The 17th Sino-US Oil and Gas Industry Forum

SINOPEC Shale Gas Development Experience and Cooperation Prospects

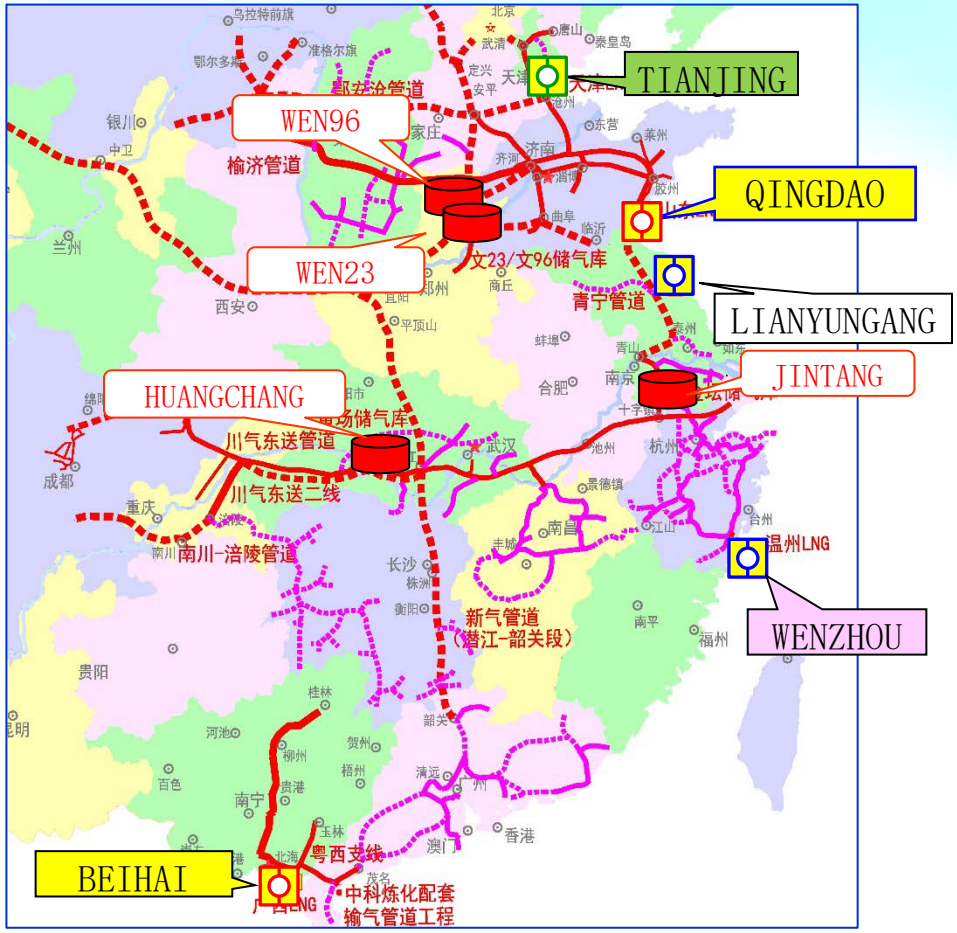
November, 2017

SINOPEC's upstream development strategy

Following the value-oriented, innovation-driven, resources-coordinating, open & cooperative, green & low-carbon strategies, SINOPEC's upstream business aims to realize a sustainable development of crude oil and fast growth of natural gas.

In recent years, SINOPEC's natural gas business has witnessed a fast growing trend. Natural gas supply goes up from 12.4 billion m^3 in 2010 to 23.9 billion m^3 in 2016 with a 12.5% annual growth rate. A diversified gas supply structure, including conventional gas and shale gas, is taking shape.

- About 8,500km of natural gas pipelines have been built by the end of 2016.
- Three LNG terminals were built. Shandong terminal and Guangxi terminal were put into operation. Tianjin terminal will be on line soon.
- One gas storage (Wen 96) has been built. The other two (Wen23, Jintan) are under construction.



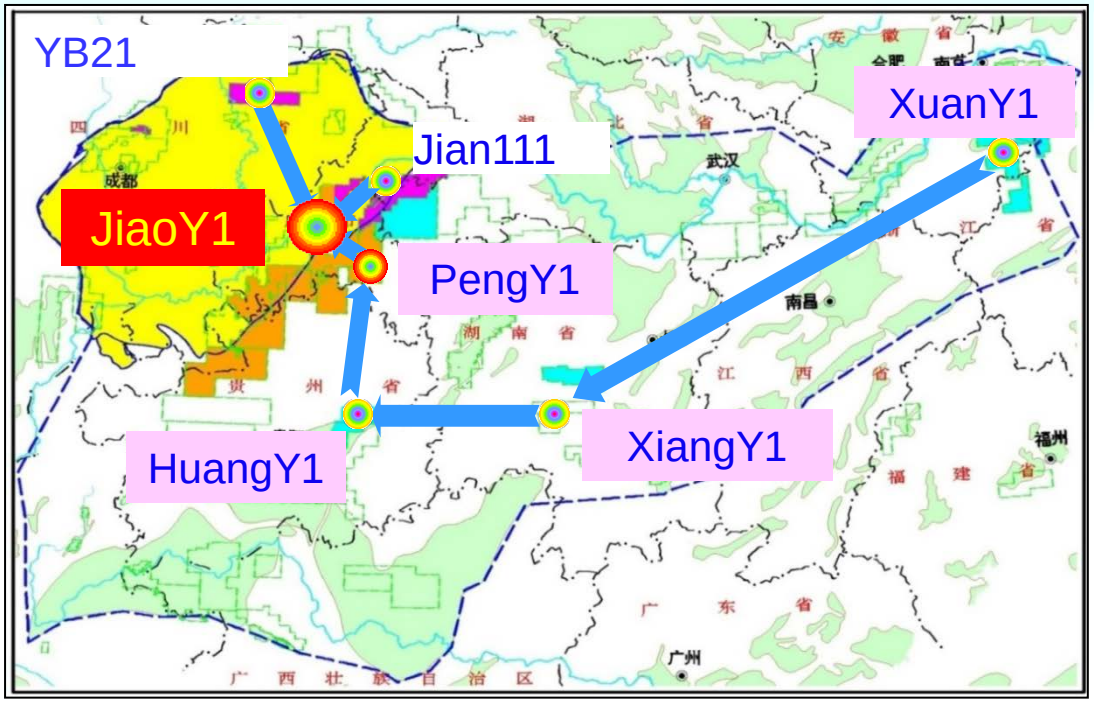
Outline

I. History and Current Situation of Shale Gas Development

II. Development Characteristics of FULING Shale Gas Field

III. Prospects and Challenges

1. Milestone events and breakthrough of shale gas exploration



Southern China (Marine Facies)

- Complex structures
- Poor preservation
- High thermal maturation

Sichuan Basin (Marine & Continental Facies)

- Hard to realize Commercial development due to the high cost and lack of mature technologies

Southeastern of Sichuan Basin (Marine Facies)

- Marine shale gas exploration achieved breakthrough in Jiaoshiba

- **2010, Well Xuanye1, Heye1——shale formation was discovered with gas shows**
- **2011, Well Huangye1, Xiangye1——shale formation was discovered with low gas flow**
- **2012.7, Well PengyeHF-1——high-quality shale formation was discovered and industrial gas flow was realized**
- **2012.12, Well Jiaoye1HF——With 15 hydraulic fracturing stages, JY1HF reached the industrial gas flow of 203,000 m^3/day, which marks the breakthrough of shale gas exploration**

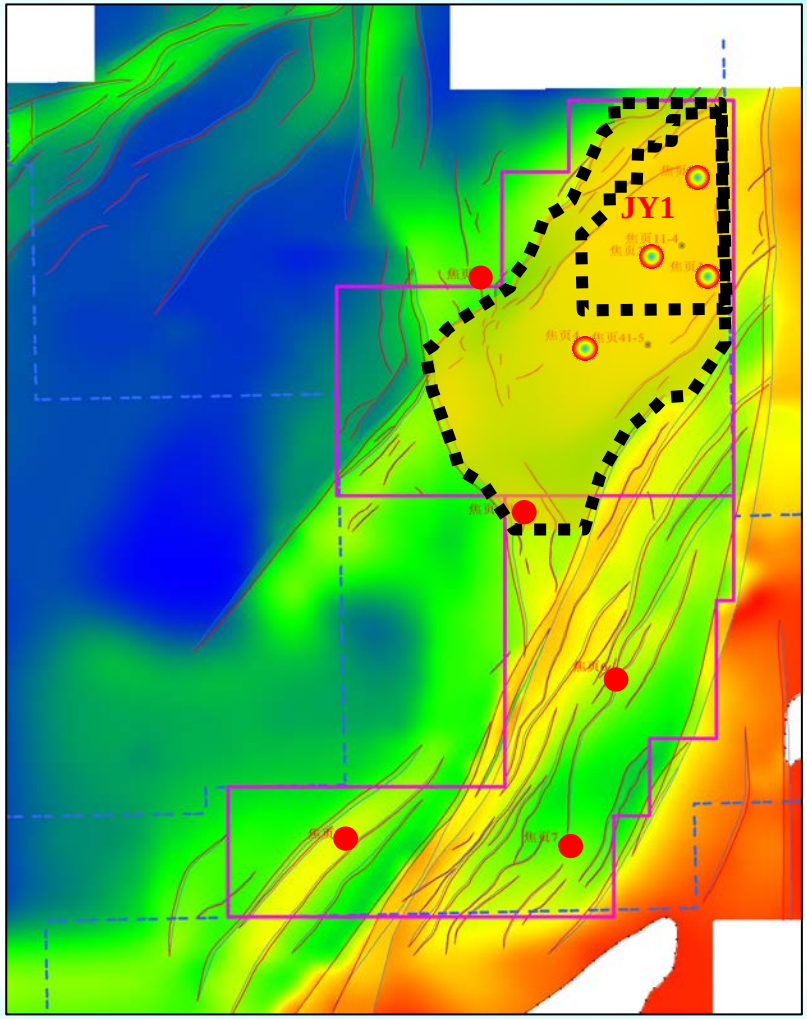
2.1. Extend the exploration area to figure out the OGIP of Fuling Gas Field

Discovery： Shale gas production of Well Jiaoye1-HF drilled in the Silurian Longmaxi Formation reached 203,000 m^3/d

Main Targets Exploration: Deploy 3 exploration wells and 3D seismic 600 km^2

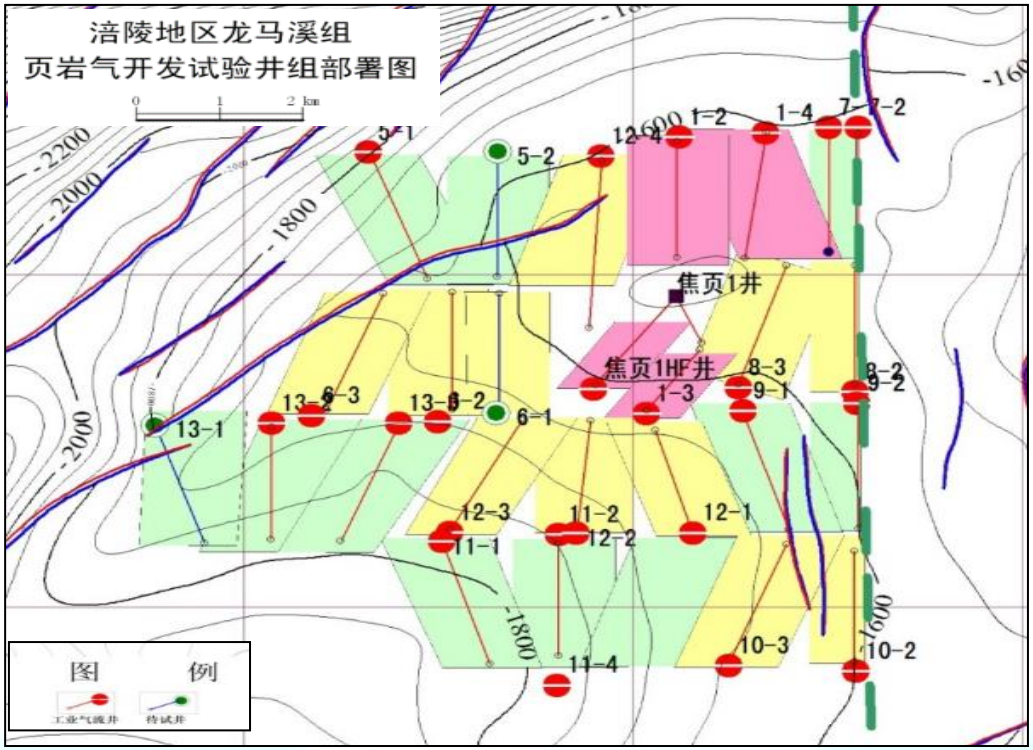
Exploration Expansion： Deploy 5 exploration wells and 3D seismic 550 km^2

Accumulated gas bearing area reached 600 km^2, with 600 billion m^3 OGIP.



2.2 Conduct field tests on development wells and implement development technology policy

Based on the commercial discovery of Jiaoye1-HF, favorable areas are selected to test and evaluate the development shale gas wells in order to get critical development parameters and optimize the development plan.



List of Field Test

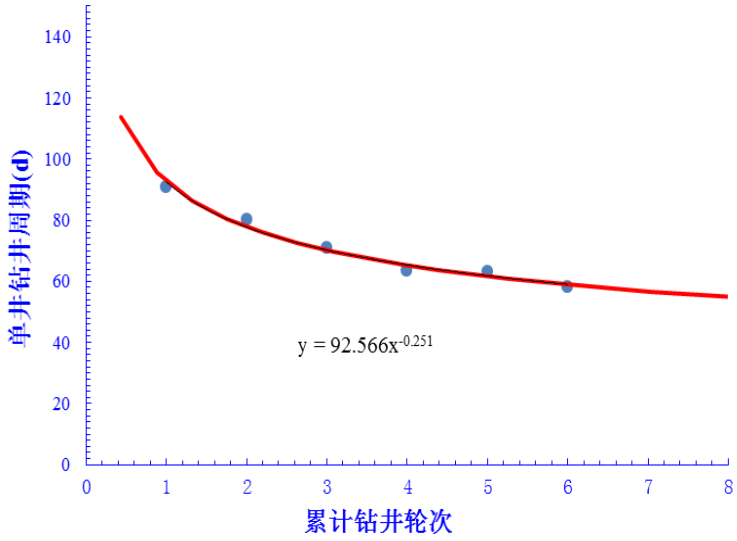
- Length of horizontal wells
- Direction of horizontal wells
- Horizontal trajectory
- Well space
- Producing with constant gas rate or flowing pressure
- Fracturing technology

2.3. Through technology research and a shared learning system, Fuling Shale Field have been developed efficiently.

- **Focus on "Well Pad" technologies and equipment researches and tests in mountainous regions to realize a large-scale production construction.**
- **Push forward the shared learning curves to greatly improve the operation efficiency.**

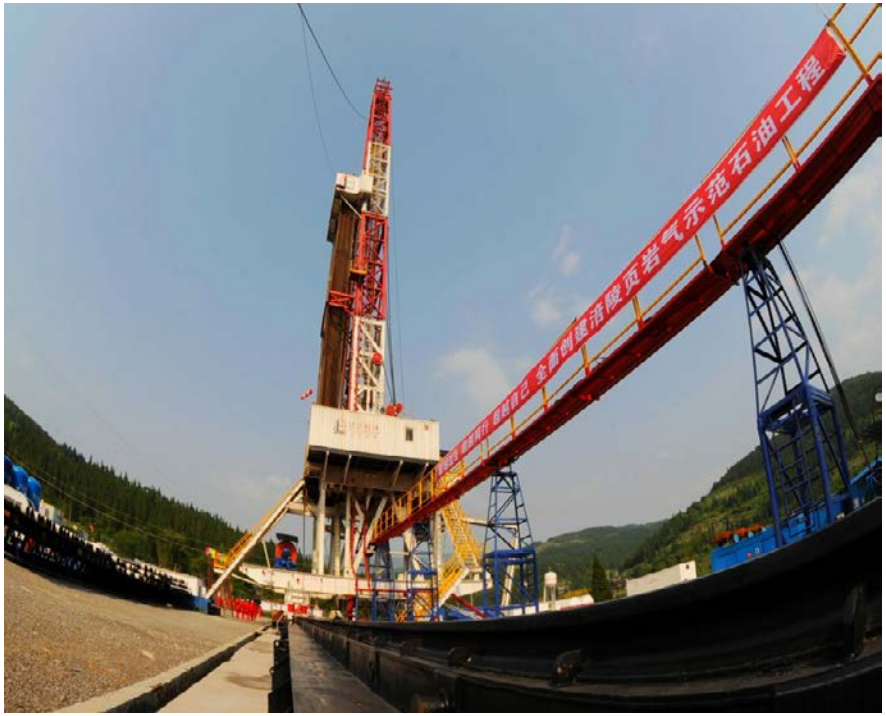
Large-scale fracturing

Drill Tower in Qingshan



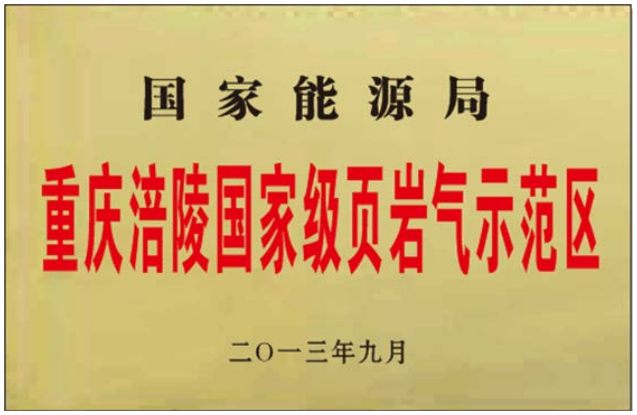
Learning curve of drilling in the main target area

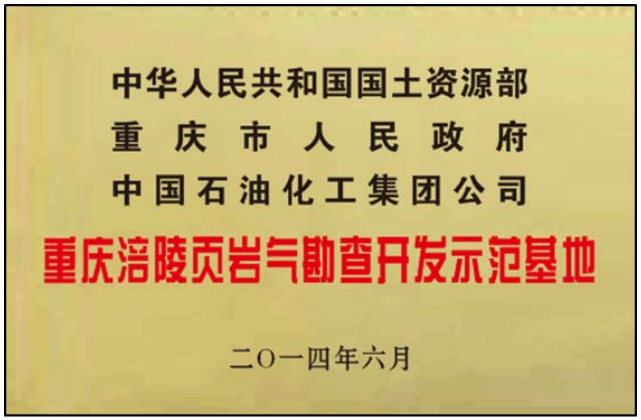
2.4. Established a shale gas field with a 5 billion m^3 production capacity within 3 years and 10 billion m^3 within 5 years.



- 2013, the annual productivity of shale gas reached 500 million m^3
- 2014.3, Fuling field became China's first shale gas field which was announced to enter its commercial development
- 2015, Fuling National Shale Gas Demonstration Area was founded with a 5 billion m^3 production capacity
- 2017, the accumulated production capacity in Fuling Field is 10 billion m^3 and accumulated gas production have reached 15.4 billion m^3

Fuling field is not only the first built shale gas field in China but also one of the largest shale gas fields in the world besides those in North America, attracting more and more attention from the global oil and gas industry.





Chongqing Fuling National Shale Gas Demonstration Area is a successful example of China's shale gas exploration and development, and significantly increases confidence in the development of China's shale gas industry.

From National Energy Administration

3. New discoveries in Sichuan Basin and its surrounding areas

Silurian Longmaxi Form

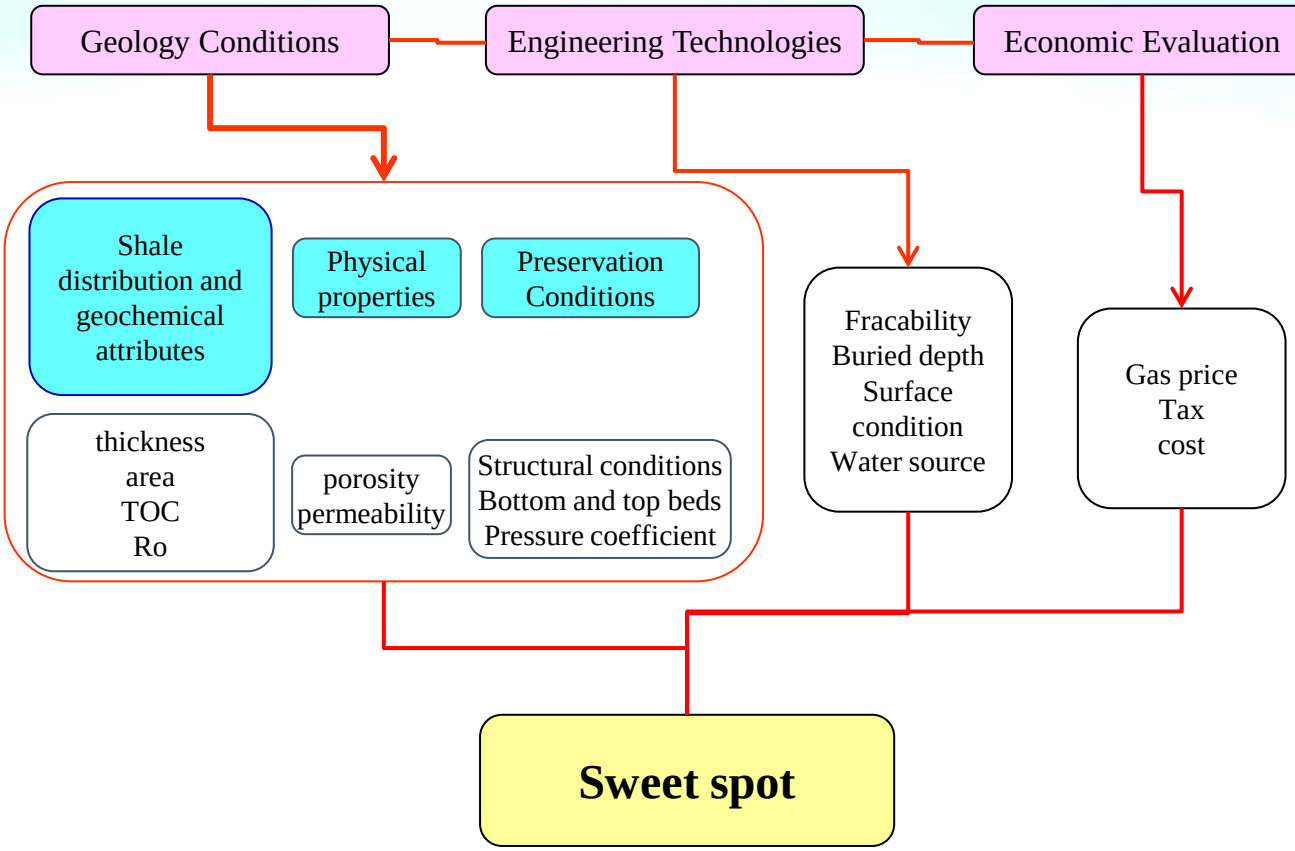
- Weiyuan-Rongxian: Weiye1HF, 175,000 m^3/d
- Rongchang-Yongchuan: Yongye1HF, 141,000 m^3/d
- Qijiang-Dingshan: Dingye2HF, 40,000-100,000 m^3/d
- Pengshui-Wulong: Longye1HF, 46,000m^3/d

Cambrian Qiongzhusi Form

- Jingyan-Qianwei: Jinye1HF, 84,000m^3/d

4. The marine shale gas technology system

4.1 “sweet spot” evaluation methods for marine shale gas



Considering the multistage tectonic movements, we focused on organic-rich shales, preservation conditions, engineering technologies and economic feasibility to create the “sweet spot” evaluation methods for marine shale gas.

4.2. Multistage hydraulic fracturing system for horizontal wells with depth <3,500m.

Using the advantages of Sinopec industrial chain and strengthening the R&D of related technologies, Sinopec has created 3 majors (drilling, logging and downhole operation), 9 systems and 57 technical series.

Wheel rig on the drill site of Jiaoye30

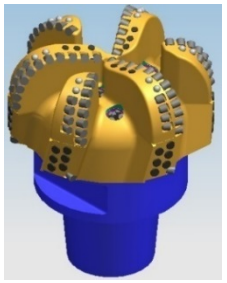
4.3 Localized Manufacturing of key equipment and tools

We have the capacity to manufacture key equipment and tools, execute construction and provide engineering services all by ourselves, which enable us to lower the cost and improve the efficiency.

Wheel rig

3000HP fracturing truck

Drillable plug
(cost reduced from 200,000RMB to 25,000 RMB)



PDC drill bit
(net drilling time increased from 42hr to 80hr)

Coiled Tubing

4.4 Replicable green shale gas development mode ready for broader application

(1) “Well Pad” operation mode in mountainous regions

“Well Pad” drilling site

“Well Pad” fracturing site

We created the “Well Factory” operation mode, compiled China’s first land “Well Pad” drilling operation standard, thus the operation cycle has been cut by 40%.

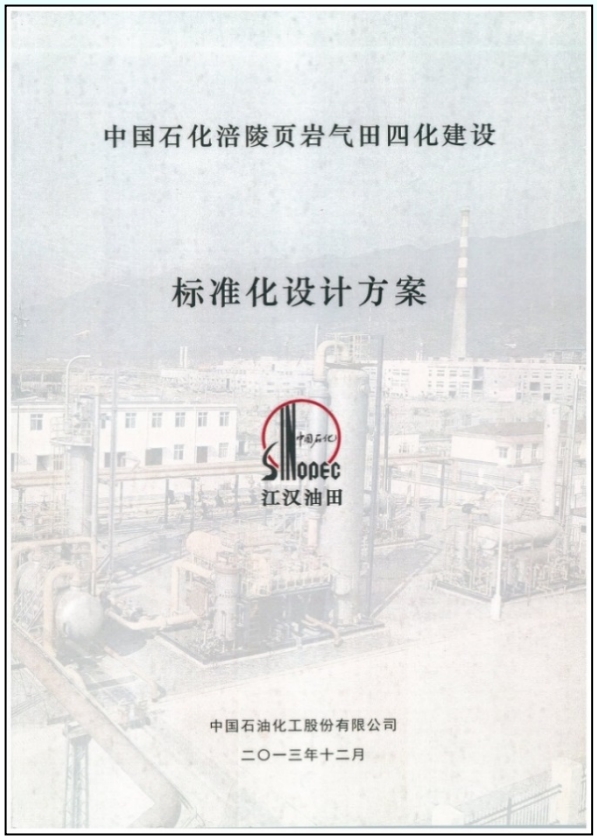
(2) Supporting technologies for gas field safety and environmental protection

- Land Resources： Intensified utilization
- Water treatment： Recycling and reuse
- Air： Pollution prevention
- Solid Waste： harmless disposal
- Noise： Pollution control

Green Well Site

Gas Gathering Station

(3) Standardized surface construction mode



Skid mounted module

Intelligent production scheduling and control center

The surface construction mode is characterized by standardized design and procurement, modular construction and information enhancement to help realize the factory prefabrication, skid-mounted modulation and installation, and digital management.

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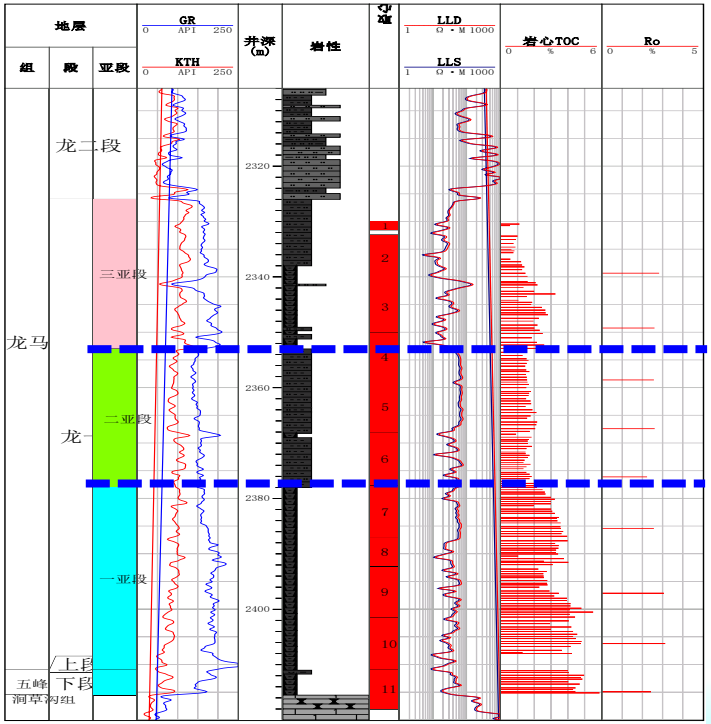
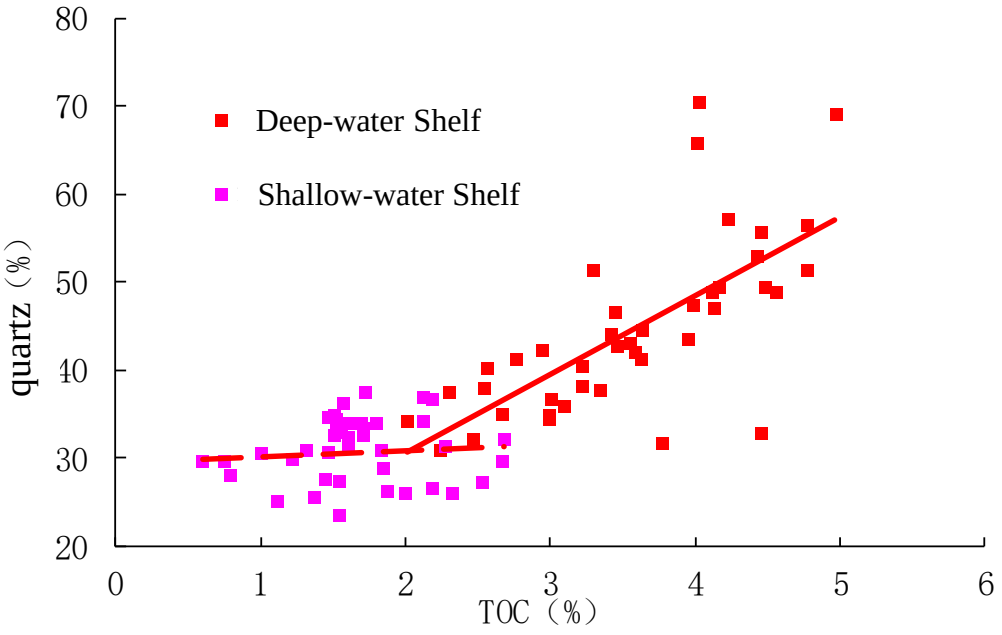
1.1 Prominent source rock is the base

Lower part of Wufeng—Longmaxi Formation deposited on a deep-water shelf where shales are enriched with carbon and silicon. There are 9 layers divided vertically. 1-5 layers are defined as prominent shales with high thickness(38-42m), high TOC(>3%) and a stable distribution.

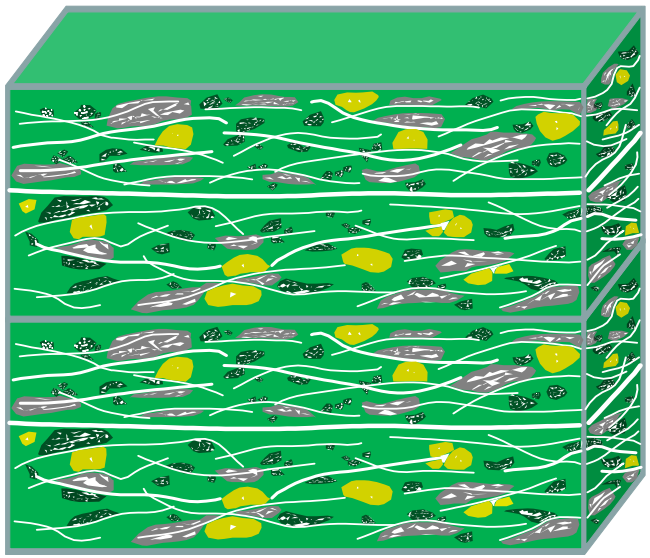
TOC in the 1st section of Wufeng-Longmaxi Formation, Well Jiaoye1-HF

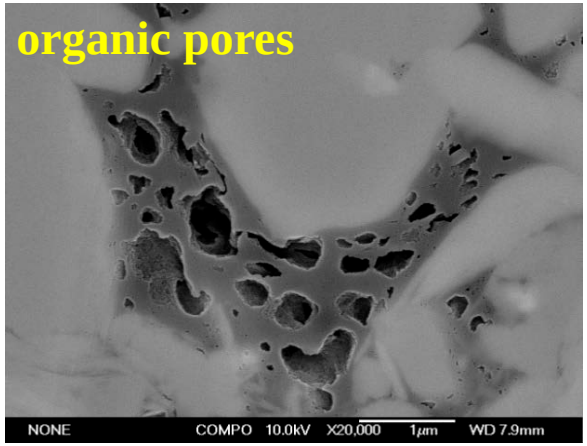


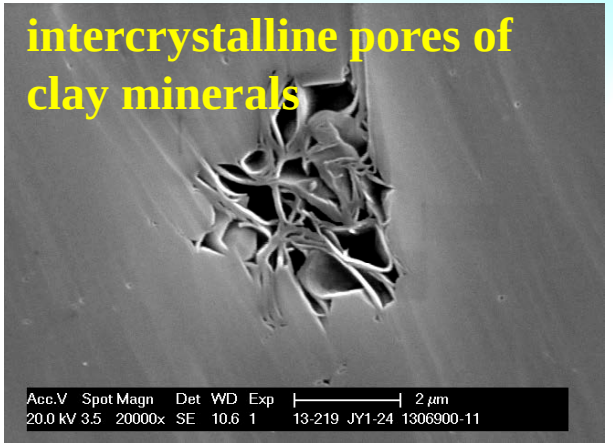
TOC vs Quartz Content in Well Jiaoye1-HF

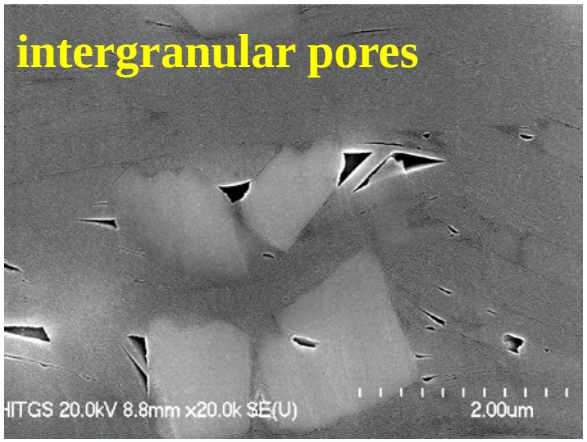


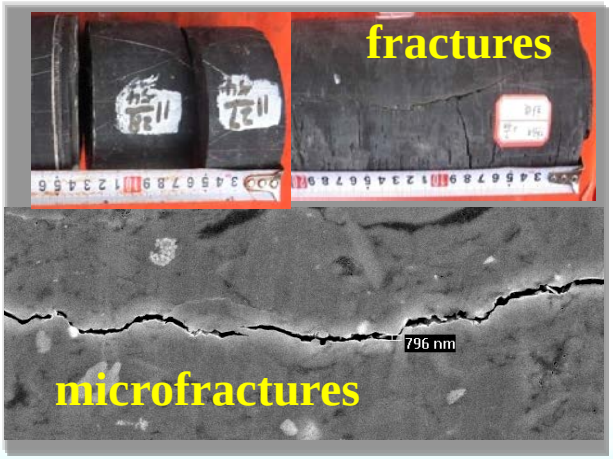
A key factor of high yield is the complex pore-fracture storage space including organic pores and micro-fractures





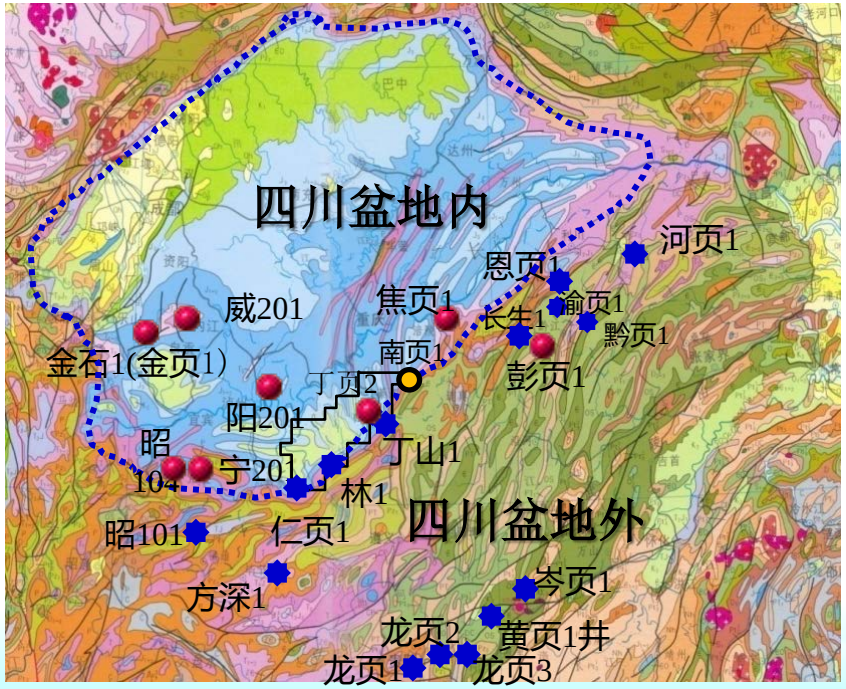


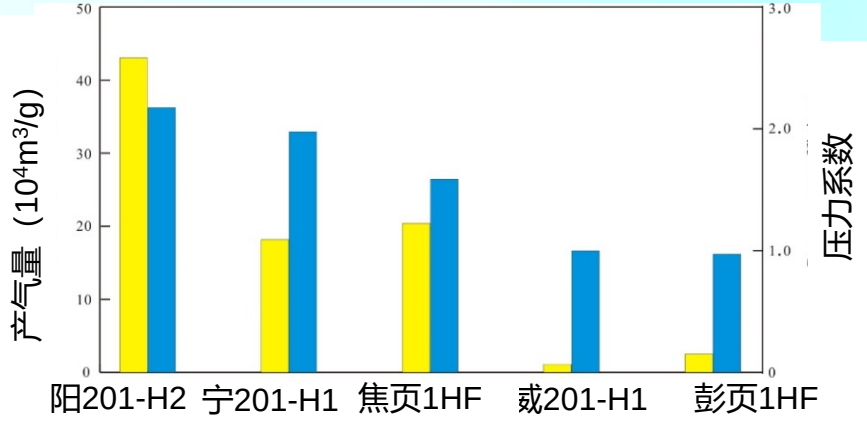


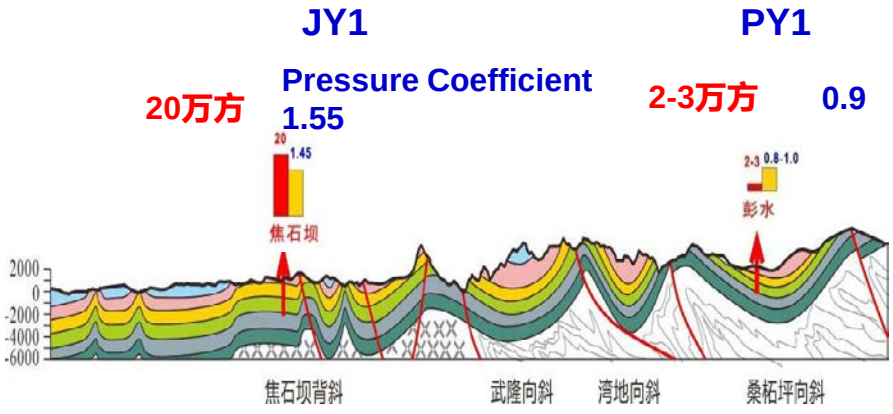


1.2 Preservation condition is the core

High production gas wells are mainly distributed within the Sichuan Basin with high pressure coefficient, while low production gas wells are located outside the basin which is an underpressured system.







Structural section map

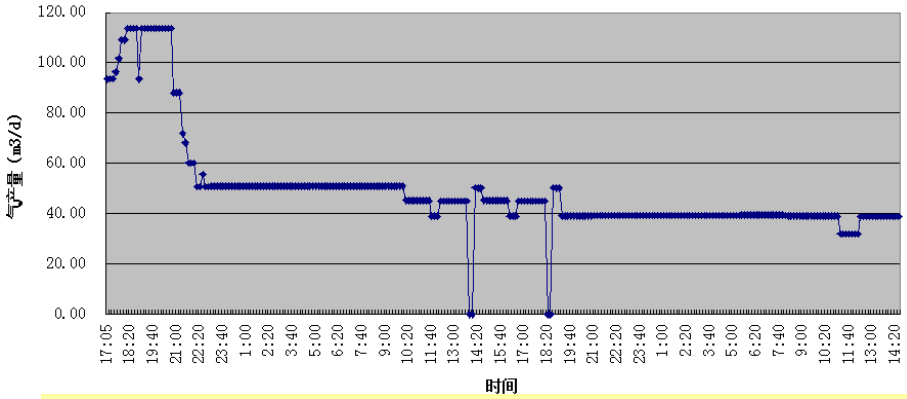
1.3 Hydraulic fracturing is the key

A well-designed multistage horizontal well fracturing is the key to create connected hydraulic fractures and fully stimulate the reservoir. Wellbore trajectory and placement have direct impacts on stimulation efficiency.

Main engineering factors controlling the shale gas production

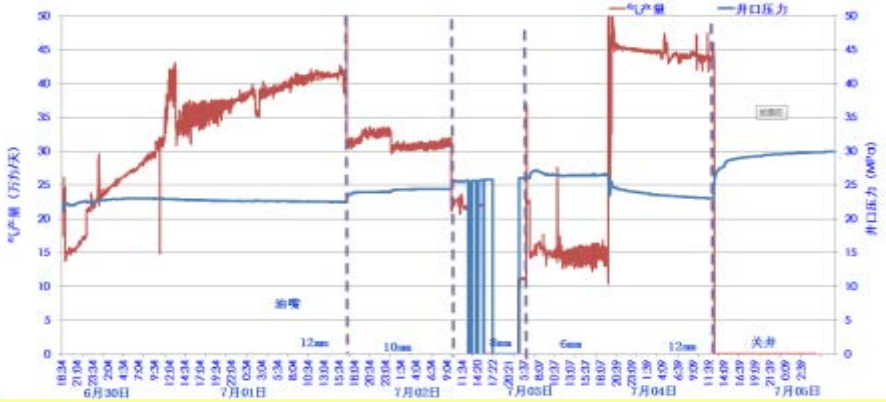
- **Wellbore trajectory: high TOC and high brittleness**
- **Well placement: Perpendicular to the maximum principal stress**
- **Height difference between target points A and B: less than 200m**

Test Production Curve of Well Jiaoye11-4



Jiaoye11-4 is a vertical well without fracturing, test production is 40-93 $\times 10^4$ m^3/d after perforation

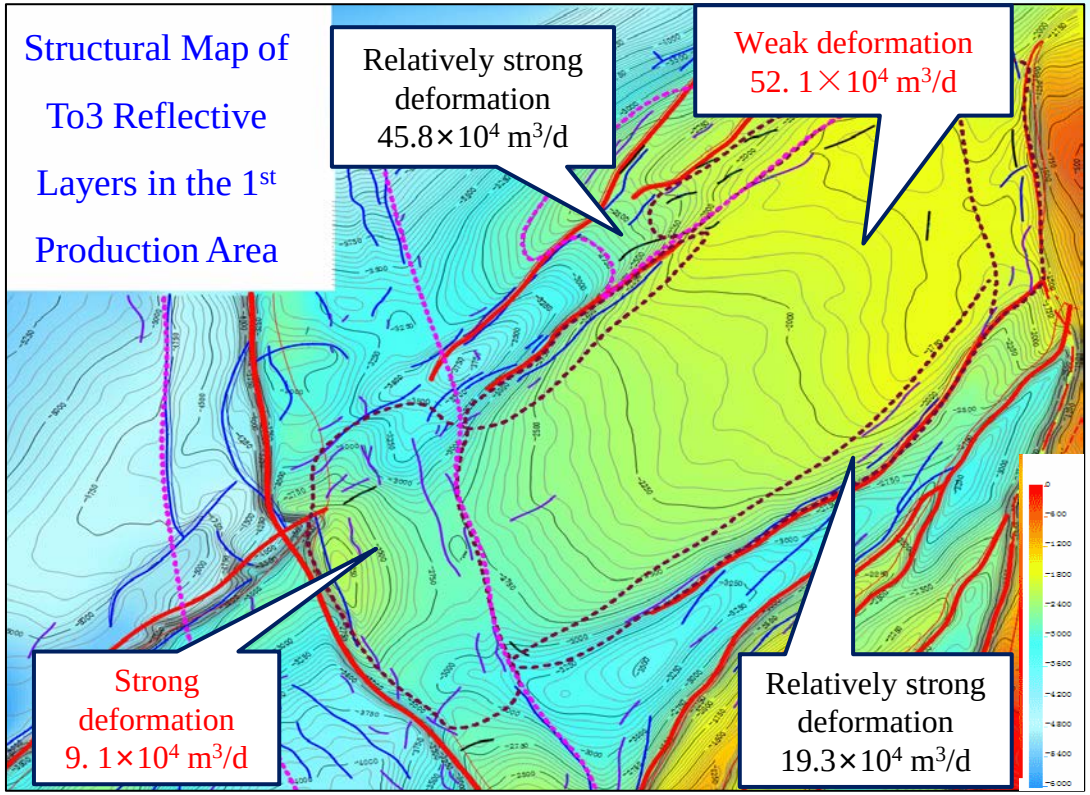
Test Pressure and Temperature Curves of Well Jiaoye11-2HF



Jiaoye11-2HF has a lateral length of 1385m, with 14 stages and test production of 15-45 $\times 10^4$ m^3/d

2.1 Open flow of shale gas wells are generally high with diversities in different regions.

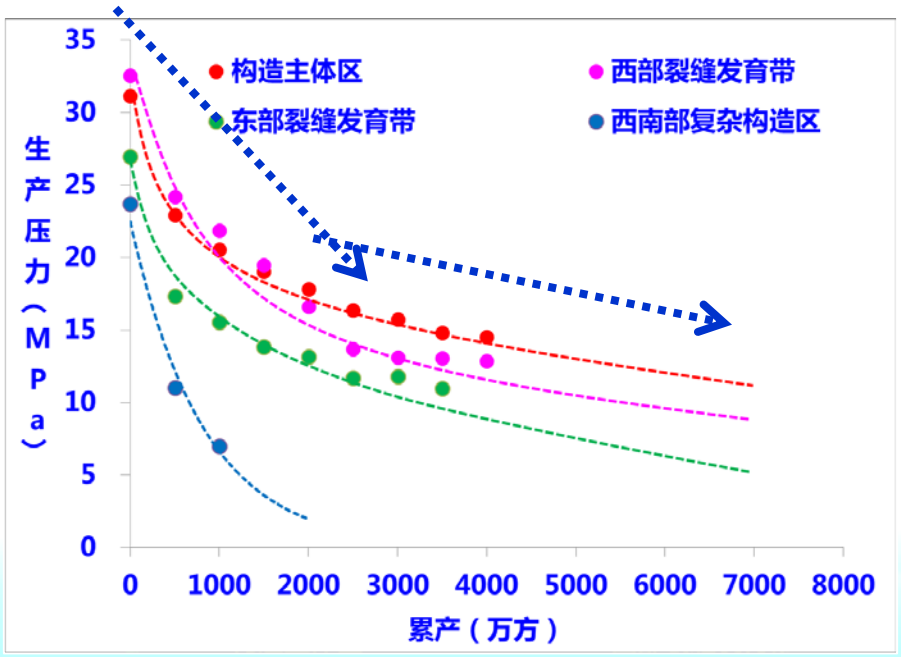
The average open flow in the 1st production area is 385,000 m^3/d; Regionally, open flow is higher in the north and central area, and lower in the south area, east and west sides.



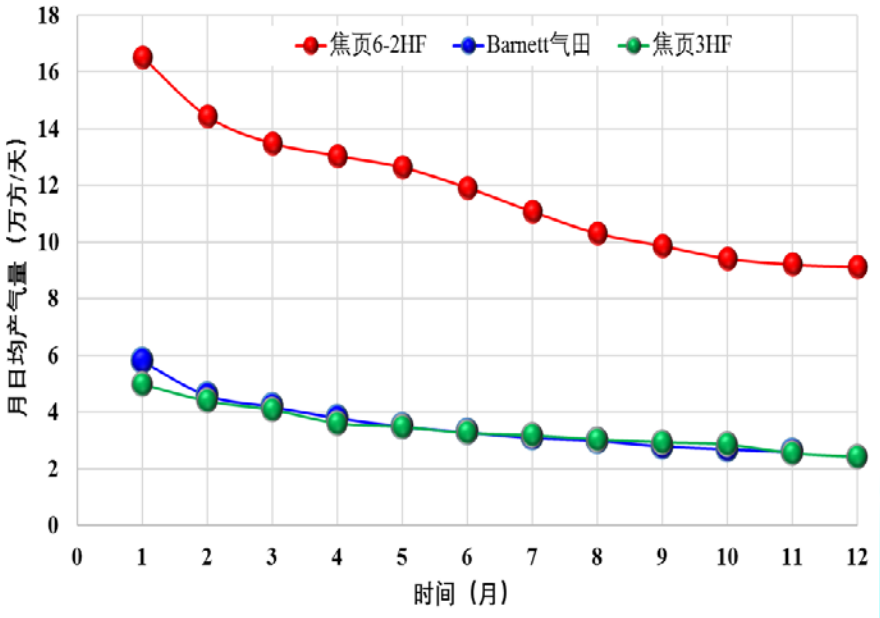
2.2 shale gas wells show multistage production characteristics which vary in different areas

Decline curves of some shale wells overlap with that in Barnett, showing a much higher decline rate initially and then become lower. Different blocks have different decline rate.

Production pressure vs cumulative production in different areas

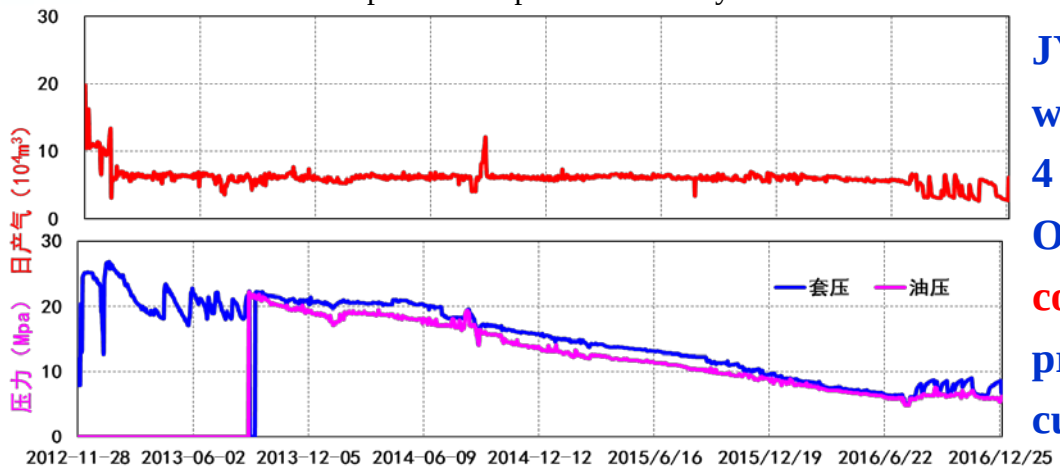


Normalized 1st year production rate of a single well in Fuling compared with that in Barnett



2.3 With a constant production rate, the gas wells have a production stable period

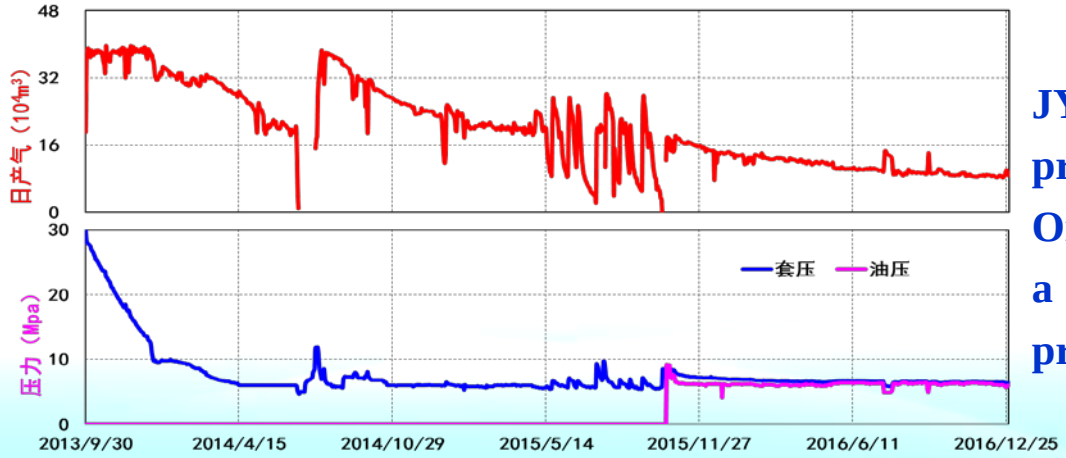
Production curve of JY1HF
（stable production period: 1302 days）



JY1HF has the longest production time with a stable production period of almost 4 years.

On Nov. 28, 2012, JY1HF produced with a constant rate of 60,000 m^3/d. Its current production rate is 25,000 m^3/d, with a cumulative production of 101 million m^3.

Production curve of JY6-2HF
（accumulative gas production is the highest）



JY6-2HF has the highest cumulative production of 255 million m^3.

On Sep. 29, 2013, JY6-2HF produced with a large pressure difference. Its current production rate is 74,000 m^3/d.

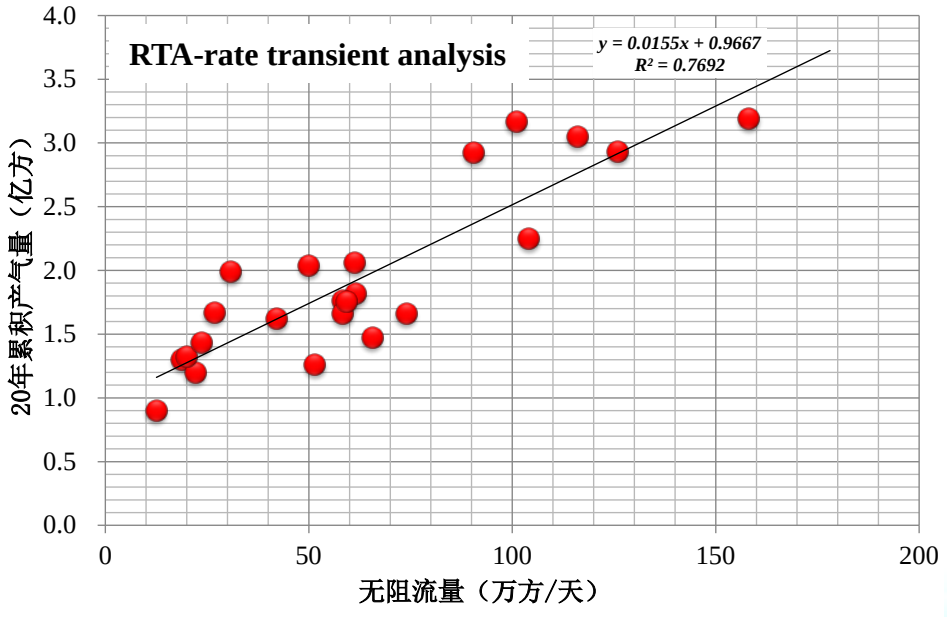
2.4 Recoverable reserves of single well are generally high

- **The average economic recoverable reserves of single well is 172 million m^3 in the main area of Fuling shale gas field.**
- **Well-control reserves of single well are different and show a positive relationship with open flow.**

Well-control reserves in Fuling Gas Field

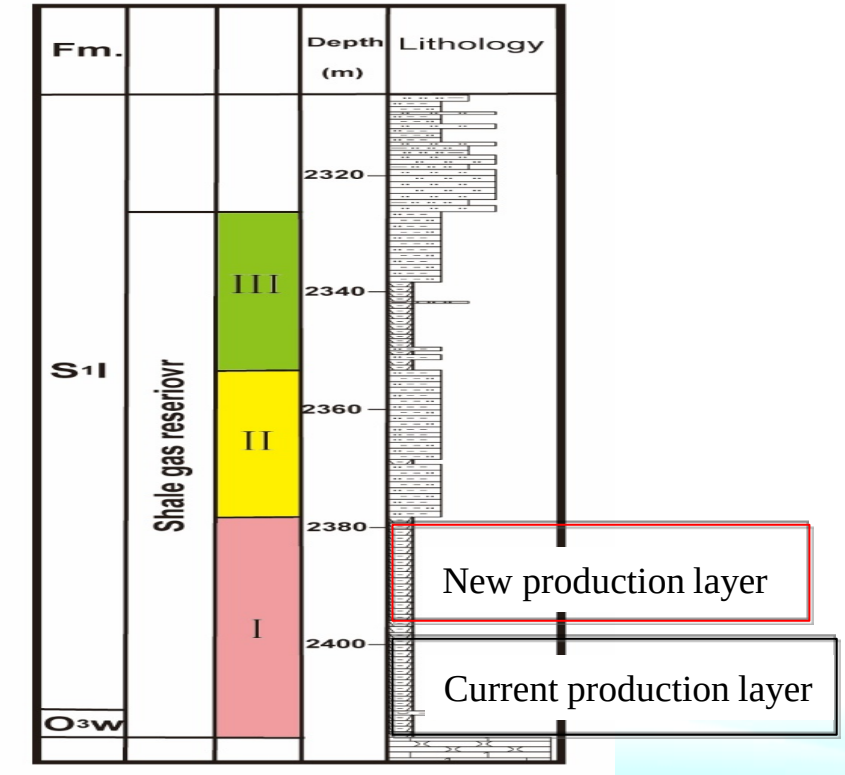
Year	Average well-control economical recoverable reserve (10^8 m^3)
2013	1.23
2014	1.76
2015	1.80
2016	1.72

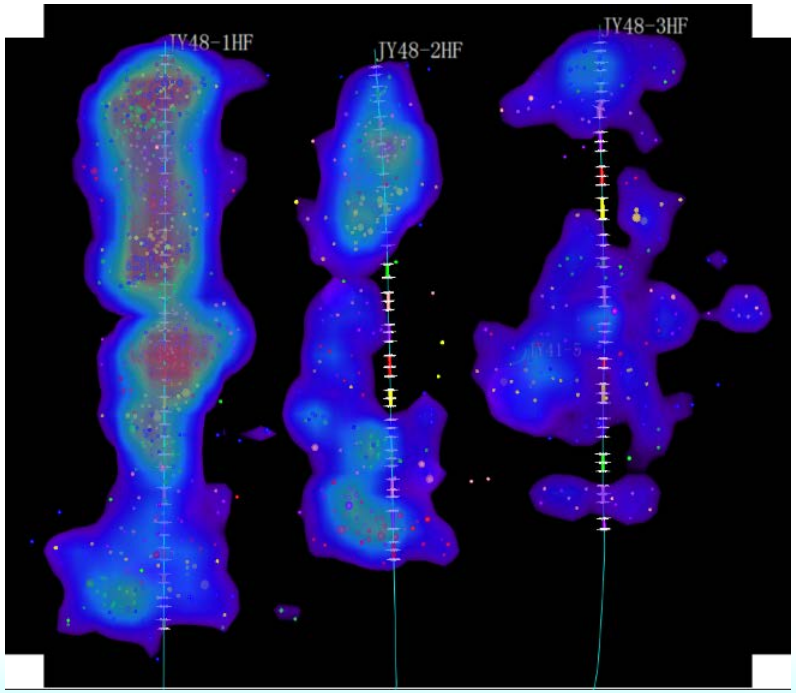
Single well open flow vs 20-year cumulative production



2.5 Further development of Fuling Field through infill wells

- **Drilling data shows the current production wells mainly stimulated the lower part of the target formation, leaving the upper part available to further develop.**
- **Microseismic data confirmed that there is enough space for infill wells to be drilled between fractured production wells.**





Fracture network image monitored by microseismic

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1. Rich shale gas resources and great exploration potential in China

China's petroliferous basins have marine facies, continental facies and transitional facies with multiple organic-rich shales. Currently, Silurian formation in Sichuan Basin and its surrounding areas shows great development potential and has realized commercial development.

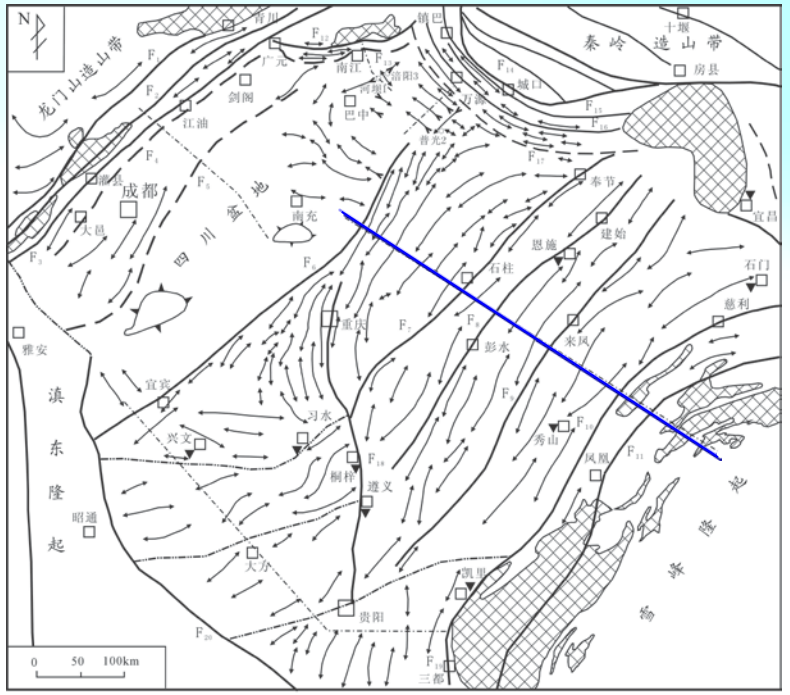
Institution	Year	Estimated OGIP ($10^{12}m^3$)	Estimated Recoverable Reserves ($10^{12}m^3$)	Remarks
EIA	2011	144.5	36.1	Sichuan and Tarim Basin marine facies
EIA	2013	134.4	31.57	Major basins
China's Ministry of Land and Resources (MLR)	2012	134.42	25.08	Continental areas
Chinese Academy of Engineering	2012		10-13 (Avg. 11.5)	Major basins and areas
Petroleum Exploration and Production Institution, SINOPEC (PEPRIS)	2015	80.45	12.85	Major basins
PEPRIS	2014		18.6	Continental areas
MLR	2015	122 (<4500m)	22	Continental areas

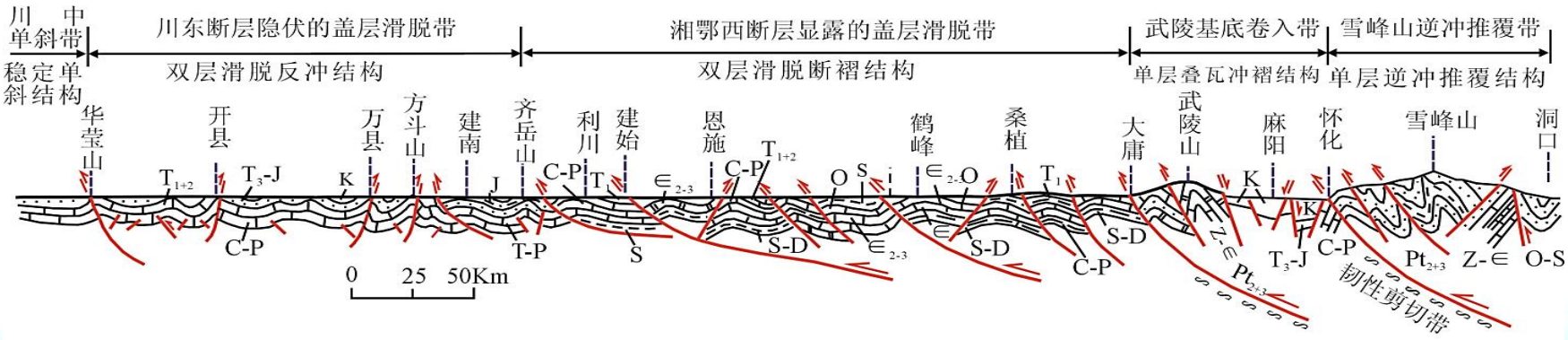
According to the Ministry of Land and Resources statistics in 2015, technical recoverable resources of shale gas in China reached $22\times10^{12}m^3$ among which $13\times10^{12}m^3$ is marine facies, $4\times10^{12}m^3$ is continental facies and $5\times10^{12}m^3$ is transitional facies.

2. Marine shale gas

Marine shale in China has been strongly affected by the multi-phase tectonic movements, thus preservation conditions vary a lot in different areas.

- **Depression areas within the basin have a favorable preservation condition. Buried depth of marine shale is large, generally ＞4,000m.**
- **Syncline area outside the basin have a relatively poor preservation condition. Production of underpressured shale gas is low.**



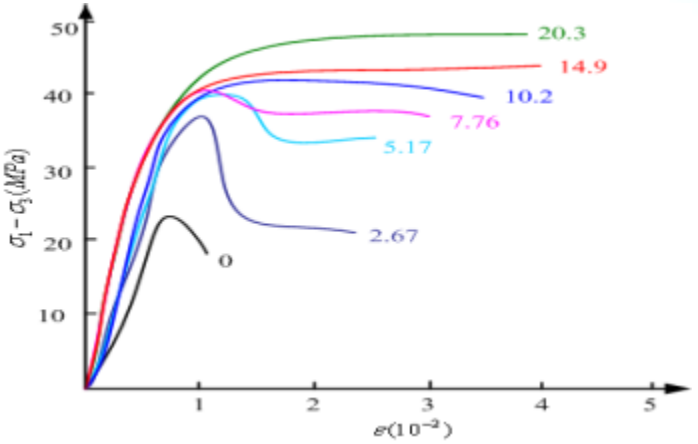


2.1 Deep shale gas （>4000m）

Challenges

- Due to the high in-situ stress, current engineering techniques are able to frac shales with low brittleness.
- Sweet spot evaluation methods for deep shale gas are still under exploration.
- High cost of deep shale gas development bring great challenge to shale gas development.

Stress and strain curves of mudstone under different confining pressure



In-situ stress of 3 wells

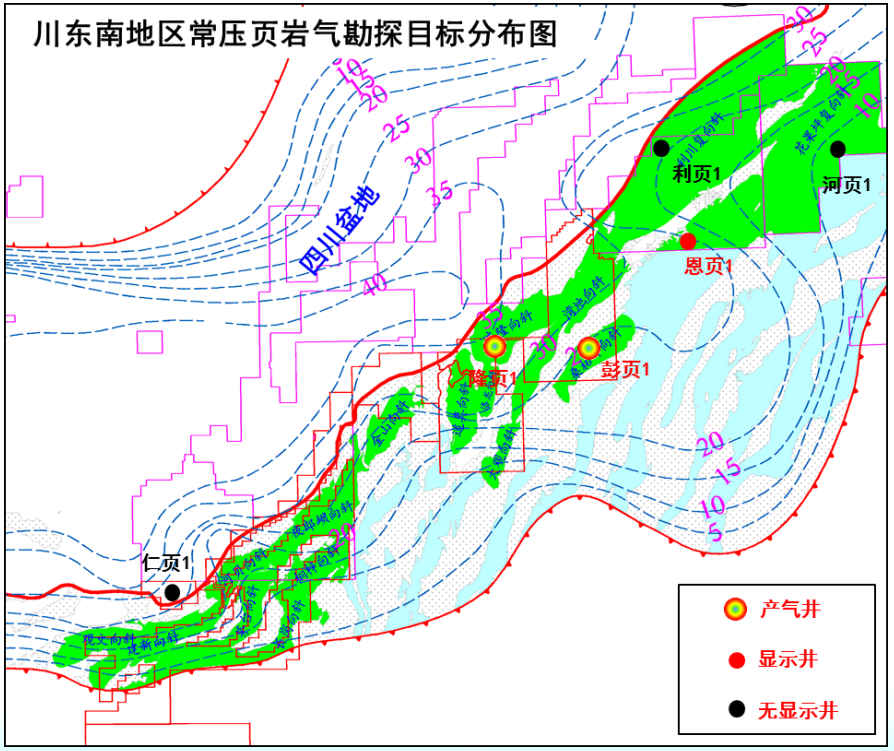
No.	Well	Formation	Depth(m)	3 principle stress (MPa)		
				Overburden stress	Maximum horizontal stress	Minimum horizontal stress
1	DY1	Longmaxi	2044.87- 2045.04	48.73	48.59	43.6
1	DY2		4353.05-362.55	145	121.6	109
3	JY1		2380.7	58.62	63.50	47.39

2.2 Underpressured shale gas

Influenced by multistage tectonic movements, preservation conditions are unfavorable in areas with buried depth < 2000m, Most areas are underpressured shale gas reservoirs which are common in China.

Challenges

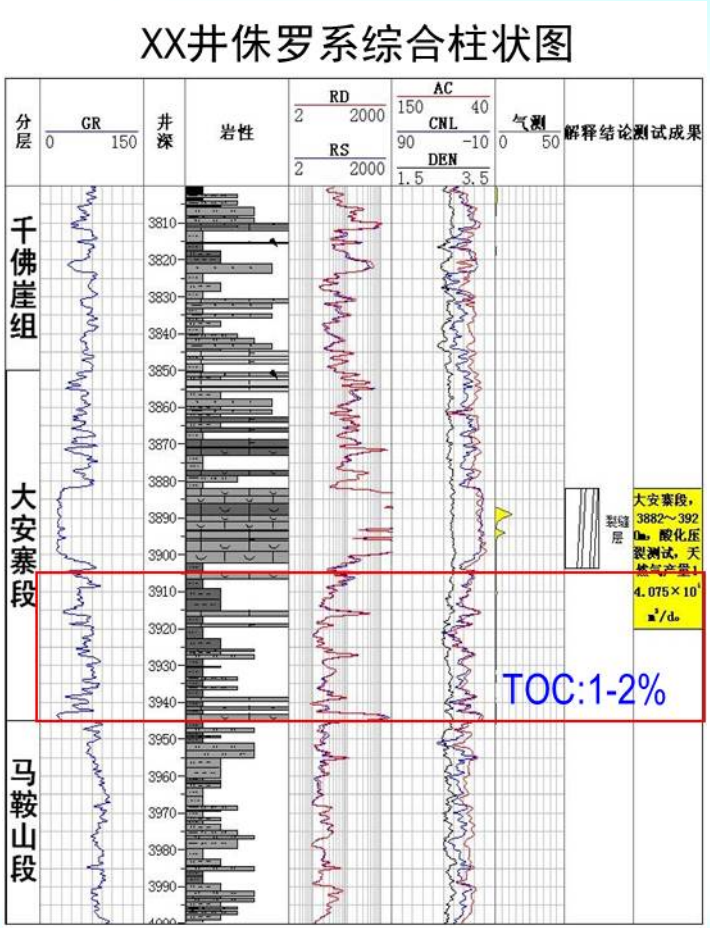
- **Shale gas production is generally less than 30,000 m^3/d.**
- **Developing the underpressured shale gas reservoirs is difficult with current techniques and high engineering costs.**



3. Continental shale gas

Lithofacies of continental shale formation change fast with high clay content. Relevant engineering technologies are under development.

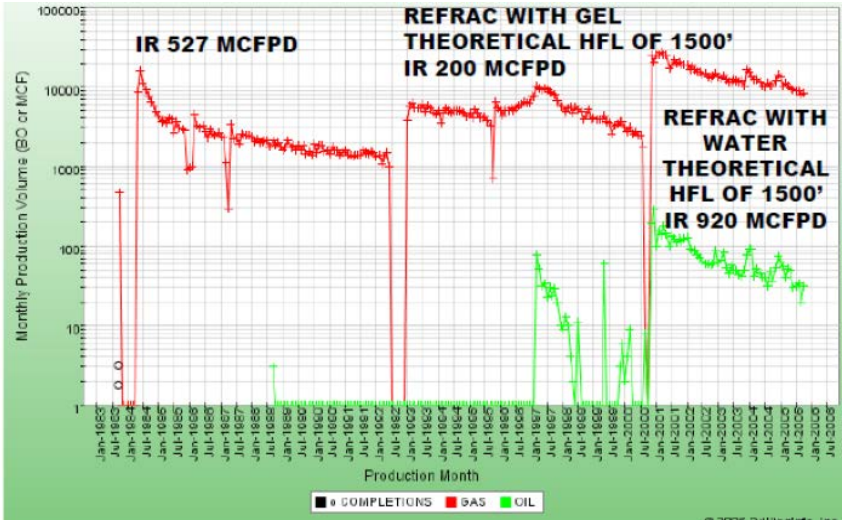
- **Lithofacies of shale formation change fast horizontally, and vertically the shale formation are frequently interbedded with carbonate or siltstone.**
- **Continental shale formation features moderate thermal maturity and lower organic content, compared with the marine shale.**
- **Continental shale shows lower siliceous minerals and relatively higher carbonate content, as well as a poor fracability.**



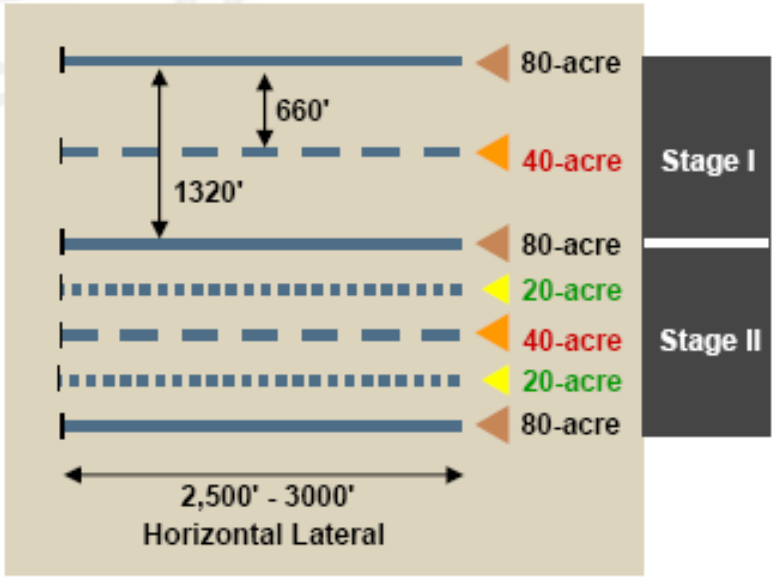
4. Stable production technologies

Most production wells in Fuling Field are already in decline period with difficulties to maintain a stable production.

- **Pressure-boosting technology**
- **Refracturing technology**
- **Infill drilling**



Through Refracturing technology, decline rate of shale gas production in Barnett was reduced by 30%



Changes of well space with time for Barnett shale wells

Development Measures

Theoretical innovation

- Enrichment and high production theories for marine shale gas under complex structural conditions
- Enrichment and high production theories for continental shale gas
- Efficient development theory

Technical innovation

- “Sweet spot" evaluation method
- Multistage hydraulic fracturing technology for deep horizontal wells
- Low cost development technology for underpressured shale gas
- New fracturing technology with no water or less water
- Optimized shale gas development technology
- Environment evaluation and protection technology

Management innovation

- Optimized the mining rights management to integrate the shale gas E&D
- Multiple investment and cooperative development
- Communication and cooperation platform
- Encouraging new technology test and application system
- Security and environment protection monitoring system

Wish 17th Sino-US Oil and Gas Industry Forum a round success!

Thank you!