Hotspot Uranium Metallogenesis in North Hebei Province, China

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1 Geologic Setting

Guyuan area, namely northern Hebei province in China, is one of the most important volcanic-type uranium-polymetllic metallogenic zones. The 460 large uranium-molybdenum deposit, 534 medium size uranium-polymetllic deposit, 781 and 951 uranium occurrences have been discovered in this area, and is an important uranium exploration base in north China. The tectonic position lies in cross-cut parts of Sertengshan - Taipusiqi magmatic arc (Ar3) of northern margin of the North China Craton and Daxinganling NNE-trending Mesozoic-Cenozoic volcanic magmatic active belt, which is called Guyuan mesozoic volcano collapse basin. The basement rocks are the Hongqiyingzi group of new Archean, the cover layers are mainly composed by Baiqi group and Zhangjiakou group in upper Jurassic, and Huajiying group in lower Cretaceous. Late Archean potassic migmatites, Late Paleozoic crustal remelting type granites, Late Jurassic crustal remelting type porphyry, rhyolite porphyry, trachyte and quartz porphyry are the main types of igneous rocks in the region. The NE-trending fault F 45 is the main ore-controlling regional fracture, nearly all the discovered deposit and occurrences are distributed along this fault or its secondary fracture.

2 Hotspot Uranium Metallogenesis

Hotspot Uranium mineralization is a uranium mineralization process due to the role or effect of hotspot (Li, 2006). The typical mineralization characteristics mainly include those (1) the element of uranium is concentrated in the late melt or advanced fluid of complex multi-stage magmatism or fluid interaction; (2) uranium mainly originated in the deep of earth; (3) the main factor of ore-controlling is the combined effects of hotspots and structures. Wang Baode et al (2005) suggest that mantle-branch structures do exist by studying the Au and Ag deposit in North Hebei Province. By researching the geological and mineralization characteristics of typical uranium deposits in Guyuan area, hotspot uranium mineralization is recognized in the region.

3 Characteristics of Uranium Mineralization

3.1 Multi-stage magmatism

There were strong magmatic activity in north Hebei Province, mainly as multi-stage magmatic intrusion and volcanic activity. For granitic magmatism, has occurred from Hercynian, Indosinian to Yanshanian. Reported age include 306 Ma, 252 Ma, 212 Ma, 210 Ma, 206 Ma, 205 Ma, 187 Ma, 176 Ma, 172 Ma, and 165 Ma. Volcanic activities mainly occurred in Mesozoic, and perform as multi-cycle volcanic eruption, only Zhangjiakou group in Upper Jurassic can be divided into three lithological rhythmic and eight layers. Taking Zhangmajing (460)-Daguanchang (534) volcanic belt as the center, forming the Guyuan Mesozoic volcanic basin. The mantle basaltic magma originated in Himalayan strong tensile rift tectonic environment indicated the end of magmatism.

Overall, the magma in the region with characteristics of multi-stage, acidic component -based and end of mafic magmatism, reflecting the effect of hotspots.

3.2 Deep origin ore-forming fluids

Geochemical analysis results of Mesozoic volcanic and subvolcanic rock show that, $^{87}\text{Sr}/^{86}\text{Sr}$ values ranging between 0.7051 and 0.7134, $\sigma$Sr value is generally 16 to 135, $\sigma$Nd value is generally -10 to -19, $^{206}\text{Pb}/^{204}\text{Pb}$ values are commonly less than 18, all these with a significant mantle source characteristics, suggesting that the rocks are derived from the incompatible element enriched upper mantle, and are the products of varying degrees of assimilation and contamination of the parent magma or from fractional crystallization after the remelting of crustal materials. Mafic volcanics $\sum\text{REE} = 10^6$ to $278 \times 10^6$.

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acidic volcanic rocks $\Sigma$REE = $228 \times 10^6$ to $358 \times 10^6$, (La/Yb)$_N$ = 12.7-37, (Ce/Yb)$_N$ = 7.8-36, and similar to the REE characteristics of continental rift volcanic.

$S$ and Pb isotope of uranium deposits results also showed that ore-forming fluids with a deep source characteristics. In detail, value of $\sigma^{34}S$ of pyrite from 460 deposit is 4.4 $\%$o ~ 7.4 $\%$o, value of $\sigma^{34}S$ of galena from 534 deposit is -8.3 ~ 1.2 $\%$o; $206^Pb/204^Pb = 16.792 \sim 17.071$, $207^Pb/204^Pb = 15.34 \sim 15.453$, in the diagram of $206^Pb$/$204^Pb$ vs $207^Pb$/$204^Pb$, the plotted points are mainly distributed in the curve of the mantle area, reflecting the mantle material is an important part of or the composition of the ore-forming fluids. Meanwhile, the U-Pb isotopic system basically are a single-stage evolution model since the formation of the earth until the time of mineralization, this situation is most likely caused by differentiation of the mantle, it indicates that there is a upper mantle component added to the metallogenic materials.

3.3 Ore controlled by compounding of structure and magma

The model of control of ore deposits by compounding of structure and magma is the common style of ore-controlling in the research area. For example, The 460 uranium-molybdenum deposit is controlled by compounding structure system of NE-trending basement fault (F$_{36}$), NW-trending secondary fault (F$_3$) and cryptovolcaniccaldera, meanwhile, the ore body generally occurred in the rock of rhyolite porphyry and the outer contact zone, 534 uranium-polymetallic deposit located at the position where confined by NE-trending F45, NEE-trending F(I)-2 and SN-trending F(I)-1, while closely associated with the deep-seated rhyolite porphyry.

3.4 Uranium enriched in the advanced fluid

From the basement composed of New Archean Hongqiyangzi Group and Permian uranium (3 ~ 5 $\times 10^6$) to the Late Jurassic acidic - alkaline volcanics and subvolcanic, uranium content was significantly higher trend, in which the uranium content of rhyolite porphyry in upper Jurassic Zhangjiakou group up to (10~15) $\times 10^6$. Furthermore, different rocks in the same volcanic cycle, the uranium content is also gradually increased from earlier to later, especially the acidic subvolcanic of latest volcanic eruption, for example, obsidian, pitchstone and layered rhyolite thatformed round volcanic crater or late volcanic cycle have the highest uranium and thorium content, on the contrary, the uranium content of other types of rocks such as trachyte, tuff and lava breccia is relatively low ($3.9 \sim 4.5 \times 10^6$).

Through statistical the formation age of host rock (intrusiverock) and the mineralization age of uranium to discovered that the mineralization ages are younger than the age of host rock or intrusive rock, and showed the characteristics of multi-stage mineralization It consist with the regular pattern of hot uranium mineralization that the element of uranium enrichment in advanced fluid.

3.5 Combination of ore-forming elements

The symbiosis and associated elements analysis of 460 deposit showed that the elements of Cu, Pb, Zn, Mo, Ni, Cr in ore was significantly enricher than in hostrock. Similarly, the main associated elements of 534 deposit are Mo, Pb, Zn, Ag, etc. This result is consistent with the proposed that the main associated elements are Th, Sr, Ba, Cu, Pb, Zn, Mo, W, Ni in hotspot uranium mineralization (Li, 2006).

3.6 Temperature and pressure of ore-forming fluid

Inclusionanalysis is used to measure the temperature and pressure for the different stages in the process of uranium deposit. The result show that the temperature of the pre-mineralization stage is 300°C, the temperature of uranium mineralization stage is 260~310°C, and the pressure of mineralization is ($50-580$) $\times 10^6$ Pa, belong to the medium-high temperature and high pressure hydrothermal deposit, which is conformed to the characteristics of fluid of hotspot uranium mineralization. Moreover, the deposit oxygen fugacity is low, the H$_2$S in the solution accounts for 99.3% of the total sulfur, which is a typical reducing environment.

4 Conclusions

In summary, the aspects of regional magmatism, ore-controlling mode, origin and properties of ore-forming fluids, resources and enrichment regularity of U, and Combination of elements are characterized by hotspot uranium mineralization. Hence, 460 and 534 deposits are typical hydrothermal uranium deposits controlled by hotspot. Hot uranium metallogenic model confirmed for peripheral and deep prospecting of the known depositsprovide a theoretical basis.

References
