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Keynote lecture: Developments in GIS-based Mineral Prospectivity Mapping: An Overview

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Abstract - This keynote presentation provides an overview of the developments in GIS-based mineral prospectivity mapping during the past 30–40 years or so.

I. INTRODUCTION

MINERAL PROSPECTIVITY mapping concerns the quantification and mapping of the chance that mineral deposits may be found by prospecting in an area, whereas mineral potential mapping concerns the quantification and mapping of the chance that mineral deposits with economic potential exist in an area. These two terms are interchangeable, and are hereafter both denoted as MPM.

The process of MPM involves collecting, analyzing and integrating multi-source geochemical, geological and geophysical data to measure spatial associations between indicators of mineralization (i.e., anomalies) and known mineral deposits of the type sought, and apply the measured spatial associations for MPM. Integrating maps of anomalies, obtained by analysis of multi-source geo-exploration data, has been done customarily by using a light-table, over which maps of the same size and scale are piled on top of each to delineate prospective areas outlined by overlapping anomalies. However, during the past 30–40 years or so, MPM has become more useful by using a GIS (geographic information system).

A year-by-year search of the literature using "mineral potential mapping" AND "GIS" as search terms in Google Scholar indicates that the first publication where the term mineral potential mapping was used is a book chapter by Bonham-Carter and Agterberg [1]. Therefore, the term mineral potential mapping was introduced by the Canadians, because Bonham-Carter and Agterberg worked then for the Geological Survey of Canada. A similar search but using the search terms "mineral prospectivity mapping" AND "GIS" indicates that the first publication where the term mineral prospectivity mapping was used is a journal article by Brown et al. [2]. Therefore, the term mineral prospectivity mapping was introduced by the Australians, because Brown and his colleagues worked then for certain academic institutions in Australia. Indeed, papers on MPM in peer-reviewed journals indicate that development of GIS-based MPM have been pioneered by the Canadians for ~30 years since the late 1970s, but developments in GIS-based MPM have expanded globally in the last ~20 years.

II. METHODS OF GIS-BASED MPM

Overall, GIS-based MPM is either data- or knowledge-driven. Quantification of spatial associations of anomalies with known mineral deposits of the type sought is involved in data-driven MPM, which is appropriate for well-explored (or brownfield) areas where it is aimed to outline further targets for exploration. Knowledge-driven MPM is based on expert judgment of spatial association of anomalies with mineral deposits of the type sought, and is appropriate for under-explored (or greenfield) areas where it is aimed to outline new

exploration targets. Developments in GIS-based MPM in the past 30–40 years were mostly concerned with testing and application of a variety of new methods, by taking into account the assumptions as well as the advantages/disadvantages of each and every method.

Progress in research on data-driven MPM has preceded that for knowledge-driven MPM by more than a decade. The main reason for this is that MPM is chiefly a form of deductive modeling, whereby spatial patterns are analyzed from data to define a model (hypothesis/theory) of mineral prospectivity or potential. The most widely used method for data-driven MPM is weights-of-evidence (WofE) modeling whereas for knowledge-driven MPM it is fuzzy logic (FL) modeling. Bonham-Carter et al. [3, 4] and Agterberg et al. [5] have pioneered the development of data-driven MPM by WofE modeling, whereas An et al. [6] have pioneered by the development of knowledge-driven MPM by FL modeling. There are usually 2–4 papers on WofE modeling of MPM published annually since its development in 1988. In contrast, the number of papers on FL modeling of MPM has been increasing in the past 5–10 years since its development in 1991.

III. MINERAL SYSTEMS APPROACH TO GIS-BASED MPM

Various journals have documented the developments in GIS-based MPM in the last four decades. However, the journals owned by the International Association for Mathematical Geosciences (i.e., Computers & Geosciences, Mathematical Geosciences, Natural Resources Research) have altogether published ~45% of papers on GIS-based MPM. This reflects that developments in GIS-based MPM in the last 30–40 years chiefly involved the development of robust numerical methods for analyzing and synthesizing spatial evidence of mineral prospectivity. However, it is remarkable that *Ore Geology Reviews*, which is an economic geology journal, has published ~18% of papers on GIS-based MPM. This and the decline in research on data-driven (or empirical) MPM with respect to the growth in research on knowledge-driven (or conceptual) MPM in the past four decades or so, as noted above, reflect that definition of geologically-focused models of mineral prospectivity (i.e., the adoption of the mineral systems approach to exploration targeting) was a significant component of the developments in GIS-based MPM.

The concept of "mineral systems" for exploration targeting [7] considers "all geological factors that control the generation and preservation of mineral deposits, and stress the processes that are involved in mobilizing ore components from a source, transporting and accumulating them in more concentrated form and then preserving them throughout the subsequent geological history". Therefore, the mineral systems approach to exploration targeting considers the interplay of three critical elements (or geological processes) for mineral deposit formation, namely: source of metals, fluid pathways, and traps. These critical elements must be translated

into spatial proxies or mappable criteria of mineral prospectivity for GIS-based MPM [8, 9, 10]. The mineral systems approach to exploration targeting has been increasingly adopted in GIS-based MPM in the last decade.

Before the mineral systems approach to exploration targeting was adopted in GIS-based MPM (i.e., mainly before 1997), mappable criteria of mineral prospectivity for GIS-based MPM were defined chiefly according to mineral deposit models, which describe the geological characteristics that are typical of certain types of mineral deposits. Because particular deposit-types in certain areas may have geological characteristics that are different from those that are typical of certain types of mineral deposits, considering mineral systems (i.e., using the source-pathways-traps paradigm) makes GIS-based MPM process-based and geologically-robust.

IV. CONCLUSION

Therefore, developments in GIS-based MPM can be divided into two main stages: (1) an earlier stage (mainly during 1977–2006) dedicated to research of robust numerical methods for analyzing and synthesizing of spatial evidence of mineral prospectivity; and (2) a later stage (mainly during 2007–present) dedicated to research of geologically-robust models of mineral prospectivity. The Canadians have motivated the initial stage, and the Australians have stimulated the second stage. The border between these two stages is fuzzy, as there is strong overlap between them because researchers who have been involved in the development of GIS-based MPM have certainly endeavored to develop numerically- as well as geologically-robust mineral prospectivity models.

Future needs/challenges in developing GIS-based MPM further will include: (a) availability of software for 3D MPM; (b) ability to integrate the mineral systems approach with emerging tools, such as big data analytics and data science; and (c) ability to predict where undiscovered deposits are in predicted prospective areas.

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