Study on The Difference of Pore-Fracture Structure Between High-Low Rank Coal under SEM And Its Influence on Development

Ya-lan Zhang[1,3,4](✉), Yu-hang Xiao[1,3,4], Jun-ying Liu[1,3,4], Yang Zhang[2,3,4], Lei Wang[1,3,4], Yan Liu[1,3,4], Xue-feng Su[1,3,4], You-jun Cai[1,3,4], and Li Yu[1,3,4]

[1] Exploration and Development Research Institute, PetroChina Huabei Oilfield Company, Renqiu 062552, Hebei, China
`yjy_zhangyl@petrochina.com.cn`
[2] Engineering Technology Research Institute, PetroChina Huabei Oilfield Company, Renqiu, China
[3] Key Laboratory of CBM Resources Efficient Development of Hebei Province, Renqiu, China
[4] Exploration & Development Research Institute, North China Oilfield Company, Renqiu, China

Abstract. The pore-fracture in coal rock is the space of accumulation and migration of coalbed methane, it is the key to affect the development of coalbed methane. Field emission scanning electron microscopy was used to study the pore-fracture characteristics of high-low rank coal reservoirs. Taking the high-rank coal of FJ-1 well in Fanzhuang block, southern Qinshui Basin and the low-rank coal of JM18-2 well in Jiergalangtu sag, Erlian Basin as the research objects, observing and analyzing the pore-fracture types, genesis, structures and spatial distribution.Combined with the development characteristics of its blocks, the differences between the high-low rank coal reservoirs and their impact on development were studied. It is found that the structure of high-rank coal is tight, its pores are mainly micropores, the pore type is mostly gas pore and mould pore, the primary pore is rare affected by metamorphism, occasionally can see the deformed closed cellular pore, the breccia pore are little developed, high-rank coal fractures are mainly developed in vitrinite, mostly are endokinetic fractures and tensile fractures, some of which are filled, poor spatial association and general connectivity, while low-rank coal has loose structure, the pores is dominated by macropores, there are a lot

---

J. Lin (Ed.): IFEDC 2023, SSGG, pp. 3–16, 2024.
https://doi.org/10.1007/978-981-97-0268-8_1

of cellular pores, interclast pores, gas pores and a small number of mould pores, corroded pores and friction pores. The characteristics of pore-fracture development are mainly controlled by the grade of metamorphism, high-rank coal, small pore-fracture scale, poor connectivity, difficult to produce fluid.Low-rank coal, pore-fracture well development, it is characterized by largepore size, good connectivity and favorable for fluid migration, but low-rank coal relatively rich in water and have difficulty to drainage pressure reduction.

Keywords: High-low Rank Coal · Pore-Fracture · SEM · Channel Structuture · Development Influence

1 Introduction

The coal reservoir has a dual pore system, including pores and fractures [1]. The structural characteristics of pore-fracture greatly affect the adsorption and permeability, thus affecting the desorption and migration of coalbed methane. The study of coal reservoir pore-fracture has been conducted for a long time both domestically and internationally and has been acquired a lot of knowledge [2–8]. In the process of metamorphic evolution of coal seam, with the change of coal rank, the porosity, permeability and adsorption capacity of coal seam have changed greatly [9]. Therefore, the evolution of coal metamorphism has a controlling effect on the physical properties of coal reservoirs, resulting in differences in the physical properties of different coal-rank reservoirs. At present, there are few studies on the pore-fracture types and spatial structure differences between high-low rank coal reservoirs. In this paper, SEM is used as the research method, low-rank coal in Erlian Basin and high-rank coal in Qinshui Basin are taken as the research objects. The pore -fracture are directly observed and the types and characteristics of pore-fracture are described, compared and analyzed in detail, which provides a basis for reservoir differences in the exploration and development process of high-low rank coalbed methane.

2 Experimental Process

2.1 Experimental Instruments

The experimental equipment is an ultra-high resolution field emission scanning electron microscope, GeminiSEM500 (Fig. 1), Carl Zeiss, Germany. It can directly observe the natural section of the sample and without damage the sample during the experiment. The most realistic microscopic characteristics of the sample can be observed. In addition, the equipment has a large depth of field, high resolution, wide magnification range and continuous adjustment [10, 11], it has a unique advantage in observing the pore-fracture structure of coal samples. In this study, the secondary electron detector with a strong three-dimensional imaging sense was used. The working distance was about 5cm. According to the conductivity of the sample, the extra high tension was selected from 2kV – 20kV. At the same time, the energy dispersive spectrometer was equipped to identify the mineral composition.

Fig. 1. Field emission scanning electron microscope (GeminiSEM500)

2.2 Sample Information And Preparation

In the experiment, 12 high-rank coal samples from Well FJ-1 in Fanzhuang Block, southern Qinshui Basin (Table 1) and 12 low-rank coal samples from Well JM18-2 in Jiergalangtu sag, Erlian Basin (Table 2) were selected. The macrolithotype of well FJ-1 is mainly semibright coal, the coal structure is mainly the primary structure. The vitrinite reflectance ranges from 2.832% to 3.435%, with an average of 3.106%, which belongs

Table 1. Basic parameters of coal rock samples from well FJ-1 (V-Vitrinite;I-Inertinite;E-Exinite)

Sample	depth/m	Demineralized base/%			Mineral base/%					Ro/%
		V	I	E	Organic macerals	Clay	Sulfide	Cabonate	Silica	
3–1	573.4–573.8	88.95	11.05	/	95.19	4.1	0.53	0.18	/	3.317
3-1s	574.0–574.5	86.91	13.09	/	95.33	4.29	0.39	/	/	3.125
3–2	575.5–575.9	91.87	8.13	/	97.81	0.99	0.4	0.6	0.2	3.078
3–3	576.3–576.6	81.40	18.60	/	96.9	1.36	0.19	1.36	0.19	3.232
3–4	576.7–577.0	91.97	8.03	/	99.04	0.58	0.39	/	/	3.008
3-4s	577.0–577.3	88.34	11.66	/	97.12	2.3	0.19	0.38	/	3.078
9–1	632.6–633.0	67.87	32.13	/	98.23	0.89	0.35	0.53	/	2.871
15–1	673.7–674.2	88.97	11.03	/	97.92	1.7	/	0.38	/	3.014
15-1s	674.2–674.6	89.11	10.89	/	97.26	1.76	0.2	0.59	0.2	2.832
15–2	675.8–676.2	69.01	30.99	/	94.71	0.78	3.13	1.37	/	3.012
15–3	677.0–677.5	69.21	30.79	/	94.91	3.33	0.2	0.98	0.59	3.268
15-3s	677.5–677.7	81.44	18.56	/	95.25	4.37	/	/	0.38	3.435

to anthracite. The vitrinite content is in the range of 67% – 94%, the mineral component content is about 5%, mainly clay minerals. The macrolithotype of JM18-2 well is clastic coal, the coal structure is mainly cataclastic texture. The vitrinite reflectance ranges from 0.35% to 0.55%, with an average of 0.425%, which belongs to lignite. The macerals are mainly vitrinite, generally in the range of 60%–80%, followed by inertinite, exinite is the lowest. The mineral composition is mainly clay minerals, followed by pyrite, quartz is rare.

Table 2. Basic parameters of coal rock samples from well JM18-2 (V-Vitrinite;I-Inertinite;E-Exinite)

Sample	depth/m	Demineralized base/%			Mineral base/%					Ro/%
		V	I	E	Organic macerals	Clay	Sulfide	Cabonate	Silica	
4–1	420.7–421.0	64.05	35.95	1.46	87.61	6.48	2.96	1.67	/	0.480
4–2	421.5–421.9	66.72	33.28	0.73	91.45	7.28	0.2	0.2	0.2	0.456
4–3	422.6–422.9	63.56	36.44	0.62	93.33	4.3	0.9	0.36	0.54	0.352
4–4	423.5–423.9	69.76	30.24	1.28	89.08	6.88	1.81	0.72	0.36	0.350
4–5	424.5–424.8	65.73	34.27	2.11	89.96	7.05	/	1.08	/	0.475
4–6	424.8–425.2	67.17	32.83	0.85	92.42	5.66	0.38	0.75	/	0.438
4–7	425.6–425.9	67.63	32.37	1.35	91.39	5.86	1.32	0.19	/	0.355
4–8	426.1–426.4	69.45	30.55	0.64	91.6	6.1	1.14	0.38	0.19	0.375
5–1	664.5–664.8	77.06	22.94	1.54	93.24	3.35	1.18	0.39	0.39	0.425
5–2	665.5–665.9	75.33	24.67	0.95	91.39	4.23	1.76	0.53	1.23	0.481
5–3	667.1–667.4	80.73	19.27	1.86	91.4	2.76	2.07	0.69	1.38	0.375
5–4	668.3–668.7	77.00	23.00	1.02	93.83	2.31	1.73	0.58	0.58	0.545

Because the sample of JM18-2 well has low hardness, brittleness and fragile, it is difficult to be polished, therefore, the natural surface of the JM18-2 well is used as the observation surface. The sample of the FJ-1 well has high hardness and is convenient to be polished, so both the natural surface and polished surface of the JM18-2 well are used as the observation surface. Sample preparation begins with cutting several 1cm^3 small samples from the large coal samples, selected the vertical stratification direction as the observation surface. Some high-rank coal samples were polished, then bonded the samples to the sample holder with conductive adhesive to ensure the samples would not move, otherwise, it was easy to cause image drift during the experiment. At the same time, the surface of the sample was purged with a high-pressure dust removal tank to remove pulverized coal, sundries, etc. Finally, the treated sample was gold-plated under vacuum conditions to increase its conductivity.

3 Experimental Results

3.1 Comparative Analysis of Pore Characteristics of JM18-2 Well and FJ-1 Well under SEM

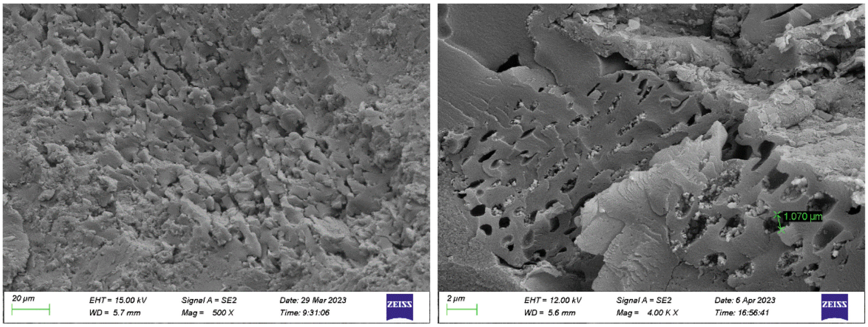
The pore types of coal rock can be divided into four categories, primary pore, epigenetic pore, external pore and mineral pore [12]. Based on these four categories, the pore characteristics of coal rock in the JM18-2 well and FJ-1 well are discussed respectively.

3.1.1 Primary Pore Characteristics

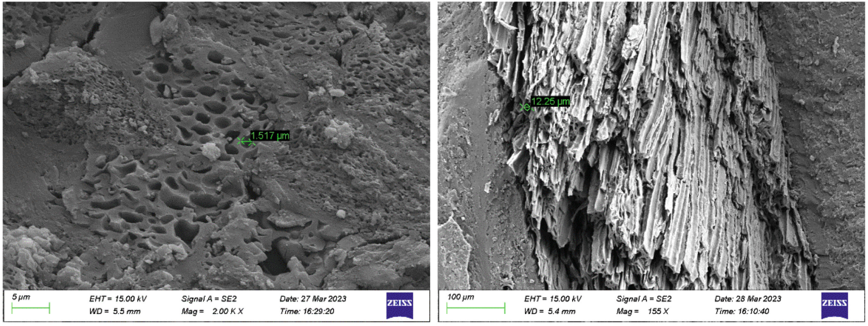
Figure 2 shows the SEM images of the primary pores of the coal samples from Well JM18-2 and Well FJ-1. Primary pores are the existing pores during the process of coal deposition, which are further divided into biopore and interclast pore. Biopore is the various pores of coal-forming plants, interclast pore refers to the pores between various organic clast in coal [12–14]. Under the SEM, a large number of biopores were developed in well JM18-2 and there were many kinds of biopores, such as cellular pores and pits. Among them, the tissue pore of telinite was poorly preserved, the cellular was mostly expanded and deformed. The cellular pores were mostly flattened into parallel short lines (Fig. 2a), some were filled with minerals (Fig. 2b). Fusinite cellular pores were well preserved, sieve-reticulate cellular pores could be seen on the cross-section (Fig. 2c) and pits could be seen on the longitudinal plane (Fig. 2d). The size of the cellular is mostly micron level, mainly large-pores. It plays a major role in gas accumulation in coal reservoirs, under the communication of fractures, it can participate in the seepage system. In addition, the tissue pores of sclerotinite, microsporidia, suberinite and alginite can be seen in the samples of well JM18-2.The tissue pores are derived from plant tissues and are generally not connected. The interclast pores are extensively developed in JM18-2, mostly several micrometers in size and partly connected (Fig. 2e). The primary pores are less developed in high-rank coal. The primary pores in the FJ-1 well are occasionally visible, mostly are deformed vitrinite cellular pores and fusinite cellular pores, the vitrinite cellular pores are mostly filled with minerals (Fig. 2f). Meanwhile, a small amount of undeformed fusinite cellular pores existed (Fig. 2g). In addition, the alginitee tissue pores are locally visible (Fig. 2h).

3.1.2 Characteristics of Epigenetic Pore

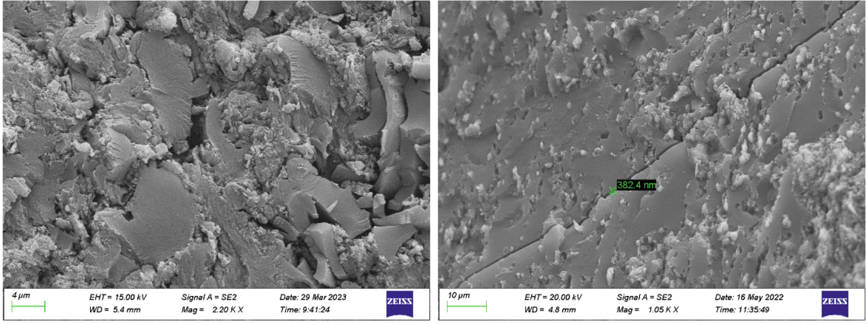
Figure 3 shows the SEM images of the epigenetic pores of coal rock samples from Well JM18-2 and Well FJ-1. Epigenetic pores mainly refer to gas pores, which are pores left by gas generation, gas accumulation, gas dissipation during the process of coal metamorphism, belong to secondary pores [12–14]. Gas pores development in different rank coals, vitrinite is the main maceral of gas pore development, inertinite has a small amount of gas pore, exinite has strong hydrocarbon-generating ability, gas pore is well development in exinite, but the exinite content in coal is too small, which has little effect on the coal reservoir. Under the SEM, the gas pores of JM18-2 well were more developed, especially in corpocollinite vitrinite (Fig. 3a), they can intergrowth with cellular or other tissue pores (Fig. 3b). A large number of stomatal groups (Fig. 3c, Fig. 3d) and stomatal



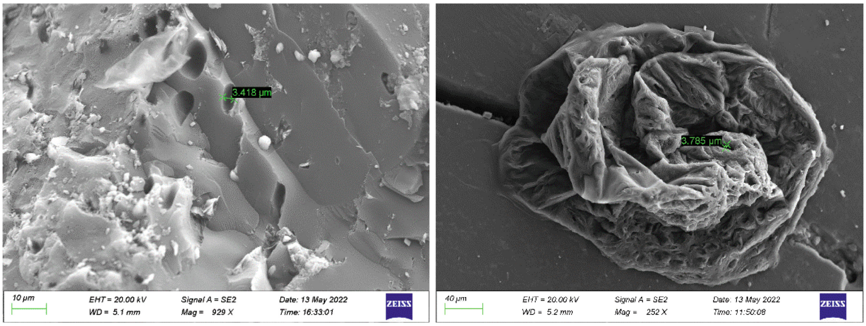
a.JM18-2 Cellular pore in vitrinite,deformed b. Cellular pore in vitrinite,partly filled



c.JM18-2 Cellular pore in fusinite d.JM18-2 Fusinite longitudinal plane and pit

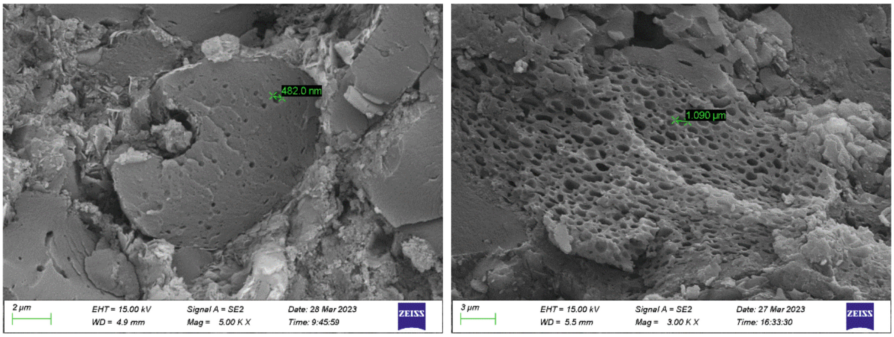


e.JM18-2 Interclast pore f.FJ-1 Cellular pore in vitrinite,partly filled

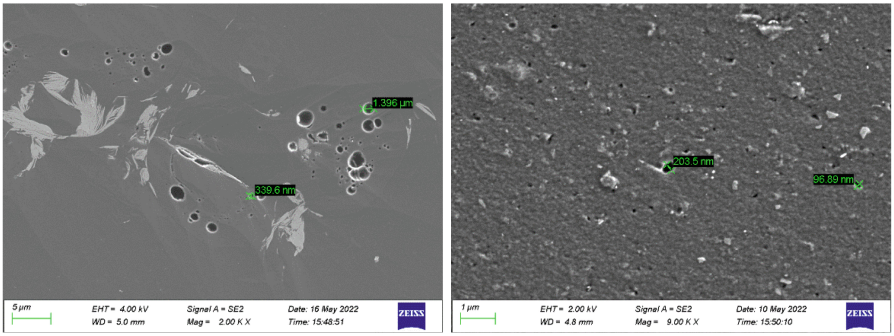


g.FJ-1 Cellular pore in fusinite h.FJ-1 Alginite tissue pore

Fig. 2. SEM image of primary pores in high-low rank coal



a.JM18-2 Gas pore group in collinite b.JM18-2 Cellular pore and gas pore intergrowth



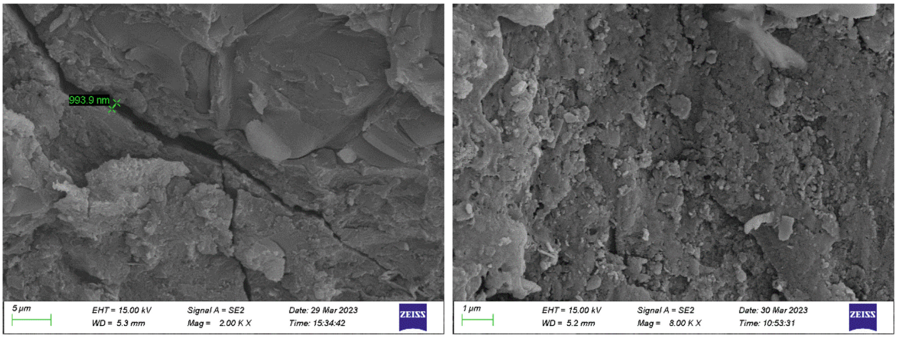
c.JM18-2 Gas pore group in telocollinite d.FJ-1Nanoscale gas pore

Fig. 3. SEM image of secondary pores in high-low rank coal

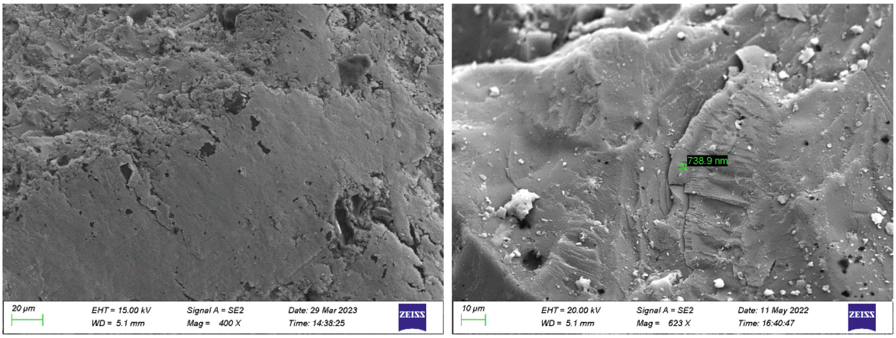
bands were also observed in well FJ-1, which were mostly developed in vitrinite. The gas pores belong to the micropore-macropore.

3.1.3 Characteristics of External Pores

Figure 4 shows the SEM images of the external pores of the coal samples from Well JM18-2 and Well FJ-1. External pores are pores formed by geological structure after coal consolidation and diagenesis. According to the grade of coal deformation, they can be divided into breccia pores, rubble pores and friction pores. The breccia pores (Fig. 4a) are pores between the breccias formed by the geological structure of the coal. It is generally large-scale and has good part connectivity. The rubble pores (Fig. 4b) are the pores between the organic components formed by the serious structural damage of the coal, which belongs to the medium-large pore level. Friction pores (Fig. 4c, Fig. 4d) are pores formed by friction between surfaces under compressive stress, which play a role in gas storage, which belongs to the medium-large pore level [12–14]. A small number of external pores can be seen under the SEM of both wells. The appropriate development of breccia pores is benifit to improving the permeability of coal reservoirs. When the number of fragments is too large, the pores and fractures will be blocked and the permeability of coal reservoirs will be reduced. The friction pores are limited to



a.JM18-2 Breccia pore b.JM18-2 Rubble pore



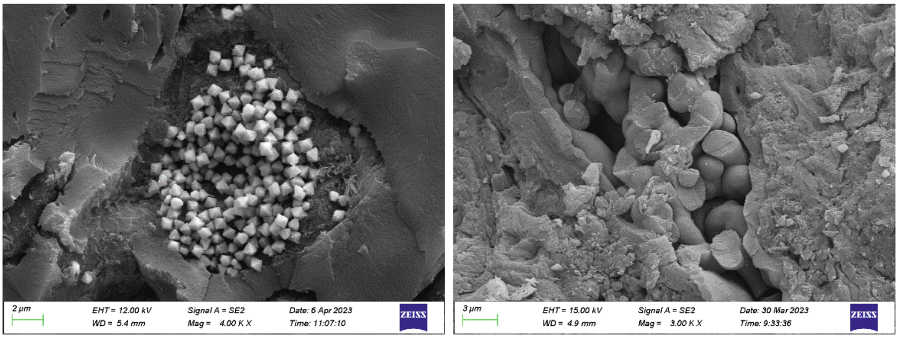
c.JM18-2 Friction pore d.FJ-1 Friction pore

Fig. 4. SEM image of internal pores in high-low rank coal

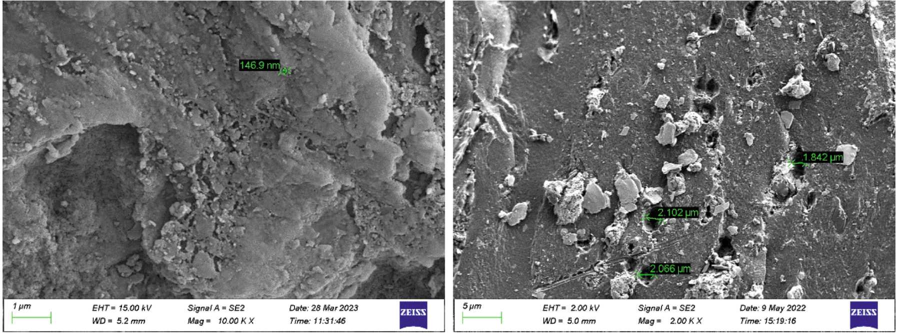
the structural surface and are not connected in space, so it has little significance to the reservoirs.

3.1.4 Mineral Pore Characteristics

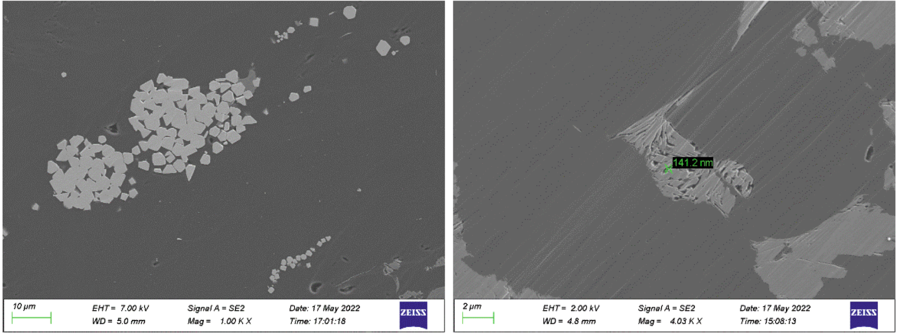
Figure 5 shows the SEM images of mineral pores in coal rock samples from Well JM18-2 and Well FJ-1. The mineral pores in both wells are mainly primary mould pores (Fig. 5d) and secondary intercrystal pores. The mould pores are mainly developed in the vitrinite, which are the evidence cast by different components in coal due to the difference in hardness [12–14]. There are more mould pores in FJ-1 well than in JM18-2 well, mould pores can be seen in both wells because of the falling off of pyrite. Intercrystal pores are the pores between mineral grains. Pyrite intercrystal pores (Fig. 5a, Fig. 5e), clay mineral intercrystal pores (Fig. 5f) can be seen in both wells, silicoide grains intercrystal pores (Fig. 5b) and quartz intercrystal pores can be seen in JM18-2 well. The corroded pore is the pore formed by the dissolution of soluble minerals under long-term gas and water interaction. Calcite corroded pores (Fig. 5c) are few developed in both wells. This type of pore has a small number and limited space distribution, which has little impact on reservoir performance.



a.JM18-2 Pyrite and intercrystal pore b.JM18-2 Silicoide grains and intercrystal pore



c.JM18-2 Corroded pore d.FJ-1 Mould pore



e.FJ-1 Pyrite and intercrystal pore f.FJ-1 Clay mineral and intercrystal pore

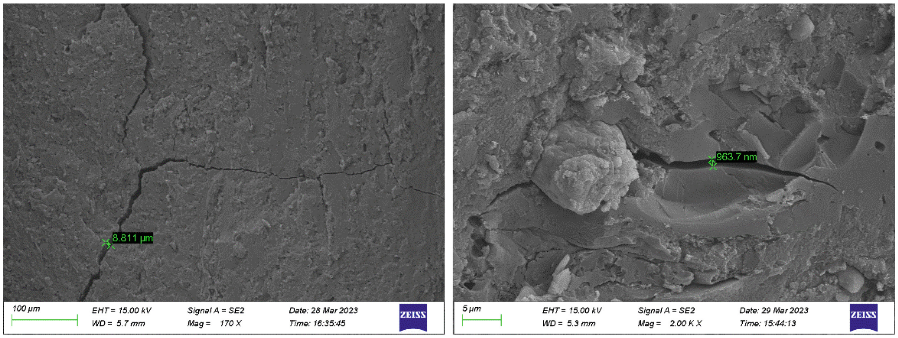
Fig. 5. SEM image of mineral pores in high-low rank coal

3.2 Comparative Analysis of Fracture Characteristics of JM18-2 Well And FJ-1 Well under SEM

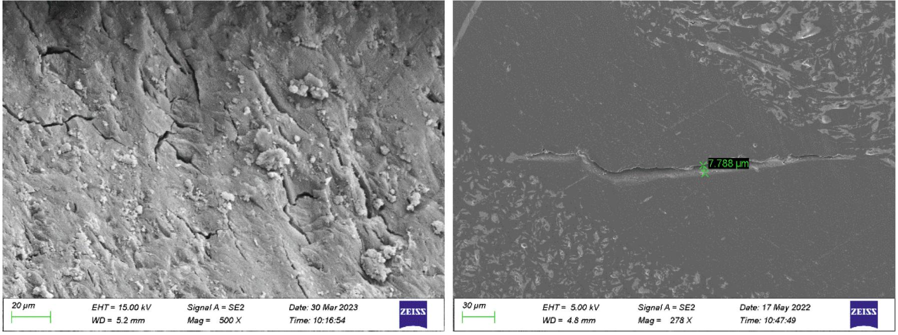
According to the cause of fomation, the types of coal rock fractures can be divided into two categories, endogenous fractures and external fractures [15]. Based on these two categories, the characteristics of coal rock fractures in the JM18-2 well and FJ-1 well are discussed respectively.

3.2.1 Characteristics of Endogenous Fractures

Figure 6 shows the SEM images of the endogenous fractures in the coal samples of the JM18-2 well and FJ-1 well. Endogenous fractures refer to the fractures caused by dehydration, devolatilization and the shrinkage of coal volume during coalification. The endogenous fractures are mostly vertical the bedding plane, without cross the bedding plane, are arranged in parallel with equal spacing, which is disconnected from each other. The endokinetic pressure fractures and dewatering fractures are all in the range of large pores, which is benifit to seepage. Although the shrinkage fractures belong to largepore, they are only partly connected [13–15]. Because the structure of low-rank coal samples is loose structure and easy to water loss, a large number of dewatering fractures can be seen in JM18-2 well under the SEM (Fig. 6a). The fracture width is micron level, which is mostly developed on the bedding surface, some fractures are interlaced and forming a irregular fracture network. Secondly, endokinetic pressure fractures (Fig. 6b) can be seen in JM18-2, which are developed in telocollinite without crossing maceral. Due to the restriction of maceral, it is difficult to form a fracture network, shrinkage fractures are occasionally seen (Fig. 6c). The endokinetic fractures (Fig. 6d) in the well FJ-1 are generally developed, with a width of nanometer-micron, partially filled with minerals and the fillings are mostly kaolinite. Shrinkage fractures are occasionally seen in the well FJ-1 and dewatering fractures are not developed.



a.JM18-2 Dewatering fracture b.JM18-2 Endokinetic fracture

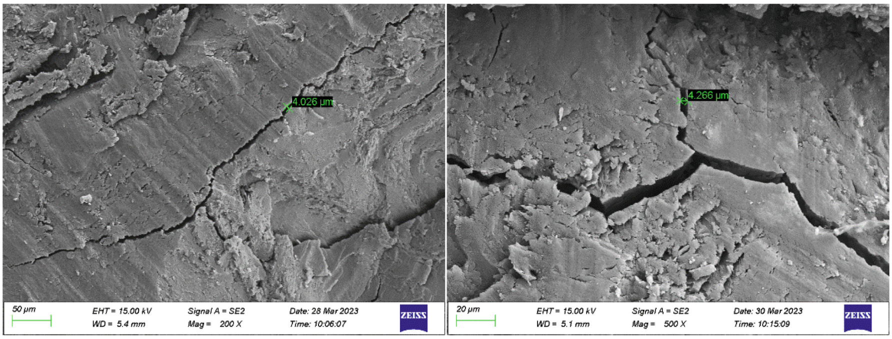


c.JM18-2 Shrinkage fractures d.FJ-1 Endokinetic fracture

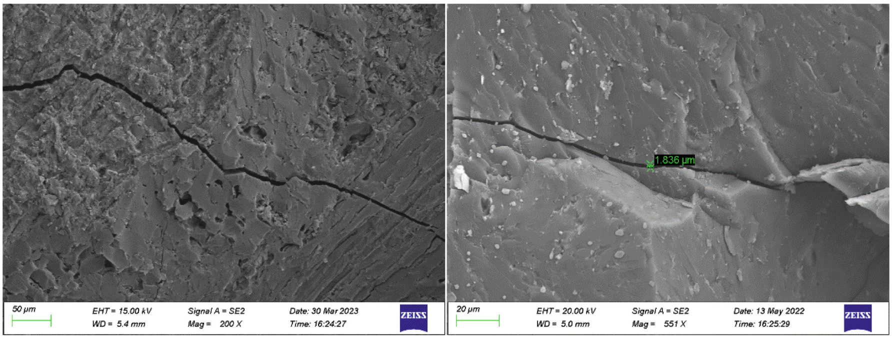
Fig. 6. SEM image of endogenic fracture in high-low rank coal

3.2.2 Characteristics of External Fractures

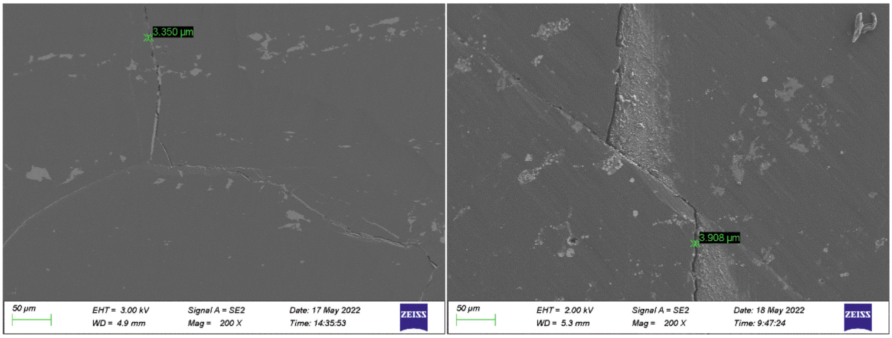
Figure 7 shows the SEM images of the external fractures of the coal samples from Well JM18-2 and Well FJ-1. The external fracture refers to the fracture produced by the stress during the tectonics period. External fractures intersect with bedding at various angles and mainly obliquely intersected, passing through different maceral and bedding planes, extending long and partially intersecting [13–15]. The coal at the intersection of external fractures is seriously damage and it is easy to produce rubbles and mylonitic. If



a.JM18-2 Relaxed fracture b.JM18-2 Relaxed fracture



c.JM18-2 Tensile fracture d.FJ-1 Tensile fracture



e.FJ-1 Tensile fracture f. FJ-1Shear fracture

Fig. 7. SEM image of external fracture in high-low rank coal

the number of rubbles and mylonitic is too large, it will adverse to the seepage. Relaxation fractures are commonly seen in well JM18-2 (Fig. 7a, Fig. 7b), which are mainly curved, the fracture surfaces are mostly serrated, which is common in the compressive structure surface. Some relaxation fractures are formed during sampling and sample preparation, which should be distinguished. In Well FJ-1, both tensile fractures (Fig. 7d, Fig. 7e) and shear fractures (Fig. 7f) are visible, but tensile fractures are more than shear fractures, some tensile fractures are filled (Fig. 7e). Many different levels of tensile fractures can form a fracture network, which is conducive to gas-water seepage.

4 Research on Development Influence

According to the results of microscopic observation, it can be concluded that the pore structure of the coal reservoir is beaded stucture (Fig. 8a), multi-level nested structure (Fig. 8b) and cluster structure (Fig. 8c). The three models all need fractures as channels to communicate them to participate in gas-water seepage. The primary pores of low-rank coal are well developed, mainly mesopore and largepore, the pore structure is mostly the cluster structure of largepore group-fracture-largepore group mode, which is very beneficial to gas storage and migration. However, the low-rank coal reservoir rich in water, it will increase the difficulty of gas desorption and diffusion, which is not conducive to gas migration. Therefore, the main problem restricting the efficient utilization of coalbed methane resources in low-rank coal reservoirs is not the difficulty of fluid migration, but how to realize the overall pressure reduction of the reservoir. Before desorption, the cumulative water production of vertical wells in Jiergalangtu sag is generally larger, the daily water production is more than 20 m^3, the peak gas production is low after gas breakthrough, the daily gas production is less than 500 m^3. The number of largepores in

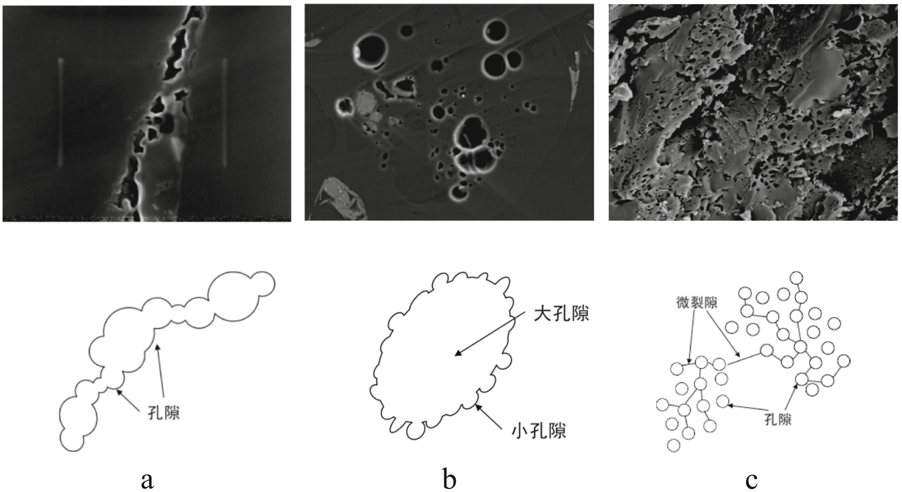


Fig. 8. Schematic diagram of pore structure a-beaded structure; b-multilevel nested structure; c-cluster structure

high-rank coal are reduced, the pores are mainly smallpores and micropores. The pore stucture is mostly beaded structure or large-small pore multilevel nested structure. In the process of high-rank coal development in Fanzhuang block, reservoir permeability has become a key factor restricting the efficient development of coalbed methane. In addition, due to the number, scale and pore fracture space combination of channel development, the coal reservoir in the area is sensitive. The peak value of high-yield vertical wells in the area is generally greater than 2000 m^3, the daily water production before the gas is less than 5 m^3, the production of gas and water is negatively correlated.

5 Conclusion

(1) The pores in low-rank coal are mainly primary plant tissue pores and intergranular pores, the largepore-mesopore are more developed. The primary pores in high-rank coal have mostly disappeared, the gas pores and mould pores are well developed, its number of largepore-mesopore is reduced but micropore is increased.
(2) The fractures in low-rank coal are mainly dewatering fractures and endokinetic fractures, the external fractures are mostly relaxed fractures, which belong to the macropore level. The fractures in high-rank coal are mainly endokinetic fractures, tensile fractures are also common to see but partially filled.
(3) Low-rank coal reservoirs are rich in water, the overall depressurization of the reservoir is the main problem for the efficient utilization of coalbed methane resources in low-rank coal reservoirs. The reservoir permeability affected by the number and scale of seepage channel as well as the spatial combination of pore-fracture, it is the key factor restricting the efficient development of high-rank coalbed methane.

References

1. Feng, Z.C., Zhao, Y.S., Wen, Z.M.: Percolation mechanism of fractured coal rocks as dual-continua. Chin. J. Rock Mech. Eng. **24**(2), 236–240 (2005)
2. Liu, D.M., Li, Z.T., Cai Y.D.: Study progress on pore-fracture heterogeneity and geological influence factors of coal reservoir. Coal Sci. Technol. **43**(2), 10–15 (2015)
3. Wang, H., Zhu, Y., Li, W.: Two major geological control factors of occurrence characteristics of CBM. J. China Coal Soc. **36**(7), 1129–1134 (2011)
4. Chen, W.W., Chen, L.W., Yang, Y.L.: Development Characteristics of micropores and microfractures in high-rank coal reservoirs and its relationship with productivity. In: Natural Gas Academic Annual Conference (2016)
5. Tao, S., Wang, Y.B., Tang, D.Z.: Pore-fracture systems and their contribution to the permeability of coal reservoirs in southern Qinshui Basin. Geol. J. China Univ. **18**(3), 522–527 (2012)
6. Yao, Y.B., Liu, D.M., Tang, D.Z.: Influence and control of coal petrological composition on the development of microfracture of coal reservoir in the Qinshui Basin. Journal of China University of Mining & Technology, 39(1), 6–13 (2010)
7. Li, C.C.: Study on pore characteristics of low rank coal reservoir in Erlian Basin, Taking Jiergalangtu Sag and Huolinhe Sag as example. Unconventional Oil Gas **9**(4), 37–45 (2022)
8. Liu, J.H., Wang, S.W., Li, D.M.: Geological modeling and fine description of fractures in low coal rank coal reservoirs of Erlian Basin Group. Coal Sci. Technol. **50**(5), 198–207 (2022)

9. Chen, X.J., Liu, J., Wang, L.: Influence of pore size distribution of different metamorphic grade of coalon adsorption constant. J. China Coal Soc. **38**(2), 294–300 (2013)
10. Fu, Z., Zhang, H., Luo, J.: Use, parameter setting and maintenance of SEM. Lab. Sci. **24**(5), 215–223 (2021)
11. Wang, D., Yu, H.H., Lin, G.H.: Routine maintenance and management of Zeiss Gemini500 field emission scanning electron microscope. Guangdong Chem. Ind. **47**(423), 151–152 (2020)
12. Zhang, H.: Genetical type of proes in coal reservoir and its research significance. J. China Coal Soc. **36**(1), 40–44 (2001)
13. Zhang, H., Jiao, S.J.: The Research on Unconventional oil and Gas Reservoir by Scanning Electronic Microscope. Geological Publishing House, Beijing (2016)
14. Zhang, H., Li, X.Y., Hao, Q.: Study on Coal in China by Scan Electron Microscope. Geological Publishing House, Beijing (2003)
15. Zhang, H., Wang, X.G., Yuan, Z.R.: Genetic types of microfractures in coal and their significance. Acta Petrol. Mineral. **21**(3), 278–284 (2002)