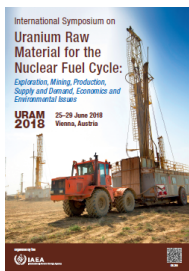


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## URANIUM DEPOSITS OF THE KARELIAN-KOLA PROVINCE (RUSSIAN FEDERATION)

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### INTRODUCTION

The Karelian-Kola uranium ore province is situated within the East European Platform and covers its fragments: the eastern Baltic Shield and the northern Russian Plate. The area of studies includes Kola-Belomorian, Laplandian-Karelian, Svecofennian megablocks and dividing suture fold-overthrust zones: East Karelian and Raakhe-Ladoga. These long-living structures are composed of Archean and Proterozoic volcanogenic and sedimentary-volcanogenic formations of various compositions subject to repeated structural transformations under the impact of tectonic, hydrothermal-metasomatic and exogenic processes of various ages. It is reflected in geochemistry of geological formations and the specifics of ore genesis.

In the Precambrian geology of the Baltic Shield, several tectonomagmatic cycles (TMC) and corresponding metallogenic epochs can be distinguished: the Early Archean (older than 3.15 Ga), the Late Archean (3.15-2.6 Ga), the Early Karelian (2.6-2.4 Ga), the Late Karelian (2.4-1.95 Ga), the Svecofennian (1.95-1.65 Ga), the Riphean (1.65-0.65 Ga), and the Vendian-Paleozoic (0.65-0.34 Ga). Each of them is characterized by specific type of sedimentation, volcanism, metasomatism and the emergence and concentration of ore. Of all the above-described uranium-ore epochs, the Svecofennian TMC epoch is most productive for uranium and complex uranium mineralization as regards the variety of ore types. It is caused by the complication of ore-forming systems in time and the superposition of later ore associations on the earlier ones.

### URANIUM TARGETS OF VARIOUS ORE-FORMATION TYPES

Intense and purposeful predictive metallogenic and prospecting studies conducted in the Russian part of the Baltic Shield led to the discovery of uranium and complex uranium deposits of different ore types: unconformities, sandstone, quartz-pebble conglomerates, veins, metasomatic, etc [1, 2, 5, 8]. Their resource potential is more than 2 MT U [5]. Zones of structural-stratigraphic unconformity (SSU) are widespread in the Baltic Shield. Uranium mineralization within the uranium-bearing SSU zones are of different grades: high-grade ore in Pre-Riphean zones, low-grade ore but with significant reserves in the Pre-Vendian SSU zones, low-grade ore in Pre-Early Proterozoic SSU zones.

The Pre-Riphean SSU zone is characterized by greatest potential because the Pasha-Ladoga through hosts the Karku unconformity-type uranium deposit. The structural-stratigraphic unconformity is caused by the gentle occurrence of Riphean sedimentary deposits on intensively dislocated Archean and Proterozoic rocks. Riphean sediments and basement rocks are intensively kaolinized, carbonatized. Sulphide and bitumen are abundant. The uranium mineralization is confined to the sandstone cement; it is represented by pitchblende and coffinite. Elevated grades of Zn, Ag, Pb are recorded. The uranium mineralization is also recorded in the basement rocks. Uranium grade ranges from 0.03% to 0.2-0.5% U, up to 19% U. The age of the mineralization varies from 1400 Ma to 200-190 Ma. Prognosticated resources of the Karku deposit are 6, 7 t.t. U (category P1) and 50 t.t. U (category P1 + P2) [7]. Riphean troughs also occur in the Belomorian block. Here there are the Tersky Bereg potentially uranium ore district. Speculative resources of the district are 63, 9 t.t. U (category P3) and 9, 387 t.t. U (category P2) [5].

The position of the targets of the pre-Vendian unconformity ore type is regionally related to the joint of the plate complex of the Russian plate with the structures of the Baltic Shield and the Baltic-Mezen fault-block zone. The sandstone and gritstone of the Vendian basal horizon overlie Early Proterozoic schist and gneiss

intruded by uranium-specialized leucogranite. Anomalous uranium concentrations have been recorded both in the sandstone and gritstone of the basal horizon and in the rocks of the weathering crust. The uranium occurs as pitchblende and uranium oxide; coffinite sometimes appears. The uranium mineralization is accompanied by pyrite, galena, molybdenite. Uranium grade ranges from 0.03% U to 0.1% U for a thickness of 0.5 to 3.5 m. The age of the formation of main uranium concentrates is 350-420 Ma. Younger ages (from 300 to 5 Ma) evidence uranium redistribution till the recent time. This ore type is represented by the Ratnitskoe, Ryabinovskoe, Slavyanka deposits.

The metasomatic in black shale ore type is recorded in the Onega depression (Onega uranium ore district). Carbon-bearing terrigenous rocks host the ore. The location of the complex uranium-gold-platinum-palladium-vanadium deposits in space are controlled by linear fold-fault zones (FFZ). Eleven zones were recognized within the Onega depression. These are systems of narrow anticline of NW strike having the length of 30 to 100 km and the width of 2 to 4 km. The ore-bearing intervals that host complex deposits are 2 to 2.5 km long and 500 to 600 m wide. In the fold-fault zones the rocks are intensively albitized, carbonatized, biotitized. By the present, several significant deposits (Srednyaya Padma, Kosmozero, Tsarevka and other deposits) and nine ore-showings of this type were discovered in the Onega depression. The uranium mineralization is represented by brannerite, coffinite, pitchblende. Average uranium grade is 0.15 to 0.25% U (up to several percent for 1-3 m), that of vanadium oxide is 2.5-3.5%. Speculative resources (category P3) are 110 t.t. U [5].

Metasomatic pegmatite ore type (metasomatic) unites numerous group of ore targets located in the rocks of the Archaean basement complex, mainly in the Ladoga-Barents Sea longitudinal fault-block zone; small showings were also identified in granite-gneiss domes of the Svecofennian Megablock.

The fault-block zones are characterized by processes of granite formation, silico-alkali and siliceous metasomatism. Ore-hosting metasomatite is dominated by quartz-microcline, quartz-albitite, and quartz-microcline-albitite metasomatite, microcline, albitite, pegmatite that form vein bodies concordant with hosting gneiss. They are from several tens of meters to several hundreds of meters long and from several meters to 30 m wide. Ore minerals are dominated by uraninite, thorite, uranothorite. The age of the mineralization ranges from 2700-2200 to 1800-1700 Ma. In the Karelian Megablock, this ore type is represented by the Gimoly, Khukkaly and other showings; speculative resources (category P2) of the Khukkaly uranium clusters are 60, 0 t.t. U [7]. In the Svecofennian Megablock, this ore type is represented by Khirsimyaki, Khotinoya, Mursula ore showings.

The initiation and evolution of Early Proterozoic protoriftogenic and protoplatform depressions was accompanied by the formation of basal horizons represented by conglomerate-gritstone strata with the weathering crust in the base. The quartz-pebble conglomerate ore type is closely associated with these rocks. The location of ore targets is controlled by deep fault zones, where basement rocks are chloritized and carbonatized; gritstone and conglomerate are carbonatized, sericitized, and silicified. The ore mineralization is represented by uraninite, uranium titanite. Gold occurs as nuggets. Uranium grades vary from 0.017% to 0.05% U. Examples of ore targets of this type are the Rigovaraka, Pjajavara, Jangozero and other ore showings.

The metasomatic (vein) type unites uranium targets located in micaceous and aluminous gneiss, in the influence zone of leucocratic granite, granodiorite of the Litsa-Araguba Complex. Chloritization, hydromicratization, albitization of host rocks were intensive in the contact zone of the granite with host rocks complicated by NE faults. The uranium mineralization is represented by pitchblende, coffinite, uraninite. Uranium grades range from 0.073-0.0138 to 1.74% U. The absolute age of the uranium mineralization is 400 - 1750-1650 Ma. The Litsevskoe, Beregovoe, Koshkajavr and other ore showings belong to this ore type.

The ore targets of the phosphorous-uranium (phosphorous) type are concentrated in the fold-fault Raahe-Ladoga zone of the Svecofennian Megablock. Skarned and intensively brecciated Jatulian dolomite and dolomitized limestone host the ore. They are characterized by elevated phosphorus and organic matter grades. The ore mineralization is represented by uraninite, fluorine-apatite; abundant sulphide and carbonaceous matter are also recorded. Average uranium grade ranges from 0.02-0.05% to 0.044% U (maximum grade is 0.098% U); phosphorous grade is 6% P. The age of the mineralization is 2300±50, 1720-1960 Ma. This ore type is represented by the Mramornaya Gora, Ruskeala, and Kharlu ore showings.

An interest in gold-uranium mineralization located in Early Proterozoic structures has increased with the discovery of the Rompas group deposits in Finland. Gold-uranium deposits are located in the Perapohja schist belt with widespread mafic volcanic rocks, black and mica schists, manifestation of intrusive magmatism in the form of late orogenic (1.84-1.80 Ga) and postorogenic (1.79 -1.76 Ga) granitoids, occurrence of abundant quartz-carbonate veins with anomalous gold grades (up to 617 ppm for 6 m Au) [3]. Gold mineralization has clear relationship with uranium mineralization. Gold minerals (native gold, hunchunite, maldonite) fill in cracks in uraninite and form fine disseminations in carbonates in the immediate vicinity of uraninite [3]. Gold mineralization, identified in the Ozernoe ore occurrence (Pana-Kuolayarvi structure, North Karelian), is similar to the Rompas group deposits as concerns its location. Uraninite grains identified in albite-carbonate metasomatite in ore zones of the Ozernoe ore occurrence have a dense system of fine fractures. Veinlets consisting of intergrowths of native gold and altaite occur in the fractures in uraninite [6].

The intrusive carbonatite (uranium-thorium-rare-metallic in carbonatite) type is related to the Kovdor, Vuori-

jarvi, Sokli and other carbonatite massifs. The mineralization is represented by tantalum-niobium and thorium-uranium ores. Main uranium concentrators are baddeleyite, perovskite, uranothorite. Uranium grades vary from 0.025 to 0.31% U. The age of the deposit is determined at 360 to 420 Ma. The Kovdor deposit, Afrikanda, Vuorijarvi and some other ore showings are among the ore targets of this type.

The lignite (black shale) type is related to the Cambrian-Ordovician black dictyonema oil shale widespread in the southern slope of the Baltic Shield. The ore bodies here are stratal. The uranium mineralization is represented by pitchblende, uranium oxide. Uranium grade varies from 0.02 to 0.046 % U. The ore targets of this type are the Krasnoe Selo, Kotlovskoe, Kingiseppskoe deposits. Of the variety of the ore types, the uranium in the pre-Riphean SSU (unconformity) ore type (Karku) and the metasomatic in black shale ore type (Srednyaya Padma and others) are of economic significance.

Main distinctive geological, petrographic-lithological, epigenetic, radiogeochemical, geophysical, and other features typical of the ore-bearing areas have been identified based on the pattern analysis of the location of uranium deposits and ore showings. Structural evidence controls the location of ore targets in space. These are deep faults, zones of schistosity, fissuring, brecciation, which are characterized by elevated permeability and promote migration of ore-bearing fluids, including from deep crustal zones into upper horizons. Zones of regional structural-stratigraphic unconformities (SSU) are the most important of them in this region. Petrographic-lithological criteria are uranium-specialized sedimentary and magmatic rocks: leucogranite, alkaline intrusive rocks, carbonatite, carbon-bearing shale, phosphate-bearing sand, bauxite-bearing rocks, etc. These rocks provide to a great degree the geochemical resource during the epigenetic ore formation. Epigenetic evidence includes ore-preparation, ore-accompanying, and ore-hosting epigenetic rock transformations. Hydrothermal-metasomatic conditions favourable for the ore formation are quartz-feldspathic pegmatite and metasomatite accumulating uranium, thorium, and other elements in ore concentrations; greisens which promote uranium transformation into migration state; albite-carbonate-micaceous metasomatite creating environment favourable for ore formation; chlorite-carbonate, albite-hydromicaceous and other metasomatites, which form near-ore and ore-hosting zones. A group of indicators evidencing the processes of ore matter concentration separated from the bedrock occurrence of the ore, is assigned to indirect features. Indicators showing immediately an occurrence of a mineral of prognostic type are direct features.

Uranium metallogenic zoning of the Karelian-Kola Area was made based on analysis of manifestation of geological evidence and prospecting indicators of uranium mineralization. Following metallogenic taxa were identified depending on the degree of ore enrichment and manifestation of ore-controlling factors: uranium and potentially uranium structural-metallogenic zones (SMZ) or regions that correspond to structural zones or their parts; uranium and potentially uranium districts corresponding to local structures; uranium clusters and potentially uranium clusters-areas characterized by high ore enrichment and the most intensive manifestation of all controlling factors.

The most industrially significant of them are the following. Onega uranium ore district, which covers the Onega depression and the Preonega depression; speculative resources of the Onega district are 100 t.t. U [5]. North - Ladoga SMZ covers the Raahe-Ladoga structural-formational zone and activated margin of the Karelian megablock. Karkulampi uranium ore cluster is established in the northern part of the North - Ladoga SMZ. Karkulampi uranium ore cluster hosts the Karku uranium deposit and a group of ore-showings confined to the pre-Middle Riphean unconformity surface in the NE Pasha-Ladoga graben. Speculative resources (category P1+P2) of the Karkulampi uranium cluster are 50, 0 t.t. U; prognosticated resources (category P1) –6,7 t.t. U [7]. South-Ladoga SMZ is situated in the zone of joint of the East European platform basement and the Vendian-Paleozoic plate complex. Uranium potential of the zone consists of deposits and ore-showings in the basal layers of the Gdov horizon and enormous uranium reserves in the Ordovician dictionemous shale. Neva-Volkhov and Baltic uranium ore districts are established in the South-Ladoga SMZ. Neva-Volkhov district hosts the Slavyanka, Ryabinovskoe and Ratnitskoe uranium deposits. Speculative resources of the Neva-Volkhov uranium district are 520, 5 t.t. U [4, 5]. Dictionemous shale of the Lower Ordovician Pakeror horizon is host rock in the Baltic uranium ore district. The ores are low-grade –0.01-0.03 % U (up to –0,07 % U); in addition to uranium, the shale is enriched in molybdenum, vanadium, and other elements. Speculative resources (category P3) are 600 t.t U [5].

## CONCLUSIONS

The zones of structural-stratigraphic unconformities and fold-fault zones have the highest potential for uranium and complex with uranium deposits. The Pasha-Ladoga graben (pre-Riphean unconformity type deposits), Onega trough (fold-fault zones) show considerable promise for uranium mineralization. Areas, hosting the uranium deposits located in the Archean-Early Proterozoic basement and controlled by the superimposed low-temperature alterations also have great potential (Litsa and other areas). The Early Proterozoic structures are promising for the gold and uranium deposits.

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