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Mineralogical Characteristics of No. 3 Coal in the Jurassic Coalfield of Northern Shaanxi

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Abstract: This study investigates the mineralogical characteristics of No. 3 coal seam in the Mahuangliang Coal Mine, located within the Jurassic coalfield of northern Shaanxi Province, China. Utilizing techniques such as low-temperature ashing (LTA), X-ray diffraction (XRD), scanning electron microscopy with energy-permissive spectroscopy (SEM-EDS), and Siroquant software, we examined the distribution and composition of the minerals present in the coal, partings, and roof and floor strata. The results reveal a rich assemblage of minerals, including quartz, kaolinite, and carbonates. The primary geological factors controlling the distribution of minerals and trace elements are the input of detrital materials from the depositional source area and the influence of hydrothermal fluids.

1. Introduction

Jurassic coal field in Northern Shaanxi is an important part of Ordos Basin, with abundant coal resources [1-5]. Recent studies have found that lithium (Li), gallium (Ga), aluminium (Al) and rare earth elements (REY) are abnormally enriched in some coals in the Ordos Basin [6-12]. In this study, No. 3 coal seam in Jurassic Coalfield in Northern Shaanxi, Ordos Basin is selected as the research object, and the theories and methods of coal geology, mineralogy, geochemistry and other disciplines are used to study the content, distribution law, occurrence state and main geological factors of metal elements in coal. This study not only has important guiding significance for the comprehensive exploration and development of energy minerals and associated metal minerals, but also has important practical significance for the clean purification and utilization of coal resources.

2. Geological setting

The Ordos Basin is a rare, giant multi-energy mineral basin in China, rich in coal, oil, and natural gas resources. It is known worldwide as a significant coal-accumulating basin. Located on the western edge of the North China Platform, it covers an area of approximately 400,000 square kilometers and developed on a stable craton [1]. The basin underwent tectonic evolution stages in the Paleozoic, Middle-Late Triassic, and Jurassic periods, resulting in the development of Carboniferous-Permian, Triassic, and Jurassic coal series. The Jurassic coal resources are the largest, amounting to 1487.66 billion tons, accounting for 75% of the total resources [2]. The northern Shaanxi Jurassic coalfield, located within the basin, includes the Shenfu Xinmin, Yushen, and Yuheng mining areas. The coal seams here are simple in structure, of good quality, and it is one of the world's eight major coalfields. The samples collected from the Mahuangliang Coal Mine in the Yushen mining area.

3. Methods of study

Based on the systematic collection of basic geological data of Jurassic coal field in Northern Shaanxi, 18 grooved samples were collected in Mahuangliang coal mine in Jurassic coal field in Northern Shaanxi. Low temperature ashing (LTA), X-ray diffraction (XRD), and siroquant software were used to accurately quantify the minerals in low temperature ash of coal and rock samples. Optical microscope and scanning electron microscope with energy spectrum (SEM-EDS) were used to observe and analyze the types, composition, morphology and occurrence characteristics of minerals in coal.

4. Characteristics of minerals

The minerals in No. 3 coal seam of the Mahuangliang Coal Mine in the Ordos Basin's Northern Shaanxi Jurassic Coalfield are primarily composed of kaolinite, quartz, pyrite, calcite, dolomite, and ankerite. Certain coal seam samples also contain chlorite, illite, calcic plagioclase, sodic plagioclase, siderite, rutile, barite, and other minerals. Additionally, zircon and trace minerals like phosphocerite, which contains rare earth elements, were observed under a scanning electron microscope (SEM).

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4.1 Quartz

Quartz, a common mineral in coal, exists in two main forms: detrital quartz and authigenic quartz. Authigenic quartz can further be classified into syngenetic (or parasyngenetic) and epigenetic types based on the period of formation. In the No. 3 coal seam of Mahuangliang Coal Mine, quartz is found in the following forms: (1) Discrete, angular, fine-grained detrital quartz dispersed within the clay matrix or organic matter, likely sourced from terrestrial sediments transported to the peat swamp by fluvial or aeolian processes. The rounding of quartz particles typically increases with the transport distance due to frequent collisions and abrasion during transport (Fig.1).

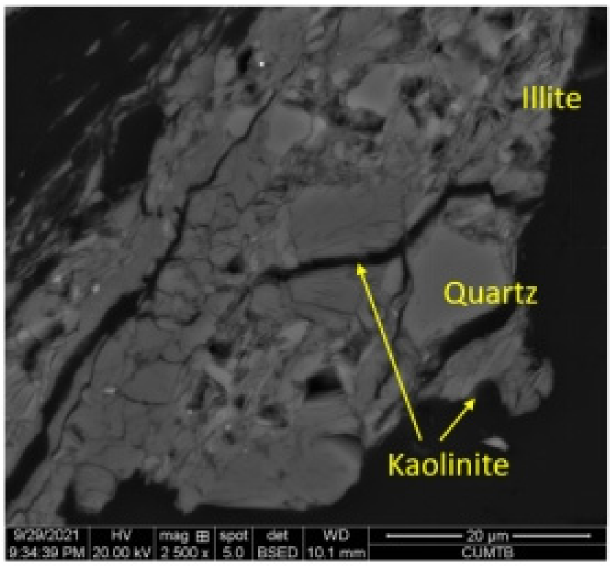

Fig. 1 Kaolinite, illite and quartz, under SEM, back scattered image

(2) Quartz filling fractures. In the No. 3 coal seam of Mahuangliang Coal Mine, quartz-filled fractures are rare, and those that do exist are small in scale, localized in occurrence (Fig.2). This vein quartz is generally considered to be epigenetic, possibly precipitated from silica-rich colloidal solutions [13,14].

4.2 Clay minerals

In this study, chlorite was found in some samples from the No. 3 coal seam of Mahuangliang Coal Mine, though in relatively low concentrations. SEM observations indicate that chlorite mainly fills organic matter cell cavities, often coexisting with kaolinite or illite (Fig.3), suggesting an authigenic origin. Illite in the No. 3 coal seam occurs in two primary forms: (1) Needle-like illite aligned with bedding planes, with the long axis of the crystals parallel to the bedding, indicating a terrigenous source (Fig.1); (2) Matrix-like mixed-layer illite-smectite, containing small amounts of K, Na, and Mg, with no clear structure.

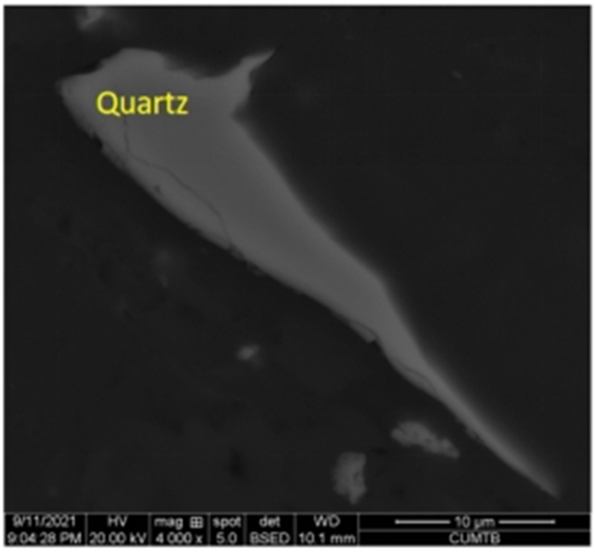

Fig. 2 Quartz: fracture-infillings, under SEM, back scattered image

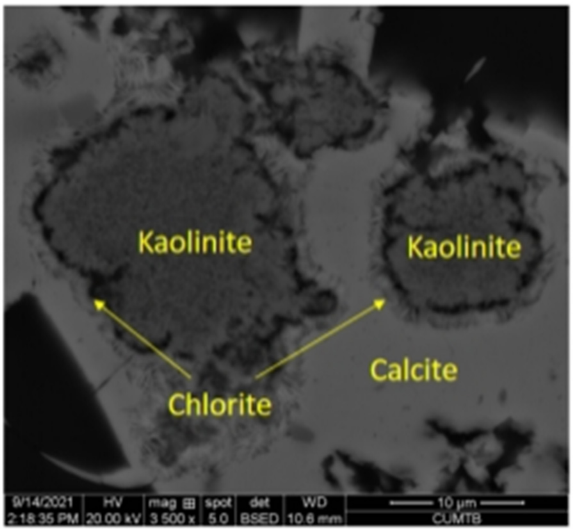

Fig. 3 Chlorite and kaolinite, under SEM, back scattered image

4.3 Carbonates

The carbonate minerals in the No. 3 coal seam are mainly siderite, calcite, dolomite, and ankerite. These carbonates primarily fill fractures and organic matter cell cavities (Fig. 4). Given the moderate rank of coal seams with high carbonate mineral content, these carbonates are presumed to be evidence of low-temperature hydrothermal processes. According to Yang Qi et al., carbonate mineralization in coal is associated with low-temperature alteration, where hydrothermal fluids passing through limestone layers precipitate carbonate veins in the coal seams. Peat bogs generally exhibit acidic conditions due to the release of humic acids during early coalification, making carbonate minerals prone to dissolution.

Consequently, most carbonate minerals are found as epigenetic fillings in fractures or pores. The calcite filling cell cavities in the No. 3 coal seam could have precipitated from Ca-rich solutions during syngenetic or early diagenetic stages, whereas vein calcite filling post-diagenetic fractures likely resulted from epigenetic hydrothermal fluid activity.

Ankerite is typically considered a secondary mineral, often forming during the late diagenetic stage. SEM observations show that ankerite mainly fills microscopic cell cavities and fractures, indicating that Fe-Mg-rich hydrothermal fluids provided the necessary Fe^{2+} and Mg^{2+} for ankerite formation. Siderite was detected in a few samples from the No. 3 coal seam, though its concentration in most samples was below detection limits. SEM observations reveal that siderite mainly occurs as irregular aggregates, a form typical of syngenetic or parasyngenetic products (Fig.5).

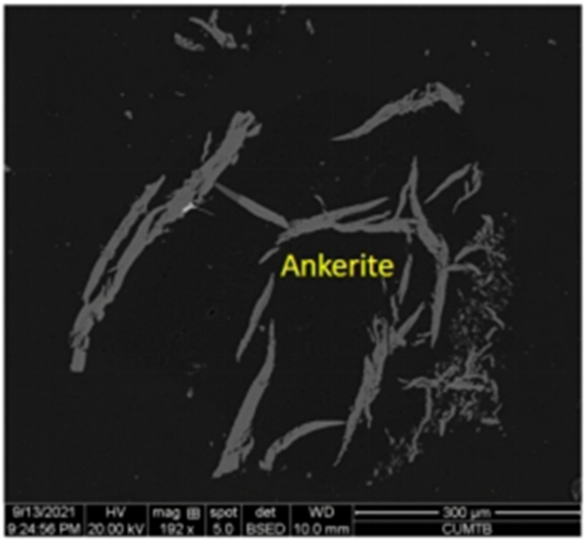

Fig. 4 Ankerite, under SEM, back scattered image

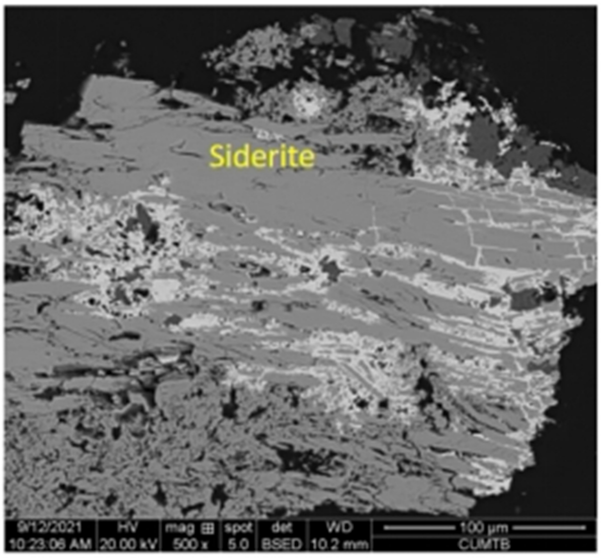

Fig. 5 Siderite, under SEM, back scattered image

4.4Sulphates

The sulfide mineral in the No. 3 coal seam is pyrite, which was observed in various forms, such as dispersed particles, cell cavity fillings, fracture fillings, and massive pyrite. This diversity suggests that pyrite formed at different stages from peat accumulation to post-coalification, with the different forms representing various coalification stages. Euhedral pyrite in coal is typically a syngenetic or parasyngenetic product, whereas vein pyrite can serve as evidence of hydrothermal fluid activity (Fig. 6).

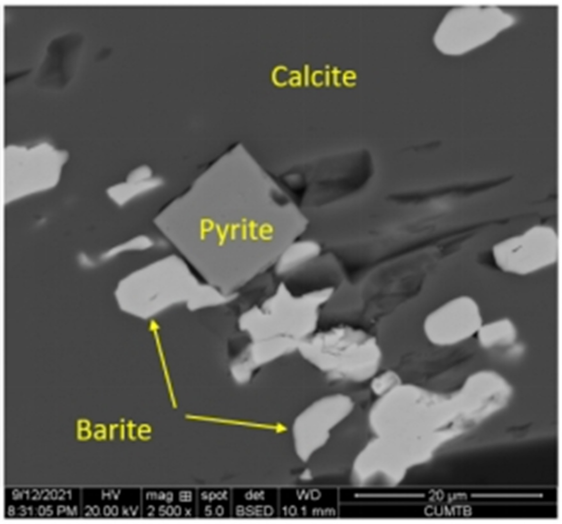

Fig.6 Barite, calcite and pyrite under SEM, back scattered image

The extensive presence of vein pyrite in the No. 3 coal seam (Fig. 7), either alone or with carbonate minerals filling fractures, with carbonate veins encasing pyrite, supports the influence of low-temperature hydrothermal processes. Zhong Ningning, while studying vein pyrite in Henan Province, suggested that vein pyrite forms from sedimentary pyrite recrystallized at relatively high temperatures, estimating the formation temperature at 130°C. The abundant vein pyrite in the No. 3 coal seam indicates the impact of low-temperature hydrothermal processes. Zhang Junying et al. found vein pyrite of low-temperature hydrothermal origin in the coals of southwestern Guizhou, noting that such pyrite often exhibits numerous irregular branches and an estimated formation temperature of 160-200°C. Low-temperature hydrothermal pyrite is also recognized as a primary carrier of Hg [15].

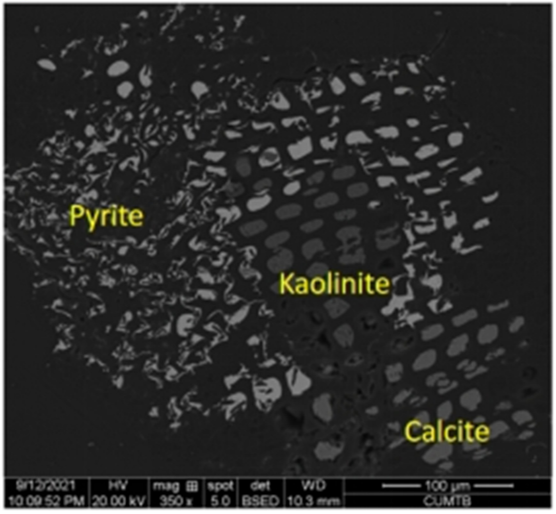

Fig.7 Pyrite, kaolinite and calcite, under SEM, back scattered image

In the No. 3 coal seam of Mahuangliang Coal Mine, intersecting vein pyrite was observed, with later-formed pyrite veins cutting through earlier ones, providing evidence for multi-phase hydrothermal fluid activity. Massive pyrite mainly forms during the late diagenetic stage of coalification, transitioning from peat to lignite. Initially, pyrite crystals develop into single crystals, which then aggregate into polycrystalline pyrite. During crystal growth, the overlying pressure during diagenesis causes lateral growth to outpace vertical growth, resulting in laminar pyrite layers [16].

The sulfate minerals in the No. 3 coal seam are primarily barite, anhydrite, and gypsum. In this study, anhydrite was detected only in the MHL-3-4 sample, typically considered a product of low-temperature coal ash formation. When gypsum in coal samples is heated to around 150°C, most of the crystallization water is removed, converting it to anhydrite ($CaSO_4 \cdot 1/2H_2O$). Some studies suggest that anhydrite might form during low-temperature ash formation due to reactions between organic sulfur and Ca associated with organic matter [17-21]. Barite was detected in three samples (3-HC, 3-BZ, and MHL-3-17), with SEM observations showing barite occurring as dispersed particles alongside authigenic calcite and pyrite (Fig. 6).

4.5Feldspar

In some roof and coal seam samples from the No. 3 coal seam, sodic and potassic feldspar were detected. SEM observations with energy-dispersive spectroscopy (EDS) reveal that feldspars in the coal seams are mainly found as discrete particles within the clay matrix, sometimes aligned with detrital quartz along bedding planes, suggesting compaction during diagenesis, and indicating a terrigenous origin for these minerals (Fig.8).

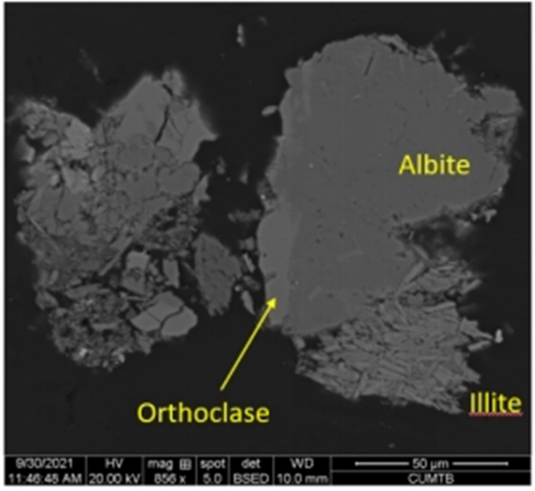

Fig. 8 Albite and orthoclase, under SEM, back scattered image

Some feldspar particles have undergone alteration and dissolution, resulting in the formation of dissolution pits on their surfaces, which are filled with secondary minerals such as pyrite. Composite particles of sodic and potassic feldspar were also observed under SEM.

5. Conclusions

The minerals in the No. 3 coal seam of the Mahuangliang Coal Mine are predominantly kaolinite, quartz, pyrite, calcite, dolomite, and ankerite. In some individual coal seam samples, chlorite, illite, calcite, albite, siderite, and rutile are also present. The quartz in the No. 3 coal seam of the Mahuangliang Coal Mine is primarily detrital quartz from the sedimentary source region, appearing as small particles sporadically distributed within the organic matter. There is also a minor amount of quartz filling fractures. Clay minerals are mainly composed of kaolinite, which predominantly fills the plant cell cavities, with a minor fraction present as detrital particles and fracture fillings from the sedimentary source region. The carbonate minerals in the No. 3 coal seam primarily consist of calcite, dolomite, ankerite, and siderite. Calcite, dolomite, and ankerite mainly occur as fracture fillings and within plant cell cavities, with occasional occurrences of calcite replacing kaolinite within the cell cavities. Siderite is mostly found as radiating aggregates within the organic matter. Pyrite mainly occurs as fracture fillings.

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References

1. Qin G H. Characteristics and genetic types of trace element enrichment in late Paleozoic coal in Ordos Basin [D]. China University of Mining and Technology (Beijing), 2020.
2. Zhang H,He Z,Jin X,et al. Tectonic Evolution and Coal Formation in the Ordos Basin - Brief Explanation of the 1:500,000 Geological Structure Map of the Ordos Basin[M]. Geology Press, Beijing: 2005: 1-2.
3. Hussain R, Luo K. Geochemical evaluation of enrichment of rare-earth and critical elements in coal wastes from Jurassic and Permo-Carboniferous coals in Ordos Basin, China[J]. Natural Resources Research, 2020, 29: 1731-1754.
4. Ning S Z, Huang S Q, Liu K, et al. Genetic correlation of abnormal metal enrichment in coal from northern and southern margins of Ordos Basin [J]. Journal of China Coal Society,2022,47(05):1795-1807.
5. Huang S Q, Ning S Z, Liu K, et al. Distribution characteristics of trace elements in coal in Ordos Basin [J]. Coal Geology of China,2021,33(S1):7-11.
6. Li J, Wang D H, Zhang H, et al. Origin and resource potential evaluation of Al-Ga-Li-Nb(Ta)-Zr(Hf) co-enrichment in coal measures in Lausangou outer exploration area, Junge Coalfield [J]. Journal of geology, 2024, 98 (08): 2299-2315.
7. Huang X L, Liang S L, Wang P L, et al. Sedimentary characteristics and sedimentary environment of Yan 'an Formation in the northwest margin of Dongsheng coalfield [J]. Coal Geology of China,2023,35(10):8-13+2.
8. Li M F, Ma D, Li L, et al. Geochemical characteristics and paleoenvironmental significance of Jurassic coal in Dongsheng coalfield, Ordos Basin [J]. Acta Geologica Sinica, 2019,98(08):2409-2423.

9. Dai S f, Zhao L, Wei Q, et al. Key metal resources in coal measures in China: enrichment types and distribution [J]. Chinese Science Bulletin,2020,65(33):3715-3729.
10. Dai S F,Zhao L, Wang N, et al. Advance and prospect of research on the mineralization ofcritical elements in coal-bearing sequences. BulletinofMineralogy,Petrology and Geochemistry,2024,43(1):49-63.
11. Dai S F, Liu C Y, Zhao L, et al. Strategic metal mineral resources in coal measures: significance and challenges [J]. Journal of China Coal Society,2022,47(05):1743-1749.
12. Zhao L, Wang X B, Dai S F. Lithium minerals in coal measures: occurrence, distribution, mineralization and resource potential [J]. Journal of China Coal Society,2022,47(05):1750-1760.Huang W, Ao W, Wen C, et al. Characteristics of coal petrology and genesis of Jurassic coal in Ordos Basin[J]. Geoscience, 2010, 24 (6):1186-1197.
13. Finkelman R B. Modes of occurrence of trace elements and minerals in coal: an analytical approach[M]. New York: 1982.
14. Ji D. Geochemistry Characteristics and Metamorphic Mechanism of High-rank Carboniferous Coal from Northern Guangxi Province, China [D]. China University of Mining & Technology, Beijing, 2017.
15. Liu D, Yang Q, Zhou C, et al. Occurrence and geological genesis of pyrites in Late Paleozoic coals in North China[J]. Geochimica, 1999, 4(28): 340-350.
16. Liu J, Ward C R, Graham I T, et al. Modes of occurrence of non-mineral inorganic elements in lignites from the Mile Basin, Yunnan Province, China[J]. Fuel, 2018, 222:146-155.
17. Ward C R. Mineral matter in low-rank coals and associated strata of the Mae Moh basin, northern Thailand[J]. International Journal of Coal Geology, 1991, 17:69-93.
18. Frazer F W, Belcher C B. Quantitative determination of the mineral-matter content of coal by a radiofrequency oxidation technique[J]. Fuel, 1973, 52:41-46.
19. Li Z, Ward C R, Gurba L W. Occurrence of non-mineral inorganic elements in macerals of low-rank coals[J]. International Journal of Coal Geology, 2010, 81:242-250.
20. Ward C R, Matulis C E, Taylor J C, et al. Quantification of mineral matter in Argonne Premium Coals using interactive Rietveld-based X-ray diffraction [J]. International Journal of Coal Geology, 2001, 46:67-82.
21. Hussain R, Luo K. Geochemical evaluation of enrichment of rare-earth and critical elements in coal wastes from Jurassic and Permo-Carboniferous coals in Ordos Basin, China[J]. Natural Resources Research, 2020, 29: 1731-1754.