Study on Uranium Minerals and Metallogenic Material Sources of Huayang Chuan Uranium Polymetallic Deposit

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Abstract. Huayangchuan uranium polymetallic deposit is located in Huaxian County, Huayin City, Shaanxi Province. The geotectonic location belongs to the Xiaojinling intracontinental orogenic belt on the southern margin of the North China block. Uranium ore bodies are layered, vein-like and thick reticulated veins. The average content of uranium is 2×10⁻⁴ in the deposit. Through microscopic identification and electron probe analysis, we believe that uranium minerals are mainly betafite, crystalline uranium and uranothorite. According to the characteristics of rare earth elements in uranium ores, we believe that the ore-forming materials mainly come from the mantle.

1. Introduction
Huayangchuan uranium polymetallic deposit is located in Huaxian County, Huayin City, Shaanxi Province. The geotectonic location belongs to the Xiaojinling intracontinental orogenic belt on the southern margin of the North China block[1]. The outcropped strata in the mining area are mainly Archaean Taihua Group and Mesoproterozoic Middle-Upper Xionger Group[2]. Uranium ore bodies are layered, vein-like and thick reticulated veins. The orebody shows obvious characteristics of planar mineralization. The main orebody is buried North-west. The average content of uranium is 2×10⁻⁴ in Huayangchuan uranium deposit. In this paper, the main types of uranium minerals are determined by microscopic identification and electron probe analysis in the deposit. The source of ore-forming materials is discussed through the analysis of rare earth elements in uranium ores.
2. Analysis of Uranium Minerals

![Figure 1. Yellow betafite (a), red betafite (b), characteristics of betafite under single polarizing microscope (c), BSE image of crystalline uranium ore (d), crystalline uranium ore in the betafite (e), characteristics of uranium-thorium ore under single polarizing light (f).](image)

2.1. Characteristics of betafite
Betafite in Huayang Sichuan hand specimens are mostly red, dark red, brown yellow and brown yellow (Figure 1a, b). With the increase of mineral particles, the diameter of individual self-shaped crystal particles can reach more than 5 mm. Betafite is red, dark red and yellowish brown in single polarized light, with very high protuberance. Betalite is well developed with cubic crystal shape, or with continuous crystal structure and ring structure (Figure 1c). Betalite has the characteristics of translucent minerals. Its reflective color is light gray, and its reflectivity is lower than that of magnetite. Its reflectivity is about 10. Electron probe data showed that the content of $\text{UO}_2$ was 27.876% - 34.463%. The content of $\text{Nb}_2\text{O}_5$ was 28.87% - 38.373%. The content of $\text{TiO}_2$ was 12.13% - 21.48%.

Betalite occurs in complex and diverse environments in Huayangchuan mining area, including gneiss surrounding rocks, granite porphyry, pegmatite and carbonate rocks. The mineral assemblages are mainly as follows: amphibole + betafite + mica; betalite + aegirine + banyan + apatite; betalite + monazite + brown epidote + mica, etc.

2.2. Characteristics of crystalline uranium ore
Crystalline uranium ore ($\text{UO}_2$) often contains a small amount of Th, Ca, Pb. Crystalline uranium deposits in Huayangchuan deposit are less distributed than betafite, but they are also the main uranium-bearing minerals. The hand specimens show that the crystalline uranium minerals are black and mainly occur in mica and Niobium-Titanium uranium ore. Crystalline uranium is difficult to identify under microscopy, and is mainly confirmed by electron probe. The backscattering pattern of uranium crystals shows that it occurs at the edge of betafite particles (Fig. 1d) and in the betafite ring (Fig. 1e). The content of $\text{UO}_2$ was 86.197% - 91.383%, with an average of 88.304% by means of electron probe analysis. $\text{ThO}_2$ content ranged from 2.95% to 6.141%, with an average of 4.924%.

2.3. Characteristics of uranothorite
U, Th, Pb, Fe, Ca, Mn and other elements are contained in uranothorite in Huayangchuan mining area. The mineral contains very high thorium and uranium elements and is the main thorium and uranium mineral in the mining area. It occurs in carbonate and pegmatite. The uranothorite in Huayangchuan mining area is yellow granular when it occurs in carbonate rocks. In pegmatite, it occurs in late veins with betafite and epidote. The size of uranium thorite particles ranges from 300 to 1000 microns. Under transmission polarization microscope, the uranium thorite particles are yellow, earthy yellow, granular...
and highly protuberant. It is completely extinction under orthogonal polarizing mirror. It has a gray tone under reflected light and a low reflectivity (Fig. 1f). ThO$_2$ content of uranothorite is 49.15%~66.43%, with an average of 59.34%. UO$_2$ content ranged from 11.8% to 29.04%, with an average of 19%. The content of SiO$_2$ accounted for 15.78%~18.11%, with an average of 16.91%.

3. Characteristics of Rare Earth Elements in Uranium Ore

Twelve uranium ores of the deposit were collected and analyzed for rare earth elements. The material source and tectonic environment of uranium ores were discussed. Rare earth element analysis was completed in the testing center of Zhongshan Nuclear Industry Group. The test results are shown in Table 1.

| Sample number | Ore types            | La  | Ce  | Pr  | Nd  | Sm  | Gd  | Tb  | Dy  | Ho  | Er  | Tm  | Yb  | Lu  | ΣREE | Uranium |
|---------------|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|----------|
| HYC-01        | Carbonate Type Ore   | 166 | 322 | 31  | 143 | 20  | 19  | 3   | 10  | 2   | 6   | 1   | 6   | 1    | 734     | 1.2      |
| HYC-02        |                      | 104 | 213 | 25  | 112 | 18  | 16  | 2   | 10  | 2   | 6   | 1   | 6   | 1    | 522     | 2.1      |
| HYC-03        |                      | 70  | 162 | 23  | 84  | 16  | 13  | 2   | 10  | 2   | 5   | 1   | 6   | 1    | 402     | 1.0      |
| HYC-04        | Uranium Ore          | 103 | 176 | 23  | 84  | 16  | 12  | 2   | 9   | 2   | 5   | 1   | 5   | 1    | 445     | 1.4      |
| HYC-05        |                      | 83  | 155 | 19  | 78  | 15  | 15  | 2   | 9   | 2   | 5   | 1   | 5   | 1    | 397     | 1.6      |
| HYC-06        |                      | 68  | 132 | 19  | 67  | 13  | 12  | 2   | 8   | 2   | 4   | 1   | 4   | 1    | 336     | 1.4      |
| HYC-07        |                      | 145 | 264 | 28  | 120 | 25  | 21  | 4   | 14  | 3   | 8   | 1   | 9   | 2    | 654     | 2.6      |
| HYC-08        | Aegirine-Bearing     | 116 | 181 | 24  | 93  | 17  | 16  | 3   | 11  | 3   | 6   | 1   | 7   | 1    | 486     | 3.3      |
| HYC-09        | Carbonate Type Ore   | 70  | 123 | 17  | 57  | 11  | 9   | 1   | 6   | 1   | 3   | 1   | 4   | 1    | 308     | 2.2      |
| HYC-10        |                      | 94  | 160 | 23  | 79  | 14  | 12  | 2   | 7   | 1   | 4   | 1   | 4   | 1    | 406     | 2.4      |
| HYC-11        |                      | 150 | 267 | 27  | 108 | 24  | 21  | 3   | 14  | 3   | 8   | 1   | 9   | 2    | 644     | 2.5      |
| HYC-12        |                      | 69  | 132 | 18  | 63  | 13  | 10  | 2   | 7   | 2   | 4   | 1   | 4   | 1    | 331     | 2.4      |

The uranium content of carbonate-type uranium ores is 2.2×10$^{-4}$-3.3×10$^{-4}$, with an average value of 2.6×10$^{-4}$+10$^{-4}$, with an average value of 473×10$^{-6}$, rare earth content is higher. The distribution curve of rare earth elements inclines to the right, showing the characteristics of light rare earth enrichment (Figure 2a). The value of LREE/HREE was 8.87-14.32, with an average of 10.47. The fractionation degree of light and heavy rare earth is obvious. The value of δEu is 1.06-1.28, and the average value is 1.15. δEu shows weak positive anomaly. The uranium content of aegirine-bearing carbonate-type uranium ore is 1.0×10$^{-4}$-2.1×10$^{-4}$, with an average value of 1.4×10$^{-4}$. The REE value is 308×10$^{-6}$-654×10$^{-6}$, the average value is 471×10$^{-6}$. The distribution curve of rare earth elements inclines to the right (Figure 2b). The value of δEu is 1.15-1.33, and the average value is 1.21. The REE characteristics of the two uranium ores are similar and have the characteristics of mantle-derived carbonate rocks[3]. Therefore, we believe that the ore-forming materials are derived from the mantle[4].
Figure 2. Rare earth partition curve of carbonate rock type uranium ore (a) and neonite carbonate-type uranium ore (b)

4. Conclusion
Based on the above studies, we believe that the uranium minerals in Huayangchuan uranium deposit are mainly beta, crystalline uranium and uranothorite. Betalite is the main uranium mineral. According to the analysis of rare earth elements in uranium ores, it is considered that the ore-forming materials mainly come from the mantle.

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