Open Access Library Journal
2023, Volume 10, e10149
ISSN Online: 2333-9721
ISSN Print: 2333-9705

An Analysis of Hydrogeological Conditions of Deep Coalbed Methane

Xiaojiao Guo[1,2]

[1]School of Earth Sciences and Engineering, Xi'an Shiyou University, Xi'an, China
[2]Shaanxi Key Laboratory of Hydrocarbon Accumulation Geology, Xi'an Shiyou University, Xi'an, China
Email: 1185307231@qq.com

How to cite this paper: Guo, X.J. (2023) An Analysis of Hydrogeological Conditions of Deep Coalbed Methane. *Open Access Library Journal*, **10**: e10149.
https://doi.org/10.4236/oalib.1110149

Received: April 13, 2023
Accepted: May 15, 2023
Published: May 18, 2023

Abstract

Hydrological conditions play a key role in the occurrence and accumulation of coalbed methane. In order to further study the hydrogeology and deep coalbed methane enrichment law, the analysis of hydrogeological conditions, formation water type, mineralization degree and groundwater parameters shows that: 1) High formation water metamorphic coefficient, low sodium chloride coefficient, low desulfurization coefficient and low magnesium calcium coefficient of common formation water in coalbed methane high gas content area; 2) The influence of groundwater dynamic conditions on coalbed methane enrichment is reflected in two aspects: first, it can dissolve coalbed methane in coal reservoirs, resulting in coalbed methane escape; second, it can block the gas and play a role in preservation; 3) The gas content increases with the increase of mineralization as a whole, and decreases with the increase of water head. This achievement provides certain theoretical support for the later development of coalbed methane.

Subject Areas

Petroleum Geology

Keywords

Deep Coalbed Methane, Hydrogeology, Salinity, Hydrodynamics

1. Introduction

Area X of Ordos Basin is rich in coalbed methane resources and has great gas production potential, but the gas production effect on the well is not ideal, and the overall performance is high water production and low gas production. Ground coalbed methane wells mainly achieve gas production through drainage

and pressure reduction, and hydrogeological conditions have an important impact on the enrichment and output of coal seam gas content [1] [2] [3] [4]. The hydrogeological conditions of Area X are complex, the research on the effect of hydrogeological conditions on the reservoir control of coalbed methane is relatively weak, and the production control characteristics of coalbed methane wells are not clear, resulting in many problems in the current layout of coalbed methane wells and relatively few production wells.

In recent years, researchers at home and abroad have successively used physical simulation and data statistics to analyze the gas control effect of hydrodynamics and water chemistry, and found that the closed and slow hydrodynamic conditions are conducive to coalbed methane enrichment, that is, rich gas in the detention area, weak runoff area, poor gas in recharge area and strong runoff area, and water chemical characteristic parameters such as mineralization, sodium chloride coefficient and desulfurization coefficient are important indicators reflecting the enrichment degree of coalbed methane. Hydraulic plugging and hydraulic sealing are conducive to coalbed methane enrichment, and hydraulic fugitive effects often lead to low coalbed content. In view of this, the author qualitatively analyzes the containment of deep coalbed methane by analyzing the characteristics of the concentration of water ions produced in the formation, in order to play a certain reference role in the enrichment and high-yield mechanism of deep coalbed methane, exploration and development.

2. Overview of the Study Area

The Ordos Basin is a large craton basin formed by the extrusion of the Yangtze plate and the North China plate, with a total area of 25×10^4 km^2, and the basin is extremely rich in coal, oil and gas resources [5]. The basin is composed of six first-class tectonic units: the Jinxi flexural belt in the east, the Weibei uplift belt in the south, the Yimeng uplift belt in the north, the Tianhuan depression in the west, the slope zone in northern Shaanxi in central China and the thrust fault zone in the west margin [6] [7]. The block belongs to the loess plateau landform, with ravines and ridges, the ground altitude is 500 - 1500 m, and the surface loess layer is 20 - 100 m thick, located in the Benxi Formation in the X area in the southern Jinxi flexural belt (**Figure 1**).

The whole block is a large wide and gentle long slope, of which the western strata are slow, the strata inclination is 0.3˚ - 2.5˚, the eastern stratum is steeper, and the fault is not developed. The tectonic trend of 8# Coal top boundary is monoclinic with high southeast and low north and west, with an inclination angle of 0.34˚ - 0.46˚, an altitude of −1000 m - −1260 m, and no obvious fault development. 8# Coal is buried between 1865 m - 2520 m, main buried depth of 2000 - 2400 m [8]. The burial depth of the coal seam is mainly affected by the geomorphology, and the stratum gradually deepens to the west, and then gradually becomes shallow. The coal structure is relatively good, with horizontal layering, mainly primary structure coal, and the fractures are relatively developed, which can be fracked.

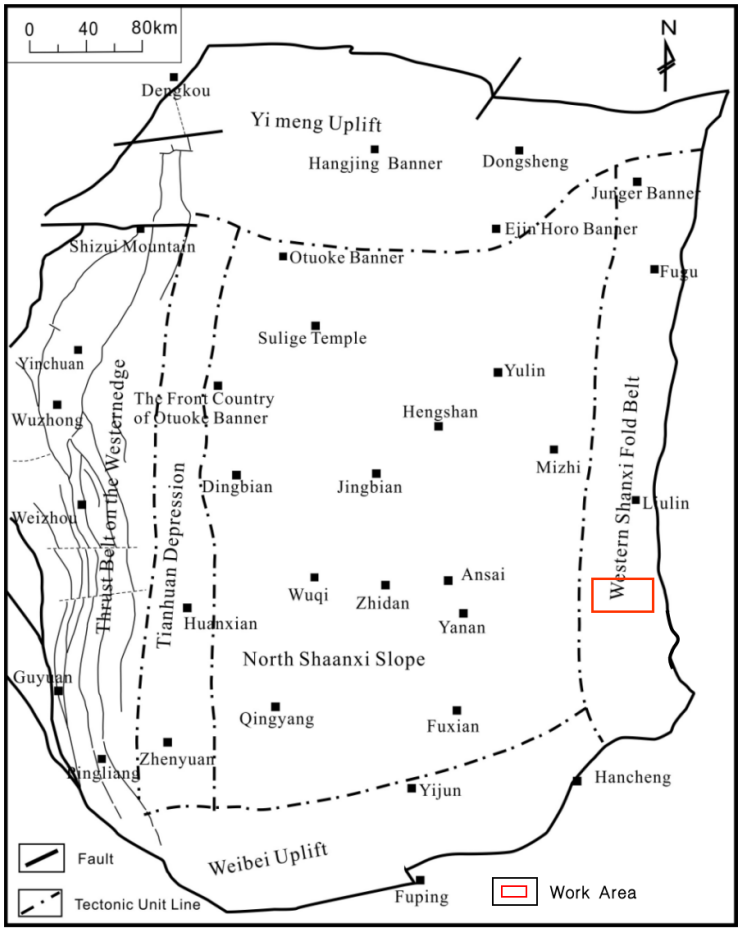

Figure 1. Overview map of the study area.

3. Hydrogeological Analysis

As a continuous unconventional gas reservoir containing groundwater, the development process of coalbed methane reservoir is greatly affected by hydrodynamics. The evolution of coal reservoir water has an important impact on the enrichment of coalbed methane [4]. In view of this, the author analyzes the hydrological characteristics of deep coalbed methane in Area X from three directions: analysis of formation water type and salinity, groundwater chemical parameters and groundwater dynamic research.

3.1. Analysis of Formation Water Type and Mineralization

The chemical composition of formation water reflects the characteristics of groundwater alternation and runoff, which has a certain indicative effect on the enrichment conditions of coalbed methane. The ion characteristics of the water produced by coalbed methane wells in the study area showed that the formation water was mainly composed of K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} and HCO_3^- ions, and contained a very small part of CO_3^{2-} ions. Deep 8# coal seam water salinity degree 35606 mg/L - 373981 mg/L, the average is 123647.842 mg/L, the water type is $CaCl_2$ type, belongs to the pressurized water area, the hydrogeolog-

ical conditions are simple, the hydrodynamic conditions are weak, the average PH value is 5.6, and the acidity is weak.

The solubility of Na^+ and K^+ ions is better than that of Ca^{2+} and Mg^{2+} ions, and they are easy to enter the dissolved state, so their migration capacity is stronger than that of Ca^{2+} and Mg^{2+}, and Mg^{2+} enrichment means that it is close to the water source recharge area. The enrichment of Na^+ and Cl^-, Ca^{2+} and Mg^{2+} are reduced as signs of good gas reservoir closure conditions. SO_4^{2-} is a sign of an oxidizing environment, and if it is present in large quantities in the original coal seam water, it indicates that the sealing conditions are not good. HCO_3^- in coal seam water is buried, when organic matter exists, Na_2SO_4 is reduced in the reduction environment, and the presence of H_2S means that the storage conditions of gas reservoirs are better [9] [10] [11]. It can be seen from the relationship between total mineralization and each ion in the study area (**Figure 2**) that the relationship between salinity and Cl^- and SO_4^{2-} is good, while the correlation of HCO_3^- is general, and it is speculated that there are areas with poor sealing conditions in the study area.

The distribution of minerality on the plane of the study area (**Figure 3**) shows high salinity in the west and north, and low mineralization in the south and east. The low salinity in the east may be related to the weak runoff zone in the east. The runoff conditions in the weak runoff area are weak, the salinity is relatively high, and the gas content is medium. The stagnation zone has the weakest runoff conditions, the highest degree of mineralization and the best gas content [12]. The results show that the salinity distribution is basically consistent with the distribution of coalbed methane enrichment, the higher the salinity, the higher the gas content, the high salinity in the western part of the work area, the relatively high gas content, the low salinity in the east, the lower the gas content, the

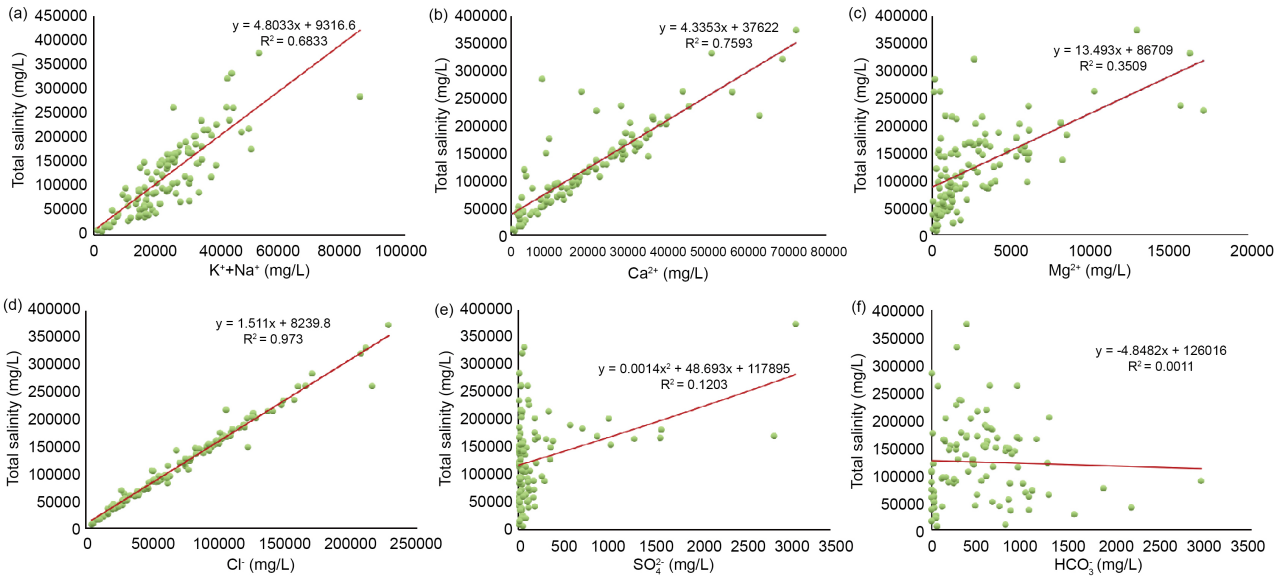

Figure 2. Relationship between anions and cations and total salinity.

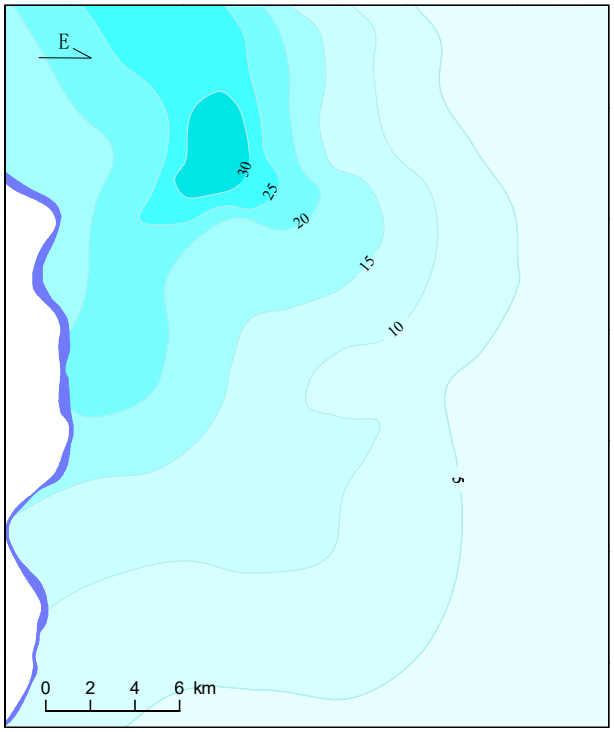

Figure 3. Planar distribution of salinity in Benxi Formation.

higher the salinity reflects the better the preservation conditions of coalbed methane and the relatively high gas content.

3.2. Analysis of Groundwater Chemical Parameters

The hydrogeochemical characteristics of coal reservoir have important indicative significance for the enrichment and development of coalbed methane, and the high formation water metamorphic coefficient, low sodium chloride coefficient, low desulfurization coefficient, low magnesium calcium coefficient and high magnesium chloride coefficient are usually found in coalbed methane high gas content areas.

The metamorphism coefficient can reflect the degree of metamorphism of the produced water of the coal seam and indicate the enrichment characteristics of coalbed methane. The metamorphic coefficient in the study area was between 9.8 - 93.1, and the average was 27.4 (**Figure 4**). The larger the metamorphic coefficient, the greater the degree of water-rock action and ion exchange, the better the closure of the CBM reservoir, and the more conducive to the preservation of the CBM reservoir [9]. The coalbed methane capping conditions in the high-value area with a water metamorphism coefficient greater than 40 are good, which is conducive to the formation of coalbed methane enrichment area.

The rNa^+/rCl^- value is the sodium and chlorine coefficient, which is not directly related to the coalbed methane enrichment reservoir, but can reflect the metamorphism degree of formation water and the hydrogeochemical environment of the reservoir [13]. According to the sodium and chlorine coefficient

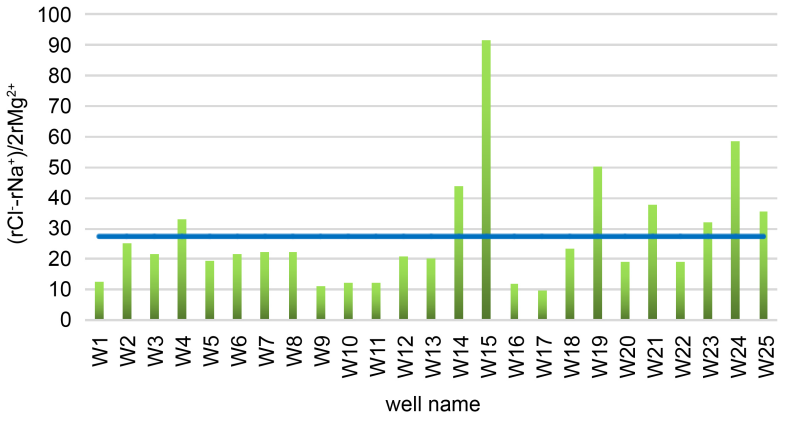

Figure 4. Histogram of metamorphic coefficient distribution.

value, the degree of metamorphism of formation water can be divided, and the smaller the value, the lower the degree of metamorphism, which is conducive to the preservation of coalbed methane reservoirs. The overall sodium chloride coefficient in the study area was less than 0.7 (**Figure 5**), and the data showed that the water metamorphism degree in the deep strata in this area was low, the water type was generally $CaCl_2$ type with low degree of metamorphism, and there were a small number of $NaHCO_3$ type with medium degree of metamorphism.

The $(rSO_4^{2-} \times 10^2)/rCl^-$ value is the desulfurization coefficient, which can characterize one of the main parameters of groundwater desulfuric acidification, and is also an important index to reflect the openness of coal seam water [13]. The desulfurization of coalbed water generally occurs in a reducing environment. The more thorough the desulfurization effect, the smaller the desulfurization coefficient and the stronger the reduction effect, indicating that the better the closure of the formation, the more conducive to the preservation of coalbed methane (**Figure 6**). The area with low desulfurization coefficient in the study area has high groundwater salinity. It reflects that the formation is well closed and the water alternating effect is slow, which is conducive to the accumulation and preservation of coalbed methane. The total salinity of stratigraphic water in W4, W5, W15, W24 and W25 wells was generally greater than 11000 mg/L, and the desulfurization effect reached 100%, indicating that the preservation conditions in this area were excellent. The magnesium-calcium coefficient (rMg^{2+}/rCa^{2+}) reflects the degree of metamorphism of the produced water in the coal seam, and the magnesium-calcium coefficient of the coal seam water in the study area $8^{\#}$ is between 0.08 - 0.79, and the average is 0.3 (**Figure 7**). According to research reports, when the magnesium-calcium coefficient is less than 0.30, the formation closure is good, which is conducive to the preservation of coalbed methane and the gas content increases. The low-value areas with magnesium-calcium coefficient less than 0.3 were mainly distributed in the W4 and W24 well areas, and the total salinity of formation water was generally greater than 11000 mg/L, which had good storage conditions and easy enrichment of

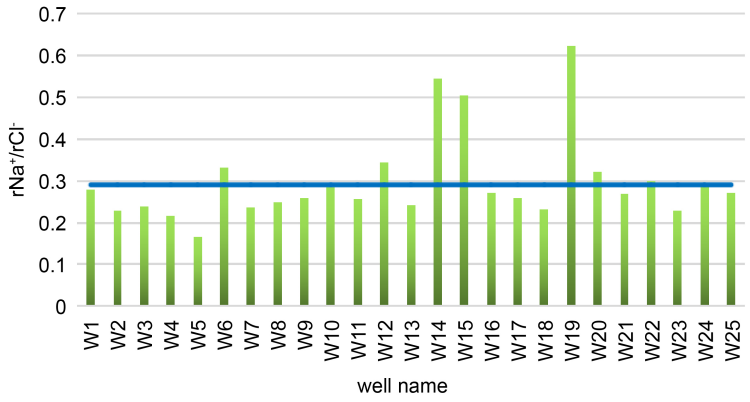

Figure 5. Histogram of sodium chloride coefficient distribution.

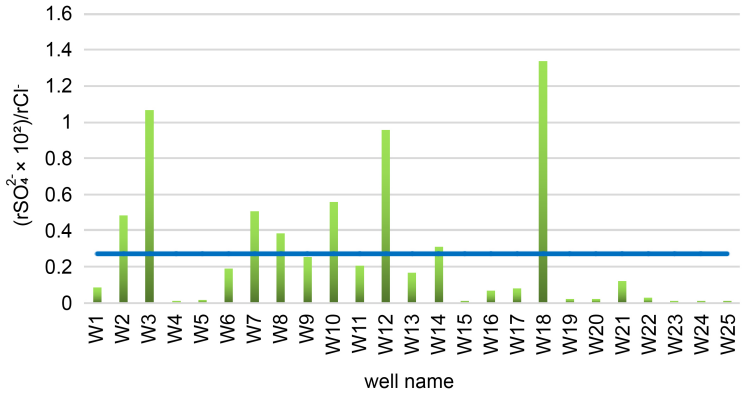

Figure 6. Histogram of desulfurization coefficient distribution.

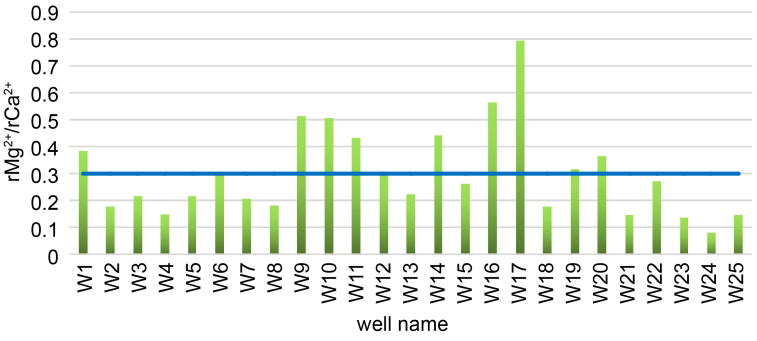

Figure 7. Histogram of magnesium-calcium coefficient distribution.

coalbed methane. The rCl^-/rMg^{2+} value in the formation water is the magnesium chloride coefficient. A higher value indicates better formation water containment conditions and a stronger degree of concentration and metamorphism (**Figure 8**).

3.3. Groundwater Dynamic Research

The direction of groundwater flow can be determined by the head, and groundwater runoff from areas with high heads to areas with low heads. In general, the calculation of the head can be obtained directly by the injection-pressure drop

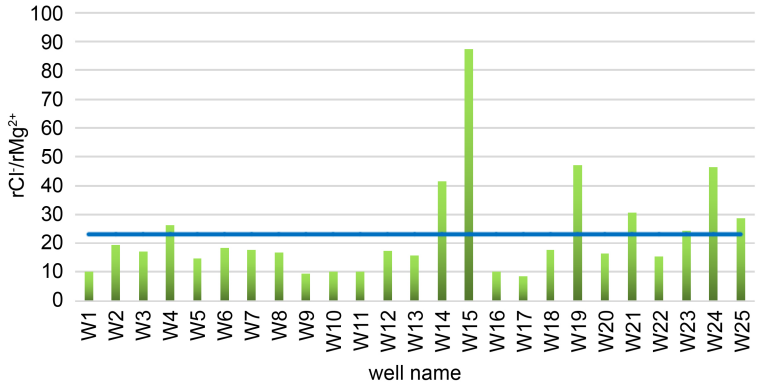

Figure 8. Histogram of magnesium chloride coefficient distribution.

experiment, but in the actual production process, the coalbed methane well should be continuously drained without pressure recovery test, this study uses the Bernoulli equation to estimate the head, using the sea level as the reference plane, the formula for finding the head height is as follows:

$$H = Z + \frac{P}{\rho g} + \frac{\alpha v^2}{\rho g} \tag{1}$$

where: H is the total head, m;

Z is the position head, m;

$\frac{P}{\rho g}$ represents the pressure head, m;

$\frac{\alpha v^2}{\rho g}$ represents the average flow rate head, m.

In general, the average flow rate head is negligible, and the total head is equal to the sum of the position head and the pressure head. The pressure head can be estimated from the static night face height of the production well, and the position head is replaced by the coal seam elevation. According to the calculation results of the head, the groundwater flow equipotential map of the study area was drawn [14]. The groundwater head is between −600 m - −1300 m, the eastern head of the study area is high, the groundwater is more active, the flow direction of groundwater flows from the east to the west, and the western groundwater momentum is low, basically in the residual environment. (**Figure 9**)

The effect of hydrogeological conditions on coalbed methane in area X can be summarized into two aspects: hydraulic damage and hydraulic protection of coalbed methane reservoirs (**Figure 10**). Hydraulic protection is reflected in hydraulic sealing and hydraulic plugging to form pressurized water areas and stagnant water areas, which are conducive to coalbed methane enrichment. Hydraulic damage mainly occurs in the process of hydraulic transport and dispersion, which leads to the dispersion of coalbed methane [4]. The hydrodynamic force in area X generally showed the characteristics of strong east and weak west, and the two slope zones in the east and west were in the pressure zone and weak runoff area, which was conducive to the preservation of coalbed methane. The

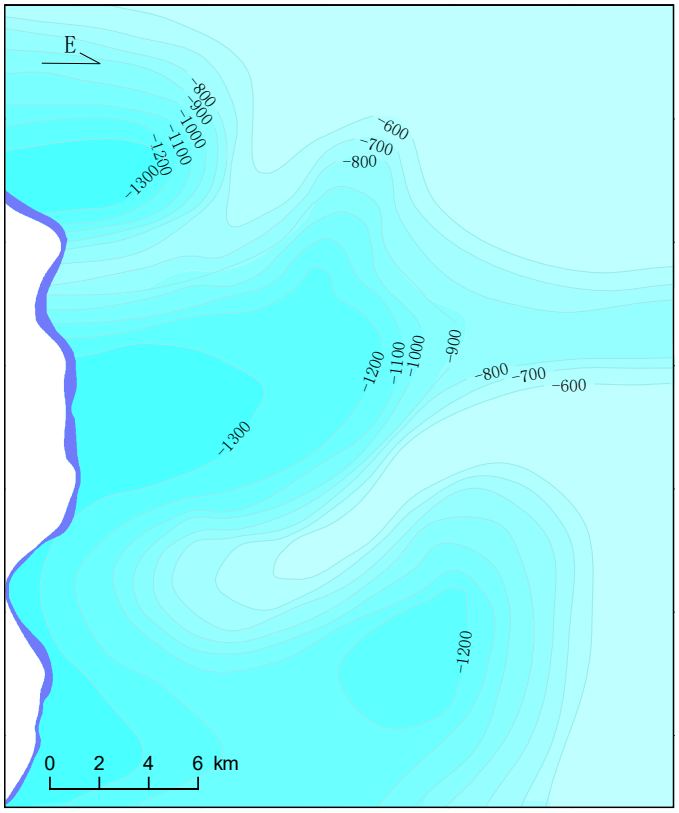

Figure 9. 8# Coal seam water momentum map.

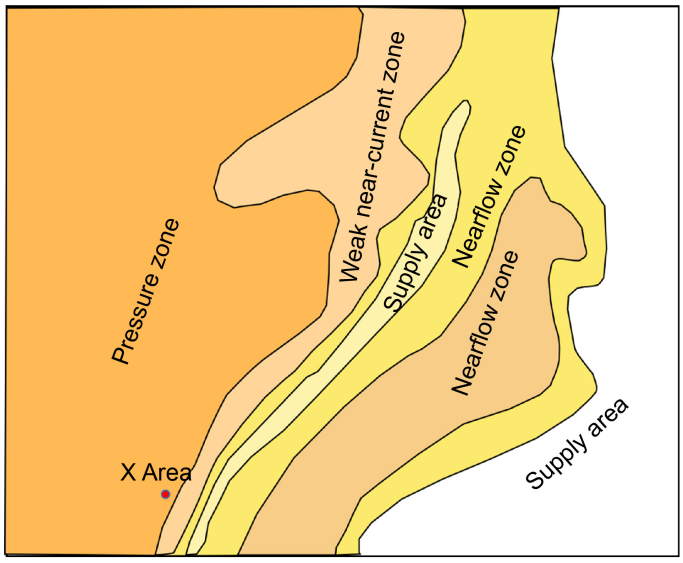

Figure 10. 8# Coal seam hydrogeological map.

whole study area slopes from east to west, and the groundwater flow direction in the area is basically consistent with the slope direction of the terrain in the area. The recharge of groundwater mainly comes from atmospheric precipitation and lateral recharge of eastern Ordovician limestone, with weak hydrodynamic force and high total mineralization, and the whole is located in the pressure-bearing

zone, which is conducive to the development of coalbed methane. The distribution of hydrodynamic field is consistent with the distribution of mineralization degree and coalbed methane enrichment, and the higher the salinity, the better the preservation conditions of coalbed methane and the relatively high gas content.

4. Conclusions

1) The ionic characteristics and mineralization degree of the produced water of coalbed methane wells can characterize the activity degree of groundwater, and the water-rock interaction of surface water infiltration into the ground will lead to a decrease in the content of Mg^{2+}, Ca^{2+} and SO_4^{2-} ions in groundwater, and a corresponding increase in the content of K^+, Na^+ and HCO_3^- ions. Low salinity represents active groundwater conditions, while high mineralization indicates that groundwater is well-closed. In environments where groundwater is retained, it is generally believed that relatively active groundwater dynamics are not conducive to the preservation of coalbed methane. In contrast, retained groundwater conditions have a good sealing effect on coalbed methane.

2) Hydrogeological conditions have two effects: hydraulic sealing and hydraulic displacement for the enrichment of coalbed methane. In general, areas with active hydrodynamic conditions are not conducive to the preservation of coalbed methane. The $8^{\#}$ coal seam in the study area is mainly located in weak runoff and pressure-bearing areas. The direction of surface runoff is consistent with the stratigraphic trend, and groundwater flows in the direction of the formation. As the buried depth of the coal seam increases, the speed of runoff slows down, which leads to the upward diffusion gas in the coal seam becoming trapped, and the groundwater runoff being in a stagnant state. These conditions are conducive to the accumulation of coalbed methane in reservoirs.

3) The groundwater type in area X is mainly $CaCl_2$, exhibiting characteristics of medium to high salinity which suggest that this area is characterized by a semi-closed to closed groundwater environment, which is favorable for hydrological gas control. The distribution characteristics of the $8^{\#}$ coal gas content in area X indicate that higher salinity corresponds to higher gas content. Consequently, the western part of the work area, where salinity levels are high, typically features higher gas content, while the eastern areas where the salinity is low, have lower gas content. As mineralization increases, gas content increases while water head corresponds to a decrease in gas content.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] Du, F.F., Ni, X.M., Zhang, Y.F., Wang, W.S. and Wang, K. (2023) Hydrological Reservoir Control Mode and Production Control Characteristics of Coalbed Methane Field in Shouyang Block. *Coal Science and Technology*, **51**, 1-9.

[2] Xu, F.Y., Wang, C.W., Xiong, X.Y., Li, S.G., Wang, Y.B., Guo, G.S., Yan, X., Chen, G.J., Yang, Z., Wang, H.Y., Feng, K., Wu, P. and Liu, Y.H. (2022) Accumulation Mode and Key Technical Countermeasures of Deep (Layered) Coalbed Methane: A Case Study of the Eastern Margin of Ordos Basin. *China Offshore Oil and Gas*, No. 4, 30-42.

[3] Yang, X.C., Xu, F.Y., Wang, H.Y., Li, S.G.., Lin, W.J., Wang, W. and Hao, S. (2022) Exploration and Development History and Enlightenment of Coalbed Methane in the Eastern Margin of Ordos Basin. *Coal Geology and Exploration*, No. 3, 30-41.

[4] Zhao, X.Y., Wei, B., Yuan, L., Ge, Y.Y., Hu, Y., Li, X., Wang, M.M., Jia, C., Mayila, A.S. and Tian, J.J. (2023) A Review of the Hydrogeological Characteristics of Coal Reservoirs and Their Significance in Coalbed Methane Development. *Coal Science and Technology*, **50**, 1-18.

[5] Dou, W.C. (2018) Study on the Tightness and Heterogeneity of Sandstones in Chang 6-Chang 7 Members in the Southwest of Ordos Basin. China University of Petroleum, Beijing, 1-106.

[6] Zhao, J.F., Mountney, N.P., Liu, C.Y., Qu, H.J. and Lin, J.Y. (2015) Outcrop Architecture of a Fluvio-Lacustrine Succession: Upper Triassic Yanchang Formation, Ordos Basin, China. *Marine and Petroleum Geology*, **68**, 394-413. https://doi.org/10.1016/j.marpetgeo.2015.09.001

[7] Liu, C.Y., Zhao, H.G., Zhao, J.F., Wang, J.Q., Zhang, D.D. and Yang, M.H. (2010) Temporo-Spatial Coordinates of Evolution of the Ordos Basin and Its Mineralization Responses. *Acta Geologica Sinica*, **82**, 1229-1243. https://doi.org/10.1111/j.1755-6724.2008.tb00725.x

[8] Li, S.G., Wang, H.N., Xu, B.RR., Zhen, H.B., Wang, C.W. and Yuan, P. (2022) Analysis of Influencing Factors of Gas Production Effect of Acidification Fracturing of Deep Coalbed Methane Wells in Daning-Ji County. *Coal Geology & Exploration*, **50**, 165-172.

[9] Hang, K.J., Zhang, Q., Wei, Y.C., Li, C.F. and Wang, A.M. (2018) Hydrogeological Characteristics of Sulfur Gully Area of Southern Margin of Junggar Basin and Its Influence on Coalbed Methane Enrichment. *Coal Geology & Exploration*, **46**, 61-65.

[10] Tian, W.G., Shao, L.Y., Sun, B., Zhao, S.P. and Huo, W.G. (2014) Chemical Characteristics of Produced Water from Coalbed Methane Wells in Baode Area and Its Effect on Gas Control. *Natural Gas Industry*, **34**, 15-19.

[11] Yang, Z.B., Tang, J., Li, G.F., Liu, S.S. and Peng, H. (2018) Comparison of Physical Properties of Coalbed Methane Reservoirs in the National Planning Mining Area of Typical Coal in Shanxi Province. *Coal Science and Technology*, **46**, 34-39.

[12] Liang, X., Shan, C., Li, Z.F. and Luo, Y.F. (2022) Innovative Practice and Key Technology of Effective Exploitation of Mountain Coalbed Methane: A Case Study of Yunlian Coalbed Methane Field in Southern Sichuan Basin. *Natural Gas Industry*, **42**, 107-129.

[13] Gao, Y.Q., Li, X., He, X.P., Chen, Z.L. and Chen, G. (2021) Study on the Main Geological Factors of High Yield of Coalbed Methane in the South of Yanchuan. *Coal Geology & Exploration*, **49**, 21-27.

[14] Zheng, S. (2020) Study on Accumulation and Enrichment of Coalbed Methane No. 8 in Daji Area. Taiyuan University of Technology, Taiyuan.