Well Mouye 1 has 10 layers of quality organic-rich shale and the total thickness is 277.6 m; after fracturing of one layer, a daily gas production of 3000 m^3 was obtained. In the southern area, important findings were obtained through the drilling evaluation of Dalong Fm and Longtan Fm of Permian System: in

Table 3
Comparison of shale reservoir characteristics between the Wufeng-Longmaxi Fms and Qiongzhusi Fm.

Key parameters	Wufeng–Longmaxi Fms	Qiongzhusi Fm
Burial depth/m	2100–4500	3000–5000
R_o	2.0–3.2%	3.0–5.0%
Brittle mineral content	30–85%	32–80%
Pressure coefficient	1.0–2.1	0.95–1.40
Pore type	Clay mineral intercrystal pore, organic matter nano-pore, natural micro fracture, lamellation crack, etc.	The clay mineral intercrystal pore, natural micro fracture, lamellation crack, etc.
Specific surface area/($m^2 \cdot g^{-1}$)	6.0–32.0 (Avg.:15.0)	2.1–10.0 (Avg.: 5.0)
Pore diameter/nm	80–90	10–20
Porosity	2.00–9.20% (Avg.: 4.91%)	0.40–7.82% (Avg.: 2.43%)
Permeability/mD	0.000 01–0.009	0.000 01–0.000 9
Gas content/($m^3 \cdot t^{-1}$)	1.02–6.91 (Avg.: 2.68)	0.50–6.02 (Avg.: 1.29)

Hubei, the core gas content of Well Baye 1 ranges from 1.0 to 2.0 m^3/t, with rich combustible hydrocarbon gases, while that of Well Hedi 1 reaches up to 3.03 m^3/t. In Hunan, core gas content of Well Xiangye 1 ranges from 0.1644 to 1.414 m^3/t, with a daily gas production of 2400 m^3 after fracturing. In Guizhou, core gas content of Well Xiye 1 and Well Fangye 1 respectively ranges from 4.926 to 19.171 m^3/t and from 1.344 to 5.562 m^3/t. Apart from this, there is no well for production test of marine—continental transitional shale gas.

1.5. Technology is the key to scale production due to the variety in continental shale gas production

Continental organic-rich shale is the source rock of main petroliferous basins in China with its main body in the oil generation stage, during which less gas would be produced. A comparative analysis shows that continental shale gas reservoir has the characteristics of large shale thickness, various types and complexity of organic matters, low maturity, in the period of oil and moisture generation and good preservation conditions [5], and the shale gas and oil coexists. For the continental shale gas, a lot of exploration had been carried out in Xujiahe Fm of Triassic System and Ziliujing Fm of Jurassic System in the Sichuan Basin and Yanchang Fm of Triassic System in the Ordos Basin. Although a few industrial gas flow wells were discovered, industrial productivity breakthrough was not achieved [6] and the prospect for exploration and development is not clear. In the Sichuan Basin, about 20 shale gas wells were drilled in Xujiahe Fm of Lower Triassic Series and Ziliujing Fm of Lower Jurassic Series, with a daily gas production of 0.1×10^4—50.7×10^4 m^3 through the fracturing test. In the Ordos Basin, about 50 wells were drilled in Section Chang 7 of Yanchang Fm of Upper Triassic Series, with a daily gas production of 0.17×10^4—4.0×10^4 m^3 through the fracturing test. Although the single well test obtained a certain volume of initial production, the progressive decrease was fast and a stable industrial production cannot be formed. So far, it is only proven that the geological reserves of continental shale gas in the Ordos Basin is 677×10^8 m^3 and the annual production capacity of 1.18×10^8 m^3 was built up; one well was put into the wellhead power production, with a daily production of about 0.4×10^4 m^3 (Fig. 4).

1.6. Preliminary geological understanding of marine shale gas accumulation & enrichment was formed

Geological conditions of China's shale gas accumulation are very complex, which are completely different from that of North America. Through the practice and research of exploration and development in Wufeng—Longmaxi Fms, the preliminary geological theory of China's marine shale gas accumulation & enrichment was formed; according to the exploration of Fuling shale gas field, Guo Tonglou et al. [7] put forward the accumulation mode of "ladder migration, anticline aggregation, breaking—sliding control joint, box shaped accumulation" and marine shale gas "binary fat gas" mode of "deep continental shelf facies are the foundation and good preservation conditions are the key". According to the progress of Fuling shale gas development, Wang Zhigang [8] held that high-quality shale of deep continental shelf facies is the foundation for the accumulation of shale gas; moderate-degree thermal evolution is conducive to the formation of marine shale organic matter pores and preservation condition is the key to marine shale gas enrichment and high productivity, namely the marine shale gas "ternary accumulation" theory. According to the study of marine shale gas accumulation conditions in south area, main control factors comparison and exploration and development analysis, Dong Dazhong [6], Zou Caineng [1] et al. initially established two kinds of marine shale gas accumulation modes — the single structure type "sweets" and large area continuous type "sweet spot" and put forward that marine shale gas accumulation and high production are controlled by such four factors as "the sedimentary environment, thermal evolution degree,

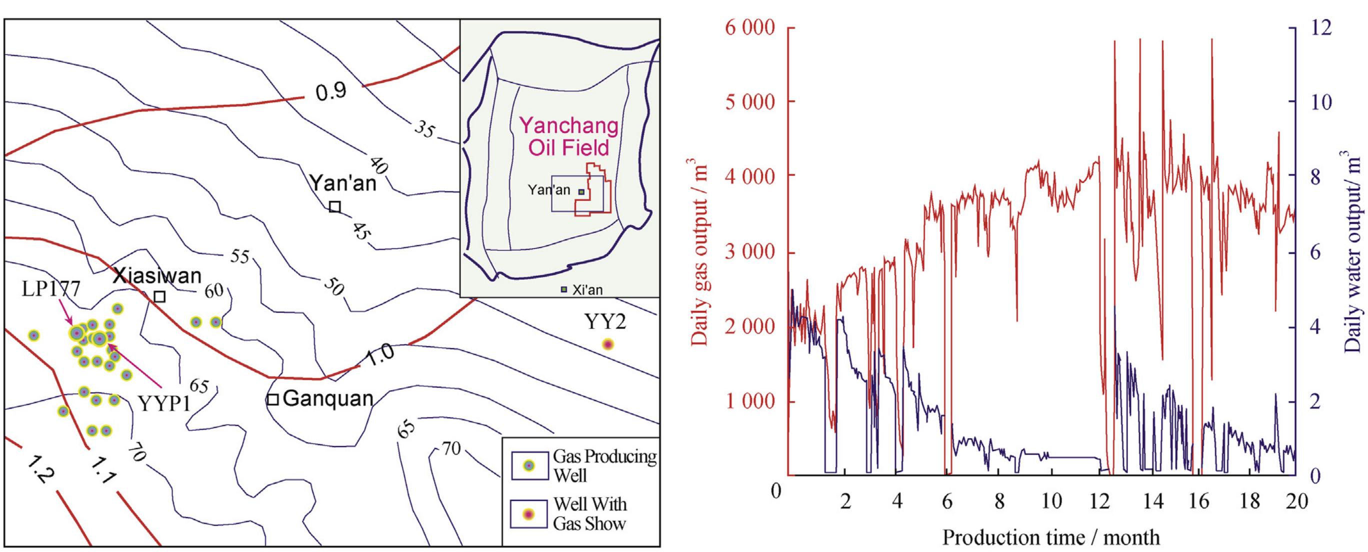


Fig. 4. Shale gas exploration and development achievements of Triassic Yanchang Fm in the Ordos Basin.

lithofacies assemblage, structure preservation". Research results show that the high *TOC*, high biological siliceous and calcareous content shale have good coupling relationship with the sedimentary environment, and semi-deep & deep continental shelf facies sedimentary environment control the scale and distribution range of Wufeng—Longmaxi organic-rich and biogenic siliceous and calcareous-rich shale. Organic-rich shale has high *TOC* of with good type, to provide good gas source for shale gas accumulation, and being in thermal cracking gas range, it also creates advantages for nano-pore development in organic matter and provides effective space for shale gas accumulation. The rock brittleness is composed of mineral composition, rock mechanics and crustal stress; the quality shale reservoir in Wufeng—Longmaxi Fms consists of siliceous shale and calcareous shale, with high siliceous and calcareous content; part of which is of biological and biochemical origin, and siliceous radiolarians and sponge spicules content partly reaches up to 30%; high biological origin siliceous and calcareous mineral not only makes the good shale brittleness, but also is easy to develop matrix pores, lamellation cracks and natural micro fractures, which provide enough space for shale gas accumulation; the preservation conditions are key to oil and gas accumulation and high production, which means that good reservoir—seal combination, locating in a relatively stable area, high and super high pressure "super pressure sealing box" are key to accumulation and high yield of marine shale gas. Practice has proved that the good preservation conditions can form high pressure and super high pressure, which may lead to accumulation and high production; Wufeng—Longmaxi shale gas initial test yield in the Sichuan Basin and its peripheral areas has significantly positive correlation with the formation pressure coefficient (Fig. 5). Further, accumulation and high production have correlation with the factors such as the structural type, depth, ground stress conditions and the development degree of natural fracture networks. Exploration practice shows that in the southern areas with complex structures and the positive tectonics in large complex back oblique relief areas, the faults are not developed and the strata are preserved better, which constitutes the major structural type of marine shale gas core area.

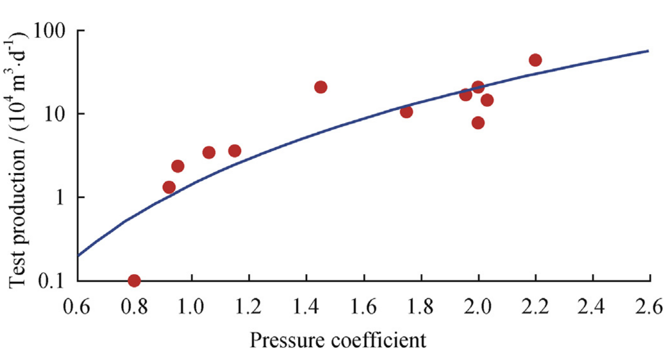


Fig. 5. Relationship between initial test yield of Wufeng—Longmaxi shale gas and the formation pressure coefficient in the Sichuan Basin and its peripheral areas.

The formation pressure coefficient of Wufeng—Longmaxi Fms is proportional to the depth; the greater the depth is, the greater the formation pressure coefficient will be and the higher the initial test yield; the depth of the shale gas fields such as Fuling, Weiyuan, Changning and Fushun—Yongchuan range from 1500 to 3800 m, with an average of 2500 m, and the pressure coefficient range from 1.2 to 2.2; when the depth is more than 2500 m, the formation pressure coefficient is generally greater than 1.5 and test production of horizontal wells is greater than 10×10^4 m^3/d.

1.7. Key technology breakthrough, key process optimization and improvement of project quality promote the massive and beneficial development of complex shale gas reservoir

Through 5 years of development, including the technology introduction, absorption and self innovation, China has earned key technologies and supporting equipment series (Table 4) applicable to shale gas exploration and development under complex geological conditions, such as the technologies of geological comprehensive evaluation, geophysical exploration, experiment test and analysis, horizontal well drilling and completion, volume fracturing, micro seismic monitoring and evaluation, as well as the mobile drilling, model 3000 large pressure fracturing vehicle crew, drillable bridge plug, efficient fracturing fluid preparation; based on the above, the localization and scale application have been basically realized. The horizontal well drilling and completion period was reduced to 60 days from 150 days (the shortest period of 34 days), staged fracturing was increased to 15 sections at least (up to 26) from previous 10 sections at most, with a daily average of 3—4 sections; the largest single-well fracturing fluid volume was 3.8×10^4 m^3; the maximum displacement was 17.2 m^3/min; the average gas production test is 15×10^4 m^3/d. The capabilities such as one-drilling for horizontal wells above 3500 m, drilling rate of more than 90% in 1500—2000 m horizontal well quality reservoir and 15 stages volume fracturing have been obtained, and 4—8 wells of 1 platform drilling in the hilly areas and the "factory" production mode of "crossing + synchronization + slide fastener" fracturing etc. have been established; the single horizontal well overall cost decreases to 55 million Yuan to 65 million Yuan from 100 million Yuan. And meanwhile, China continues to optimize the wellbore structure, prevent the pollution of surface water and actively explore the recycling, treatment and reuse of mud, debris and fracturing back-flow liquid; test, production, construction and reclamation are carried out at the same time, with effective prevention and control of air pollution; through all of the above measures, a green development mode is being established.

2. Geological characteristics of shale gas accumulation & enrichment in China

In the process of polycycle tectonic and sedimentary environment evolution in China, such 3 types of organic-rich

Table 4
Key technologies and equipment for shale gas exploration and development in China.

Technologies	Description
Technology in comprehensive geological evaluation	Geological survey technology of shale formation outcrop, seismic technology of shale reservoir identification, evaluation and prediction, logging technology of shale gas reservoir recognition, evaluation and prediction, evaluation and optimization of shale gas sweet spots, shale gas geological evaluation and resource evaluation technology, integrated evaluation of geology and engineering
Experimental analysis test	Shale organic geochemical analysis, shale rock mineralogical analysis, shale reservoir pore structure observation and testing, nano-pore 3D reconstruction, shale rock physical property testing, shale hydrocarbon content testing and evaluation, shale rock mechanics characteristics testing
Supporting technologies in drilling and completion	Horizontal well design optimization, borehole wall stability of horizontal well, horizontal well rotary steering, water-based/oil-based drilling fluid, horizontal well cementing, platform well group "factory" drilling and completion technologies
Supporting technologies in volume fracturing	Volume fracturing design, clustering perforation, fast drilling bridge plug, fracturing fluid technology, horizontal well staged fracturing, differentiation staged fracturing technological parameter optimization, composite bridge plug + cable transmission clustering perforation, shale reservoir stimulation experiment & evaluation, large-scale fluid supply method, continuous sand supply process, casing sliding sleeve, pump casing injection equipment, Model 3000 fracturing vehicle unit, standard operation specification
Shale gas development optimization technology	Experimental evaluation of shale gas development mechanism, shale gas wells decline and EUR prediction, shale gas well development and deployment optimization, shale gas development plan design, numerical simulation of shale gas reservoir, productivity prediction and evaluation
Gathering and transmission process of shale gas wells and stations	Standardized design technology, the integration of skid-mounted technology, digital management technology
Safe and clean production mode	Technology of debris not falling to the ground, technology of oil-based debris use, fracturing fluid flowback reuse, CO_2 anhydrous fracturing technology

shale as marine, marine−continental transitional and continental shale (Tables 5 and 6, Fig. 6) are developed, all of which have the basic geological conditions for shale gas accumulation, but there are large differences in the exploration and development prospects. Comparison showed that (Table 6) marine shale has the best conditions for gas accumulation, and the second was the marine−continental transitional shale gas, and the continental shale has the poorest conditions; marine shale gas is the most realistic field of exploration and development.

2.1. Geological characteristics of marine shale gas accumulation & enrichment

In North America, gas shale is mainly located in late Paleozoic Devonian System and Carboniferous System, which was formed in the Cratonic edge depression and foreland depression. China's marine shale has the characteristics of age−old, deep within the basin, strong reformation outside the basin and high thermal maturity. It was mainly developed in early Paleozoic and was formed in the intracratonic depression or edge slope area and distributed in the Sichuan Basin and its peripheral areas, Middle−Lower Yangtze region and southern regions as well as central−west China such as the Tarim Basin, of which Upper Ordovician Wufeng Fm−Lower Silurian Longmaxi Fm, Lower Cambrian Qiongzhusi Fm and the near horizon are the main layers. Except the Sichuan Basin, marine shale in the southern region is mostly located out of the basin, which experienced many tectonic transformations or large areas of exposure. Thermal maturity (vitrinite reflectance R_o) statistics shows that R_o of the marine shale in most of the regions is greater than 2.0%, in the phase of crude oil cracking and gas generation; in some sections, R_o is commonly greater than 3.0% and the organic matters are in the carbonization process, being short of the gas-producing ability. China's shale gas exploration and development practice has confirmed that marine shale is an important area for shale gas exploration and development in China. Due to old age, early gas-producing, experienced strong structural movement, the fold, fault and denudation have brought a great variety of shale gas preservation conditions [9]. Moderate−large depth, main super−ultrahigh pressure and good preservation conditions in the Sichuan Basin are good for shale gas accumulation and high production, which makes it the preferred area for shale gas exploration development. The peripheral structure is relatively complex, with a great change in the depth. Different parts of the same structure have different depths; moderate−deep parts have super formation pressure and good preservation conditions, which are good for shale gas accumulation and high production; shallow parts may have thin overlying strata or cracks, low−normal pressure, poor preservation conditions or with no preservation conditions, which are not conducive to shale gas accumulation. Outside the basin, the structure is very complex and the shale strata generally experience uplift, fracture and denudation, generally with small depth, low−normal pressure and poor preservation conditions, which are not conducive to shale gas accumulation and preservation. Therefore, the relatively stable structure, formation overpressure, good preservation conditions are the key to marine shale gas accumulation.

2.2. Geological characteristics of marine−continental transitional shale gas accumulation & enrichment

China's marine−continental transitional shale was formed in the Carboniferous−Permian period and distributed in the

Table 5
Statistics of China's continental sedimentary basins or regions rich in organic shale.

Group	System	Series	Songliao Basin	Bohai Bay Basin (North China)	Ordos Basin	Sichuan Basin	Other regions in the south	Qaidam Basin	Junggar–Turpan–Hami Basin
Cainozoic	Paleogene	Oligocene		Dongying Fm. E_3d					
		Eocene		Sha 3 Fm. E_2s^3					
				Sha 4 Fm. E_2s^4					
		Paleocene		Kongdian Fm. E_1k					
Mesozoic	Cretaceous	Upper	Nenjiang Fm. K_2n						
			Qingshankou Fm. K_2qn						
		Lower	Quantou Fm. K_1q						
			Yingcheng Fm. K_1y						
			Shahezi Fm. K_1s						
			Huoshiling Fm. K_1h						
	Jurassic	Middle				Shaximiao Fm. J_2s		Dameigou Fm. J_2d	Xishanyao Fm. J_2x
		Lower				Ziliujing Fm. J_1s		Huxishan J_1h	Sangonghe Fm. J_1s
									Badaowan Fm. J_1b
	Triassic	Upper			Yanchang Fm. Section Chang 7 T_3ych^7	Xujiahe Fm. T_3x^{1-3-5}			Baijiantan Fm. T_3b
					Yanchang Fm. Section Chang 9 T_3ych^9				
Upper Paleozoic	Permian	Upper		Shanxi Fm. P_1s	Shanxi Fm. P_1s	Longtan Fm. P_2l	Longtan Fm. P_2l		
		Middle							Lower Wuerhe Fm. P_2w (Pingdiquan–Lucaogou Fm. P_2p–l)
		Lower		Taiyuan Fm. P_1t	Taiyuan Fm.. P_1t				Fengcheng Fm. P_1f
									Jiamuhe Fm. P_1j
	Carboniferous	Upper		Benxi Fm. C_2b	Benxi Fm. C_2b				
		Lower					Jiusi Fm. C_1j	Keluke Fm. C_2k	Dishuiquan–Bashan Fm. C_1d–C_2b
							Datang Fm. C_1d		
	Devonian	Middle					Luofu Fm. D_2l		
							Yingtang Fm. D_2y		
Lower Paleozoic	Silurian	Lower				Longmaxi Fm. S_1l	Longmaxi Fm. S_1l		
	Ordovician	Upper				Wufeng Fm. O_3w	Wufeng Fm. O_3w		
		Middle			Pingliang Fm. O_2p				
		Lower							
	Cambrian	Lower				Qiongzhusi Fm. $\in_1q$			
Proterozoic	Sinian	Neoproterozoic				Doushantuo Fm. Z_2d			
	Daijianian	Mesoproterozoic		Xiamaling Fm. Jxxm					
	Jixianian			Hongshuizhuang Fm. Jxhs					
	Changchengian	Paleoproterozoic		Chuanlinggou Fm. Chcl					

Note: Marine; Marine–Continental transitional; Continental

Sichuan Basin and its peripheral areas, Middle−Lower Yangtze region, and other southern areas, the Ordos Basin, the Bohai Bay Basin and other northern areas (Table 5). Research suggests that the marine−continental transitional shale is widely distributed; syneclise−lagoon and deep bog−reed environments control the organic-rich shale thickness and distribution scale. Clayey shale and silty shale are a good lithofacies association. Matrix pore is the main type (content intergranular, intergranular pore and dissolution pore in clay minerals, etc.), and there are organic pores and micro fractures in some parts. The organic matter abundance is high and TOC content ranges from 1.44% to 7.51%; the kerogen is of mainly humic hybrid−humic type and the organic matter maturity (Ro) ranges between 1.0%−2.5%, which are generally in a gas-generation peak stage and provide gas sources for more than 50% of the proven conventional natural gas reserves in China. Stable structures, moderate depth and good overburden, controlled by basin type and hydrocarbon generation and the formation overpressure zone are favorable for shale gas accumulation, thus making it the "best zone". At the same time, marine−continental shale gas accumulation has the following disadvantages: small continuous thickness, small thickness of single layer, great change of shale facies, with coal bed, heavy sandstone interbed or lateral changes. There are only several wells drilled in marine−continental transitional facies shale gas exploration & development, which is overall in the phase of exploration and evaluation. Based on the shale gas observation of the drilled wells and shale gas flow of the existing wells, it can be known that marine−continental transitional shale gas has good accumulation conditions and a breakthrough is expected to make in exploration and development in the future.

Table 6
Accumulation & enrichment characteristics of the three types of shale gas in China.

Type	Potential area	Characteristics of concentrated section	Gas-producing potential	Gas-bearing property	Fracturing property
Marine shale	A huge area (10×10^4–20×10^4 km^2)	Huge thickness (30–80 m) continuity	A great volume of gas (I–II_1, R_o 2.0%–5.0%, mainly crude oil pyrolysis gas)	High gas content (Organic matter pore developed, large specific surface area, gas content 1.0–8.0 m^3/t)	Good (Brittle mineral content 40–60%, mainly containing illite)
Marine–Continental transitional shale	A relative large area (5×10^4–10×10^4 km^2)	Great thickness (10–20 m) discontinuity	A relatively small volume of gas (II_2–III, R_o 1.0%–2.5%, mainly thermal pyrolysis gas)	Moderate–low gas content (Organic matter pore developed partly, small–moderate specific surface area, gas content 0.5–4.0 m^3/t)	Moderate (Brittle mineral content 30–50%, mainly illite–smectite mixed layer)
Continental shale	A small area (<5×10^4 km^2)	Moderate thickness (20–200 m) variation	A tiny volume of gas (I–II_2, R_o 0.5%–1.3%, mainly crude oil)	Low gas content (Organic matter pore undeveloped, small specific surface area, gas content 0.5–2.2 m^3/t)	Poor (Brittle mineral content 20–40%, mainly montmorillonite and kaolinite)

2.3. Geological characteristics of continental shale gas accumulation& enrichment

Continental organic matter shale is formed in Mesozoic–Cenozoic and widely distributed in China's oil and gas basins, including the Songliao Basin, the Bohai Bay Basin, the Ordos Basin, the Sichuan Basin, the Junggar Basin, and the Tarim Basin, etc., of which Triassic System–Jurassic System, Cretaceous System (Qingshankou Fm) and Paleogene System–Neogene System (Shahejie Fm) are the key strata. Continental shale gas accumulation has the remarkable characteristics of "four advantages and four disadvantages". "Four

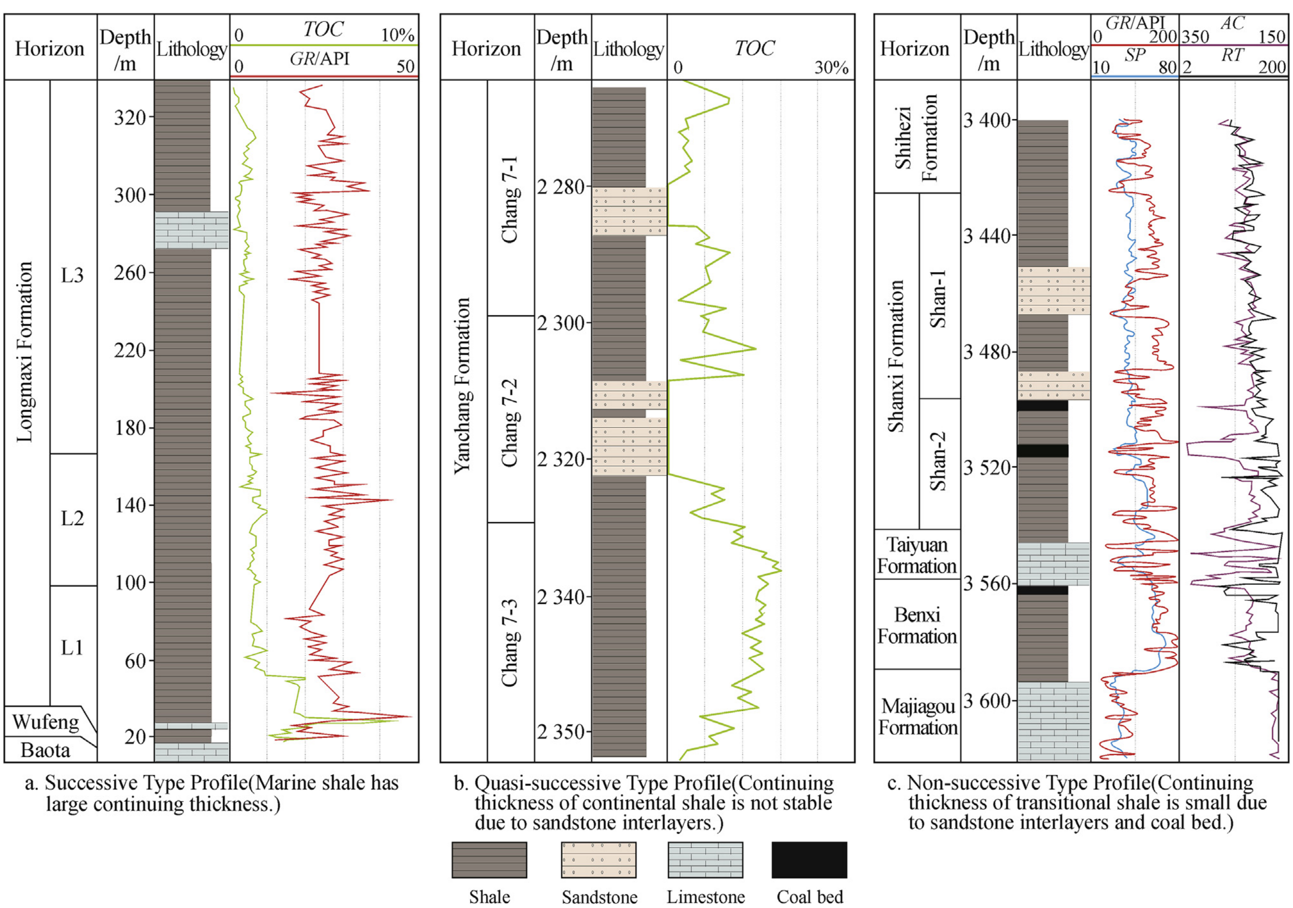


Fig. 6. Combination of China's organic-rich shale continuous thickness (in concentrated sections).

advantages" refers to the four major advantages of continental shale gas accumulation: (1) Well-developed and widely-distributed shale in deep−semi-deep lake basin center and slope area; (2) large thickness, better development of concentrated sections (generally of 20−200 m); (3) high abundance of organic matter (2.0%−8.0%), good organic matter type (sapropel type−partial humic hybrid); (4) Simple structures, formation overpressures, good preservation conditions. "Four disadvantages" refers to the four deathful weak points of the continental shale gas accumulation: (1) the low degree of thermal evolution of organic matter (R_o is between 0.5% and 1.3%), there is much crude oil and limited gas production; (2) high clay mineral content, low brittle mineral content, poor brittleness; (3) non-developed organic matter pores, poor physical properties; (4) small gas-producing areas (accounting for about 10%−30% of the effective shale areas), large depth. Via continental shale gas exploration and development, nearly 50 wells were drilled in the Ordos Basin, the Sichuan Basin, the Qaidam Basin, the Nanxiang Basin and the Bohai Bay Basin to obtain shale gas flow; there is large difference in the initial single well test production (0.1×10^4−50.7×10^4 m^3/d), indicating a rapid production decline and no industrial productivity.

3. Main difficulties in China's shale gas exploration and development

3.1. There is low degree of implementation of effective shale gas resources and insufficient preparations for new fields and new targets

The basic theories in shale gas formation, accumulation and enrichment and technology of exploration and development are in their infancy; shale gas resource evaluation standard and technology specification are being established. In 2012, the Ministry of Land and Resources organized and completed the shale gas resource evaluation on 41 basins/areas in China and selected 180 zones for shale gas development. So far, however, China has made breakthroughs only in marine shale gas exploration and development of a few areas (the Sichuan Basin) and individual formations (Wufeng−Longmaxi Fms); in most areas and formations, shale gas has been obtained in some wells. For marine−continental transitional and continental faces, although there are some wells drilled to obtain shale gas, the industrial gas breakthrough has not been made. The primary cause is that the formation, occurrence and enrichment mechanism and main control factors of the two types of shale gas resources have not been understood yet, the resources evaluation and key parameters of favorable area selection were obtained informally, and there is only macro understanding of it. Especially there is large difference in on-site analytical results of shale gas content, for most evaluators consider the isothermal adsorption simulation results to be the actual shale gas content under the formation temperature and pressure, which constituted a misleading. At the same time, the identification and prediction technology of marine−continental transitional facies and continental shale gas "sweet spots" seems immature, especially when the marine−continental transitional shale facies change fast and have thin single layer, and are often associated with coal rock and tight sandstone interlayers.

3.2. Key technologies and equipment for shale gas exploration and development need to be further improved

The gas reservoir depth of Wufeng−Longmaxi Fms of Fuling, Weiyuan, Changning (Changning−Zhaotong) shale gas fields in the Sichuan Basin is 2000−3500 m; localization and scale application has been basically achieved with shale gas exploration and development technology and equipment for the depth of less than 3500 m. However, there are more shale gas resources in most other parts of Sichuan Basin and China with the depth of more than 3500 m, where the shale gas resource exploration and development technology and equipment are under exploration and research: for example, the wells drilled in Nanchuan and Dazu of the Sichuan Basin with the depth of more than 4000 m have good geological indicators of shale gas accumulation, but no breakthrough has been made in most of the wells for lack of the technology and equipment. None in China's continental, marine−continental transitional shale gas exploration and development technology and equipment, so further research should be conducted to establish an exploration and development system suitable for the geological characteristics of shale gas in China.

3.3. Due to high cost of shale gas exploration and development, the realization of economic production is the key

In China, there are complex shale gas geological and surface conditions and the effective and high-quality shale gas resources and "sweet spots" areas are in the early stage of exploration and development, which leads to high cost; thus, some more time is needed for the realization of economic exploitation. To realize the beneficial development, we must reduce cost and increase production; comprehensive strategic planning is vital for the shale gas development in an area. Either too conservative or too radical development strategy is not advisable; the development plan should not be suspended due to a temporary drop in oil price, instead, shale gas exploration and development should be advanced in accordance with the established strategic plan.

3.4. Pipeline network construction lag restricts shale gas development

For lack of pipeline networks or the insufficient transmission capacity of pipeline networks, the shale gas fields of Fuling, Weiyuan, Changning (Changning−Zhaotong) have to suspend the production or reduce production capacity. One of the main experiences of successful development of shale gas in North America is the developed gas pipeline networks. The lack of overall pipeline networks, construction difficulty and high cost are the important factors to restrict the further development of China's shale gas resources.

4. Enlightenment from China's shale gas exploration and development

4.1. Connotation of shale gas

Shale gas is mainly found in "Organic-rich shale" zone, and shale gas province is the shale formation with a continuous distribution, similar geological and geographical characteristics and rich natural gas. In the practice of shale gas exploration and development, the connotation of shale gas in three aspects shall be noted [10]. First of all, shale gas is the natural gas in a free and adsorbed state existing in organic-rich shale, with the subject of self-generating, self-reserving and large-area continuous gas accumulation. Under the formation conditions, the shale matrix permeability rate is generally less than or equal to 0.001 mD; single well generally has no natural capacity, in which industrial gas can be only obtained by certain technical measures. Second, shale has neither the literal meaning, nor a simple definition of lithology. It is determined based on the particle size of organic matter and main ingredients. Shale in shale gas reservoir is the fine-grained sedimentary rock with the particle size of less than 0.0625 mm, which is the fine-grained sedimentary rock combination mainly consisting of shale; in addition to the shale, there may be or will be a small amount of other rocks, to constitute a lithologic combination. There is a clear definition of the composition (inorganic mineral, organic matter, etc.) For example, the shale here mentioned must be the black shale, rich in organic matter, clay minerals content, lamellation development, etc., so as to make a distinction with siltstone and lime mudstone in the lithology. Third, it must be the proven effective hydrocarbon source rock and the gas-producing source rock entering gas-producing window.

Therefore, to grasp the connotation of shale gas is very important to correctly understand shale gas accumulation. Shale gas accumulation is not to rely on natural gas migration and trap accumulation; anticline and other positive tectonics are conducive to shale gas enrichment; the peak area is the important factor (supplementary points) but not a necessary one in the evaluation and selection of shale gas "sweet spots". Necessary elements are enough organic-rich shale, the *TOC* content, moderate thermal evolution (moderate R_o), in order to ensure sufficient gas occurrence and continuous supplement; even if the slope without positive tectonics or high-spot horizontal shale formation or structure (anticline and syncline, depression, uplift, etc.) will also have rich shale gas accumulation. Essentially shale gas is natural gas with methane as the main component. The accumulation elements can be gathered, but the accumulation process must obey the basic rule of petroleum geology. Therefore, the structure preservation conditions for accumulation & enrichment are also very important. Although they are different from the strict preservation conditions for the conventional oil and gas accumulation, it is impossible for shale gas to form without certain preservation conditions and the dissipation of tectonic deformation on the shale gas cannot be ignored.

4.2. Misunderstandings of shale gas exploration and development

With breakthroughs in the shale gas exploration and development of Wufeng–Longmaxi Fms in Fuling, Changning (Changning–Zhaotong) and Weiyuan of the Sichuan Basin, there is much "over-optimistic" mood for the prospect of shale gas development in China. The primary cause is that there is no full understanding of the particularity and complexity of shale gas resources in China, so the concept of shale gas in North America is simply introduced to compare with that of China; some misunderstandings arose, such as "where there is shale there is shale gas", "Any shale gas can be developed for commercial purpose", "Conventional technology could be used to develop any shale gas". Neither the difference of geological characteristics between North America and China, nor the difference among the marine shale gas, marine–continental transitional shale gas and continental shale gas is fully understood [11,12]. In the practice of exploration and development, drilling, staged volume fracturing and other technologies were paid much attention to, while the evaluation and selection of quality resources of "sweet spots" were ignored, which resulted in the awkward situation of "Successful technology cannot obtain high production". Misunderstandings and unbalanced work divisions led to the irrational orientation of China's shale gas development stage, even there is a idea that China has entered a scale development stage of industrialization of shale gas, which would result in a higher development goal.

In fact, the successful shale gas development in the USA is not an overnight success, instead, it is based on the theoretical breakthrough, resource evaluation, technical research, pilot test phase and gradual scale development. Even so, the oil and gas companies in North America drilled more than hundreds of thousands of wells in the main shale gas production areas and carried out tens of millions times of fracturing. In Barnett, a mature shale gas production area, the output of a single well has increased by several times since 2005, but still about 40% of the fracturing sections have no output and about 30% of the fracturing sections have a little production, and only about 25% of the effective fracturing sections make a contribution to approximately 80% of shale gas production.

Similarly, no matter at what stage, the understanding of shale gas geology and resources will be always enhanced and the exploration and development technology will be improved continuously.

In North America, from vertical wells, horizontal wells to the "factory" production mode of platform well groups, the single well operation cost was greatly reduced, and also, the development cycle was shortened and the development efficiency was improved. Compared with 2010, the number of wells drilled by a drilling rig of North America in 2014 increased by 130% and the average length of horizontal well increased by 125%; the drilling speed was increased by an average of 60%, and single well cost was reduced by 50%–60%.

5. Prospect of shale gas development in China

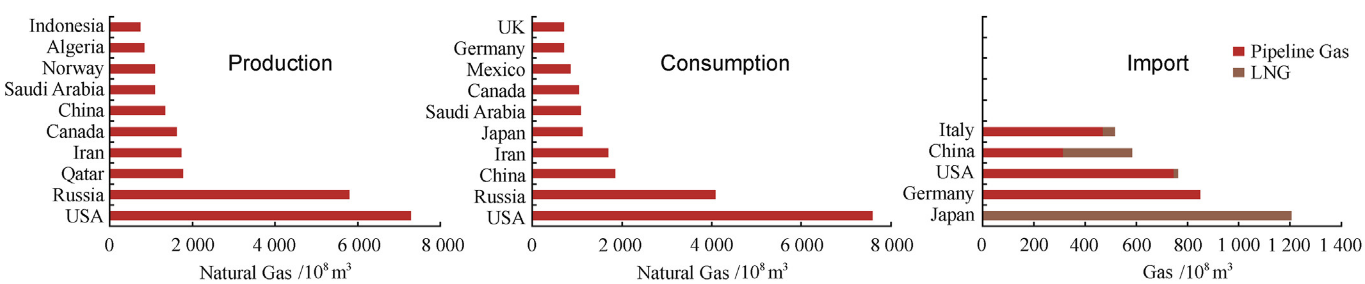
5.1. Great demands for natural gas in China's market

China's social economy continues to develop steadily and the demands for energy will continue to maintain at a high level. China became an oil net importer in 1993 and a natural gas importer in 2006. Currently, China is the world's largest energy consumer and producer and net importer (Fig. 7). China's external oil dependency surged up to 59% in 2014 from 1.2% in 1993, and from 0.8% in 2006 to 32% in 2014 in natural gas external dependency, by which China became the most important importer in the global energy market. In natural gas demand, in recent years (2006–2014), although the annual average production growth was more than 12%, one of the fastest growing countries around the world, China still has a small volume of the total gas production [13], with the volume of 1345×10^8 m^3 in 2014. Annual gas consumption in the same period rose by more than 16%, with the volume of 1855×10^8 m^3 in 2014. According to the forecast (Development Research Center of State Council, 2014), by 2020, China's annual natural gas consumption will continue to increase at a compound growth rate of 19%, and the proportion of gas in the energy structure will rise to 10%–15% from 5.6% in 2014, with the total volume up to 3500×10^8 m^3; however, the conventional gas production will be only about 2000×10^8 m^3 then, and the rest demands have to rely on the shale gas and other unconventional gas production and import.

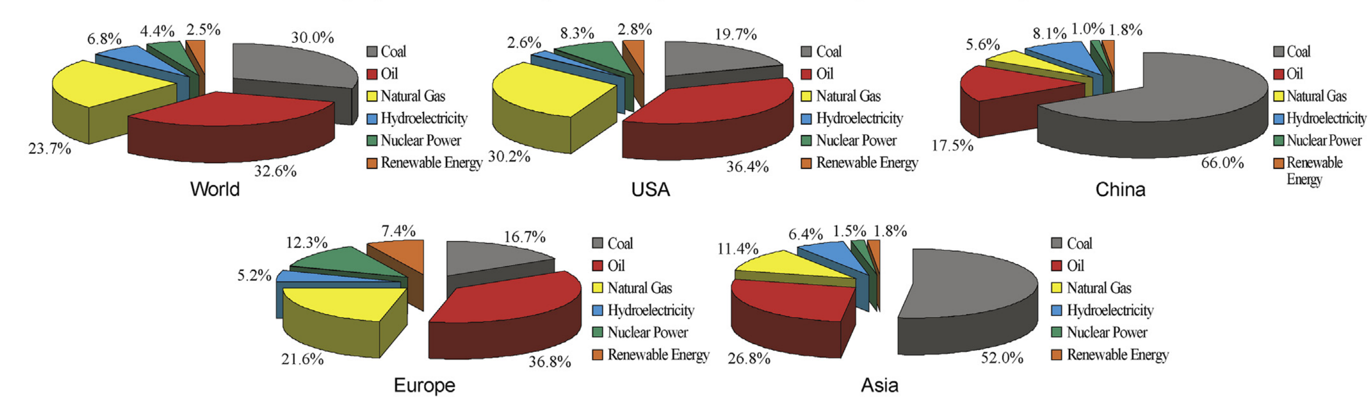
5.2. China is generally abundant in shale gas resources

At present, some departments and institutions have made preliminary estimates of shale gas resources in China with an analogy method and volume method, but they didn't fully implement the nationwide estimation, which resulted in a large difference among the predicted results (Table 7) [1]. An estimate made by EIA of the USA in 2011 and 2013 show that the geological shale gas volume is 134.4×10^{12}–144.50×10^{12} m^3 and the recoverable volume is 31.57×10^{12}–36.10×10^{12} m^3; in 2012, the Ministry of Land and Resources of China made an estimate that the geological shale gas volume is 134.42×10^{12} m^3 and the recoverable volume is 25.08×10^{12} m^3; in the same year, the Chinese Academy of Engineering estimated that the recoverable volume is 11.50×10^{12} m^3; in 2014, based on the new progress in shale gas exploration and development in China, the author predicted that the geological shale gas volume is 80.45×10^{12} m^3 and the recoverable volume 12.85×10^{12} m^3; and China Sinopec's estimated that the recoverable volume was 18.6×10^{12} m^3.

Accordingly, China generally has rich shale gas resources, with the geological resource volume ranging from 80.5×10^{12} to 144.5×10^{12} m^3 and the recoverable resource volume ranging from 11.5×10^{12} to 36.1×10^{12} m^3, most of which is marine shale gas and relatively less marine–continental transitional and continental shale gas.



a. Natural gas production,consumption and import of China and comparison with the top 10 countries in 2014



b. The proportion of natural gas in China's primary energy structure and comparison with other main countries in 2014

Fig. 7. Comparison between China and other countries in natural gas production, consumption, import and primary energy structure.

Table 7
Forecast of China's shale gas resource volume.

Institution	Time of evaluation (10^{12} m^3)	Type of resources	Marine facies	Marine–Continental transitional facies	Continental facies	Total
EIA of the USA	2011	Geological	144.50	/	/	144.50
		Recoverable	36.10	/	/	36.10
	2013	Geological	93.60	21.64	19.16	134.40
		Recoverable	23.12	6.54	1.91	31.57
Ministry of Land and Resources of China	2012	Geological	59.08	40.08	35.26	134.42
		Recoverable	8.19	8.97	7.92	25.08
Chinese Academy of Engineering	2012	Recoverable	8.80	2.20	0.50	11.50
PetroChina Research Institute of Petroleum Exploration and Development	2014	Geological	44.10	19.79	16.56	80.45
		Recoverable	8.82	3.48	0.55	12.85
Sinopec Research Institute of Petroleum Exploration and Development	2015	Recoverable		18.60		18.60

5.3. Prospect of shale gas development in China

Since the starting of shale gas exploration and development in 2005, China primarily achieved the first leaping-forward in the understanding of shale gas resources from 2006 to 2012, and made the preliminary forecast of the shale gas resources in the key areas and especially selected the most favorable areas for marine shale gas resources. Between 2010 and 2015, China realized shale gas discovery, production and proven reserves submission; large marine shale gas area was discovered in Wufeng–Longmaxi Fms of Sichuan Basin, Upper Yangtze region and Middle Yangtze region; the key gas-bearing areas in southern Sichuan, eastern Sichuan and NE Sichuan were made clear; a few shale gas fields of billions of cubic meters such as Fuling, Changning and Weiyuan were determined, with the proven reserves more than 5000×10^8 m^3. From 2013 to 2015, China realized a leaping-forward in the shale gas production; since the first 1 m^3 shale gas production in 2010, China's shale gas production exceeded 1.0×10^8 m^3 in 2012 and 10×10^8 m^3 (up to 12.47×10^8 m^3) in 2014, and will be more than 40.0×10^8 m^3 in 2015.

On this basis, the author predicted that, during the “13th Five-Year Plan”, in addition to the Sichuan Basin, Wufeng–Longmaxi Fms, there will be new breakthrough in the aspects of areas, series of strata and types of shale gas and new leaping-forward progress will be made in shale gas reserves and production; around 2020, China's shale gas production will be expected to grow to 300×10^8 m^3, laying the groundwork for the rapid development from 2020 to 2030. In terms of the shale gas production target of 300×10^8 m^3 around 2020, researches and analyses think that a shale gas production of 100×10^8–150×10^8 m^3 will be expected to achieve in the southern Sichuan region and in the eastern & NE Sichuan areas respectively. Table 8 shows the relationship between the reserves and production in different shale gas zones of the United States, additionally with the proven shale gas reserves and production of Wufeng–Longmaxi Fms in the Sichuan Basin of China. From the proved reserves and production comparison listed in Table 8, it can be foreseen that there will be significant further growth prospect in the proven shale gas reserves and production of Sichuan Basin.

6. Conclusions and suggestions

1) Shale gas exploration and development has been widely carried out throughout China. In Wufeng–Longmaxi

Table 8
Relationship between the reserves and production in different shale gas zones of USA in 2014 and that compared with the Wufeng–Longmaxi Shale in the Sichuan Basin of China.

	Situation	Shale gas reservoir	Resource volume/10^{12} m^3	Proven reserves in 2014/ 10^8 m^3	Production in 2014/10^8 m^3
USA	Appalachian Basin	Marcellus	6.87	23927.9	1387.5
	Appalachian Basin	Utica	0.26	1807.8	124.9
	Fort Worth Basin	Barnett	1.25	6887.8	517.1
	Western Gulf Basin	Eagle Ford	0.79	6697.8	533.5
	Texas–Louisiana Salt Basin	Haynesville/Bossier	5.84	4700.6	396.4
	Arkoma & Anadarko Basins	Woodford	0.63	4699.8	240.1
	Arkoma Basin	Fayetteville	1.17	3306.9	293.1
Others			0.83	4515.4	314.9
In total			17.64	56544.0	3807.5
China	Sichuan Basin	Wufeng–Longmaxi	4.50	266.8 (360.33×10^8 m^3 in total in 2015)	12.47 (>60×10^8 m^3 in total in 2015)

Note: Source of U.S. shale gas reservoir data EIA-23, Annual Survey of Domestic Oil and Gas Reserves, 2013–2014.

Fms of Sichuan Basin, the rapid development of discovery−verification−production has been realized, so a preliminary industrialization stage is presented. A few basins and areas across the country have been proven with organic-rich and gas-bearing shale, which is under an early stage of exploration and development.

2) Shale gas resources still belong to oil and gas resources, with accumulation & enrichment following the basic rule of petroleum geology and more complex than that of the conventional oil and gas resources. In terms of shale gas geology, surface features, pipeline networks and the infrastructures, China is far behind North America; in China, the degree of resource development implementation is low, therefore, the shale gas development mode of the United States cannot be simply copied by China. Only constantly establishing the shale gas exploration and development curve and gradually forming the shale gas development mode suitable for China can it be realized the great shale gas development.
3) By 2020, China's annual shale gas production will be expected to reach 300×10^8 m^3. Strengthening the geological understanding of three types of shale gas resources, effective implementation of shale gas resources and selection of "sweet spots" should be carried out to orderly promote the construction of shale gas pilot demonstration zones and make breakthroughs in key technologies and equipment both for non-marine shale gas exploration and marine shale gas development below 3500 m.
4) Theoretic & technological researches should be strengthened and shale gas "sweet spots" evaluation should be actively carried out to highlight the effective implementation of shale gas resources and gradually lay a solid foundation for its development. China should attach great importance to the early evaluation of exploration and development and control the schedule of evaluation, drilling and capacity construction. Comprehensive summary of the experiences in the rapid shale gas exploration and development should be made; the key indicators demonstration and evaluation should be highlighted; breakthrough and replacement in new zones, new fields and new formations should be strengthened.

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