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The challenges to explore and discover an unconformity deposit at depth

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INTRODUCTION

Proterozoic unconformity uranium deposits are considered the highest grade deposits in the world. The most recognized deposits occur in the Athabasca basin in Canada [1]. As indicated in the 2016 "Red Book", Proterozoic unconformity deposits account for about one-third of the world's uranium resources based upon reasonably assured resources [2]. In 2017, the only two producing uranium mines in Canada allowed for over 20% of the world supply utilizing underground mining methods [3]. One matrix using current research of active mining operations with publicly disclosed data involving ore reserves, calculated according to an international standard, has outlined Cameco's Cigar Lake and McArthur River operations as having the most valuable ore [4].

Expenditure spending in the search for deposits has diminished since a peak spot price of uranium in 2007 [5]. There are a number of well documented factors related to a decline in uranium prices that has led to a weak demand for the product. A few of the reasons for the lack of demand, but not limited to, include the events in Fukushima, Japan in 2011, economic challenges from fuel sources with cheaper capital costs for start-up, secondary supplies from government inventories as well as re-enrichment sales has also provided excess inventory.
Even with the previous described "headwinds"in the nuclear power industry there are reasons for optimism due to the new builds and forecasted growth in central and eastern Asia. The IAEA's high case projection has the global nuclear generating capacity increasing from 2016 levels by 42% in 2030, by 83% in 2040 and by 123% in 2050 [6].
Current statistics obtained from the Saskatchewan Mining Association indicate that exploration expenditures in the Athabasca Basin were $CAD44.8millionin2016[7].MajoruraniumcompaniessuchasOranoCanada(previouslyAREVARe$

CURRENT LAND STATUS IN THE ATHABASCA BASIN

An internal review of the current land disposition in the Athabasca Basin (includes the provinces of Alberta and Saskatchewan) involving uranium exploration was conducted in February, 2018. Upon review, it is estimated that 40There are numerous factors, mainly conjectural, that can be implied to interpret the current land status in the Athabasca Basin including a company's available funding for exploration, current exploration portfolio, company strategies, availability of favourable geological trends and access to a project area.

RATIONAL FOR LOOKING AND DISCOVERING NEW ECONOMIC DEPOSITS AT GREATER DEPTHS

Potential for discovering new economic deposits can be evaluated by ranking different projects according to multiple parameters among which the depth of the targets at the unconformity or in the basement can be considered as of most importance. Exploration maturity can be also judged on the basis of potential based on available conductor strike length following the traditional unconformity-type model [8]. Thus, the probability to find a new economic deposit at depth lower than 250m with the minimal footprint such as the Cigar Lake deposit is limited taking into account the existing spacing of drill holes along the main conductive trends. However exploring high grade pods at shallow depth remains a short to medium term objective as these targets may be economic by small open pit means or if the possibilities of surface access borehole extraction methodology becomes cost effective.

In a long term vision, the critical depth of exploration within the Athabasca Basin will likely evolve and it is probable that the deepest portions of the basin, will be considered for greenfield exploration. However, several economical and technical challenges will have to be faced. What type of mineral deposit and which size will have to be targeted to become economic? Can we expect some technical and scientific breakthrough that would improve significantly the resolution of the geophysical methods, the drilling technologies and our ability to vector our geological exploration?

This new frontier and challenges are discussed in relation to the present state of art and in reference to the Cigar Lake deposit. As a hypothesis, one considers that other world class deposits exist at the unconformity at depths greater than 500 metres. Although the geological conditions under which such a deposit can be formed are not fully understood [8], it is unlikely that these conditions were only met in a single locality over the whole extent of the Athabasca Basin. As a support to this hypothesis, other deposits like Shea Creek [9, 10] or Phoenix [11, 12] are formed under near identical mineral systems: association with long lived deeply penetrating and steeply dipping structures, enhanced permeability fault system within a compressive tectonic context, leaching of huge volume of sedimentary and metamorphic lithologies by oxidized basin and reduced basement fluids, formation of uranium deposits from highly concentrated uranium-bearing acidic brines [13].

An economic scenario for deep unconformity deposits is presently very difficult to define. Kerr and Wallis [14] consider that, if low grade deposits can be economically mined at depth lower than 200m, only purely basement hosted deposits and unconformity hosted giant deposits will possibly be qualified as reserves below 200 metres. A high level study can be completed to determine the economics of a hypothetical mining and milling operation located in the centre portion of the basin. However, such calculation is very sensitive to the uranium price and capital cost and a detailed scenario is out of the scope of this discussion.

To follow up the discussion, one considers that the footprint of the targeted deposit should be an unconformity type deposit, comparable if not larger than the Cigar Lake deposit to be effectively economic at an uranium price of $US40/lbsU3O8[15].Thisdepositstyleisselectedduetothealterationhalothatreachesupto2$

THE CHALLENGE TO EXPLORE AND DISCOVER A GIANT UNCONFORMITY DEPOSIT AT DEPTH

There is no direct uranium detection for deposits buried at depth. Our present exploration technologies for depth greater than 500 metres are limited by several factors as the cost of drilling, in particular in remote sectors, and the decreasing resolution of geophysical modelling at increasing depth. However, some technical and scientific breakthrough in the coming years may improve our ability to vector our geological exploration.

Junior and major companies are investing millions of dollars every year for geophysical surveys, downhole geophysical probing and acquisition of complete petrophysical datasets including density, magnetic susceptibility and resistivity. Numerous case studies of ground and airborne electromagnetics (EM) and magnetics surveys, resistivity ground campaign, downhole geophysics are regularly presented and should enable the definition of best practices according to the different geological context if a complete return of experience could be achieved. Moreover, such analysis should guide the developments for the acquisition, processing and modelling. Thus, the principle of combined acquisition and joined inversion of EM, magnetotellurics (MT) and resistivity surveys is the current inherited way to explore at depth and to improve the resolution of the geophysical 2D and 3D models.

The main budget of exploration is oriented to drilling. One of the main problems faced today by the companies is the cost of drilling in purely greenfield terrain, the high risk of lost holes in zones of sandstone dissolution (that induces high cost and then limitation of the meterage to be drilled) and the low recovery of cores in fault zones that hampers the structural reconstruction of the architecture of the explored domains and a careful study of the mineralizations. Innovations should be deployed to use or test equipment in order to limit the risk of hole lost because of difficult geological environment, improve the drilling practices and for example generalize the use of directional drilling to explore large zones at depth from a pilot hole. The monitoring of the drilling parameters should also help to control the progress of the drilling in these zones and enhance the quality of coring. High resolution imagery of the structures of the hole and recording of the physical properties while drilling should also be an objective to be elaborated and tested by the drilling and exploration companies.

Exploring Cigar Lake analogs at the base of the unconformity can benefit of the geological knowledge that has been acquired since exploration and exploitation started. The Cigar Lake deposit is located 420-445 metres below the surface within the Athabasca Group's Manitou Falls Formation. The mineralization has a flat to tubular shaped lens approximately 2000 metres in length, ranges between 20 and 100 metres in width and with an average thickness of about 6 metres [17-19]. The mineralization has a crescent-shaped cross-sectional outline that closely reflects the topography of the unconformity. The alteration halo surrounding the Cigar Lake deposit is extensive and affects both sandstone and basement rocks, characterized by extensive development of Mg-Al rich clay minerals (illite and chlorite). It is presently possible to build a 3D earth model reconciling geological and geophysical data, based on extensive datasets including geological, geochemical and physical properties centered on the deposit but also extending along trend and other underexplored conductive trends. This type of modelling of the Cigar Lake domain could use recent developments performed on the application of Artificial Intelligence and learning machine [20, 21] to update the footprint of the deposit. It will also provide an excellent return of experience for defining appropriate acquisition parameters, processing and modelling of geophysical methods considered above as a first step to be accomplished for exploring at greater depth.

An earth model resulting of the updated footprint of Cigar Lake domain could be used to simulate the geological, geochemical and geophysical footprint that could be created by such a deposit in different localities at the base of the basin. Reprocessing and acquisition of complementary geological and geophysical datasets, linked to the measured, estimated or interpolated petrophysical datasets, should then provide a set of unconstrained and constrained inversions that will be compared with the simulated footprint. This modelling, both data and knowledge driven, could lead to a virtual exploration of Cigar lake analogs at the base of the Athabasca Basin.

Finally, as the exploration will provide new datasets from drilling, the new information could be used to refine constrained inversion and to evaluate the possibility to vector exploration towards new deposits.

In conclusion, this long term vision can be put in perspective with the challenges that were faced by the oil and gas industry when exploration targeted deeper, more structured and remote reservoirs. Although the geology is much more complex than oil and gas reservoir, pre competitive research and development programs could be set up in order to be on time when greenfield exploration will become open for defining a new critical depth for unconformity related uranium deposits.

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