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# Main Controlling Factors of Gas-Water Distribution in Tight Gas Reservoirs of Sulige Gas Field

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## ABSTRACT

[Objective]Aiming at the complex gas-water relationship faced in the development of the Sulige Gas Field, this study explores the main controlling factors of gas-water distribution in its tight gas reservoirs to provide a theoretical basis for the efficient development of the gas field[1]. [Methods]By analyzing the hydrochemical characteristics of formation water, classifying the types of produced water, and combining parameters such as the chlorosodium coefficient and metamorphism coefficient, the planar distribution characteristics of gas and water were studied. The influencing factors of gas-water distribution were analyzed from aspects including hydrocarbon generation intensity, reservoir physical properties, microstructures, and tectonic features. [Results]The formation water is dominated by $CaCl_2$type with high salinity (25–32 g/L)[2], which can be divided into three categories: formation water, condensate water, and residual flowback fluid. The gas-water distribution shows spatial heterogeneity: water layers are widely developed in the lower part of He 8 Member, while water layers in Shan 1 Member appear as isolated lens bodies. In areas where the hydrocarbon generation intensity is lower than $20\times10^8$ $m^3/km^2$, water layers account for 65%; the gas displacement efficiency of high-quality reservoirs (porosity >9.32%, permeability >0.67 mD) exceeds 75%[3]; gas enrichment occurs in the overlapping areas of the west-dipping monocline structural high and delta distributary channel sand bodies. [Conclusions]Hydrocarbon generation intensity dominates the macro-differentiation of gas and water, reservoir physical properties determine the micro-occurrence, and tectonic features regulate the gas-water distribution pattern. This study provides a geological basis for the "avoiding water and seeking gas" development strategy of the gas field.

## KEYWORDS

Ordos Basin Sulige Gas Field; gas-water distribution; distribution law; main controlling factors.

## 1. INTRODUCTION

As China's largest tight sandstone gas field, the Sulige Gas Field faces challenges of complex gas-water relationships and prominent contradictions between high production and low efficiency during development[4]. Existing studies have shown that the sealing property of formation water (such as $CaCl_2$-type water) is closely related to gas reservoir preservation. This study reveals the main controlling mechanisms of gas-water distribution through parameters such as the chlorosodium coefficient ($\gamma Na^+/\gamma Cl^-$) and metamorphism coefficient [$(\gamma Cl^- - \gamma Na^+)/\gamma Mg^{2+}$], combined with hydrocarbon generation intensity and reservoir physical properties, providing a theoretical basis for efficient development[5]. The Sulige Gas Field is located in the northern Ordos Basin and is currently the largest natural gas field discovered in China, with a natural gas geological reserve exceeding $2\times10^{12}$ $m^3$. Drilling shows that the Upper Paleozoic in this area is widely developed with oil and gas shows, and multiple gas-bearing intervals can be divided from bottom to top into the Carboniferous Benxi Formation, Permian Taiyuan Formation, Shanxi Formation, Shihezi Formation, and

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Shiqianfeng Formation[6]. Among them, the Shihezi Formation can be divided into eight gas-bearing intervals from He 1 to He 8 from top to bottom, and the Shanxi Formation can be divided into two gas-bearing intervals, Shan 1 and Shan 2. The main gas-bearing intervals in the Sulige Gas Field are the He 8 Member of the Permian Shihezi Formation and the Shan 1 Member of the Shanxi Formation.Organization of the Text

## 2. REGIONAL GEOLOGICAL BACKGROUND

The Ordos Basin covers an area of $37\times10^4$ km², spanning five provinces/regions including Shaanxi, Gansu, Ningxia, Inner Mongolia, and Shanxi. It is the second largest sedimentary basin in China. Developed on the North China Craton, this large superimposed basin is characterized by stable intra-basinal structures and active margins, with tectonic features of north-south uplift, westward thrusting, and eastward uplifting. Overall, it exhibits a resource distribution pattern of "oil in the upper part and gas in the lower part" and "gas throughout the basin, oil in half of the basin". The oil and gas reservoirs in the Ordos Basin are dominated by low-permeability tight oil/gas and shale oil/gas[7], among which lithologic reservoirs account for over 95% of the reserves. Structural reservoirs are only locally developed around the basin margin. The Sulige Gas Field is located in the northwest of the Ordos Basin (Figure 1), with an exploration area of $4\times10^4$ km². The main gas-bearing intervals are the He 8 Member of the Lower Shihezi Formation and the Shan 1 Member of the Shanxi Formation in the Permian. It is characterized by a large exploration area, multiple gas-bearing sequences, tight reservoirs, low pressure, and low abundance. The cumulative thickness of coal seams from the Benxi Formation, Taiyuan Formation to the Shanxi Formation is 6–15 m, with TOC values generally exceeding 70%. Dark mudstones are widely distributed with a thickness of 30–50 m and TOC values of 2%–3%[8]. The strata are gently distributed, trap boundaries are blurred, and gas-water relationships are complex, showing characteristics of continuous charging and dynamic reservoir formation. According to current exploration and development analysis, the Upper Paleozoic in the gas field contains gas in multiple sequences, but the abundance is mostly $(0.8–1.5)\times10^8$ m³/km², which is significantly lower than that of similar gas fields[9]. It belongs to a typical low-abundance to ultra-low-abundance gas field, posing great development challenges.

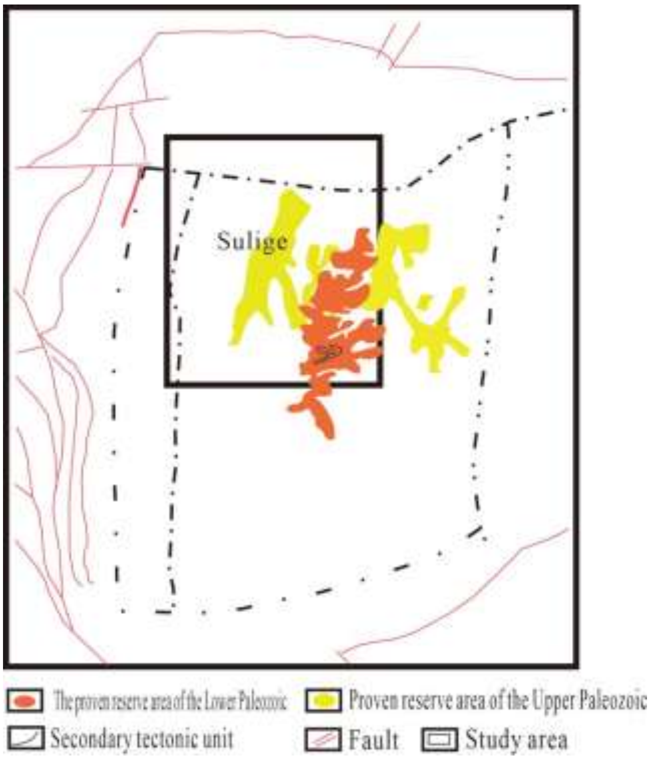



**Fig. 1** Tectonic Unit Division of Ordos Basin and Location of Sulige Gas Field

# 3. GEOCHEMICAL CHARACTERISTICS OF FORMATION WATER

## 3.1. Classification of Produced Water Types

The formation water in the study area is dominated by high salinity (25-32 g/L) $CaCl_2$ type, with $Cl^-$ accounting for more than 90% of the total anions. The chlorosodium coefficient (0.51±0.06) and metamorphism coefficient (8.08±1.24) indicate strong sealing properties[10] (Table 1). Three types of produced water are distinguished based on ion composition and salinity:

Formation water: Characterized by high $Cl^-$ (14.57-18.98 g/L), high salinity (>10 g/L), and a single water type ($CaCl_2$ type), reflecting the primary sedimentary environment.Condensate water: Features low $Cl^-$(<5 g/L) and low salinity (<10 g/L), formed concomitantly with natural gas condensation.

Residual flowback fluid: Exhibits high $Ca^{2+}$ and $Mg^{2+}$ (>4 g/L) and low pH (<6), affected by drilling fluid contamination.

**Table 1** Types and Characteristics of Produced Water in the Study Area

| Water type | Formation water | Condensate water | Residual backflow fluid |
|---|---|---|---|
| ion | Cl-、Na++K+ | lowCl-、lowNa++K+ | highCl-、highCa2+、Mg2+ |
| pH | 6—8 | 6—8 | Basically<6 |
| Mineralization degree | >10g/L | <10g/L | Basically>100g/L |
| Water type | CaCl2 | CaCl2、NaHCO3 | CaCl2 |

## 3.2. Analysis of Formation Water Chemical Characteristics

The major components in formation water, including $Cl^-$, $SO_4^{2-}$, $HCO_3^-$, $CO_3^{2-}$, $Na^+$, $Mg^{2+}$, $Ca^{2+}$, $K^+$, etc., typically show low $CO_3^{2-}$ content in deep formation water of the basin. The content of $K^+$ in formation water is often much lower than that of $Na^+$ due to adsorption and participation in mineral formation, so it is usually considered together with $Na^+$ ($Na^+$+$K^+$). Soviet scholar Sulin classified formation water based on the milliequivalent of ions. According to the equivalent ratio relationship among $Na^+$, $Mg^{2+}$, $Cl^-$, and $SO_4^{2-}$ in water, formation water is divided into $CaCl_2$ type, $MgCl_2$ type, $NaHCO_3$ type, and $Na_2SO_4$ type (Table 2).

**Table. 2** Comparison of Hydrochemical Characteristics of Formation Water in Different Blocks

| | Ca2+ (g/L) | Mg2+ (g/L) | Na++K+ (g/L) | Cl- (g/L) | SO42- (g/L) | HCO3 -(g/L) | Mineralizatio n degree(g/L) | Sodium-chloride coefficient | Deterioratio ncoefficient |
|---|---|---|---|---|---|---|---|---|---|
| SX41-33 | 4.41 | 0.62 | 6.31 | 18.59 | 1.63 | 0.39 | 31.96 | 0.51 | 8.08 |
| A6 | 3.87 | 0.43 | 6.02 | 15.99 | 1.59 | 0.39 | 28.30 | 0.57 | 7.64 |
| A36-11 | 3.90 | 0.47 | 4.95 | 14.57 | 1.69 | 0.37 | 25.95 | 0.51 | 8.09 |
| A54 | 4.82 | 0.76 | 5.73 | 18.98 | 1.79 | 0.33 | 32.38 | 0.51 | 10.88 |
| Sea | 0.42 | 1.31 | 11.04 | 19.32 | 2.69 | 0.15 | 35 | 0.85 | 0.75 |

Sulin's formation water classification has genetic and environmental significance, and it is believed that $CaCl_2$-type water with high salinity is most closely related to hydrocarbon migration and accumulation. The ionic ratio coefficients of formation water can reflect the source of formation water, formation environment, and the intensity of water-rock reactions to a certain extent. The main ionic ratio coefficients used in the study of formation water chemical characteristics include the chlorosodium coefficient ($\gamma Na^+/\gamma Cl^-$) and the metamorphism coefficient [$(\gamma Cl^- - \gamma Na^+)/\gamma Mg^{2+}$], etc. The cations in formation water of the study area are mainly $Na^+$+$K^+$,followed by $Ca^{2+}$,with the lowestcontent of $Mg^{2+}$; the anions are mainly $Cl^-$, accounting for more than 90% of the anionic content, while the contents of $SO_4^{2-}$ and $HCO_3^-$ are low. The chemical characteristics of formation water in different blocks are similar, with an average salinity ranging from 25 to 32 g/L (Figure 2), but it is significantly different from surface river water and seawater. The chemical characteristic parameters of formation water indicate that the underground sealing conditions of formation water are good, and it has experienced strong water-rock reactions.

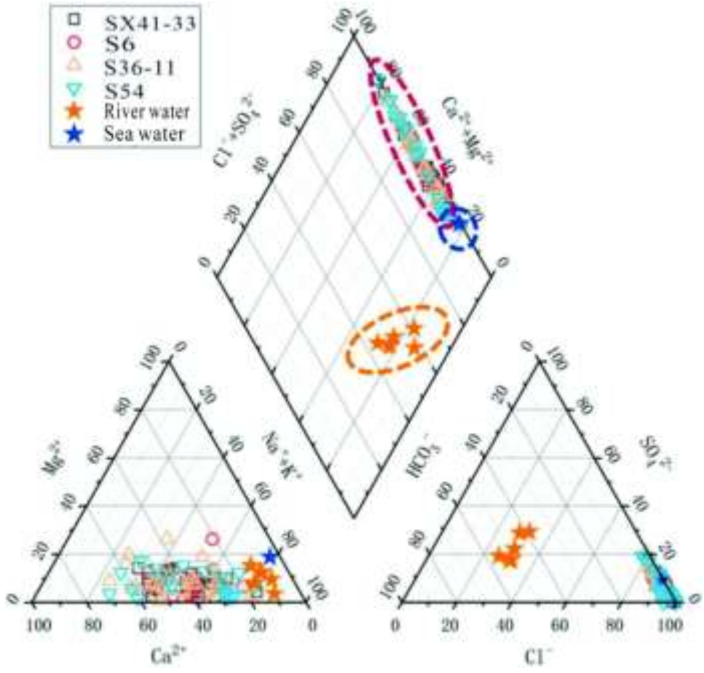



**Fig. 2** Trilinear Diagram of Hydrochemical Characteristics of Strata Water in Different Blocks

# 4. MAIN CONTROLLING FACTORS OF GAS-WATER DISTRIBUTION

## 4.1. Hydrocarbon generation intensity governs macroscopic gas-water differentiation

The negative correlation between hydrocarbon generation intensity and water layer development is remarkable in Block A54 of the Sulige Gas Field, a phenomenon constrained by multiple factors including the scale of source rocks, organic matter abundance, and source-reservoir configuration relationships. The hydrocarbon generation intensity in Block A54 is lower than $20\times10^8$ m³/km², significantly below the threshold of the study area. The total thickness of coal seams in the Benxi, Taiyuan, and Shanxi formations is only 7.95 m, and the TOC values of coal-measure mudstones range from 2% to 3%. The overall hydrocarbon supply capacity is weak, leading to insufficient natural gas charging intensity (charging coefficient <0.4), which fails to effectively displace the original water in reservoirs. As a result, water layers account for up to 65% (Figure 3). The vertical source-reservoir configuration (source-below-reservoir-above model) further aggravates the inverted gas-water pattern. The Upper Paleozoic source rocks (coal seams and mudstones in the Shanxi and Taiyuan formations) are located below the reservoirs (lower He 8 Member). When natural gas migrates vertically through capillary force and buoyancy, it preferentially charges the high-porosity and high-permeability sandbodies in the lower He 8 Member (porosity 8.5%, permeability 0.39 mD). However, the upper Shan 1 Member is farther from the source rocks and has tighter reservoirs (porosity 9.8%), reducing the natural gas charging efficiency by more than 30%. This forms a vertical differentiation feature of "water layers in the upper part and gas layers in the lower part". In contrast, in Block A6 with a hydrocarbon generation intensity $>30\times10^8$ m³/km², the water layers in the lower He 8 Member are distributed as isolated spots, and the charging coefficient >0.7, confirming the macroscopic control of hydrocarbon generation intensity on gas-water distribution. The coupling relationship between source-reservoir configuration and hydrocarbon supply capacity essentially reflects the reservoir-formation mechanism of "near-source charging and strong charging for water displacement" in tight gas reservoirs.

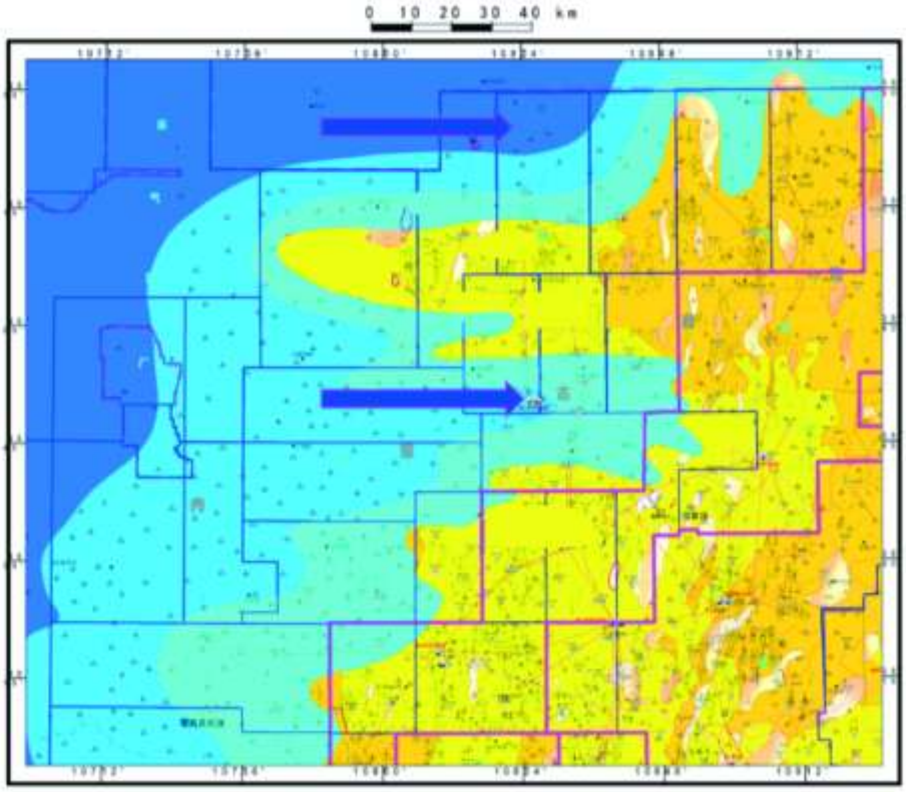



**Fig. 3** Macro-scale Water Body Distribution Map of the Central-Northern Sulige Area

### 4.2. Reservoir physical properties determine the micro-scale occurrence of gas and water

The porosity (9.32%−15.29%) and permeability (0.67±0.51 mD) of gas layers show an order-of-magnitude advantage over those of water layers (porosity <9.48%, permeability <0.27 mD), and such physical property differences directly determine the micro-scale occurrence state of gas and water. In terms of pore-throat structure[11], high-quality reservoirs (such as delta distributary channel sandbodies) are dominated by medium-high porosity and permeability fine sandstones, with an average pore-throat radius of 3.2 μm. The capillary pressure curve shows coarse skewness characteristics, and the displacement pressure is only 0.12 MPa. Natural gas can effectively displace pore water under the action of buoyancy, forming reservoirs with high gas saturation (gas saturation 59.69%±15.23%). In contrast, tight sandstones where water layers develop (such as channel flank siltstones) have pore-throat radii mostly <1.5 μm and a displacement pressure as high as 0.85 MPa. The capillary resistance significantly inhibits natural gas charging, leading to the retention of original formation water (gas saturation only 10.85%±6.32%)[12]. The thickness of source rocks in Block A54 is smaller than the average thickness of the entire Sulige Gas Field (coal seams <8 m, dark mudstone thickness <20 m), the hydrocarbon generation intensity is less than $20\times10^8$ $m^3/km^2$, the natural gas charging degree is low, and gas displacement of water is insufficient. In Blocks A6, A36-11, and SX41-33, the source rocks are thicker and have strong hydrocarbon generation intensity, with water layers mostly distributed as isolated spots (Table 3). Sedimentary facies-controlled reservoir heterogeneity further aggravates this differentiation: the main distributary channel sandbodies form a "high porosity-permeability-low irreducible water" system due to strong hydrodynamic force and good particle sorting (Figure 4), and the gas displacement efficiency can reach more than 75%. In contrast, the sedimentary microfacies of channel flanks and overbank areas form tight units of "low porosity-permeability-high irreducible water" due to high argillaceous matrix content (>15%) and close particle contact, making it difficult for water bodies to be effectively replaced, which is consistent with the correlation analysis results of physical properties[13] and gas saturation in the lower He 8 Member of Block SX41-33.

**Table. 3** Thickness Characteristics of Source Rocks in Different Horizons of Different Blocks

| Block | Benxi Formation coal seam thickness(m) Min-Max | Taiyuan Formation coal seam thickness(m)Min-Max | Shanxi Formation Coal Seam Thickness(m)Min-Max | Total thickness of coal seam(m)Min-Max | Total thickness of coal-bearing mudstone(m)Min-Max |
|---|---|---|---|---|---|
| SX41-33 | 1-12(3.18) | 1-10(1.37) | 0.5-12(1.37) | 0.5-12(9.72) | 0.11-21(9.72) |
| A6 | 1-12(2.68) | 0.9-9(2.68) | 0.8-10(4.45) | 0.8-12(8.9) | 1-19(5.23) |
| A36-11 | 1-14(3.00) | 0.15-29(2.38) | 0-11(2.89) | 0-29(8.26) | 1-21(3.34) |
| A54 | 1.37-8.46(4.72) | 0.35-9.15(2.97) | 0-4.24(1.35) | 3.3-13(7.95) | 2-35.01(19) |
| Sulige Region | 0.25-13.69(3.9) | 0-9.15(1.9) | 0-11.1(3.0) | 0.4-27(8.82) | 0.8-99.4(34.97) |

In the study area, except for a small number of faults developed in Block A54, the reservoir physical properties of other blocks are poor, making it difficult for natural gas to migrate on a large scale. It follows the reservoir-formation model of "source below and reservoir above, vertical migration, and near-distance accumulation". Water layers are mainly distributed in the upper part of He 8 Member[14], while gas layers are mainly distributed in the lower part of He 8 Member and Shan 1 Member.8.Summary.

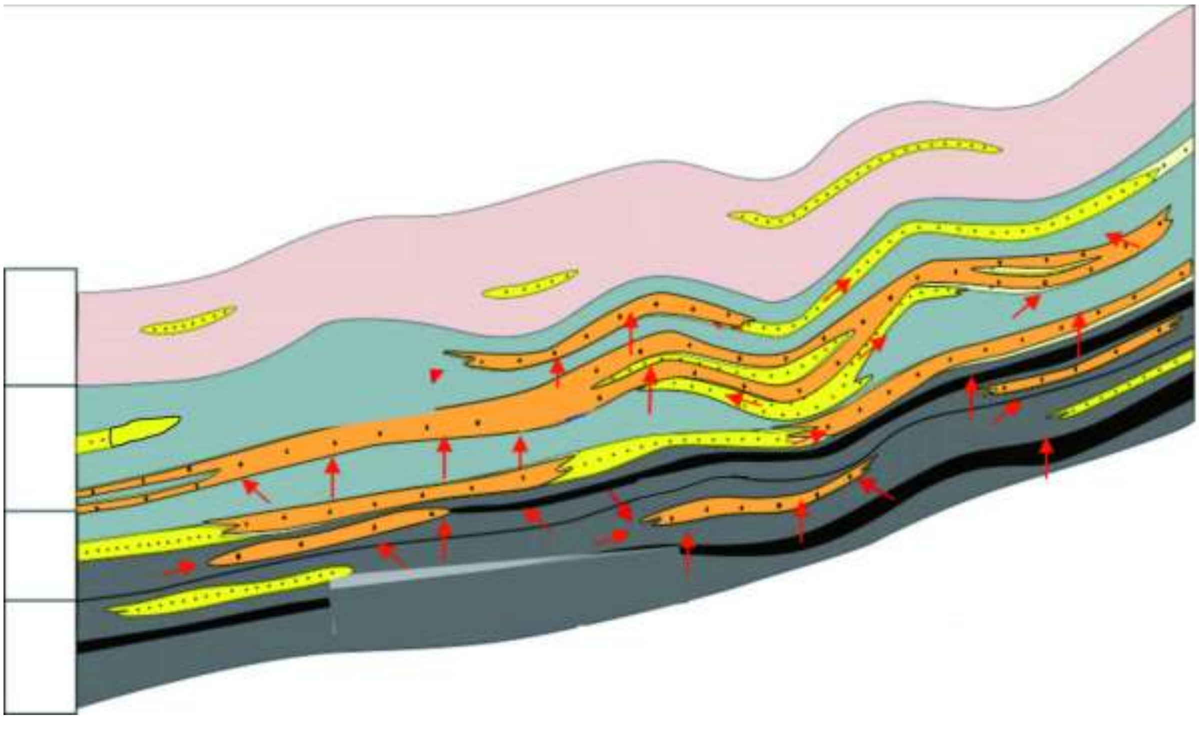


**Fig. 4** Petroleum Accumulation Model Map of the Upper Paleozoic in Ordos Basin

### 4.3. Microstructure Regulates Local Gas-Water Accumulation

Against the backdrop of a west-dipping monocline, natural gas is enriched in structural highs (such as the northern area of SX41-33), with the initial daily gas production reaching $3\times10^4$ $m^3/d$, which is 50% higher than that in lower positions (Figure 5). Due to the seepage advantage at the axis of the nose structure, a "sweet spot" area is formed (Table 4).

**Table. 4** Physical Properties of Gas and Aquifer Layers and Gas Saturation Characteristics in SX41-33 Block

| | Gas layer | Poor gas layer | Gas-water contact layer | Gas-bearing water layer | Water layer |
|---|---|---|---|---|---|
| Porosity(%) | 2.89-15.29 | 3.86-13.14 | 4.73-13.88 | 3.26-12.65 | 3.71-9.48 |
| | 9.32 | 7.74 | 9.87 | 8.05 | 6.74 |
| Permeability(mD) | 0.01-2.89 | 0.01-2.07 | 0.22-2.08 | 0.01-1.65 | 0.06-0.89 |
| | 0.67 | 0.39 | 0.82 | 0.50 | 0.27 |
| Gas saturation(%) | 23.85-88.56 | 20.56-77.57 | 34.01-56.57 | 4.94-50.66 | 0.23-24.77 |
| | 59.69 | 45.06 | 43.01 | 25.19 | 10.85 |

Minimum value-Maximum value
Average value

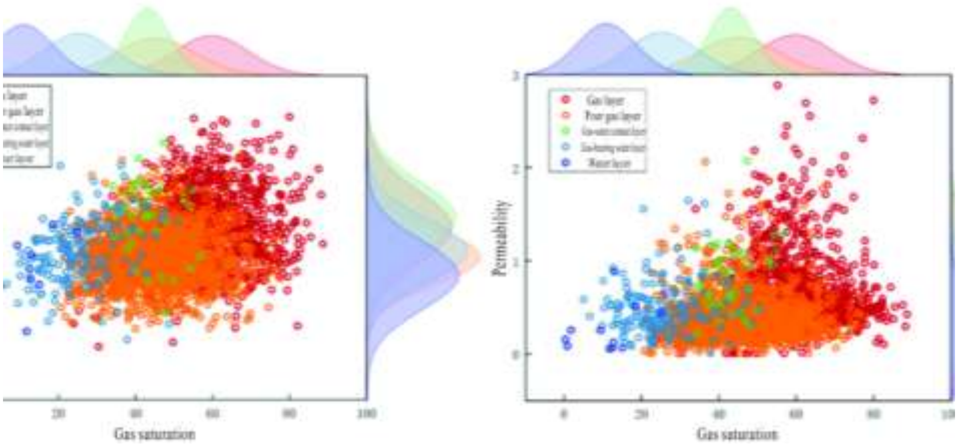
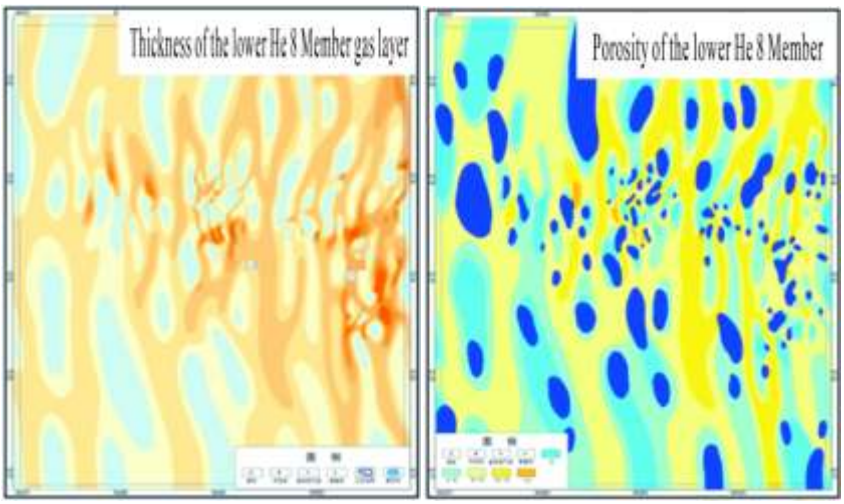



**Fig. 5** Distribution Characteristics of Porosity, Permeability and Gas Saturation in SX41-33 Block

During the migration of natural gas,it preferentially enters high-quality reservoirs with low resistance and good pore-throat permeability conditions, displacing the water in the pores to form gas layers. In contrast, water in sand layers with poor physical properties is difficult to drain, forming water layers or gas-bearing water layers. Planar distribution of gas-water layers shows a good correspondence with porosity and permeability.



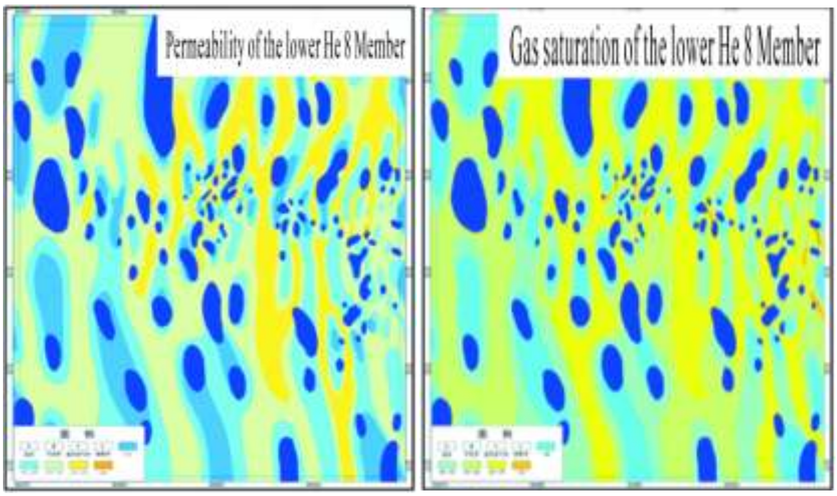



**Fig. 6** Planar Map of Thickness, Porosity, Permeability and Gas Saturation of Lower He 8 Aquifer in SX41-33 Block

### 4.4. Tectonic Features Control the Gas-Water Distribution Pattern

The planar tectonic pattern of the Sulige Gas Field is characterized by a west-dipping monocline. The coupling of the tectonic stress field and fluid potential directly controls the migration direction of natural gas. Driven by capillary force and buoyancy, natural gas preferentially migrates along permeable sandbodies to structural highs, forming a macroscopic differentiation pattern of "gas enrichment in highs and water enrichment in lows"[15-18]. Although faults serve as vertical migration channels to improve local seepage conditions, gas escape is prone to occur when faults penetrate the caprock, leading to a 20%−30% decrease in gas saturation of reservoirs on both sides of the fault and forming an abnormal distribution of "water enrichment in fault zones and gas enrichment in non-fault zones". As shown in Figure 4-6, the thickness of water layers in fault-developed areas is 3−5 m greater than that in non-fault areas.

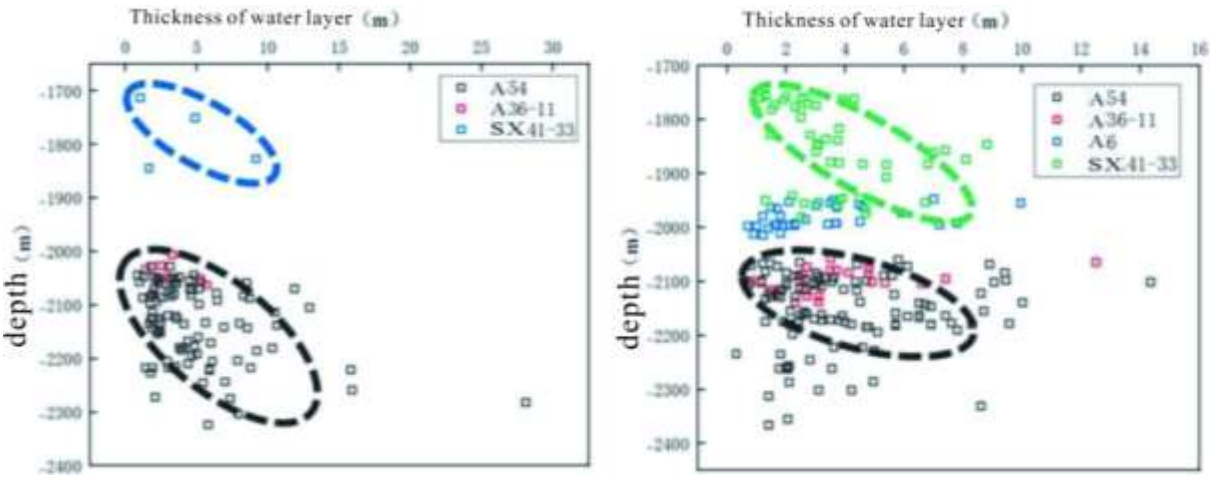



**Fig. 7** Relationship between Aquifer Thickness and Depth in the Study Area

The influence of the tectonic pattern on development dynamics is significantly reflected in the productivity difference of gas wells: the initial daily production of wells in the structural high of the northern part of Block SX41-33 reaches approximately $3.2\times10^4$ $m^3/d$, which is about 58% higher than that of wells in the southern low-lying area. This is closely related to the weak compaction degree of reservoirs in the structural high (average porosity of 9.8%) and the high natural gas charging efficiency (charging coefficient of 0.65). The tectonic-sedimentary composite reservoir control model indicates that the overlapping area of delta plain facies distributary channel sandbodies and structural highs (Figure 4-7) is a favorable zone for natural gas enrichment. In contrast, homogeneous thick sandbodies in structural lows are prone to forming large-area stagnant water bodies due to the lack of effective shielding, which provides a geological basis for the "avoiding water and seeking gas" development strategy in tight gas reservoirs.

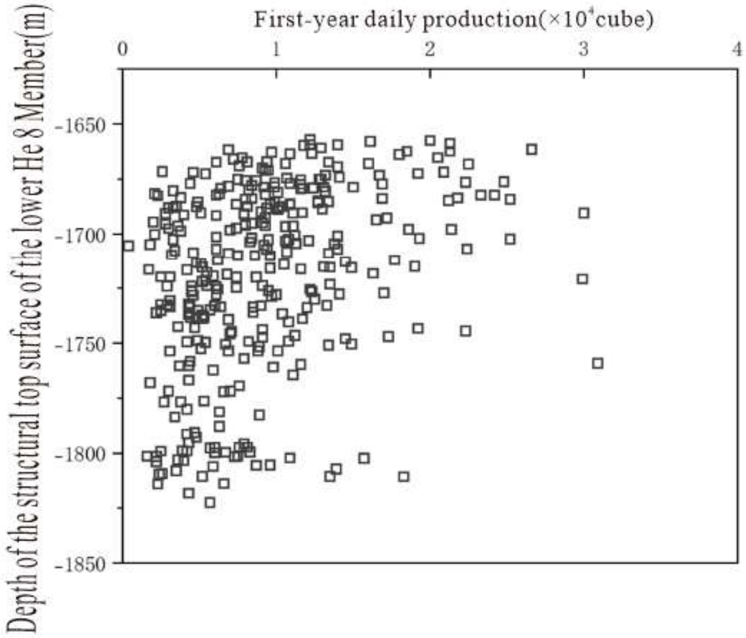



**Fig. 8** Relationship between Structural Depth of Wells in the Northern Part of Block SX41-33 and Daily Production in the First Year

## 5. CONCLUSIONS

The study on the characteristics and patterns of gas-water distribution in the Sulige Gas Field shows that:

(1) Characteristics and types of formation water: The formation water in the study area is dominated by high salinity (25−32 g/L) $CaCl_2$ type, with $Cl^-$ accounting for more than 90% of anions, indicating strong sealing properties. The produced water is divided into three types:

Formation water: Reflecting the primary environment, characterized by high $Cl^-$ (>10 g/L) and $CaCl_2$ type.

Condensate water: Formed with natural gas condensation, featuring low $Cl^-$ (<5 g/L) and low salinity (<10 g/L).

Residual flowback fluid: Affected by drilling fluid contamination, with high $Ca^{2+}/Mg^{2+}$ and low pH (<6).

(2)Spatial heterogeneity of gas-water distribution: - In the upper He 8 Member, water layers are distributed pointwise, with continuous water bodies in the northwest of some blocks. - In the lower He 8 Member, the range of water layers narrows with local enrichment. - In the Shan 1 Member, water layers are sporadically distributed. - In the Shan 2 Member, water layers are more developed than those in the Shan 1 Member with local concentration. - Water types include edge-bottom water, stagnant water, and isolated lenticular water.

(3)Main controlling factors of gas-water distribution: - There is a negative correlation between hydrocarbon generation intensity and water layer development. Water layers are widely developed in areas with low hydrocarbon generation intensity, while they are isolated in areas with high intensity. - The porosity and permeability of gas layers are significantly better than those of water layers, and high-quality reservoirs have high gas displacement efficiency. - In the west-dipping monocline, structural highs are gas-enriched, and lows are water-enriched. Delta plain facies sandbodies are conducive to gas reservoir formation, while homogeneous thick sandbodies easily retain water bodies.

## REFERENCES


[1] Cao Tongsheng, Zhang Tinghan, Zhang Yue, et al. Study on Gas-Water Distribution in Tight Sandstone Reservoirs under Different Hydrocarbon Accumulation Environments: A Case Study of the Xiashihezi Formation in the Shilijiahan Gas Area of the Dongsheng Gas Field [J]. Journal of Chengdu University of Technology (Science & Technology Edition), 2024, 51(01): 60-75.

[2] Chen Dongxia, Wang Qiaochu, Zhu Weiping, et al. Gas-water distribution characteristics and genetic mechanisms of deep superimposed continuous tight sandstone gas reservoirs in the Western Sichuan Depression [J]. Earth Science, 2025, 50(01): 110-26.

[3] Dai Jinyou, Li Jianting, Wang Baogang, et al. Gas - water distribution and its formation mechanism in the western Sulige Gasfield [J]. Petroleum Exploration and Development, 2012, 39(05): 524 - 529.

[4] Dong Jin. Control mechanism and evaluation of gas-water distribution by pore structure of low permeability reservoirs [D], 2020.

[5] Dou Weitan, Liu Xinshe, Wang Tao. Genesis of formation water and distribution law of gas and water in Sulige Gas Field, Ordos Basin [J]. Acta Petrolei Sinica, 2010, 31(05): 767 - 773.

[6] Gao Shumin, Fan Yunjie, Zhu Junyang, et al. Logging response characteristics and main controlling factors of gas-water layer distribution in Ma 56 - 57 sub - members of Majiagou Formation in Daniudi Gas Field [J]. Sino - Global Energy, 2025, 30(02): 50 - 56.

[7] BAI J, LI Z, ZHANG J, et al. Proton exchange membrane water electrolysis at high current densities: Response time and gas-water distribution [J]. AIChE Journal, 2023, 69(12).

[8] CHEN D, WANG Q, ZHU W, et al. Characteristics and genetic mechanisms of gas-water distribution in deep superposed continuous tight sandstone gas reservoirs in the Western Sichuan Depression [J]. Earth Science-Journal of China University of Geosciences, 2025, 50(1).

[9] HE X, LI J, DUAN D, et al. Driving Forces of Natural Gas Flow and Gas–Water Distribution Patterns in Tight Gas Reservoirs: A Case Study of NX Gas Field in the Offshore Xihu Depression, East China [J]. Energies, 2023, 16(16).

[10] MATTHEWS M J, SU R, YONISH L, et al. A Review of Artificial Intelligence, Algorithms, and Robots Through the Lens of Stakeholder Theory [J]. Journal of Management, 2025, 51(6): 2627-76.

[11] MOSHTAGHI P, HAJIALIGOL N, RAFIEI B. A comprehensive review of artificial intelligence applications in wind energy power generation [J]. Sustainable Futures, 2025, 9: 100638-.

[12] PING G, RU Z, ZHENGKUN T, et al. Gas and water distribution characteristics of water-driven gas process in tight sandstone gas reservoirs: A microscale study by molecular simulation and experiment [J]. Energy Reports, 2022, 8: 7025-36.

[13] TANG T, LI H, FU L, et al. Gas–Water Distribution and Controlling Factors in a Tight Sandstone Gas Reservoir: A Case Study of Southern Yulin, Ordos Basin, China [J]. Processes, 2025, 13(3): 812-.

[14] WEITAO W, JINGZHOU Z, XINSHAN W, et al. Evaluation of gas-rich “sweet-spot” and controlling factors of gas–water distribution in tight sandstone gas provinces: An example from the Permian He8 Member in Sulige Gas Province, central Ordos Basin, Northern China [J]. Journal of Asian Earth Sciences, 2022, 227.

[15] XINSHE L, XING P, HUITAO Z, et al. Control of differential diagenesis of tight sandstone reservoirs on the gas–water distribution: A case study on the Upper Paleozoic He 8 Member in the northern Tianhuan depression of the Ordos Basin [J]. Energy Exploration & Exploitation, 2022, 40(1): 302-27.

[16] XU T, JIA A, HUANG Y, et al. Distribution and Main Controlling Factors of Gas and Water in Tight Sandstone Gas Fields: A Case Study of Sudong 41-33 Block in Sulige Gas Field, Ordos Basin, China [J]. ACS omega, 2024, 9(19): 20807-18.

[17] XUEQUN T, CHAO J, JIANDANG L, et al. Gas and water distribution in the tight gas sands of the northwestern daniudi gas field, ordos basin, China: Impact of the shale barrier [J]. Fuel, 2022, 317.

[18] YANG Z, ZHOU J, CHEN J, et al. Gas-Water Distribution and Gas Reservoirs Accumulation Properties of Upper Paleozoic Sequence in the Western Yishan Slope, Ordos Basin, NW China [J]. ACS omega, 2024, 9(52): 51463-73.