Mineral potential modelling of gold systems in the Tanami: A multi-technique approach to support the next discovery in the NT

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Introduction

The Granites-Tanami Orogen (GTO) is a remote, largely concealed Palaeoproterozoic orogenic gold province that straddles the border between the Northern Territory and Western Australia. The GTO is highly prospective with several operating and past producing gold mines with globally significant gold endowment. Prodigy Gold's Tanami Project is located ~400 km northwest of Alice Springs and encompasses ~14 000 km^2 of the GTO within the Northern Territory. Due to the considerable area of their project, Prodigy Gold is using a multi-technique Mineral Potential Modelling (MPM) approach to best assist in targeting large-scale gold systems (Roshanravan *et al* 2023). Numerous companies have undertaken more traditional regional-scale prospectivity analysis in the GTO, including AngloGold Ashanti, Newmont and Prodigy Gold, while the (GIS-based) multi-technique MPM is designed to further reduce risk and improve mineral exploration targeting potential. The power of MPM as an effective targeting tool is demonstrated by Chalice Mining Limited with the discovery of Gonneville, a significant palladium-platinum-nickel–cobalt–copper–gold deposit in Western Australia (Chalice Mining Limited 2020), which represents the first world-class discovery that can be, at least partly, attributed to MPM.

Geology

The GTO is part of the Precambrian North Australian Craton and is comprised of Palaeoproterozoic folded sedimentary, volcanic and granitic rocks, with an established tectono-stratigraphic evolution identified through multi-disciplinary studies (Bagas *et al* 2008, 2014; Joly *et al* 2012; **Figure 1**). Since gold was first discovered in the GTO in 1900, over 175 gold occurrences have been detected with a cumulative endowment of >20 Moz of gold (Baggott *et al* 2016). Prodigy Gold has advanced understanding in the GTO through litho-geochemical analysis with results (presented at AGES 2018 and 2019) used to revise geological maps (Schmid *et al* 2018); these results were subsequently combined with the co-funded Northern Territory Geological Survey (NTGS) 2018 aeromagnetic survey. The associated reprocessing and integration of magnetic surveys in 2018 has significantly improved the interpretation of structures associated with gold endowment in the GTO (**Figure 1**).

Prodigy Gold continues to refine interpretation through on-ground spatial-data acquisition and consequent integration into ongoing prospectivity mineral potential modelling (Roshanravan *et al* 2020, 2021, 2023). Prodigy Gold is using the predictor maps generated through the multi-technique approach to MPM as an unbiased exploration tool to improve targeting confidence and high-level (tenure-related) decision making.

Concept – GIS based Prospectivity Mineral Potential Modelling (MPM)

Conceptual uncertainty has been demonstrated to be a risk factor for geo-scientific decision making when interpretation of data contains limited information (Bond *et al 2007)* or when spatial autocorrelation and data distribution concerns involve spatial heterogeneity (Marsily G *et al* 2005, Griffith D 2017). As discussed by Hronsky and Kreuzer (2019), singular input variables (alone) often fail to provide a consistent and impartial representation of regional areas of interest, oftentimes leaving out crucial parameters that are relevant for targeting and having significant unacknowledged interdependence with other variables or mechanisms. Developing reliable predictor maps necessitates a thorough understanding of the primary ore-forming mechanisms for the specific type of ore deposit being targeted and their discernible indicators.

These indicator datasets are highly valuable for objective analytical prospectivity modelling (Lisitsin and Rawling 2011) and can be described as a 'weights-of-evidence model'. The weights-of-evidence model is employed to forecast the likelihood of an event taking place in a study area using known evidence to evaluate the relative significance of each variable based on training data. When applied to regional mineral systems, the regional-system integration concept can be a more versatile and comprehensive approach than the conventional deposit-focused approach of source-transport-trap analysis. Biases in traditional prospectivity analysis outlined by Hronsky and Kreuzer (2019) can be reduced using GIS-based, multi-model automated approaches (Ekins S *et al* 2020).

The creation, manipulation, and weighting of predictor maps have the potential to introduce uncertainty, bias and inaccuracy. To create accurate regional predictive models, it is crucial to incorporate and prioritize multiple datasets that have relationships with known deposits in the area of study. To enhance the weights-of-evidence predictive approach in the GTO, additional information in the form of interpretive/conceptual data, such as favorable rock types and geological interpretation of local deposit settings, were incorporated and modeled.

The mineral systems concept encompasses ore deposit formation within the context of larger-scale lithospheric processes and is encapsulated within a multi-technique MPM approach (Roshanravan *et al* 2023) for the study

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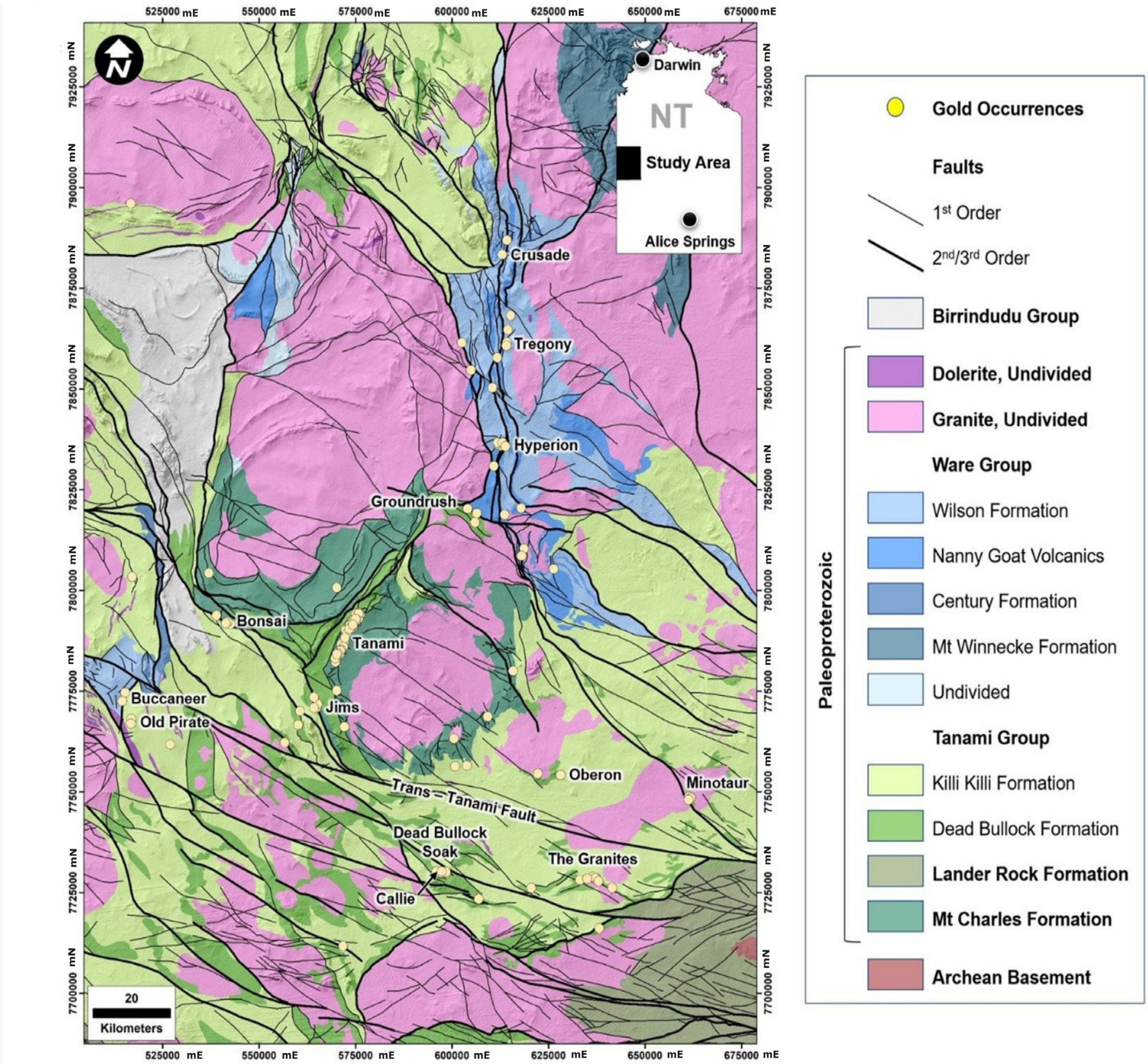

Figure 1. The Granites-Tanami Orogen solid geology map coinciding with the prospectivity mineral potential modelling study area (modified from Dr. Leon Vandenberg, unpublished data; reproduced and adapted from Roshanravan et al (2020, 2023). Also showing significant gold occurrences and structural interpretation.

area in the GTO. The multi-technique approach to MPM offers several advantages: it allows for the optimisation of available conceptual and empirical information, assists in reducing stochastic and systemic uncertainties, enables cross-validation of prospectivity models, and facilitates comparison of resulting models. To create an effective and validatable MPM, it is essential to develop multiple associative predictor maps based on suitable input variables while selecting for appropriate modelling tools.

Visually presented as an output predictor map, Roshanravan *et al* (2023) compared two random forest (RF) models. A previous model employed 19 predictor maps (Roshanravan *et al* 2020), while the updated model used 23 predictor maps, which included four new predictors based on more detailed geophysical data not previously available (Roshanravan *et al* 2023). In this presentation, 19 robust variables are considered as competent predictor maps that were developed in the framework of a mineral systems approach (Roshanravan *et al* 2020; **Table 1**). These predictor maps serve as spatial proxies for the chosen mappable mechanisms involved in orogenic gold mineralisation in the GTO (**Table 1**).

To establish the multi-model approach for MPM, a series of models were run with the following eight methods selected as the most robust for predicting the known deposits in the GTO and incorporating Prodigy Gold data (Roshanravan *et al* 2020, 2021, 2023; **Figure 2)**:

1. Continuous fuzzy gamma prospectivity
2. Geometric average prospectivity model
3. Data-driven index overlay prospectivity model.
4. ‘Original’ random forest
5. Cuckoo optimisation algorithm for support vector regression
6. Fuzzy inference systems
7. Feed-forward deep neural network
8. ‘Normalised’ random forest

Table 1. Critical processes and spatial proxies for orogenic gold deposits in the GTO (from Roshanravan et al 2020, 2023).

Critical Processes	Predictor Maps	Rationale
Transport	Domains of greater metallogenic trend line density	There is a strong spatial association between the known gold deposits and metallogenic trends, defined as directions of maximum continuity of gold deposit alignment as revealed by a Fry analysis. These trends are thought to be representative of basement structures acting as first-order controls on fluid flow.
	Proximity to D1 and D2 folds	Folds (ie anticlines and synclines) are known to host gold mineralisation and while synclines may be less well-endowed, they are often less explored.
	Domains of greater metallogenic trend line intersection density	As outlined above, these trends are thought to be representative of basement structures acting as first-order controls on fluid flow. Fluid flow would likely have been enhanced at the intersection of permeable basement structures.
	Domains of greater fault density	Greater fault density is assumed to be associated with a greater likelihood of dilation, brecciation and fluid flow.
	Proximity to domains of remanent magnetisation	The remanent magnetisation can be interpreted as a proxy for gold-related hydrothermal fluid flow and the structures that controlled the location of gold mineralisation.
	Proximity to faults	The second- and third-order faults possibly represent major camp- to district-scale fluid pathways.
	Proximity to major faults	The major, first-order faults act as fundamental, first-order controls on hydrothermal fluid migration in the upper crust at the time of gold deposition.
	Proximity to gravity worms	The gravity worms with the highest levels of upward continuation can be interpreted as long-lived, multiply reactivated, deep-seated basement structures that would have acted as first-order controls on fluid migration.
	Proximity to gravity lineaments	The gravity data respond well to the deeper crustal architecture in the basement to the GTO and provide clues as to where these deep-seated structures may have interacted with those of the upper crust (ie the 'thin-skinned' tectonic domain) to control the location of gold mineralisation.
	Proximity to pseudo gravity worms	The pseudo gravity worms with the highest levels of upward continuation can be interpreted as upper-crustal faults and shear zones, and thus, potential fluid pathways.
Trap	Proximity to compositionally heterogeneous rock packages	These units are interpreted to be more likely to develop breaching or damage zones that may give rise to localised fracturing, dilation and permeability, focusing fluid flow at or close to lithological contacts and/or to possess strong chemical gradients across internal lithological boundaries, which may give rise to redox reactions and destabilisation of gold complexes carried by hydrothermal fluids.
	Proximity to fault/fold intersections	Fault/fold intersections encompasses the intersections between faults and pre-D3 folds. These intersections represent potential highly favourable trap sites.
	Domains of greater fault intersections density	Greater fault intersections density represents potential breaching/damage zones, which may have acted to enhance fluid flow and as physical traps.
	Domains of greater lithological contact density	Domains of greater lithological contact density are considered to have enhanced potential for rheological and chemical contrast.
	Proximity to contacts between the Dead Bullock and Killi Killi formations	These contacts separate stratigraphic units of potentially high rheological ± chemical contrast.
	Proximity to potential host lithologies	All pre-Mesoproterozoic lithologies in the GTO have potential for hosting gold deposits and collectively constitute the gold permissive tract.
Deposition	Proximity to geochemical anomalies	Known gold deposits in the GTO have gold and pathfinder element (As, Ag, Bi, Cu, Mo and Sb) geochemical signatures. Anomalous Au, As, Ag, Bi, Cu, Mo and Sb values were extracted from a large, proprietary, GTO-wide geochemical database comprising >164 000 surface and >93 000 interface (mostly vacuum and rotary air blast drilling) samples.
	Domains of greater quartz vein density	Domains of greater quartz vein density acts as a proxy for structural permeability and hydrothermal activity.
	Domains of greater mafic dyke density	Areas of greater density of mafic dykes are considered to have elevated potential for lithological competency gradients and geochemical gradients.

Discussion and conclusion

In order to optimise the conceptual and empirical information, reduce systemic uncertainties, enable cross-validation of prospectivity models and facilitate comparison of resulting models, a multi-technique approach is suggested (Roshanravan 2023). This was established by running, incorporating, and comparing multiple models (Hronsky and Kreuzer 2019, Roshanravan *et al* 2023). Roshanravan (2023) mitigated statistical limitations in the predictor maps through Mamdani-type fuzzy inference system (FIS), feed-forward deep neural network (FF-DNN), and transformed predictor map-based RF methods to: (i) model orogenic gold potential in the GTO; and (ii) compare the performance of these models to those previously generated for the same study area and using the same targeting model and predictor maps.

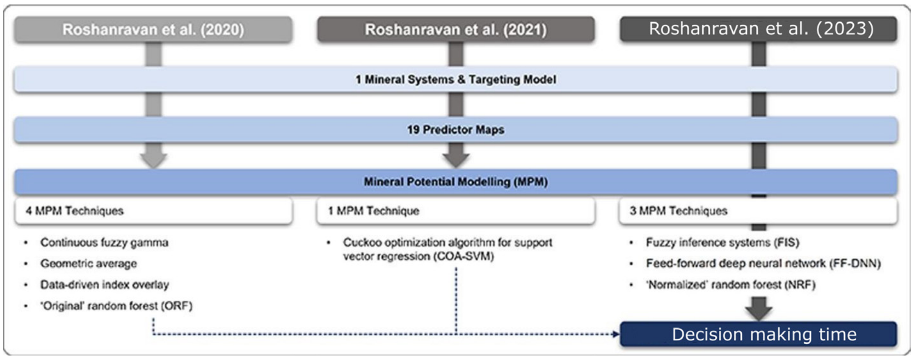

Figure 2. Graphical abstract displaying the multiple techniques used in the 2023 multi-technique approach for prospectivity mineral potential modelling; adapted from Roshanravan *et al* (2023).

The evaluation of model effectiveness revealed that the RF technique exhibited superior performance compared to the other seven models. The outcome of Roshanravan *et al* (2023) highlights the beneficial impact of using modified predictor maps on the effectiveness of the RF model to create more robust exploration targets. The resulting first order exploration targets, identified from the RF model encompassing regions with exceedingly high gold potential, comprise 2% of the investigation area, while also encompassing 76% of the confirmed gold deposits. Having much better than an order of magnitude reduction of the search space is the hallmark of a well-performing and practically useful targeting technique (Hronsky and Kreuzer 2019).

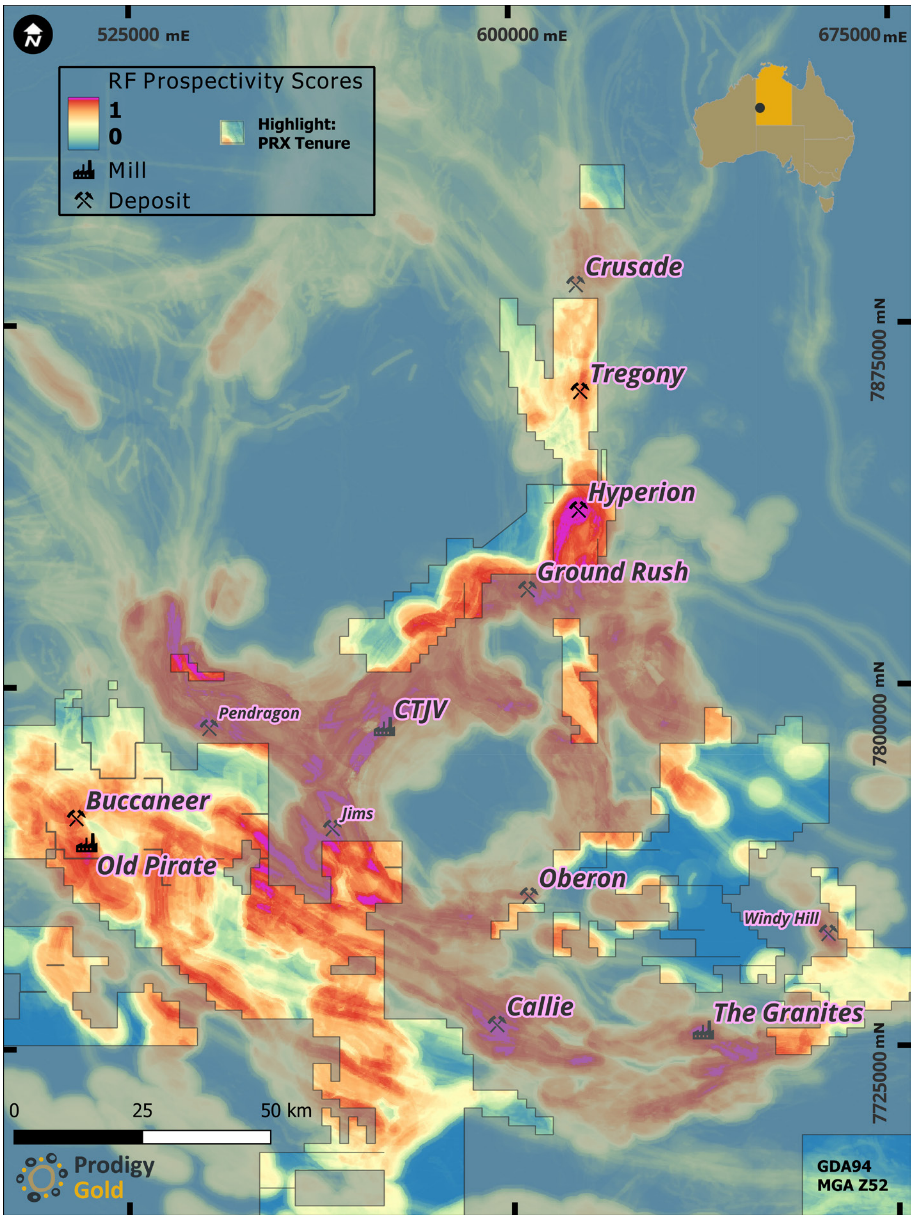

Figure 3. Random forest potential map generated by combining the 19 normalised competent predictor maps. Note that the Hyperion, Callie and CTJV areas are identified as the most prospective (hot colours). *Note the same study area as shown in **Figure 1**.

The results of the recent prospectivity analysis undertaken by Roshanravan *et al* (2023) has reinforced Prodigy Gold's confidence to target the Hyperion–Tregony trend (**Figure 3**) on its 100% owned tenements. The results were considered as an important unbiased decision-making tool to bring forward application tenements into granted status where the RF model suggested first order targets are present. Previously open ground (unpegged) has also been subsequently applied for by Prodigy Gold where the RF predictive model suggested likelihood of significant mineralisation.

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