Possibility for Uranium Mineralization of the Trans Urals According to Regional Geochemical Data

L A Krinochkin¹, O K Krinochkina²

¹Institute of Mineralogy, Geochemistry And Crystal Chemistry of Rare Elements
Department of Regional Geochemistry, Veresaeva 15, Moscow 121357, Russia
²Moscow State University of Civil Engineering, Department of Engineering Survey
and Geocology, Yaroslavskoe sh. 26, Moscow 129337, Russia

E-mail: vdvinaok@mail.ru

Abstract The article discusses the prospects of hydrogenic uranium mineralization in the Trans Urals. Dolmatovskaya geochemical zone is mapped out and minerogenic potential of its anomalous geochemical areas (AGCAs) is estimated from experimental data. A total of twelve ACGAs are ranked by prospectivity using values of minerogenic potential and other geochemical parameters. Minerogenic potential is calculated from N.A. Bykhover’s formula using analogical models and can be equated to expected reserves. Previously studied Khokhlovsky AGCA is ranked promising and is expected to increase its potential uranium reserves. Previously unknown Garkashinsky and Petrovsky-Medvezhoresky ACGAs are identified as potential areas of medium prospectivity. These areas are geochemically identical to the anomalous geochemical fields of reference uranium ore locations in the zone in question, thus indicating potential commercial uranium reserves.

1. Introduction

World leaders in uranium reserves are Australia, Kazakhstan and South Africa. Kazakhstan, located not far from the object of our study, ranks second in explored uranium reserves. Mineral reserve base of Kazakhstan consists mainly of hydrogenous uranium deposits of interlayer infiltration type [¹, ², ³].

Uranium is one of the extremely scarce minerals in Russia. According to Mashkovtsev G.A. et al [⁴] the situation is further aggravated by significant excess of uranium demand over regeneration coupled with meager developed reserves.

Identifying new prospective provinces is a key factor in shifting the uranium balance. One of the target regions is Trans Urals where geochemical studies point to Dolmatovskaya zone as showing attributes of prospective uranium fields of infiltration type mineralization.

Studies of Mesozoic and Cenozoic metallogeny of uranium-bearing sedimentary basins of Eurasia, including Trans-Urals, were conducted by Grushevoy G.V., Petchenkin I.G. [⁵] and many other researchers. Group of Chuvilin V.A. explored Butkino-Baikalovskaya area of Trans Urals on a scale of 1:200,000 to 1:50,000 in order to prioritize prospective areas of hydrogenous uranium deposits.

Present work is a first assessment of Trans Ural prospectivity using geochemical approach [⁶] based on the interpretation of AGCAs geochemical parameters and minerogenic potential.
2. Geological setting

Study area is a portion of West Siberian uranium-bearing belt, exemplifying Mesozoic uranium mineralization of palaeovalley type.

Platform cover in this region commonly consists of sedimentary rocks of Paleogene and Neogene. Cretaceous deposits were mapped out at the Urals border (see Figure). Middle Jurassic-Lower Cretaceous ore-hosting complex is not exposed on the surface.

The composition of the sediment cover rather is sustained. They are formed by sand, silt, clay, pebbles and other sedimentary rocks. The weathering crust has a significant distribution.

Known prospective mineralization of uranium refers to rare earth uranium terrigenous formation [7] in the zones of interlayer oxidation of palaeovalley-related. It consists of Dolmatovsky, Khokhlovsky and Dobrovolsky fields [8].

Mineralization in the region dates back to two geological ages: (1) Turn of Jurassic and Cretaceous/early Cretaceous – 130-140 million years ago and (2) Cretaceous-Eocene – 40-80 million years ago. Dating of Dolmatovsky deposit ores corresponds to the first age [8].

3. Experimental

Creation of the geochemical basis on 1:100,000 scale using O-41 (2015-2017) and N-41 (2009-2011) format involved characterization of soil and bottom sediments on a 10 km\times10 km grid as described in [10].

Search for overlaid uranium deposits started with determination of mobile fractions of uranium and other elements in soil and bottom sediment using ICP/MS facilities of the Institute for Mineralogy, Geochemistry and Crystal Chemistry of Trace Elements (Moscow, Russia)

AGCAs were ranked in prospectivity by their minerogenic potential and parameters of anomalous geochemical fields. The latter include complexity, contrast, intensity of anomalies and other. In general, higher values of minerogenic potential of AGCA and other parameters together with more pronounced content differentiation of ore-forming elements and their common companions imply greater prospectivity ranking [11]. As a result, AGCA were divided into promising, unclear and unpromising categories.

The complexity of the anomalous geochemical fields of a number of the studied areas is very high (up to 30 elements or more). However, elements with a sufficiently high level of accumulation and / or differentiation of their contents have practical significance in association. The level (contrast) of the accumulation of elements was estimated by the ratio of their average contents in AGHP to the background of the natural landscape of the region: high (Kc ≥ 4.0), medium or moderate (Kc = 2.0-3.9) and low (Kc <2 , 0). The degree of heterogeneity of the anomalous field was estimated by the coefficient of variation in the contents of elements (in%): high (V ≥ 75), medium or moderate (V = 75-50) and low (V <50).

Since known and predicted uranium occurrence is of hidden and concealed type it is impossible to calculate minerogenic potential directly as instructed in [12] for lithochemical halos of exposed ore deposits. Therefore, this work resorts to analogue models and N.A. Bykhover’s formula [13], recommended for regional geochemical assessment [14]. Minerogenic potential \(Q\) found in this manner can be equated to expected reserves:

\[
Q = 0.5KqV,
\]

where 0.5 is the confidence factor of predicted uranium reserves; \(K\) is the analogy ratio between studied and reference areas; \(q\) is the specific ore content of the reference area, t/km²; \(V\) is the size of studied area, km². In our case, \(K\) was taken to be unity since the two objects are similarly located and belong to the same mineralization type.

Minerogenic potential is classified as high – over 20,000 tons, medium – 5,000-20,000 tons, and low – less than 5,000 tons as defined in Dictionary of Metallogenesis [15] and Russian Federation Government Regulation No. 116 [16].
4. Results and discussion

Superposition of lithochemical halos in soils and bottom sediments for the region under investigation has led to discovery of anomalous geochemical areas not only confirming known location of uranium ores, but also suggesting a number of new ones, including potentially uranium-bearing ores of hydrogenous infiltration type. Overall, twelve anomalous areas have been mapped out and combined into Dolmatovsky geochemical zone (see Fig.).

It is important to note that AGCAs of Dolmatovsky geochemical zone are located in sub-boreal forest landscapes of pediment outwash plains, away from the anthropogenic sources of uranium. Under these conditions substrate erosion from local sources forms lithochemical dispersion trains.

Dolmatovsky geochemical zone is located in-between Tobol and Pyshma rivers. It is of submeridional strike, extending about 500 km from north to south, with a maximum width of 250 km in the middle.

In the zone, the middle Dolmatovskoye and small Khokhlovskoye deposits and manifestations of pale-valley uranium are known.

Soils of abnormal geochemical areas are typically characterized by the following accumulation levels $K_i$ (in the subscript) relative to geochemical background: $U_{3.1}$, $Re_{2.3}$, $Th_{2.2}$, Zn$_{1.9}$, Sr$_{1.9}$, Mo$_{1.8}$, Bi$_{1.8}$, Cs$_{1.7}$, Hf$_{1.6}$, Zr$_{1.6}$; bottom sediments: $U_{3.7}$, Sr$_{3.0}$, Ta$_{2.5}$, Mo$_{2.3}$, Re$_{2.2}$, Zr$_{2.0}$, Pb$_{2.0}$, Hf$_{2.0}$, Nd$_{1.9}$, Be$_{1.9}$, Cd$_{1.9}$, Ag$_{1.9}$, Zr$_{1.8}$, Ba$_{1.8}$, V$_{1.7}$, Si$_{1.6}$, Bi$_{1.6}$, Cu$_{1.6}$, Th$_{1.5}$, Sc$_{1.5}$ (subscript, hereinafter, the level of accumulation (Cc) relative to the geochemical background).

As evidenced by the above accumulation series, uranium takes a leading position in both assemblages. All elements of the soil assemblage, with the exception of cesium, are also found in abnormally high concentrations in bottom sediments. However, bottom sediment assemblage of the elements is more relevant since it also contains known uranium complimentary elements, namely, Pb, Nb, Be, Cd, Ag, Ba, V, Sb, Sc.

A comparative analysis of associations shows that soils and bottom sediments of uranium-bearing areas are characterized by a common list of elements-indicators of hydrogenic uranium deposits (U, Sr, Th, Hf, Cs, Zr).

Both associations are characterized by moderate accumulation, high and increased differentiation of the contents of most chemical elements. U and Zn are characterized by relatively high concentrations in soils, and U and Th in bottom sediments. It is noteworthy that uranium itself, as well as Zn, Mo, Sr, Th, Cs, are distinguished by a very high degree of differentiation of the contents, which is usually a sign of the connection of elements with the ore-forming processes.

Dolmatovsky geochemical zone encloses AGCAs of Dolmatovsky (13) and Khokhlovsky (16) ore districts. Dolmatovsky district hosts a known medium size Dolmatovsky uranium deposit (19), Khokhlovsky district – small size Khokhlovsky deposit (23).

The most thoroughly studied is Dolmatovsky deposit. Its mineralization is associated with Middle-Late Jurassic sediments forming creating Early Mesozoic beds cut into the surface of pre-Jurassic foundation and filled with alluvial sediments. Uranium is accompanied by increased concentrations of Mo, Re, Se, Y, Sc, Tr [17].

Dolmatovsky deposit reserves of (A+B+C1) categories are estimated at 7,735 tons, C2 – 1,828 tons, off-balance reserves – 1,607 tons, comprising a total of 11,170 tons [18]. Area of Dolmatovsky district AGCA is 853 km$^2$, which translates into specific ore content of 13.1 t/km$^2$. This value was adopted by the authors to assess minerogenic potential of other areas within Dolmatovsky zone (Table).

Anomalous geochemical areas of Dolmatovsky (13) and Khokhlovsky (16) districts were studied using a limited number of samples. In order to obtain more reliable (unbiased) geochemical characteristics of these reference areas, the two sample arrays were combined and amounted to 20 samples of soils and 20 samples of bottom sediments.

Following levels of accumulation were established in the soil of uranium-bearing areas in question: $U_{4.5}$, Zn$_{2.0}$, Mo$_{2.2}$, Sr$_{2.2}$, Th$_{1.9}$, Hf$_{1.9}$, Cs$_{1.7}$, Zr$_{1.6}$. Here superscript denotes grade variation.
Bottom sediments from these districts feature a more representative accumulation series assemblage compared to soil: U$_{3.6}^{117}$, Th$_{3.0}^{115}$, Hf$_{2.4}^{74}$, Zr$_{2.4}^{73}$, Pb$_{2.4}^{155}$, Be$_{2.3}^{72}$, Sr$_{2.3}^{69}$, Co$_{2.1}^{108}$, Bi$_{2.0}^{82}$, Ag$_{2}^{83}$, Cu$_{1.9}^{51}$, Sc$_{1.9}^{77}$, V$_{1.8}^{74}$, Y$_{1.7}^{54}$, C$_{1.7}^{57}$, Cs$_{1.5}^{130}$, Cd$_{1.5}^{99}$, Rb$_{1.5}^{93}$.

Both assemblages are characterized by moderate accumulation of most of the elements. It is noteworthy that the uranium, as well as Zn, Mo, Sr, Th, Cs are distinguished by a remarkably high degree of content differentiation, which is a typical sign of connection to mineralization processes.

For the known Khokhlovsky ore district (16) minerogenic potential is estimated at 7,873 tons, placing it into the ‘promising’ category and predicting additional uranium ore reserves.

Minerogenic potentials of Garkashinsky (9), Pokrovsko-Medvezhosersky (17), and Suleymanovsky (18) areas (Table) suggest their ‘promising’ ranking. However, accumulation levels of uranium in the assemblages of Pokrovsko-Medvezhosersky (U$_{2.4}$) and Suleymanovsky (U$_{2.8}$) areas are significantly lower than in the case of Dolmatovsky and Khokhlovsky areas (U$_{4.5}$). At the same time, accumulation of uranium in Garkashinsky area (U$_{2.1}$) is higher than in the reference. Taking into account minerogenic potential, complexity of the anomalous fields and intensity of uranium accumulation, Garkashinsky area is assigned ‘promising’ category while Pokrovsk-Medvezhosersky and Suleimanovsky areas are relegated to ‘unclear’ prospectivity.
Table 1. Prospectivity forecast for the anomalous geochemical areas in Dolmatovsky geochemical zone.

| Area (No. on the map) | Size, km² | Minerogenic potential, tons | Prospectivity   |
|----------------------|-----------|-----------------------------|----------------|
| Anokhinsky (8)       | 716       | 4,690                       | Unclear        |
| Garashkinsky (9)     | 1564      | 10,244                      | Promising      |
| Basmanovsky (10)     | 697       | 4,565                       | Low            |
| Olkhovskiy (11)      | 906       | 5,934                       | Unclear        |
| Tersyuksky (12)      | 603       | 3,950                       | Low            |
| Nizhnemiasskyy (14)  | 891       | 5,836                       | Low            |
| Saltosoriysky (15)   | 1006      | 6,589                       | Low            |
| Khokhlovsky (16)     | 1202      | 7,873                       | Promising      |
| Petrovsky-Medvezhorsky (17) | 1669 | 10,932                     | Unclear        |
| Suleymanovskiy (18)  | 2420      | 15,851                      | Unclear        |
| Ust-Uisky (19)       | 754       | 4,939                       | Low            |

Other areas of Dolmatovsky geochemical zone are characterized by low to medium values of minerogenic potential (Table).

Out of those, Olkhovsky (11) and Anokhinsky (8) areas can boast relatively high accumulation and differentiation of uranium content: $U_{5.6}$ in bottom sediments and $U_{5.9}$ in soils, respectively. However, due to the low complexity of the anomalous fields and judging from other geochemical parameters, prospectivity of both areas is deemed unclear.

The rest of Dolmatovskaya zone areas have low to moderate accumulation levels of ore-forming uranium and its companions as well as poor content differentiation of their content, which, in the authors’ opinion, reflects their low prospectivity.

5. Conclusion
Prospectivity assessment of Trans Ural province based on the superposition of geochemical parameters and minerogenic potential of AGCAs has led to some new findings suggesting potential commercial uranium reserves in Khokhlovsky and Garkashinsky areas in addition to the known Dolmatovsky area. Prospectivity of commercial reserves in Pokrovsky-Medvezhorsky, Suleymansky, Olkhovsky and Anokhinsky areas call for further clarification while rest of the studied areas is regarded by the authors as unpromising.

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