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Jingbian CCS Project, China: Second Year of Injection, Measurement, Monitoring and Verification

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Abstract

Jingbian CCS-EOR pilot project is the first full chain CCS-EOR project in China. Sponsored by China Ministry of Science and Technology, Shaanxi Yanchang Petroleum (Group) Co. Ltd started to conduct CO_2 capture from its coal chemical company and injected CO_2 in Jingbian Field which cooperated with Northwest University from 2012. Our target is to inject at least 10,000 tons CO_2 in Jingbian Field of Shaanxi Yanchang Petroleum (Group) Co. Ltd. At the same time, we are developing an integrated MMV (Measurement, Monitoring and Verification) technique to monitor the safety of CO_2 sequestration from surface to subsurface by using environmental, geophysical monitoring methods and geological analysis. At this low porosity and low permeability reservoir of Jingbian Field, we planned to inject CO_2 in more than 5 wells and tried to get enhanced oil recovery ratio about 5% to 8% and form CO_2-EOR techniques and a demonstration pilot project so that we may apply CCS-EOR in Ordos Basin which is the largest oil and gas production basement in China. Jingbian CCS-EOR pilot project is the same as the other CCS projects in the world. It includes site selection, CO_2 storage and injection equipment construction, CO_2 capture equipment construction, CO_2-EOR laboratory tests and MMV study.

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Keywords: CO_2 sequestration, CO_2-EOR, CO_2 leakage, MMV, environmental monitoring;

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1. Introduction

At present, centered in Shaanxi Province, the crude oil equivalent production in Ordos Basin exceeds 60 million tons and ranks first in China. While the coal reserves in Shaanxi Province ranks first and 450 million tons coal production ranks third in the country (Gao and Wang, 2013). The energy and chemical industry output value accounted for 78% of the total GDP in Shaanxi Province. There are still ten large coal chemical projects under construction. By 2015, when these projects put into operation, CO_2 emissions in Shaanxi will increase 180 million tons.

Large amounts of CO_2 emission lead to a fast-rising average temperatures and climate change in Shaanxi Province. Climate change makes severe drought in parched loess plateau in Shaanxi Province. Drought has severe impact on the crop and fruit industry, especially the world's largest producer of high quality apple production is seriously threatened. Food production is affected a large part of Shaanxi Province as well. In some areas, even it appeared dried up reservoirs and no drinking water.

In accordance with the requirements of the Chinese Government and the Shaanxi Government, carbon emission will be decreased 35% by 2015 comparing with amount of CO_2 emission in 2005. CO_2 emission of Shaanxi Province was 133 million tons in 2005 and 234 million tons in 2011 roughly estimated by Liu, Zhang and Li (2013), and recent year emission data is not made public. CO_2 emission increases rapidly with the provincial high GDP increasing rate. Shaanxi needs to reduce CO_2 emission in the hundreds of millions of tons of per year. CCS-EOR technology becomes an important option for fast emission reduction.

In early 2012, sponsored by China Ministry of Science and Technology, Shaanxi Petroleum (Group) Co. Ltd. (abbreviated as Yanchang Petroleum Group) started Jingbian CCS-EOR pilot project cooperating with Northwest University (Ma et al., 2013). CCS-EOR site is selected as Qiaojiawa area in Jingbian Field of Yanchang Petroleum Group.

The most important reason for Yanchang Petroleum Group to choose Qiaojiawa area of Jingbian Field as CCS site is that this area is close to CO_2 source. Well site is close to provincial highway as well

To choose CCS-EOR site, the first consideration of Yanchang Petroleum Group is the production increasing effect through CO_2-EOR. The oil production in Jingbian Field exceeded 1 million tons in 2011. However, Jingbian Field is facing ineffective water flooding and sharply decreasing reservoir pressure. It is in desperate need of new technology to improve oil recovery. Next consideration of Yanchang Petroleum Group is CO_2 transport convenience and economics of CO_2 injection platform. Jingbian Field is close to CO_2 source from Yulin Coal Chemical Company. The distance from CO_2 source to CO_2 storage site is about 140 km., In Jingbian Field, Qiaojiawa area is close to the provincial highway, and traffic is relatively easier than other area. Because the oil production platforms in Ordos Basin were built mostly based on flattened hills and oil is output from pipe lines, generally there are no good roads to the production platform in hills. Even if Qiaojiawa area is not far from provincial highway, Yanchang Petroleum Group still spent lots of money building the road from the highway to CO_2 injection platform so that 20 tons CO_2 transportation trucks may reach the injection platform in hills.

The reservoirs in Jingbian Field are Chang 6 reservoir of Triassic Yanchang Formation (Ma et al., 2013), where Chang 6 has three sandstone zone Chang 6_1,Chang 6_2 and Chang 6_3. Main producing reservoir Chang 6_2 is currently the CO_2 injection layer. The depth of Chang 6 reservoir in Jingbian Field ranges from 1409 to 1661 meters. Reservoir thickness is 15.2-32.5 meters. The effective sand thickness is 12.3 meters, and maximum thickness of sand is greater than 10 meters. Other parameters of reservoir are: the average permeability is 1.236 mD, average reservoir porosity is 8.18%, temperature is 44^0C, original reservoir pressure is 12 MPa and salinity of brine $CaCl_2$ is 50.52 g/L～95.11 g/L.

Qiaojiawa area started oil production after fracturing in August 2007. It began injecting water in March 2008. After 12 months fracturing and producing, 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 (Fig. 1).

Later, the use of CO_2-EOR was taking into account. If the injection of CO_2 in such typical low porosity and low permeability reservoir could get a better oil recovery than water injection, there would be no doubt to make effective use of CO_2 and reduce CO_2 emissions in the region. Furthermore, there would be a big potential to promote CCS-EOR in Ordos Basin and other similar basins in China.

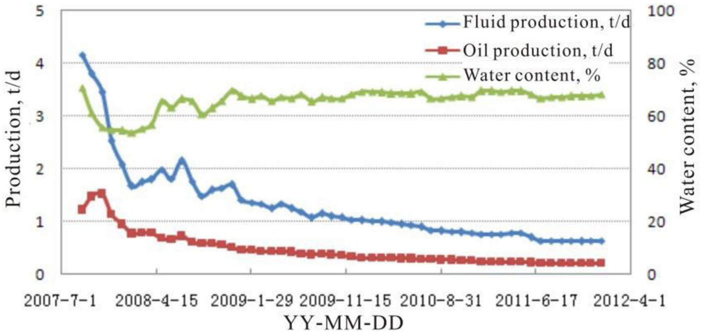

Fig. 1. Water flooding effect before CO_2 injection in Jingbian Field.

2. CO_2 capture, transportation and injection site construction

2.1. CO_2 injection site construction

CO_2 injection site construction included building CO_2 storage tank, pumping stations, field stations and road to CO_2 injection wells. Besides road building, Yanchang Petroleum Group also expended the parking lot and area of well site.

The designed 5 CO_2 injection wells in Jingbian Field are located in one platform (Jing 45543 well platform of Qioajiawa area). In order to utilize the existing platform and save investment, Yanchang Petroleum Group built one CO_2 injection station in the Jing 45543 well platform (Fig. 2). This station can make CO_2 injection for three wells at the same time. The use of fully flexible injection equipment will make full use of limited area in one platform. Injection wellhead equipment has also been replaced by anticorrosion material.

2.2. CO_2 transportation

Before CO_2 capture equipment in Yunlin Coal Chemical Company of Yanchang Petroleum Group was put into operation, the injected high purity CO_2 was purchased from Shaanxi Xingping Fertilizer Plant of Yanchang Petroleum Group. The purchase price of high purity CO_2 is very high and transported by two 20 tons trucks rented from a private company. The transport distance was about 500 km. CO_2 bought from Shaanxi Xiangping Fertilizer Plant had been injected into Jingbian Field from September 4, 2012 to March 2013 until Yunlin Coal Chemical Company's 50,000 tons CO_2/year capture equipment put into use. When CO_2 source was converted to supply by Yunlin Coal Chemical Company, the transport distance was shortened to 140 km.

2.3. CO_2 capture

Although Chinese government has been expecting Jingbian CCS-EOR pilot project to utilize CO_2 captured from coal-fired power generation enterprises, however there is no coal fired flue CO_2 capture equipment in Shaanxi and nearby provinces. In addition, the high cost of CO_2 captured from coal-fired power company makes us to give up coal-fired CO_2 capture and choose to build lower price CO_2 capture equipment in coal chemical company which is similar to CO_2 source in Weyburn project. Considering the budget of CCS-EOR project, it is reasonable for us to choose a cheaper CO_2 source.

In June 2012, Yulin Coal Chemical Company of Yanchang Petroleum Group started to build 50,000 tons/year CO_2 capture equipment within its an annual output of 200,000 tons methanol, 200,000 tons acetic acid and rectisol purification project. CO_2 capture equipment had been finished in November 2012, and started to provide CO_2 for Jingbian Field in March 2013. Although CO_2 capture costs from coal chemical equipment are lower, taking into account the construction costs of CO_2 capture equipment, Yulin Coal Chemical Company still sells CO_2 in a relative high price to Jingbian Field.

In order to reduce the cost of CO_2 transportation, Yanchang Petroleum Group invested about USD 6 million to build its second 50,000 tons/year CO_2 capture equipment in its new coal chemical basement in Jingbian City. The capture amount will be expanded to 370,000 tons/year. When this CO_2 capture equipment put into use, the CO_2 transportation distance will be shortened to 10km, and it will significantly reduce the CO_2 transport costs, and may provide a stable, cheaper CO_2 to the oil field. Meanwhile, CO_2 injection wells in Jingbian Field will be increased from current one group into 10-20 groups. CO_2 injection amount will reach 50,000 tons/year.

3. CO_2-EOR lab study and field experiment

3.1. CO_2-EOR lab study

For low porosity and low permeability reservoirs in Jingbian Field, natural energy is low and the transmibility is poor. During oil exploitation, reservoir pressure drops quickly. When reservoir pressure drops, reservoir flow capacity decreases rapidly. This makes fluids production decline quickly. When reservoir permeability decreases, even if restore reservoir pressure recovered, permeability could not be restored to its original condition.

Laboratory experiments show that CO_2-oil minimum miscible pressure in Chang 6 reservoir is 22.4 MPa and formation fracture pressure is 24 MPa. Core sample laboratory tests in Jingbian Field proved that CO_2 injection capacity has more than 5 times higher than that of water injection for the same low porosity and low permeability of reservoir. Under the same conditions of injection wells net, if we inject CO_2 and later changes to water alternative gas (WAG) injection, where the average single well injection is 10 tons/day, the reservoir pressure will recovery faster. If the reservoir pressure could be recovered and maintained at around 12 MPa as the original reservoir pressure during the entire CO_2 injection, we would get a better oil production.

One of the targets of CO_2-EOR is to solve low permeability reservoir water injection difficulties and map up reservoir energy. While maintaining a high production rate, we need to make up reservoir energy efficiently to increase oil production time. Taking into account the possible impact of gas channeling during CO_2 injection and laboratory CO_2-EOR experiments, continues CO_2 injection and then transferring water alternative gas (WAG) injection methods are recommend in Jingbian Field.

3.2. CO_2-EOR field experiment

Jingbian CCS-EOR pilot project started CO_2 injection on September 4, 2012 in Jing 45543-03 well (Fig. 2). In March 2013, Jing 45543-05 and Jing 45543 wells began to inject CO_2. Till the end of July 2014, accumulated amount of CO_2 injection reached 18500 m3. The injection rate is 50 m3 a day.

For the first injection well Jing 45543-03, when we switch the CO2 source from Shaanxi Xingping Fertilizer Plant (Now Shaanxi Xinghua Chemistry Co. Ltd.) to Yulin Coal Chemical Company in March 2013, we temporarily stopped injection. However, when we started to inject the new source CO_2, backwater from bottom of well was strong and we were unable to inject CO_2. Therefore the well Jing 45543-03 was forced to shut down. Currently, we inject CO_2 into Jing 45543-05 and 45543 wells (Fig. 3).

Before CO_2 injection started in September, 2013, the main producing oil well platforms (three platforms) produced fluids 230 m3 where oil is about 100 tons. After injection CO_2 a month later, in October, 2013, fluids production was 332 m3 where oil produced 130 tons, Average single well production increased by 45%.The monthly average oil production increased 47.4 tons. 13 months later after injection (Fig. 4), the cumulative increasing oil production was 616 tons. Through the analysis of well production change, we know that the injection and production wells in the area have very good connectivity and flow relationships. This makes CO_2 injection get a better enhanced oil recovery in a short time.

Before CO_2 injection test in Jing 45543-03, the output gas composition analysis showed that there was no CO_2 and the produced gas is mainly methane, ethane. After injecting CO_2 a month, we found CO_2 came out from well Jing 45543-05 in northeast of Jing 45543-03 and Qiao 44-2 in southwest of Jing 45543-03 (Fig. 2). Later Jing 45543-05 was transferred into CO_2 injection well. The leakage of CO_2 has been stable and content of CO_2 is 2%. No CO_2 leakage was found in other wells.

The output gas analysis proved that the main flow direction is northeast-southwest direction in CO_2 injection area. The CO_2 leakage should be found in wells along both northeast-southwest directions. The early CO_2 breakthrough should be happened and monitored in these directions as well.

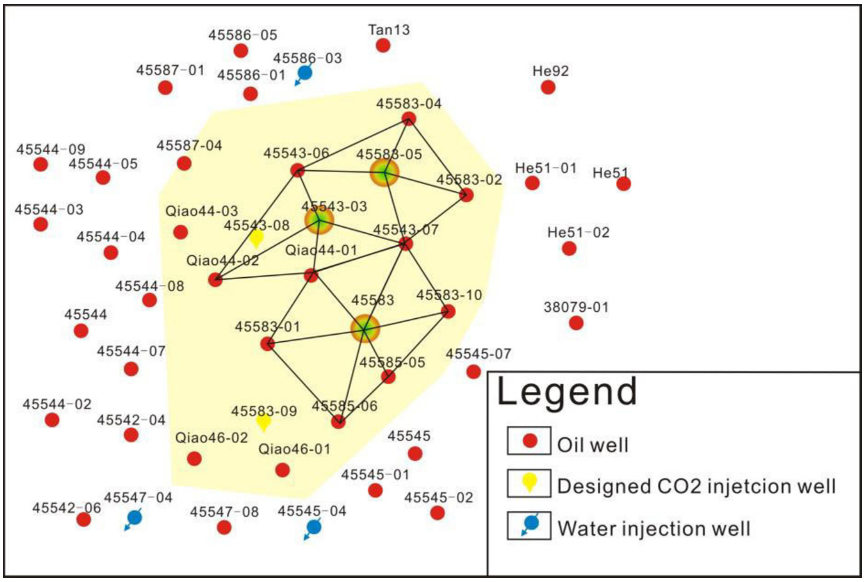

Fig. 2. Three CO_2 injection wells and CO_2 injection pattern in Jingbian Field.

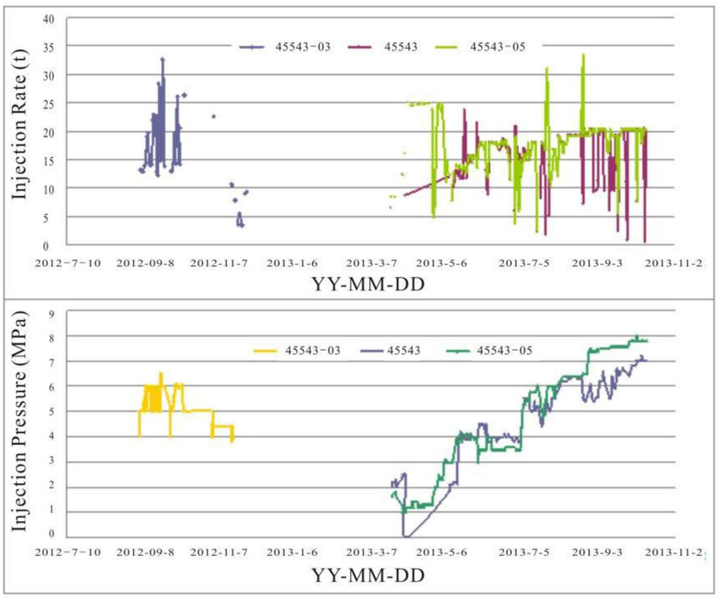

Fig. 3. Fluids production and oil production curves in different months. Note, CO2 injection started from Sep.4, 2012.

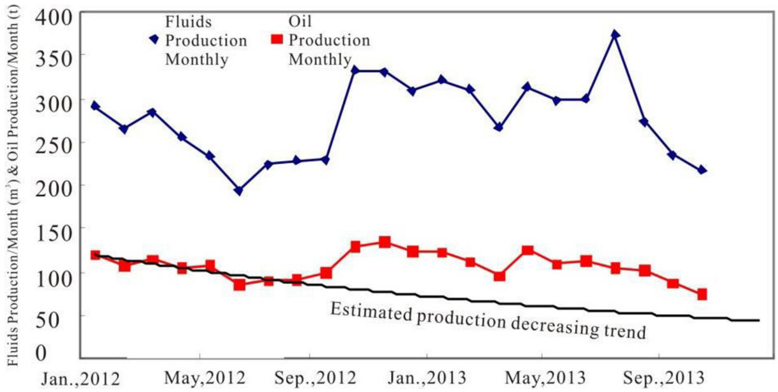

Fig. 4. Fluids production and oil production curves in different months. Note, CO2 injection started from Sep.4, 2012.

4. Measurement, monitoring and verification for CO_2 sequestration

In order to monitor the safety of CO_2 sequestration in Jingbian Field, we carried out ground environmental monitoring and studies, subsurface geological studies and near-surface geophysical studies. The main methods and studies are as follows:

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

- The cost of 4D seismic acquisition we proposed was lower than the geophysical companies wanted. Higher field labour costs, higher seismic instruments transportation fee for such small land 3D area and much higher compensation for shooting sources at farmers ' agricultural land also resisted geophysical company to accept seismic acquisition project;
- 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 signal to noise ratio of shot gather is quite low, especially in the top of the hills and slopes. Poor 2D seismic acquisition effect has long been the research problems in Ordos Basin. 3D seismic acquisition in the region was just conducted in recent years in the north desert area which is relative ground flat area of Ordos Basin. In the central Ordos Basin with steep hills, there are quite few successful 3D seismic examples. Geophysical companies could guarantee if they could get satisfied two vantages of 3D seismic data, and Yanchang Petroleum Group are concerning if we could detect seismic reflection differences caused by CO_2 injection through 4D seismic data. There are some risks in front of us.
- Although Jingbain Field belongs to the area of relatively flat terrain in Ordos Basin, the drop from hill to valley is about 100 meters. Seismic static correction has been and will still be problems in this area. In the slope of hills, it is very hard to make shots and receivers in the same location when acquiring vantages of 3D seismic data. In addition, Yanchang Petroleum Group wants geophysical company to use new geophones and minimum 3D seismic data is a 200-fold survey that will also increase the cost. The technical difficulties and higher cost delayed 4D seismic acquisition;
- Continuing global warming and historically long-term droughts in northern of Ordos Basin caused the underground water table decline quickly. Regular depth of seismic shot hole drilling could not get a better shot gather. If geophysical companies drill deeper holes, seismic acquisition cost will increases much more than the budget.

Before designing 4D seismic acquisition, we had acquired core samples from Jingbian Field and started seismic rock physics experiment to measure the elastic parameters of samples in The Institute of Geology and Geophysics, Chinese Academy of Sciences. Meanwhile, we started to make 4D seismic AVO forward model and study if could observe the 4D seismic difference before and after CO_2 injection. Time-lapse well log is also designed in Jingbian Field in cooperate with 4D seismic interpretation. Because seismic acquisition has been postponed, we also postponed time lapse well logging.

Driven by good CO_2-EOR effect in Jingbian Field and pushed of the Chinese Government, Yanchang Petroleum Group decided to expand CO_2-EOR application area. Wuqi Field in Wuqi City, which is located in 80 km southwest of Jingbian Field and has a better reservoir condition, is selected to do a large-scale CCS-EOR. CO_2 will be supplied from the coal chemical basement in Jingbian City, where Yanchang Petroleum Group is planning its 370,000 tons/year CO_2 capture equipment. Considering that CO_2 injection has not been carried out in Wuqi Field, we made decision to move 4D seismic acquisition from Jingbian Field into Wuqi Field. However, the topographical features are more complex and seismic acquisition risks are in Wuqi Field than that in Jingbian Field. For the limited budget, we decide to acquire only 3D seismic baseline survey and in the future try to apply for more budgets for monitoring 3D seismic data acquisition. Currently, we are negotiating with several geophysical companies for this 3D seismic acquisition.

4.2. Geological study

As the CO_2 geological storage capacity and safety of storage are main geological problems, we studied Chang 6 and Chang 4+5 oil reservoir distribution, reservoir porosity, permeability as well as safety of caprock seal ability and borehole integrity. The possible fracture distribution in the reservoir and caprock is also studied to evaluate the safety of storage. Reservoir model and numerical simulation is under studying as well. Different from conventional CO_2 geological storage, we not only studied Chang 6 oil reservoir which is CO_2 injection target but also studied the adjacent oil reservoirs and aquifers so that we will conduct stack CO_2 sequestration in these layers in the future. Geological studies in Jingbian Field mainly include four aspects.

4.2.1 Analysis of geological controlling factors of CO_2 sequestration

- A detailed and more precise well log interpretation is conducted. Then reservoir distribution and characterization of each set of formation are reinterpreted and remapped in Yanchang Formation;
- Combing well log interpretation and features of rock type, grain degrees, deposition structure, deposition constructed and deposition cycles, we studied deposition system and deposition phase type that could affect reservoir features and closed performance of caprock for CO_2 sequestration.

4.2.2 CO_2 flooding reservoir performance analysis of demonstration area

- By using reinterpreted well log data, we traced sandstone and studied the distribution and connectivity of sandstone. Then we mapped major oil-bearing sand body's distribution (Fig. 5);
- Through thin-section analysis, scanning electron microscopy analysis, we obtained major mineral composition of rock pore structure, type, content, and contact relationships, types of sorting and cements, and then analyzed the petrological characteristics of Chang 4+5 and Chang 6 Formation;
- We evaluated factors of forming fractures in adjacent areas and fractures in CO_2 flooding area, and then predicted the development of fractures in the study areas;
- Core sample test and analysis data are used to calibrate well log interpretation. This calibration improves the accuracy of porosity and oil saturation which calculated from well log curves. Then based on calibrated well log interpretation, we mapped more accurate porosity, permeability and oil saturation contour in Jingbian Field (Fig. 6 to Fig. 8);
- Combing with reservoir heterogeneity analysis and reservoir production data, we estimated the residual oil distribution and studied the effects of geological heterogeneity on oil distribution.

4.2.3 Evaluation of caprock sealing ability

- After discriminating and interpreting all single caprock from well log data above Chang 4+5 reservoir and Chang 6 reservoir. we mapped caprock development scale, thickness, and lateral distribution in Jingbian Field (Fig. 9 and Fig. 10);
- Because caprock samples were too fragile to be sampled and measured after core drilling, we had to get caprock core sample from the adjacent boreholes outside CO_2 injection area, and used outcrop samples to make up for the caprock of Chang 4+5 and Chang 7 and evaluated sealing ability of caprock.

4.2.4 Reservoir and caprock micro-sealing difference analysis

- From casting thin section identification of reservoir and caprock, we obtained the mineral composition content of rocks (classic composition and fillings), pore structure, size, contacts of grains, cemented sorting type, rounding, and other parameters;
- From grain size analysis of the core samples of reservoir and caprock samples, we got parameters such as particle size range and ratio of rock. Analysis indicates that sandstone within the study area is mainly fine sand and silt;
- From high pressure Hg injection experiment of reservoir and caprock samples, we got the mercury injection curve, median pressure, median radius, displacement pressure, sorting coefficient, variation coefficient and skewness parameters of pore throat characteristics;
- A total of 73 physical properties of reservoir and caprock samples have been tested. Then we got total 73 porosity and permeability test data and made the relationship between porosity and permeability in CO_2 injection area;
- 13 reservoir core samples were used to made nuclear magnetic resonance experiment. The experiment shows the average water porosity is 11.88% and the bound water content is 60%;
- We chose 20 core samples of caprock and reservoir to make X-ray diffraction analysis including whole-rock analyses and analysis of clay minerals and gained content of main mineral samples and a variety of clay mineral content.

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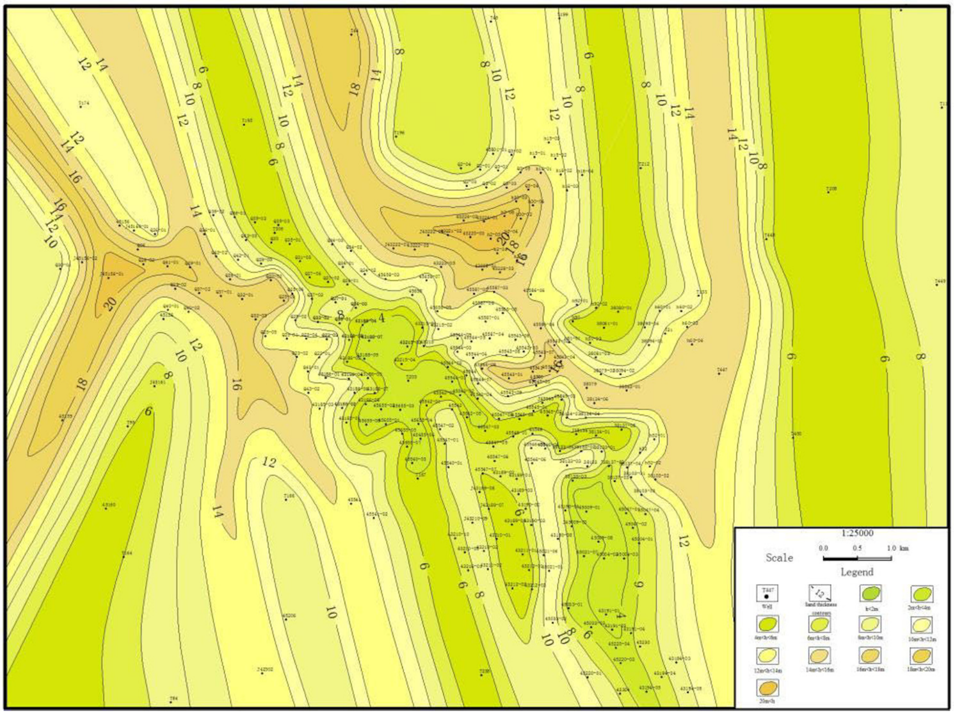


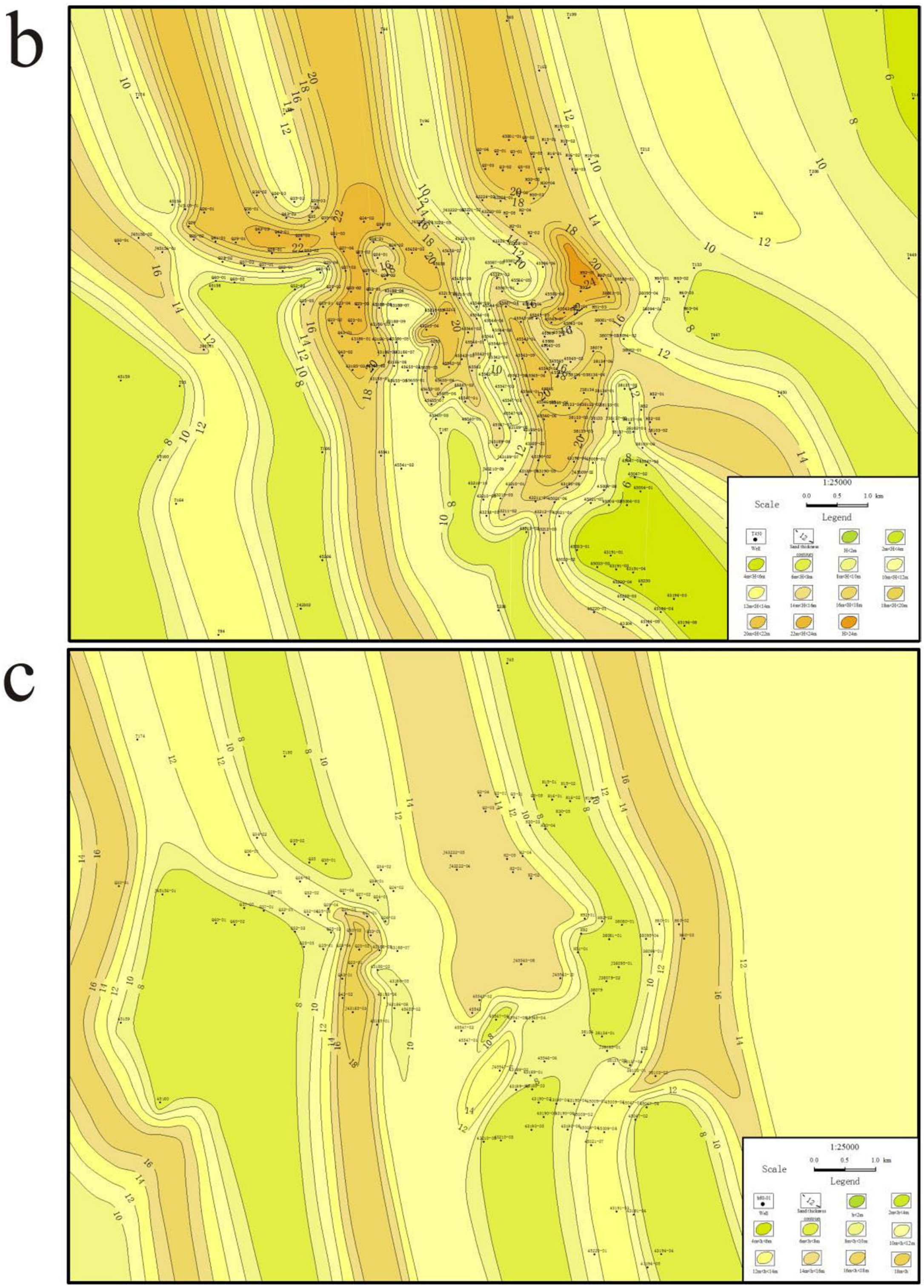
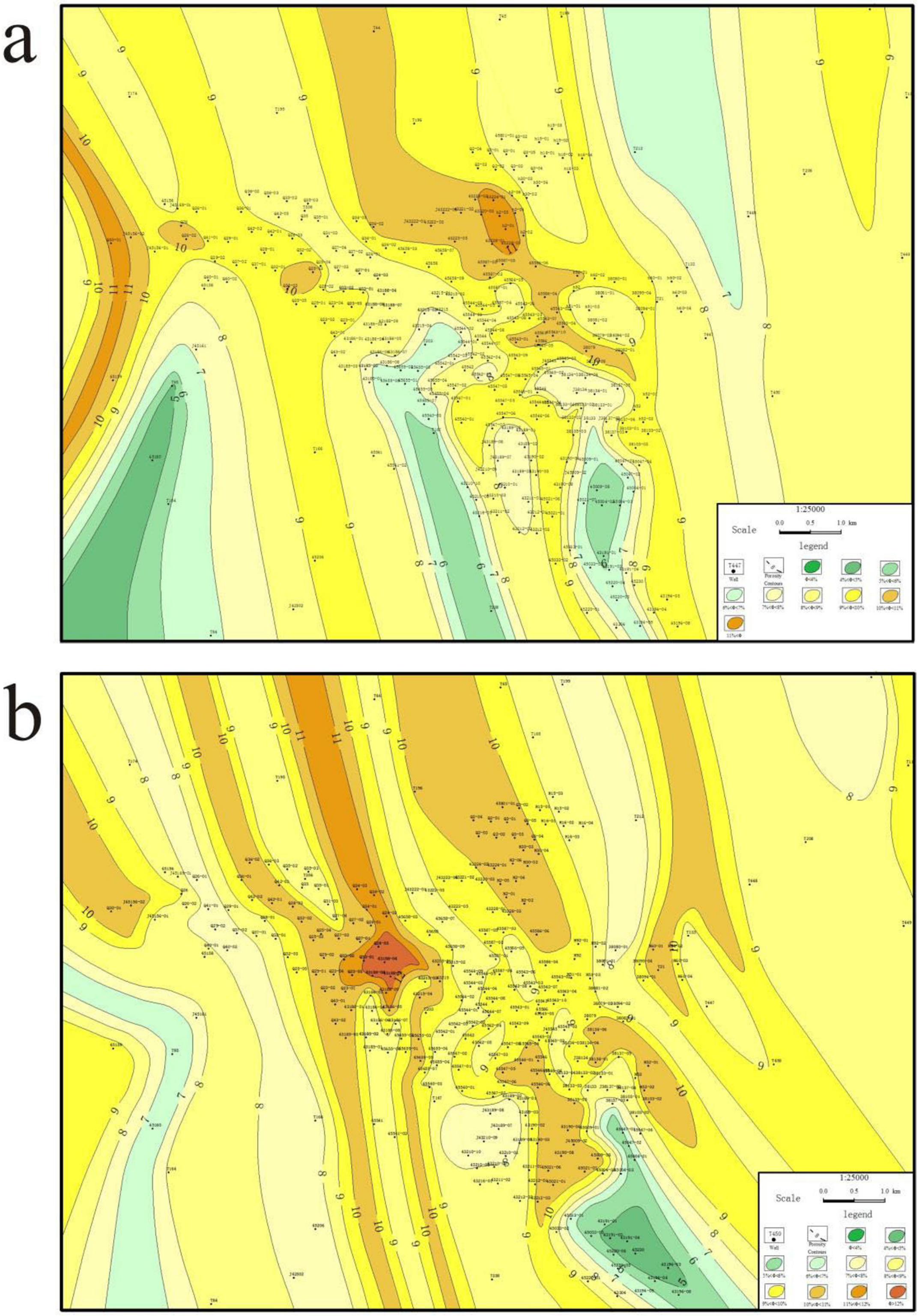


Fig. 5. Thickness of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.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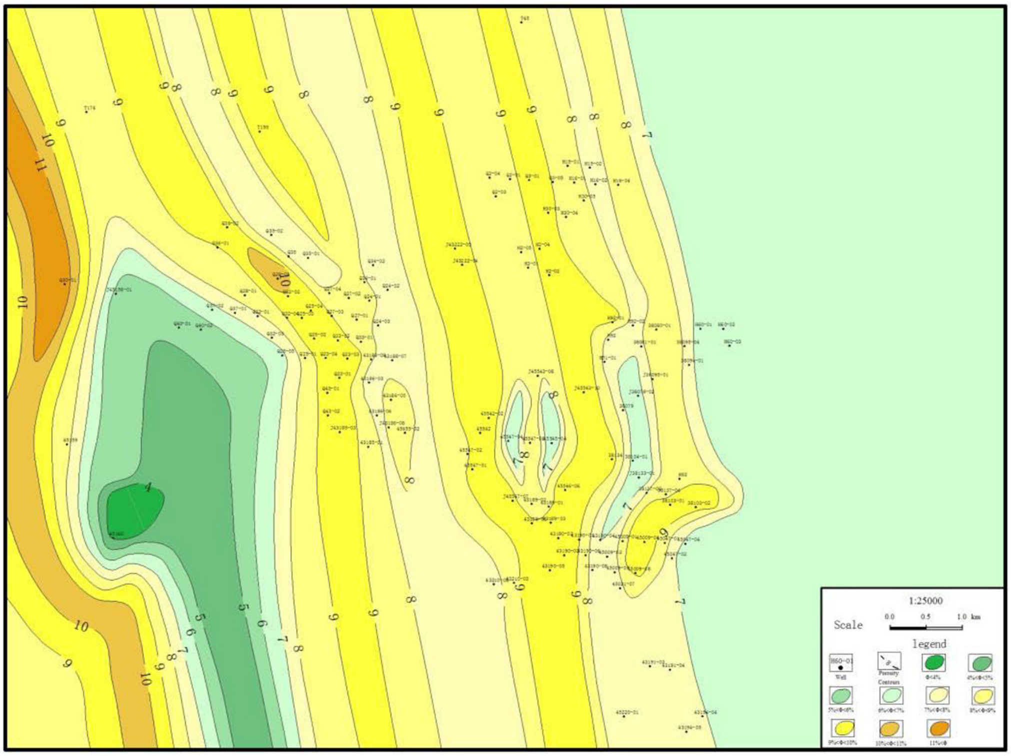

Fig. 6. Porosity of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.

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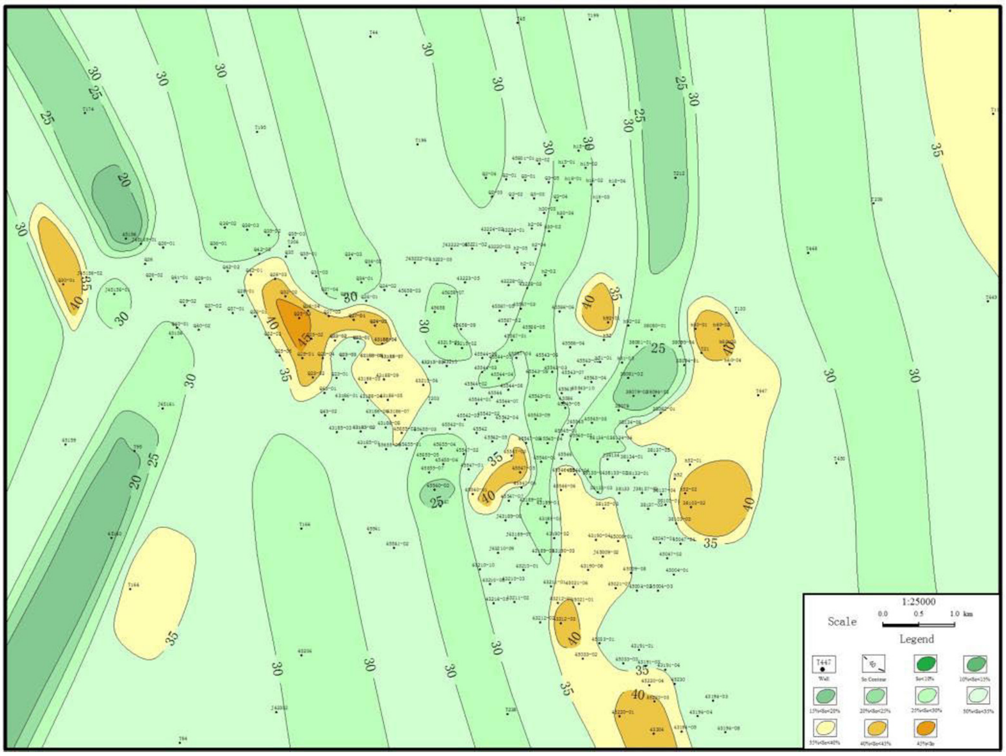

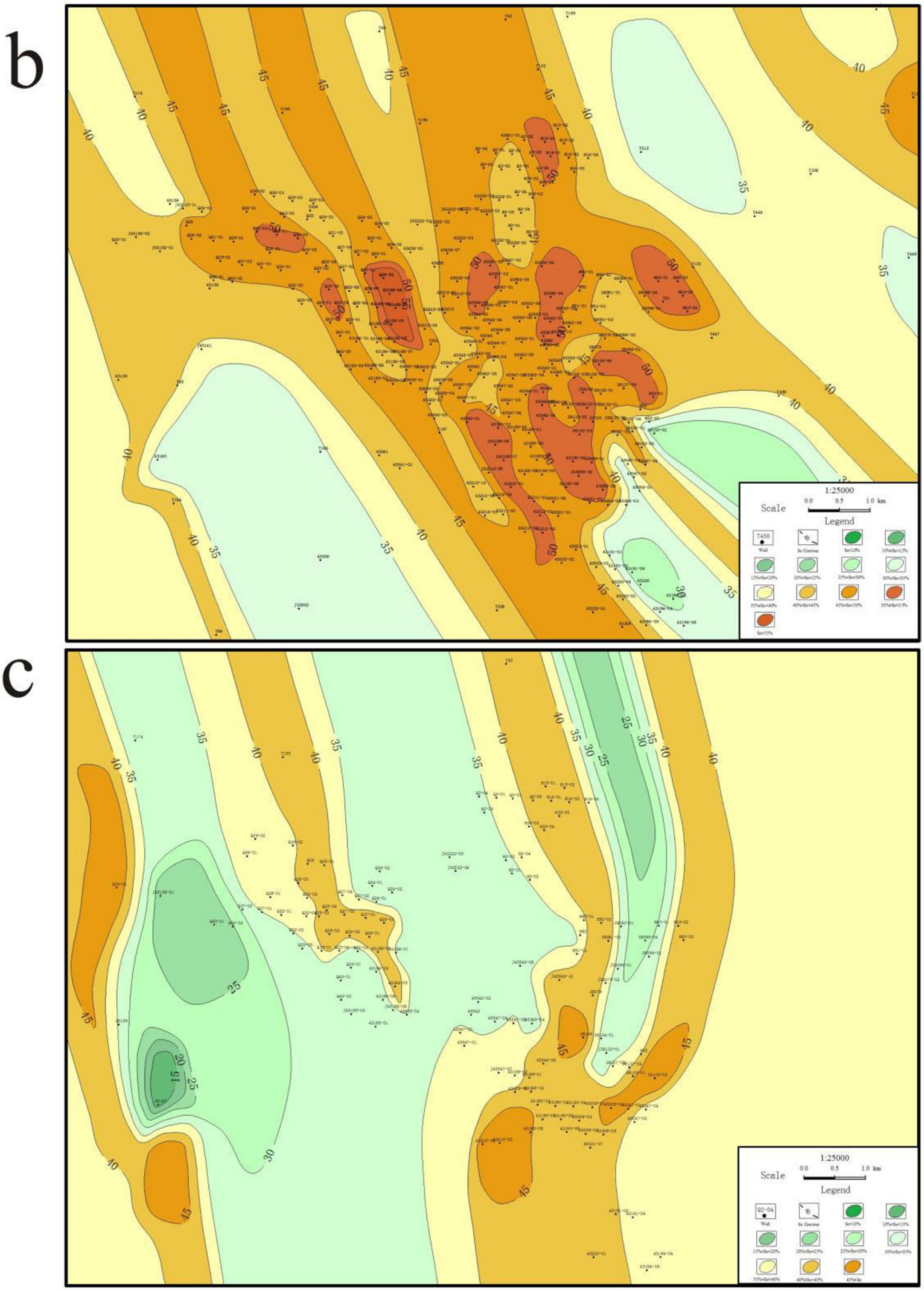

Fig. 7. Oil saturation of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.

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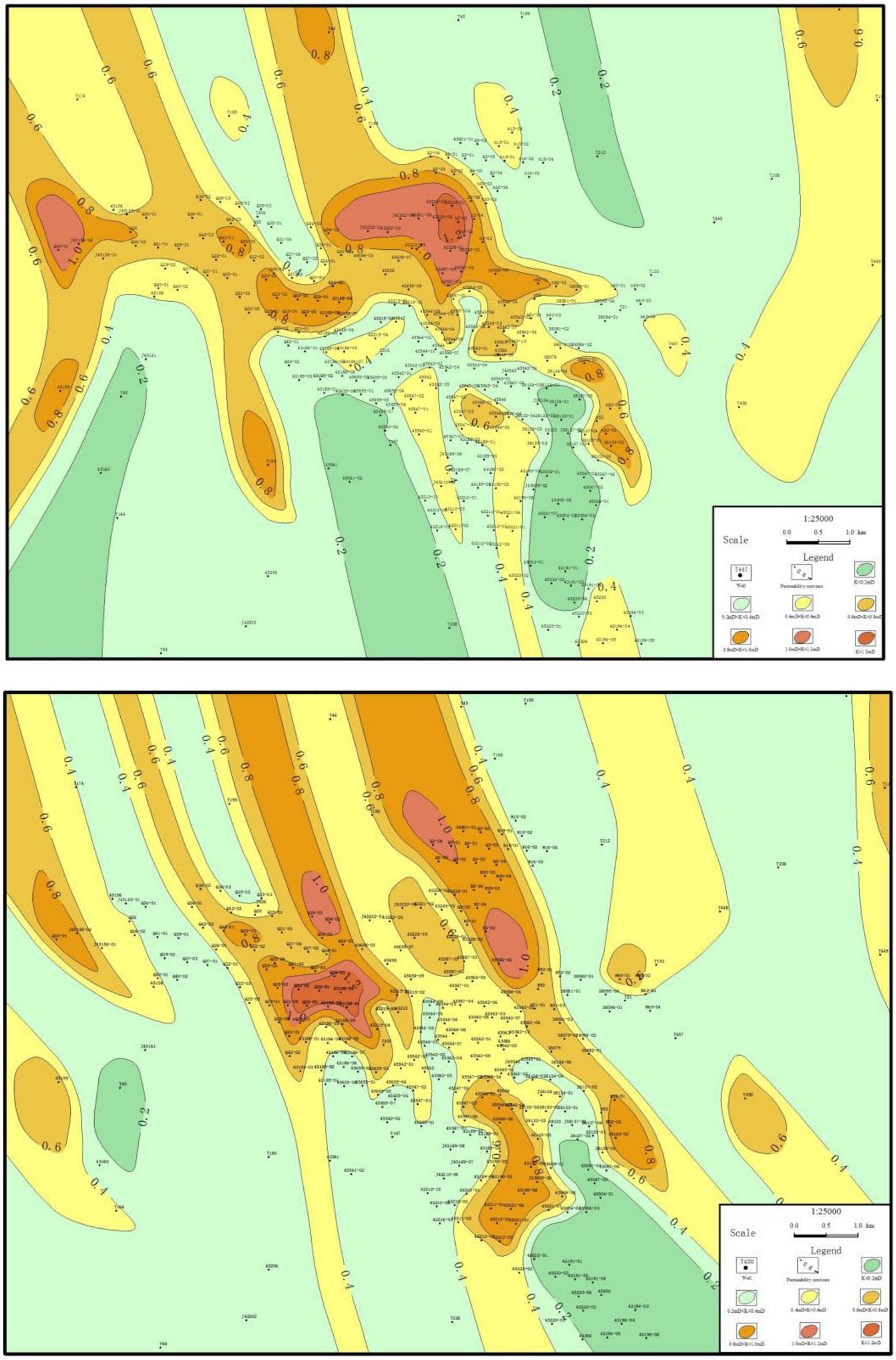


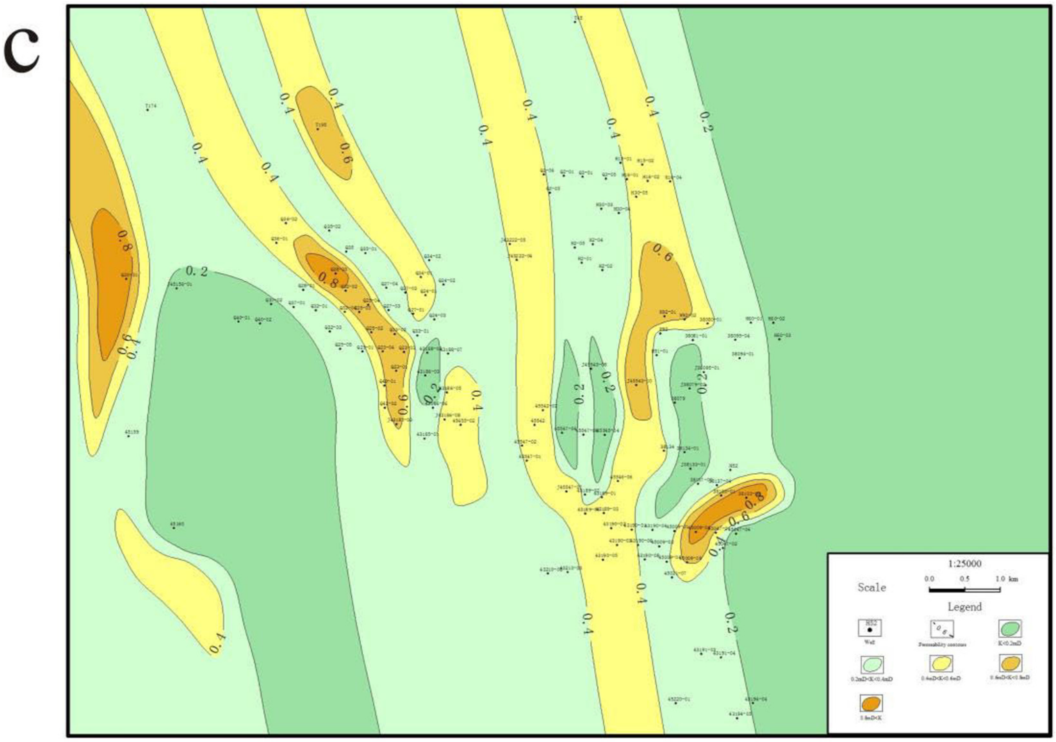
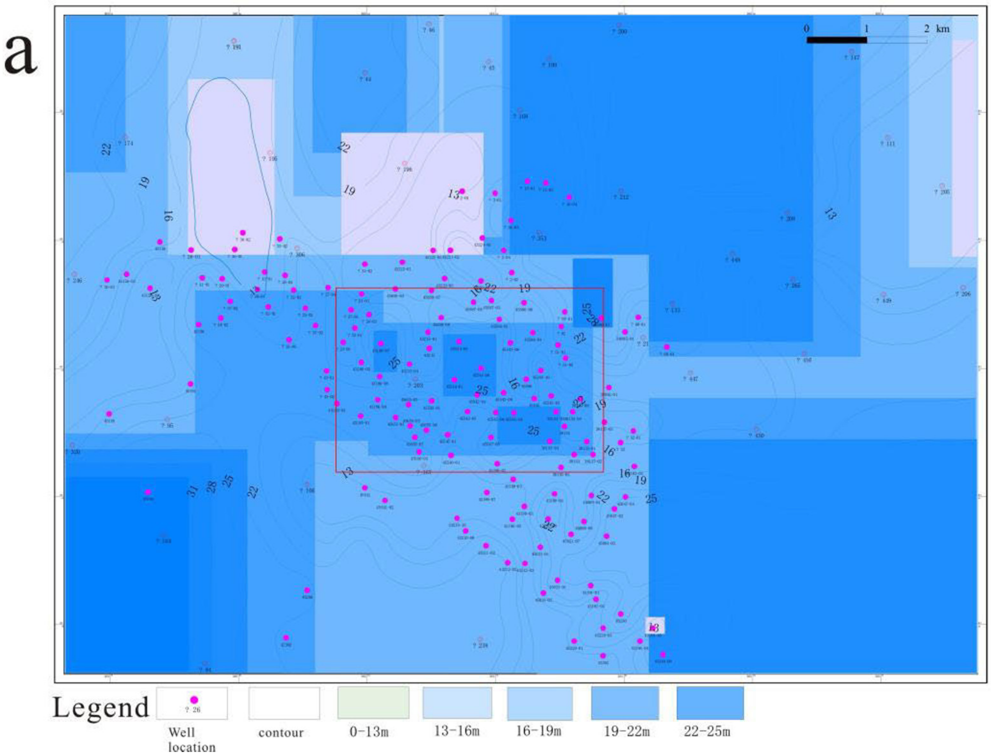


Fig. 8. Permeability of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.



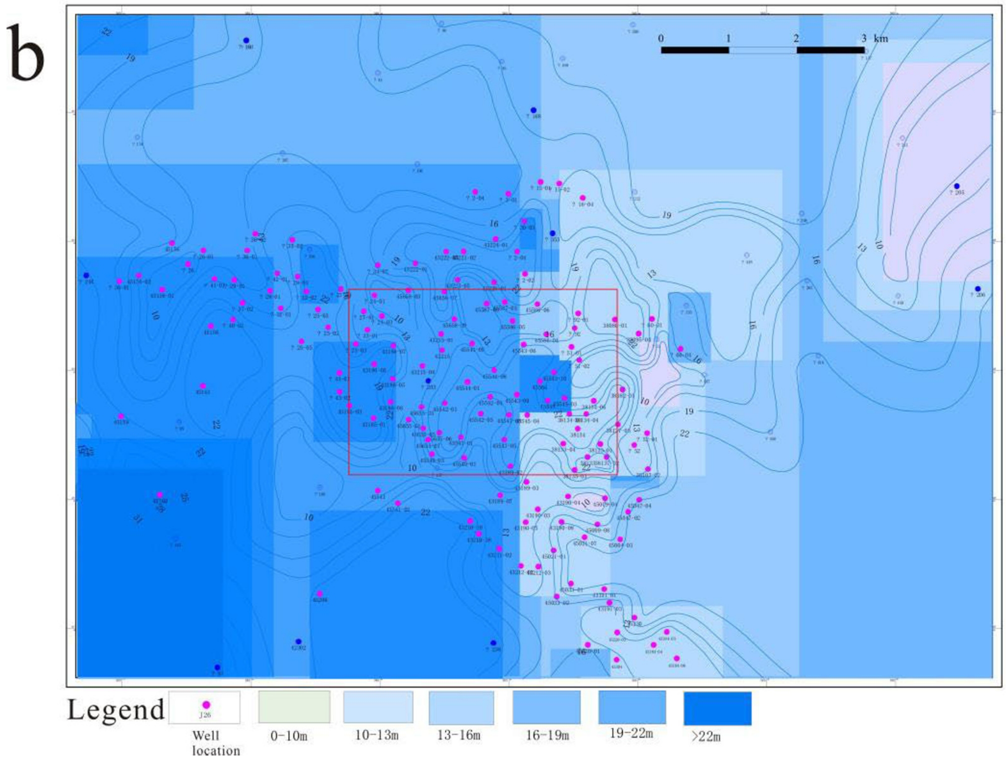
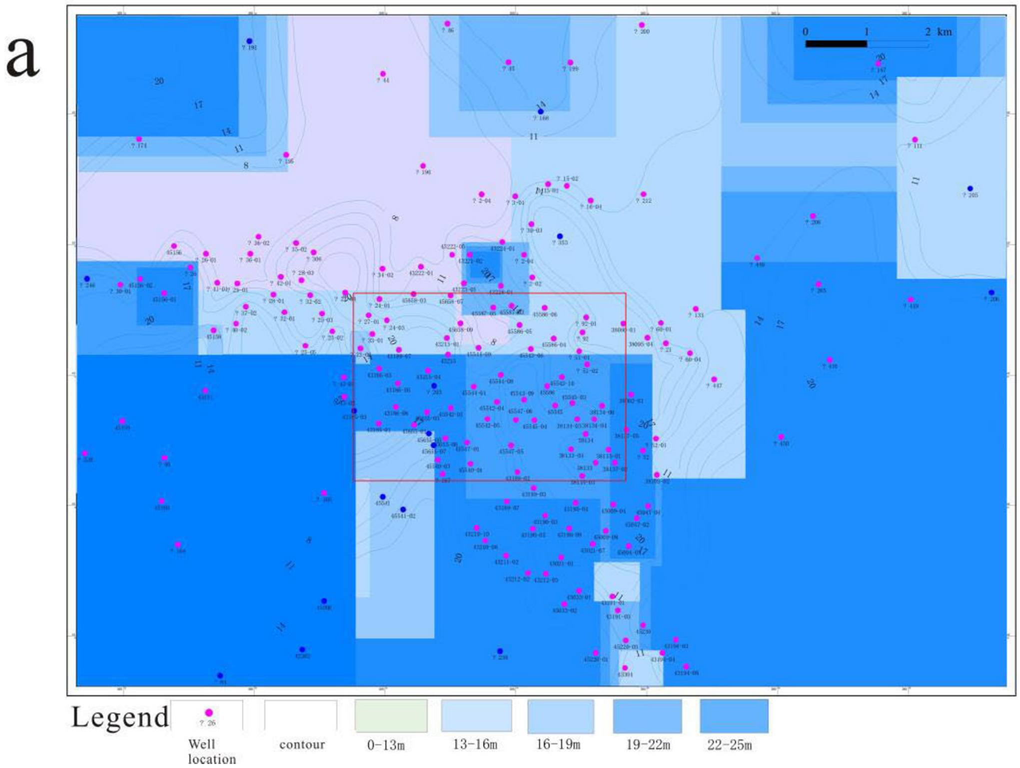


Fig. 9. Caprock thickness of Chang 4+5. (a) Chang 4+5_1; (b) Chang 4+5_2.



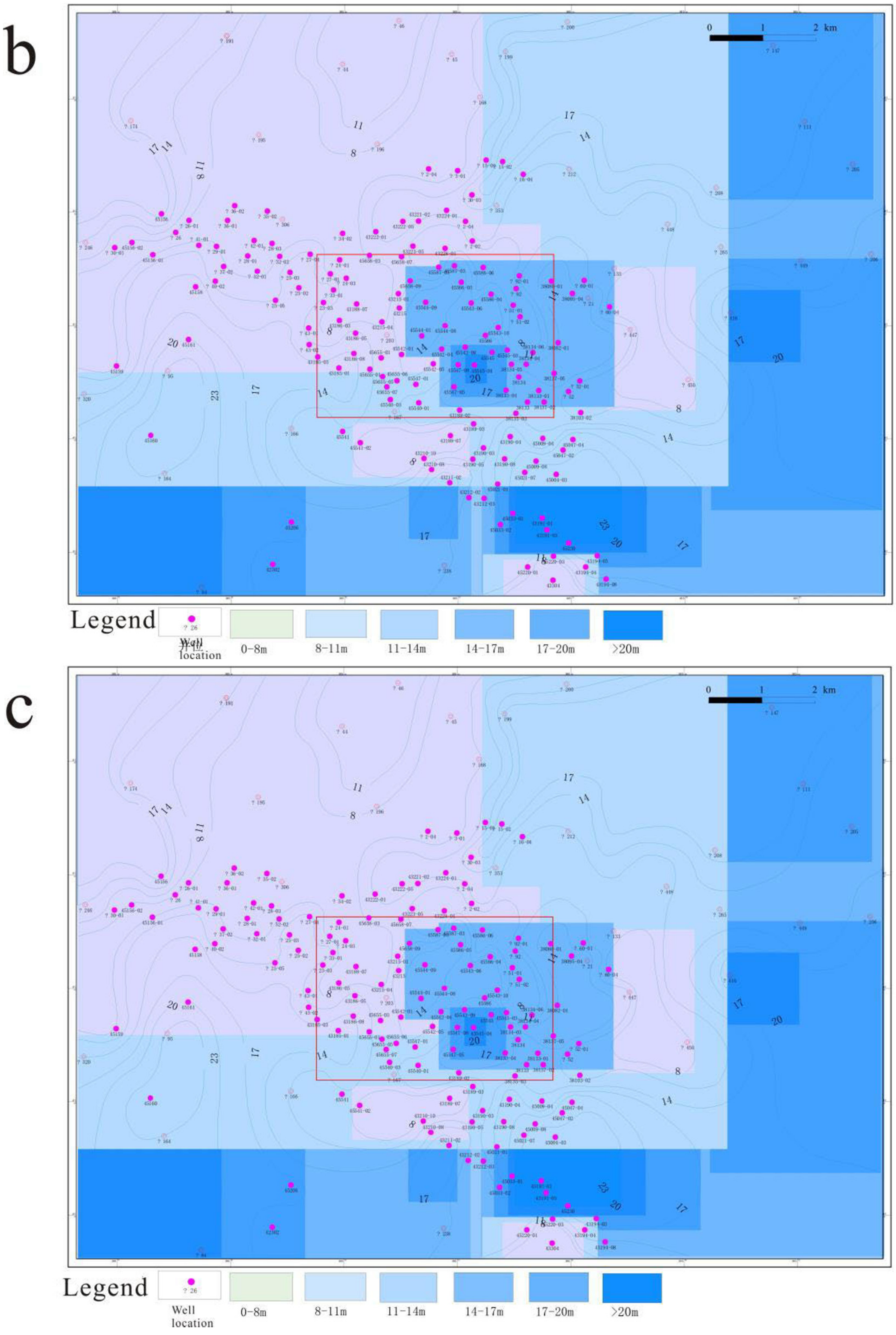


Fig. 10. Caprock thickness of Chang 6. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.

5. Environmental monitoring

We established the soil, water, plant monitoring system and developed an online monitor instrument so that dozens of CO_2 monitoring data may be measured at the same time. In order to study the CO_2 concentration in different seasons, we observed the baseline CO_2 content in different seasons. These baseline CO_2 content and ^{13}C will be compared to that before and after CO_2 injection. Then we will use difference data to detect CO_2 leakage and analyze the environmental impact of CO_2 leakage.

By using remote sensing data, we studied land usage survey and cartography. Through combining field and remote sensing methods, 10 typical sample points were randomly chosen to establish interpretation signs of vegetation, map vegetation area and measure vegetation types.

According to difference in geomorphic and in land use type, we set up 13 soil profiles in the study area. Along each soil profile, we collected 26 samples in 0-20 cm and >20cm depths and analyzed soil mechanical composition in Spring and Summer, common ion in soil, soil fertility and heavy metal indicators (Wang et al., 2013).

The surface water, river water quality, groundwater quality are investigated near CCS site. We also chose soy beans, green beans, buckwheat and potato of C3 crops and maize, sorghum, millet, and glutinous millet of C4 crops which are classical crops near Jingbian City, and carried out crop seed germination tests at normal atmospheric concentration of CO_2 (control group), 10000 ppm, 20000 ppm, 40000 ppm, 80000 ppm. Experiment of soil was acquired from a farm in Jingbian County within 0~20 cm depth. The tests are mainly used to measure form, and physiological and the bio volume response of plant seedling on high CO_2 concentration (Xue and Ma, 2014).

We did simulation and erosion properties of CO_2 concentration in the ground water, and measured leaching ion concentrations in water at two different pressures. The influence of CO_2 leakage to fish is under studying now.

6. Discussion

The biggest difficulty lies in Jingbian CCS-EOR pilot project is that CO_2-EOR efficiency is lower than our expectation. Although a great deal of laboratory experiment and the use of small scale core samples prove the high efficiency of CO_2-EOR, CO_2-EOR efficiency increases not much in the field CO_2 injection. The reasons we analyzed as below:

- Jingbian Field has produced oil and injected water for a long time. Reservoir pressure is very low and CO_2 injection in the early stages is to make up for the shortfall of reservoir pressure. This stage may take a long time but we do not know when we would get the best CO_2-EOR effect. Meanwhile, we need to avoid CO_2 breakthrough during CO_2 injection or take measures to mitigate CO_2 breakthrough;
- Jingbian Field had been producing oil by a private company before it was bought by Yanchang Petroleum Group in 2003. The oil producing was a damaging exploitation. Some early boreholes have no log curves, or have not enough log curves, have no coring data, pressure data, borehole data and other necessary information. Not to say without seismic data. It is difficult to figure out reservoir characterization, especially reservoir heterogeneity using current geological information;
- Jingbian Field is a low porosity and super low permeability reservoir. Reservoir is extremely tight sand. The exploitation of tight reservoir is the world's scientific problem. This is the first time that we conduct CO_2-EOR in such tight reservoir in China. The difficulty and risks are great;
- Current injection pattern in Jingbian Field is to inject CO_2 into the vertical wells. If we drilled horizontal wells and inject CO_2 into horizontal wells in the future, CO_2-EOR could get a better oil production;
- Jingbian Field has been developed over ten years and is in the late stage of oilfield development. Residual oil saturation is low. Therefore, we might not expect CO_2 inject could get higher EOR as that in Weyburn (Wilson and Monea, 2004) and other oil fields.

4. Conclusions

Jingbian CCS-EOR pilot project is an important attempt by Chinese government in dealing with climate change. This CCS pilot project established the first full chain CCS or CCUS project in China including CO_2 capture, transport, utilization and geological storage. It plays an exemplary role in extremely low porosity and low permeability reservoir in Ordos Basin and in China.

Government's funding in Jingbian CCS-EOR pilot project is inadequate that restricts us to carry out MMV studies. Investment from industry is mainly used in engineering and seldom used in research. Therefore, we could not confirm the distribution of CO_2 underground and the safety of CO_2 sequestration from current information and study. More research funding must be invested in acquiring basic data at different injection stages from surface to underground.

It is the first time in CCS project in China to acquire baseline surface soil, water, plants and other monitoring data. We also tested CO_2 concentration effect to plants in Jingbian Field in the laboratory. However, these environmental data in the shallow ground has not been monitored because of our limited budget. It is necessary to monitor CO_2 changes and distribution from surface to dozens of meters deep. Financial constraints also made us to collect limited samples in the CCS site. That may not enough to reflect the baseline environmental information in the area.

CO_2 comes out from production well has not been recycled because CO_2 recycle equipment has not been completed in our project. As CO_2 injection volume increases, leakage will continue to increase. CO_2 leakage from borehole would affect environmental monitoring results.

How to postpone CO_2 breakthrough time is the main problem of improving the efficiency during CO_2 flooding in the region. By conducting 4D seismic acquisition, time-lapse well log and other research may help us to understand characteristics of reservoir heterogeneity and determine best flooding scheme.

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