The Advanced Technology of Drilling and Completion for CBM in China*

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Abstract

China is the world's most populous country with a fast-growing economy that has led it to be the largest energy consumer and producer in the world. Substantial energy demand growth and an appeal for environment protection have increased pressure on China to utilize a wide range of energy sources, especially clean energy. Coalbed methane is a global resource, poised to become a major contributor of clean, abundant energy. China has the third largest proven recoverable coal reserves, which accounts for 13.5% of the world total. In recent years, CBM projects have rapidly proliferated in China. In 2013, CBM production in China reached 2.98 billion m^3. Accompanying production increases, however, are challenges, including complex high-rank coalbed geology, wellbore collapse, reservoir damage, and low well production. These challenges play a restraining role in China's effort toward CBM industrialization.
After a background of CBM development in China, this paper will describe state-of-the-art in multilateral horizontal well technology, underbalanced-drilling technology, and completion technology. Field results are discussed. Finally, a brief focus on the future technologies associated with CBM development is presented.

1. State-of-the-art of China's CBM Drilling and Completion Technology

This section begins with a review of the current situation of drilling and completion in China CBM industry. Main problems encountered are listed out, and options to solve these problems are analyzed. China is still on the way to find an economic package of solutions comprised of drilling, completion, and stimulation methods that is suitable for the high rank, low-permeability coal seams. This section concludes with some recommendations for change.

2. CBM Multilateral Well Technology

Multilateral drilling was introduced to China in 2004. The large-scale application commenced in 2009. Through drilling practices from 2009 to 2012, CNPC has been capable of utilizing this technology to develop CBM fields. Well construction costs have been reduced dramatically

from RMB $15 million at the beginning to about RMB $9 million at present. Well completions and stimulations for CBM have generally been chosen by trial-and-error, because there has not been much consensus, unlike wells in conventional sandstone. To increase well production, CNPC has proposed a new cost-effective drilling practice named “L-pattern horizontal well”. Another alternative considered is to drill the main bore beneath the lower edge of the coal seam and then the laterals upward into the coal seam.

New adaptive equipment, including Electromagnetic MWD, DRMTS, and Truck-mounted drilling machine, has emerged in the last few years. The Electromagnetic MWD system is introduced to meet the needs of the growing number of projects involving under-balanced drilling in the CBM industry. Dynamic azimuth gamma is available with this system, which is capable of precisely determining the upper/lower edge of the seams. DRMTS is a solution for intersection of wellbores between a vertical well and a horizontal well. With the range of up to 70 meters, the DRMTS allows for significant trajectory correction prior to intersection. DRMTS has been used in more than 30 first-time intersections in China. CNPC has designed and built its first prototype of truck-mounted drilling machine especially for the domestic CBM industry.

3. CBM Underbalanced Drilling

Due to the low-pressure reservoirs, overbalanced drilling may cause severe reservoir damage, thereby leading an unexpected methane production. Slightly underbalanced drilling helps minimize coal formation damage. Three kinds of underbalanced drilling technologies, including gas drilling, aerated freshwater drilling, and circulated microbubble drilling, have been tested in China. At present, CBM wells drilled with aerated freshwater are becoming more common. This technique is suitable for a formation with pressure coefficient ranging from 0.7-1.0 g/cm^3. In addition, it is free to the influence of formation influx.

A key hardware in underbalanced drilling is the rotating control head, which is able to maintain a pressure seal between drill pipe and casing even as the drill string is turning. For consideration of being suitable for the CBM application, a custom-made rotating control head is designed to operate at 500 psi (3.5MPa) rotating and 1,500 psi (10.5MPa) static. In aerated underbalanced drilling, the use of expensive air compressors and injection equipment is required, which leads increased costs. An alternative to aerated underbalanced drilling is a special drilling fluid named fuzzy ball. Being able to adjust the density in a range of 0.7-1.0 g/cm^3, (the average reservoir pressure coefficient is 0.88 in China); fuzzy ball can be used as a kind of underbalanced drilling fluid. Besides that, fuzzy ball can also solve many problems including lost-circulation control, formation damage, stabilization of multi pressure sequences with one fluid, and possible differential sticking. In the end, a case study on lost-circulation control will be presented.

4. CBM Horizontal Well Completion Technology

In China, borehole collapse is one of the main obstacles for the large-scale development of horizontal wells in the CBM industry. Coalbed collapse will bring high risk for drilling and extraction operations. Three completion tools including slotted PE (polyethylene plastic pipe) screen completion, slotted GRE (Glass Reinforced Epoxy pipe) screen completion, and water swellable packers, which have been widely used to overcome the instability problem, will be introduced in this section.

Key hardware in PE screen completion includes a hydraulic-driven injector and a roll of PE screens with custom-made slots. Running PE screens down to the desired TD involves connecting an anchor at the bottom of the PE screens, running down through the drilling pipe pushed by the injector, and with the arms of the anchor opened and fixed in the seams, pulling the drilling pipe without disturbing the PE screens.

Compared with PE screens, slotted GRE screens could hold much higher compressive strength and provide a larger inner diameter, which would facilitate stimulation operations. Operationally, the benefit of the slotted GRE screen completion is simplicity. Screens are simply run to the depth, similar to the slotted liners. In addition, even more important, there is no potential risk for the post mining operations. In recent years, slotted GRE screen completion is popular in China.

In Australia, wells with slotted liners completion in the openhole often experienced coal fines plugging problems. On average, Pumps needed inspection every 6-12 months. Water swellable packers were used to provide a cost efficient and competent annular isolation of reservoir intervals. The isolation system has proven successful in preventing the coals and fines from the upper sections entering the borehole, reducing the possibility of solids plugging of the pumps, thereby leading an extended inspection period and less need of intervention.

5. Challenges and Future Technologies

China's government, recognizing the value of this resource, named CBM development as one of 16 major projects in the 11th "Five-Year Plan". Production targets are 10 billion m^3 by 2010, 30 billion m^3 by 2015, and 50 billion m^3 by 2020. At present, the average well production from vertical wells is less than 600 m^3/day, and the average well production from horizontal wells is about 7,000 m^3/day. Given what is happening now, it is difficult if not impossible to realize the desired production targets. China has been redoubling its efforts to increase well production and improve the economics of CBM development. Several innovative technologies, which are either currently being tested or already in use, are covered in this section. Some examples include air drilling, special drilling fluids; CBM coiled tubing technique, enhanced CBM, and underground coal gasification.

THE ADVANCED TECHNOLOGY OF DRILLING AND COMPLETION FOR CBM IN CHINA

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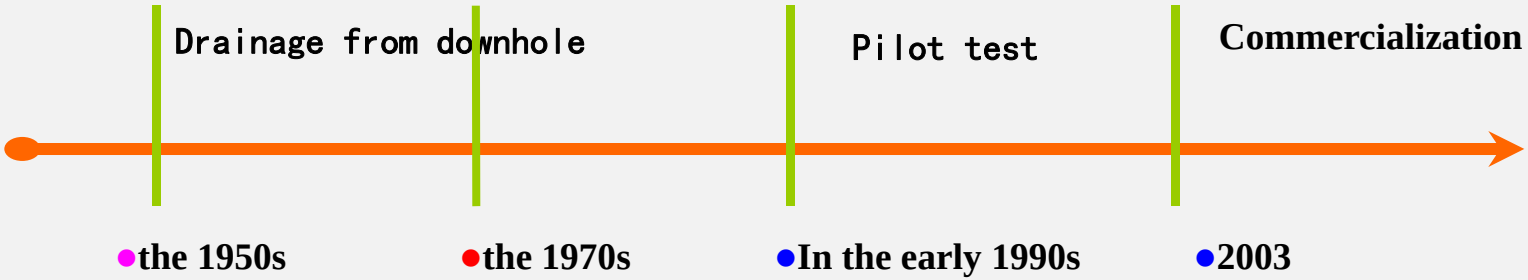
February 13, 2015

Overview

CBM Progress in China

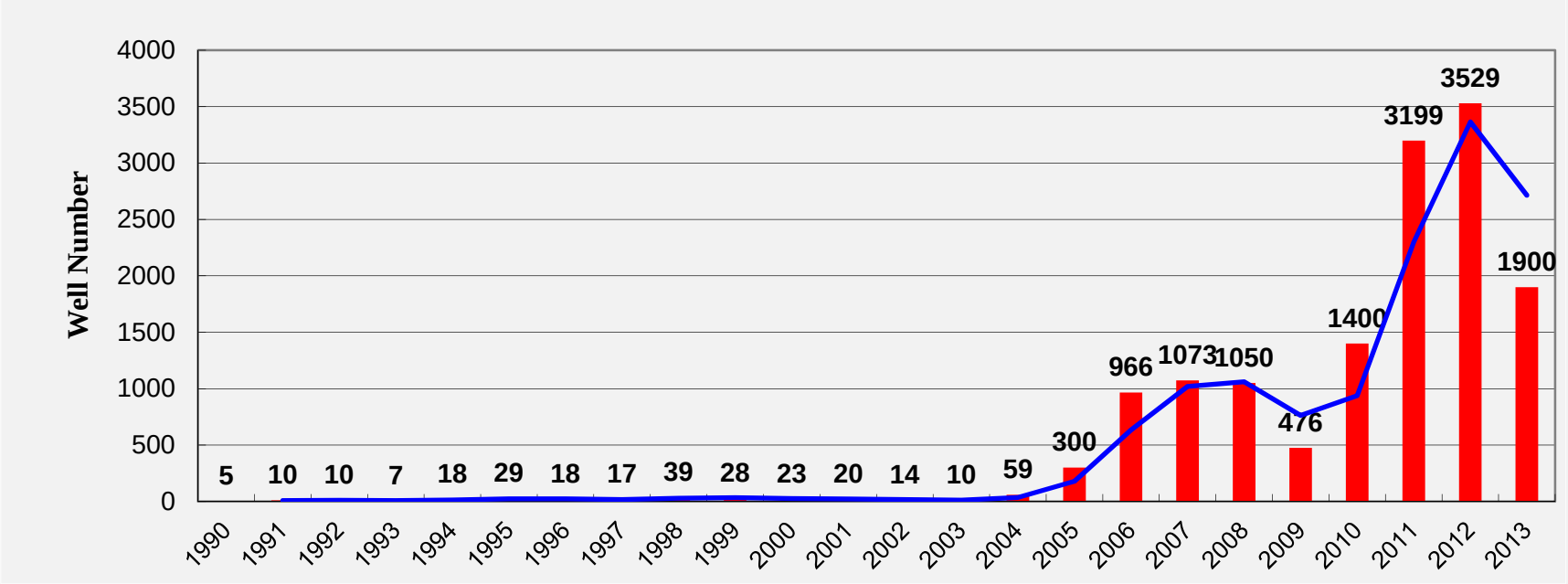
- From the 1950s to the 1990s ----CBM drainage from downhole
- In the early 1990s ---pilot test of exploration and development
- Since 2003 ----commercialization



Overview

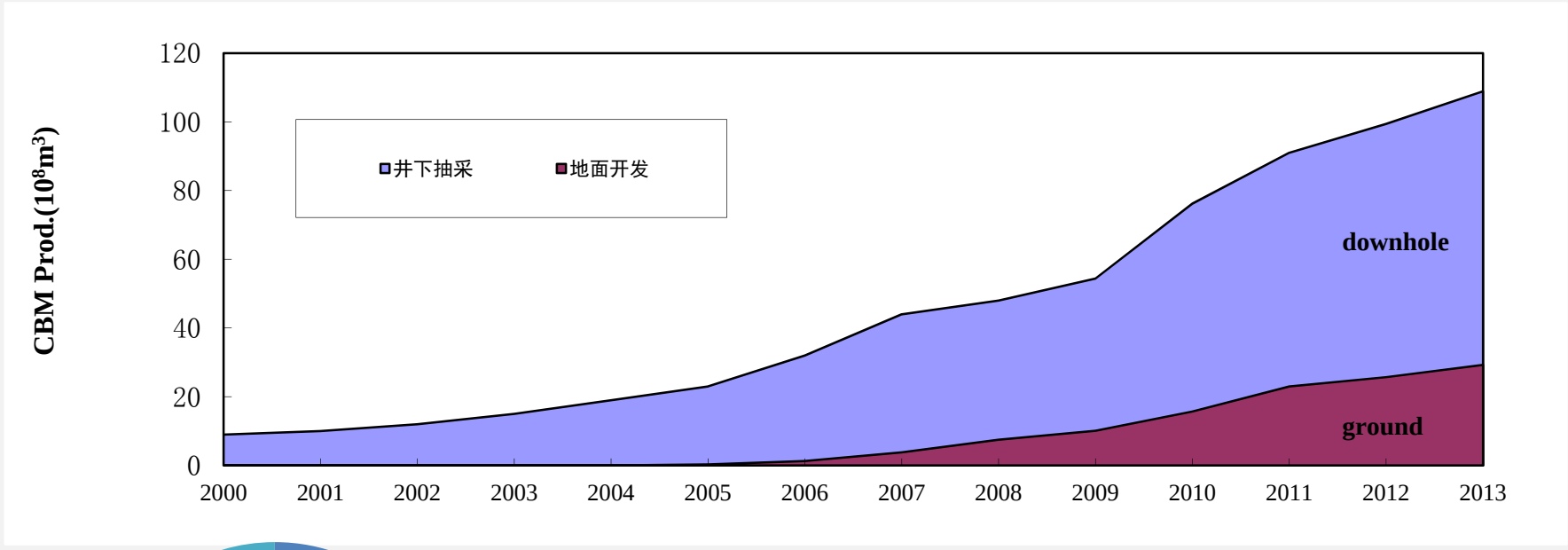
- ✓ Over 14,000 wells drilled by the end of Jan. 2014
- ✓ The number of new wells drilled yearly is gradually increasing, and peaked at 3,529 in 2012
- ✓ In the recent two years, the quantity of drilling activities is reducing due to low well production

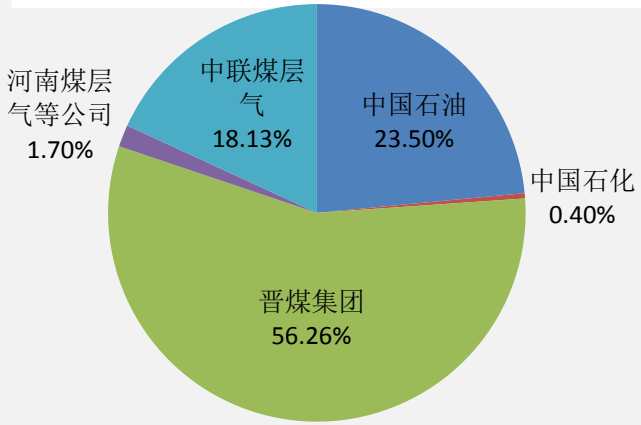
Number of CBM Wells Drilled in China



Overview

CBM Prod. In China





year	2005	2006	2007	2008	2009	2010	2011	2012	2013
Downhole	23	32	44	48	54.4	76.2	91	99.4	108.87
From ground	0.3	1.3	3.8	7.5	10.1	15.7	23	25.7	29.26

10^8 m^3/year

I. Overview

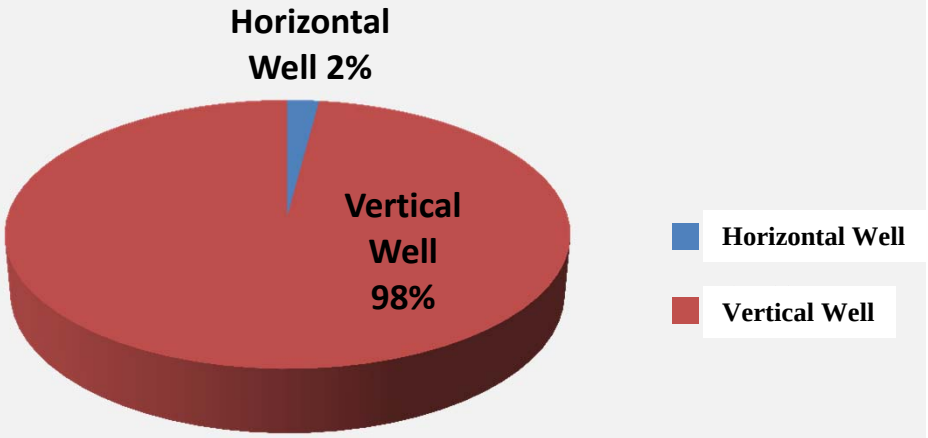
II. Low-Cost CBM Vertical Well

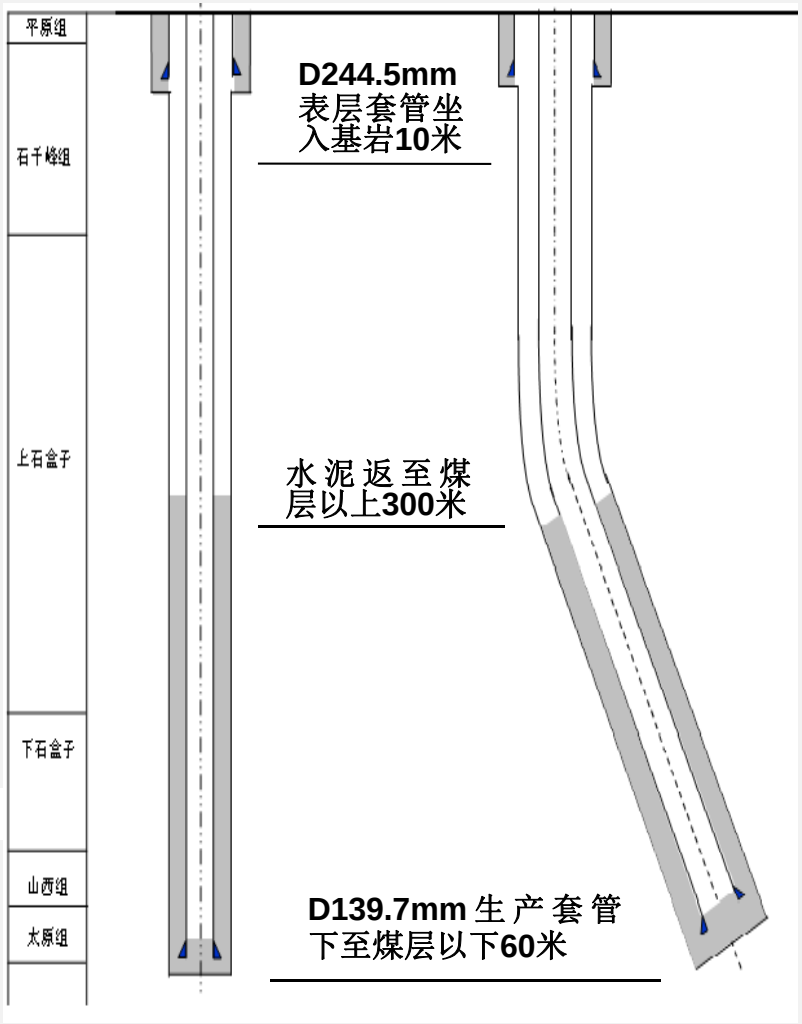
III. Drilling Technology and Equipment for CBM Horizontal Well

IV. Conclusions

Low-Cost CBM Vertical Well

- Vertical well is the main cost-effective well type to develop CBM reserves
- Widely used in the Qinshui Basin and Eastern Ordos Basin
- By the end of Feb. 2013, China had drilled **11,850 CBM wells** including vertical wells and cluster wells, which accounted for **98%** of total wells

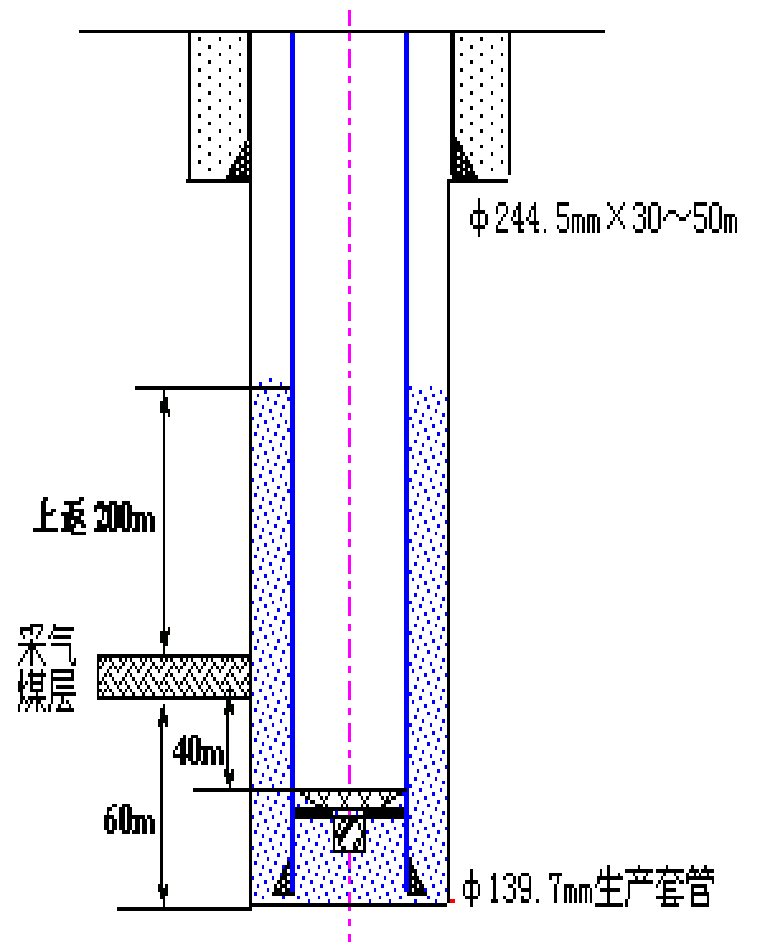




Low-Cost CBM Vertical Well

(1) Optimal Design of Well Profile

- Two-layer casing structure
- First Spudding: 12 ¼-in bit
- Second Spudding: 8.5-in bit + 5.5-in production casing
- Fracturing



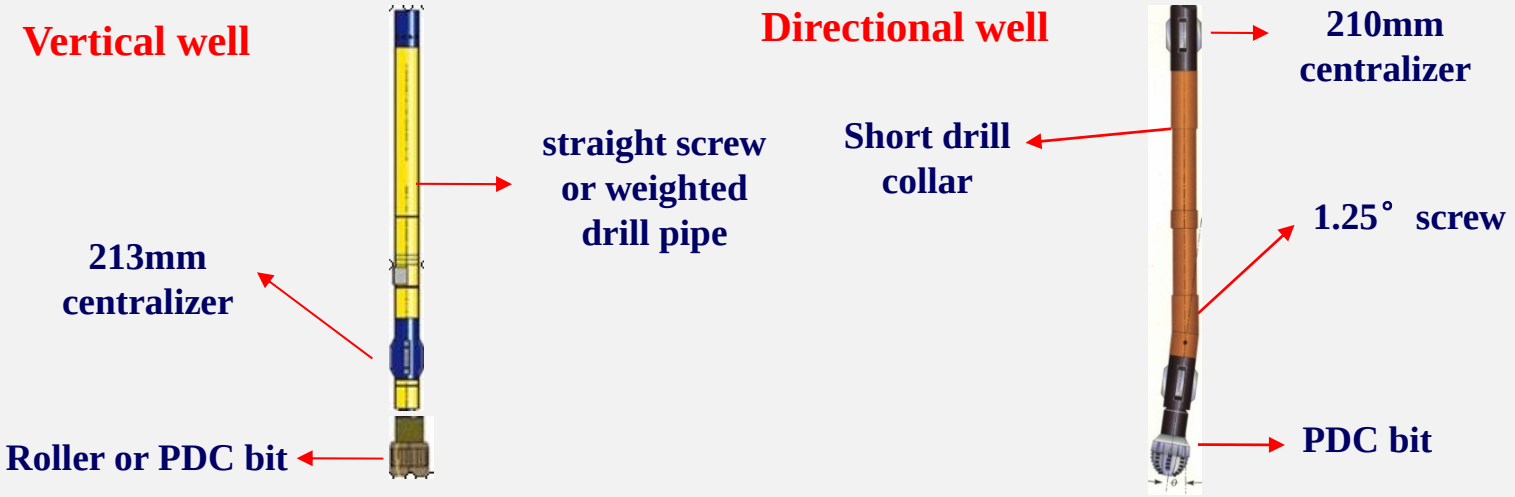
Low-Cost CBM Vertical Well

(2) Bit and BHA

Use PDC bits in the mudstone and roller bits in the sandstone

Vertical segment + angle maintaining interval: combined drilling

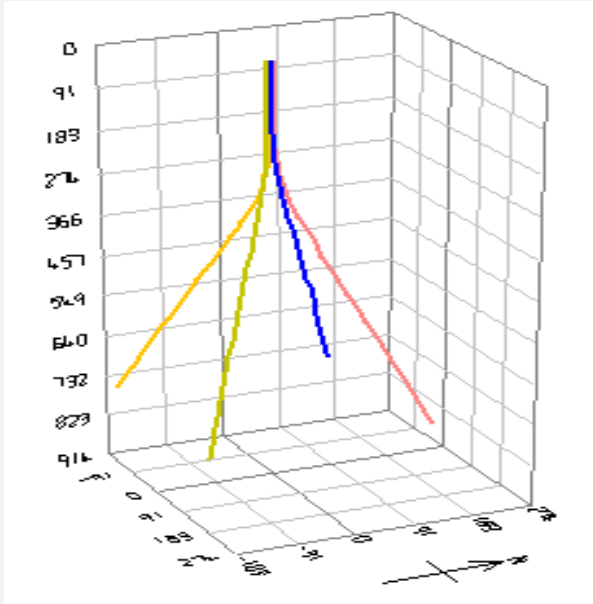
Deflecting interval: slide drilling



Low-Cost CBM Vertical Well

(3) Cluster Well

- Small footprint
- Few pipelines
- Lower cost
- easier production management
- Widely used in China

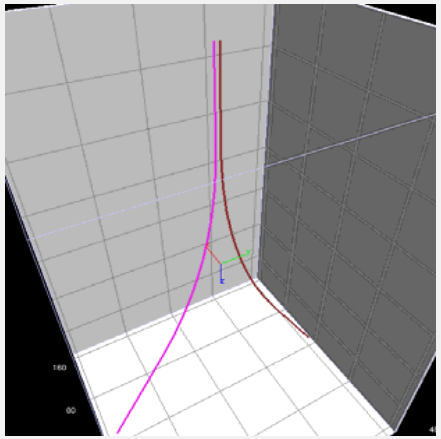


井名	造斜点(m)	总井深(m)	最大井斜角(°)
CBM1	160	807.40	28.16
CBM2	130	804.14	25.80
CBM3	160	807.40	28.16
CBM4	130	804.14	25.80

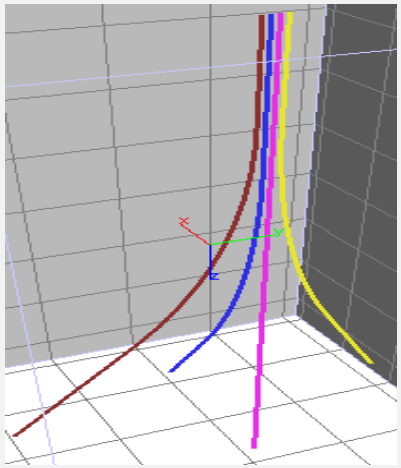
Low-Cost CBM Vertical Well

Cluster Well Design Principles

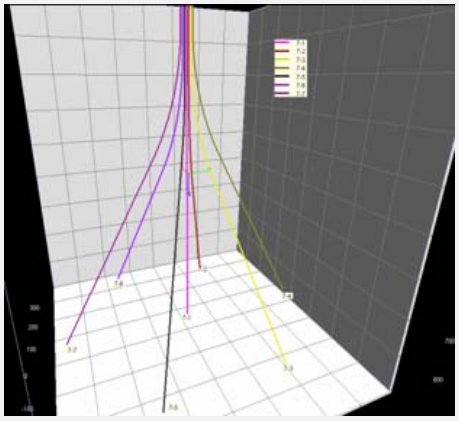
- ✓2 branches—TVD 540m+
- ✓3 or 4 branches—TVD 570m+
- ✓7 branches—TVD 860m+
- ✓11 branches—TVD 1200m+



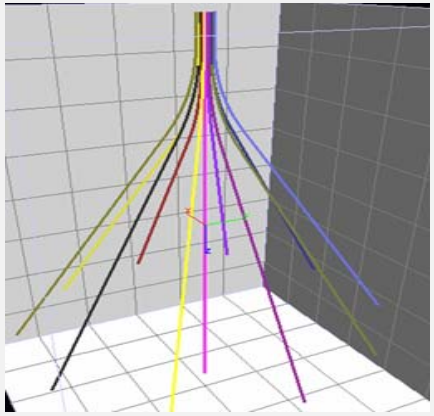
2 branches



3 or 4 branches



7 branches

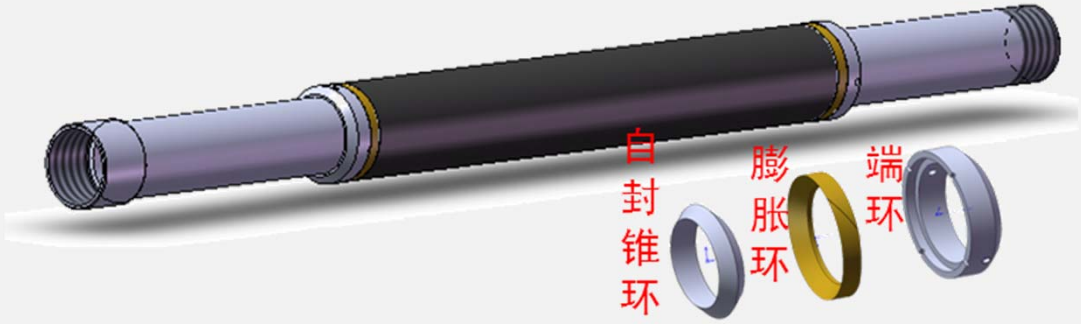


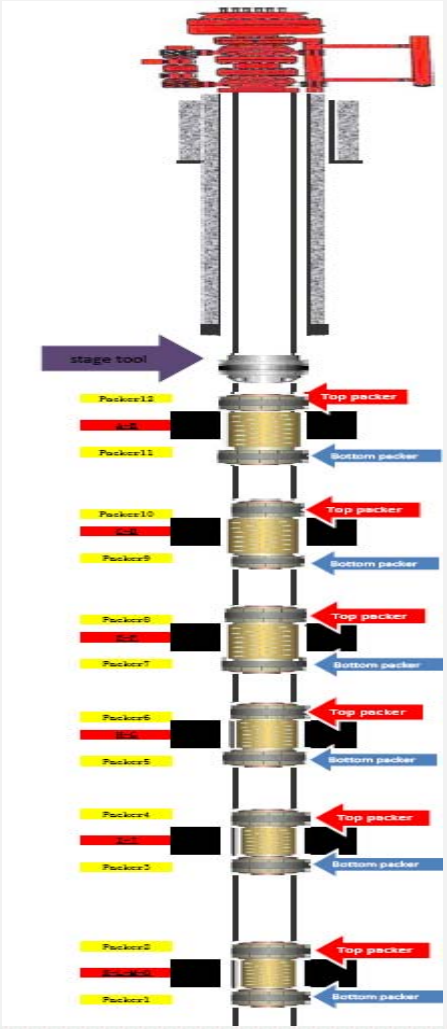
11 branches

Low-Cost CBM Vertical Well

(4) Water Swellable Packers Assist Multi-Seam Production with Vertical Wells

- To prevent the coals from the upper intervals entering the borehole, thereby reducing the possibility of solids plugging of the pumps
- Over 560 packers have been used successfully in Australia





Low-Cost CBM Vertical Well

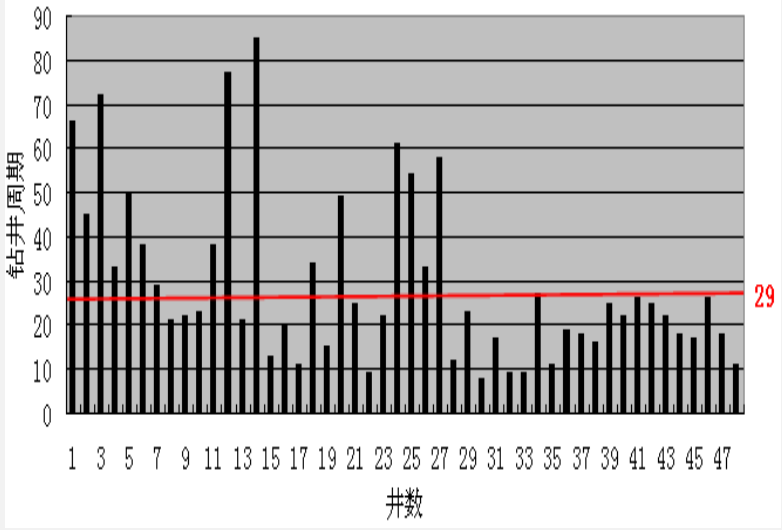
Drilling Cycle

A Block: 29 days to 22 days

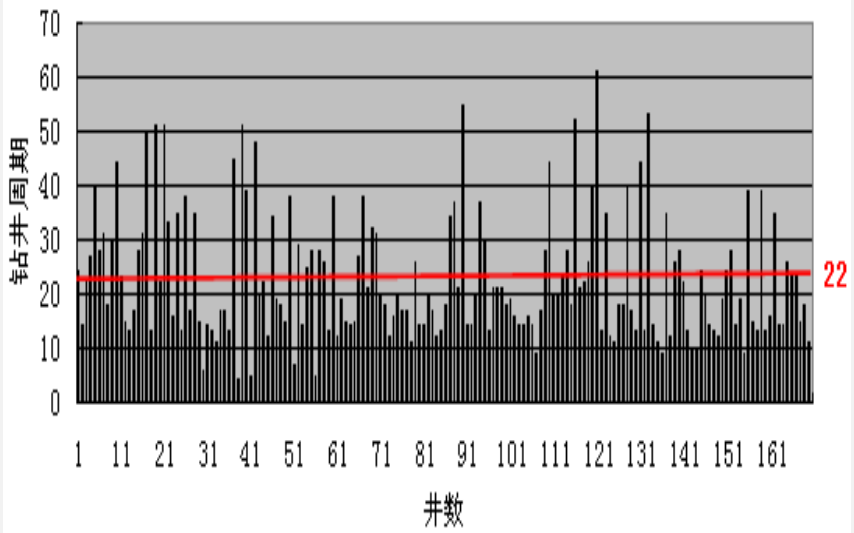
B Block: 12 days to 7 days

C Block: 28 days to 24 days

Drilling Cycle for A Block



Drilling Cycle for A Block



I. Overview

II. Low-Cost CBM Vertical Well

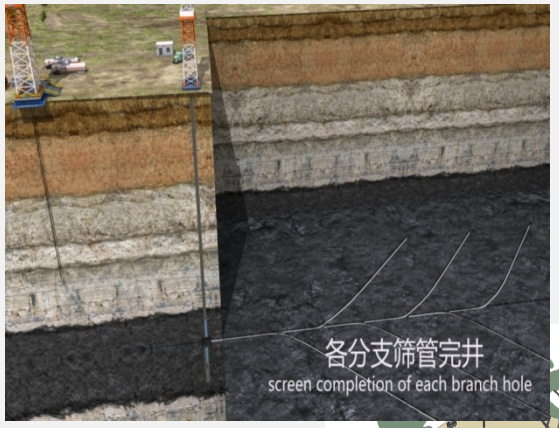
III. Drilling Technology and Equipment for CBM Horizontal Well

IV. Conclusions

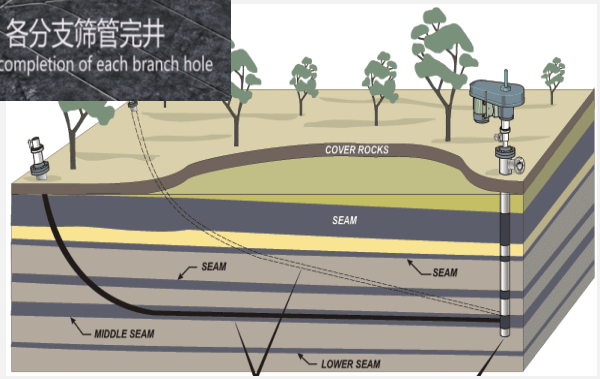
Drilling Technology and Equipment for CBM Horizontal Well

China recognizes the value of horizontal wells in the CBM development due to its advantages including:

- ✓ Larger drainage area per well
- ✓ **High well production in the low permeability seams**
- ✓ Fast production
- ✓ High recovery
- ✓ Small footprint



1、Multilateral Horizontal Well

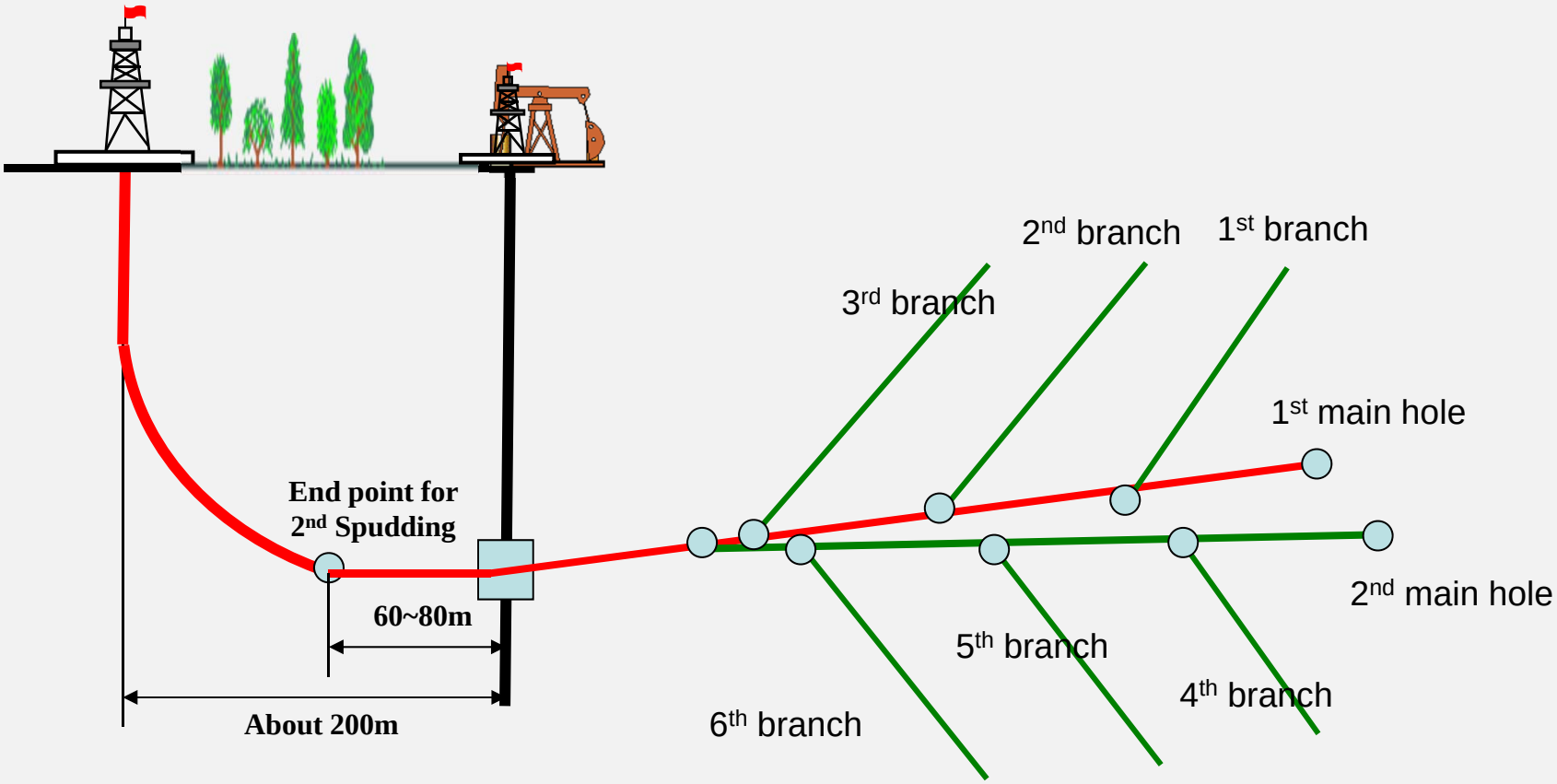


2、U-type Horizontal Well

Country	Basin	Rank	Permeability (mD)	Well Type	Completion	Well Prod.（m^3/d）
The U.S.	West Virginia	low	3~4	pinnate horizontal well	Open hole	28000~56000
Australia	Bowen	middle	1~30	V-type	PE slotted screen	15000~2000
China	**Qinshui**	**high**	**<1**	**multilaterals、U-type、L-type**	**Open hole、slotted screen**	**5000**

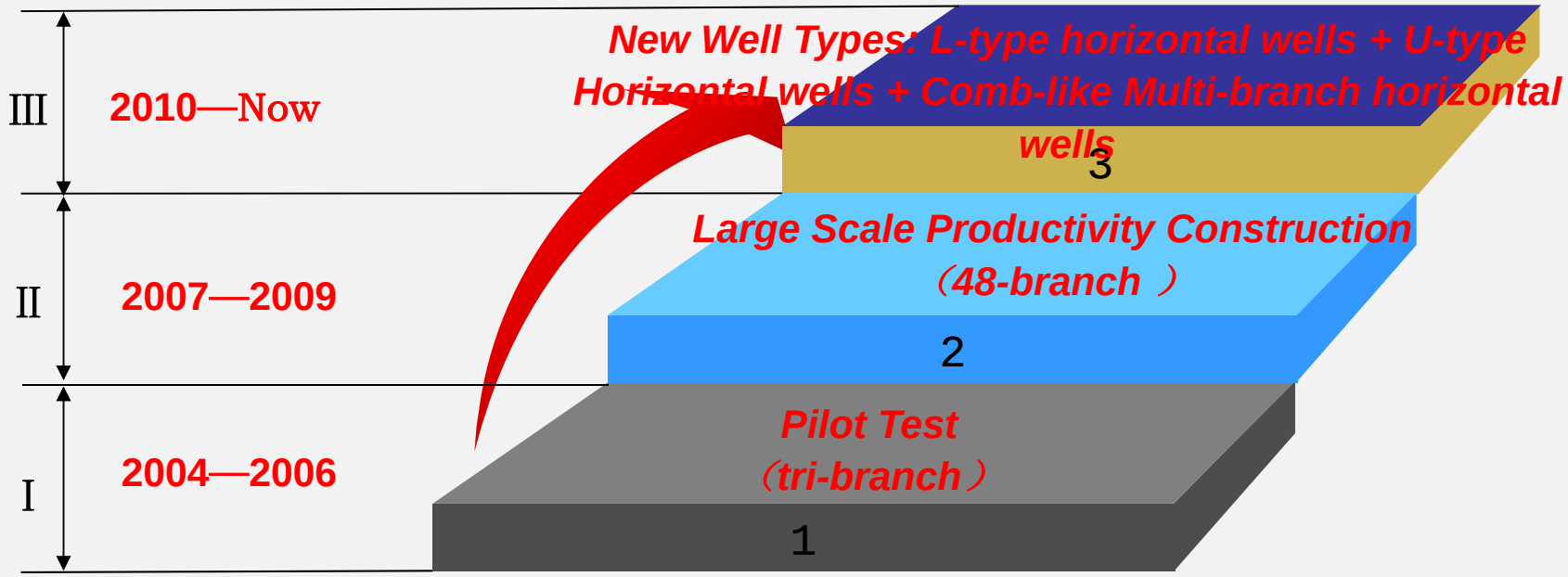
Drilling Technology and Equipment for CBM Horizontal Well

- In China, horizontal wells were firstly test-drilled in 2004, and have been widely used since 2007.



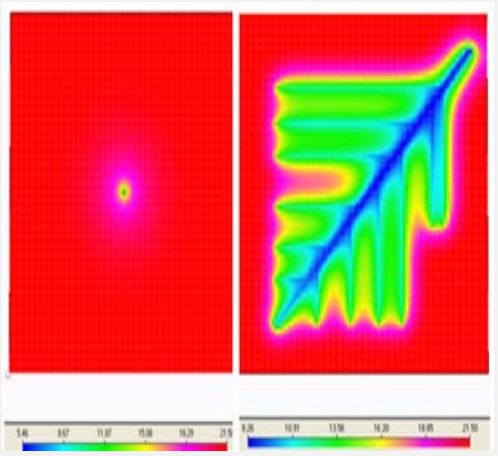
Drilling Technology and Equipment for CBM Horizontal Well

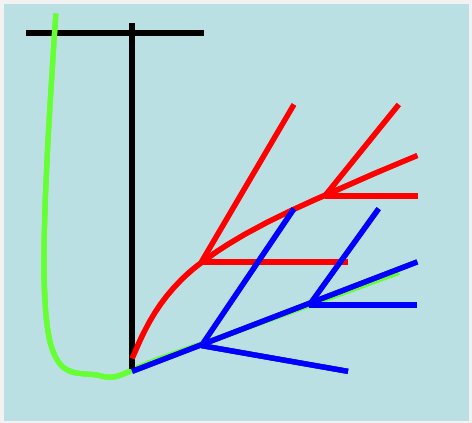
3 stages for the progress of CBM Horizontal Wells in China



Drilling Technology and Equipment for CBM Horizontal Well

- **Multi-branch horizontal wells is one of the core technologies to realize the productivity construction in the Qinshui Basin.**
- **Average cost has decreased from $15 million Yuan at the beginning to less than $10 million Yuan.**



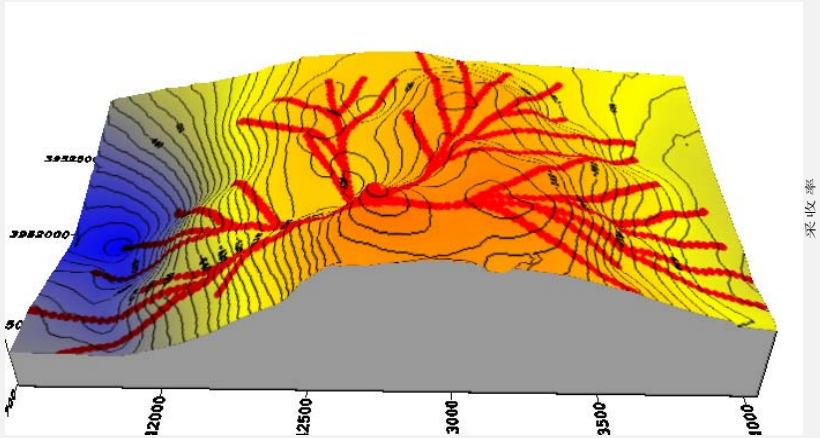


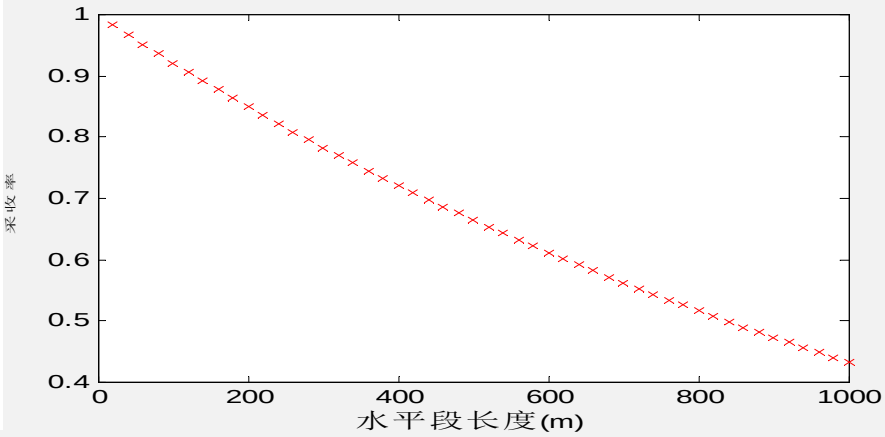
Drilling Technology and Equipment for CBM Horizontal Well

1、Well Design Optimization

➢**In principle trajectory of multilaterals must be upward to facilitate water drainage and improve CBM recovery, while trajectory of U-type wells must be downward.**

$$\eta_p = \frac{1}{L}\int_0^L \left(1 - \frac{\rho g l \sin(\theta)(p_L + p_{cd})}{p_{cd}(p_L + \rho g l \sin(\theta))}\right) dl$$

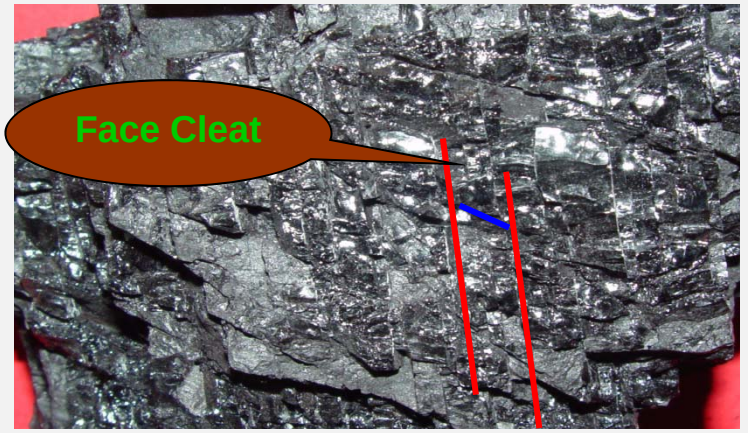


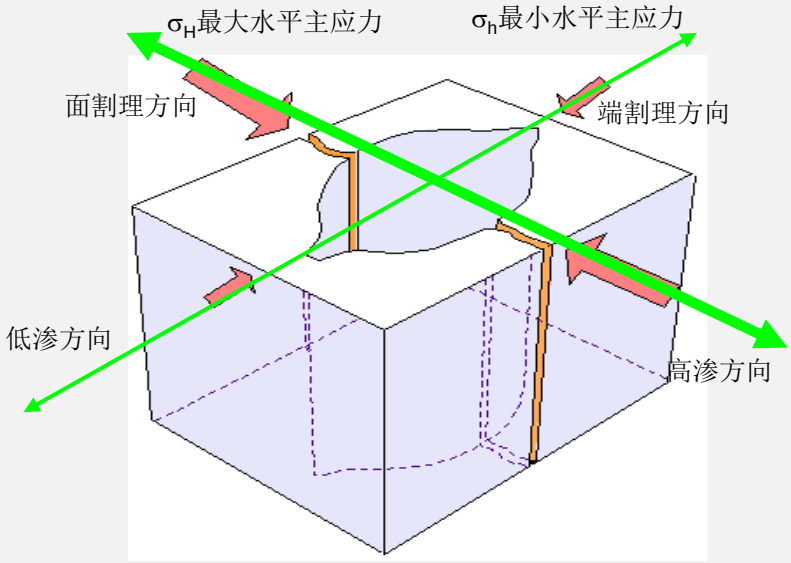


Drilling Technology and Equipment for CBM Horizontal Well

➢Well trajectory should be perpendicular to the face cleat.

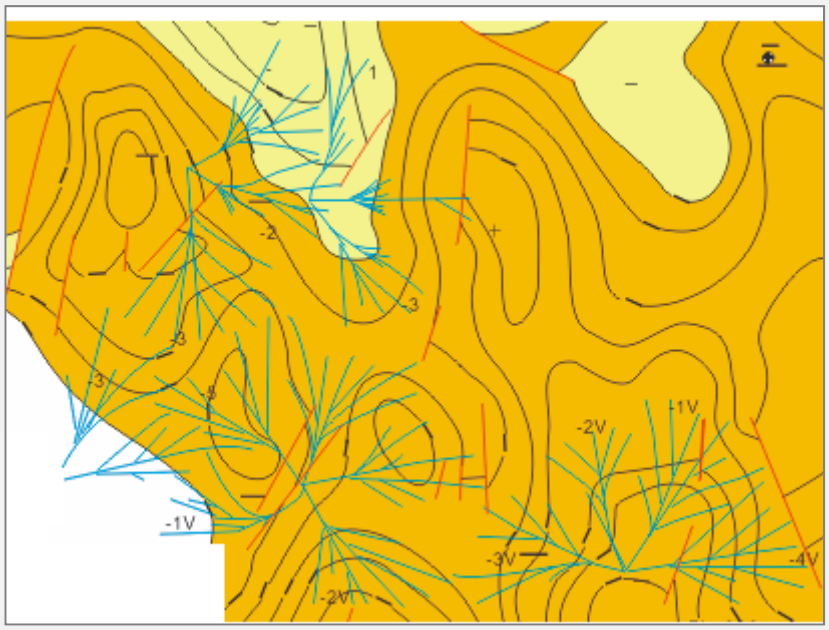
- *In general, face cleat is approximately perpendicular to the butt cleat.*
- *The run of the face cleat is parallel with the maximum horizontal main stress, while the run of the butt cleat is parallel with the minimum horizontal main stress.*
- *To drill along with the direction which is perpendicular to the face cleat would facilitate connection of cleat system, thereby improving drainage of gas and produced water.*



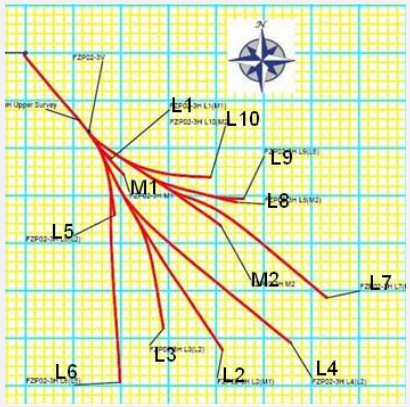


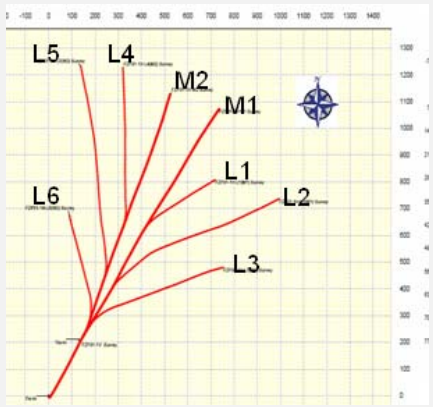
煤岩地应力状态与割理系统关系图

Drilling Technology and Equipment for CBM Horizontal Well



- ✓ Fractures in X Block is well-developed in the direction of NE65－85° and NW20－50°
- ✓ Wells with branches drilled in the direction of NNE and NNW had good gas production.





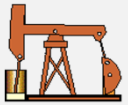
Well	Gas Prod. m^3/d	Accum. Gas Prod. m^3	Direction
FZP1-1	9,900	1,796,632	NNE
FZP2-3	49,300	16,251,918	NNW
FZP4-2	18,700	3,861,660	NNW
FZP4-5	40,600	5,531,348	NNW

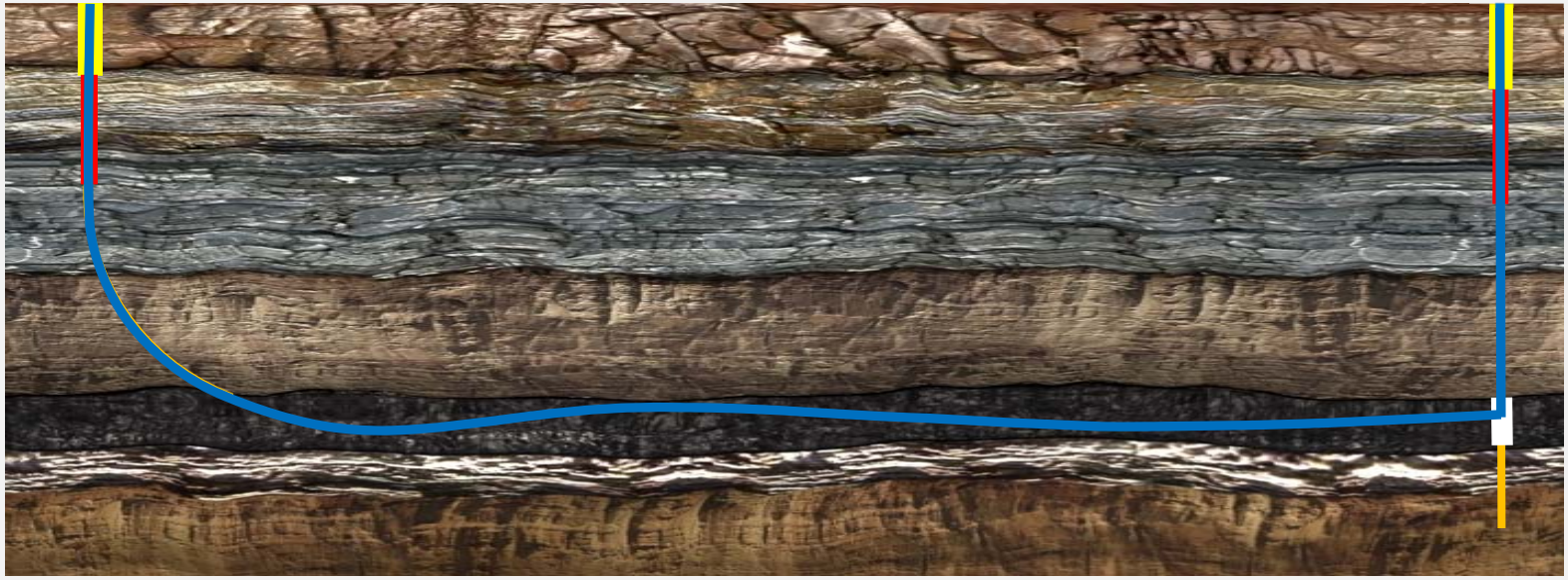
Drilling Technology and Equipment for CBM Horizontal Well

✓to improve well production, China has tested new well types in the Qinshui Basin and Eastern Ordos Basin, including

- **U-type horizontals**
- **L-type horizontals**
- **comb-like horizontals**

✓some kinds of **hydraulic fracturing** were also tested

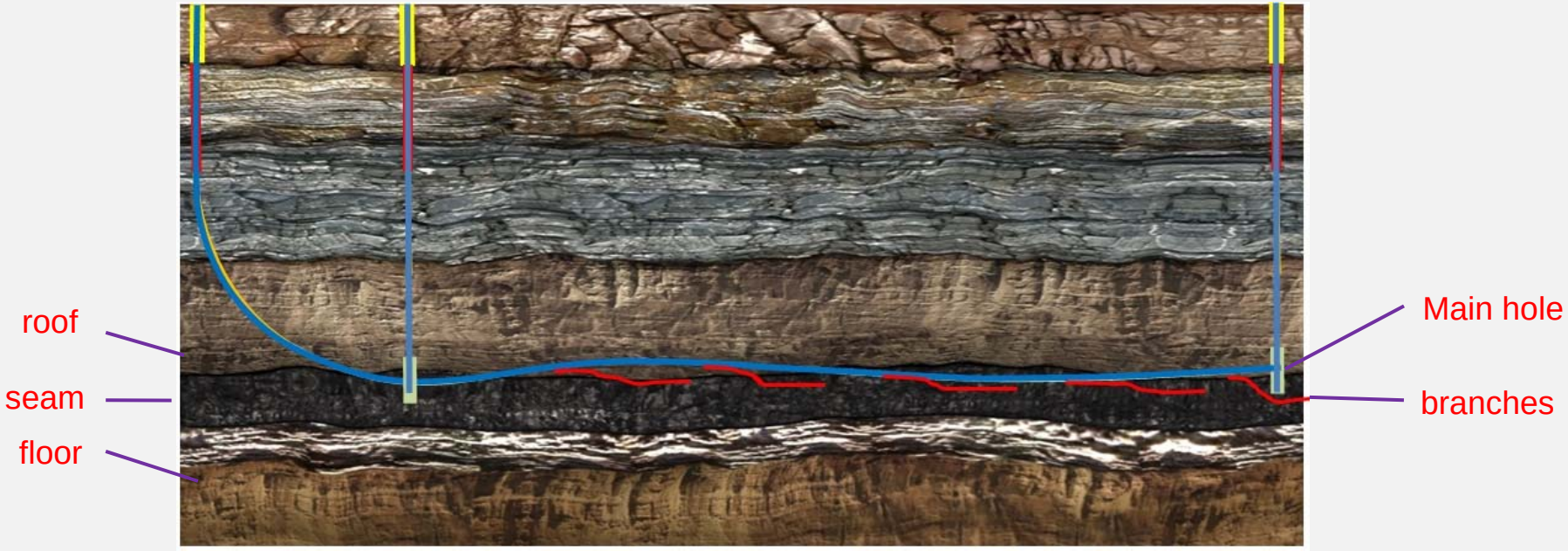




Drilling Technology and Equipment for CBM Horizontal Well

Comb-like Multilaterals

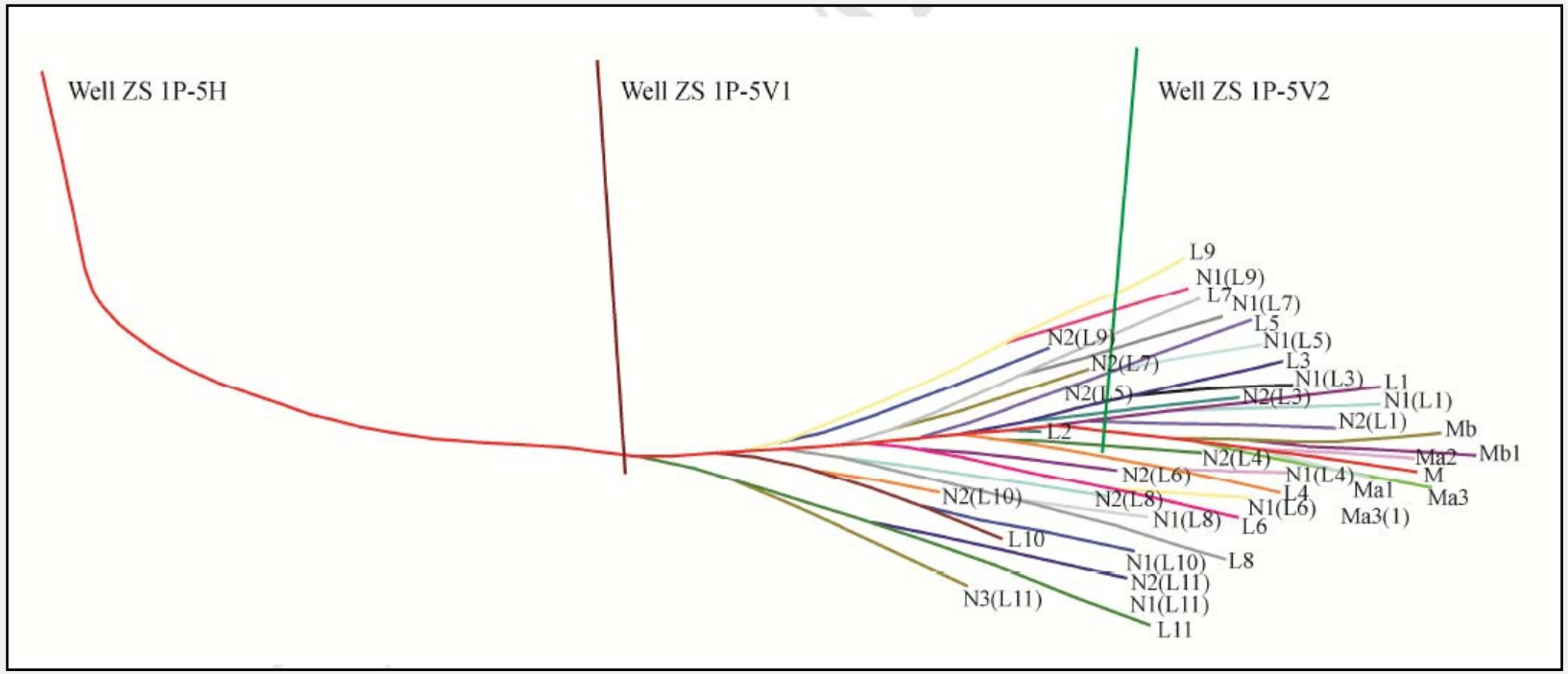
- ✓ **main hole in the stable roof to prevent collapse**
- ✓ **branches drilled downwards for gas drainage**



Drilling Technology and Equipment for CBM Horizontal Well

Comb-like Multilaterals

- ✓ **1 main hole, 13 laterals, 26 sub-laterals**
- ✓ **a vertical well for production, a vertical well for monitoring**
- ✓ **total footage is 12,288m**
- ✓ **No accident**



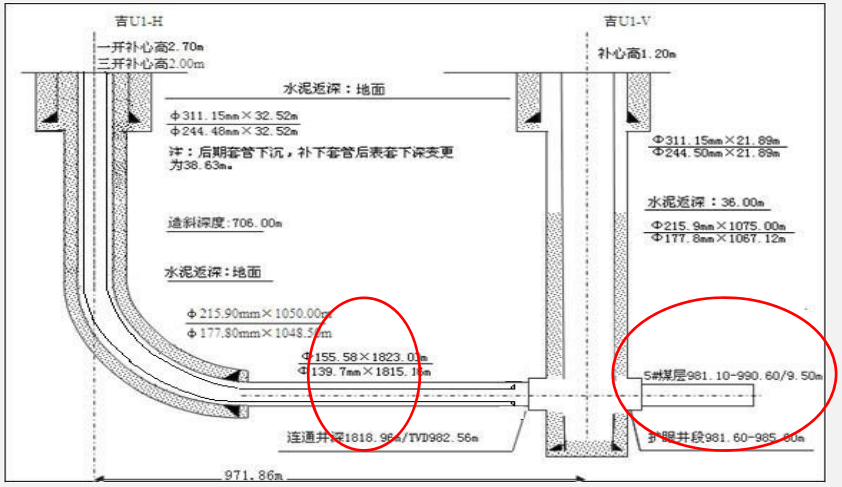
Quoted from: A new attempt of a CBM tree-like horizontal well: A pilot case of Well ZS 1P-5H in the Qinshui Basin

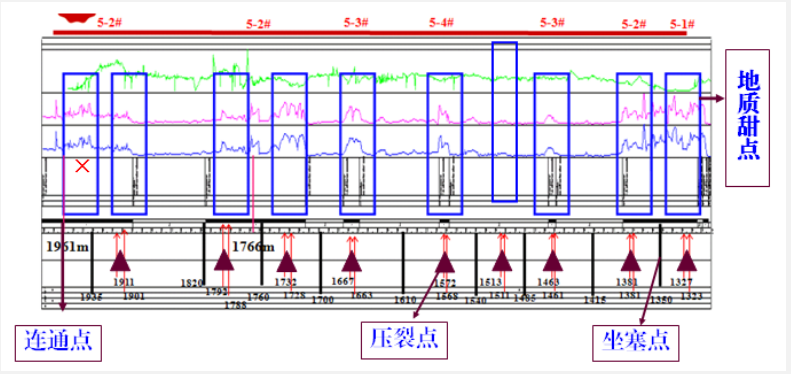
Drilling Technology and Equipment for CBM Horizontal Well

Horizontals + Fracturing

CNPC did its first pilot test in the Eastern Ordos Basin using Staged Hydraulic Fracturing.

- Ji-U2: Fast Drill Bridge Plug + Wireline Perforating + Staged Fracturing, BHP is 760psi, casing pressure is 120psi, water production is 13 m^3/d, **gas production is over 2,000 m^3/d.**
- Ji-U1: 7 staged hydraulic jet fracturing, casing pressure is about 290psi, BHP is 990psi, water production is 0.03 m^3/d, **gas production is over 2,000 m^3/d.**

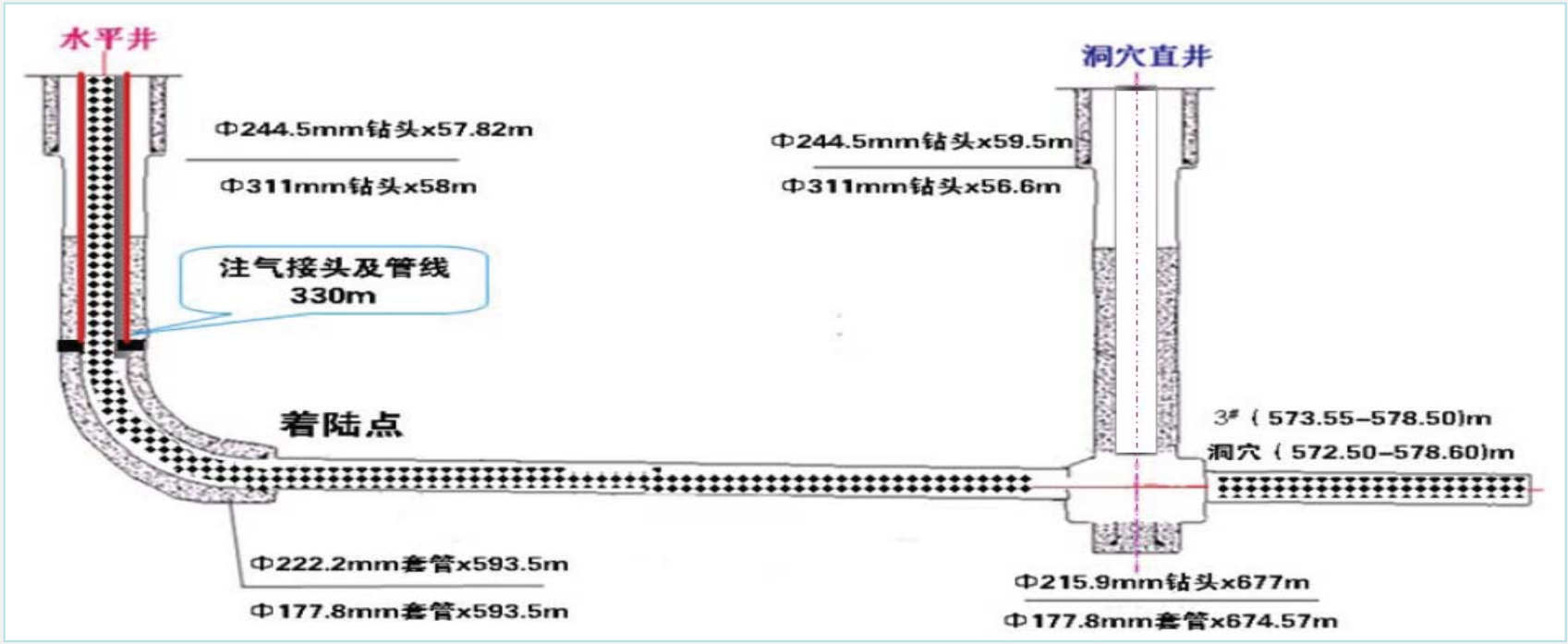




Drilling Technology and Equipment for CBM Horizontal Well

U-type Horizontals + PE Slotted Screens

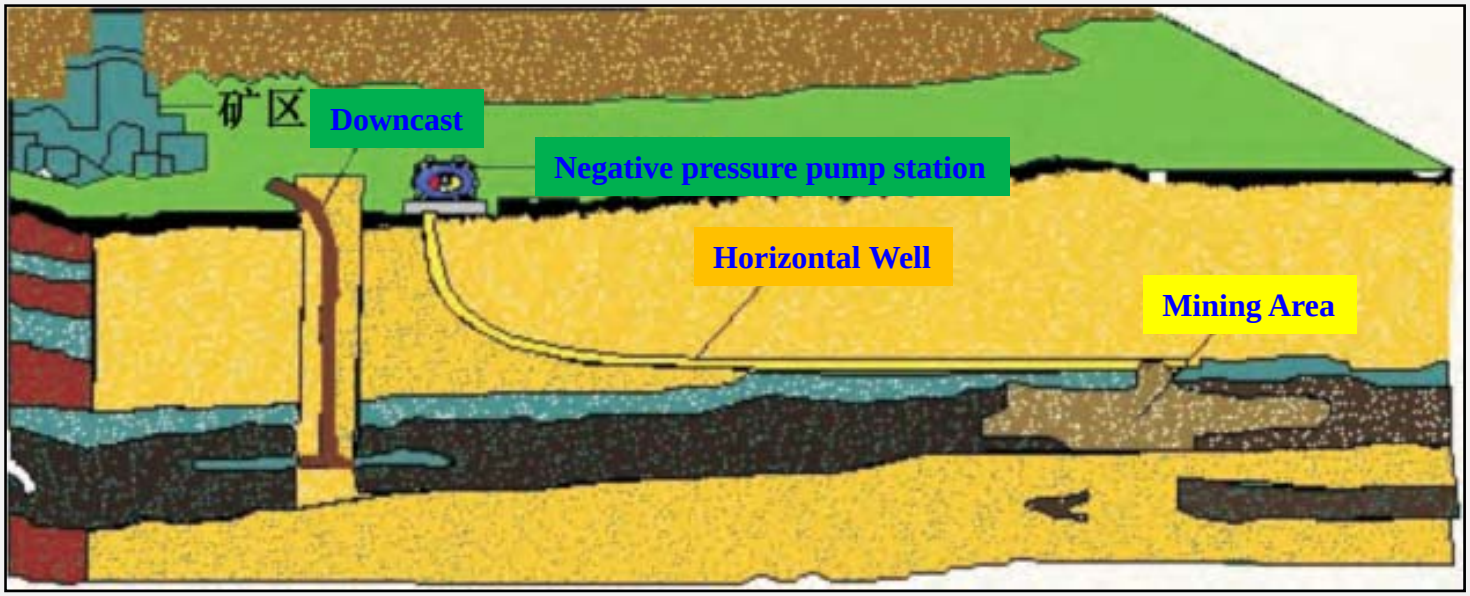
- CNPC drilled its first U-type horizontal well, named ZhengShiPing9U, in 2012.
- Total depth is 1,420m.
- Completed with 2-in PE screens



Drilling Technology and Equipment for CBM Horizontal Well

Low Cost L-type Horizontals

- Drilling a horizontal from the area which is near the downcast, with the trajectory in the rock layer above the coal seam and following its upper edge, and then going into the fractured zone above the mining area
- Using a negative pressure pump station on the ground for producing pressure-relief gas
- reported maximum production: **28,000 m3/d**



Drilling Technology and Equipment for CBM Horizontal Well

Intersection Technology: DRMTS

Purpose

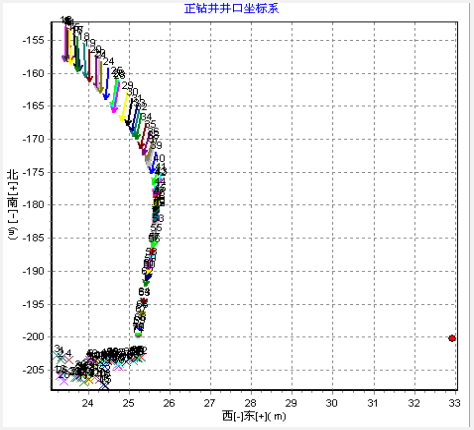
A solution for intersection of wellbores between a vertical well and a horizontal well

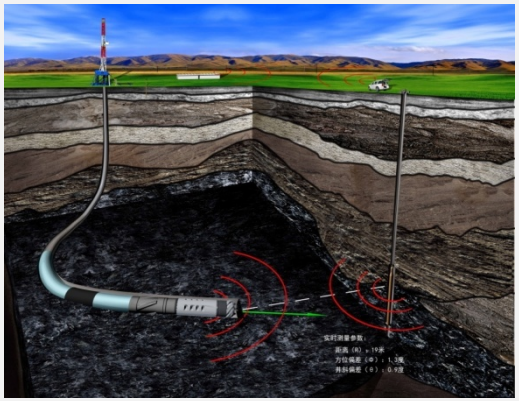
Features

- ✓ The resolution is 0.1nT
- ✓ Maximum sensing range is up to 80 meters
- ✓ Has no blind zone

Experiences

DRMTS has been used in more than 30 first-time intersections in China, including 3 intersections with fiberglass tubes directly.





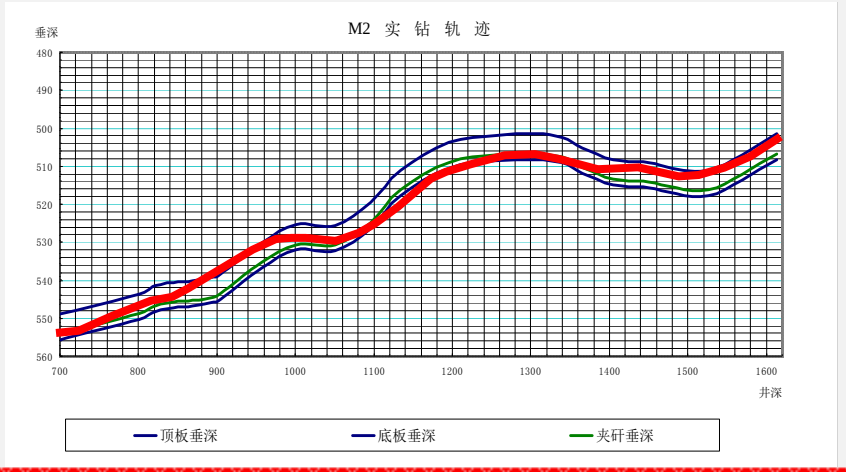
Drilling Technology and Equipment for CBM Horizontal Well

DREM-MWD

CNPC has successfully developed its EM tool called DREM-MWD to meet the needs of the glowing number of projects involving under-balanced drilling in the CBM industry. Data transmitted includes the **inclination and azimuth angles** of the borehole, the drilling system **toolface**, and the **dynamic azimuth gamma**.

Features

- ✓ Available in 4-3/4 in. and 6-3/4 in. sizes
- ✓ With a data transmission speed of 2 -7 bit/s
- ✓ With an accuracy of ±0.1º for inclination and ±0.5º for toolface and azimuth
- ✓ Data transmission from depths of 2000 m in favorable conditions
- ✓ **Azimuthal gamma provides clear upper and lower edge of the seam**

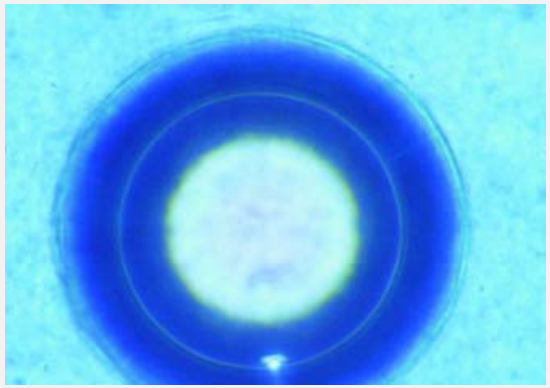


Drilling Technology and Equipment for CBM Horizontal Well

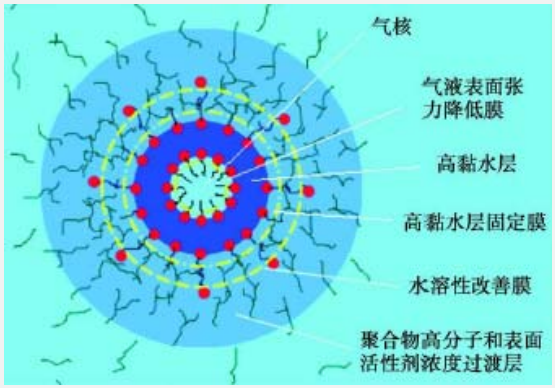
4. Recyclable Microbubble drilling fluids

Microbubble drilling fluids are water-based fluids containing stabilized air cores which are formed physicochemically using special surfactants and polymers.

- self-adaptively matching the sizes of thief zones
- good cuttings carrying capacity due to high shear thinning
- could be pushed back out of a permeable formation easily, thus minimizing formation damage
- Density of the fluid can be adjusted using compatible weighted materials



micrograph of dyed microbubble

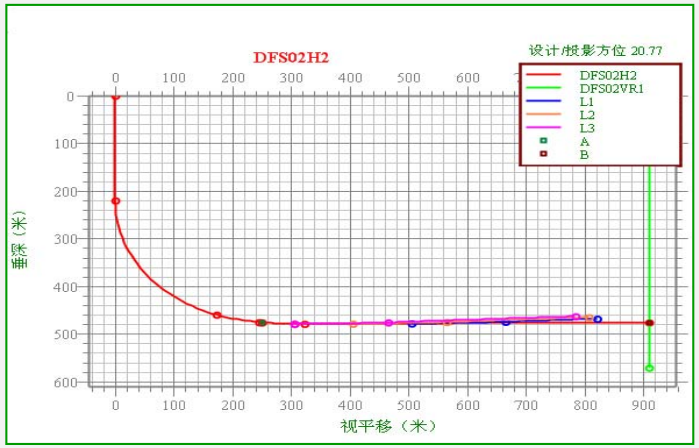


theoretical microstructure of microbubble

Drilling Technology and Equipment for CBM Horizontal Well

Case Study-Lost Circulation Control

- DFS-02 well experienced partial lost circulation during the second spudding and the third spudding. Total lost circulation occurred at the depth of **1,074** meters.
- Various conventional lost circulation control materials, including cottonseed hulls, saw ducts, and cements, have been tried but none has been successful.
- **Microbubble drilling fluids** were used to address this problem. After 7 days' drilling-while-leaking operations, the target depth of **1,275** meters was reached successfully.

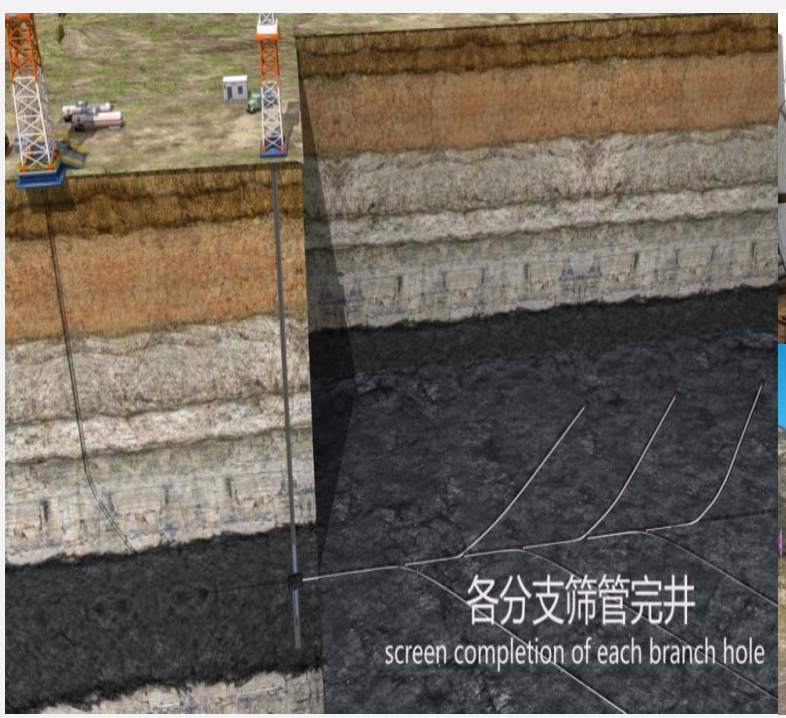


Drilling Technology and Equipment for CBM Horizontal Well

5. CBM Completion Technology

(1) DRPSC Slotted Screen Completion Technology

To address the problem of blockage caused by borehole collapse, CNPC has developed PE slotted screen completion technology, named **DRPSC**.



Drilling Technology and Equipment for CBM Horizontal Well

By the end of March 2014, we had applied 2-in PE screens for 8 CBM wells and proven successful.

well	Block	Clients	Well Type
ZhengShi9U-H	Qinshui Basin	Huabei Oilfield Company	U-type
HuaLiPing1H	Qinshui Basin	Huabei Oilfield Company	U-type
CLU-02H	Qinshui Basin	CNOOC	U-type
HuoU1-1H	Inner Mongolia	RIPEDCNOOC	V-type
HuoU1-2H	Inner Mongolia	RIPED	V-type
CLU-01H	Qinshui Basin	CNOOC	U-type
FanShiU1	Qinshui Basin	Huabei Oilfield Company	U-type
FanShiU2	Qinshui Basin	Huabei Oilfield Company	U-type

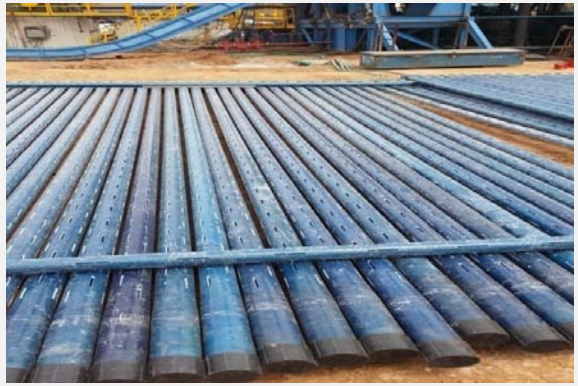
Drilling Technology and Equipment for CBM Horizontal Well

(2) GRE Slotted Screen Completion Technology

Glass **R**einforced **E**poxy pipes, the so-called fiberglass pipes, have been widely used in recent years in China.

- can hold much higher compressive load (2030 psi)
- provide a bigger inner diameter (75mm), facilitate post-operations
- coupling connections (can hold up to 10 ton force)
- Overall simpler operation, fast installation and accurate placement of the screens
- Present no potential risks for the post mining operations

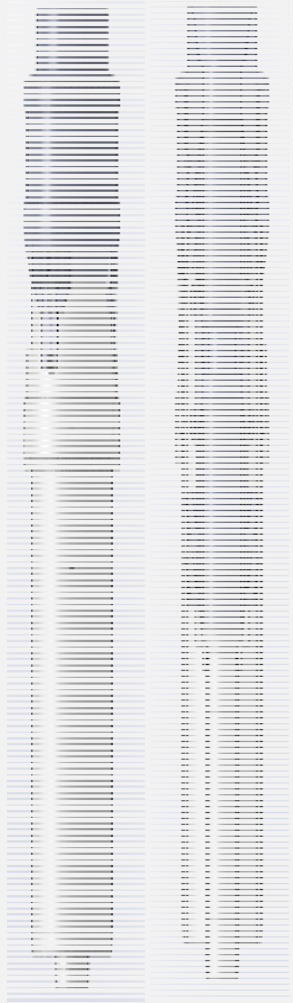
Up until recently, we have used over **5,000m** fiberglass pipes with OD **88.9mm** for **6** CBM wells in Shouyang, Shanxi Province.



Drilling Technology and Equipment for CBM Horizontal Well

◆ Multi-functional Screen Hanger

Washing pipes are used to assist in running down the fiberglass pipes. When the obstruction is present in the wellbore and causes it difficult to run the screen down, this method is able to circulate the well clean.



Functions of the hanger are as follows:

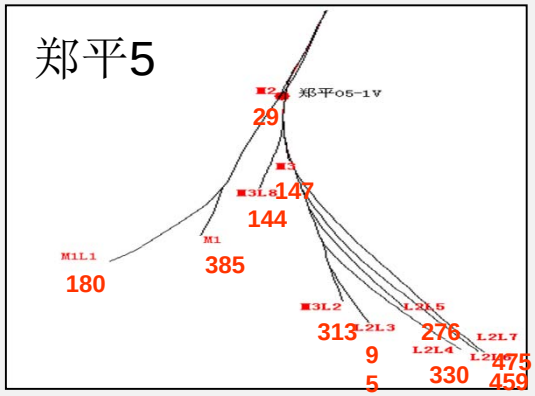
- ✓ Connect with both the screen and the washing pipe
- ✓ **Anchor** the screen in the casing
- ✓ Provide a means of **separation** of the screen from the drill pipe
- ✓ Hanger and screens are retrievable

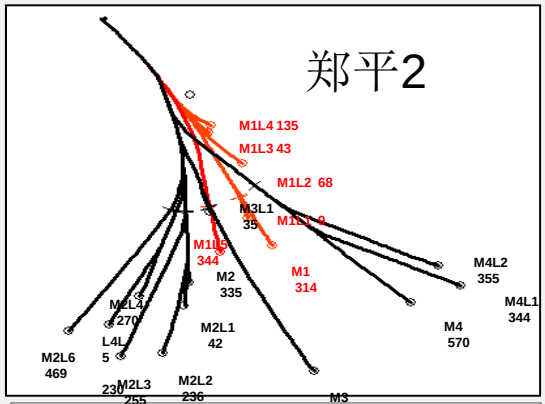
Drilling Technology and Equipment for CBM Horizontal Well

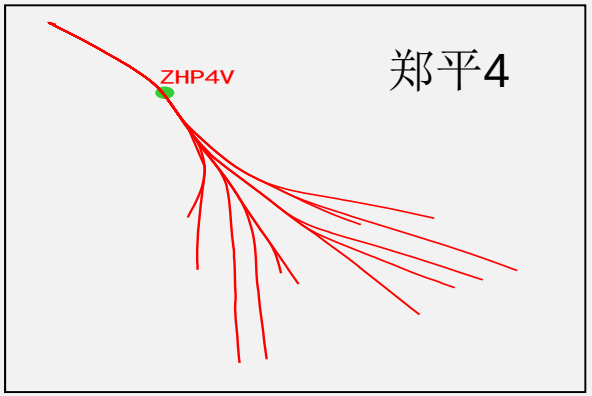
6. CBM Horizontal Well Drilling at a Glance

Through engineering practice, horizontal well technology has seen vast improvements over the past 10 years with **fewer accidents downhole**, **larger drainage area per well** and **less drilling cycle**.

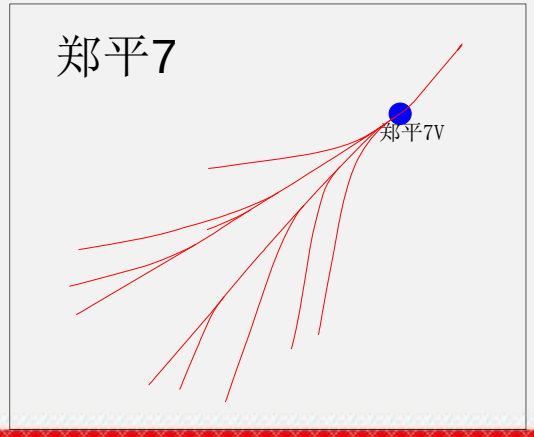
2010

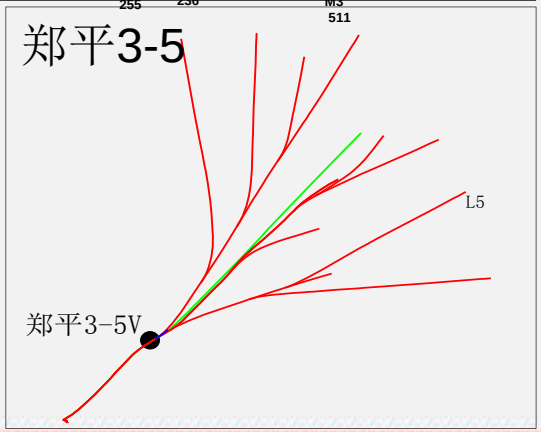


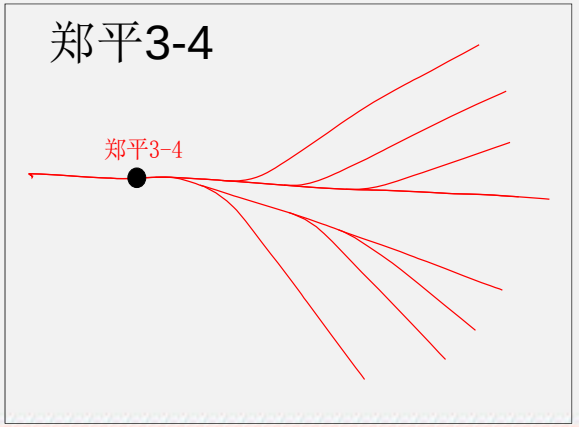




2011

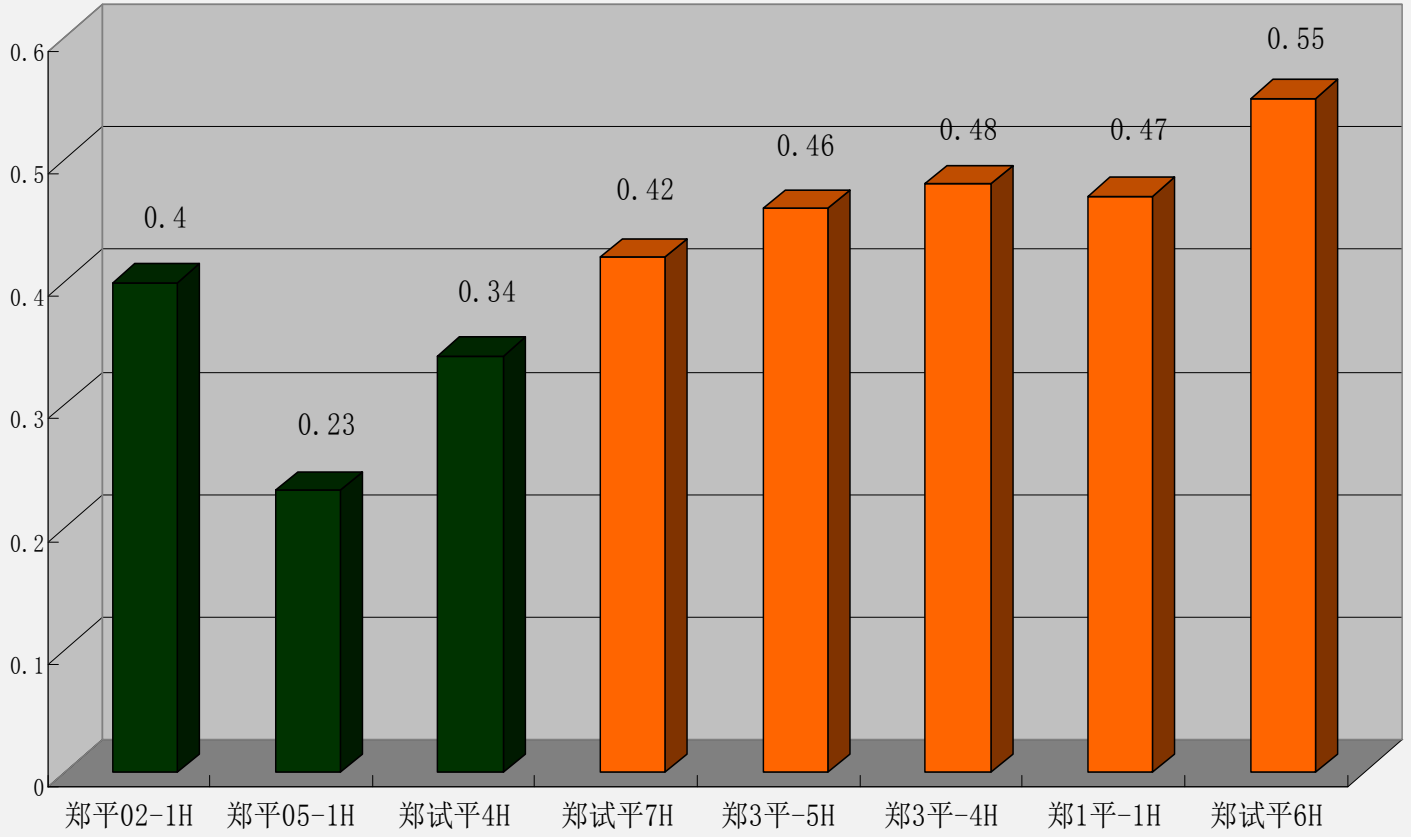






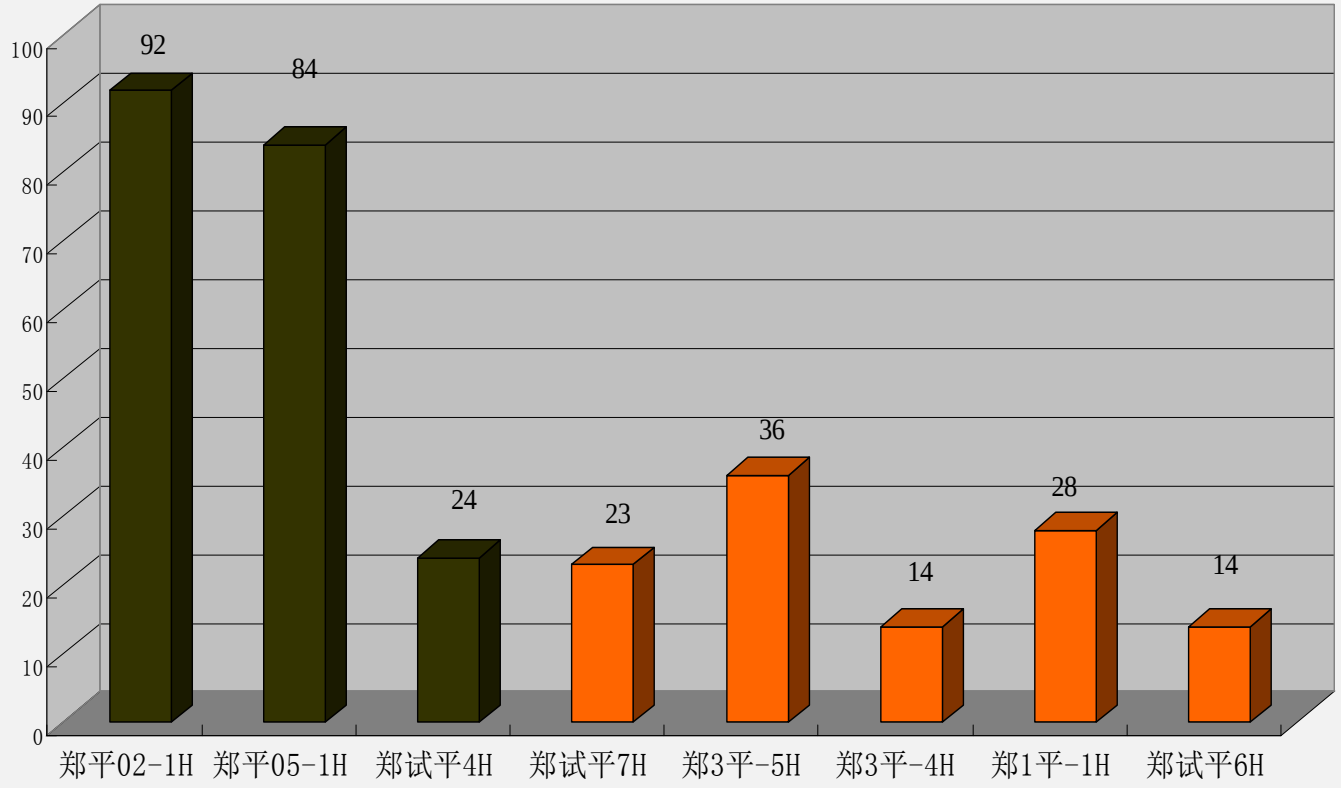
Drilling Technology and Equipment for CBM Horizontal Well

With more branches, average drainage area per well increases by 0.16 km²



Drilling Technology and Equipment for CBM Horizontal Well

Drilling cycle for horizontal segment decreases substantially.



I. Overview

II. Low-Cost CBM Vertical Well

III. Drilling Technology and Equipment for CBM Horizontal Well

IV. Conclusions

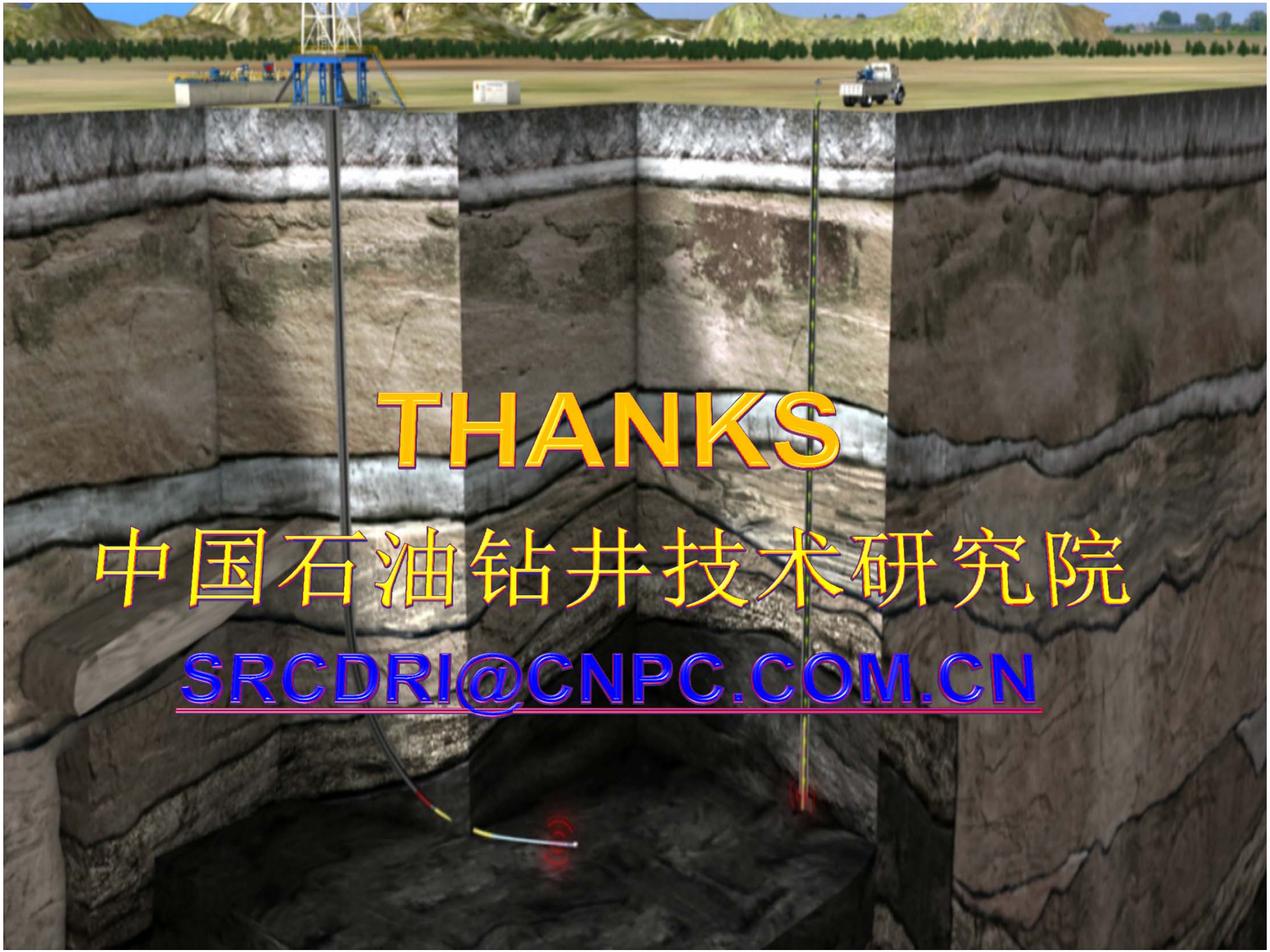
CONCLUSIONS

① **Low-cost vertical wells** and **cluster wells** are widely used in China, and become the main methods for CBM productivity construction.

② **Special multilaterals**, **U-type wells** and **L-type wells** are developed to deal with high rank coal seams with lower permeability. Average well cost has been reduced by **one third**.

③ **DRMTS** and **DREMWD** have been developed to realize domestic design and manufacture of key CBM equipment.

④ **PE and GRE screen completion** provide a cost-effective and competent way to prevent blockage of the borehole, which usually happens with open hole completion.


THANKS
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