Contribution ID: **212**　Type: **ORAL**

Using continent-scale spatial targeting to delineate permissive areas for sandstone-hosted uranium

Wednesday, 27 June 2018 10:00 (20 minutes)

INTRODUCTION

An ambitious sandstone-hosted uranium mineral prospectivity model covering the entire Australian continent hints at undiscovered mineral potential. Australia was chosen to demonstrate the usefulness of huge-scale multi-criteria analyses due to the relatively large volume of publicly available data covering the entire continent and because it is host to a considerable number of spatially distributed and economically significant deposits (e.g., Beverley, Manyingee, Bigrlyi). It is important to note that although all of the deposits under consideration are similarly classed as 'sandstone-hosted', significant differences exist in their host rock and mineralisation ages, mineralogy and in their underlying mineralising processes. Can a single predictive model really be expected to account for the distribution of all these genetically diverse systems?

Traditional approaches to mineral potential mapping involve interpretation of individual maps, or manual overlay of groups of 'predictor maps'to delineate favourable exploration areas. In the (not so distant) past, simple overlays were commonly performed using light tables and analogue interpretation methods (i.e., a pencil). An inevitable consequence of the rapid advancement in both the availability of vast, high-resolution digital data sets and the inexorable growth in computing power has been that geographical information systems (GIS) and spatial analysis have rapidly become ubiquitous in mineral exploration. Traditional approaches have been supplanted by the use of GIS and digital overlays, allowing for the rapid interpretation of a huge variety of spatial data with an ever increasing assortment of analytical techniques. Multi-criteria spatial targeting is now being deployed routinely in the search for, and assessment of areas that have potential to contain economic concentrations of desirable minerals [1-9].

The ultimate goal of this study is to reduce a wide range of complex conceptual models of ore genesis to their most fundamental mappable components. These basic elements are then reconstructed in a targeting model which aims to imitate the thought processes of the exploration geologist. The underlying challenge is to construct a single mathematical model which adequately describes the distribution of known sandstone-hosted uranium deposits across a wide variety of terrains, ages and mineralisation (sub-)styles for an entire continent. The success criteria are that the model must be capable of effectively 're-discovering'all areas of known mineralisation, yet it must be discerning enough that it doesn't highlight vast areas which are confidently regarded as having limited upside potential. Areas highlighted by such a model which lie outside of known mineralised zones logically possess all of the critical components of sandstone-hosted uranium mineralising systems. These areas are potentially under-explored and may be worthy of further investigation.

METHODS AND RESULTS

The basic premise of this GIS-based mineral prospectivity analysis (MPA) is the recognition of the essential criteria of sandstone-hosted uranium deposits [10] and translation of those criteria into quantifiable spatial parameters which can then be handled mathematically. The first step is to acquire and assess any spatial data that may be turned into useful proxies for components of the mineralisation genetic model. This generally requires a thorough audit of all publically available data. Data sets that were selected as being of potential use for the construction of the Australia-wide MPA include:

- surface geology (1:1m, 1:5m & 1:2.5m scale)
- crustal elements
- Australian geological provinces
- metamorphic grade and ages
- structural data
- radiometrics
- digital elevation models (SRTM and derivatives)
- drainage pathways
- sedimentary basin extents and thicknesses
- paleo-channel distribution

Australian explorers have access to an extraordinary amount of publicly available, multi-disciplinary data sets of very high quality. However, not all these data are useful for their straightforward inclusion in a continent-scale MPA. Some lack sufficient resolution, while others are too data-rich to be practical at the continent scale without significant modification.

A holistic mineral systems approach [11 - 13] is used to classify and combine the data so that a meaningful output can be generated. This approach considers all geological factors which control the generation and preservation of mineral deposits (including sources of metals, ligands and energy, fluid migration pathways and focusing mechanisms, and chemical and/or physical causes for precipitation at the trap site). A range of 'predictor maps', which represent mappable components of the mineralisation system under consideration, are derived from the spatial data. For this study, predictor maps are designed to represent individual components of the 'Source'(e.g., basement, uranium-enriched felsic igneous rocks), 'Transport'(e.g., faults, drainage pathways) or 'Trap'(e.g., reduced sediments, morphological barriers) parts of the mineral system. The creation of predictor maps and the subsequent analysis was performed in ESRI ArcGIS (Version 10.4.1).

Data preparation and the creation of predictor maps commonly involve some simplification and interpretation. For example, complex geology data can be re-classified into simpler stratigraphy and lithology predictor maps, each comprising a manageable number of classes. Multi-ring buffers can be constructed around features (e.g., granite bodies) to test proximity effects, with each concentric buffer being treated separately in the model. Thresholding can be used to simplify geophysical and other raster data into classes that can be handled more readily in the mathematical model. The construction of some of the 26 predictor maps used in this study is briefly outlined in this presentation.

A knowledge-driven approach (Fuzzy Logic) relies entirely on expert input to assign weights to individual predictor maps and their components to account for the relative importance of each feature in the mineralising system. A relatively simple method is used to calculate 'Fuzzy Membership'values in this study. 'Class weights' (0-10) are assigned to each feature within a predictor map based on the relative prospectivity of the feature. Additionally, 'Map weights'(0-10) are assigned to each predictor map based on the relative importance of the component it represents in the genetic model, and confidence in the underlying data. Multiplying the class by the map weights for each feature in a predictor map gives a 'class score'for that particular feature; dividing the class score by 100 results in a 'Fuzzy Membership'value between 0 and 1 for the feature. This is done for every feature in every predictor map. This is the value that is used in the final analysis. The (vector) predictor maps are converted to numerical raster grids based on the Fuzzy Membership value, allowing mathematical operations to be carried out on the newly created 'stack'of rasters on a cell-by-cell basis.

A logic network combining the input predictor rasters is carefully constructed such that it follows sound geological reasoning appropriate to the targeting model. The judicious use of Fuzzy 'AND', 'OR', 'SUM', 'PRODUCT'and 'GAMMA'logic operators allows quite complex relationships between components to be expressed in the model, reflecting the way in which a geologist might think but extrapolated up to the scale of the analysis (continent-scale in this example) and over a multitude of simultaneous input criteria. In our model, the three major mineral system components (Source, Transport and Trap) are treated separately before being combined in the final stage of the logic network. Solving the logical arguments for each corresponding cell in the stack of weighted predictor map rasters, results in a numerical grid that is interpreted to represent spatial variations in prospectivity. This can then be reclassified and displayed as a colour-coded, multi-class favourability map.

DISCUSSION AND CONCLUSION

We consider the fuzzy logic mineral prospectivity model presented herein to be a successful first-pass GIS-based analysis for sandstone-hosted uranium deposits on the Australian continent. Crucially, the majority of known sandstone-hosted uranium deposits and provinces occur within areas of elevated to very high favourability in the resulting favourability map, demonstrating the geological validity of the model. Additionally the model identifies several regions that should contain all the ingredients for sandstone-hosted uranium but may have been overlooked or underexplored by previous explorers.

However, the model has substantial limitations that must be kept in mind when interpreting the resulting favourability map. At the continental scale and due to the necessary use of highly simplified and modified versions of the spatial data, substantial uncertainties in the properties of the inputs remain. This is particularly true of the heavily modified geology (simplified lithology and stratigraphy) predictor maps but affects all data sets to some extent. Due to these uncertainties, the continental-scale model presented herein is not considered useful for delineating specific exploration targets but is particularly effective at identifying broader permissive areas, as well as regions of elevated favourability within these zones.

It is also important to note that the output generated from this model represents just one of an infinite number of possible solutions. Every step in the process, including initial data selection, predictor map design, assigning weights to features and maps and construction of the logic network was driven by a very small group of 'experts'. While we maintain a high level of confidence in our analysis, the opinions of alternative 'experts' are likely to differ (at least somewhat). A significant advantage of this type of analysis over more traditional approaches is that it allows for rapid iterative modification. New data, weights or modified logic network designs that target specific deposit types, or that consider alternate genetic models (for example) can be readily accommodated and tested.

The MPA methodology has the ability to quickly reduce the search space, highlighting specific zones of elevated mineral potential. These targets can then be ranked and prioritised for more detailed follow-up, ground-truthing or higher resolution MPA. At a continental scale, such target zones effectively highlight so-called 'permissive tracts'[14], representing geological regions that have potential to host undiscovered mineral deposits. The delineation of a permissive tract can contribute to estimating the potential number and size of undiscovered mineral deposits in an area, which has a variety of important economic, land, resource and environmental planning applications [15 –16].

The continent-scale Fuzzy Logic MPA for sandstone-hosted uranium in Australia demonstrates that GIS-based targeting concepts can be used to objectively delineate and visualise permissive areas for uranium, thereby dramatically reducing the search space and assisting with area selection and decision making processes. This study demonstrates how multiple specifically designed and weighted input predictor maps can be combined using a carefully constructed logic network to create a spatial representation of relative favourability for a specific mineral deposit type at the continental scale.

This study clearly benefits from the relatively large volume of high quality, relevant and publicly available spatial data for the Australian continent. However, this type of study is possible in areas where less (or different) data are available because the analysis is built up around to the type of mineralising system under consideration and according to the available data. The veracity of any MPA depends heavily on the quality of suitable input data ("rubbish in –rubbish out") so questionable data should be rejected as part of the preliminary data assessment. A simpler model is always preferable to one containing erroneous data.

If performed carefully and meticulously, GIS-based Fuzzy Logic mineral prospectivity modelling can provide an extremely powerful visualisation and decision-making tool.

A comprehensive account of the methods used in this study, including the rationale for using particular data sets, the construction of predictor maps, assigning fuzzy membership values and construction of the logic network is presented as a chapter in an upcoming IAEA TecDoc on "Spatial and quantitative modelling of undiscovered uranium resources"[17].

REFERENCES

[1] TURNER, D.D., Predictive GIS model for sediment-hosted gold deposits, North-Central Nevada, USA, Proceedings of Exploration 97: Fourth Decennial International Conference on Mineral Exploration (1997) 115–126.

[2] HARRIS, J.R., WILKINSON, L., HEATHER, K., FUMERTON, S., BERNIER, M.A., AYER, J., DAHN, R., Application of GIS Processing Techniques for Producing Mineral Prospectivity Maps –A Case Study: Mesothermal Au in the Swayze Greenstone Belt, Ontario, Canada. Natural Resources Research 10, No. 2 (2001) 91–124.

[3] PORWAL, A., CARRANZA, E.J.M., HALE, M., Extended weights-of-evidence modelling for predictive mapping of base metal deposit potential in Aravalli Province, Western India, Exploration and Mineral Geology 10 (2001) 273–287.

[4] LUO, X., DIMITRAKOPOULOS, R., Data-driven fuzzy analysis in quantitative mineral resource assessment. Computers and Geosciences 29 (2003) 3–13.

[5] NYKÄNEN, V., SALMIRINNE, H., Prospectivity analysis of gold using regional geophysical and geochemical data from the Central Lapland Greenstone Belt, Finland Geological Survey of Finland, Special Paper 44 (2007) 251–269.

[6] JOLY, A., PORWAL, A., MCCUAIG, T.C., Exploration targeting for orogenic gold deposits in the Granites-Tanami Orogen: mineral system analysis, targeting model and prospectivity analysis, Ore Geology Reviews 48 (2012) 349–383.

[7] LISITSIN, V.A., GONZÁLEZ-ÁLVAREZ, I., PORWAL, A., Regional prospectivity analysis for hydrothermal-remobilised nickel mineral systems in western Victoria, Australia, Ore Geology Reviews 52 (2013) 100–112.

[8] LINDSAY, M., BETTS, P.G., AILLERES, L., Data fusion and porphyry copper prospectivity models, southeastern Arizona, Ore Geology Reviews 61 (2014) 120-140.
[9] CHUDASAMA, B., PORWAL, A., KREUZER, O.P., BUTERA, K., Geology, geodynamics and orogenic gold prospectivity modelling of the Paleoproterozoic Kumasi Basin, Ghana, West Africa. Ore Geology Reviews 78 (2016) 692-711.
[10] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO) with Uranium Deposit Classification, Vienna, IAEA-Tecdoc-1629 (2009) 126pp.
[11] WYBORN, L.A.I., HEINRICH, C. A., JAQUES, A.L., Australian Proterozoic mineral systems: essential ingredients and mappable criteria, Australasian Institute of Mining and Metallurgy Annual Conference Proceedings (1994) 109–115.
[12] KNOX-ROBINSON, C.M., WYBORN, L.A.I., Towards a holistic exploration strategy: Using geographic information systems as tool to enhance exploration, Australian Journal of Earth Sciences 44 (1997) 453-463.
[13] JOLY, A., PORWAL, A., MCCUAIG, T.C., CHUDASAMA, B., DENTITH, M.C., AITKEN, A.R., Mineral systems approach applied to GIS-based 2D-prospectivity modelling of geological regions: Insights from Western Australia. Ore Geology Reviews, 71 (2015) 673-702.
[14] SINGER, D.A., Basic concepts in three-part quantitative assessments of undiscovered mineral resources, Nonrenewable Resources 2, vol 2 (1993) 69–81.
[15] CUNNINGHAM, C.G., ZAPPETTINI, E.O., VIVALLO S., WALDO, CELADA, C.M., QUISPE, JORGE, SINGER, D.A., BRISKEY, J.A, SUTPHIN, D.M., GAJARDO M., MARIANO, DIAZ, ALEJANDRO, PORTIGLIATI, CARLOS, BERGER, V.I., CARRASCO, RODRIGO, SCHULZ, K.J., Quantitative mineral resource assessment of copper, molybdenum, gold, and silver in undiscovered porphyry copper deposits in the Andes Mountains of South America, U.S. Geological Survey Open-File Report 2008-1253 (2008) 282 p.
[16] SINGER, D.A., JAIRETH, S., ROACH, I., A three-part quantitative assessment of undiscovered unconformity-related uranium deposits in the Pine Creek region of Australia. IAEA TecDoc, Spatial and Quantitative Modelling of Undiscovered Uranium Resources (in preparation).
[17] BIERLEIN, F.P., BRUCE, M.D., A continent-scale GIS-based assessment of the distribution and potential for sandstone-hosted uranium deposits. IAEA TecDoc, Spatial and Quantitative Modelling of Undiscovered Uranium Resources (in preparation).

Country or International Organization

Australia

Primary author: Mr BRUCE, Matthew (Thunderbird Metals)

Co-authors: Mr BIERLEIN, Frank (Thunderbird Metals); FAIRCLOUGH, Martin (International Atomic Energy Agency)

Presenter: Mr BRUCE, Matthew (Thunderbird Metals)

Session Classification: Advances in Exploration

Track Classification: Track 4. Advances in exploration