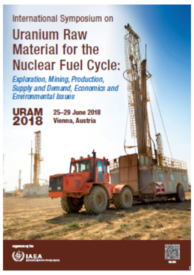

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Features of geological modelling, Mineral Resources and Reserves estimation of uranium roll-front deposits

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INTRODUCTION

Roll-front deposits in Kazakhstan are the source of 40% of the world uranium production [1]. These deposits are characterized by having low production costs due to the use of in-situ recovery ("ISR") methods for uranium extraction. Consulting companies prepared reports based on international standards (NI 43-101, JORC) and local standards (GKZ system) before 2012. This approach often led to an underestimation of Mineral Resources [2]. CSA Global developed a robust methodology for geological modelling, Mineral Resource and Ore (Mineral) Reserve estimation for roll-front deposits in Kazakhstan from 2012 through 2017. This methodology was applied to Budenovskoye and South Inkai deposits in Chu-Sarysu province, and Zarechnoye and Kharasan-1 deposits in Syrdarya province [3], [4], [5], [6], [7].

CHARACTERISTICS OF ROLL-FRONT DEPOSITS

The first characteristic of roll-front deposits is the very complicated morphology of mineralisation. Uranium mineralisation occurs in unconsolidated lacustrine-alluvial sediments of Late Cretaceous –Paleogene horizons in two regional basins in South Kazakhstan: Chu-Sarysu ans Syradarya. Mineralised bodies of these deposits are represented as weaving ribbons of various width and length per unit area and are controlled by the oxidation zone boundary. The mineralised bodies consist of several morphological elements, including noses, knees, upper and lower wings (limbs), and residual bodies (satellites) located at the rear of the roll front. An important feature is the variation in the proportion of uranium and radium throughout these bodies. Uranium dominates in the nose and decreases in the wings, whereas radium dominates in the residual bodies. The uranium to radium ratio is described by the radioactive equilibrium factor ("REF"), which is part of a more general definition of radiological factors. The width of the deposits may vary from tens to hundreds of meters and is often dependent on the thickness and frequency of impermeable lenses / interbeds, which complicate the boundary of the zone of formation oxidation ("ZFO"). The extended upper limb of a roll, complicated by step-wise "sliding"of the geochemical boundary, is, as a rule, observed when the thickness of the horizons is considerable, and several confining lenses are available in the area of ZFO boundary thinning. Multistage bodies consisting of a number of mineralised lenses are typical of the deposit stratigraphy and confirm the extreme complexity of the enclosing rock sequence.

The second characteristic of roll-front deposits is the use of ISR methods. ISR transfers a significant proportion of hydrometallurgical processing to the subsurface to directly obtain solutions of uranium. For ISR to be successful, deposits need to be permeable, and the uranium readily amenable to dissolution by leaching solutions in a reasonable period of time, with an acceptable consumption of leaching reagents [8].

MODELLING AND MINERAL RESOURCE ESTIMATION

Modelling and Mineral Resource estimation of roll-front uranium deposits consist of the following stages which takes account of the characteristics of these deposits:

• Selection of mineralised intervals by correct application of radiological factors. The first radiological factor is radon removal/concentration which is evaluated based on a comparison between gamma-logging results and the results of core sampling and analysis for radium [9]. The second step is determination of a radium cut-off grade, being 0.01% U equivalent in different geochemical zones (oxidized, reduced), which allows radium halos to be excluded around uranium mineralised bodies. Radium halos at the boundaries have a significant influence on mineralised intersections. These halos are diffuse and manifest as mineralised intersection margins in which equilibrium is shifted towards an abundance of radium. Finally, a correction for REF = C (radium) / C (uranium) is introduced to calculate the uranium grade after establishing mineralised interval boundaries and calculation of the average radium grade. REF studies are carried out for various geological and geochemical environments such as the nose, wing and residual parts of rolls, as well as permeable and impermeable sediments, and different mineralised horizons. The ratio between uranium and radium is calculated using assay data for uranium and radium and extrapolation of defined patterns to intervals defined by gamma-logging.

• Estimation of permeable / impermeable intervals. Electrical logging (resistivity logging and spontaneous polarization) is the most common method for lithological interpretation. Comparison of core lithological logging, granulometry and electrical logging allows identification of impermeable zones.

• Modelling of sedimentary cycles (horizons) which are controlled by continuous clay/silt horizons and controls the distribution and location of ZFOs. Analysis of the distribution of mineralised intervals and oxidised sediments shows that mineralisation in different horizons (cycles) occurs in separate roll-fronts. However, sometimes mineralisation "overflows"between horizons due to breaks in the clay horizons between cycles. Digital terrain models ("DTMs") are used for modelling borders between sedimentary cycles. Continuous impermeable layers should be modelled at this stage together with sedimentary cycles.

• Mineralised intervals are divided into morphological elements –nose, knee, upper wing, lower wing and residual parts separately for each ZFO. This is completed by using geochemical data as follows:

o The intervals where mostly reduced rocks are developed both in the mineralised interval and above and below are attributed to the nose or knee.
o The intervals where reduced rocks are developed in the mineralised interval and mainly and above are attributed to the upper wing.
o The intervals where reduced rocks are developed in the mineralised interval and mainly on lower side are attributed to the lower wing.
o The intervals where there are mainly oxidised rocks developed above or below the mineralised interval are attributed to the residual part. The mineralised interval itself can be represented both by reduced and oxidised rocks.

The distribution of nose / knee parts is controlled by the ZFO. 3D modelling of roll-front deposits allows morphology to be clarified and positioning of ZFOs and oxidized sediments, which control the distribution of mineralisation. For example, at the Zarechnoye deposit, the location of the ZFOs were changed and as result understanding the direction of flow of uranium-bearing solutions. The orientation was changed from north-west to south-west. New uranium mineralisation was discovered due to the new interpretation.

• Modelling of interbeds of impermeable sediments inside mineralised horizons. This allows construction of a lithological wireframe model with mineralised bodies and permeable/impermeable sediments and can be used for design of operation blocks and define intervals for screens (filters).

• Interpolation of grades into mineralized bodies by Ordinary Kriging or Multiple Indicator Kriging.

• A gridded model is generated for each wireframe in order to estimate uranium Grade-thickness ("GT") based on block models. GT or productivity cut-off is more appropriate for ISR deposits than cut off grades [8]. The vertical extent of the cells of the gridded model depends on the thickness of the mineralisation. Uranium GT is calculated by multiplying the vertical size of the cells by the uranium grade. Gridded models are two-dimensional. In order to estimate the GT in three-dimensional space, it is necessary to compare each cell of the gridded model with a column of cells in the original block model. This is completed by indexing the block model cells by comparison with the cells of the gridded model. Using the indices, the GT values of the mineralised bodies from the gridded model is coded into the block model.

• Depletion of Mineral Resources. For ISR deposits, the depletion of Mineral Resources is measured not by how much rock is removed, as is the case with most traditionally mined resources, but rather by lowering of uranium grade (and GT).

ORE (MINERAL) RESERVE ESTIMATION

'Modifying Factors'are considerations used to convert Mineral Resources to Ore (Mineral in NI 43-101) Reserves. These include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors [10].

The main technical Modifying Factors for Ore Reserve estimation are mining and metallurgy.

The ratio of Liquid to Solid (L:S) required to achieve the desired extraction of uranium. This ratio is calculated based on the volume of solutions that pass through the operational block over the entire period of operation, and on the tonnage of the operational block [8]. Graphic extraction vs L:S is the most relevant consideration for exploration target evaluation. Usually target extraction is calculated by decreasing uranium concentrations in pregnant solutions to breakeven cut-off grade, that reflect on the graph by a flattening curve.

Dilution is included in the operational block calculation as the volume is based upon the effective thickness of the production zone. The Mineral Resource estimate includes Measured and Indicated Resources within the operation blocks. Dilution estimates are prepared based upon the difference in tonnage between the Mineral Resource estimate and the operation block tonnage estimate.

DISCUSSION AND CONCLUSION

Application of 3D modelling techniques for roll-front deposits allows the creation of lithologicl and resource models and reliable Mineral Resource / Ore (Mineral) Reserve estimation. Based on the experience of the author, the difference between Mineral Resources and Ore (Mineral) Reserves, based on operational wells and the geological / resource model, does not exceed 5–7%. These models are used for more accurate screen set ups in operational wells, hydrodynamic and physic-chemical modelling of uranium leaching in operational blocks and, and finally, more accurate estimation of Mineral Resource depletion after constraining of operational blocks.

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