ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0032

# Comprehensive Evaluation of Gas Sealing Capability of the Caprock of the He 8 Member in the West Area of Sulige Gas Field

Fengfan Fan[1,*], Zhiyuan Li[1] and Weiwei Tian[1]

[1]School of College of Earth Science and Engineering, Shandong University of Science and Technology, Qingdao, Shandong 266590, China.

*Corresponding author Email: 17854253565@163.com

## Abstract

**According to data such as drilling, logging, core analysis, stratum burial history, etc., based on a comprehensive analysis of the macroscopic development characteristics and microscopic sealing mechanism of deep mudstone caprocks, lithology, caprock thickness, porosity, permeability and displacement pressure are selected In order to evaluate the parameters and measure the effectiveness of the sealing capacity of the caprock, the sealing performance of the mudstone caprock of the Shihezi Formation in the Sulige area of the Ordos Basin is comprehensively evaluated. The results show that: the thickness of the mudstone caprock in the middle and southeast of the study area is large, the displacement pressure is high, the mudstone caprock has strong sealing ability, and the caprock sealing effectiveness is high; while the western and northern caprocks of the study area are thin, The replacement pressure is small, and the physical sealing performance is poor.**

## Keywords

**Sulige Gas Field; Stone Box Group Cover; Displacement Pressure; Sealing Capacity; Comprehensive Evaluation.**

## 1. Introduction

Ordos Basin is located in the western margin of the North China Platform, and is the second largest sedimentary basin in China, among which the Sulige gas field is the largest onshore gas field in China. Cap rock is a necessary condition to ensure oil and gas accumulation, and its sealing performance directly affects the formation, scale and preservation conditions of gas reservoirs. Therefore, the comprehensive evaluation of the sealing ability of cap rock in He 8 member of Sulige gas field is of great significance for exploration and research in Sulige area. Although a lot of previous studies have been done on the Ordos Basin, there are few studies on the relationship between the sealing performance of basin cap rock and oil and gas accumulation in the aspects of basin tectonic evolution, sedimentary facies, reservoir and gas accumulation characteristics, and few systematic evaluations on the sealing performance of mudstone cap rock in Sulige area. In order to provide reference and basis for gas exploration and development in Sulige gas field, this paper attempts to comprehensively evaluate the sealing ability of mudstone cap in He 8 Member of Sulige area, Ordos Basin from two aspects of macroscopic development characteristics and microcosmic sealing mechanism.

## 2. Regional Geological Background

Ordos Basin is the second largest sedimentary basin in China, spanning five administrative provinces of Shaanxi, Gansu, Inner Mongolia and Shaanxi. The basin covers an area of about 250,000 square kilometers with simple tectonic conditions and can be divided into six first-order tectonic units,

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0032

including Yimeng uplift, Weibei uplift, Jinxi torsion fold belt, Tianhuan depression, Yishan slope and western margin thrust belt. At present, the Ordos Basin is mainly a rectangular basin with asymmetric north-south direction, which is wide and slow in the east and steep and narrow in the west (Fig. 1).

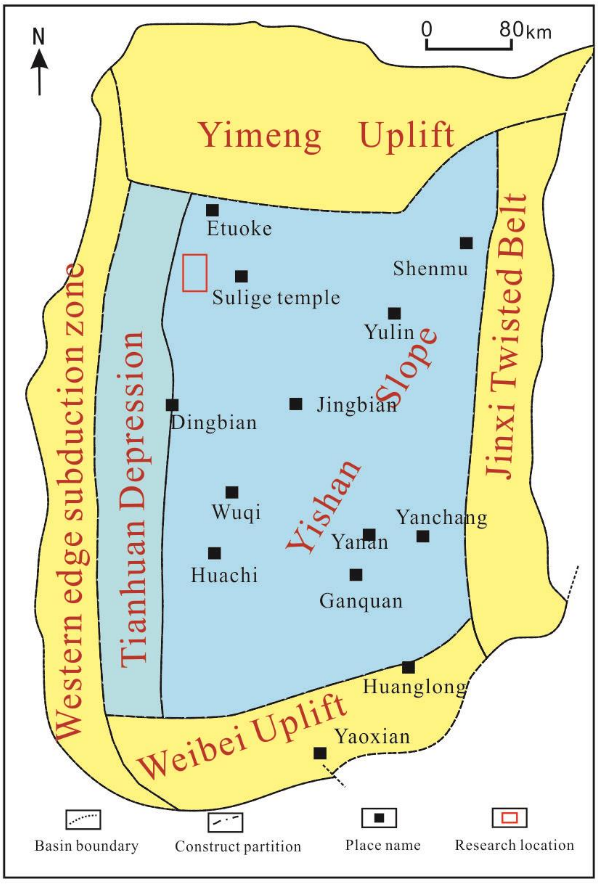


Fig. 1 Geographical location of Sulige area

The present structural characteristics of the Ordos Basin indicate that the basin has experienced six stages of tectonic evolution from Archean to Cenozoic. Six tectonic evolution stages were formed in the early proterozoic basin basement formation stage, the middle and late proterozoic aola valley development stage, the early Paleozoic pre-platform stage, the late Paleozoic - early middle Triassic coastal plain stage, the late Triassic - cretaceous inland basin development stage, and the Cenozoic faulted basin development stage.

Table 1. Sulige area Statistical table of accumulated mudstone thickness and mud-floor ratio of Xiashihezi Formation

| Well location | Layer thickness (m) | Thick mud (m) | Mud ratio | Hashtag | Layer thickness (m) | Thick mud (m) | Mud ratio |
|---|---|---|---|---|---|---|---|
| S120-52-75 | 53.036 | 46.918 | 0.885 | S49 | 48.498 | 28.498 | 0.588 |
| S120-52-82 | 54.885 | 44.763 | 0.816 | S121 | 52.999 | 36.749 | 0.693 |
| S120-49-79 | 55.477 | 39.233 | 0.707 | S179 | 54.393 | 42.769 | 0.786 |
| S120-46-94 | 55.383 | 45.261 | 0.817 | S119 | 54.507 | 40.757 | 0.748 |
| S120-41-96 | 66.582 | 52.83 | 0.793 | S164 | 55.883 | 47.011 | 0.841 |
| S120-52-95 | 40.198 | 30.323 | 0.754 | S178 | 47.693 | 41.943 | 0.879 |
| S120-54-96 | 52.791 | 42.667 | 0.808 | S195 | 50.882 | 43.885 | 0.862 |
| S120-63-89 | 51.994 | 36.245 | 0.697 | S175 | 53.161 | 41.043 | 0.772 |
| S120-58-89 | 49.899 | 39.649 | 0.795 | S169 | 47.893 | 19.521 | 0.408 |

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0032

The study area has entered the sea-land interaction stage since the Late Carboniferous, and deposited coal-bearing clastic rock, limestone, and marl formation, forming the Middle-Upper Carboniferous marine carbonate gas source rock and the Benxi Formation paleoweathering crust regional caprock And local caprocks of the Taiyuan Formation; during the early Permian Shanxi Formation deposition period, seawater withdrew and developed fluvial-lacustrine coal-bearing formations and delta deposits, forming Carboniferous-Permian coal-measure gas source rocks and good regional caprocks. At the end of the Early Permian, the northern area uplifted, and the north-south difference increased, with braided rivers, deltas and stable lacustrine mudstone deposits developed. Mudstone has a wide distribution area and large thickness, forming an important regional caprock of the Shihezi Formation. The Shihezi Formation in the Sulige area has good hydrocarbon source conditions and reservoir-caprock assemblages, and its exploration potential is huge.


Fig. 2 Thickness contour map of Su 120 mudstone

## 3. Macro parameters in the seal evaluation of cap layer

### 3.1 Cover thickness

The thickness of cap layer is an important parameter to evaluate the cap layer, and many scholars have done a lot of research work [14-16]. Sedimentologically, only when the cover thickness is large, the sedimentary environment formed by it is stable, the sediment homogeneity is good, and the macropores do not develop. On the contrary, if the cap thickness is small, the sedimentary environment formed is unstable, the sediment homogeneity is poor, and the macropores are developed. Statistical analysis of the study area around the layer thickness of cap rocks and mud than

ISSN: 2414-1895
DOI: 10.6919/ICJE.202106_7(6).0032

characteristics shows that the accumulated formation mudstone thickness and mud stone box than characteristics (Table 1), stone box formation mudstone under the cumulative thickness distribution in the range is 0 to 60 m, most of the underground stone box formation mudstone cumulative thickness within 20 to 50 m, and accumulated in the mudstone thickness difference is not big, mud stone box set of strata distribution at 0-0.9, than the mud than frequency distribution in two main interval 0.6 to 0.8. The total thickness ratio of mudstone to stratum in some areas in central China is more than 80%, and the highest can reach 96%. However, in the northwest corner of the study area, the mud thickness is relatively thin, and the mud to ground ratio is less than 50%. It can be seen that the accumulated thickness of argillaceous rocks in the middle of the Lower Shihezi Formation is generally large, the ratio of argillaceous rocks is generally high, and the lateral distribution is wide, so it is a very ideal direct cap rock for the sealed natural gas in this area.

### 3.2 Plane distribution characteristics of the cap layer

The spreading characteristics of the cover layer on the plane include the thickness distribution characteristics of the cover layer on the plane and the plane spreading continuity characteristics of the cover layer. When the cap layer has a large thickness on the plane and the continuity of the plane spread is good, it can be used as a good set of regional cap layer. When the thickness of the cap layer is small or the plane spread continuity is poor, it can only be used as a partial cover. Floor. Since the lithology of the Shihezi Formation caprock is mainly argillaceous rock and silty mudstone, the thickness characteristics and planar distribution continuity characteristics of the argillaceous rock in this interval can reflect the plane characteristics of the macroscopically developed caprock in this interval.

Based on the analysis of data, a plane distribution map of the thickness of direct cap mudstone of Shihezi Formation in the study area was drawn (Fig. 2), from which it can be seen that the thickness distribution of cap mudstone in the study area has a certain heterogeneity. The overall thickness of the S 120 area is large, the mudstone in the northwest is thinner, and the mudstone in the northeast and central area is thicker, and the overall mudstone thickness is between 40 and 60m. The thickness of mudstone in well S169 area is lower than 35m, and the thickness of mudstone in surrounding area is thinner. The mudstone thickness > 45m in well S120 in the south is a high value area, and the surrounding mudstone thickness is generally thick.

The mudstone in the northeast of the study area is thin, while the mudstone in the middle and south of the study area is thick. The thickness of mudstone in some areas is between 50-60m, which is the high value area. The increase of the thickness of the mudstone can improve the sealing quality of the cap rock, because the sedimentary environment of mudstone is relatively stable, and the sedimentary thickness of the mudstone with fine grain size is generally thicker. The larger the thickness of mudstone deposition is, the stronger the sealing ability of cap rock is, and the stronger the sealing ability of reservoir is. Therefore, the thick mudstones in the central and southern parts of the SU 120 have better sealing ability, while the thick mudstones in the northeastern and northwestern parts of the SU 120 have poorer sealing ability.

## 4. Microscopic parameters in the seal evaluation of cap layer

### 4.1 Porosity and permeability

Porosity and permeability are important parameters to reflect the microseal performance of cap rock. The smaller the porosity, the smaller the pore throat radius, the lower the permeability, the greater the capillary force, the better the sealing ability of cap rock; On the contrary, the less closed. The porosity and permeability of the mudstone of Shihezi Formation in the study area were studied by analyzing the laboratory data. It was found that the porosity of the mudstone cap of Shihezi Formation in Sulige area was mainly distributed between 0.56% and 3.85%, and the permeability distribution range was $0.013\text{-}0.024\times10^{-3}um^{-2}$. The variation law of permeability is similar to porosity. The porosity and permeability of mudstone in Shihezi Formation are low on the whole, and the sealing ability of cap rock is good.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0032

Table 2. Local cap displacement pressure gauge in Su120 block

| Well location | Acoustic time (us/m) | Displacement pressure (MPa) |
|---|---|---|
| S120-73-70 | 244 | 11.81 |
| S120-63-89 | 228 | 9.51 |
| S120-63-81 | 231 | 8.89 |
| S120-49-74 | 225 | 10.42 |
| S120-41-76 | 234 | 7.68 |
| S366 | 235 | 7.37 |

### 4.2 Displacement pressure

Displacement pressure refers to the minimum pressure required for the wetting phase fluid in the rock to be displaced by the non-wetting phase fluid, which is approximately equal to the capillary pressure of the largest connected pore in the rock numerically. Underground free phase oil and gas migration through the pore throat of cap rock is bound to be blocked by the displacement pressure difference between cap rock and reservoir. Only when the energy of natural gas is greater than the displacement pressure difference between cap rock and reservoir, can natural gas drive the water in the pore of cap rock and migrate. Because the displacement pressure of the reservoir rock is too small, it is negligible compared to the displacement pressure of the cap rock.

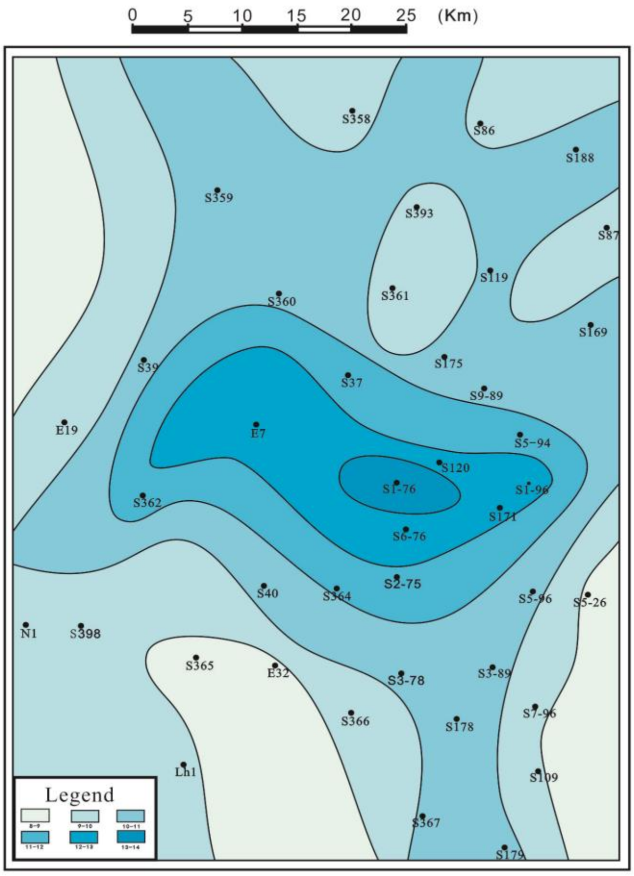


Fig. 3 Displacement pressure contour map

Therefore, cap rock displacement pressure is the most direct and fundamental parameter to evaluate the physical sealing ability of cap rock. The higher the cap rock displacement pressure is, the stronger the physical sealing ability will be, and vice versa.

Li Mingrui studied the relationship between the breakout pressure of the Upper Paleozoic and the acoustic time difference in the eastern Ordos Basin, and proposed the calculation formula as follows:

$$Pd = -89.314\ln(\Delta t) + 502.78 \quad \Delta t \geq 237.5\mu s/m \tag{1}$$

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0032

$$Pd = 79\text{-}0.3048\Delta t \quad \Delta t<237.5\mu s/m \tag{2}$$

By referring to the above formula, the displacement pressure of cap rock in typical block of Sulige gas field can be calculated:

The data in the analysis table (Table 2) can be seen: In Block S120, the displacement pressure of the caprock is mainly between 7-12, and the displacement pressure is relatively high.

According to the local cap displacement pressure gauge, the displacement pressure distribution plan of block 120 is drawn (Fig 3). It can be seen that:

The displacement pressure in the northwest of Su120 block is small, mainly between 8 and 10, indicating poor sealing in the northwest of Su120 block. The displacement pressure in the middle region is relatively high, which is distributed in the range of 11-13 and mainly in the east-west stripe distribution, indicating that the middle region has a good sealing property.

The greater the displacement pressure, the better the sealing effect. It can be seen from the figure that the displacement pressure of S120 cap rock is relatively high on the whole, and the area around well S120 in the middle has the highest displacement pressure and the best sealing ability, which has a good plugging effect and is conducive to sealing off a large amount of natural gas generated in the main hydrocarbon generation period.

## 5. Closure evaluation of cap layer

The sealing ability of cap rock is influenced by its thickness and displacement pressure, that is, the greater the thickness of cap rock, the greater the displacement pressure, and the stronger the sealing ability of cap rock. On the contrary, the sealing ability of cap layer is weaker. In addition, the effectiveness of cap sealing ability has an important effect on gas accumulation.

The effectiveness of cap rock sealing capacity refers to the matching relationship between the formation period of the cap rock sealing capacity and the source rock's massive exhaust period. Only when the cap rock sealing capacity is formed earlier or at the same time as the source rock's massive exhaust period, the cap rock can be sealed. The large amount of natural gas discharged from the source rock has good gas sealing effectiveness; on the contrary, if the formation period of the cap rock sealing capacity is later than the large exhaust period of the source rock, the amount of natural gas that the cap rock can seal is controlled by the time difference between the two. The smaller the time difference between the two, the larger the amount of natural gas discharged from the source rock that can be sealed by the cap rock, and the better the sealing effectiveness; otherwise, the worse.

Table 3. Cap layer sealing effectiveness parameter

| Well location | Displacement pressure | Cover thickness (m) | CSI |
|---|---|---|---|
| S120-73-70 | 13.65 | 112 | 0.63 |
| S120-63-89 | 12.54 | 108 | 0.55 |
| S120-63-81 | 13.28 | 123 | 0.67 |
| S120-63-78 | 11.44 | 116 | 0.54 |
| S120-49-74 | 14.22 | 120 | 0.7 |
| S120-41-76 | 14.02 | 100 | 0.57 |
| S366 | 12.91 | 125 | 0.66 |
| S358 | 12.17 | 102 | 0.51 |

In addition to the influence of its own development characteristics (cap rock displacement pressure and thickness), the cap rock’s gas-sealing capacity is also affected to a certain extent by the cap rock’s gas-sealing effectiveness. Therefore, the comprehensive evaluation of the cap rock’s gas-sealing capability should be considered. The effect of layer sealing gas effectiveness.

CSI (Cap Seal Idex) quantitatively reflects the sealing ability of the cap layer. The larger the CSI value, the stronger the sealing ability of the cap layer; otherwise, the weaker.

**ISSN: 2414-1895** **DOI: 10.6919/ICJE.202106_7(6).0032**

$$\mathrm{CSI} = f \cdot \frac{P \cdot H}{k}$$

(When ts≧tr, the value of f is 1, when ts<tr, f=ts/tr)

CSI is a comprehensive evaluation parameter of caprock gas sealing ability;

f is the sealing effectiveness coefficient of the caprock, which is determined by comparing the formation period of the sealing capacity of the caprock (ts) with the period of massive exhaust gas (tr)

P is the minimum displacement pressure of the caprock in the evaluation area, MPa;

H is the effective thickness of the caprock, in m, which can be obtained from the interpretation results of drilling data and seismic data;

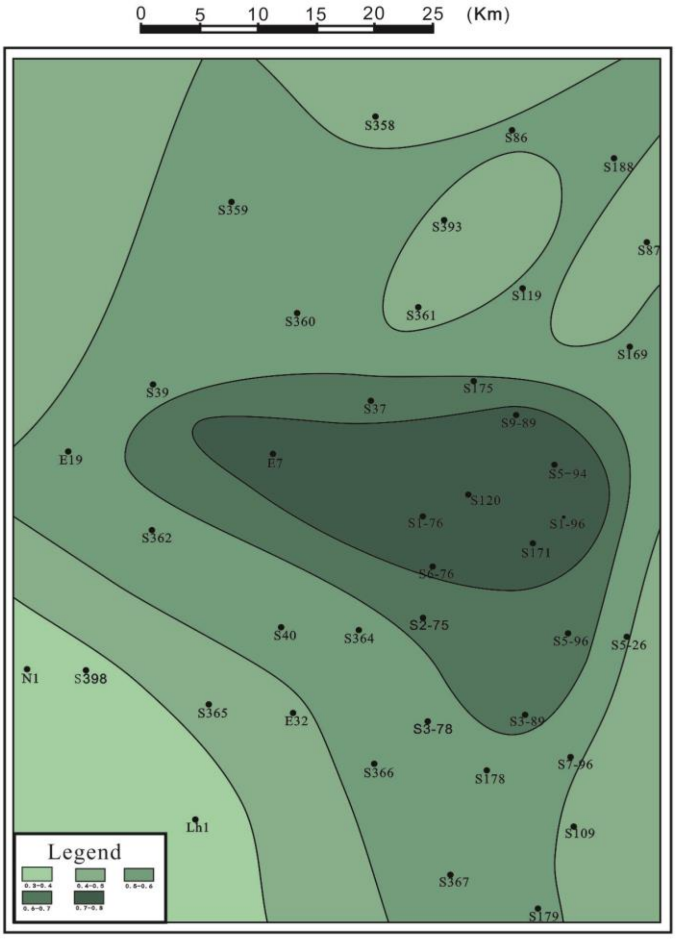


Fig. 4 CSI contour map

k is the gas reservoir pressure coefficient, dimensionless, and can be obtained by dividing the measured reservoir pressure by the static water column pressure.

After calculation, it can be obtained (Table 3):

The cap sealing capacity parameter CSI of Block Su120 ranges from 0.51 to 0.7, with an average of 0.60. From the table, it is found that the well sites with high caprock thickness and high displacement pressure have high CSI and better comprehensive caprock sealing ability.

It can be seen from the CSI contour map (Fig 4):

The central area of the Sulige Gas Field is a high-value area, and the northwest is a low-value area. The comprehensive evaluation parameter CSI of the caprock sealing capacity is large, and the caprock sealing capacity is strong, indicating that the central sealing capacity is strong, and the northwestern sealing capacity is weak.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0032

## 6. Conclusion

1) The mudstone caprock in the middle of the 8th member of the Sulige area is thick, continuous, and has a strong micro-sealing capacity, making it a good set of regional caprocks.

2) The mudstone caprock of the He 8 Member has the largest thickness in the central area, with high displacement pressure, high effective sealing parameter value, and good sealing capacity; while the sealing capacity in the northwestern area is weak.

3) The cover layer in the He 8 section can effectively seal natural gas, which is conducive to the accumulation and preservation of oil and gas.

## Acknowledgments

Achievements funded by the National Natural Science Foundation of China (41402120) and the Science and Technology Research Project of the Exploration and Development Research Institute of PetroChina Changqing Oilfield Branch.

## References

[1] Fu Jinhua. The gas reservoir- forming conditions and accumulation rules of Upper Paleozoic in Ordos Basin[D]. Xi'an: Northwestern University, 2004.

[2] Ma Li, Chen Huanjiang, Gan Kewen, et al.Geotectonics and petroleum geology of marine sedimentary rocks in South China[M]. Beijing: Geological Publishing House, 2004: 328-364.

[3] Li Shuangjian, Wo Yujin, Zhou Yan, et al. Controlling factors affecting sealing capability of well-developed muddy cap rock[J]. Acta Geologica Sinica, 2011, 85(10):1 691-1 697.

[4] Meng Xiaoling, Zhang Hongbo, Feng Qianghan, et al. Gas accumulation conditions of the Permian Taiyuan Formation in Shenmugas field, Ordos Basin[J]. Oil & Gas Geology, 2013,34(1):37-41.

[5] Peng Xiumei. Study on standard of regional cap rock depths and thickness by rock mechanics test[C]// Marine Geology and petroleum in Yangtze.Beijing: Petroleum Industry Press, 1993:262-269.

[6] Zhang Changjiang, Pan Wenlei, Liu Guangxiang, et al.Dynamicevaluation to the cap formation of Silurian Argillaceous Rock, Southern China[J]. Natural Gas Geoscience, 2008,19(3):301-310.

[7] Ren Zhanli, Zhang Sheng, Gao Shengli, et al. Tectonic thermalevolution history of Ordos Basin and its hydrocarbon accumulation and metallogenic significance[J]. Science in China: Series DEarth Science, 2007, 37(supplement):23-32.

[8] Chen Ruiyin, Luo Xiaorong, Chen Zhankun, et al. Estimation ofdenudation thickness of Mesozoic Strata in the Ordos Basin andits geological significance[J]. Acta Geologica Sinica, 2006,80(5):685-693.

[9] Fu Jinhua. A study of the sealing properties of the Palaeozoic caprocks in Ordos Basin[J]. Natural Gas Industry, 1991,11(6):6-11.

[10] Fu Guang, Chen Zhangming, Jiang Zhenxue. Evolution of the sealing ability of caprock and its application [J]. Petroleum Exploration and Development, 1995,22(3):46-51.

[11] Swarbrick R E, Osborne M J. Mechanisms that generate abnormalpressures: An overview [C]// Law B E, Ulmishek G F, Slavin V I. Abnormal pressures in hydrocarbon environments. AAPG Memoir, 1998, 70:13-34.

[12] Min Qi, Fu Jinhua, Xi Shengli, et al. Characteristics of natural gasmigration and accumulation in the Upper Paleozoic of Ordos Basin[J]. Petroleum Exploration and Development, 2000, 27(4):26-32.

[13] Li Zhongdong, Hao Shumin, Li Liang, et al.Compartments in the Upper Paleozoic of northern Ordos Basin and their relationshipwith gas enrichment[J]. Oil & Gas Geology, 2007, 28(4):466-472.

[14] Li Guoping, Shi Qiang, Wang Shuyin. A study of reservoir- caprock log interpretation method[J]. Well Logging Technology, 1997, 20(2):98-104.

[15] Li Jian, Luo Xia, Shan Xiuqin, et al.Natural gas accumulation inthe Upper Paleozoic of Ordos Basin, China[J]. Petroleum Exploration and Development, 2005,32(4):54-59.

[16] Hao Shisheng, Huang Zhilong. Natural gas capcrock experimentalresearches and assessment[J]. Acta Sedimentologica Sinica, 1991,9(4):20-26.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0032

[17] Yang Junjie. Tectonic evolution and gas reservoirs distribution inOrdos Basin[M]. Beijing: Petroleum Industry Press, 2002:33-38.

[18] Ingram G M, Urai J L, Naylor M A. Sealing processes and top sealassessmen [tM]// Pederson P M, Koestler A G. Hydrocarbon seals-Importance for exploration and production, NPF special publication no.7. Amsterdam:Elsevier, 1997:165-174.

[19] He Zixin. Evolution and petroleum in Ordos Basin[M]. Beijing:Petroleum Industry Press, 2003:66-83.

[20] Liu Xinshe. Basin analyses and simulation of Up-Paleozoic in Ordos Basin[D]. Xi'an: Northwestern University, 2005.

[21] Bretan P, Yielding G, Jones H. Using calibrated shale gouge ratio to estimate hydrocarbon column heights[J]. Aapg Bulletin, 2003,87(3):397-413.

[22] Epard J L, Jr R H G. Kinematic model of detachment folding including limb rotation, fixed hinges and layer-parallel strain[J]. Tectonophysics, 1995, 247(1):85-103.

[23] Akrout,D., Ahmadi,R., Mercier,E., et al.Natural HydrocarbonAccumulation Related to Formation Overpressured Inter-val: Study Case is the Saharan Platform (Southern Tunisia). Arabian Journal of Geosciences, 2011, 5(4):849–857. https://doi.org/10.1007/s12517-011-0287-6.

[24] Chen Jie, Xie, Mei, Shi, Jianan, et al. Reservoir Characteristics of Xi-aganchaigou Formation in Mabei Area of Northern QaidamBasin. Natural Gas Geoscience, 201122(5):821–826.

[25] Fu Guang. Prediction Method and Application of Caprock Faulted-Contact Thickness Lower Limit for Oil-Gas Sealing in Fault Zone. Journal of China University of Petroleum, 2015.39(3):30–37.

[26] Li Jianming. Reservoir Diagenesis of Lower Juras-sic in Lenghu Area. Journal of Oil and Gas Technology, 2005, 27(6):695–698.

[27] Lash, G.G., 2006. Top Seal Development in the Shale-Dominated Up-per Devonian Catskill Delta Complex, Western New York State. Marine and Petroleum Geology, 23(3):317–335. https:// doi.org/ 10.1016/ j.marpetgeo. 2006.02.001.

[28] Li Changgu, et al. Evaluation on Sealing Abilities of Mudstone Caprocks in the Lower Part of Dameguaihe For-mation of Hailaer Basin.Journal of Daqing Pertroleum Insti-tute, 1999, 23(2):12–14.

[29] Li Fengjie, Liu,Qi, et al. Characteristics and Influential Fac-tors of Low-Ganchaigou Formation Reservoir in North Edge of Qaidam Basin.Natural Gas Geoscience, 2009,20(1):44–49.

[30] Lü Yanfang, Fu Guang, et al. Quantitative Study on Seal-ing Ability of Ultra—Pressure Caprock. Acta Sedimentologica Sinica, 2000, 18(3):465–468.

[31] Ma Li. Geotectonics and Petroleum Geol-ogy of Marine Sedimentary Rocks in South China. Geological Publishing House, Beijing.

[32] Sun Mingliang. Features of Cap Rocks of Gas Poolsand Criteria of Identification. Natural Gas Industry, 2008, 28(8):36–38.

[33] Xiao Anchen.et al. The Study of Late Cre-taceous Paleostructural Characteristics in Northern QaidamBasin. Earth Science Frontiers, 2005,12(4):451–457.

[34] Yu L.injie, Fan, Ming. et al.Seal Mechanism of Cap Rocks. Petroleum Geology & Experiment, 2001, 33(1):91–95.

[35] Zhang Min. Ytrategy of Hydrocarbon Explo-ration in the Petroleum System of the Northern QaidamBasin. Acta Sedimentologica Sinica 2005, 23(1):143–149.

[36] Zhou Yan, Jin, Zhijun, Zhu, Dongya, et al.Current Status and Progress inResearch of Hydrocarbon Cap Rocks. Petroleum Geology & Ex-periment, 2012,34(3):234–245,251.