

Relationship between sandstone-type uranium deposits and hydrocarbon in the northern ordos basin

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Abstract. The Ordos Basin is one of the largest prolific basins and also one of the most important uranium-bearing basins in China. It is characterized by the coexistence of petroleum and uranium in the northern part of the basin. To understand the coexistence mechanism, more studies are called for on the genesis of sandstone-type uranium deposits in the northern part of the basin, especially on the role of hydrocarbon in uranium mineralization. In this study, we investigated the relationship between uranium and hydrocarbon in the northern Ordos Basin using the methods of petrology, mineralogy and geochemistry. Our results show that the hydrocarbon seepage plays an important role in the mineralization of sandstone-type uranium deposits. It greatly affects the reduction in mineralization and the environmental rehabilitation to protect the ore body from being destroyed by the groundwater after mineralization.

1. Introduction

The organic-inorganic interaction has been a hot and challenging research topic in earth science [1-3]. In the current uranium mineralization theory, one important issue concerning the interaction is the relationship between hydrocarbon (organic) and sandstone-type uranium deposit (SUD) (inorganic). In fact, that uranium deposits coexisting with hydrocarbon or bitumen has been found worldwide, such as in some basins of Texas, Colorado Plateau, Europe, and Tarim Basin of China [4-5]. The study on the role of hydrocarbon in uranium mineralization has important scientific significance and application value for in-depth understanding of the relationship of organic-inorganic symbiotic accumulation and mineralization.

The Ordos Basin is one of the largest oil-gas basins in China. Oil, gas, coal and uranium coexist in the basin. In recent years, many world-class SUDs have been discovered. However, there is some controversy about the origin of ore deposits [6-7]. It is not yet known whether the oil and gas take part in the uranium mineralization process or not. This not only has become a difficult scientific problem, but also has hindered the expansion of deposit scale. The present study was therefore conducted to investigate the relationship between hydrocarbon and SUDs using the methods of petrology, mineralogy and geochemistry. We aimed to better understand the role of hydrocarbon in uranium mineralization



and to understand the uranium mineralization mechanism. The potential exploration direction was also proposed.

2. Geological setting and deposit profile

The Ordos Basin is a large depression-type basin located in the west of the North China craton. It is in the first quadrant of "Cross Tectonic Belt", spanning over 25×10^4 km. The Ordos Basin is surrounded by mountains, with the Cenozoic graben basins in between separating them (Fig. 1). The Paleozoic and Meso-Cenozoic sedimentary strata have been formed in the basin. The Ordos Basin produces a variety of energy minerals such as oil and gas, coal and SUDs, and therefore being a large energy base of China. The SUDs in the northern Ordos Basin were mainly produced in Zhiluo Formation sandstone of Jurassic, with a (super) large scale (≥ 10000 t), and even world-class scale in some parts. The Zhiluo Formation can be divided into upper and lower units from the bottom upward. The uranium mineral was produced in the second section of the lower unit ($J_2Z_1^2$) (Fig. 1), and the ore-bearing rocks are gray medium-sized sandstones.

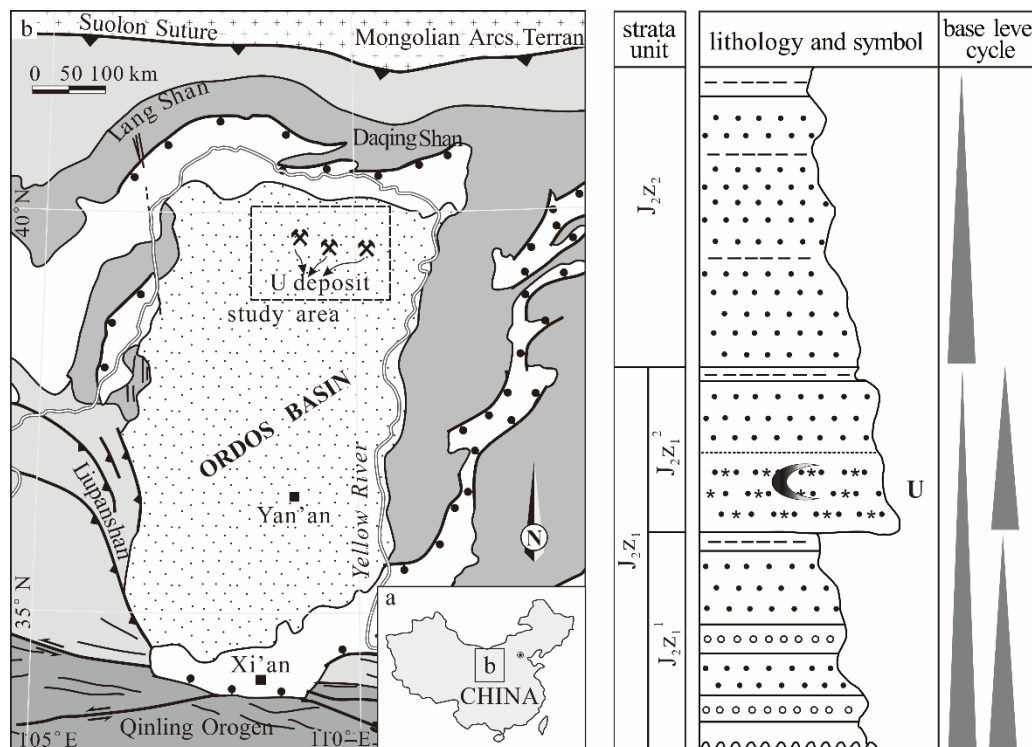


Figure 1. Geological setting and Stratigraphic column of Middle Jurassic Zhiluo Formation in the Ordos Basin (left: modified from [8])

3. Petrologic characteristics

3.1. Characteristics of field outcrop and core

The geological characteristics of ore-bearing rocks can be seen from Shenshangou field outcrop in the northern Ordos basin. Zhiluo Formation is mainly composed of grey and green sandstones, and the red sandstone is visible in the outcrop and well core. The gray sandstone contains a large number of plant charcoal chips and coal debris, and some green sandstones have red patches (Fig. 2). It can be inferred from the structural morphology that the red patches might be residues of the green altered sandstone, which suggests that the early red sandstone has been altered and changed into green sandstone by certain fluid in a later stage, but there remained a portion of red sandstones that has not been altered completely.

Zhiluo Formation has also developed lots of calcareous sandstones, which were mainly cemented by calcite. These calcareous sandstone nodules were arrayed in a discontinuously line along the strata (Fig. 2). Their density is significantly higher than that of the surrounding rocks. This is because that the calcareous sandstones foamed when they encountered hydrochloric acid.



Figure 2. Outcrop profiles and core characteristics of the northern Ordos Basin

A: outcrop of bleached sandstone; B: altered sandstone; C: linear arrayed calcareous sandstone concretion; D: green sandstone including remaining red sandstone; E: grey sandstone; F: grey sandstone with coal debris; G: red sandstone with green spot

3.2. Mineralogy characteristics

The thin slices of various altered sandstones and uranium ores were observed. The results show that the color of the red sandstone is mainly caused by the minerals such as limonite, and the color of the green sandstone is mainly caused by the chlorite film. Moreover, the calcareous sandstone is cemented. Its particles, floating in the cements, are composed mostly of quartz and feldspar. Under the optical microscope, the calcareous sandstone is shown to have the inclusions, which contain hydrocarbon substances, as evidenced by the fluorescence.

The results of the Electron Probe Microanalysis (EPMA) show that uranium ores and pyrites are closely symbiotic. Uranium ores are surrounded by pyrites (Fig. 3). This indicates a possible link of

causes between the two. The uranium minerals are mainly coffinite ($\text{U}(\text{SiO}_4)_{1-\omega}(\text{OH})_{4\omega}$) and uraninite ($\text{mUO}_2 \cdot \text{nUO}_3$).

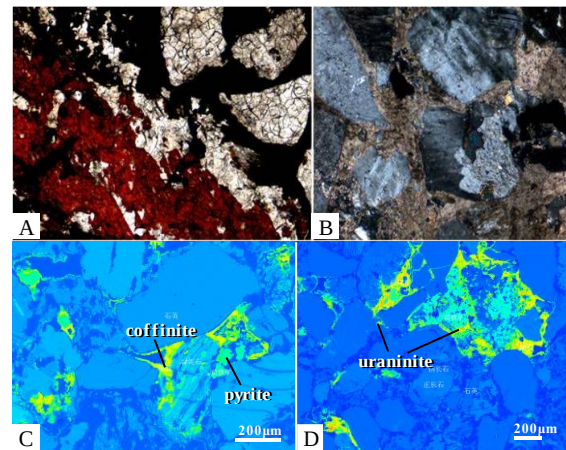


Figure 3. Calcite cement and uranium mineral in sandstone

4. Geochemical characteristics

The essence of alteration is the interaction between fluids and rocks, which causes the change of the composition of rocks and minerals. In fact, the change of the composition can be characterized by geochemical characteristics. They can indicate the migration and emigration of rocks, and thus can reflect the fluid alteration of rocks. In this study, we selected four different types of rocks (10 pieces per type) to perform the major element analysis (Fig. 4). The results for the rocks of the same type were averaged.

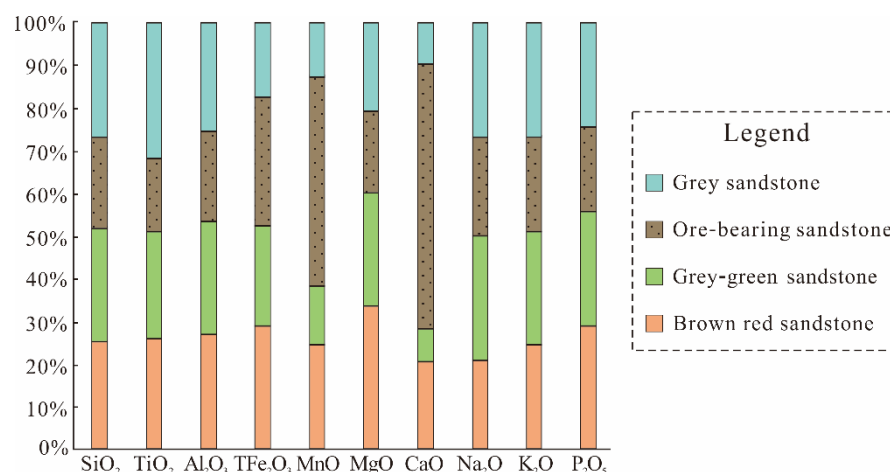


Figure 4. Distribution characteristics of major element content of four types of altered sandstone

1) The amount of TFe_2O_3 in the three altered sandstones increases slightly compared to that in the grey sandstone, indicating that there is the migration of Fe in the process of fluid alteration. Moreover, the amount of TFe_2O_3 in the gray-green sandstone is lower than that in the brown red sandstone, which indicates the changes of the valence state of Fe and the migration of Fe in the later stage of the secondary reduction of oil and gas.

2) The amount of Al_2O_3 in the four rocks (more than 11%) is almost the same, which is higher than that of the normal lithic sandstone (8.1%) and the feldspar sandstone (8.7%). This indicates that the four

rocks contain a high proportion of clay minerals, and the hydrolysis of feldspars and transformation of clay minerals did not migrate or emigrate Al in the sandstones considerably.

3) The amount of CaO in the ore-bearing sandstone is the highest among the four rocks, with an average proportion of 7.97%. This is primarily because of the presence of the carbonate cements in the ore-bearing sandstone. The corresponding hydrocarbon fluid, along with the alkaline fluid, caused an important mixed fluid alteration in the process of epigenetic alteration. This alteration process is closely related to the uranium mineralization. The resulting brown red altered sandstone contains the most MgO, followed by the green altered sandstone.

5. Discussion on the relationship between uranium mineralization and hydrocarbon

5.1. Spatial distribution relationships between uranium deposits and hydrocarbon

Hydrocarbon and uranium deposits coexist in the Ordos basin. They are distributed closely in the spatial dimension. Uranium deposits are mainly distributed on the edge of the basin, concentrating in Dongsheng-Hangjingqi of the north basin, Diantou-Huangling of the south basin and Huianbao-Ciyaobao of the west basin. Oil reservoirs are mainly distributed in the southern basin, mostly concentrating in the Chang 7 period deep lake area of the basin and nearby. Gas reservoirs are mainly distributed in the north region, the Yulin-Inner Mongolia area, and also the central and southern Yan'an region, according to the recent discoveries. Some shale gas reservoirs with exploration potential have also been found in the area bearing Chang 7 hydrocarbon source rocks. Oil is primarily produced in Yanchang Formation (T_{3y}) and Yanan Formation (J_{2y}), while natural gas in the Upper Paleozoic and part of Lower Paleozoic and the SUDs in the Jurassic Zhiluo Formation. That is, the minerals rank in the order of natural gas reservoir, oil reservoir and uranium deposit from the bottom up.

SUDs in the Ordos Basin mainly concentrate in Yimeng Uplift area (the north of the basin), which is also the direction and seepage area of Paleozoic gas. There formed faults in the northern Ordos Basin, and part of which cut through the Upper Cenozoic rock and gas reservoir. The BoerJianghaizi Fault remained active during the Cenozoic. It could provide the natural gas a channel for the upward migration and northeast-ward seepage.

As seen above, the distribution of hydrocarbon and uranium deposits in the Ordos Basin have a certain spatial pattern. This pattern is not only determined by their own characteristics of accumulation or metallogenic, but also by the interaction between various minerals.

5.2. Age comparison between hydrocarbon accumulation and uranium mineralization

The maturing of the Upper Paleozoic source rocks and the mass generation of hydrocarbon in the Ordos Basin can be traced back to the end of the early Cretaceous, about 120~100 Ma. According to the thermal history of the basin, there were significant thermal anomalies in the basin during this period. Consequently, the hydrocarbon source rocks of different ages became mature simultaneously, making this period the peak of hydrocarbon expulsion and the main period of hydrocarbon accumulation in the basin. We tested the ore-forming age of Dongsheng-Hangjingqi SUD and found that the uranium deposits were formed mainly in three periods, i.e., 120~90 Ma, 80~60 Ma and 30 Ma~10 Ma [9]. The age before 30 Ma should be the pre-enrichment age of the sedimentary period, whereas the age after 30 Ma is the late and ultra-late mineral age and the age of reformation. Note that the 120~90 Ma is about the same period as or slightly later than the formation and large-scale loss of natural gas reservoirs in the basin. It therefore seems reasonable to assume that the formation of SUD is in sync with or slightly later than the formation and dissipation of natural gas in the Paleozoic. They are very likely to have a link of causes.

5.3. Uranium metallogenic mechanism

In the preceding context, we analyzed the petrological and geochemical characteristics of the hydrocarbon and uranium. We also explored the spatial distribution of SUDs and oil and gas reservoirs. Furthermore, we compared their reservoir-forming and ore-forming age. The results show that in the

process of mineralization of SUDs in the northern Ordos Basin, the hydrocarbon seepage occurred and the oil and gas concentrated along the shallow strata. They interacted with the uranium-bearing fluid, causing the reduction of the uranium element. After being precipitated in the Zhiluo Formation, the uranium element concentrated to form the uranium deposit. Since the formation of Hetao Fault Depression during Late Cenozoic, the oil and gas that have seeped to the northeastern part of the basin have created a reducing environment for the uranium deposits formed earlier. They protected the ore body from being destroyed by the groundwater after mineralization. And Yimeng Uplift, the uplift of the northern part of the basin, has become a favorable prospecting area for SUD.

6. Conclusion

(1) The green alteration in Zhiluo Formation results from the secondary reduction of oil and gas. Its predecessor is the red sandstone formed in the oxidizing environment. The oil and gas seeping to the northeastern part of the basin could form green alteration, white alteration and pyrite as a result of the fluid-rock interaction.

(2) The oil and gas plays an important role in uranium mineralization. The seepage of oil and gas interacts with the uranium-containing and oxygen-containing fluid, reducing U^{6+} to U^{4+} . After being precipitated in Zhiluo Formation, the uranium element would concentrate to form the uranium deposit.

(3) The reduction environment due to the hydrocarbon seepage can protect the ore body from being destroyed by the groundwater after mineralization.

(4) In the northern part of the basin, the Yimeng Uplift area serves as a good indicator of the hydrocarbon seepage, where the sandstone-type uranium deposits are likely to form. Its exploration potential is tremendous.

Acknowledgments

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