International Journal of Advanced Engineering and Technology Research
ISSN: 3106-8677 (Print), ISSN: 3106-8685 (Online) | Vol. 2, No. 1, 2026

Evaluation of Coal Reservoir Fracturability Based on Mechanical Stratigraphy

Chi Cheng *

School of Resources and Environment, Henan Polytechnic University, Jiaozuo 454003, China

Abstract: The difficulty of coal reservoir stimulation is a key bottleneck restricting coalbed methane (CBM) development. Scientific and accurate evaluation of coal reservoir fracturability is essential for achieving commercial CBM production. Given the complexity and uncertainty of coal reservoir geological conditions, the concept of mechanical stratigraphy was introduced in this study. Seven quantitative indicators were selected to establish a fracturability evaluation system, including the geological strength index (GSI), in-situ stress difference coefficient, critical strain energy release rate, brittleness index, fracture pressure, mosaic index, and water inrush coefficient. The analytic hierarchy process (AHP) was adopted to determine the weight of each indicator. Membership functions and membership degrees were defined according to relevant industry standards, and an evaluation model together with a grading set was constructed. Reservoir fracturability was divided into three grades: Class I reservoirs with strong fracturability (index $\geq$ 0.8), Class II reservoirs with moderate fracturability (0.6–0.8), and Class III reservoirs with weak fracturability ($\leq$ 0.6). A case study was carried out in a block on the eastern margin of the Ordos Basin, and the evaluation results were verified by actual well gas production performance. The results show that coal reservoir fracturability presents a vertical distribution pattern from top to bottom: Class I, Class II, Class III, Class II. Class I engineering sweet spots are widely developed in gentle slope zones and structural platforms where the formation dip angle is less than 3°, with weak Yanshanian–Himalayan tectonic deformation. In such areas, Class I mechanical layers are thick and laterally continuous, the coal reservoir structure remains relatively intact, the in-situ stress difference coefficient is low, and the fracture pressure is relatively high. These structural locations are favorable for the formation and deployment of CBM engineering sweet spots. The coal reservoir fracturability evaluation system based on mechanical stratigraphy exhibits good practicability and reliability. It can provide a scientific basis for CBM favorable area optimization and hydraulic fracturing design.

Keywords: Coal Reservoir, Coalbed Methane, Mechanical Stratigraphy, Fracturability, Reservoir Stimulation.

1. Introduction

China possesses abundant coalbed methane (CBM) resources. According to the latest statistics from the Ministry of Natural Resources, the geological resources of CBM at depths shallower than 2000 m and deeper than 2000 m are 30.05 trillion cubic meters and 40.71 trillion cubic meters, respectively, with total resources exceeding 70 trillion cubic meters[1]. However, by the end of 2021, more than 23,000 various types of CBM wells had been drilled cumulatively in China, with over 13,000 wells in operation. Yet, China's annual CBM production in 2021 was only 10.47 billion cubic meters, the commercial production success rate was less than one-third, and the single-well gas production was generally low. This is closely related to the poor fracturing adaptability of China's coal reservoirs. Having undergone multi-stage tectonic movements, these reservoirs are difficult to effectively fracture and reconstruct; existing fracturing technologies struggle to establish effective fluid migration and production channels within such complex coal reservoirs. Therefore, it is imperative to bridge the gap between geological constraints and engineering stimulation technologies by conducting research on reservoir fracturability[2-5].

In the evaluation of fracturability, the ability to form a complex fracture network is crucial. For a considerable period, engineering practices relied merely on the rock brittleness index to characterize reservoir fracturability. However, increasing engineering practices have shown that reservoir fracturability is not only related to the ease of fracture initiation but also requires consideration of the complexity of the fracture network and the connectivity between new and existing fractures. Relying solely on a single brittleness index cannot comprehensively reflect reservoir fracturability. Scholars from various countries have further analyzed the main factors affecting reservoir fracturability, comprehensively considering brittleness, in-situ stress, natural fractures, and other factors, to establish more effective evaluation models.

Yao Yanbin et al. pointed out that the key geological factors affecting coal reservoir fracturability include coal texture, macroscopic lithotypes, tectonic deformation, in-situ stress, and the difference in tensile strength between the coal seam and its roof/floor. Based on the reservoir geological conditions of the Zhengzhuang block, they provided value ranges and scores for each evaluation parameter and established a comprehensive quantitative evaluation model for coal reservoir fracturability. Li Shuguang et al. used gas logging peaks and mud logging displays as geological sweet spot evaluation indicators, and introduced engineering sweet spot indicators such as roof/floor lithology, stress difference between the coal seam and roof/floor barriers, and the brittleness index of the roof/floor. They established a "geology-engineering" sweet spot classification standard and applied it to the Daning-Jixian block.

Although these methods have thoroughly discussed the factors influencing fracturability and provided corresponding classification standards—which are of great significance for production area classification and guiding well placement in underperforming areas—their reference value for optimizing development intervals is quite limited. Zeng Zhiping et al. comprehensively considered the effects of rock brittleness,

fracture toughness, in-situ stress environment, and natural fracture development. They used the Analytic Hierarchy Process (AHP) to calculate the weight of each factor, established a fracturing capability evaluation method suitable for deep tight sandstone, and determined the optimal fracturing intervals for single wells in the study area, though further research is still required for the evaluation of the entire reservoir.

To comprehensively understand the resource abundance, gas content, strength characteristics, and rock mechanical brittleness index of the reservoir, as well as their corresponding vertical distributions, and to identify the optimal production zones and fracturing intervals, it is urgent to introduce new research methods. To this end, this paper proposes a new classification system based on the theory of Mechanical Stratigraphy. By applying the research methods of this theory, we can not only systematically investigate the 3D heterogeneity characteristics of coal reservoirs and accurately characterize the complexity of subsurface geological bodies to build more realistic and accurate geological models, but also provide a scientific basis for CBM reservoir stimulation, thereby significantly improving the reliability of evaluation results and the practical effectiveness of engineering applications.

2. Geological Overview of The Study Area

(1) Tectonic setting

The Ordos Basin, located in the western part of the North China Craton, is a large intracontinental superimposed residual basin controlled by multistage tectonic events, multiple evolutionary stages and diverse sedimentary systems. It consists of six first-order tectonic units: the Yimeng Uplift in the north, the Western Thrust Belt and Tianhuan Depression in the west, the Yishan Slope in the central area, the Jinxi Flexure Belt in the east, and the Weibei Uplift in the south. The Daning–Jixian Block lies in the southeastern Ordos Basin, at the eastern margin of the Yishan Slope and the southern end of the Jinxi Flexure Belt (Figure 1a). It is dominated by a gently dipping monocline, with strata striking west-northwest and dipping at 1°–3°. Six major reverse faults are developed in the study area, all trending north-northeast with small fault throws and short lateral extents (Figure 1b).

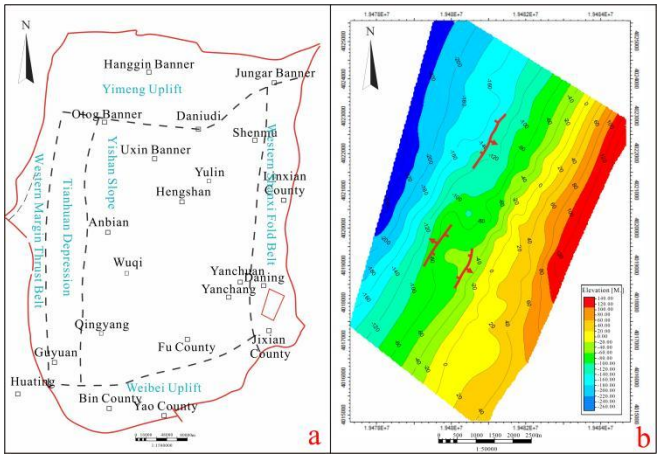


Figure 1. Geological overview of the study area

(2) Stratigraphic characteristics

From top to bottom, the coal-bearing strata in the study area include the Middle Permian Shihezi Formation, Lower Permian Shanxi Formation, Upper Carboniferous Taiyuan Formation and Upper Carboniferous Benxi Formation, which are characterized by favorable gas-bearing properties and high resource abundance. The Shanxi Formation is bounded above by the base of the Luotuobozi Sandstone and maintains conformable contact with the Lower Shihezi Formation; it is bounded below by the base of the Beichagou Sandstone and is in conformable contact with the underlying Taiyuan Formation.

The Shanxi Formation is mainly composed of sandstone and siltstone, with sandstone, siltstone and sandy mudstone showing obvious rhythmic interbedding. Taking the base of the Jinjiagou Sandstone as the boundary, the formation is divided into the Shan 1 Member and Shan 2 Member. The No. 5 coal seam, the main minable coal seam of the Shanxi Formation in the study area, is hosted in the Shan 2 Member.

The Shan 2 Member has a thickness of 40–60 m and belongs to the delta front subfacies of marine-continental transitional deposits. It develops interbedded microfacies of underwater distributary channel, interdistributary bay swamp and peat swamp, with multiple coal seams well developed. It forms a favorable source-reservoir assemblage composed of thick mudstone–shale intervals and multiple sandstone layers. The base of this member is the Beichagou Sandstone, and both the roof and floor of the coal seam consist of mudstone and shale.

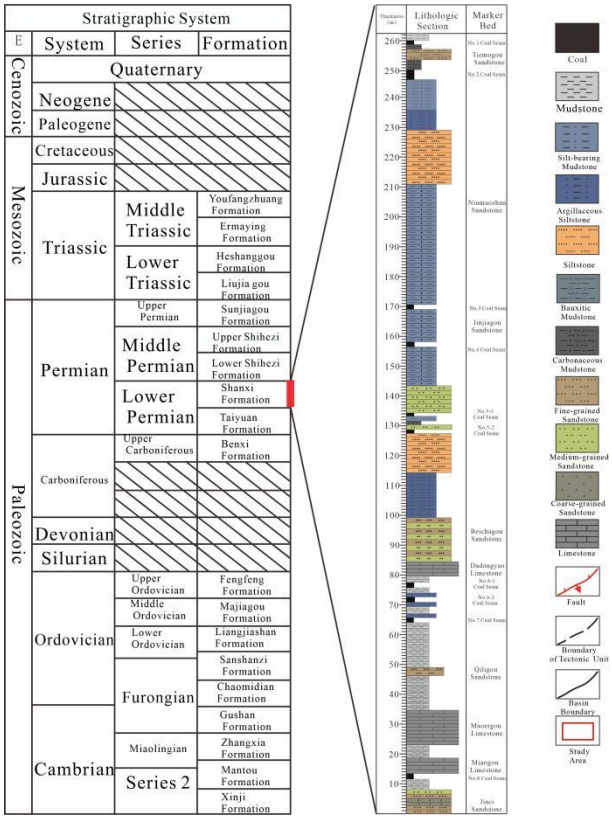


Figure 2. Stratigraphic summary table of the study area

(3) Characteristics of main coal reservoirs

Macroscopic lithotypes are dominated by bright coal, followed by semi-bright coal and dull coal. Bright coal mostly develops thick banded structures and vertically transitions into semi-bright coal and dull coal in layered distributions. The coal seam exhibits both simple structures without mudstone partings and complex structures containing interbedded partings, with mudstone parting thickness ranging from 0.1 to 1.0 m. For the main coal seam, the average vitrinite content is 74.6%, average ash content is 13%, average volatile matter content is 15.2%, and average

moisture content is 1.53%.

The burial depth of the No. 5 coal seam in the Daning–Jixian Block gradually decreases from west to east, with a maximum burial depth of 1458.58 m, a minimum of 889.07 m and an average of 1121.93 m. The coal seam thickness ranges from 0.53 to 5.83 m, with an average of 5.47 m, showing a pattern of thinning in the central part and thickening toward the periphery. The roof elevation of the coal seam ranges from -265.31 to 136.99 m, with an average of -80.86 m, and overall becomes progressively shallower from southeast to northwest.

3. Fracturability Evaluation and Its Influencing Factors

Fracturability mainly includes four connotations: the transformability of coal reservoir rock mass, the ease of fracture initiation and propagation, the complexity of fracture network morphology, and proppant supporting capacity. The water inrush coefficient directly controls whether reservoir hydraulic fracturing can connect with peripheral aquifers. Once hydraulic fractures communicate with aquifers during stimulation, water invasion and well flooding are very likely to occur, resulting in direct failure of reservoir reconstruction.

From the perspective of static characteristics of coal-measure mechanical stratigraphy, six indicators are selected: the Geological Strength Index (GSI) is adopted to characterize the development degree of natural fractures; the rock brittleness index is used to reflect the ease of hydraulic fracture initiation; the critical strain energy release rate represents the energy consumption for sustained fracture propagation; the in-situ stress difference coefficient characterizes the complexity of artificial fracture networks; the breakdown pressure denotes the critical pressure required to fracture the reservoir rock; the mosaic index is selected to describe the degree of proppant embedment after fracturing stimulation.

Meanwhile, as a hydrodynamic parameter in the static evaluation system of coal-measure mechanical stratigraphy, the water inrush coefficient is introduced to characterize the risk of hydraulic fracture connection with aquifers. The multi-level fuzzy mathematical method is applied to construct a hierarchical evaluation structure model and realize quantitative characterization of each index, which provides a reliable basis for comprehensive evaluation, discrimination and comparative analysis of reservoir fracturability.

(1) Geological strength index (GSI)

Coal texture is generally divided into four types: primary structural coal, cataclastic coal, granulated coal, and mylonitic coal. Primary structural coal and cataclastic coal retain relatively intact coal rock mass structures with high mechanical strength, showing good reservoir fracturability. Cataclastic coal zones generally have favorable permeability and serve as the primary target intervals for CBM exploration and development. In contrast, granulated coal and mylonitic coal are soft and low in strength with poor permeability. They are prone to engineering hazards such as drilling tool sticking, sand burial and wellbore plugging, making them unsuitable as CBM production intervals [6].

The Geological Strength Index (GSI) is a quantitative evaluation method for rock mass quality proposed by Hoek et al. It is established based on rock mass integrity, joint surface roughness, weathering degree and fracture development characteristics. The introduction of GSI into coal texture analysis enables quantitative characterization of coal structural integrity.

In general, with the increase of tectonic fragmentation, coal rock mass becomes looser, and internal pores and fractures are more developed. Correspondingly, logging curves exhibit low bulk density, low resistivity, high acoustic travel time and high caliper value. In some cases, fractures filled by groundwater or minerals also result in high compensated neutron logging response and high natural gamma ray value. Based on the comprehensive correlation between logging responses and GSI values, a logging-based GSI calculation formula is established as follows:

$$GSI = a \times CAL_{av} + b \times DEN + c \times CNL + d \times AC + e \times \ln RD + f \times \ln RS + g \quad (1)$$

Where GSI is the quantified Geological Strength Index (dimensionless); a, b, c, d, e, and f are regression coefficients (dimensionless); CAL_{av} is the average caliper (mm); DEN is the bulk density (g/cm³); CNL is the compensated neutron log (PU); AC is the acoustic travel time (μs/m); RD is the deep lateral resistivity (Ω·m); and RS is the shallow lateral resistivity (Ω·m).

(2) Differential stress coefficient

Rock brittleness reflects the ease with which rock undergoes fracturing. It is generally characterized by two methods: the mineralogical brittleness index and the rock mechanics brittleness index. The mineralogical brittleness index characterizes formation brittleness based on brittle mineral content (the percentage of felsic and carbonate minerals relative to the total mineral assemblage). The rock mechanics brittleness index characterizes the fracturing propensity of rock based on its bulk mechanical properties, using Young's modulus and Poisson's ratio [7].

Young's modulus reflects the ability of shale to maintain fracture conductivity after stimulation, whereas Poisson's ratio reflects the tendency of shale to fracture under applied stress. It is generally accepted that the greater the Young's modulus and the smaller the Poisson's ratio, the higher the rock brittleness.

In general, a higher brittleness index facilitates the formation of complex fracture networks during hydraulic fracturing. Conversely, poor brittleness reduces hydraulic fracture conductivity, which impairs reservoir stimulation effectiveness. Based on a comprehensive analysis of the relationships among logging curves, Young's modulus, and Poisson's ratio, logging-based calculation formulas for dynamic Young's modulus and dynamic Poisson's ratio are established as follows:

$$E_d = \left(\frac{\rho}{\Delta t_s^{\,2}}\right) \times \left(\frac{3\Delta t_s^{\,2} - 4\Delta t_p^{\,2}}{\Delta t_s^{\,2} - \Delta t_p^{\,2}}\right) \times 8.64 \times 10^6 \quad (2)$$

$$V_d = 0.5 \times \left(\frac{\Delta t_s^2 - 2\Delta t_p^2}{\Delta t_s^2 - \Delta t_p^2}\right) \quad (3)$$

$$E_{Brit} = \frac{E - E_{min}}{E_{max} - E_{min}} \quad (4)$$

$$\mu_{Brit} = \frac{\mu - \mu_{min}}{\mu_{max} - \mu_{min}} \quad (5)$$

$$BI = \frac{E_{Brit} + \mu_{Brit}}{2} \quad (6)$$

Where Ed is the dynamic Young's modulus (MPa); ρ is the bulk density (g/cm³); Δts is the shear wave slowness (μs/m); Δtp is the compressional wave slowness (μs/m); and V_d is the dynamic Poisson's ratio (dimensionless).

(3) Critical strain energy release rate

In-situ stress refers to the internal stress per unit area within rock mass generated by geological deformation. It mainly consists of overburden stress induced by the weight of overlying strata and regional tectonic stress. As a critical controlling factor, it triggers the rupture of rock internal defects, stress concentration at fracture tips, and subsequent fracture propagation in formations. In engineering practice, in-situ stress is generally simplified into three orthogonal principal stresses: vertical stress, maximum horizontal principal stress, and minimum horizontal principal stress [8].

During hydraulic fracturing, hydraulic fractures always initiate and propagate along the path of least resistance. Fractures initiate perpendicular to the orientation of the minimum principal stress and extend deep into the reservoir. With continuous fracture propagation, the orientation of the minimum principal stress may change, resulting in deflection of the fracture propagation direction. To characterize and constrain the lateral expansion of hydraulic fractures, only the horizontal stress difference is generally considered.

$$P_0 = P_i - (P_i - P_n)(\frac{\Delta t_n}{\Delta t_s})^c \tag{7}$$

$$\begin{cases} \sigma_v = \int_0^H \rho(h) g dh \\ \sigma_h = (\frac{v_s}{1-v_s} + \gamma)(\sigma_v - aP_0) + aP_0 \\ \sigma_H = (\frac{v_s}{1-v_s} + \beta)(\sigma_v - aP_0) + aP_0 \end{cases} \tag{8}$$

$$\sigma = \frac{\sigma_H - \sigma_h}{\sigma_H} \tag{9}$$

Where P_0 is the pore pressure (MPa); Pi is the overburden pressure (MPa); Pn is the normal formation pore pressure (MPa); Δtn is the acoustic slowness (μs/m); Δts is the acoustic slowness value on the normal compaction trend line at the same depth (μs/m); c is the compaction index, a regional constant (dimensionless), obtained through joint inversion of measured pressure data and logging data; σv is the vertical in-situ stress (MPa); ρ(h) is the function of formation density varying with depth (kg/m³); Vs is the dynamic Poisson's ratio (dimensionless); γ and β are the tectonic stress coefficients in the horizontal direction (dimensionless); P0 is the pore pressure (MPa); σH is the maximum horizontal principal stress (MPa); σh is the minimum horizontal principal stress (MPa); a is the effective stress coefficient (dimensionless), generally taken as 0.7 for low-permeability reservoirs; σ is the in-situ stress difference coefficient (dimensionless); σH is the maximum horizontal principal stress (MPa); and σh is the minimum horizontal principal stress (MPa).

(4) Critical strain energy release rate

In linear elastic fracture mechanics, unstable rock fracture propagation occurs when the strain energy accumulated at the crack tip of an elastic medium reaches a critical value. The strain energy released per unit fracture area during unstable propagation is defined as the critical strain energy release rate. This parameter characterizes the capacity for sustained fracture extension after fracture initiation. A lower critical strain energy release rate means less energy is required for subsequent fracture propagation, which is favorable for the development of complex hydraulic fracture networks [9].

$$G = (1 - \mu^2) \times \frac{(0.313 + 0.227 E_d)^2}{E_d} \times 10^3 \tag{10}$$

Where G is the critical strain energy release rate (J/m²); Ed is the dynamic Young's modulus (MPa); and μ is the dynamic Poisson's ratio (dimensionless).

(5) Breakdown pressure

Breakdown pressure is defined as the minimum external pressure required to rupture formation rock and generate new artificial fractures. Formation fracturing occurs once the applied pressure exceeds the breakdown pressure. Breakdown pressure is closely controlled by rock physical and mechanical properties, in-situ stress, burial depth and tectonic setting. Generally, breakdown pressure increases with growing burial depth, in-situ stress and rock mechanical strength [10].

$$P_f = 3\sigma_h - \sigma_H - aP_0 + S_d \tag{11}$$

Where P_f is the breakdown pressure (MPa); σ_h is the minimum horizontal principal stress (MPa); σ_H is the maximum horizontal principal stress (MPa); α is the effective stress coefficient, generally taken as 0.7 for low-permeability reservoirs; P_0 is the pore pressure (MPa); and S_d is the dynamic tensile strength (MPa).

(6) Mosaic index

After hydraulic fracturing of coal reservoirs, fluid pressure gradually declines, while the effective stress acting on fracture walls increases continuously. Once the effective stress exceeds the compressive strength of reservoir rock, proppants will embed into fracture walls, narrowing fracture width or even inducing fracture closure, and further impairing fracturing effectiveness [11].

The calculation formula for the embedment index is:

$$MI = \frac{\sigma_h - P_0}{\sigma_d} \tag{12}$$

Where MI is the embedment index (dimensionless); σ_h is the minimum horizontal principal stress (MPa); P_0 is the pore pressure (MPa); and σ_d is the dynamic compressive strength (MPa).

(7) Water inrush coefficient

During the development of coal measure gas, it is occasionally observed that fractures communicate with aquifers during reservoir stimulation, leading to water inrush accidents and directly causing the failure of the stimulation [12].

$$T = \frac{P}{M} \tag{13}$$

Where T is the water inrush coefficient (MPa/m); P is the actual water head value borne by the floor aquiclude (MPa); and M is the thickness of the floor aquiclude (m).

4. Fracturability Evaluation Model

From the perspective of static geological characteristics of coal-measure mechanical stratigraphy, seven evaluation indices are selected. The Geological Strength Index (GSI) is adopted to characterize natural fracture development; the rock mechanical brittleness index is used to reflect the ease of hydraulic fracture initiation; the critical strain energy release rate represents the energy required for sustained fracture propagation; the in-situ stress difference coefficient characterizes the complexity of fracture networks; the breakdown pressure denotes the critical pressure for reservoir rock rupture and fracture generation; the embedment index is applied to evaluate the degree of proppant embedment after fracturing.

In addition, as a hydrodynamic parameter in the static evaluation system of coal-measure mechanical stratigraphy,

the water inrush coefficient is introduced to quantify the risk of hydraulic fractures connecting with aquifers during stimulation.

(1) Parameter Standardization

To eliminate dimensional differences among multiple evaluation indicators, all parameters are standardized by two approaches: constructing membership functions and adopting range transformation.

Membership functions are established for the Geological Strength Index, rock mechanical brittleness index, in-situ stress difference coefficient, and water inrush coefficient.

$$C = \begin{cases} -\frac{2}{175}GSI + \frac{61}{35}, 65 < GSI \leq 100 \\ \frac{1}{50}GSI - \frac{3}{10}, 45 < GSI \leq 65 \\ \frac{3}{125}GSI - \frac{12}{25}, 20 < GSI \leq 45 \\ 0, GSI \leq 20 \end{cases} \quad (14)$$

$$C = \begin{cases} 1, BI \geq 77 \\ \frac{40}{11}BI - \frac{9}{5}, 55 < BI < 77 \\ 0.2, BI \leq 55 \end{cases} \quad (15)$$

$$C = \begin{cases} 0.2, \sigma \geq 0.5 \\ -4\sigma + \frac{11}{5}, 0.3 < \sigma < 0.5 \\ 1, \sigma \leq 0.3 \end{cases} \quad (16)$$

$$C = \begin{cases} 0, T \geq 0.1 \\ 1, T < 0.1 \end{cases} \quad (17)$$

The range transformation method is applied to standardize the critical strain energy release rate, breakdown pressure, and embedment index. Among these, the embedment index is a positive indicator, while the critical strain energy release rate and breakdown pressure are negative indicators.

(2) Establishment of the Evaluation Model

A judgment matrix A is established, where the elements represent the proportional scale values between any two of the following parameters: the Geological Strength Index (GSI), rock mechanics brittleness index, critical strain energy release rate, in-situ stress difference coefficient, breakdown pressure, and embedment index.

The eigenvector wi_1 of the judgment matrix A is calculated. Based on $wi_1 = [W_1\ W_2\ W_3\ W_4\ W_5\ W_6]T$, the weight proportions are determined as follows: W1 is the normalized weight of the Geological Strength Index, W_2 is the normalized weight of the coal reservoir brittleness index, W_3 is the normalized weight of the critical strain energy release rate, W_4 is the normalized weight of the in-situ stress difference coefficient, W_5 is the normalized weight of the breakdown pressure, and W_6 is the normalized weight of the embedment index.

The water inrush coefficient is considered independent of the other evaluation indicators and directly determines the suitability for stimulation. If an aquifer is connected during the reservoir stimulation process, it can easily cause well flooding accidents, leading directly to the failure of the stimulation.

$$FI = (W_1GSI + W_2BI + W_3G + W_4\sigma + W_5P_f + W_6MI)T \quad (18)$$

Where FI is the fracturability index (dimensionless); GSI is the normalized Geological Strength Index (dimensionless); BI is the normalized rock mechanics brittleness index (dimensionless); G is the normalized critical strain energy release rate (dimensionless); σ is the normalized in-situ stress difference coefficient (dimensionless); Pf is the normalized breakdown pressure (dimensionless); MI is the normalized embedment index (dimensionless); and T is the normalized water inrush coefficient (dimensionless).

(3) Evaluation Results

Referring to field production experience, coal measure gas reservoirs are classified into three categories based on the fracturability index. Category I refers to coal reservoirs with strong fracturability, where the fracturability index is greater than or equal to 0.8; Category II refers to coal reservoirs with moderate fracturability, where the index ranges between 0.6 and 0.8; and Category III refers to coal reservoirs with weak fracturability, where the index is less than or equal to 0.6.

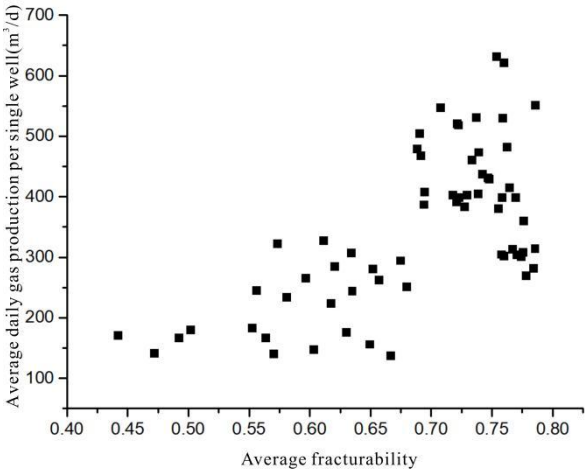


Figure 3. Correlation between gas production and fracturability

Table 1. Classification scheme for the fracturability grades of coal reservoirs

Comment Set	Grade I (Strong fracturability)	Grade II (Moderate fracturability)	Grade III (Weak fracturability)
Fracturability Index	FI≥0.8	0.6<FI<0.8	FI≤0.6

5. Conclusion

(1) Based on mechanical stratigraphy theory, core sampling data and well logging interpretation results, seven factors including coal texture, brittleness index, breakdown pressure, critical strain energy release rate and in-situ stress are selected as the evaluation indicators of coal reservoir fracturability. An evaluation method suitable for the Daning-Jixian Block is established using the Analytic Hierarchy Process (AHP). Coal-measure mechanical layers in the coal reservoir are classified based on the fracturability index.

The coal reservoir is divided into three grades: Grade I mechanical layer with strong fracturability (fracturability index ≥ 0.8); Grade II mechanical layer with moderate fracturability (0.6–0.8); Grade III mechanical layer with weak fracturability (≤ 0.6).

(2) In accordance with the above classification criteria, the coal seam in the study area is divided into four mechanical layers, numbered Layer 1 to Layer 4. Among them, Mechanical Layer 1 belongs to Grade I with strong fracturability; Mechanical Layers 2 and 4 belong to Grade III with weak fracturability; Mechanical Layer 3 belongs to Grade II with moderate fracturability.

In the study area, the thickness of Grade I coal reservoirs ranges from 0 to 7.8 m, with an average of 5.2 m and a

relatively stable lateral distribution. Areas with a thickness greater than 5.5 m are mainly distributed in the central and western parts of the block. These areas are characterized by good reservoir fracturability, a high proportion of Grade I mechanical layers, and favorable gas production performance.

References

[1] Qu Peiran. The Nation's First CBM Field with Annual Production Exceeding 2 Billion Cubic Meters Completed: Prominent Industrial Environmental and Safety Benefits [N]. China Energy News, 2022-07-04(05).

[2] LuoPingya. A discussion on how to significantly improve the single-well productivity of CBM gas wells in China [J]. Natural Gas Industry, 2013, 33(06): 1-6.

[3] QIN Yong, SHEN Jian, SHI Rui. Strategic value and choice on construction of large CMG industry in China [J]. Journal of China Coal Society, 2022, 47(01): 371-387.

[4] XU Fengyin, HOU Wei, XIONG Xianyue, et al. The status and development strategy of coalbed methane industry in China [J]. Petroleum Exploration and Development, 2023, 50(4): 669-682.

[5] Geng Meng, Chen Hao, Chen Zhenhong, et al. New recognization of CBM enrichment pattern and resource potential in China [J]. Natural Gas Geoscience, 2016, 27(9): 1659-1665.

[6] WANG Junhui, YAN Wanzi, WAN Zhijun, et al. Prediction of Permeability Using Random Forest and Genetic Algorithm Model [J]. Computer Modeling in Engineering & Sciences, 2020, 125(3): 1135-1157.

[7] HU Qiujia, LIU Chunchun, ZHANG Jianguo, et al. Machine learning-based coalbed methane well production prediction and fracturing parameteroptimization [J]. Petroleum Reservoir Evaluation and Development, 2025, 15(2): 266-273, 299.

[8] CAI Ming, ZHOU Qingwen, YANG Cong, et al. An intelligent lithology identification method for sandstone and mudstonestrata and its applications: A case study of the Jurassic strata in the Lunnan area, Xinjiang, China [J]. Coal Geology & Explora-tion, 2025, 53(1): 235-244.

[9] LAI Jin, WANG Guiwen, FAN Zhuoying, et al. Research progress in brittleness index evaluation methods with logging data in unconventional oil and gas reservoirs [J]. Petroleum Science Bulletin, 2016, 03: 330-341.

[10] LAI Jin, BAI Tianyu, XIAO Lu, et al. Well-logging evaluation of in-situ stress fields and its geological and engineering significances [J]. Oil & Gas Geology, 2023, 44(4): 1033-1043.

[11] CHEN Jianguo, DENG Jingen, YUAN Junliang, et al. Determination of fracture toughness of modes I and II of shale formation [J]. Chinese Journal of Rock Mechanics and Engineering, 2015, 34(06): 1101-1105.

[12] GUO Dali, WANG Yuji, ZHANG Xiaoshuan, et al. Prediction of fracture pressure based on logging-while-drilling data [J]. Science Technology and Engineering, 2023, 23(5): 1923-1930.