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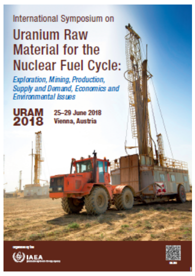

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STOCHASTIC MODELLING OF URANIUM ROLL-FRONT DEPOSITS BASED ON STREAMLINE SIMULATION

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INTRODUCTION

Rollfront deposits are an accumulation of minerals in reduced permeable sandstones or other sediments between mostly reduced and pervasively oxidized environments [1]. Rollfronts are classified as epigenetic mineral deposits, i.e. their genesis occurred after hosting environment was created, that that often can be found in arid areas and trapped within permeable sedimentary environments. Deposits of rollfront type are crucial to uranium industry. As much as 60% of the worldwide production from recoverable uranium resources in sandstone environments can be accounted to rollfronts [2]. Rollfronts can be found in various sandstone provinces including the Colorado Plateau, Wyoming, Texas Coastal Plain, Mali-Nigeria, Czech Cretaceous Plate, Chu-Sarysu, Syr-Daria, Moynkum, Inkai and Mynkuduk (Kazakhstan), Crow Butte and Smith Ranch (USA) and Bukinay, Sugraly and Uchkuduk (Uzbekistan), Kyzylkum [3, 4]. Uranium can be extracted from rollfront deposits in a safe and convenient manner with In-Situ leaching method (hereinafter ISL). 39% of all uranium produced in the world in 2016 could be accounted to Kazakhstan, where almost all uranium deposits are being developed with ISL [2]. Furthermore, Kazakhstan is the second largest country in the World by uranium resources with close to a million tons of recoverable uranium (1Mt U in 2013), almost 70% of which can be recovered using ISL technique [2].

One of the main difficulties in the exploration of uranium rollfront type deposits lies in the limited number of available exploration techniques that, at small scale, are generally limited to the drilling of numerous costly wells network patterns in perspective areas [4], which in itself is a long and costly process.

Two basic approaches to modeling exist at the moment: the traditional interpretation of geophysical data with the subsequent connection of ore contours; and geostatistical 3D modeling [6]. Presently, there are a number of stochastic methods for modeling rollfront uranium deposits by Renard D., Beucher H. [7], Petit et al [8] and Abzalov et al [6]. Renard D. and Busher G. V, developed the technology of three-dimensional modeling of such deposits based on the model of “PluriGaussian Simulation” [7].

Unfortunately, current modeling techniques rarely account for the hydrodynamic and geochemical processes involved in the genesis of rollfront uranium deposits. The authors propose to supplement existing stochastic models with additional methods of computational hydrodynamics.

METHODS AND RESULTS

Rollfront deposits were formed due to dissolution of minerals from mountain rocks, their subsequent migration along porous canals and deposition in so-called geochemical barriers between oxidized and reduced medium. The formation of rollfront uranium deposits can be divided into three stages: leaching of uranium by oxygen rich meteoritic water, downstream migration of the dissolved chemical uranium components and precipitation of uranium in reduced environments. Upon reaching reduced environments, the dissolved uranium together with other elements such as iron and sulfurs precipitate as uranium minerals (such as pitchblende or coffinite), thereby forming a rollfront type deposit. It is important to note, that the re-deposition of minerals is a dynamic process sustained by a continuous flow of oxygenated meteoritic water which push minerals further downstream. In other words, in active deposits, minerals continuously dissolve from the upstream side of the mineralization zone and precipitate at the front. When no more oxygen is available in the water flow, often because it has been consummated previously by the oxidation of the organic matter before reaching the mineralized zone, the rollfront deposits stabilize.

It is clear that the process of genesis of uranium rollfront deposits is highly linked to the infiltration process of dissolved uranium compounds. Therefore, honoring the hydrodynamics of infiltration processes can further increase the precision of any geostatistical approach that is used in modeling rollfront deposits.

Well log information is usually used as input data for geostatistical modeling of rollfront uranium deposits. In addition to uranium concentration, such data commonly includes filtration properties of stratum.

Application of various estimation methods such as inverse distance weighting or kriging are based on weight assignment to well data in order to determine value at any specific node on a computational grid. Weight assignment technique is a determining factor that differentiates one estimation algorithm from another. For instance, while in kriging based methods, variogram is used for weight computation, in inverse distance based methods (as the name suggests) the length of space between nodes is main influencing factor. In many implementations of aforementioned methods, search ellipsoid is used to gather input information from well log data. The form of this ellipsoid is usually dictated by anisotropy of a particular geological formation.

In current work, based on filtration properties gathered from well data and natural head difference, streamlines of solution flow through stratum under consideration were determined. These streamlines were further used as a search shape for distance based methods, while variograms were calculated along the streamline by substituting distance variable with "time of flight"(a property specific to streamline simulation methods).

To verify the stochastic modeling approach of uranium rollfront deposits based on streamline simulation, well log data from Kazakhstan deposits were used. In each verification iteration one or more well data were excluded from modeling input for later comparison between numerical and hard data. For further verification purposes, synthetic deposits were simulated based on reactive transport models by reproducing involved uranium rollfront deposit formation.

DISCUSSION AND CONCLUSIONS

Results show that in terms of error, as compared to conventional estimation algorithms stochastic modeling of uranium rollfront deposits based on streamline simulation provided qualitatively, as well as quantitively, better picture. In most of the cases, stochastic modeling based on streamline simulation provided lower average error for every node in computational grid, as well as slightly more accurate resource estimation. Modeling approach was further investigated for various well placement patterns to identify optimal distances between exploration wells.

Overall, the aim of this work was to stochastically model rollfront deposits by honoring hydrodynamics properties of the stratum by constructing variograms along streamlines of groundwater flow to provide additional information on variability, as well as to redefine the process of weight assigned to hard data. In several cases stochastic modeling of uranium rollfront deposits based on streamline simulation provided results with higher accuracy as compared to conventional methods based on kriging or gaussian simulation.

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Country or International Organization

Kazakhstan

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