Distribution Characteristics and Enrichment Factor Gallium in Coal Seam No.4 in Majialiang-Fangziping area, Fugu mining area

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Abstract. Based on the latest exploration data in the study area, the distribution of gallium in the 4 coal seams in Majialiang Fangping area of Fugu mining area and its geological influencing factors are analyzed. The results show that the weighted average mass fraction of gallium is 18 μg/g, which is 1-4 times higher than the global average. The yield of ash and the content of SiO₂ and Al₂O₃ in coal ash are positively correlated with the content of gallium in coal. The content of total sulfur, organic sulfur, Fe₂O₃ in coal ash and the index of ash composition have negative correlation with the content of gallium in coal. These characteristics indicate that the mineral carrier of gallium in coal is mainly clay mineral, and the peat swamp with strong hydrodynamic force and weak reducibility may be conducive to the enrichment of gallium in coal.

1. Introduction
Coal quality characteristics play a decisive role in the development and utilization of coal resources. In this study, by comparing the experimental data of coal quality, the distribution characteristics of gallium elements in No. 4 coal in Majialiang Fangping area are analyzed, and the geological influencing factors are discussed, which has guiding significance for the comprehensive utilization of coal resources.

2. Geological overview
Majialiang Fangping is located in the north of Fugu County, about 45-60km away from the county, in a north-south zonal distribution, about 10.77-14.12km long in the north-south direction, about 7.7km wide in the east-west direction, and about 101km² in area. The administrative divisions are under the jurisdiction of Ma Town and Ha town, Fugu County, Shaanxi Province.

The coal bearing strata in the study area are the upper Carboniferous Taiyuan Formation (c²t) and the lower Permian Shanxi Formation (p₁s). There are five minable coal seams, numbered 2, 4, 6, 8 and 9-2 coal seams from the top to the bottom. Coal seams 2 and 4 are located in the Shanxi Formation, and coal seams 6, 8 and 9-2 are located in the Taiyuan formation.

Coal seam 4 is one of the main minable coal seams in the area, which is located in the upper part of the first cycle of Shanxi formation, with stable horizon and wide distribution. The thickness is 5.17-24.88m, with an average of 10.82m. The structure of the coal seam is complex and complex, generally containing 3-5 layers of gangue. The lithology of the gangue is mainly mudstone, followed by carbonaceous mudstone. The No.4 coal seam is thick and abundant in resources. It is of great
significance for the comprehensive development and utilization of coal resources in the future to analyze and study the distribution characteristics of gallium elements in the coal.

3. Coal quality characteristics

The macroscopic coal rock types of No.4 coal seam are mainly semi bright and semi dim type, followed by dim type, occasionally bright type. According to the drilling micro coal rock data (Table 1), the total organic content of coal seam 4 is 75.6-91.7%, and the vitrinite content is 33.9-55.6%. The vitrinite mainly consists of matrix vitrinite, homogeneous vitrinite and structural vitrinite; the inertinite content is 31.2-38.8%, mainly consisting of filar body, hemifilar body and their fragments, coarse-grained body and elastic inertinite; the shell content is 2.7-3.9%, mainly consisting of sporophyte Cuticle, resinite and bark. The inorganic macerals are mainly clay minerals, which are massive, micro layered and filled with cell cavities, accounting for 6.9-23.7%, followed by carbonate minerals, which are calcite vein like and filled in fractures, accounting for 0.8-1.3%.

| No. | Drilling number | Micro quantitative results of coal and rock (%) | Total organic content | Average maximum reflectivity (%) |
|-----|----------------|-----------------------------------------------|----------------------|---------------------------------|
| 4   | 0-5            | Vitrinite 33.9 Inert 38.8 Chitin 2.9           | 75.6                 | 23.7                            | 0.8                             | 24.4                            | 0.70                            |
| 4   | 8-9            | Vitrinite 55.6 Inert 31.2 Chitin 3.9           | 90.6                 | 8.7                             | 0.8                             | 9.4                             | 0.74                            |
| 4   | 23-1           | Vitrinite 53.1 Inert 31.2 Chitin 3.2           | 87.5                 | 11.6                            | 1.0                             | 12.5                            | 0.73                            |
| 4   | 24-13          | Vitrinite 54.2 Inert 34.8 Chitin 2.7           | 91.7                 | 6.9                             | 1.3                             | 8.3                             | 0.74                            |

No.4 coal is classified according to China Coal Classification (GB / T 5751-2009). No.4 coal is mainly composed of gas coal and a small amount of 1/2 Sticky coal. The sulfur and ash content of coal seam are relatively low. According to the standard for classification of coal quality (GB / T 15224-2010), coal 4 is generally low ash medium ash low sulfur coal. In terms of sulfur composition, pyrite sulfur generally accounts for about 2/3 of total sulfur, i.e. inorganic sulfur is the main sulfur (Table 2).

The ash composition in coal is mainly composed of SiO2, Al2O3, Fe2O3, Cao and MgO, and the sum of the five items accounts for more than 90%; the sum of SiO2 and Al2O3 accounts for more than 80% of the ash composition, and the relationship between the sum and the content of Fe2O3 is the same (Table 1). Indicating that the minerals in coal are mainly clay minerals, and the positive correlation between Fe2O3 content and sulfide sulfur content indicates that sulfide sulfur in coal mainly comes from pyrite minerals (Fig. 1).
isomorphic replacement, replacing Al with Gallium, as a typical dispersed element, mainly enters into the lattice of other minerals in the form of clay minerals. In other words, the mineral carrier of gallium in the coal is mainly clay mineral.

swamp is favorable for the enrichment of gallium in coal. First, the coal is mainly composed of terrigenous clastic materials, and the strong hydrodynamic condition of peat swamp is favorable for the enrichment of gallium in coal. The occurrence state and genetic mechanism of gallium in coal are discussed.

The statistical analysis of 60 coal core samples shows that the gallium content of 4 coals in this area is 4-56 μg/g, and the weighted average value is 18 μg/g. The average mass fraction of gallium in global coal is 6 μg/g. The content of gallium in coal in this area is about 1-4 times higher than the global average. Among them, the highest content of gallium in single sample is 24-13 holes, the mass fraction of gallium is 56 μg/g, and that in 15-5 holes is 32 μg/g, that in 16-9 holes is 42 μg/g, and that in 23-5 holes is 56 μg/g, and the mass fraction of gallium in 0-5 holes is 38 μg/g, that in 0-9 holes is 31 μg/g, that in 7-1 holes is 31 μg/g, that in 15-5 holes is 32 μg/g, that in 16-9 holes is 42 μg/g, and that in 23-5 holes is 33 μg/g.

4. Distribution characteristics of gallium in coal
According to the statistics of 60 coal core samples, the gallium content of 4 coals in this area is 4-56 μg/g, and the weighted average value is 18 μg/g. The average mass fraction of gallium in global coal is 6 μg/g. The content of gallium in coal in this area is about 1-4 times higher than the global average. Among them, the highest content of gallium in single sample is 24-13 holes, the mass fraction of gallium is 56 μg/g, and the mass fraction of gallium in 0-5 holes is 38 μg/g, that in 0-9 holes is 31 μg/g, that in 7-1 holes is 31 μg/g, that in 15-5 holes is 32 μg/g, that in 16-9 holes is 42 μg/g, and that in 23-5 holes is 33 μg/g.

5. Occurrence state and genetic mechanism of gallium in 4 coal
The statistical analysis of 60 coal samples shows that the gallium content of coal in the area has a certain correlation with the parameters of ash yield, sulfur analysis and ash composition analysis. Furthermore, the occurrence state and genetic mechanism of gallium in coal are discussed.

Firstly, there is a positive correlation between the ash yield and the gallium content in the coal. As the ash yield increases, the gallium content in the coal tends to increase (Figure 2). On the one hand, the ash yield of coal and the content of organic matter in coal are in a relationship of one change to another. The higher the ash yield, the lower the proportion of organic matter in coal. On the other hand, the ash in coal mainly comes from terrigenous clastic material. The higher the content of terrigenous clastic material, the stronger the hydrodynamic condition of peat swamp to some extent. Therefore, gallium in coal is mainly composed of terrigenous clastic materials, and the strong hydrodynamic condition of peat swamp is favorable for the enrichment of gallium in coal.

Secondly, the content of SiO2 and Al2O3 in ash increases, and the content of gallium in coal increases accordingly (Fig. 3). Indicating that there is also a positive correlation between SiO2 and Al2O3 content, which is an indication of aluminosilicate minerals. Aluminosilicate minerals in coal are usually clay minerals. In other words, the mineral carrier of gallium in the coal is mainly clay mineral. Gallium, as a typical dispersed element, mainly enters into the lattice of other minerals in the form of isomorphic replacement, replacing Al3+ and some Fe3+ and Ti4+ ions in minerals. It can also replace part of silicon in silicon oxygen tetrahedron with gallium.

Table 2. Basic data of coal 4 in Majialiang Fangping area of Fugu mining area

| Drilling number | Coal seam | Industrial Analysis Wb/% | Sulfur analysis Wb/% | Composition analysis of coal ash Wb/% | (Ga)μg/g |
|-----------------|-----------|--------------------------|----------------------|--------------------------------------|---------|
|                 |           | Ad | Vdaf | St,d | Ss,d | Sp,d | So,d | FeO | Al2O3 | CaO | MgO | SiO2 | Max | min | average |
| 0-1             | 4         | 17.16 | 39.92 | 0.66 | — | — | — | — | — | — | — | — | 5.84 | 36.53 | 7.13 | 0.46 | 41.55 | 20 | 6 | 14 |
| 0-5             | 4         | 19.38 | 36.16 | 0.32 | 0.01 | 0.08 | 0.23 | — | — | 3.41 | 45.77 | 2.95 | 0.38 | 40.43 | 38 | 15 | 27 |
| 0-9             | 4         | 21.71 | 38.91 | 0.37 | 0.01 | 0.08 | 0.28 | — | — | — | — | — | — | 31 | 18 | 23 |
| 7-1             | 4         | 32.47 | 36.99 | 0.35 | 0.01 | 0.06 | 0.28 | — | — | — | — | — | — | 31 | 31 | 31 |
| 7-1             | 4         | 24.14 | 35.02 | 0.42 | 0.01 | 0.13 | 0.28 | — | — | — | — | — | — | 25 | 25 | 25 |
| 7-1             | 4         | 21.89 | 38.55 | 0.39 | 0.01 | 0.16 | 0.22 | 5.55 | 38.72 | 4.52 | 0.57 | 42.46 | 25 | 16 | 21 |
| 7-5             | 4         | 31.26 | 38.66 | 0.38 | — | — | — | — | — | — | — | — | — | 23 | 20 | 21 |
| 7-9             | 4         | 20.98 | 38.47 | 0.81 | 0.01 | 0.36 | 0.43 | 3.82 | 31.88 | 10.2 | 0.26 | 42.53 | 24 | 11 | 18 |
| 8-5             | 4         | 24.4 | 39.25 | 0.39 | — | — | — | — | — | — | — | — | — | 29 | 9 | 19 |
| 8-9             | 4         | 19.99 | 39.21 | 0.46 | 0.01 | 0.05 | 0.41 | 3.7 | 36.01 | 6.53 | 0.75 | 44.01 | 14 | 12 | 12 |
| 8-15            | 4         | 28.52 | 39.75 | 0.42 | 0.01 | 0.05 | 0.36 | 2.25 | 41.57 | 9.38 | 0.33 | 38.12 | 32 | 32 | 32 |
| 8-15            | 4         | 21.52 | 38.36 | 0.43 | 0.01 | 0.05 | 0.37 | 3.44 | 44.85 | 6.96 | 0.43 | 35.57 | 22 | 13 | 16 |
| 15-1            | 4         | 23.1 | 40.38 | 0.41 | — | — | — | 3.51 | 37.32 | 5.61 | 0.48 | 45.68 | 26 | 12 | 17 |
| 15-5            | 4         | 35.72 | 39.01 | 0.45 | 0.01 | 0.02 | 0.42 | 3.03 | 39.57 | 3.57 | 0.39 | 44.38 | 36 | 36 | 36 |
| 15-5            | 4         | 27.61 | 37.55 | 0.44 | 0.01 | 0.04 | 0.39 | — | — | — | — | — | — | 21 | 21 | 21 |
| 15-9            | 4         | 17.65 | 38.1 | 0.48 | — | — | — | — | — | — | — | — | — | 28 | 9 | 14 |
| 16-9            | 4         | 14.72 | 38.16 | 0.34 | — | — | — | — | — | — | — | — | — | 42 | 11 | 21 |
| 23-1            | 4         | 20.95 | 38.76 | 0.4 | 0.01 | 0.06 | 0.32 | 2.48 | 38.44 | 3.74 | 0.24 | 47.27 | 19 | 12 | 15 |
| 23-5            | 4         | 22.2 | 38.48 | 0.42 | — | — | — | — | — | — | — | — | — | 33 | 9 | 20 |
| 24-13           | 4         | 18.3 | 38.58 | 0.5 | 0.01 | 0.24 | 0.38 | 9.13 | 31.16 | 8.17 | 0.88 | 41.21 | 56 | 4 | 15 |
Thirdly, the content of total sulfur, organic sulfur and Fe\textsubscript{2}O\textsubscript{3} in coal ash has a negative correlation with the content of gallium in coal (Figure 4A-figure 4C). It can be seen from Figure 1 that Fe\textsubscript{2}O\textsubscript{3} in coal mainly comes from pyrite. Therefore, the negative correlation between Fe\textsubscript{2}O\textsubscript{3}, total sulfur and gallium content in coal indicates that the environmental conditions favorable for pyrite formation may be unfavorable for gallium enrichment. Compared with total sulfur, the negative correlation between organic sulfur content and gallium content in coal is more significant. Usually, the stagnant flow of the marsh water leads to the enhancement of the reducibility of the sedimentary water medium, which is conducive to the formation of pyrite and other minerals. The other side also promotes the gelation process, which makes the sulfate ion and organic matter combine to generate organic sulfur. The organic sulfur content formed in the syngenetic-quasi syngenetic stage is more indicative of sedimentary environment. Therefore, the environment of peat swamp with strong reducibility may be unfavorable to the enrichment of gallium.

Fourth, there is a negative correlation between gallium content and ash composition index (Fig. 4D). Zhao Shiqing[1981] established the coal ash composition index RI=[Fe\textsubscript{2}O\textsubscript{3}+MgO+Cao]/[SiO\textsubscript{2}+Al\textsubscript{2}O\textsubscript{3}] by studying the late Paleozoic Coal in North China to judge the reduction degree of peat swamp. Generally, the greater the index of ash composition, the stronger the reducibility of peat swamp. Therefore, the negative correlation between the content of gallium in the coal and the index of ash composition indicates that the condition of peat swamp with strong reducibility is not conducive to the enrichment of gallium.

![Fig. 1 Correlation between sulfide sulfur Fe\textsubscript{2}O\textsubscript{3} contents in coal seam](image1)

![Fig. 2 Correlation between gallium content and ash yield in coal seam](image2)

![Fig. 3 Correlation between gallium and SiO\textsubscript{2},Al\textsubscript{2}O\textsubscript{3} contents in coal seam](image3)
6. Conclusion
1) The weighted average mass fraction of gallium in the four coal seams in Majialiang Fangping area is 18 μg/g, which is 1-4 times higher than the global average. The content of gallium in some drilling coal exceeds its boundary grade.

2) With the increase of the ash yield and the content of SiO2 and Al2O3, the content of gallium tends to increase. It shows that the main mineral carrier of gallium in coal is clay mineral.

3) The content of total sulfur, organic sulfur, Fe2O3 in coal ash and the index of ash composition have negative correlation with the content of gallium in coal. With the increase of total sulfur, organic sulfur, Fe2O3 content and ash composition index, gallium content in coal tends to decrease. Therefore, the conditions of peat swamp with strong hydrodynamic force and weak reducibility are beneficial to the enrichment of gallium in coal.

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