Preliminary studies on deep-penetrating geochemical methods in exploration for concealed volcanic-type uranium deposit

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Abstract. Volcanic-type uranium deposit is one of the most important type of uranium resources in China. It has been proved by the scientific deep drilling work accomplished in 2015 that uranium mineralization can be detected at the depth of more than one thousand meters, where there are no significant radiometric or other exploration geochemical anomalies that can be acquired on ground surface. With the progress of exploration for uranium resources in China, deposits which are exposed on surface or shallow-buried are all almost discovered already. It has become a challenging task to explore the deep-buried deposits for uranium geologists. Application experiments are carried out in Xiangshan uranium deposit field using two kinds of deep-penetrating geochemical methods, including the Selective Leaching of Mobile Metals (MOMEO) and Electro-geochemistry techniques (CHIM). The U ore bodies are manifested as a clear CHIM anomaly of U. The adsorbed and exchangeable forms of U obtained with the MOMEO technique is demonstrated as lower single peak anomalies compared with the CHIM technique. The ‘total’ U element content shows no clear anomaly over the uranium mineralization, while there is only a single point high value with an intensity up to 12.5 ppm of U. The polonium-210 shows no significant anomalies over the uranium mineralization. According to the results obtained in this paper, two kinds of deep-penetrating geochemical signatures demonstrate more effective role in detecting the concealed uranium mineralization than traditional methods. The deep-penetrating geochemical methods are bound to play an important role in exploring for deep-buried and concealed uranium deposits in China.

1. Introduction

The volcanic-type uranium deposits located in Xiangshan area were firstly discovered by radiometric survey in 1950s and they have been explored for more than 60 years\textsuperscript{[1]}. In recent years, uranium mineralization has been detected by drilling at a depth of more than 1000 meters, where there are no significant radiometric anomalies that can be acquired on ground surface. The main problem, however, is how to acquire the weak signal aroused by the concealed uranium orebodies with traditional geochemical techniques.

Several kinds of deep-penetration geochemical techniques are widely used in detection of blind mineral resources in China after the concept of 'deep penetration' were first proposed by Cameron in 1998\textsuperscript{[2]}. The electro-geochemical extraction (CHIM) was invented in the former Soviet Union in 1970s\textsuperscript{[3]}. It is based on the migration of ions in an electric field and it has been proved a kind of effective method to locate concealed mineral deposits, especially for Cu, Pb, Zn, Au and U deposits\textsuperscript{[4]}.
In China, the CHIM was used in exploration for Pb, Zn, Cu, Ni, Au, Ag, Sn, U, and oil and gas with an “effective detection depth of hundreds of meters”[5,6]. Research of formation mechanism of electro-geochemical anomaly has been carried out based on the migration mechanisms and field results in sandstone-hosted uranium deposits in Erdos basin[7]. The electro-geochemical U content is demonstrated as jumping anomaly over known uranium deposits, which can be regarded as a prospecting indicator for concealed sandstone-hosted uranium deposit. The Selective Leaching of Mobile Metals (MOMEO) was also developed by the IGGE group, and it was a kind of regional deep-penetration technique to cover large exogenic or volcanic areas[8,9,10]. The CHIM and MOMEO methods were compared in Au deposit in Jinwozi gold deposit, Xinjiang province, China. The results show that strongly anomalous values are corresponding to the concealed deposits under 200 meters of post-ore sedimentary rocks and desert sand. Selective leaching of metals occluded in Fe-Mn oxide coating sand electro-geochemical extraction of ions are both effective for indicating to concealed deposits in arid desert terrain[11,12]. A kind of extractant called ‘MML-U’ to selectively leaching the mobile forms of elements from soil was developed by the IGGE in recent years, and it was proved to be effective to delineate the U, Mo and V anomalies over the concealed orebodies in the Sunjialiang section of Dongsheng sandstone-type uranium deposit[13].

In order to evaluate the effectiveness of the deep-penetrating geochemical methods, several kinds of geochemical techniques, including electro-geochemical extraction, the MOMEO, polonium-210 and standard soil geochemistry were carried out over the known volcanic-type uranium deposits in Shidong site, Xiangshan area.

2. Study area
Xiangshan uranium deposit is located in the Xiangshan volcanic collapse basin, Jiangxi province, China. Basement of the basin consists of Nanhuaian-Sinian system Epimetamorphic rock. The basin cover mainly consists of volcanic rocks and Cretaceous red beds, while the latter is located in the west of the basin[14,15]. Basement structure, cover structure and volcanic apparatus are well developed, which control the occurrence of the uranium mineralization in common[16]. The thickness of the volcanic rocks is more than 2000m. The upper layer of the volcanic rocks, Ehuling formation, is mainly composed of glutenite, crystal tuff and porphyroclastic lava with a large thickness. The lower layer, Daguding formation, is composed of glutenite, sandstone, ignimbrite and rhyodacite. Faults, overlying of acid and alkaline alternation, interfaces between inter-layer and basement, late granite porphyry are the main ore-controlling factors[17]. Among these factors, faults play the most vital role. Only cut by faults can volcanic structure become the favorable location for uranium mineralization. Structures developed in basement are regarded as the transporting and depositing space for uranium bearing hydrothermal solution. Structural fracture zone beside the interfaces between inter layers or basement, and also the late granite porphyry are recognized as the suitable space for occurrence of uranium orebody.

3. Methodology

3.1. Sampling methods
The CHIM electrodes were made of graphite rod with a length of 10cm. Electrodes coated by absorbent materials containing electrolyte compose the element collectors, which were buried underground at a depth of 30 to 40 cm. The distance between the positive and negative electrodes was 80 cm. The ground around the electrodes should be wet by the addition of 10% HNO₃. The voltage of the artificial applied DC power is constant 9V. There are 18 element collectors buried underground and the distance between measurement points is 20 m. The collectors were taken out and sent to laboratory for analyzing after 24 hours. The soil samples were taken from the same point and weighed no less than 1000g. After air-dried, the samples were crumbled by a wooden hammer, sieved with -80 mesh for analysis. The soil total content, MOMEO and polonium-210 were analyzed using the same soil sample.
3.2. Analytical techniques

Each CHIM sample was digested in aqua regia. Inductively coupled plasma mass spectrometry (ICP-MS) was then used for the determination of U. All soils for the MOMEO analyses were hand screened to -80 mesh (<0.177 mm) and split into the required number of bags. Analytical work of standard soil geochemistry, CHIM and MOMEO was conducted in the central laboratory of Institute of Geophysical and Geochemical Exploration (IGGE). The polonium-210 concentration in soils was analyzed using Mini20 alpha & beta multi-detector in the Analytical laboratory Beijing Research Institute of Uranium geology.

4. Results

The main ore body is intersected by boreholes at a depth of about 300 m. The host rock is present in form of porphyroclastic rhyolite in Upper Ehuling formation, covered by overburden which mainly consists of weathered rocks and soils. Rhyodacite in Upper Daguding formation is underlying the host rock and there is a clear interface between them. Typically, ‘total’ U element content is difficult to identify the mineralization (Figure 1a), while there is only a single point high value with an intensity up to 12.5 ppm of U. So the ‘total’ U is no meaningful in detecting the deep-buried orebodies and only shows the geochemical characteristic of soil near the shallow ground. The polonium-210 also shows no significant anomalies over the uranium mineralization (Figure 1b). The U ore bodies are manifested as a clear CHIM anomaly of U detected directly above (Figure 1c). The typical response to uranium mineralization appears to be a single peak anomaly. The transversal width of CHIM anomaly of U is approximately 80 m, with an intensity up to 4.4 ppm of U with a background of 1.9 ppm of U. The adsorbed and exchangeable forms of U obtained with the MOMEO technique is demonstrated as a lower single peak anomalies compared with the CHIM technique (Figure 1d). The MOMEO anomaly of U is approximately 60 m wide, with an intensity up to 2.3 ppm of U with a background of 1.3 ppm of U.

5. Discussion and conclusions

Studies presented in this paper have demonstrated the effectiveness of electro-geochemical CHIM extraction and MOMEO techniques in exploration for concealed uranium mineralization buried at a depth of more than 300 m. It is confirmed that the form of mobile U can migrate over large distances, which makes it possible to detect the CHIM anomalies of U on ground surface. The comparison of both deep-penetrating geochemical techniques, standard soil geochemistry and polonium-210 results showed that the CHIM and MOMEO anomalies of U are more distinct over the known U orebodies, while the standard soil geochemistry and polonium-210 anomalies cannot delineate the anomaly distinctly. As can see from the data, the MOMEO and CHIM techniques both show as single peak anomalies over the deep-seated U mineralization, but the latter gives a better contrast response. In Xiangshan area, the soils are easy to lump because of its high humidity, so the soils were sieved with -80 mesh. According to some studies, the fine-grained soils had the advantageous abilities in absorption of uranium elements, compared to the coarse-grained soils[13]. It is needed to make some further studies on the MOMEO technique in exploration for deep-seated uranium orebodies. The CHIM method has been proved useful in exploration for volcanic-type uranium deposits in this application case. This approach also has an effective application in the exploration for other kinds of uranium deposits, such as sandstone-type uranium deposits[7]. Also, there are many challenges and questions including determining the suitable field sampling conditions for different kinds of minerals, mechanisms of the electro-geochemical migration of U and reasonable interpretation of anomaly that remain to be further studied.
Figure 1. Results obtained employing standard soil geochemistry (a), polonium-210 (b), CHIM (c) and MOMEO (d) over Shidong site in Xiangshan area, China. (1) Quaternary regolith sediments. (2) Porphyroclastic rhyolite in Lower Ehuling formation. (3) Porphyroclastic rhyolite in Upper Ehulin formation. (4) Rhyodacite in Upper Daguding formation. (5) Metamorphic rock in basement. (6) Uranium orebodies. (7) Boreholes. (8) Fault.

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