陕西延长石油(集团)有限责任公司
SHAANXI YANCHANG PETROLEUM(GROUP)CO.,LTD.

Jingbian CCS Project

Shaanxi Yanchang Petroleum (Group) Co., Ltd., China

June 15, 2015

Outline

1. Introduction
2. Objectives and Anticipated Outcomes
3. Description and Relevance
4. CO_2 capture and injection site construction
5. Technical Description
6. Conclusions

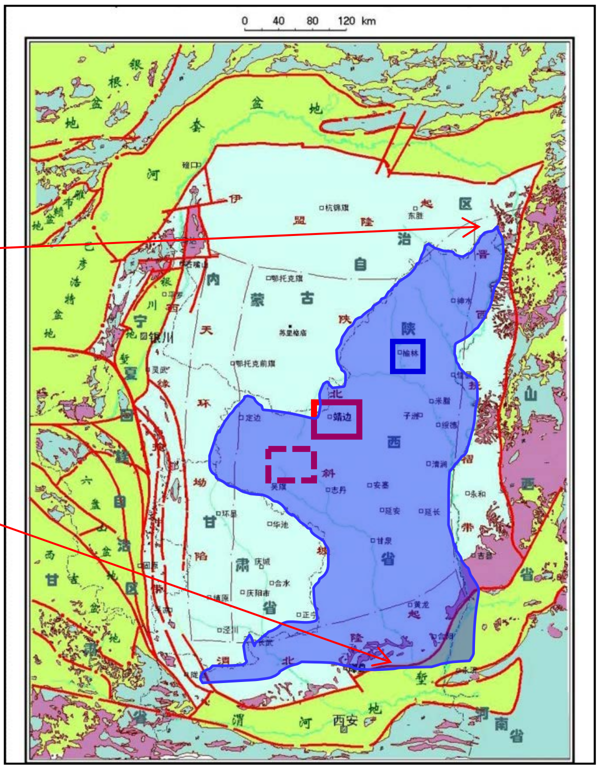
1. Introduction

(1) Location

CO_2 Storage Site: Jingbian city, Shaanxi Province, China

Map of China

Structure of Ordos Basin



Location of Jingbian Field and CCS site (Red box). Source of CO_2 is captured from Yulin Coal Chemical Company of Yanchang Petroleum in Yulin City (Blue box).

1. Introduction

(2) Project Goals

To utilize the CO_2 captured from coal chemical company and implement CO_2-EOR and CO_2 sequestration in Ordos Basin.

- To capture CO_2 through the use of low-temperature methanol wash coal chemical production processes.
- To transport CO_2 by trucks and inject CO_2 into nearby oil fields instead of water flooding.
- To improve oil recovery through CO_2-EOR in ultra-low permeability and porosity reservoir in Ordos Basin.
- To store CO_2 permanently and safely underground in Ordos Basin.

1. Introduction

(3) Project Timeline

Description	Important Date
Project preparation	Oct.2009, Yanchang Petroleum Group started CO_2-EOR test in Chuankou Field. From March,2011 to Dec,2013, Yanchang started to evaluate CO_2 sequestration site under framework of China-US Clean Energy Research Center (CERC).
Project start date	January 1, 2012. China Ministry of Science and Technology (MOST) started to support Jingbian CCS Project.
Research project of the first phase finished	April 30,2015. CO_2 will continue to be injected in Jingbian Field.
CO_2 injection start date	September 4, 2012.
CO_2 capture start date	November 29, 2012, at Yulin Coal Chemical Company.
GCCSI started to sponsor	July 2, 2013.
Becoming China's Demonstration Project	Sep.5, 2014. The National Development and Reform Commission (NDRC) chose Jingbian CCS Project as a key low carbon demonstration project of China.
Amount of injected CO_2	about 43,000 tons on May 31, 2015.

2.Objectives and Anticipated Outcomes

- Planned to improve the efficiency of coal resource utilization and utilize the CO_2 which is the byproduct of coal chemical company of Shaanxi Yanchang Petroleum Group.
- Planned to build 50,000 tons/year CO_2 capture equipment Yulin Coal Chemical Company of Shaanxi Yanchang Petroleum Group in Yulin City, Shaanxi.
- Planned to inject CO_2 in more than 5 wells and get EOR ratio about 5% to 8% at the low porosity and permeability reservoir of Jingbian Field.
- Planned to develop an integrated MMV (Measurement, Monitoring and Verification) technique and formed CO_2-EOR techniques and a CCS demonstration pilot project.

3. Description and Relevance

(1) Ordos Basin is the largest oil and gas production area in China

Oil & Gas Equivalent production in 2014		Coal Production of Shaanxi in 2014
Yanchang Petroleum Group	Changqing Oil Company (PetroChina)	520 MT
13.75 MT	55.45 MT	

Fossil Fuel Reserves of Shaanxi Yanchang Petroleum Group in Ordos Basin

	Crude Oil	Natural Gas	Shale Gas	Coal
Proved Reserves	23×10^8t	3374×10^8Nm^3	290×10^8Nm^3	150×10^8t

3. Description and Relevance

(2) The excessive production of fossil fuels leads to large CO_2 emission

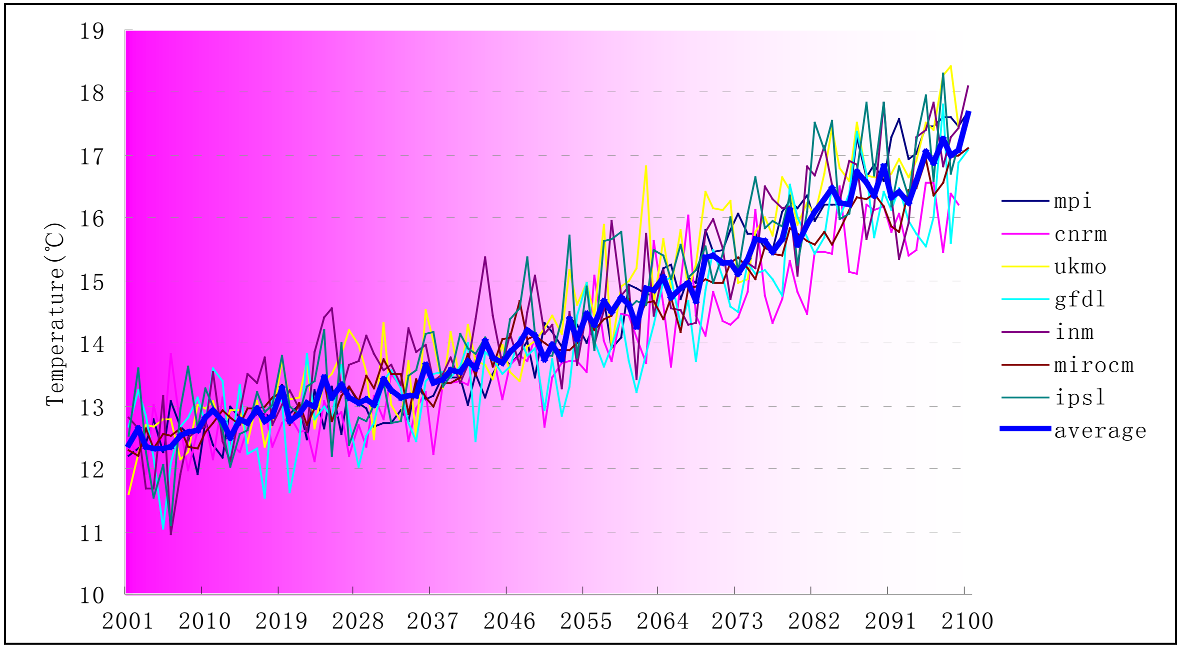
- CO_2 emission of Shaanxi Province was 133 million tons in 2005 and 234 million tons in 2011 roughly estimated by Liu et al. (2013). The average CO_2 emission per person in Shaanxi is 1.6 times as that in China.

- There are still ten large coal chemical projects under construction in Shaanxi. By 2016, when these projects put into operation, CO_2 emissions in Shaanxi will increase 180 million tons.

3. Description and Relevance

(3) Large CO_2 emission leads to Climate Change in Shaanxi

The estimated Shaanxi provincial average temperature curves from year 1990-2100 (Shaanxi Meteorological Administration, Jiwen Du, 2009)



Yulin City of Shaanxi is threaten by desertification and in the desert margin.

- Large amounts of CO_2 emission caused a fast-rising average temperature and climate change in Shaanxi Province.
- Climate change intensified the severity of dust storm and desertification in the north of Shaanxi.

3. Description and Relevance

● A warmer climate impacts on fruits through over-ripening, drying out, rising acidity levels, and greater vulnerability to pests and disease, resulting in changes in fruits quality, production, etc.

● If temperature increased 1 degree Celsius in Shaanxi, Shaanxi would not be the world's largest high quality (Fuji) apple planted area.

● Highest temperature in Shaanxi breaks record every year and makes worse drought, poor harvest and drinking water supply.

Kiwi fruit trees were affected by high temperature and drought in Shaanxi in2014. http://www.weather.com.cn/shaanxi/tqxs/08/2170869.shtml

The high temperature broke record in Shaanxi. Fengcun Reservoir of Sanyuan, Shaanxi nearly dried up on Aug.2,2014

3. Description and Relevance

(4) China's Action on Climate Change

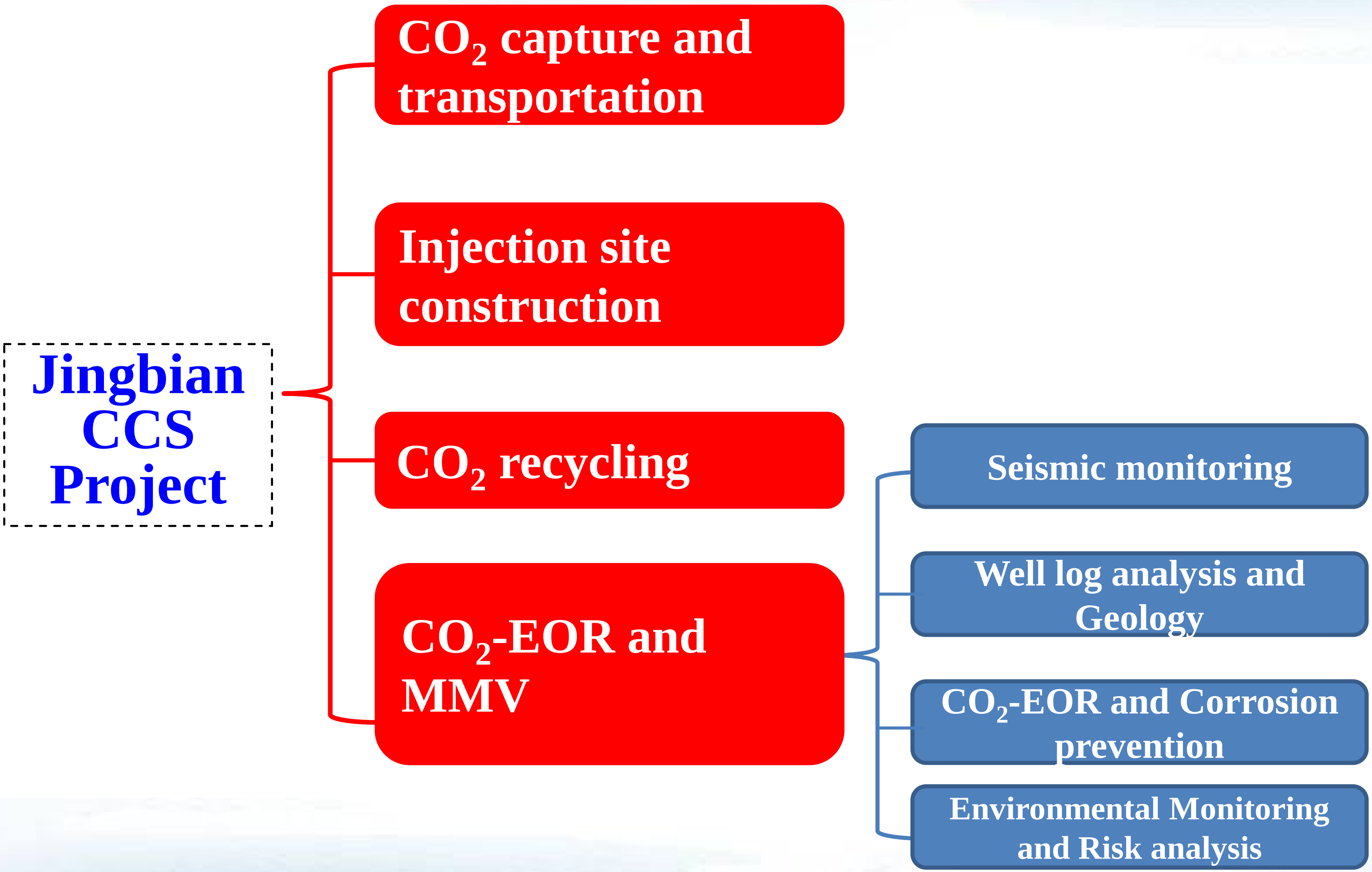
- On Nov.12, 2014, China promised that its emissions would peak "around" 2030 on China-US Joint Announcement on Climate Change.

- National Medium- and Long-term Program for Science and Technology Development (2006-2020), China's National Climate Change Program, China's Scientific and Technological Actions on Climate Change, National 12th Five-Year Plan on Science & Technology Development listed CCS as key technology to mitigate climate change.

- Shaanxi is selected as one of the first batch of selected localities to promote low carbon pilot projects in 2010 when China launched a national "low-carbon province and low-carbon city" experimental project

(5) Management of CO_2 emissions in Yanchang Petroleum Group

Year	Sponsor	Activity	Funding (Million)
2007	MOST	CO_2-EOR pilot test in Chuankou oil-field	RMB 3.12
2010	Shaanxi Yanchang Petroleum Group	Systemly study CO_2-EOR in Ordos Basin,China	RMB 4.8
2011	MOST & Shaanxi Yanchang Petroleum Group	CO_2 capture from coal chemical industry and CO_2-EOR demonstration project in North Shaanxi	RMB 56.1
	US-China Clean Energy Research Center	Integration of Enhanced Oil Recovery with CO_2 Storage in Mature Oil Fields of the Ordos Basin, China	RMB 0.6
2012	MOST& Shaanxi Yanchang Petroleum Group	Shaanxi Yanchang Petroleum Group and Northwest University started the first CCS-EOR pilot project in Jingbian Field	RMB 8.92
2013	GCCSI	China-Australia international demonstration project of CCUS integration	AUD 2.30
2013	Government of Shaanxi	CCS technology and pilot test of CO_2-EOR in North of Shaanxi	RMB 0.3


Jingbian CCS Project
CO_2 capture and transportation
Injection site construction
CO_2 recycling
CO_2-EOR and MMV
Seismic monitoring
Well log analysis and Geology
CO_2-EOR and Corrosion prevention
Environmental Monitoring and Risk analysis

4. CO_2 Capture and Injection Site Construction

(1) CO_2 Capture and Transportation

- Yulin Coal Chemical Company of Shaanxi Yanchang Petroleum Group will produce acetic acid 1 million tons/year. In its first phase, it has been producing acetic acid about 200, 000 tons/year with CO_2 emission about 52,000 tons/year since March, 2011.

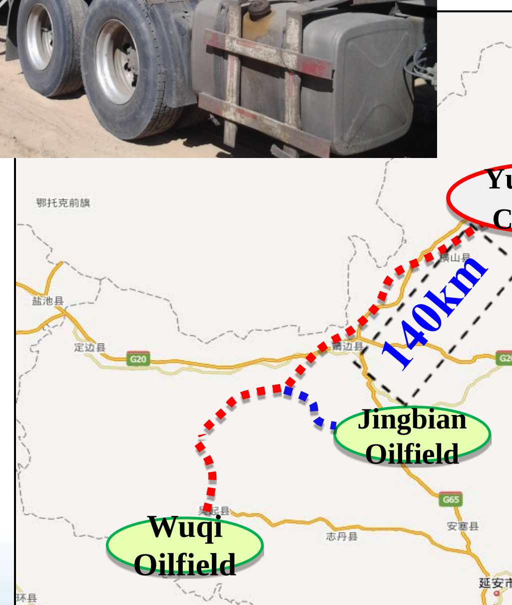
- In November of 2012, the CO_2 capture equipment (50,000 tons/year) was put into operation in in Yulin Coal Chemical Company.

- The capture technology is rectisol, the CO_2 concentration of product is about more than 99.9%. The cost for CO_2 capture is about USD18.8.

- CO_2 was transported from Yulin city to Jingbian Field by two 20 tons tankers and is now by four 25 tons tanks rented from a private company.

25 tons tanker

25 tons
tanker



4. CO_2 Capture and Injection Site Construction

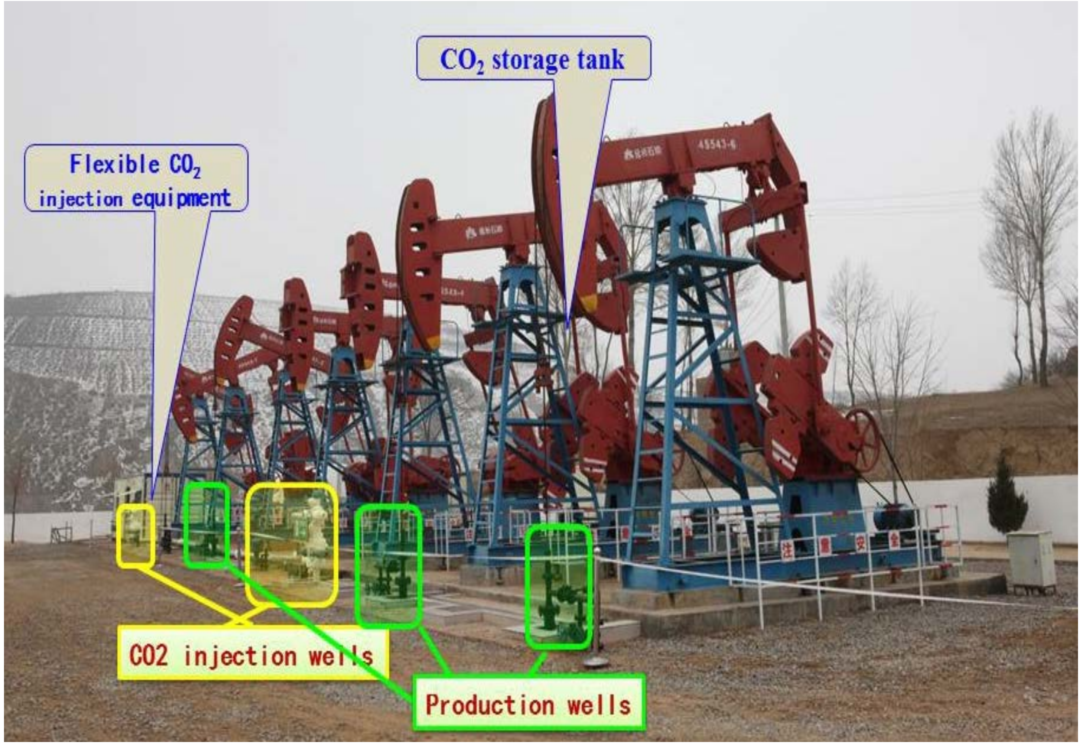
(2) CO_2 injection site construction

Injection site construction includes: **CO_2 storage tank, pumping stations, field stations, road to CO_2 injection wells, parking lot and area of well site.**

4. CO_2 Capture and Injection Site Construction

(2) CO_2 injection site construction

- Five CO_2 injection wells are located in the existing cluster well platform (Jing 45543 well platform of Qiaojiawa area) that saved the investment.
- The designed flexible CO_2 injection equipment makes full use of limited area in one platform.

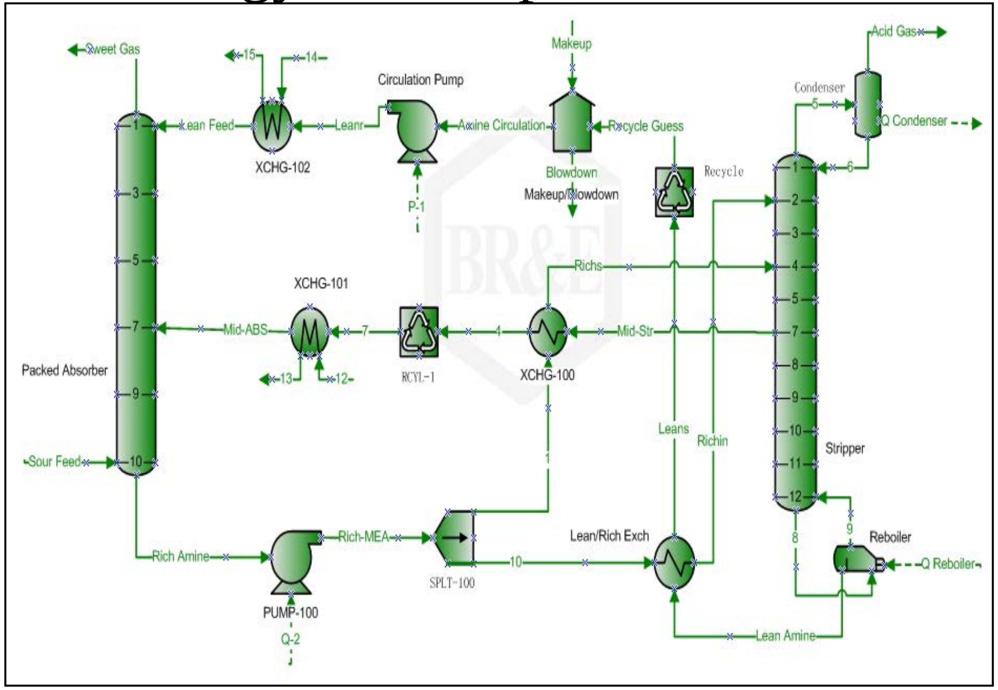


- CO_2 injection wellhead equipment has been replaced by anticorrosion material.

4. CO_2 Capture and Injection Site Construction

(3) CO_2 recycling

The facility of CO_2 captured and seperated from production well is being developed by Shaanxi Yanchang Petroleum Group, China Huaneng Group and Hunan University. The method of CO_2 removal and separation is amine absorption based on the low energy consumption.



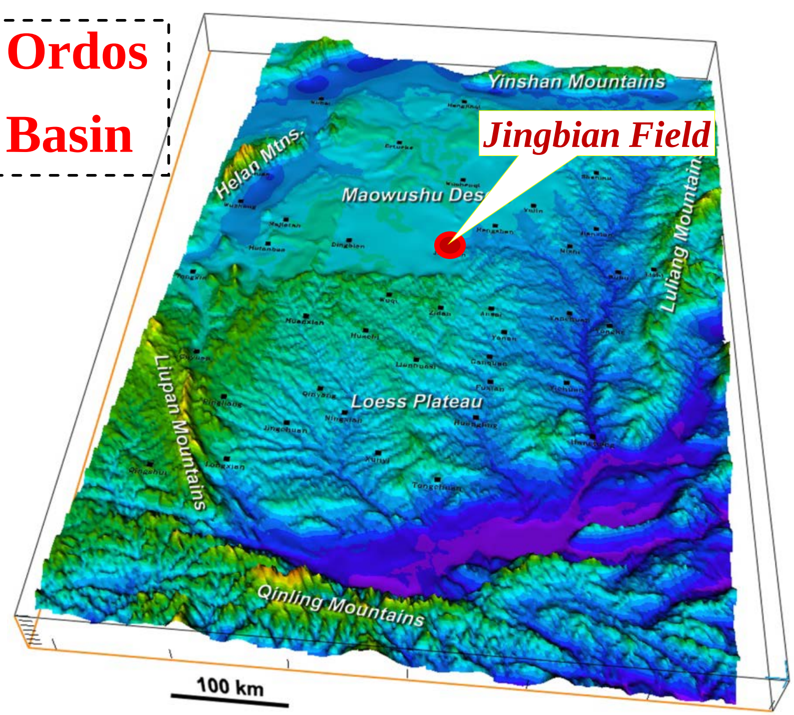
Pilot-plant of CO_2 removal and separation in Yanchang Petroleum Group

5. Technical Description

(1) Geology Background of Jingbian Field

- Jingbian Field is located in central Ordos Basin in northern Shaanxi slope.
- The oil production was 350,000 tons in 2003, 960,000 tons in 2011 and 1 M tons in 2012.
- Initial average production rate is about 1.6 tons/day after being fractured and without nature productive ability.

Ordos Basin



Jurassic	Upper	Fenfanghe Fm.			
	Middle	Anding Fm.			
		Zhiluo Fm.			
	Lower	Yanan Fm.	Yan 9		Reservoir
			Yan 10		Reservoir
		Fuxian Fm.			
Triassic	Upper	Yanchang Fm.	Chang 1		
			Chang 2		Reservoir
			Chang 3		
			Chang 4+5		Caprock
			Chang 6	Chang 6_1	Reservoir
				Chang 6_2	Reservoir
				Chang 6_3	Reservoir
			Chang 7		
	Middle	Zhifang Fm.			
	Lower	Heshanggou Fm.			
		Liujiagou Fm.			

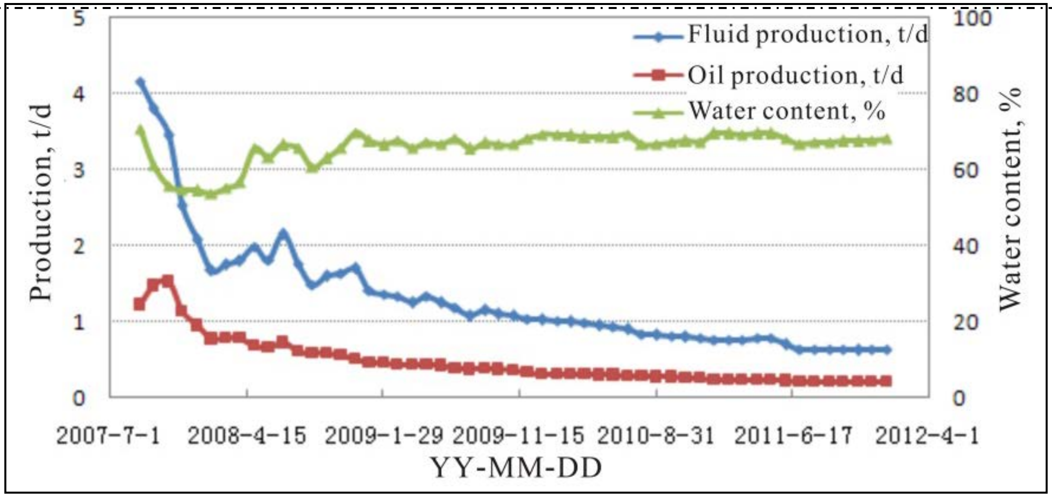
Reservoir Parameters in Jingbian Field

Parameters	Baseline	Monitor
Temperature (^{0}C)	44	Measuring
Primary oil viscosity (mPa,s)	4.84	
Primary oil density (g/cm^3)	0.85	
Reservoir depth (m)	1550	
Residual oil saturation (%)	42.2	
Pore pressure (MPa) near injection well	1.5~3 (before injection) 12 (in situ reservoir)	Measuring. Estimated 20-22 MPa
Pore pressure (MPa) near production well	1.5~3	Increasing
Permeability ($\times 10^{-3} \mu m^2$)	0.5~3.5	Decreased obviously
Porosity (%)	9-12	Decreased 0.61%~3.66%
GOR (m^3/t)	54~76	
Gas gravity	1.1545	
Salinity (PPM) $CaCl_2$	50,520-95,110	171,500
PH	5.5	5.38

5. Technical Description

(2) History of Jingbian Field

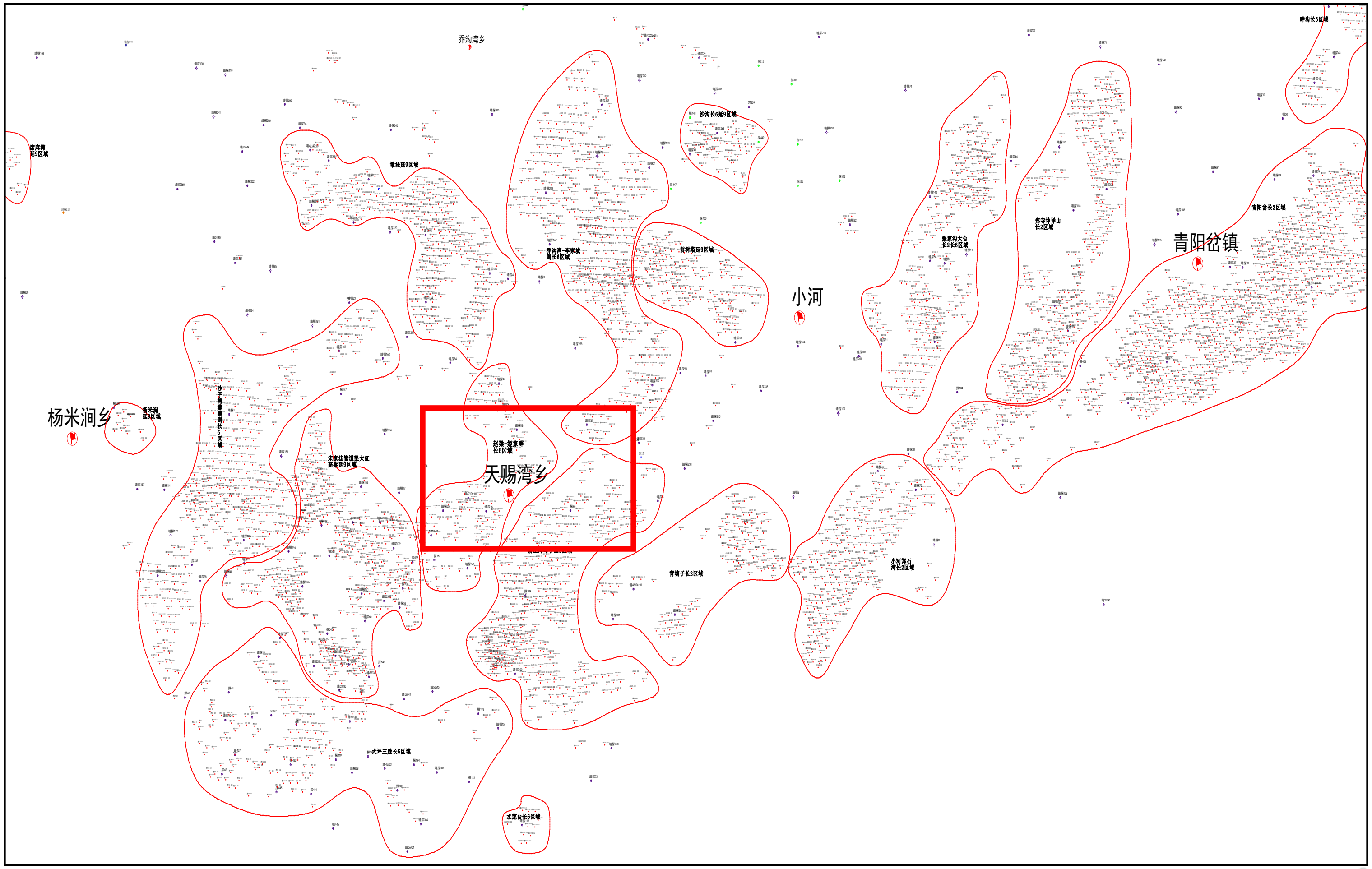
- Before 2003, the private companies had begun drilling for oil and gas for over 10 years.
- In 2003, Yanchang Petroleum Group owned Jingbian Field.
- August 2007, it started oil production after fracturing.
- March 2008, it began injection water for EOR. After 12 months oil production declined 74%.
- The average fluid production was 0.5 tons per day, where oil production was 0.18 tons.
- Water flooding effect was not obvious in this area.



- The reservoirs of this area is low porosity and low permeability.
- Natural energy is low and the transmissibility is poor.
- The reservoir pressure and flow capacity drops quickly.

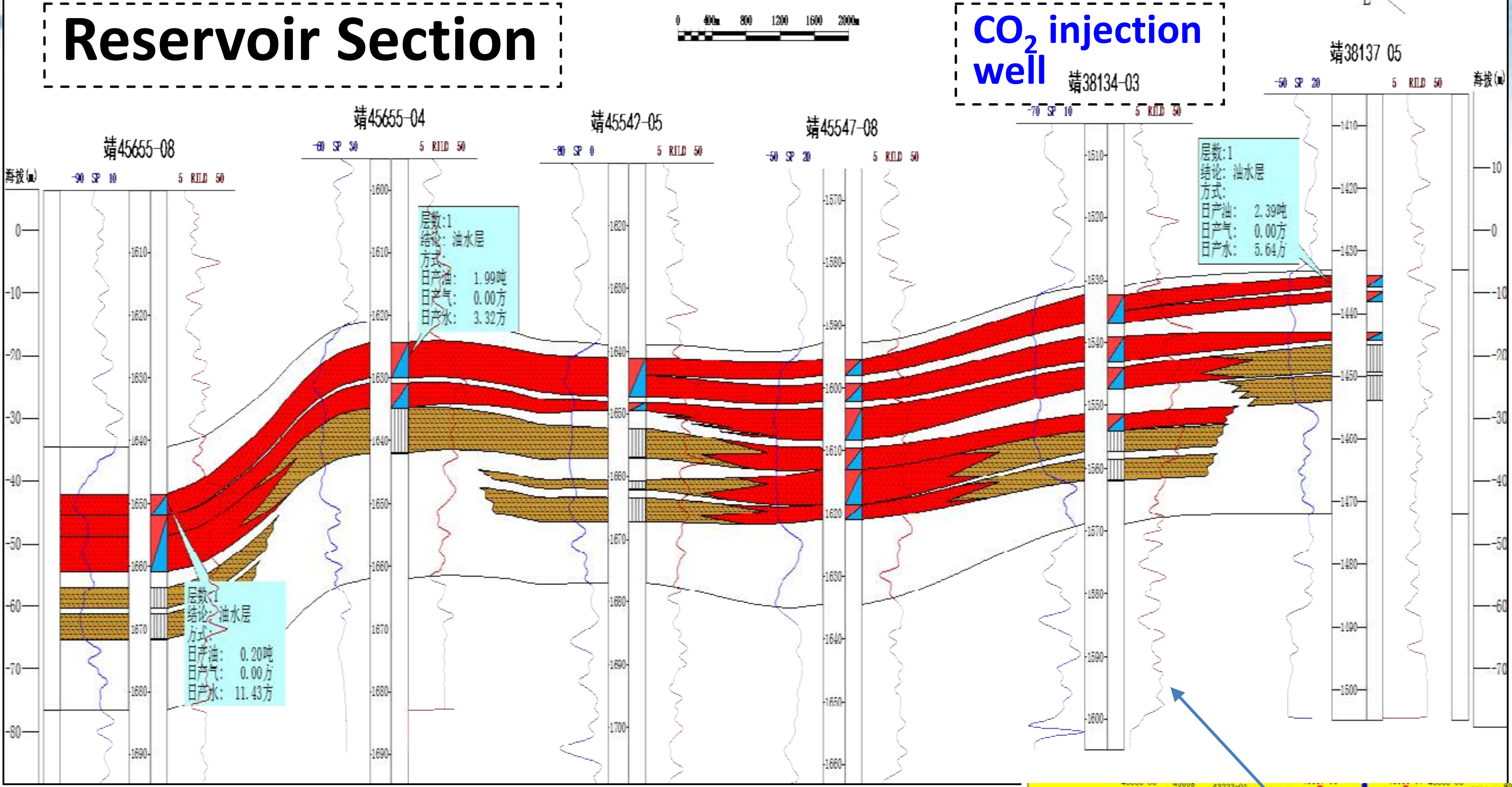
5. Technical Description

(3) Geological Characterization

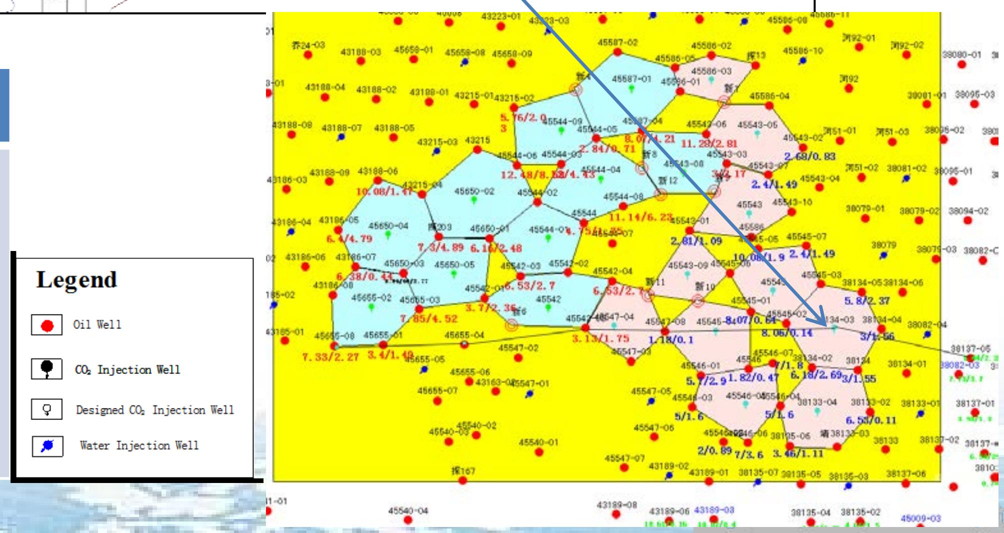


Location of CCS-EOR site in Jingbian Field

Reservoir Section



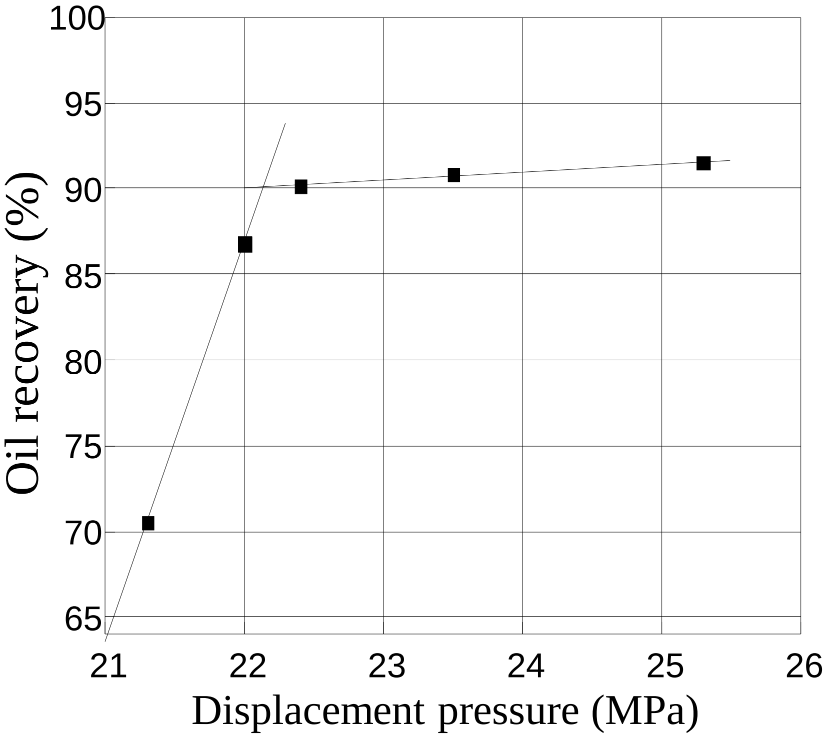
Planned	First batch wells
20 CO_2 injection wells Oil producing wells: 70 Closed water wells outside: 19 Area: 7.41 km2 Controlled reserves: 3.32 MT	10 CO_2 injection wells Main oil producing wells: 35 Area: 4 km2 Controlled reserves: 1.79 MT



5. Technical Description

(4) CO_2-EOR lab study

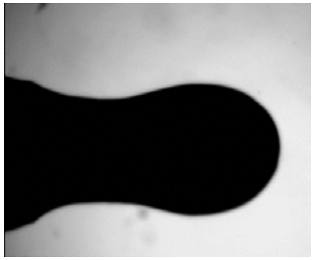
CO_2-EOR VS Pressure



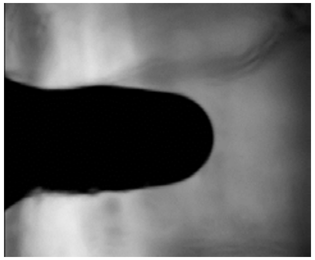
Jingbian Field CO_2 miscible displacement pressure test of Chang 6_2--Slim tube experiment

Minimum miscible pressure: 22.4MPa

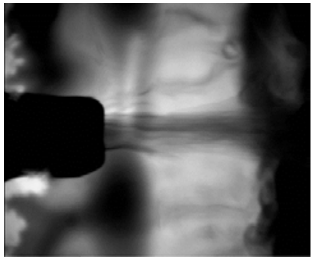
Experiment Pressure (MPa)	Volume of gas injection (%P.V.)	Oil recovery (%)	Note
21.3	75.45	70.48	Immiscible
22	94.9	86.78	Immiscible
22.4	98.76	90.14	Miscible
23.5	100.06	90.86	Miscible
25.3	101.6	91.52	Miscible



（a）10MPa



（b）20MPa



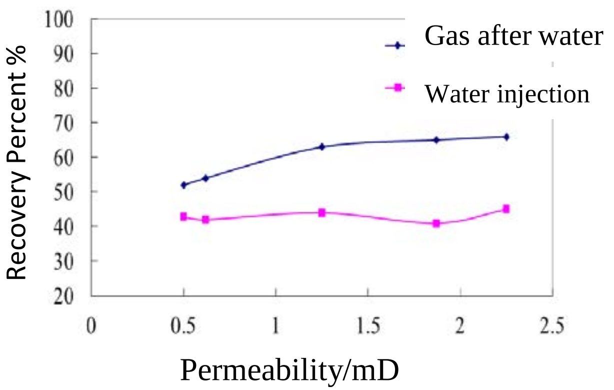
（c）24MPa

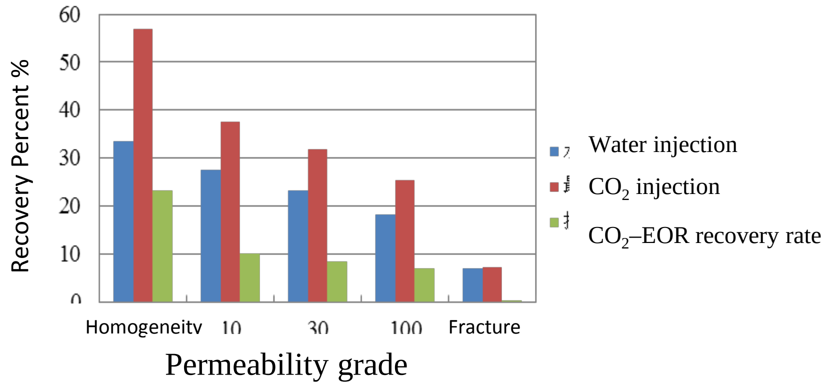
Formation	Chang4+5_1	Chang4+5_2	Chang6_1	Chang6_2
Caprock fracture pressure（MPa）	20.5~23.1	19.8~22.8	16.7~23.5	24.8~25.2
	21.9	20.7	20.9	24.9

5. Technical Description

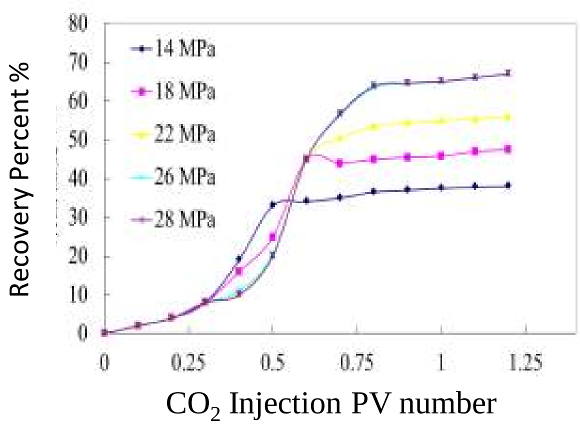
Factors influencing CO_2 -EOR

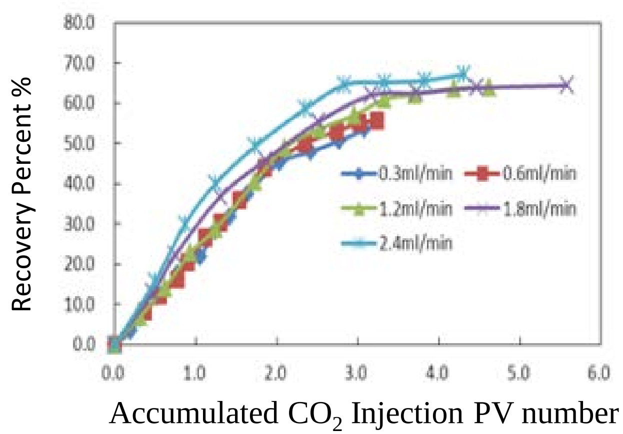
Permeability





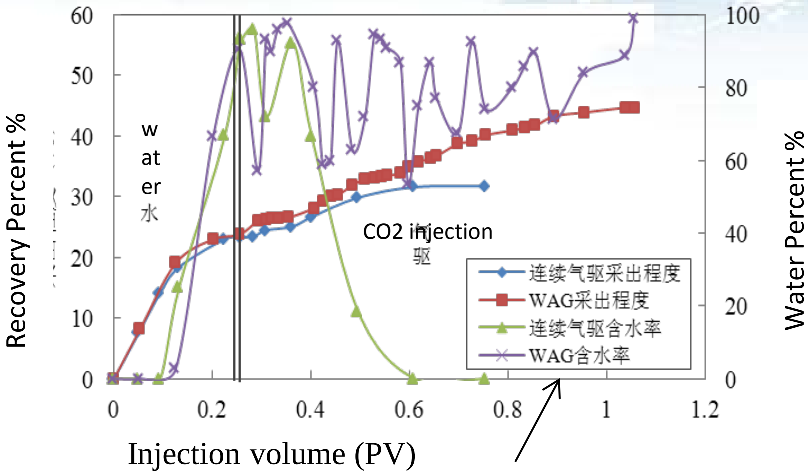
CO_2 Injection pressure, speed



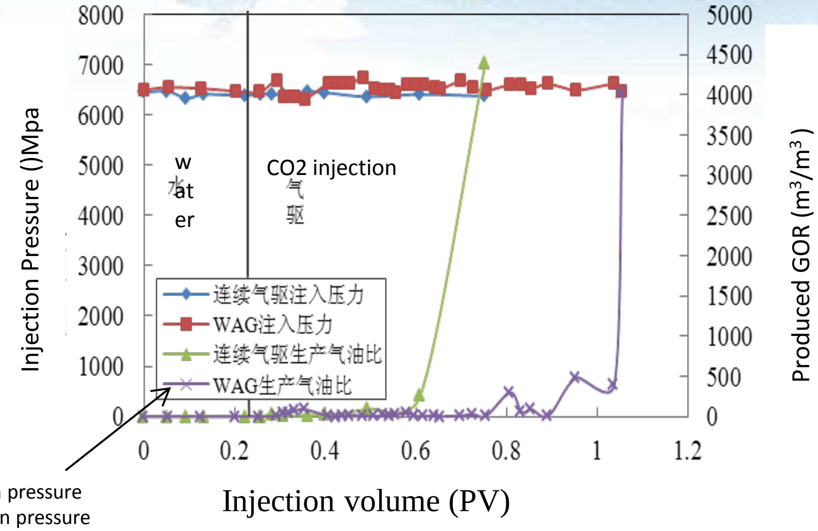


High speed CO_2 injection →High injection pressure → Obvious miscible effect → High CO_2-EOR efficiency

Injection methods



- CO2 injection recovery rate
- WAG injection recovery rate
- Water content by CO2 injection
- Water content by WAG



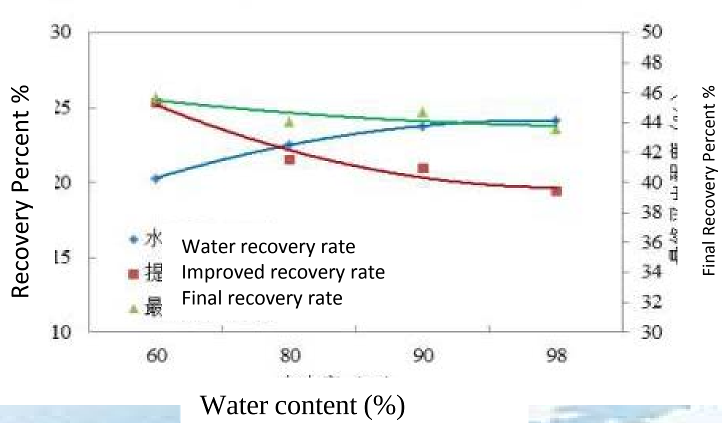
- CO2 injection pressure
- WAG injection pressure
- Produced GOR by CO2 injection
- Produced GOR by WAG

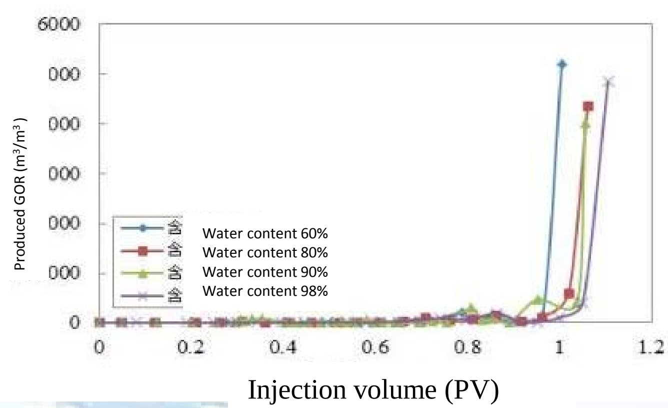
WAG and Gas injection enhance oil recovery curves (permeability grade is 30)

- Oil recovery increased 8.41% and final oil recovery reached 33.73% by CO_2 injection;
- Oil recovery increased 20.95% and final oil recovery reached 44.70% by WAG.
- Breakthrough by CO_2 injection is faster than that by WAG.

Injection opportunities

When water content reached 60%,80%,90% and 98% during water injection





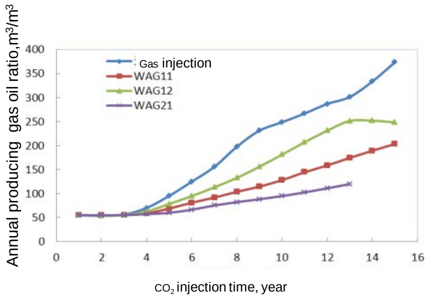
5. Technical Description

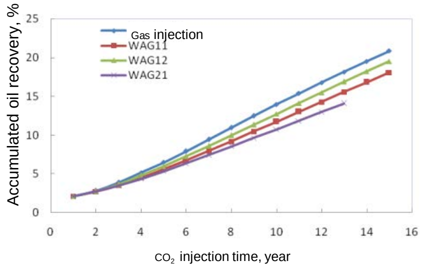
Gas oil ratio, Oil recovery level, oil displacement rate and water rate curves under different CO_2 injection pattern.

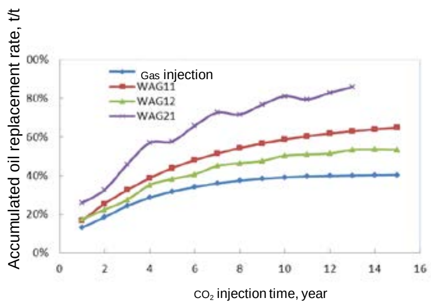
WAG11—After Injecting CO_2 three months, change to water injection three months.

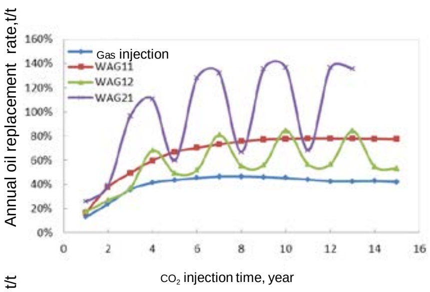
WAG12—After Injecting CO_2 three months, change water injection six months.

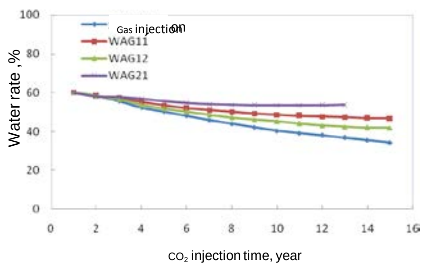
WAG21—After Injecting CO_2 six months, change to water injection three months.

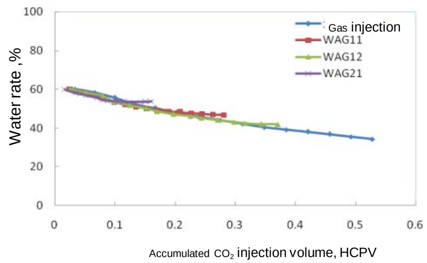


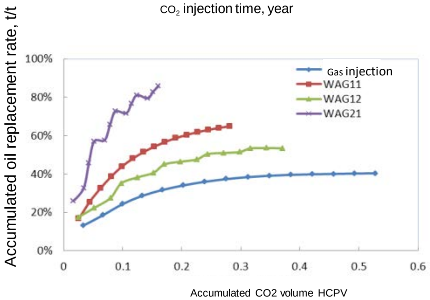


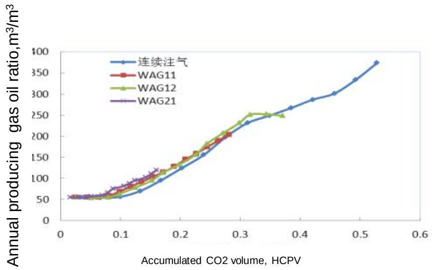


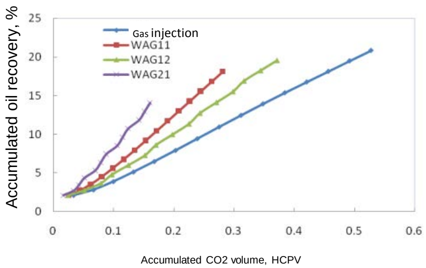


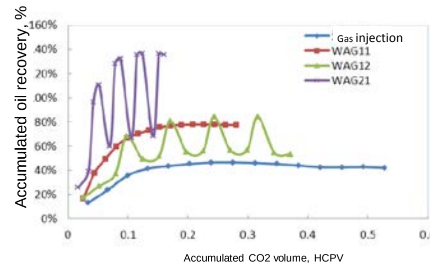








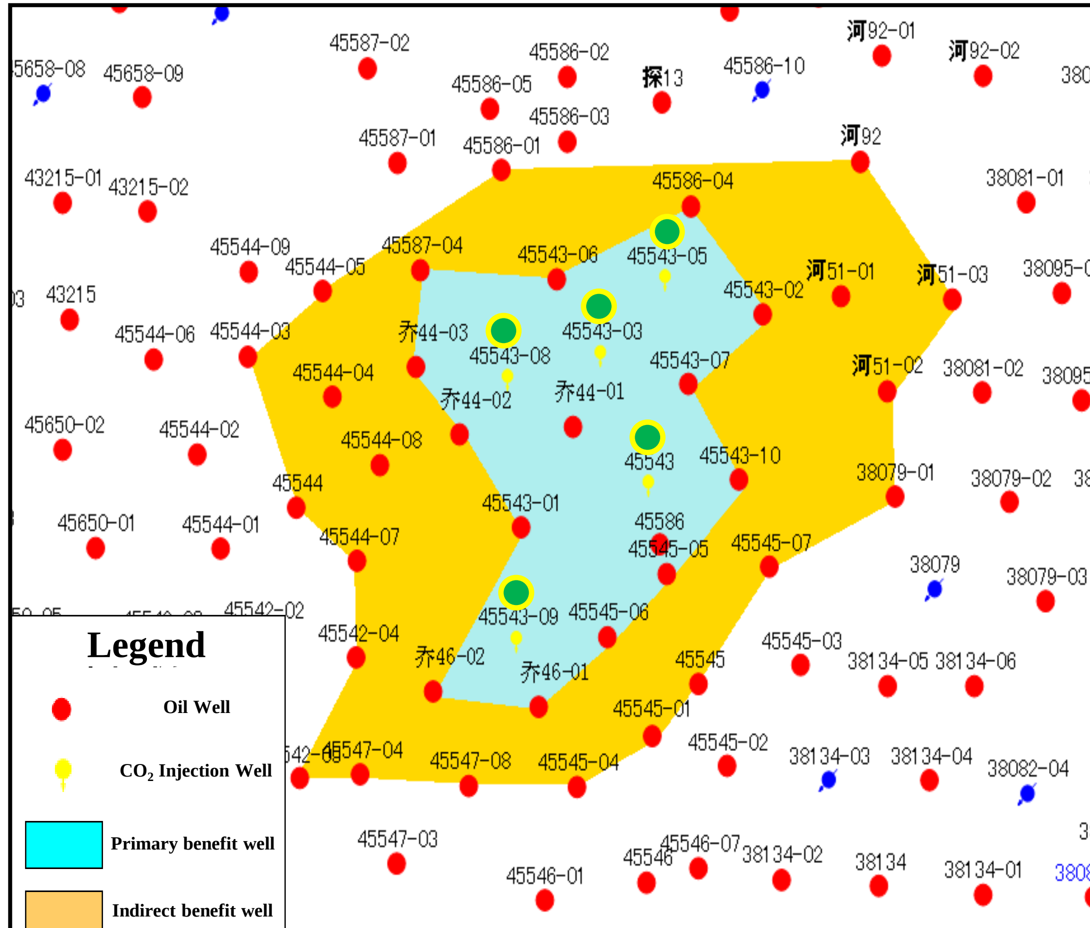




5. Technical Description

(5) Field experiment of CO_2-EOR

Well No.	Injection Date	Started injection Pressure (MPa)	Current injection pressure (MPa)	Accumulated injectionvolume (t)	Current status
45543	Mar.23, 2013	2.0	8.2	6426.4	Normal
45543-03	Sep.4, 2012	4.0	6.0	1724.78	Stopped in Nov, 2012 and reinjected in March, 2014
45543-05	Mar.23, 2013	1.6	8.7	7808.95	Normal
45543-08	June 8, 2014	4.0	5.8	254.20	Normal
45543-09	June 8, 2014	3.5	4.5	243.1	Normal
Accumulated volume of CO_2 injection till June 19,2014: 15736.4 t					

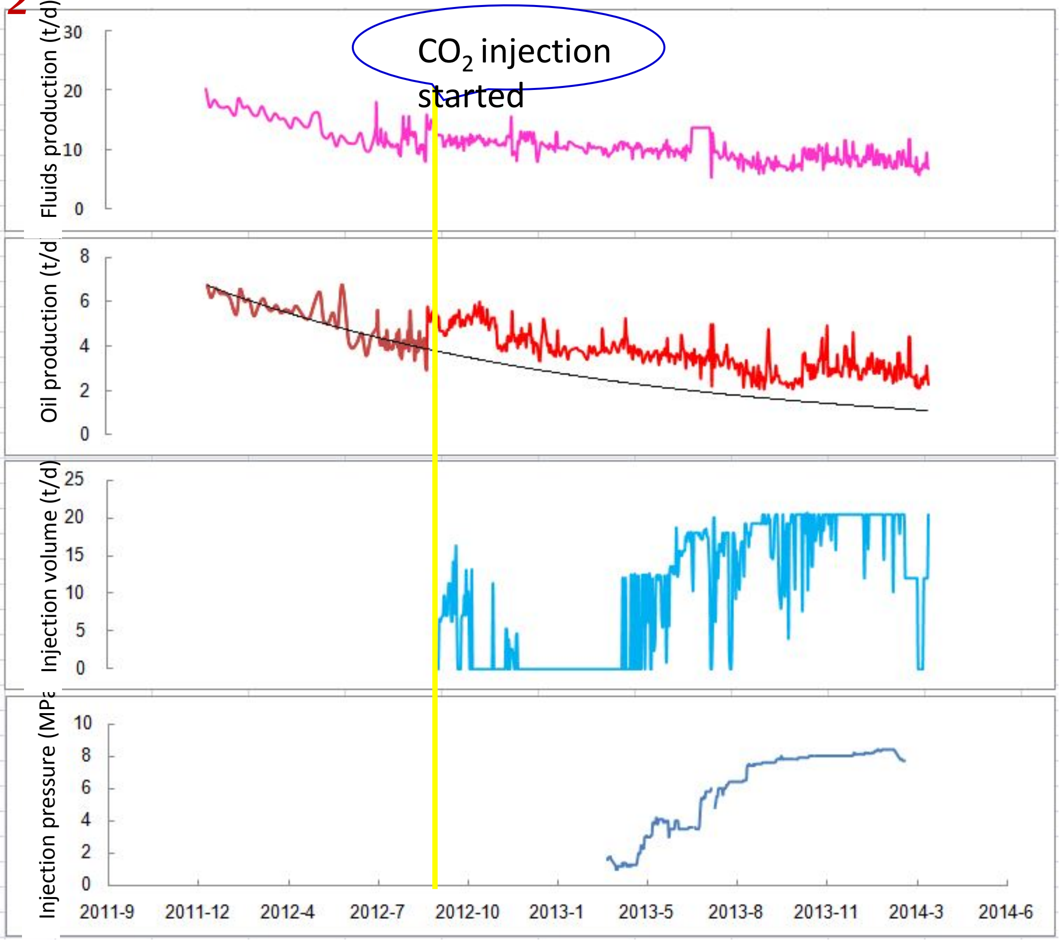


Accumulated CO_2 injection was 43,000 tons by the end of May , 2015.

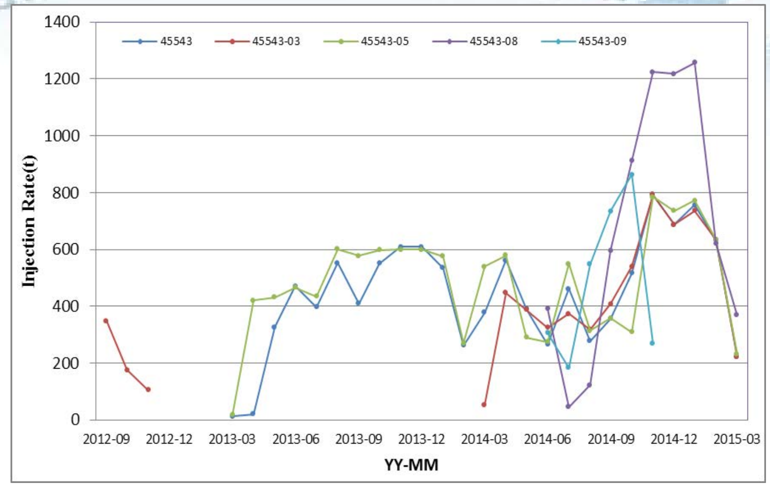
5. Technical Description

(5) Field experiment of CO_2-EOR

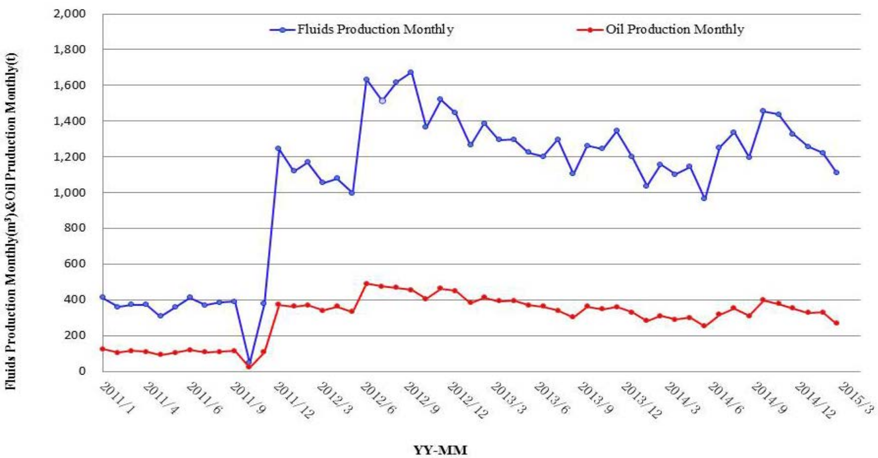
After injecting CO_2 13 months, the cumulative increasing oil production was 616 tons.

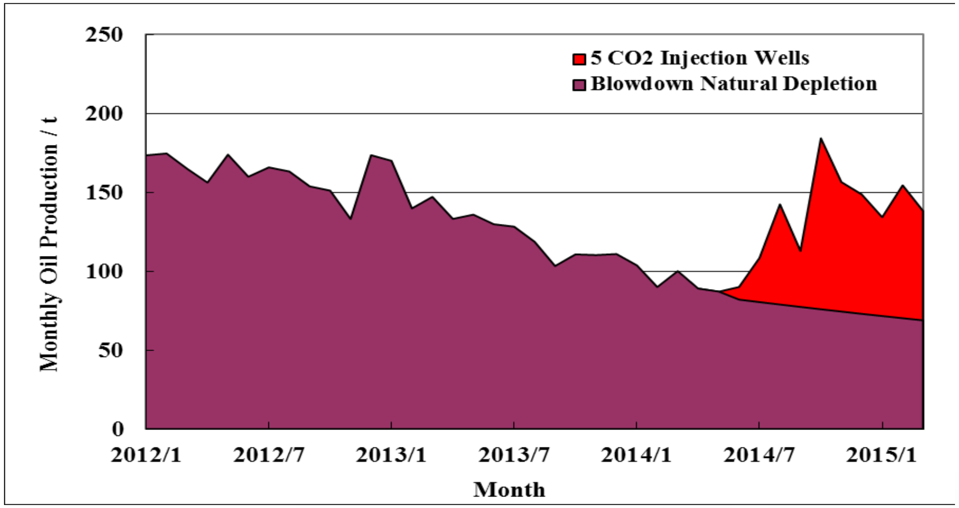


Injection curves in Jing-45543 injection well station. Note the injection effects before CO_2 injection (before Sep. 2012) and after CO_2 injection (after Sep.2012). (Courtesy Chunxia Huang).



Injection curves in Jing-45543 injection well station. Currently there are 5 CO_2 injection wells (after Sep.2012).(Courtesy Chunxia Huang).





For these 5 well groups, before CO_2 injection the oil production was 88 tons per month, and after CO_2 injection the oil production is 140 tons per month. The oil production increased about 60%. Oil recovery increased 5.73% comparing with water recovery.

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5. Technical Description

(6)Measurement, Monitoring and Verification and CO_2-EOR

What we are studying in Jingbian Field?

- Storage volume, structural and stratigraphic traps, fault seal, seal thickness, CO_2 capillary pressures, geomechnics, geochemistry, reservoir simulation, etc.
- More accurate reservoir parameters from well log analysis and rock sample.
- Efficiency of CO_2-EOR and Injection Strategy
- Confirmation of wellbore integrity, and anticorrosion, CO_2 plume movement.
- Confirmation of secondary trapping and safety of caprock.
- Fast and online monitoring techniques near surface and at atmosphere.
- Environmental effect of CO_2 leakage (Soil, groundwater, temperature, animals, plants, microbe, etc.).

5. Technical Description

(7) Geophysical Methods

Before CO_2 injection in Jingbian Field in early 2012, Yanchang Petroleum Group agreed to acquire 5 km^2 3D seismic baseline and monitoring data two times in Jingbian CCS-EOR site. Australia GCCSI has also funded part of 4D seismic acquisition.

We also planned time-lapse well logging and seismic rock physics experiment. Seismic rock physics experiment is still in testing.

3D seismic baseline data has not been acquired in Jingbian Field. The reasons are as below:

5. Technical Description

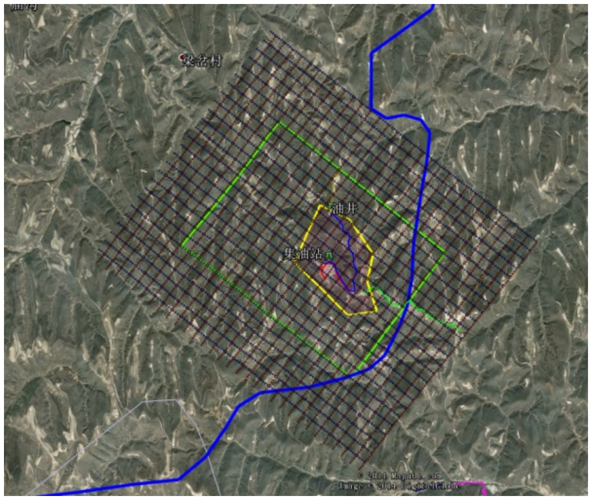
- The cost of 4D seismic acquisition we proposed was lower than the geophysical companies wanted.
- The rugged surface and thick loess conditions in loess plateau of Ordos Basin has been the main reasons that lead to poor seismic acquisition quality
- The drop from hill to valley is about 100 meters. Seismic static correction has been and will still be problems in this area.
- Continuing global warming and historically long-term droughts in northern of Ordos Basin caused the underground water table decline quickly.

5. Technical Description

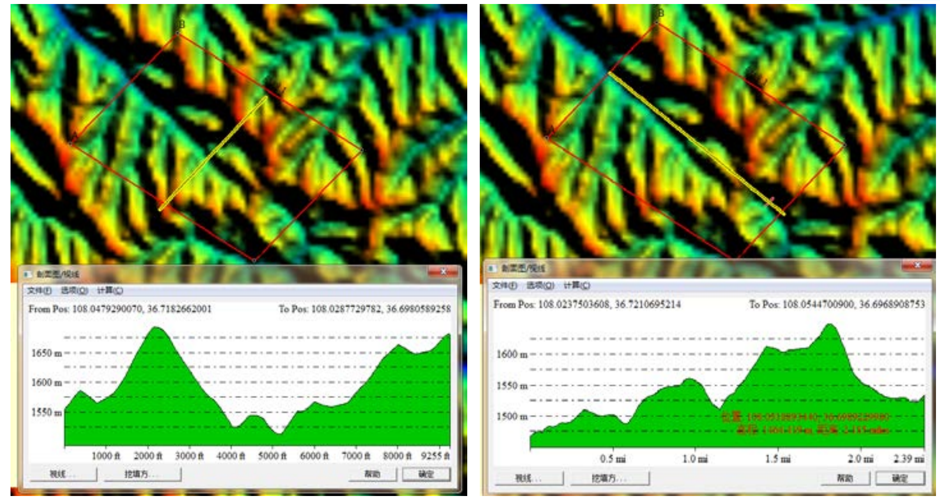
4D seismic survey in Wuqi Field

Topography of loess plateau in Wuqi Field

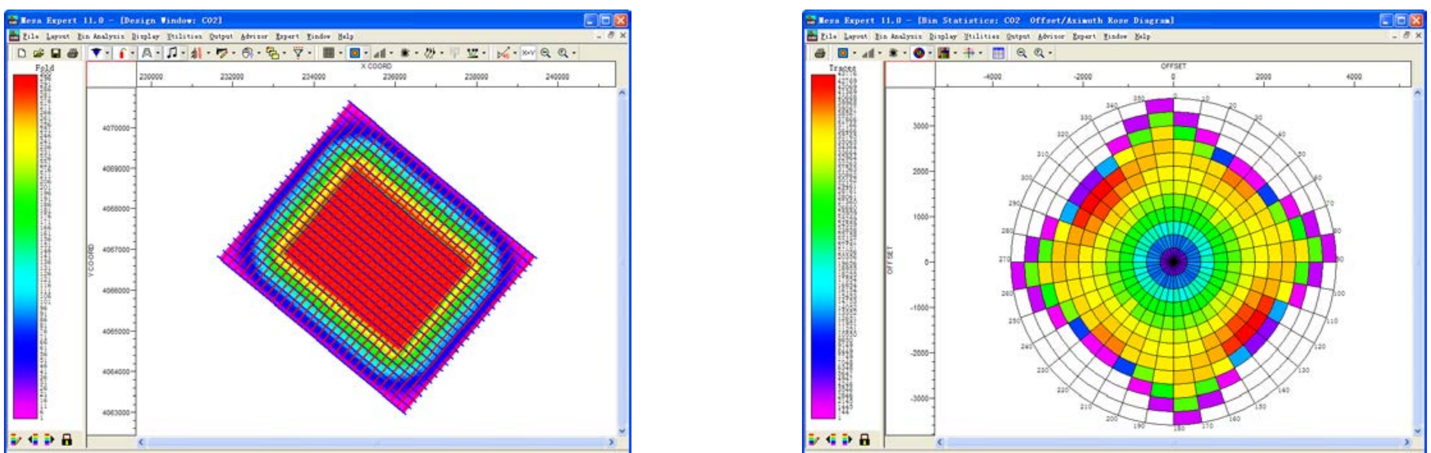
5. Technical Description



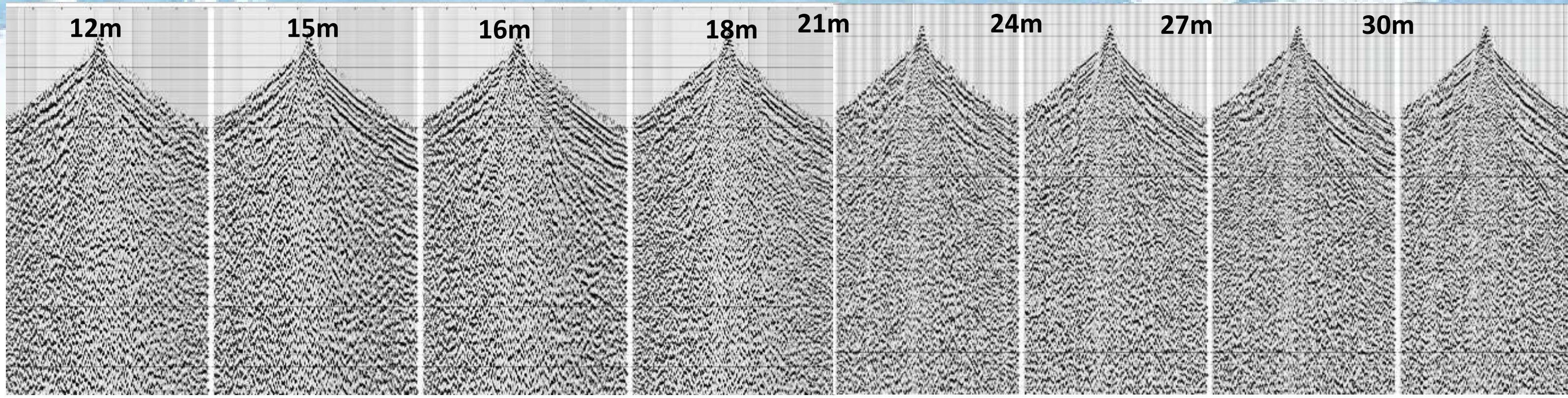
Designed baseline 3D seismic acquisition area in Wuqi Field.



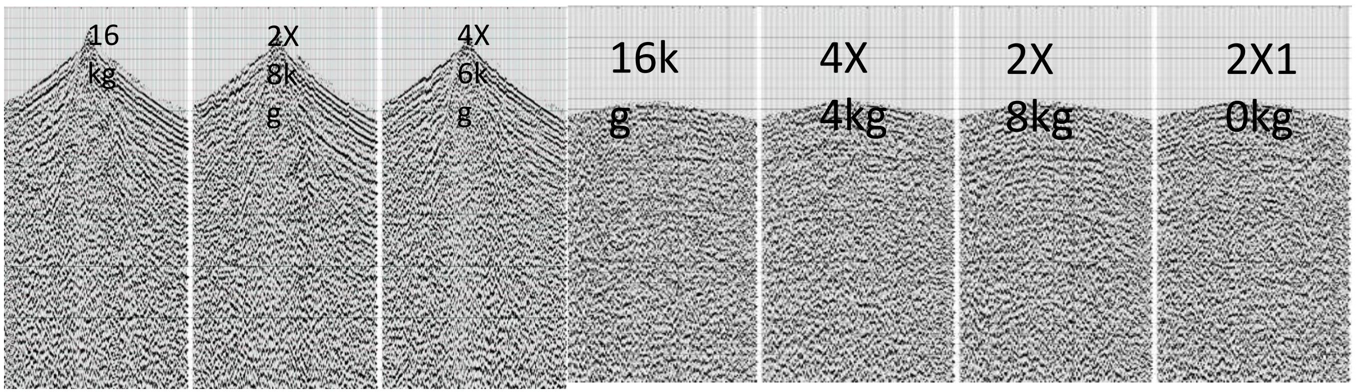
Topography in Wuqi Field.



Designed baseline 3D seismic geometry (fold and azimuth)

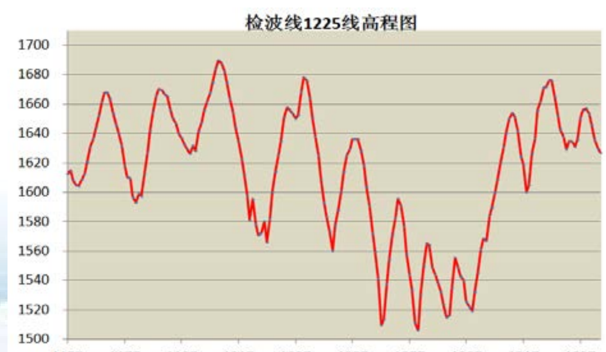


Shot gathers obtained from different depth of dynamite source



Shot gathers obtained from different explosive charge of dynamite source (4X6kg means four shots with 6 kg size of charge each shot)

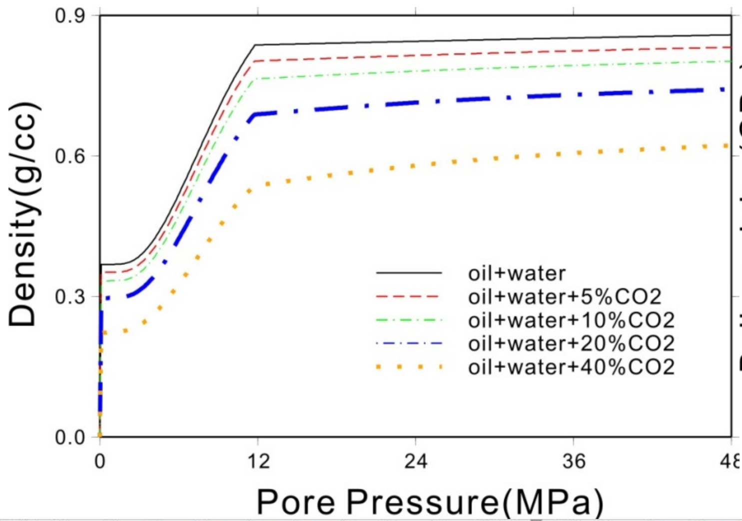
Source line interval	200 m
Receiver line interval	200 m
Source interval	50 m
Receiver interval	25 m
Max fold	144
Geometry	4*24 line
Shot number	100 /km^2
Area	10.5 km^2

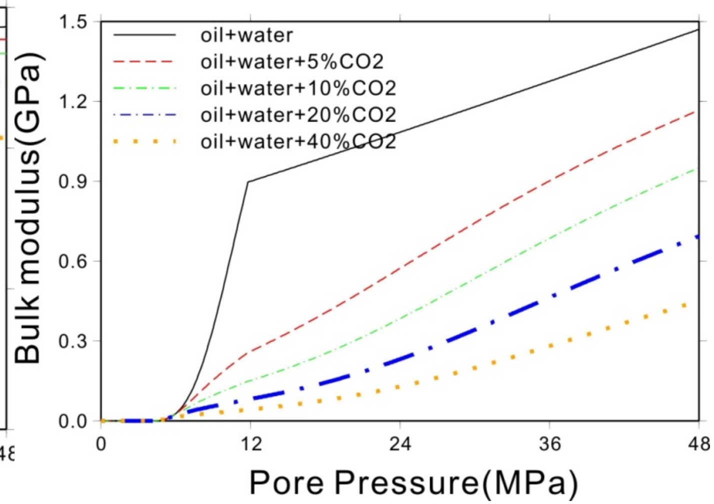


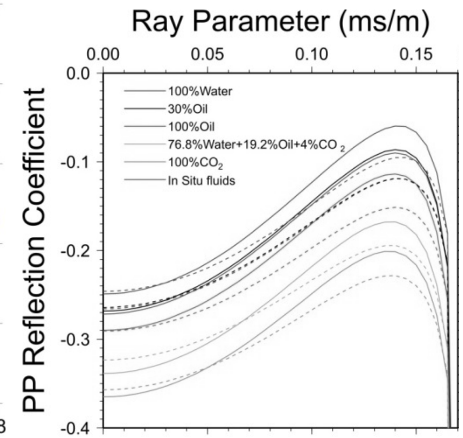
Receiver elevation of receiver location in two test seismic line in Wuqi.

5. Technical Description

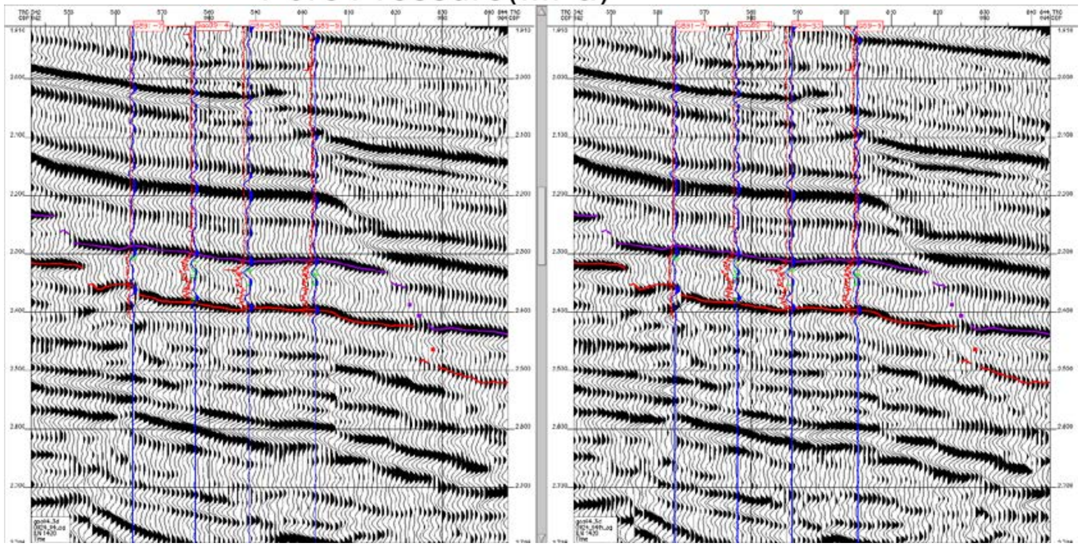
Fluid elastic properties of mixed CO_2+Oil+Brine



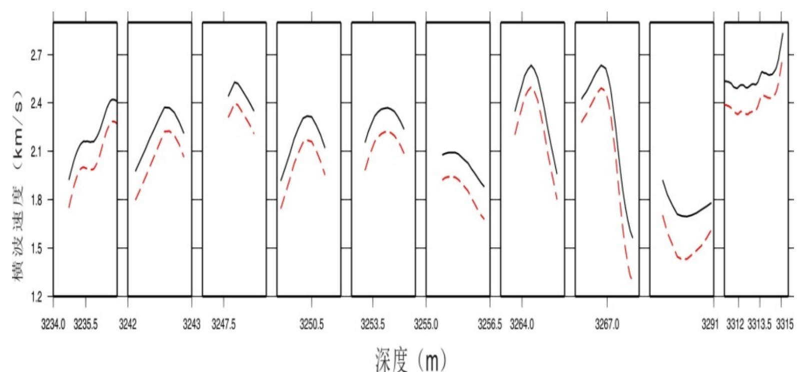




4D AVO forward model



Baseline and monitor 3D seismic processing,East China



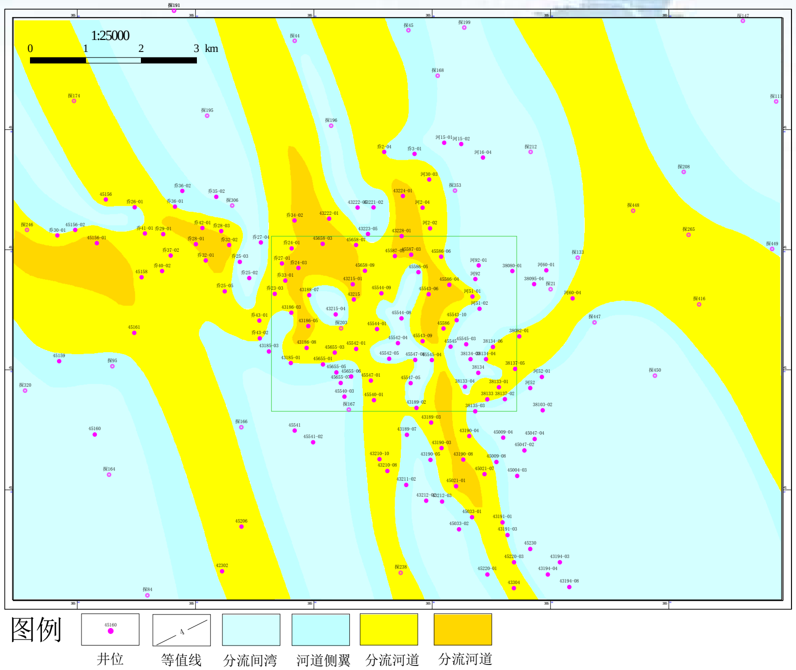
Shear wave velocity prediction at different depth.

5. Technical Description

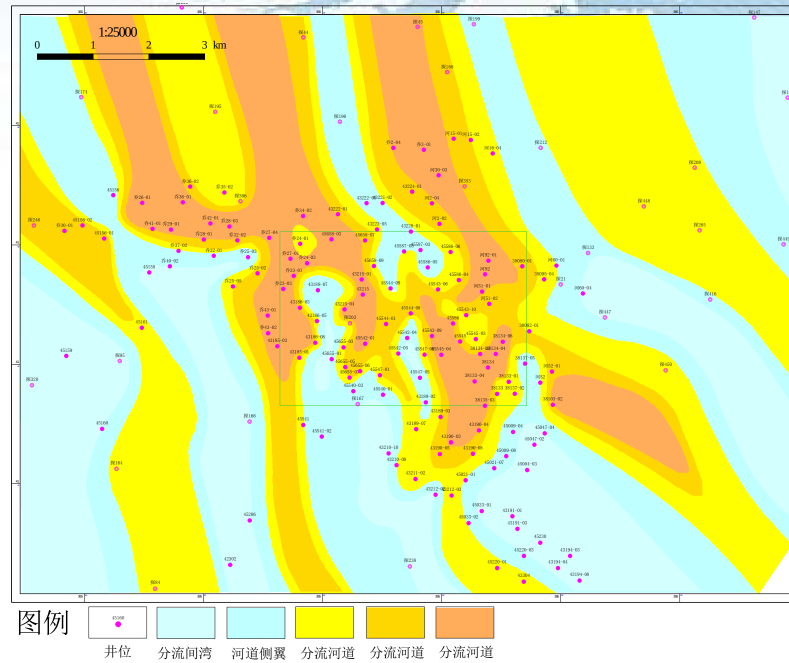
(8) Geology Study

- Analysis of geological controlling factors of CO_2 sequestration
- CO_2 flooding reservoir performance analysis of demonstration area
- Evaluation of caprock sealing ability
- Reservoir and caprock micro-sealing difference analysis

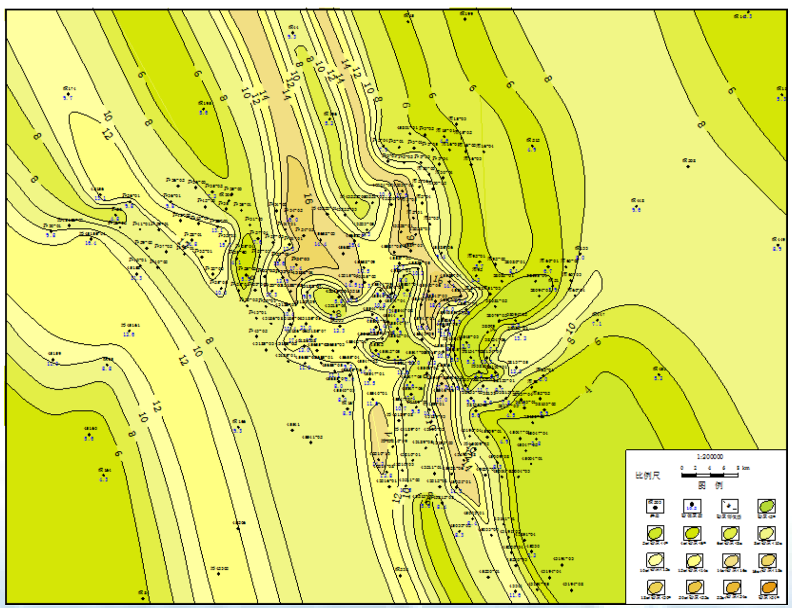
Microfaces of Chang $4+5_1$



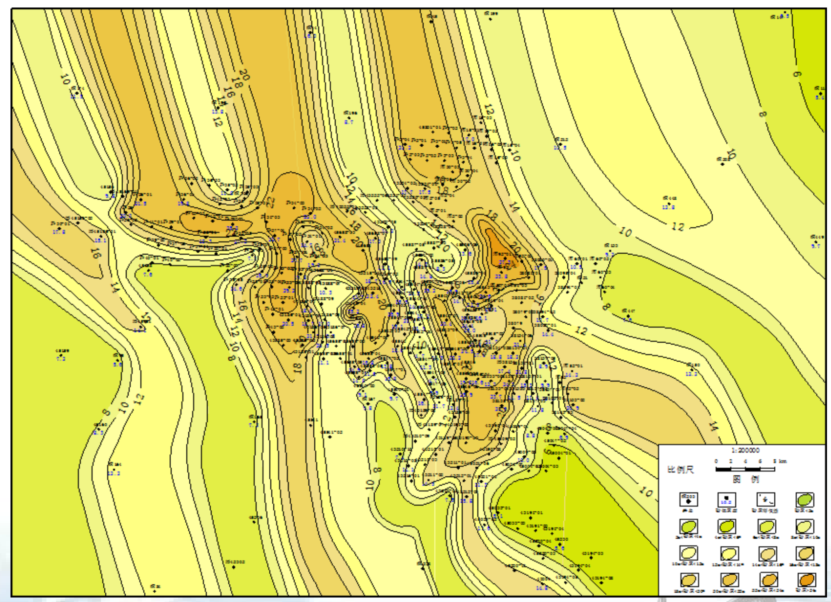
Microfaces of Chang 6_2



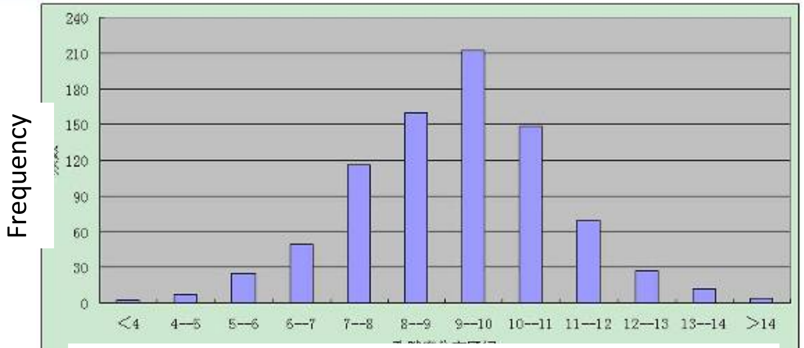
Sand distribution of Chang $4+5_1$



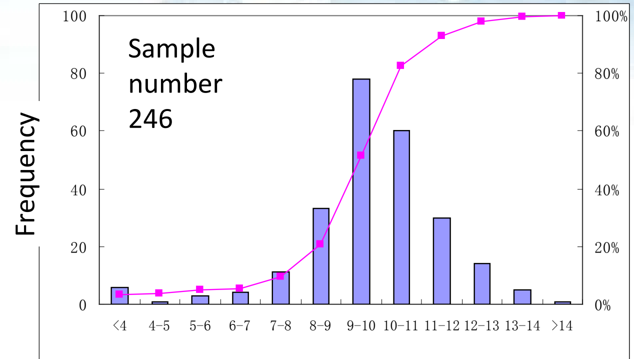
Sand distribution of Chang 6_2



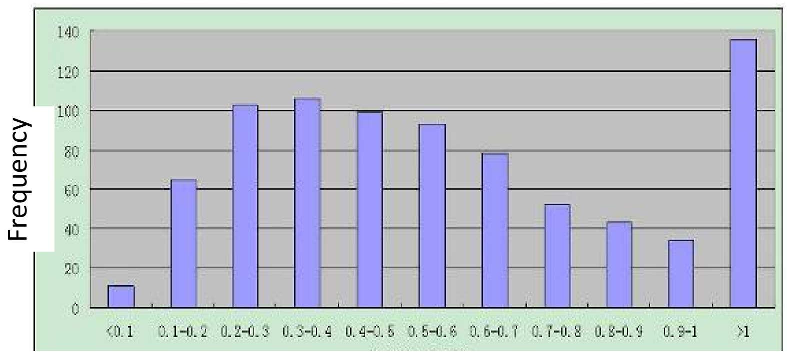
Histogram of porosity, permeability and water saturation of reservoir



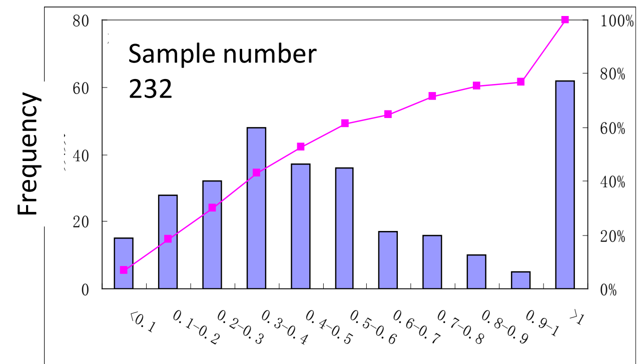
Well log interpreted porosity



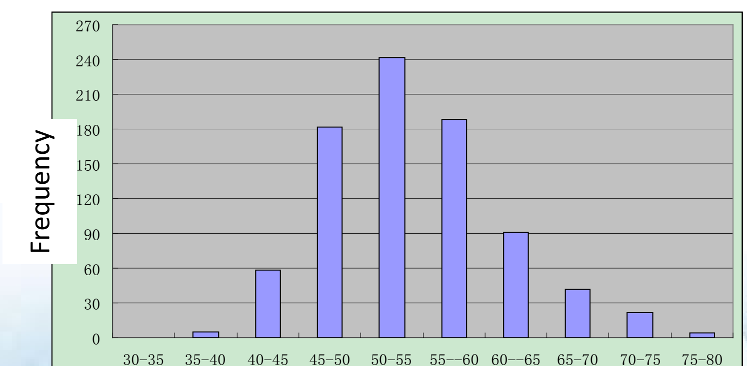
Core sample porosity



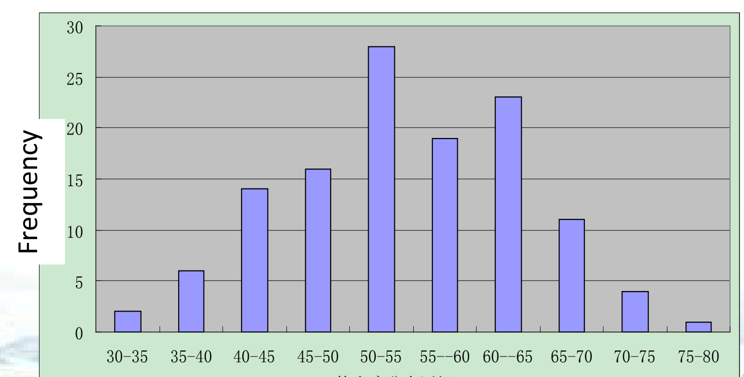
Well log interpreted permeability



Core sample permeability

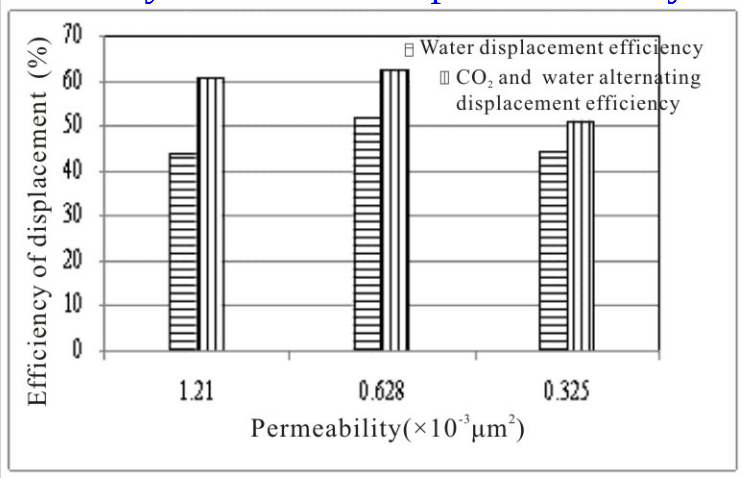


Well log interpreted water saturation

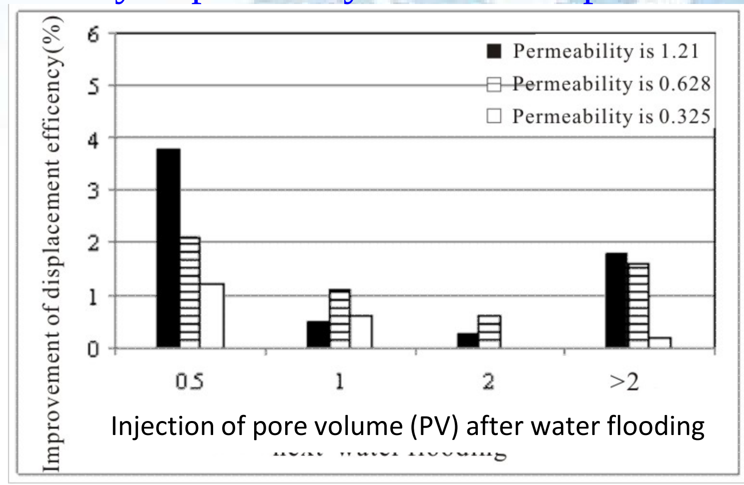


Core sample water saturation

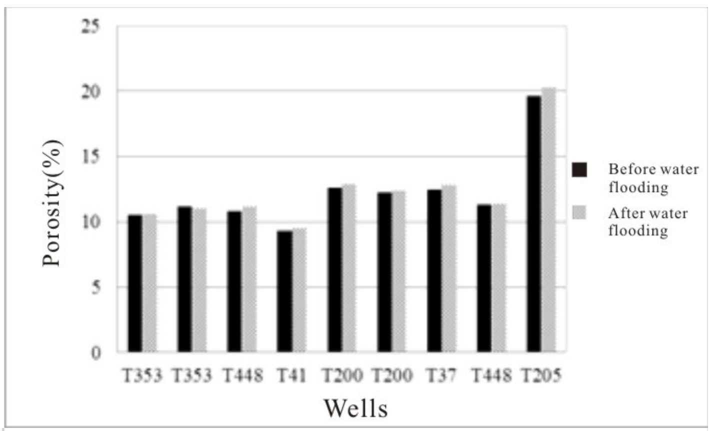
Efficiency of different displacement ways

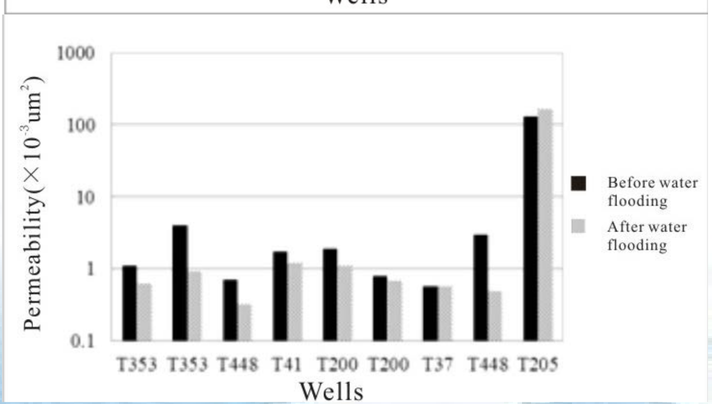


Efficiency improved by different displacement ways

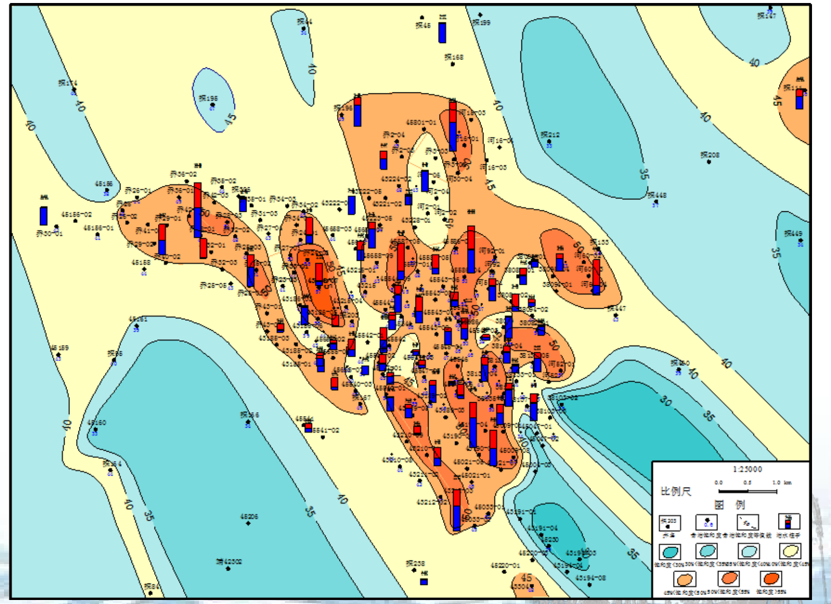


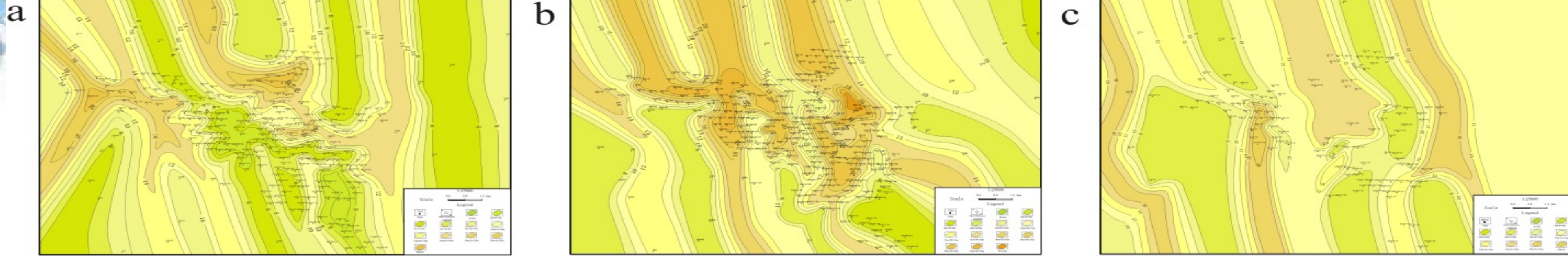
Porosity and permeability variation before and after CO_2 flooding



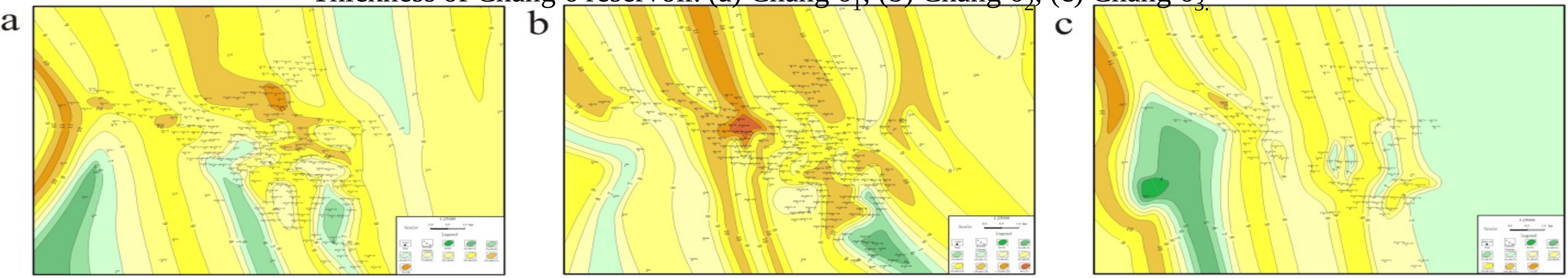


Oil saturation contour of Chang 6_2 overlaid with with oil production

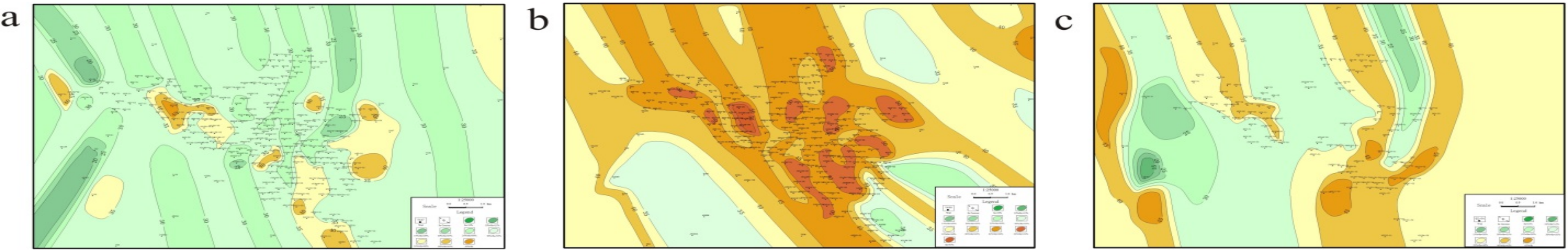




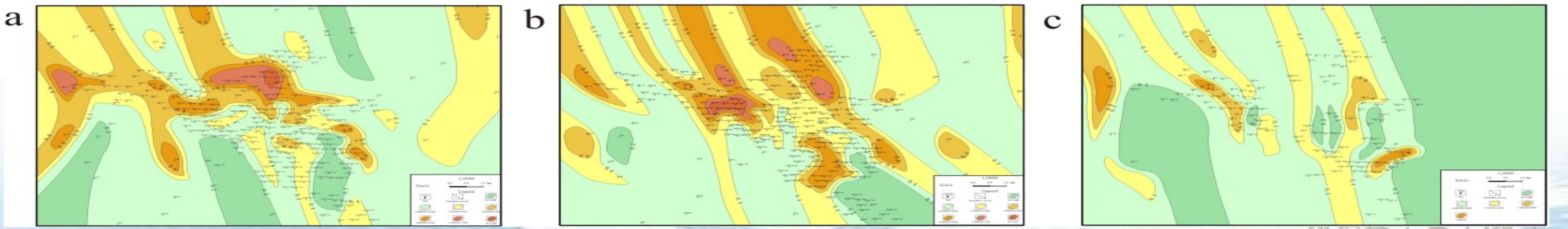
Thickness of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.



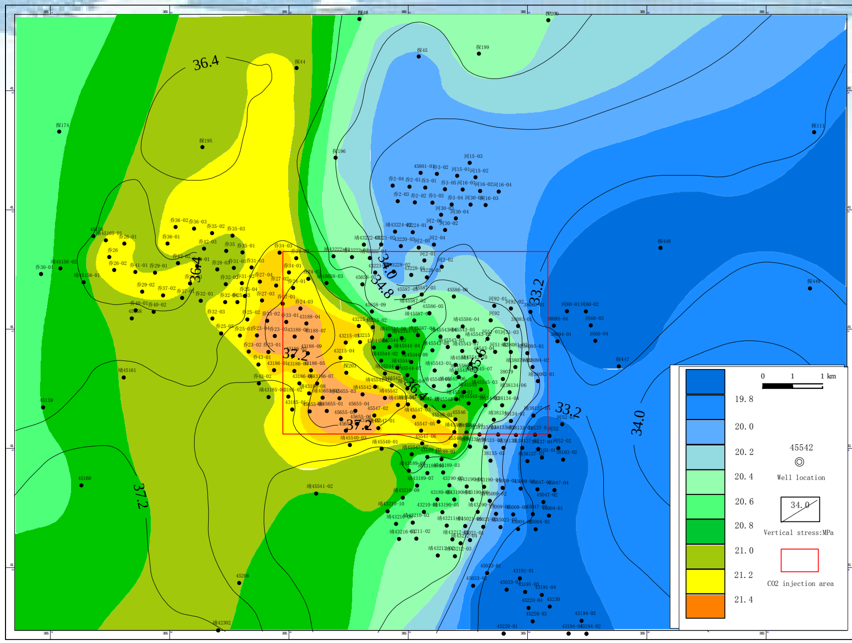
Porosity of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.



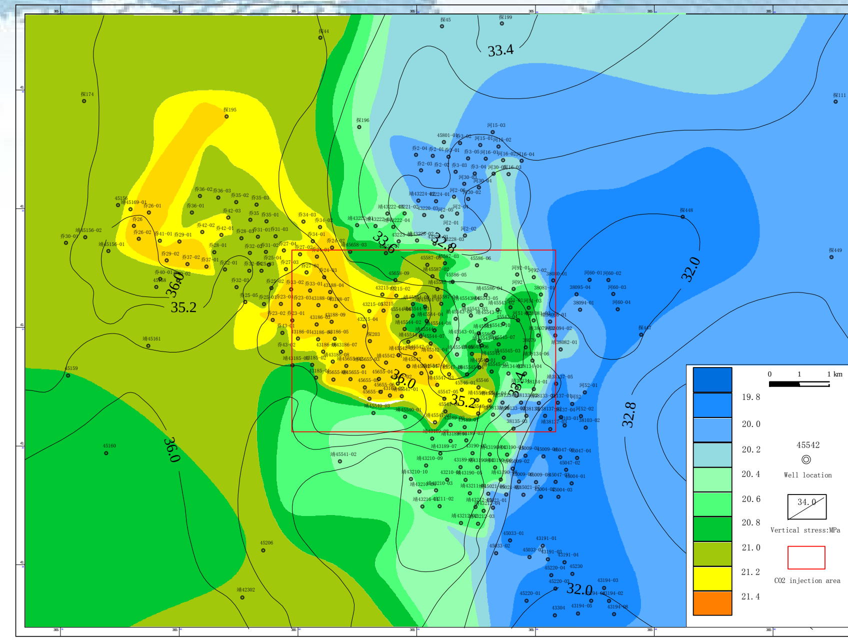
Oil saturation of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.



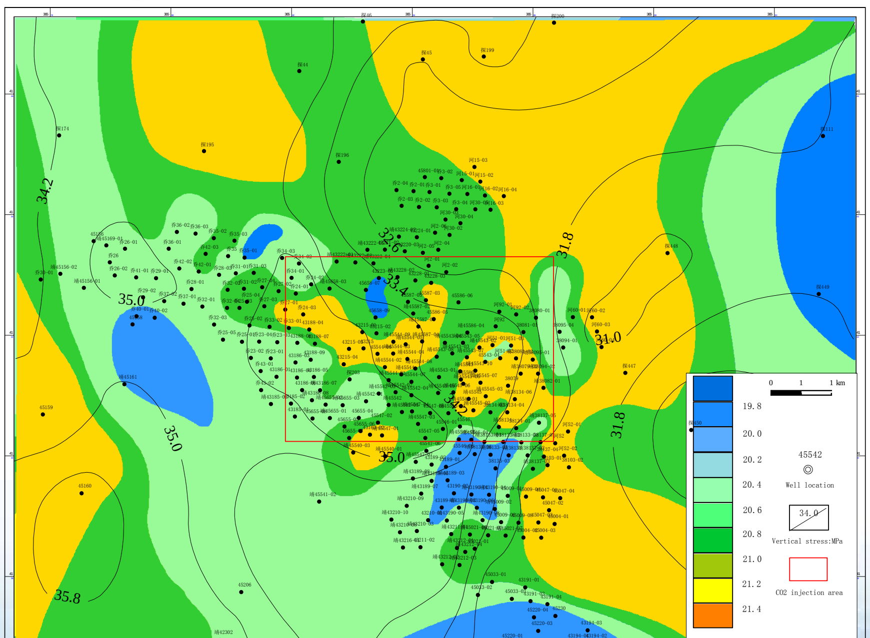
Permeability of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.



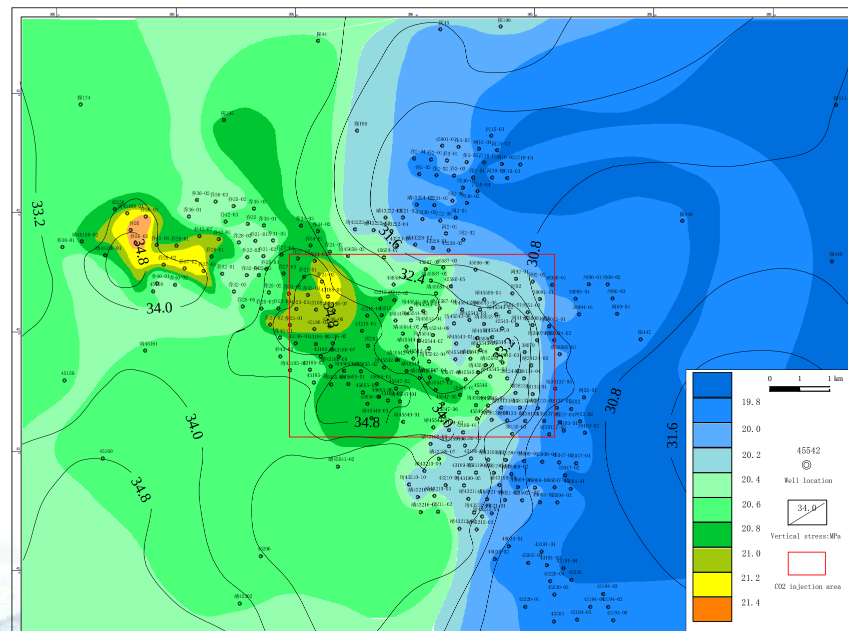
Chang 6_2 formation fracture pressure -vertical stress.



Chang 6_1formation fracture pressure -vertical stress.

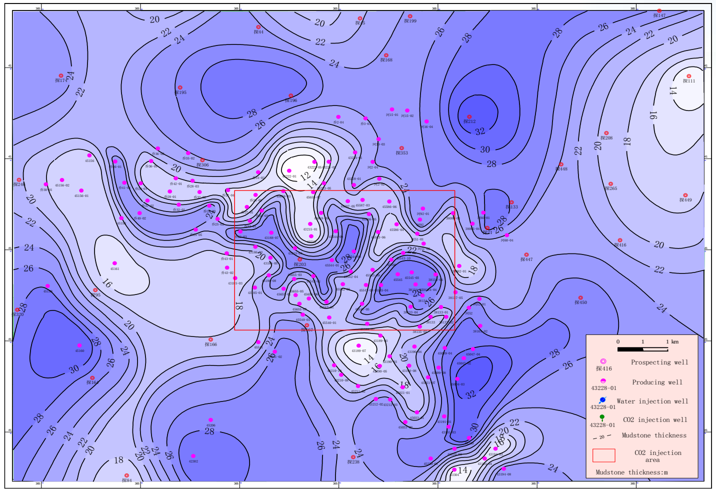


Chang 4+5_2 formation fracture pressure -vertical stress.



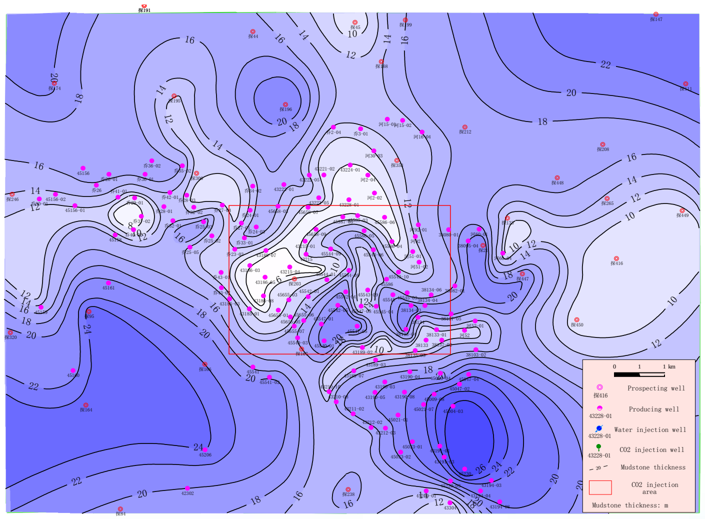
Chang 4+5_1 formation fracture pressure -vertical stress.

Caprock characterization



Regional seals Chang 4+5$_1$ (Left): accumulated average thickness of shale is 21.92 m. In the CO_2 injection area (red square), the average thickness of shale is 22 m. The accumulated thickness of shale can be up to 24 m or more. The overall thickness of seal is relatively stable. It meets the requirements of trapping CO_2 or second trapping.

Interbed Chang 6$_2$ (Right) : an average thickness of shale is about 13.86 m. CO_2 injection (red square) is in the thinnest area of shale. However, thick shale on both sides of injection area may seal CO_2 laterally into the reservoir.



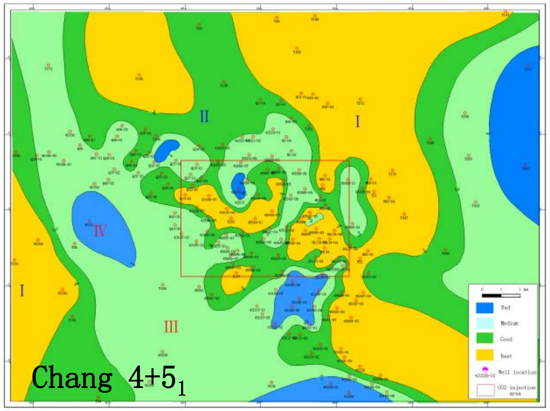
Sealing Ability of Caprock

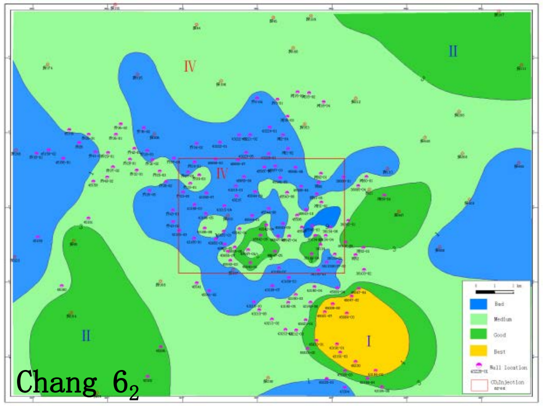
We defined a comprehensive assessment index A according to macroscopic and microcosmic parameters as

$$A = \frac{h r_m P_0 S_o}{Z k}$$

Where h is stacking thickness of caprock; r_m is mudstone stratum ratio; P_0 is displacement pressure; S_O is oil saturation; Z is burial depth and k is pressure coefficient.

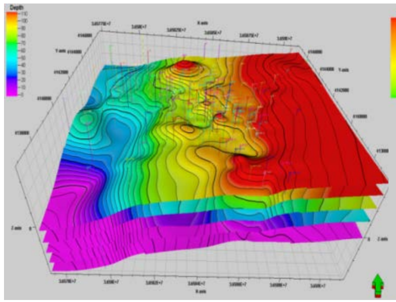
Caprock Comprehensive Assessment Level	Ⅰ-The best	Ⅱ-Good	Ⅲ-Medium	Ⅳ-Poorer
Comprehensive Assessment Index A	A>3.2	2.2<A<3.2	1<A<2.2	A<1
Mudstone thickness (m)	25.91	21.49	16.92	11.14
Displacement pressures (MPa)	6.38	6.31	6.28	6.24
Mudstone stratum ratio	0.71	0.59	0.45	0.29
Oil saturation (%)	46.98	45.78	45.11	45.13
Depth (m)	1548.83	1552.28	1554.38	1558.84
Pressure coefficient	0.86	0.87	0.86	0.87



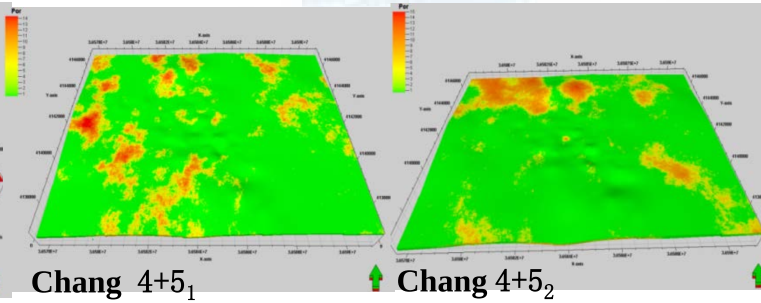


Modeling of CO_2 Storage Body

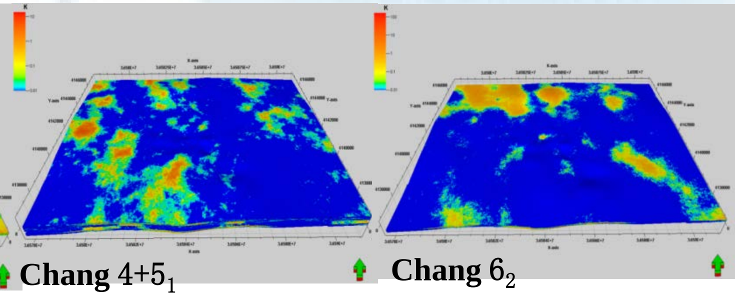
Geologic Structure Model



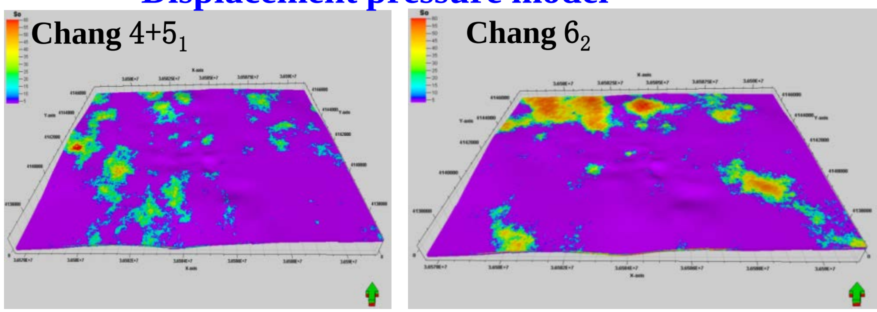
Porosity Model



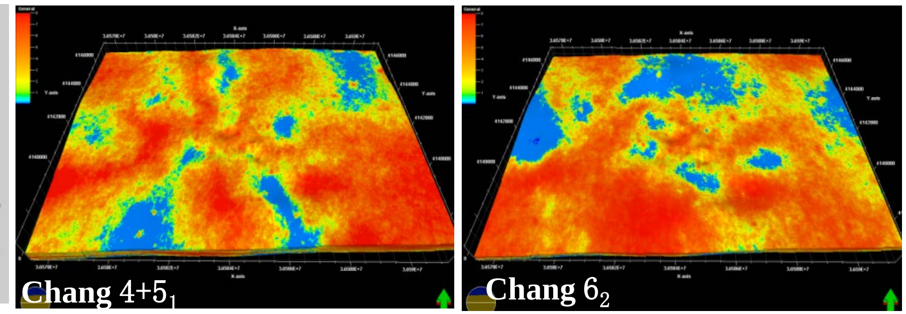
Permeability Model

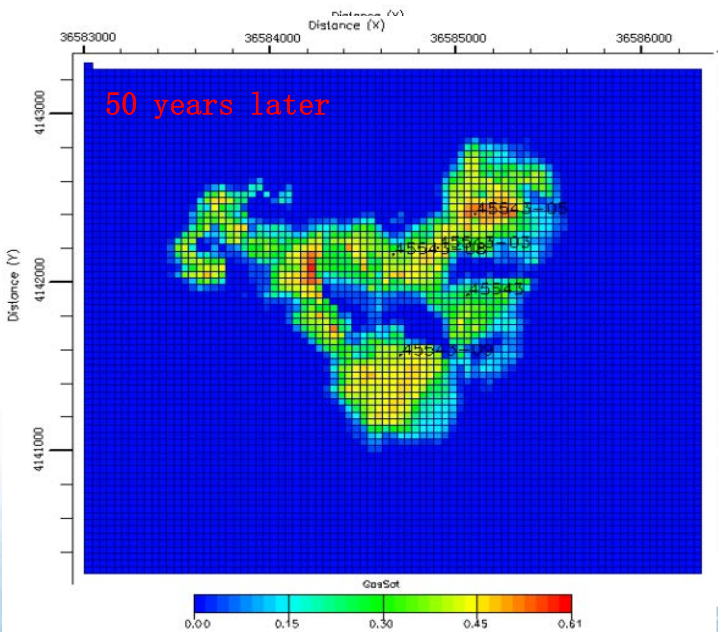


Displacement pressure model

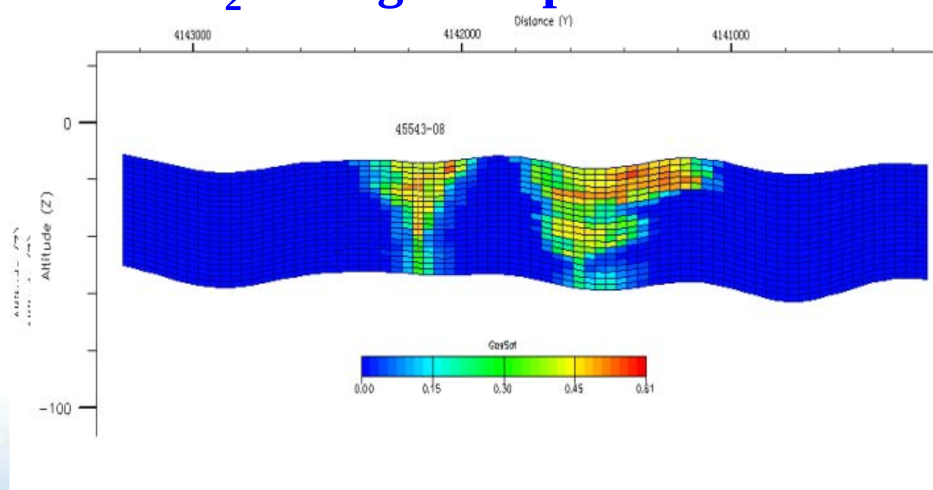


Oil saturation model

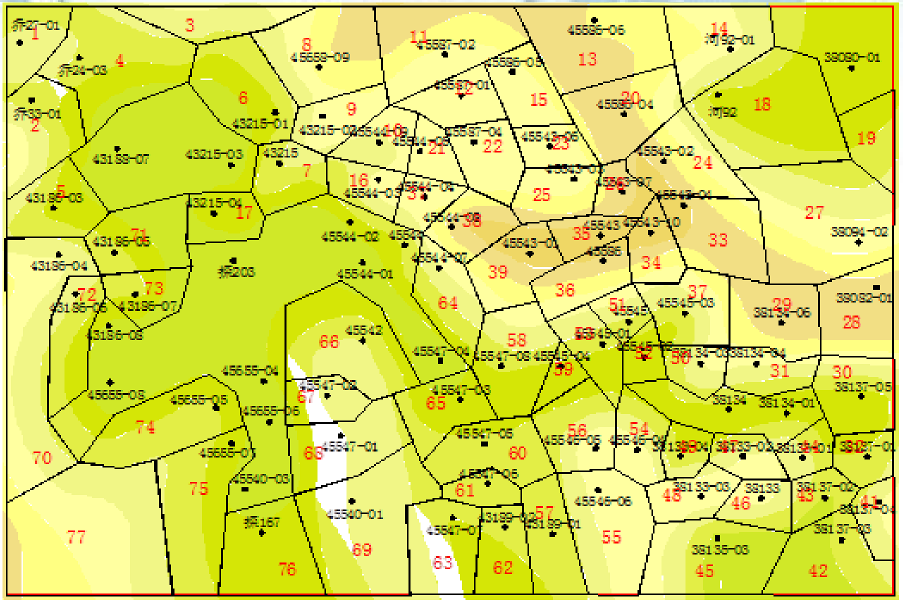




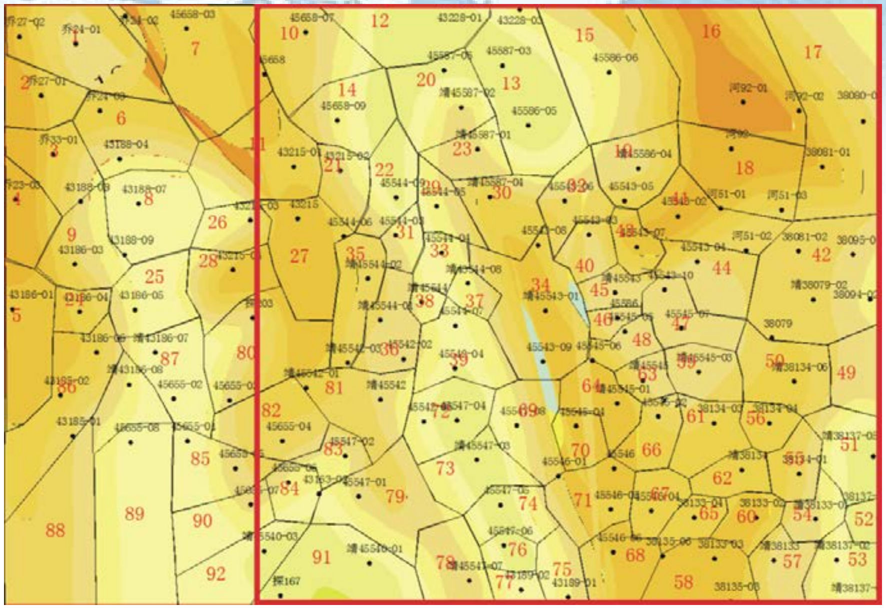
CO_2 leakage risk prediction



CO_2 saturation distribution vertically



CO_2 injection area unit of Chang 6_1



CO_2 injection area unit of Chang 6_2

We estimate that the maximum volume for CO_2 storage in Chang 6_2 unit is $1.4 \times 10^7 m^3$, CO_2 capacity is 127,000 t.

5. Technical Description

(9) Environmental monitoring

- Fast monitoring techniques near surface and at atmosphere.

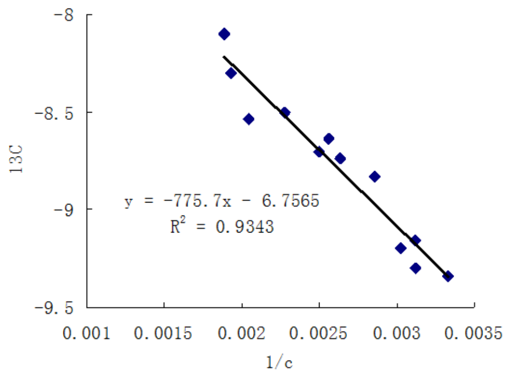
- The impact of CO_2 leakage on environment.
  - Soil, groundwater, temperature, human health, animals, plants, etc.
  - Purity of CO_2 (CO_2, H_2S, CO, SO_2, NO_x)

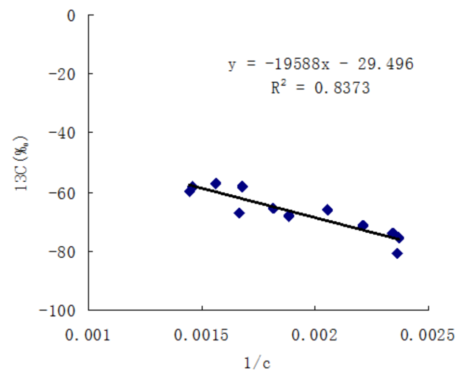
- Quantitatively prove the leakage of CO_2 ?

Remote sensing image on May 11,2011

Combining the sample collection device and isotope measureing instrument to establish an assay method for ^{13}C and ^{14}C.

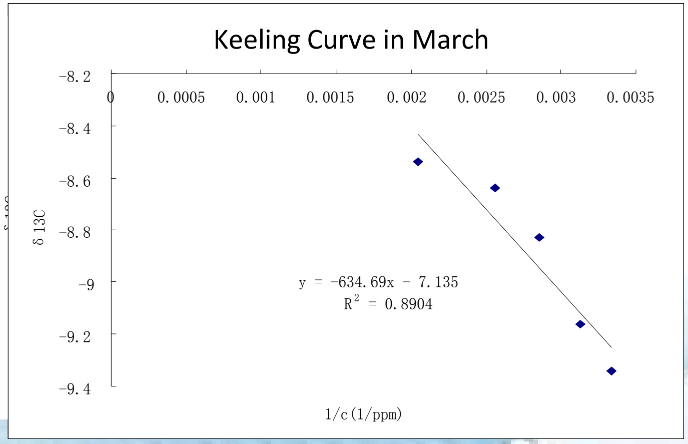
- Using this method, we measured the content of ^{14}C and ^{13}C in near-surface before and after CO_2 injection and used the Keeling Curve to determine the background value.

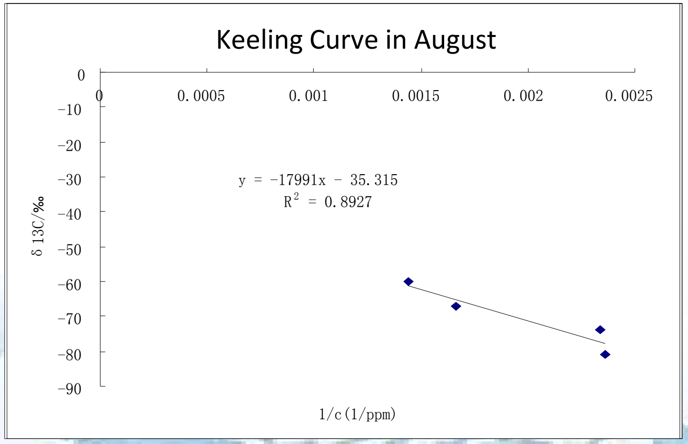




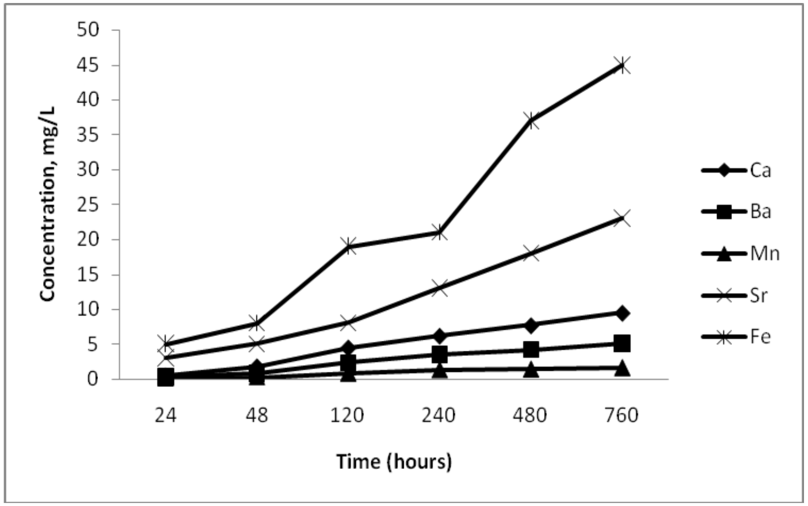
In March, the intercept -6.8 is approaching the value of 13C in the air,-8.0; In August, the intercept -29.5 is approaching the value of 13C in the vegetation,-26.

- After injection of CO_2, we have measured the near-surface ^{13}C content around the wellhead and 50~100 m from the wellhead. Using the Keeling Curve, the linear intercept is -9.7 in March and -17.6 in August , respectively.

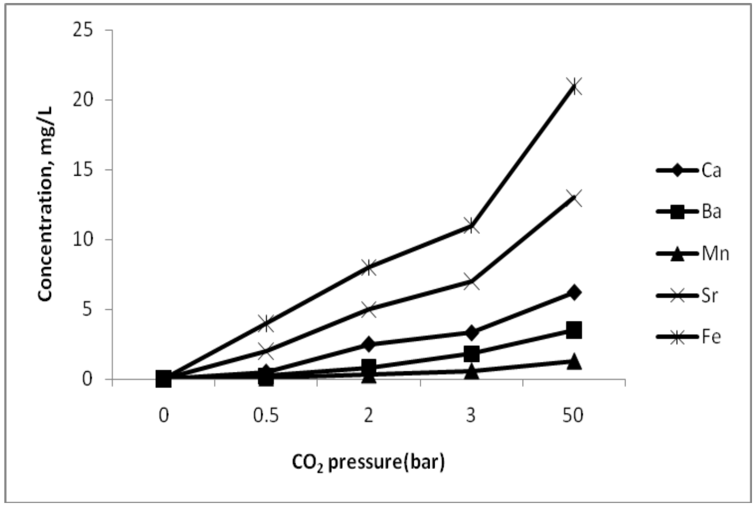




The relationship between the dissolution rate and the etching apparatus time of CO_2.

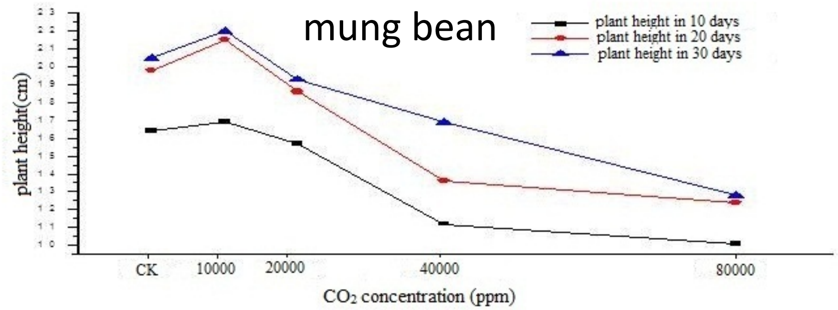


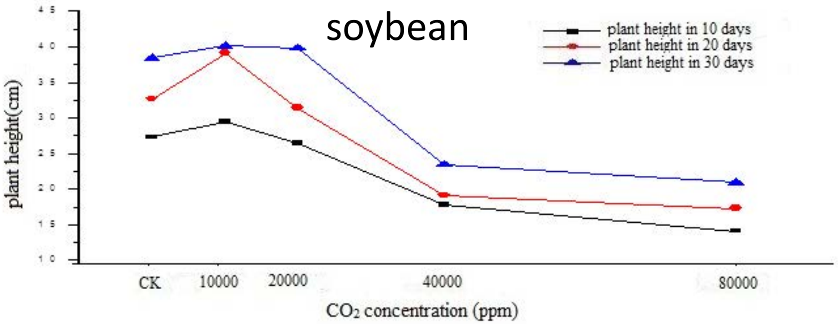
The relationship between the dissolution rate and the partial pressure of CO_2.

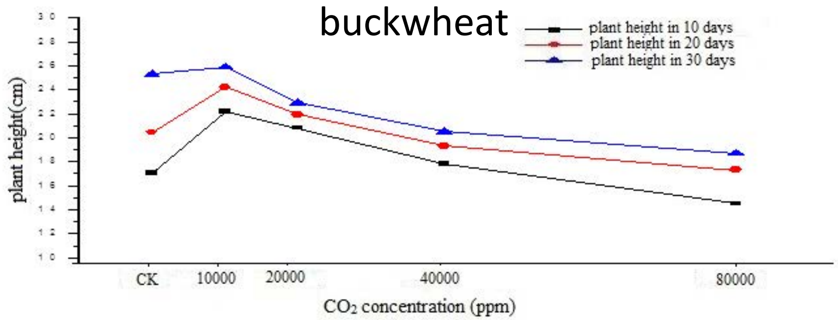


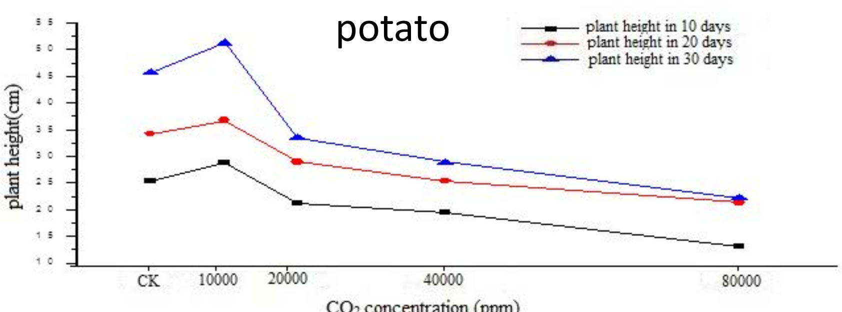
- Dissolved CO_2 in water may accelerate the digestion of metal ion in mineral, the dissolving-out amount is related to the etching time and pressure of CO_2.
- If the CO_2 came up into the ground water, the content of metal ion in ground water will be increased and water quality will be changed.

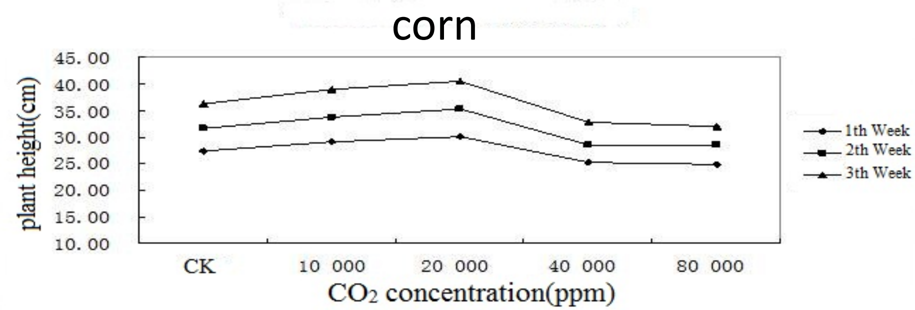
Environmental monitoring
near Jingbian CCS site.

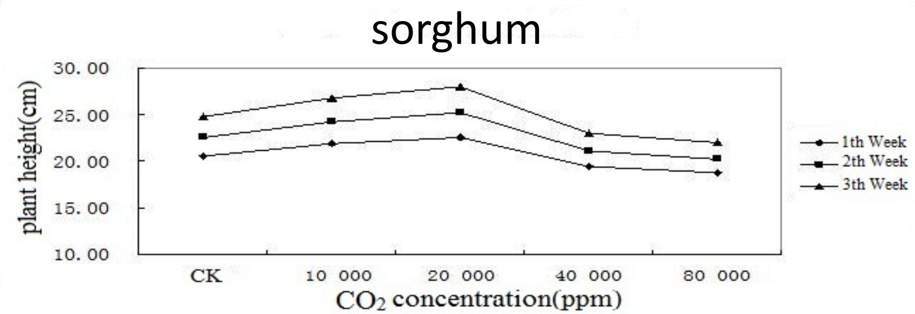


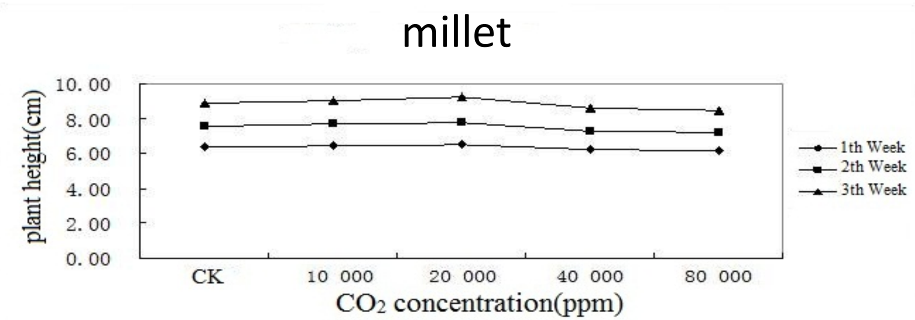


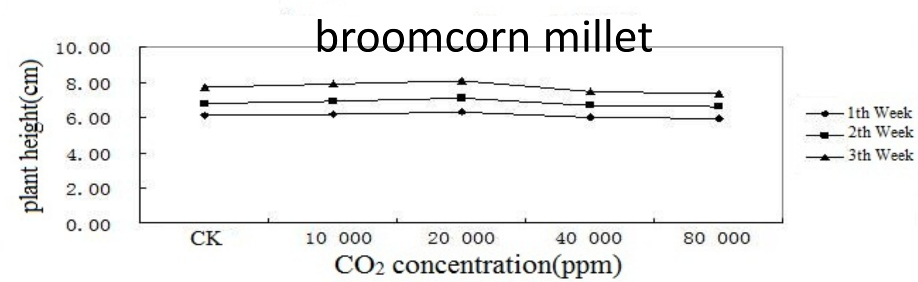




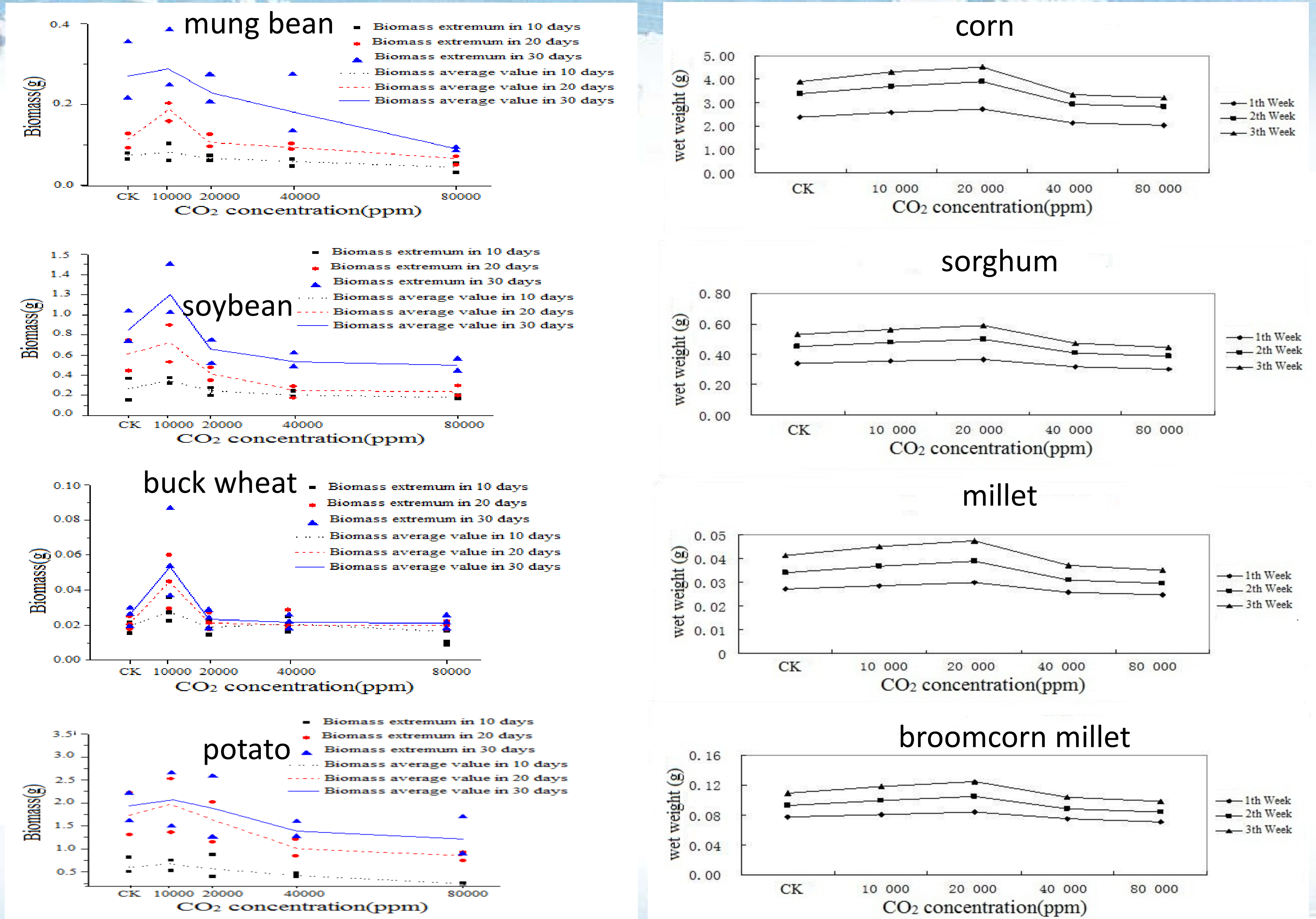




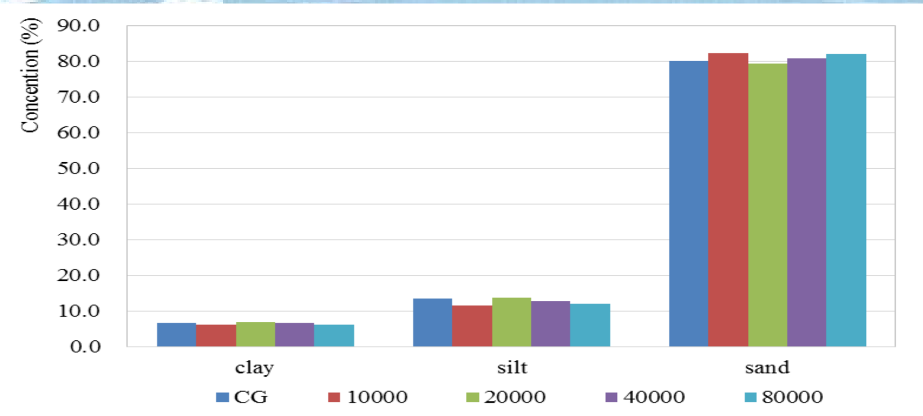


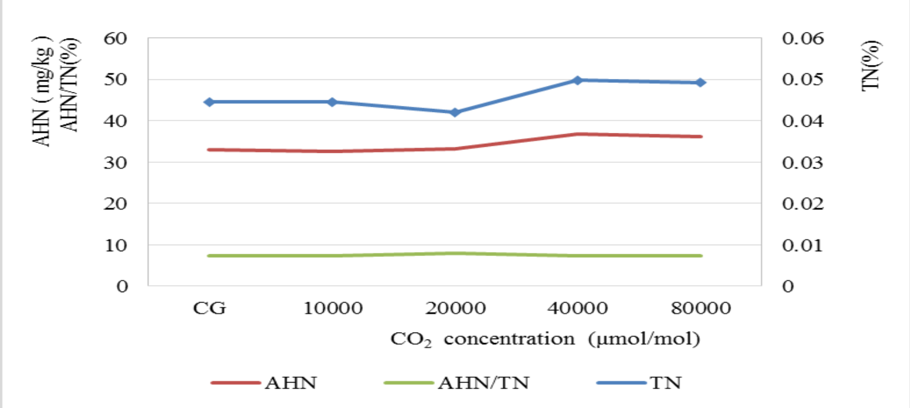


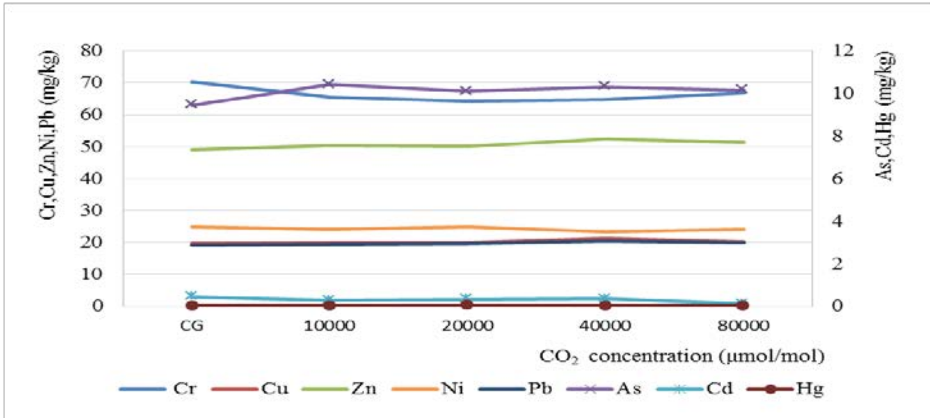
The impact of CO_2 on the morphological indexes of C3 crops.

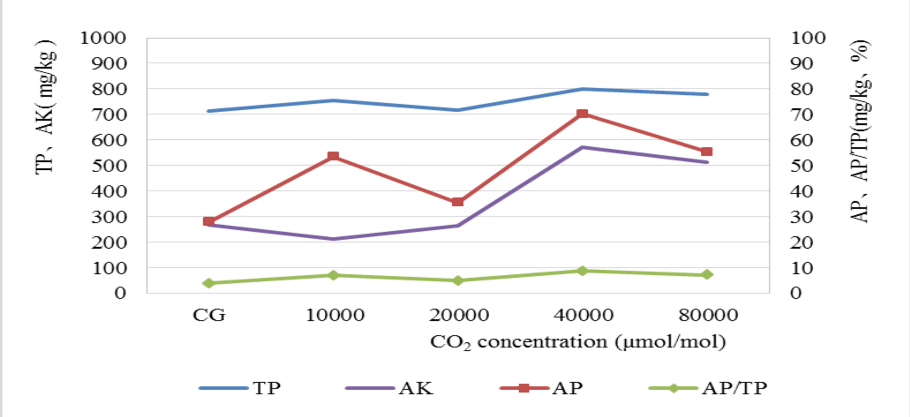


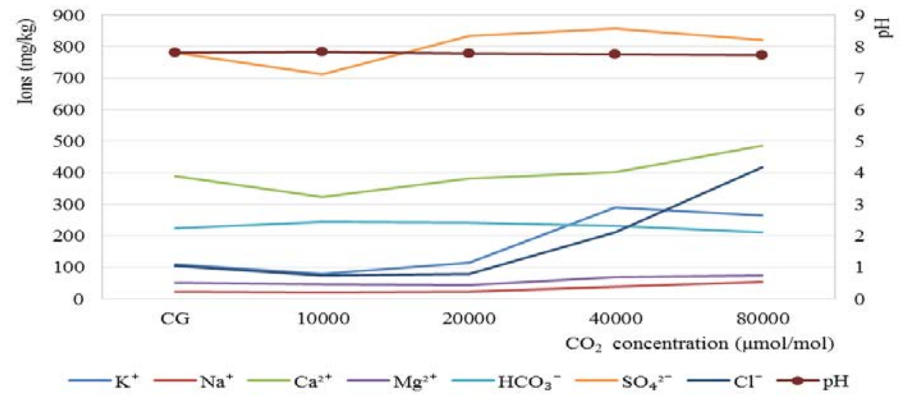
The impact of CO_2 on the biomass of C3 crops.

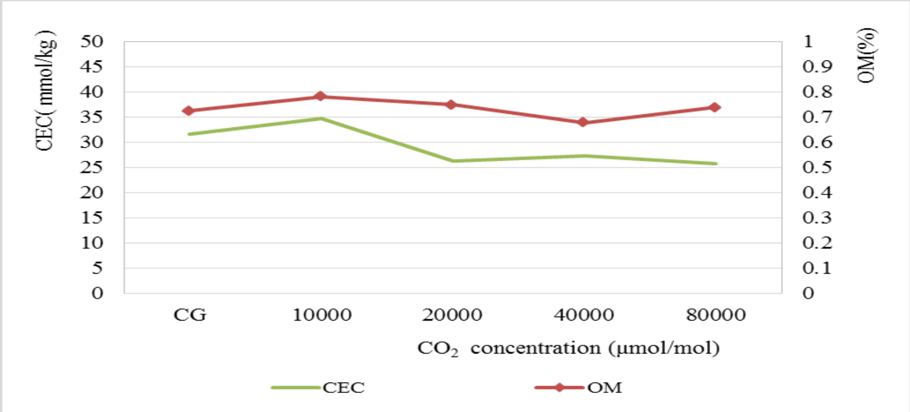




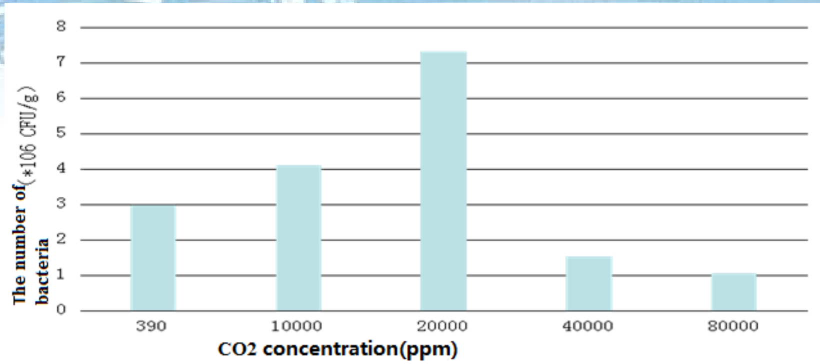




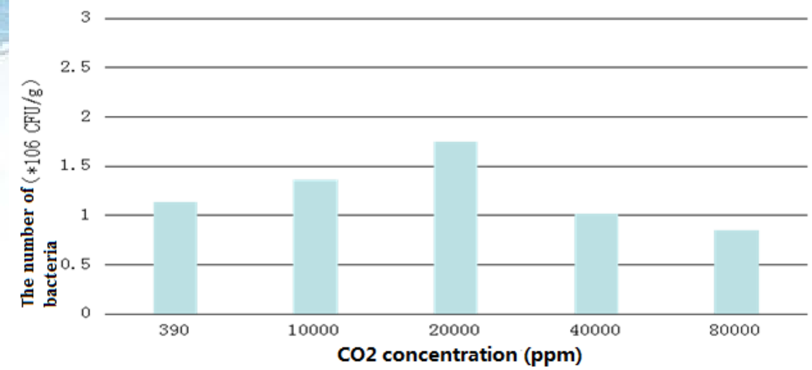




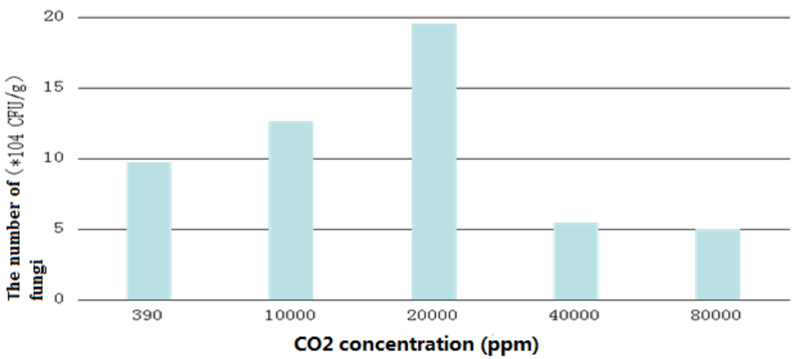
The impact of CO_2 on the soil composition and properties.



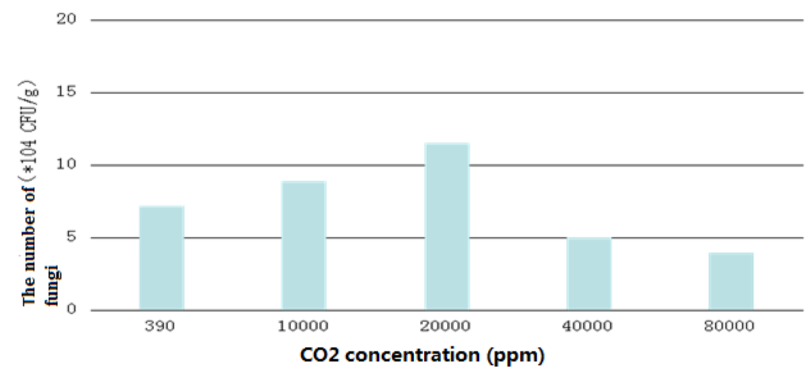
The number of bacteria (corn)



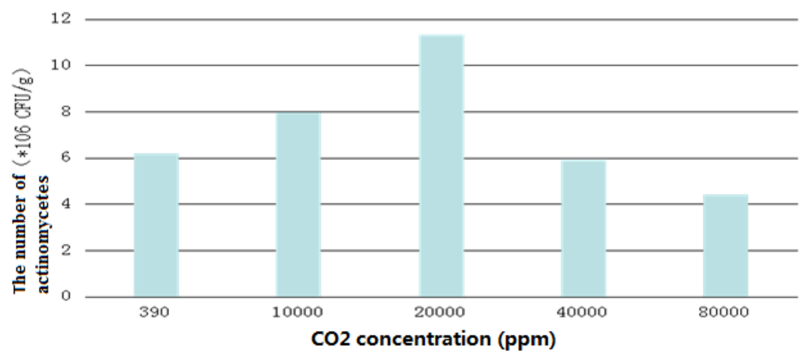
The number of bacteria (millet)



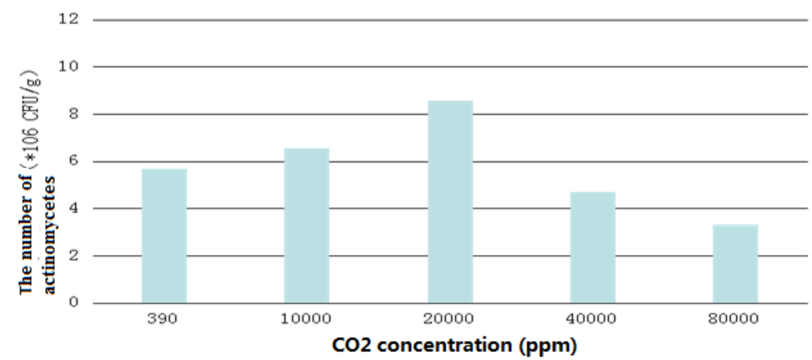
The number of fungi (corn)



The number of fungi (millet)



The number of actinomycetes (corn)



The number of actinomycetes (millet)

The impact of CO_2 on the population of microorganisms.

Selection of indicative bacteria

- ✓ **By comparing the DGGE electrophoresis of C4 crops under different CO_2 concentration, the study shows:**
- ✓ **In soil of planting corn , when the CO_2 concentration was at 80000 ppm, *Desulfomicrobium thermophilum* can be used as an indicative bacteria.——1**
- ✓ **In soil of planting sorghum, when the CO_2 concentration is at 10000ppm, *Burkholderia cepacia, Brucella suis, Thiohalocapsahalophil, Porphyromonas gingivicanis* and *Bacteroides intestinalis* can be used as indicative bacteria.——5**
- ✓ **In soil of planting millet,when the CO_2 concentration was at 10000ppm, *Brucella suis, Thiohalocapsa halophil, Pelomonas aquatica, Hydrogenophaga intermedia, Prevotella dentalis*** and ***Sphingomonas oryziterrae*** can be used as **indicative bacteria.——6**
- ✓ ***Brucella suis* and *Thiohalocapsa halophil* were the common soil indicative bacteria microbes of sorghum and broom corn millet at the 10000ppm of CO_2 concentration.**
- ✓ **DGGE bands of millet root soil bacteria were not significantly different, it had difficulty to choose the indicative bacteria microbe.**
- ✓ **There were 10 indicator bacteria microbes being used as indicators of CO_2 leakage .**

- **CO_2 impact for animals**
  - **CO_2 impact for mouse**
    - Semi-lethal concentration
    - The behavior influence
    - The blood gas influence
  - **CO_2 impact for fish**
    - Water quality
    - Semi-lethal flow of CO_2
    - Blood gas

5. Technical Description

(10) Anticorrosion and wellbore integrity

Anticorrosion

During CO_2 injection process, the corrosion may severely damage the down-hole tubular system.

- Simulating CO_2 injection under different environmental condition.
- Obtain the corrosion rule of the typical materials.
- Sift and evaluate coating, corrosion and scale inhibitor.
- Provided the support for corrosion control.

5. Technical Description

(11) Anticorrosion and wellbore integrity

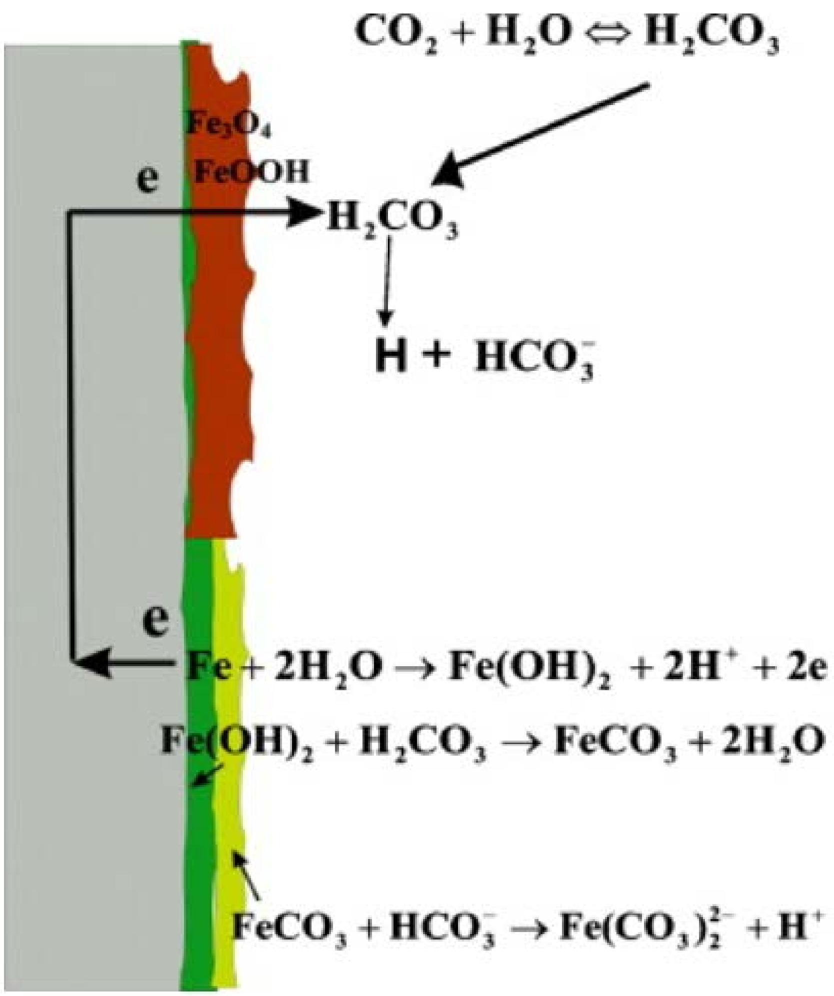
Corrosion effects during CO_2 flooding

Environmental factors

- Pressure
- Temperature
- PH value
- Medium ion
- Organic acid
- Microorganism
- H_2S
- Dissolved O_2
- Flow rate
- Flow pattern

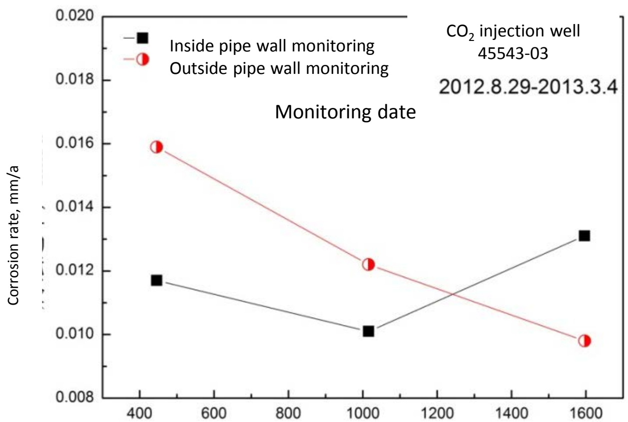
Material factors

- Alloying element
- Thermal treatment
- Metallographic structure
- Corrosion product film

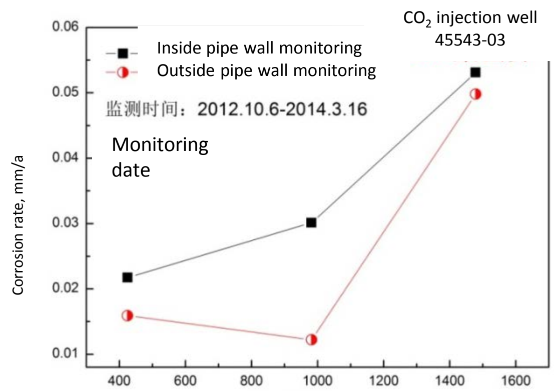


Anticorrosion

- Screening corrosion inhibitor.
- TK70 coating protection.
- Wellbore corrosion protection device.
- Coating + sacrificial anode technology.
- Impressed current cathode protection optimization techniques.

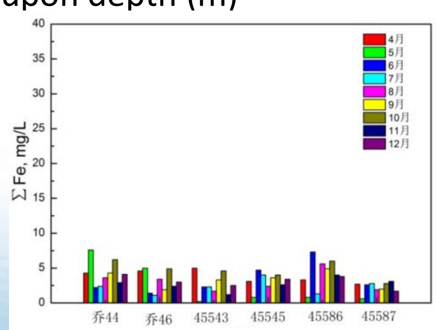


Corrosion coupon depth (m)

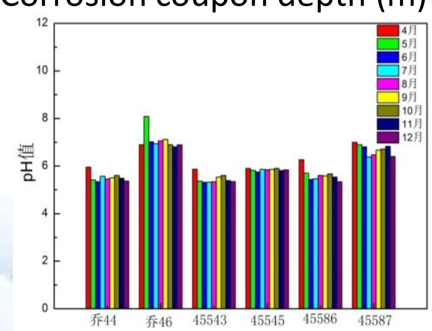


Corrosion coupon depth (m)

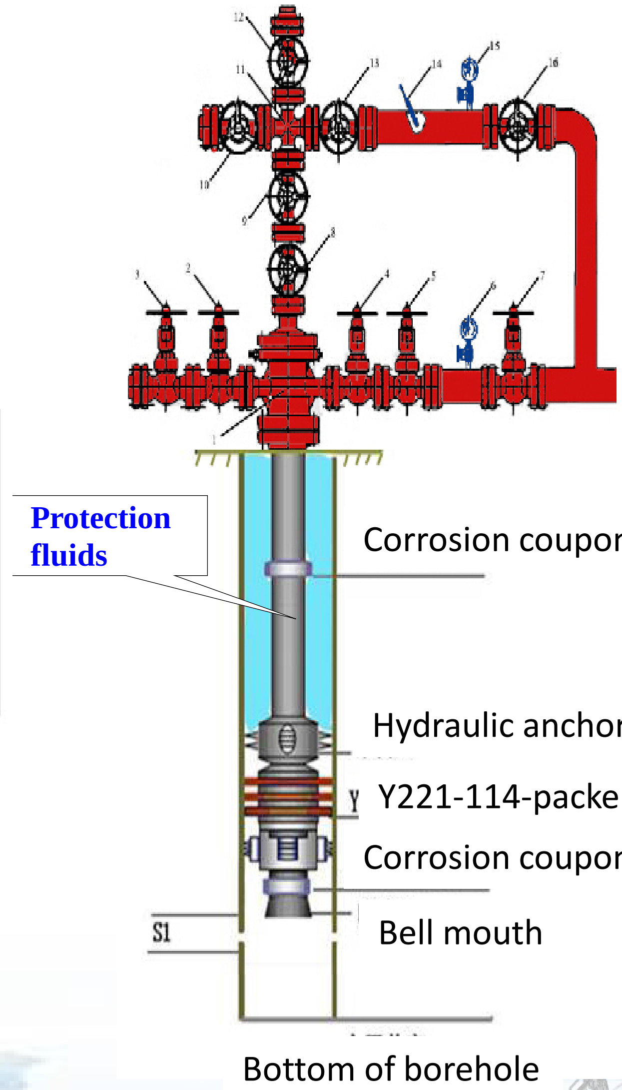
Inside and outside of the tubing corrosion rate is less than 0.076 mm/a.



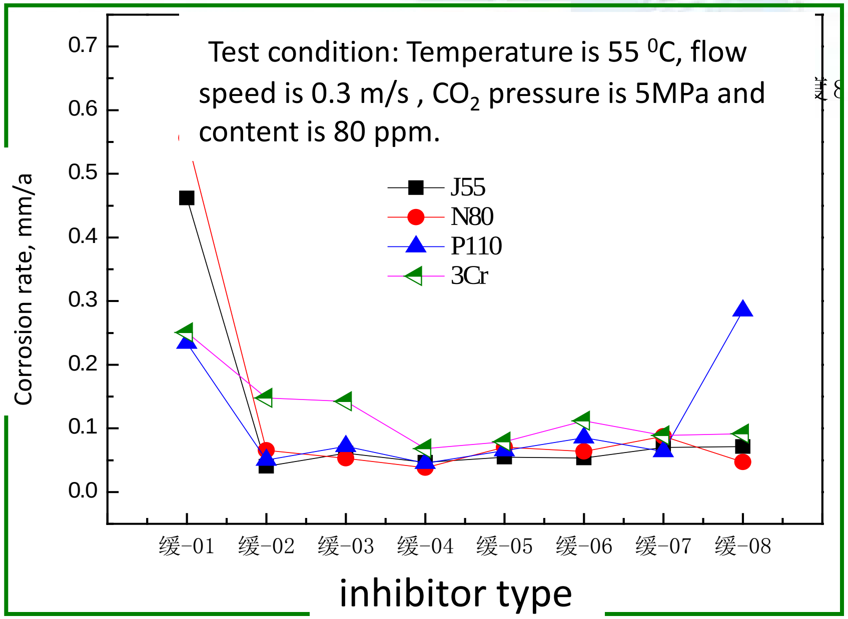
Well name)



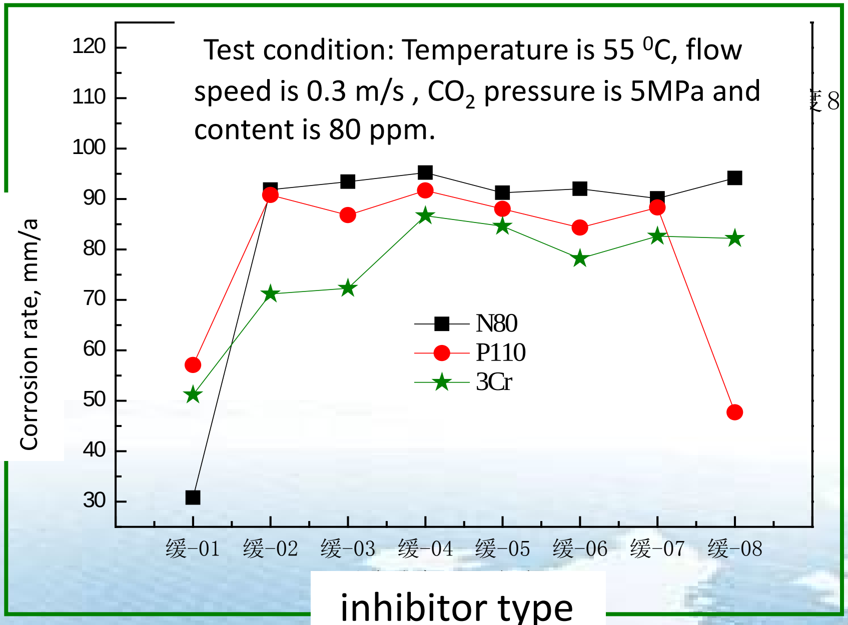
Well name)

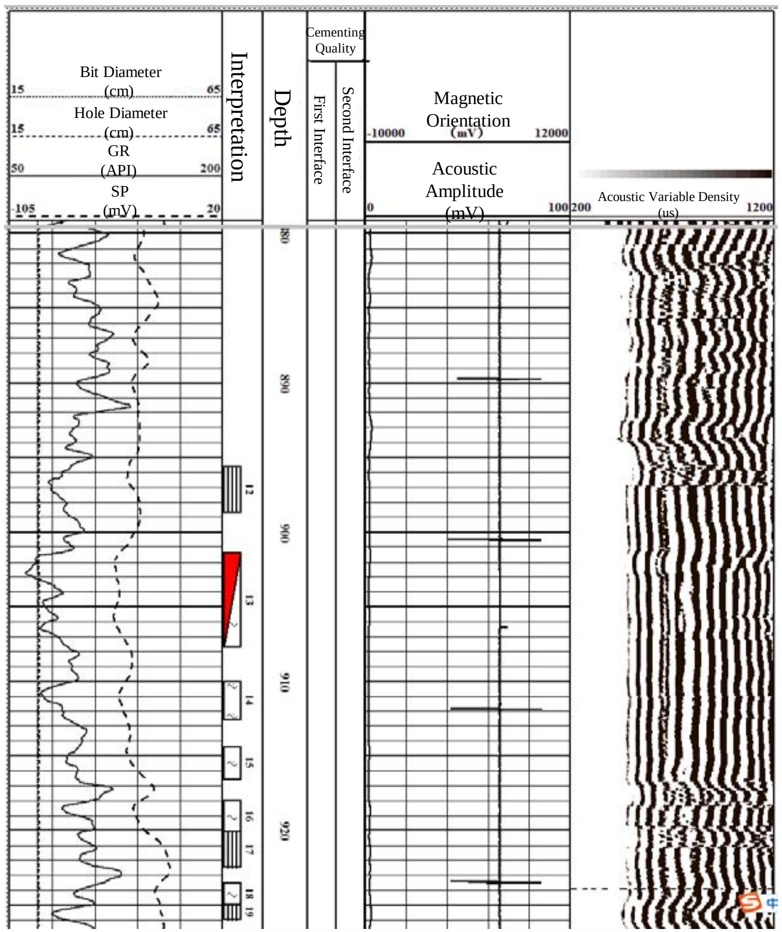


(11) Anticorrosion and wellbore integrity



Imidazoline and modified imidazoline inhibitor were used in Jingbian Field





We detected the cementing quality of cased well by logging Acoustic Variable Density in the north of the Jingbian Field.

6. Conclusions

- Cheaper CO_2 source that captured from coal chemical plant makes the full chain Jingbian CCS project into reality.

- CO_2-EOR recovered more oil than water injection in low porosity and permeability reservoir in Ordos Basin. This inspires more companies to invest in CCS in Ordos Basin and China.

- MMV study shows the safety of CO_2 geological storage in Jingbian CCS site.

- Current CO_2 leakage from borehole is less than 2% and would affect environment and environmental monitoring. When our CO_2 recycle equipment put into use, there will be no CO_2 leakage from wellbore.

6. Conclusions

- It is the first time in China for us to acquire baseline surface soil, water, plants and other monitoring data. The integrated and life time MMV is necessary and need more funding.

- It is not easy for us to make Jingbian CCS Project into practice. There are more obstacles for CCS in China than developed countries. However, there are also more opportunities for CCS in China.

- Current Jingbian CCS demonstration does not make money, however, it creates significant social benefits and environmental benefits for our society.

Acknowledgements

- **Ministry of Science and Technology of China (MOST) – Key Technique for CO_2 Sequestration (Grant 2012AA050103)**
- **Ministry of Science and Technology of China (MOST) – Technology Demonstration of the Coal-chemical Industry CO_2 Capture, storage and CO_2-EOR in North Shaan area (Grant 2012BAC26B00)**
- **Department of Science and Technology of Shaanxi – Grant 2011KTCQ03-09**

Halliburton University Grant

Experts from WVU visited Jingbian CCS site.

Experts from DOE of U.S visited Jingbian CCS site.

Mr. Peng Sizhen of MOST visited Jingbian CCS site.

Agreement with GCCSI of Australia.

Jinbian CCS is one small step for Yanchang, one giant leap for China!