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Exploration targeting for orogenic gold deposits in the Granites-Tanami Orogen: Mineral system analysis, targeting model and prospectivity analysis

Aurore Joly [a,*], Alok Porwal [b,c], T. Campbell McCuaig [a]

[a] Centre for Exploration Targeting, School of Earth and Environment, The University of Western Australia, M006 35 Stirling Highway CRAWLEY WA 6009, Australia
[b] Centre for Exploration Targeting, Western Australian School of Mines, Curtin University of Technology, G.P.O. Box U 1987, Perth, WA 6845, Australia
[c] Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, Powai, Mumbai, 400 076, India

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ABSTRACT

A major challenge for mineral exploration geologists is the development of a transparent and reproducible approach to targeting exploration efforts, particularly at the regional to camp scales, in terranes under difficult cover where exploration and opportunity costs are high. In this study, a three-pronged approach is used for identifying the most prospective ground for orogenic gold deposits in the Paleoproterozoic Granites-Tanami Orogen (GTO) in Western Australia.

A key input to the analyses is the recent development of a 4D model of the GTO architectural evolution that provides new insights on the spatio-temporal controls over orogenic gold occurrences in the area; in particular, on the role of pre-mineralization (pre-1795 Ma) D_{GTOE}–D_{GTO1}–D_{GTO2} architecture in localization of gold deposits and the spatial distribution of rock types in 3D. This information is used to build up a model of orogenic gold minerals system in the area, which is then integrated into the three mutually independent but complementary mineral prospectivity maps namely, a concept-driven "manual" and "fuzzy" analysis; and a data-driven "automated" analysis.

The manual analysis involved: (1) generation of a process-based gold mineral systems template to aid target selection; (2) manual delineation of targets; (3) manual estimation of the probability of occurrence of each critical mineralization process based on the available information; and (4) combining the above probabilities to derive the relative probability of occurrence of orogenic gold deposits in each of the targets. The knowledge-based Geological Information System (GIS) analysis attempts to replicate the expert knowledge used in the manual approach, but queried in a more systematic format to eliminate human heuristic bias. This involves representing the critical mineralization processes in the form of spatial predictor maps and systematically querying them through the use of a fuzzy logic model to integrate the predictor maps and to derive the western GTO orogenic gold prospectivity map. The data-driven 'empirical' GIS analysis uses no expert knowledge. Instead it employs statistical measures to evaluate the spatial associations between known deposits and predictor maps to establish weights for each predictor layer then combines these layers into a predictive map using a Weights of Evidence (WofE) approach.

Application of a mineral systems approach in the manual analysis and the fuzzy analysis is critical: potential high value targets identified by these approaches in the western GTO lie largely under cover, whereas traditional manual targeting is biased to areas of outcrop or sub-crop amenable to direct detection technology such as exploration geochemistry, and therefore towards areas that are data rich.

The results show the power of combining the three approaches to prioritize areas for exploration. While the manual analysis identifies and employs human intuition and can see through incomplete datasets, it is difficult to filter out human bias and to systematically apply to a large region. The fuzzy method is more systematic, and highlights areas that the manual analysis has undervalued, but lacks the intuitive power of the human mind that refines the target by seeing through incomplete datasets. The empirical WoE method highlights correlations with favorable host stratigraphy and highlights the control of an early set of structures potentially undervalued in the knowledge driven approaches, yet is biased due to the incomplete nature of exploration datasets and lack of abundant gold deposits due to the extensive cover.

The results indicate that the most prospective areas for orogenic gold in western GTO are located in the central part of the study area, largely in areas blind to previous exploration efforts. According to our study, the procedure to follow should be to undertake the analyses in the following order: manual prospectivity analysis, followed by the conceptual fuzzy approach, followed by the empirical GIS-based method. Undertaking the manual analysis first is important to prevent explorationists from being biased by the automated GIS-based

* Corresponding author. Tel.: +61 0 6488 7147; fax: +61 8 6488 1178.
E-mail address: aurore.joly@gmail.com (A. Joly).

outputs. It is however emphasized that all of the prospectivity outputs from these three methods are possible, and they should not be treated as 'treasure maps', but instead, as decision-support aids. Therefore, a final manual prospectivity analysis redefined by the mutual consideration of output from all of the methods is required.

The strategy employed in this study constitutes a new template for best-practice in terrane- to camp-scale exploration targeting that can be applied to different terranes and deposit types, particularly in terranes under cover, and provides a step forward in managing uncertainty in the exploration targeting process.

1. Introduction

A challenge in any exploration program is the generation and prioritization of exploration targets at various scales. Targeting is particularly difficult at the terrane to camp scale (100's to 10's of kilometers), in that there is no systematic detection technology to assist the search at this scale, and the opportunity cost of choosing the wrong area is very high (Hronsky, 2004; McCuaig and Hronsky, 2000; McCuaig et al., 2010).

The main problems with traditional targeting approaches, which are based on heuristic appraisal of multiple geoscience data, are as follows. Firstly, exploration targeting is generally driven by rigid deposit models and focuses more on specific features associated with mineral deposits than on the processes that formed them. The targeting is highly subjective in that target areas are selected based on the geological features that are considered relevant by the targeting geologist. The judgment on the relevance of various geological features could vary from geologist to geologist, and change as deposit models evolve with new discoveries. Secondly, geological knowledge on the regional scale can only be effectively represented and spatially queried in geographic information systems (GIS) software in 2D. This is a major limitation given that mineralization processes are best understood in a 4D space-time framework and are best represented by 3D datasets. Thirdly, these targeting approaches, which range from conceptual to empirical in nature, are hampered by varying degrees of stochastic and systemic uncertainties (McCuaig et al., 2007). This leads to a high degree of uncertainty in the resultant prospectivity analysis and targeting. Clearly, there is a need to develop a holistic approach to exploration targeting that addresses, or at least mitigates, the limitations listed above. The industry–academia collaborative study reported in this paper develops such an approach to guide orogenic gold exploration in the Paleoproterozoic Granites-Tanami Orogen (GTO) in Western Australia (Fig. 1). One of the key motivations of this study is to develop a template for best-practice in terrane- to camp-scale exploration targeting that can be applied to different terranes and deposit types, and particularly to terranes under challenging cover.

A 4D geological model of the GTO has previously been developed and constrained by integrated surface mapping, structural analysis, geochemistry and geophysical data (detailed in Joly et al., 2010). This knowledge is used herein to develop a targeting model for orogenic gold deposits in the framework of a mineral systems approach (cf. McCuaig et al., 2010; Wyborn et al., 1994). Key mappable exploration criteria are identified which are essential to drive the prospectivity analysis and to rank new delineated exploration targets in the western GTO (Fig. 1).
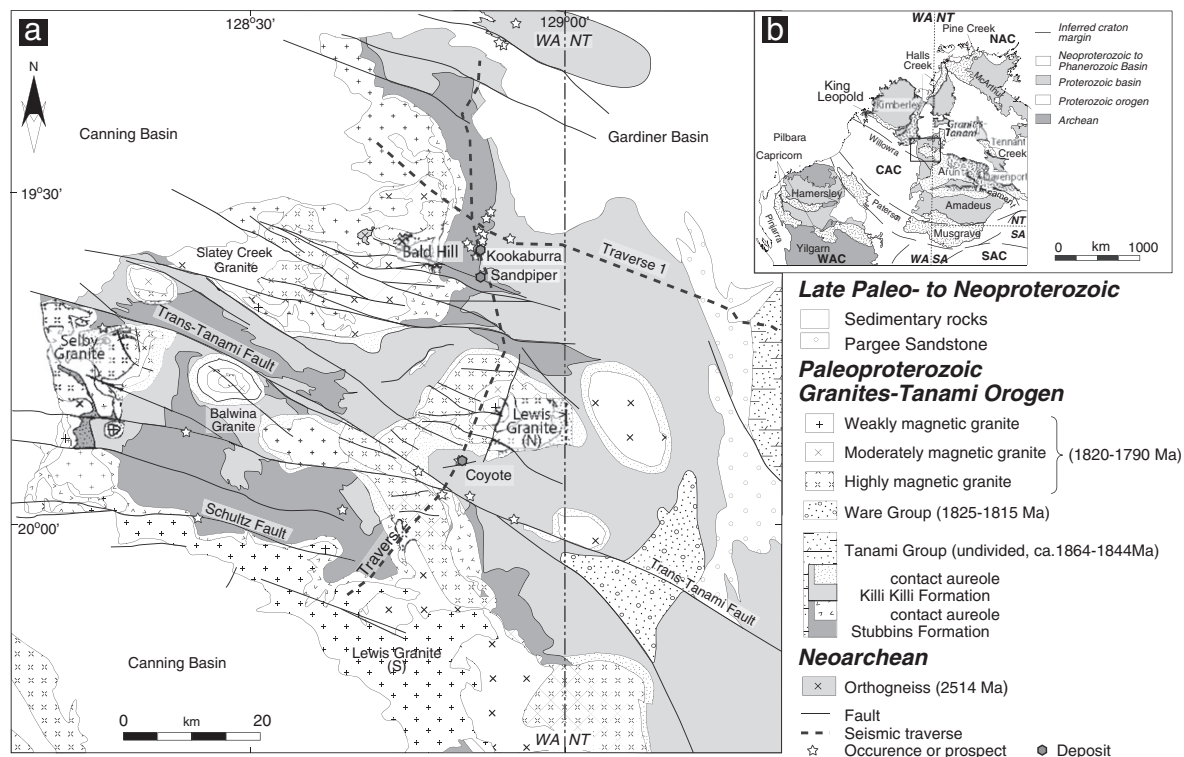

Fig. 1. (a) Geological map of the western Granite-Tanami Orogen based on the field mapping and interpretation of the magnetic data (modified after Bagas et al., 2009). (b) The location of Archean terranes and cratonic boundaries (modified after Bagas et al., 2010). Western, Central, South and North Australian Cratons are respectively labeled as WAC, CAC, SAC and NAC.