International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues (URAM-2018)

Contribution ID: **132** Type: **ORAL**

Spatial analysis of prospectivity for surficial uranium deposits: a case study in British Columbia, Canada

Wednesday, 27 June 2018 10:20 (20 minutes)

INTRODUCTION

Surficial uranium (U) resources exist in the southernmost part British Columbia (Canada). The known U resources in the region (hereafter denoted as SBC) are comprised by four surficial U deposits and 32 small prospects/showings. The prospectivity of the SBC for surficial mineralization has, however, not been entirely evaluated yet. Here, results of spatial analysis of prospectivity for surficial U in the SBC, using a geographic information system (GIS) and following the mineral systems approach [1], are presented.

SURFICIAL U MINERAL SYSTEM IN THE SBC

In the SBC, surficial U mineralisation consists of fluviatile and/or lacustrine/playa U occurrences within loose, pervious fluvial sediments of Late Miocene age along paleodepressions or paleochannels [3]. The mineralisation is composed largely by uranyl carbonates [2] and/or uranous phosphates such as autunite, ningoyite and saleeite [3].

The rocks that are probable sources of U in the SBC include small units of uraniferous pegmatites in the Shuswap Metamorphic Complex of Palaeozoic age, granitoids of Jurassic–Cretaceous and Eocene–Oligocene age, and volcanic rocks of Eocene age [2], [3]. Data on reactive U content of rocks [3] suggest that Okanagan granites/pegmatites of Jurassic–Cretaceous age are major sources of U in the SBC. The release of U from the potential sources has probably been favoured by repeated tectonism and multiphase intrusions that have taken place in the SBC during the ancient geologic past [3].

Tectonically deformed intrusive rocks cut by interconnected faults/fractures also favoured deep-seated flow and wide-distribution of U-bearing groundwater, which ultimately permeated pervious sediments along paleodepressions or paleochannels [2]. The U, in these surficial environments, exists as soluble uranyl carbonate complexes carried by oxygenated alkaline groundwater [4]. Flow of groundwater is focused through pervious paleodepressions or paleochannels filled with permeable fluviatile sediments. Energy for flow of groundwater is chiefly due to gradient along paleodepressions or paleochannels.

In playa/lacustrine environments, organic-rich sediments act both as physical and chemical traps for surficial U formation [2]; whereas in pervious zones of channel fluviatile environments, organic-rich soils or sediments act both as physical and chemical traps In either environment, surficial U forms mainly by either evaporation or reduction. The latter is due to bacteria or to sediments that are rich in organic matter. However, because no common U minerals are known in the SBC, the role of evaporation in the SBC is less likely, as groundwater is not saturated with respect to typical U phosphates [5]. Thus, in the surficial U mineral system in the SBC, adsorption onto organic-rich sediments is the most probable factor of surficial U mineralisation, followed by reduction owing to bacteria or organic-rich sediments [2], [5].

SURFICIAL U MINERALISATION: CRITERIA FOR TARGETING, SPATIAL PROXIES

The deposits/occurrences of surficial U in the SBC are alike but dissimilar to the most significant surficial U deposits worldwide, namely calcrete-hosted carnotite [6], [7], [8], [9]. Therefore, mapping of surficial U prospectivity in the SBC will make use of criteria for targeting and respective spatial proxies that somewhat differ from those used exactly for the same purpose in the Yeelirrie area (Australia) [1]. The criteria for targeting that were used here include: (a) source rocks for U; (b) pathways; and (c) traps.

A single U source targeting criterion, namely felsic volcanic or intrusive rocks with reactive U, was used. The corresponding spatial proxy used was presence of and/or proximity to felsic volcanic or intrusive rocks with reactive U. Instead of using Euclidean distance to model proximity, fuzzy proximity (representing probability-like values) was used because the fuzzy set theory [10] was used here for mapping surficial U prospectivity. To model fuzzy proximity, Euclidean distances were transformed through a logistic function [11] to non-linearly decreasing values ranging from 1 for the nearest distance to 0 for the farthest distance. Three maps of fuzzy proximity to probable U-source rocks (i.e., Jurassic–Cretaceous Okanagan Batholith, Eocene–Oligocene Coryell Plutonic suite, Eocene Volcanics) were combined into a single map of fuzzy proximity to U-source rocks, by applying a weighted fuzzy algebraic sum operator whereby the weights are defined from the reactive U content of each of the three rock units.

A single pathways criterion, namely Tertiary to Recent paleochannels, was also used. The corresponding spatial proxy used was fuzzy proximity to paleochannels. The paleochannels were remotely-sensed using a digital elevation model and night-time ASTER thermal infrared data [12], [13].

For chemical traps, two criteria were used: (1) bicarbonate contents of fluvial waters; and (2) U-rich groundwater. The respective spatial proxies used were: (1) fuzzy alkalinity of fluvial waters, modelled by applying a non-linear logistic function to data on stream water pH [14]; and (2) fuzzy U-abundance of fluvial waters, modelled by applying a non-linear logistic function to data on U content of fluvial waters [14]. Bicarbonate contents of strongly alkaline fluvial waters in the SBC range from 50 to 600 ppm. This considerably boosts the ability of soils/sediments in paleodepressions of paleochannels to concentrate U [2]. Dispersion of U from source rocks and its enrichment in surface water and groundwater permits huge quantities of this element to reach trap areas wherein surficial U mineralisation ensues.

For physical traps, two criteria were used: (1) nearly-stationary fluvial water in paleodepressions or paleochannels [1]; and (2) size of source area [1]. The corresponding spatial proxies used were: (1) presence of and fuzzy proximity to nearly-level topographic depressions, modelled by applying a non-linear logistic function to topographic slopes derived from a digital elevation model; and (2) fuzzy flow accumulation, modelled by applying a non-linear logistic function to sizes of catchments derived from a digital elevation model. Because surficial U precipitates from nearly-stationary fluvial water in paleodepressions or paleochannels [1], depressions in the topography with level or nearly-level slopes were used as spatial proxies because it can be expected that substantial fluid modification occurs in such locations but not in locations having dissimilar topographic characteristics. Because locations where fluvial water flow accumulates from huge U-source rock areas are prone to amass, enrich, and precipitate more U, a map of flow accumulation was used as spatial proxy because it represents areas that may contain significant potential U-source rocks for surficial U mineralisation.

MODELLING OF REGIONAL-SCALE SURFICIAL U PROSPECTIVITY

The spatial proxies generated were combined in systematic way that mimics the interaction of processes involving sources, pathways and traps, which result in surficial U mineralisation. This was achieved by adapting an inference engine that symbolise hypotheses or knowledge regarding the interactions of a variety of processes that are relevant to a surficial U mineral system [1], [15]; thus, a mineral systems approach. Therefore, a fuzzy inference engine was used to model regional-scale surficial U prospectivity in the SBC according to the above-discussed surficial U mineral system and regional-scale criteria for targeting (and respective spatial proxies) for surficial U mineralisation in the SBC. Considering its simplicity and flexibility, the fuzzy set theory [10] is regarded by [16] to be the most appropriate for integrating spatial data to model the interaction of certain geologic processes.

For every step in the fuzzy inference engine used, a suitable fuzzy operator was used to combine at least two spatial proxies to mimic the interaction of at least two processes pertinent to surficial U deposit formation. The fuzzy inference engine and the fuzzy operators that were used formed a sequence of logical rules that successively combined the fuzzy spatial proxies, and they also served to negate the influence of spatial proxies with significant uncertainty.

As mentioned earlier, a map of integrated U sources spatial proxy was derived by using a weighted fuzzy algebraic sum operator to combine the potential U-source rocks spatial proxies. A map of integrated chemical traps spatial proxy was derived by using fuzzy AND operator to combine the U-abundance and alkalinity of fluvial waters spatial proxies. That is because both U-abundance and alkalinity of fluvial waters are needed for surficial U deposits to form. A map of integrated physical traps spatial proxy was derived using fuzzy OR operator to combine the flow accumulation and nearly-level depressions spatial proxies. That is because adequate physical constrain on surficial U deposit formation may be provided by either catchments with voluminous flow accumulation or nearly-level depressions. Finally, a map of surficial U prospectivity was derived by using fuzzy AND operator to combine the pathways spatial proxy with the integrated U sources, chemical traps, and physical traps spatial proxies. That is because formation of surficial U deposit requires all the processes symbolised by these spatial proxies. Experiments on different map combinations were then performed to determine (a) sensitivity of the prospectivity to input spatial proxies, (b) which spatial proxies are best predictors, and (c) which prospectivity map can be best used to guide further exploration for surficial U deposits in the SBC. The predictive performance of each out prospectivity map [17] was determined by using the four known deposits and 32 prospects/showings of surficial U in the SBC.

RESULTS AND DISCUSSION

The two best maps of surficial U prospectivity that were generated here are inclusive of the proximity to potential U-source rocks spatial proxy, indicating the significance of data on reactive U content of rocks in modelling of surficial U prospectivity and the efficacy of the weighted fuzzy algebraic sum operator to integrate such kind of data in spatial analysis of surficial U prospectivity. The two best prospectivity maps are exclusive of the nearly-level depressions spatial proxy, indicating the inadequacy and thus inaptness of this spatial proxy in modelling of surficial U prospectivity in the region, or the better efficacy of the flow accumulation spatial proxy. However, if, among the traps spatial proxies, only the U-abundance of fluvial waters spatial proxy was combined with the pathways and potential U-source rocks spatial proxies, the output surficial U prospectivity map is just very slightly inferior to the two best prospectivity maps. This demonstrates that either the flow accumulation spatial proxy or alkalinity of fluvial waters spatial proxy just has very little influence on the predictive capacity of prospectivity mapping even though they are important criteria for targeting of surficial U in the region. Nevertheless, the results show that alkalinity of fluvial waters is more efficient than U-abundance in fluvial waters as spatial proxy of U-transporting ability of surface waters. These limitations demonstrate that the prospectivity model requires updating when more appropriate data become available.

The two best-performing prospectivity maps derived here suggest presence of undiscovered surficial U resources in the SBC. However, the identified prospective areas mostly identified are those where the known deposits/occurrences of surficial U are mostly present in the SBC. This indicates that two best-performing prospectivity maps carry type II (or false-negative) error with respect to possible undiscovered resources of surficial U in other parts of the SBC, whereas the two worst-performing prospectivity maps carry type I (or false-positive) error with respect to the known deposits/occurrences of surficial U in the SBC. The type I and type II errors are equivalent to over- and under-estimation of prospectivity, respectively. Avoiding type I error is crucial as this will render failure to discover new deposits, whereas type II error will render missed chance for discovery of new deposits.

CONCLUSIONS

The above-discussed methodology for spatial analysis of regional-scale prospectivity for surficial U in southern British Columbia (Canada) is quite straightforwardly implementable by using a geographic information system. A more intricate fuzzy inference system consisting of more elaborate logical rules representing expert reasoning for delineating zones prospective for surficial U [1] is likely to be as instructive for researchers with more profound insight to the surficial U system in the region.

REFERENCES

[1] PORWAL, A., DAS, R.D., CHAUDHARY, B., GONZÁLEZ-ÁLVAREZ, I., KREUZER, O., “Fuzzy inference systems for prospectivity modeling of mineral systems and a case-study for prospectivity mapping of surficial uranium in Yeelirrie area, Western Australia”, Ore Geology Reviews 71, 839-852 (2015).

[2] CULBERT, R.R., BOYLE, D.R., LEVINSON, A.A., “Surficial Uranium Deposits in Canada”, In: “Surficial Uranium Deposits”, IAEA-TECDOC-322, IAEA, Vienna, pp. 179-191 (1984).

[3] BOYLE, D.R., “The Formation of Basal-type Uranium Deposits in South Central British Columbia”, Economic Geology 77, 1176-1209 (1982).

[4] CULBERT, R.R., LEIGHTON, D.G., “Uranium in alkaline waters –Okanagan area, British Columbia”, CIM (Canadian Institute of Mining & Metallurgy) Bulletin 71, 103-110 (1978).

[5] TIXIER, K., BECKIE, R., “Uranium depositional controls at the Prairie Flats surficial uranium deposit, Summerland, British Columbia”, Environmental Geology 40, 1242-1251 (2001).

[6] CARLISLE, D., “Surficial uranium occurrences in relation to climate and physical setting”, IAEA-TECDOC-322, IAEA, Vienna, pp. 25-35 (1984).

[7] CAMERON, E., “The Yeelirrie calcrete uranium deposit, Western Australia”, IAEA-TECDOC-322, IAEA, Vienna, pp. 157-164 (1984).

[8] MISRA, A., PANDE, D., KUMAR, K.R., NANDA, L.K., MAITHANI, P.B., CHAKI, A., “Calcrete-hosted surficial uranium occurrence in playa-lake environment at Lachari, Nagaur District, Rajasthan, India”, Current Science 101, 84-88 (2011).

[9] KHOURY, H.N., “Geochemistry of surficial uranium deposits from Central Jordan”, Jordan Journal of Earth and Environmental Sciences 6, 11-22 (2014).

[10] ZADEH, L.A., “Fuzzy sets”, IEEE Information and Control 8, 338-353 (1965).

[11] YOUSEFI, M., CARRANZA, E.J.M., “Fuzzification of continuous-value spatial evidence for mineral prospectivity mapping”, Computers & Geosciences 74, 97-109 (2015).

[12] STAMOULIS, V., "ASTER night-time thermal infrared data: interpreting subsurface features from high resolution data", MESA Journal 43, 36-39 (2006).
[13] THAKUR, S., CHUDASAMA, B., PORWAL, A., GONZÁLEZ-ÁLVAREZ, I., "Sub-surface paleochannel detection in DeGrussa area, Western Australia, using thermal infrared remote sensing", Proceedings SPIE 9877, Land Surface and Cryosphere Remote Sensing III, 98772C (May 5, 2016), doi:10.1117/12.2223626.
[14] LETT, R., "Regional Geochemical Survey Database", GeoFile 2011-07, British Columbia Geological Survey (http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/GeoFiles/Pages/GF2011-7.aspx) (2011).
[15] CARRANZA, E.J.M., HALE, M., "Geologically constrained fuzzy mapping of gold mineralization potential, Baguio district, Philippines", Natural Resources Research 10, 125-136 (2001).
[16] BARDOSSY, G., FODOR, J., "Geological reasoning and the problem of uncertainty". In: Cubitt, J., Whalley, J., Henley, S. (Eds.), Modeling Geohazards: IAMG2003 Proceedings, Portsmouth UK. Portsmouth University, UK (2003).
[17] AGTERBERG, F.P., BONHAM-CARTER, G.F., "Measuring performance of mineral-potential maps", Natural Resources Research 14, 1–17 (2005).

Country or International Organization

PHILIPPINES

Primary author: Prof. CARRANZA, John (UNIVERSITY OF KWAZULU-NATAL)

Presenter: Prof. CARRANZA, John (UNIVERSITY OF KWAZULU-NATAL)

Session Classification: Advances in Exploration

Track Classification: Track 4. Advances in exploration