Outcomes from using mineral potential modeling as a tool to support decision making in mineral exploration and resource development

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Abstract. Finding new metal deposits has become more difficult due to exploration maturity and information and data overloads. This means that traditional subjective exploration targeting is less effective. New computer-based exploration targeting techniques, including machine learning, should be used more often by the Exploration Industry, to address the issues of data overload. However, the Exploration Industry rarely uses the new targeting techniques in real world exploration. This appears to be due to a lack of trust in the results from these systems and a lack of understanding of how the results from mineral potential modeling can be used to help support decision making in exploration and mine development. Mineral potential modeling was used as a decision support tool in the acquisition and development of the Greenfields Bundarra copper, silver and gold porphyry system in Central Queensland and also to help constrain resource estimation at the Tampia Gold mine in Western Australia. These case studies are examples of how mineral potential modeling can be used at either end of the exploration and mining value chain and provide ideas on how mineral potential modeling can be integrated into exploration and mining decision support systems from Greenfields exploration targeting through resource development to mining.

1 Introduction

The science, techniques, tools and data availability of Mineral Potential Modeling (MPM) has come a long way since the publication of the book by Bonham-carter (1994). Mineral exploration targeting starts at global to regional scales, with follow up exploration data acquisition used to vector into new discoveries at local and mine scales. Currently, most exploration targeting is performed by searching prospect information from mineral occurrence databases and geological maps or subjectively choosing areas based on personal experience. While these types of analyses, which largely rely on near surface exploration techniques, were effective in the past, many areas have now been subject to multiple cycles of exploration that have now either exhausted near surface potential, or simply failed to identify less well exposed, mineral deposits. The advent of modern data collection and storage technologies and a global effort by national geological surveys to provide precompetitive digital data has resulted in a huge increase in data volume. This means exploration decision-making and management has become much more complex. However, the opportunity for making new discoveries using these advances has increased at the same time. Classic exploration approaches also fail to incorporate the recent research advances that have been made in the understanding of mineral systems. Despite this the Mineral Exploration Industry still rarely uses MPM techniques in real world exploration, in particular help make the decisions that lead to discovery and the development of new economic mineral deposits.

Government geological surveys appear to be more comfortable using MPM to support their business objectives, with examples including the Geological Survey of NSW recently completing a project mapping the main mineral systems in NSW using MPM (e.g. Ford et al. 2019a and Ford et al. 2019b) and the Geological Survey of Finland GTK (e.g. Nykänen 2020). Both geological surveys have not only used MPM to help market the prospectivity of their jurisdiction to encourage investment in mineral exploration, but they also recognise the power of MPM to support resource and land management decisions by government. This supports the ideas presented by Yousefi et al. (2019) for the need for the development, and the research into the use in business, of decision support systems that incorporate MPM techniques and outputs that can easily be accessed by mineral explorers and other stakeholders.

Two case studies are provided where the results of MPM are used to support investment and management decisions that are routinely required to be made by Exploration Companies in the discovery, development and mining of new orebodies. These examples provide ideas on how MPM can be used in Mineral Exploration not only to discover new ore bodies but also help develop new mines by reducing subjective decision making throughout the exploration and mining value chain.

2 Using MPM as a support tool for discovery at the regional scale: The Cretaceous Bundarra copper, silver and gold porphyry system

MPM can help exploration decision making at the regional targeting scale by mapping and spatially statistically measuring the likelihood of the occurrence of the complex geological processes that lead to the formation of concentrations of metal in the Earth's crust, so providing confidence to invest capital for data acquisition at the various stages of exploration that are

required to discover new ore deposits.

The Mineral Exploration Industry appears to be more accepting of the use of MPM for regional targeting as it tends to better match the resolution of data available and operational scales for these types of studies. In this case study, the initial aim of the project was to map the potential for porphyry style mineralization in Central Queensland in any age of rocks in contrast to the accepted exploration models used presently, which focus on Permo-Carboniferous systems. The case study is also a good example of the power of using MPM with regional scale data that uses bed rock geology as the main targeting source, with support from datasets like geophysical and geochemical data.

The study started with a review of historic literature, compiling available publicly available data mainly from the Queensland Geological Survey, testing of predictor maps, leading to the generation of a MPM post probability map using the Weights of Evidence technique. Details of the study and the resultant exploration of the Bundarra project, with a range of maps, sections, diagrams and photographs are available on kenex.com.au/Projects/bundarra.asp and duke-exploration.com.au/. The Bundarra Project area was mapped from the regional porphyry prospectivity modeling over Central Queensland as being one of the most prospective targets, confirming that many of the required geological features for porphyry style mineralization were present in an area more known for coal mining where the target intrusive phases were younger than the coal being mined from the region. Follow up exploration including field mapping and drilling confirmed that the area mapped by MPM had the potential for immediate exploration and resource development for copper, silver and gold from a porphyry system related to the intrusion of the Bundarra pluton (Fig. 1).

More detailed geological mapping and geochemical analysis suggested the mineralization around the Bundarra pluton was potentially part of a lode-style porphyry mineral system, consistent with an Andean-style convergent margin model. For example, the Resolution (Magma) deposits in Arizona and the Butte deposits in Montana. The recently discovered Thursday's Gossan in the Mount Stavely Volcanic Complex in the Grampians-Stavely Zone in Western Victoria is an Australian example of this type of deposit.

Figure 1. Drill core from the follow up drilling at the historic Mt Flora underground mine, with the Bundarra pluton as the flats surrounded by the hills that represent the hornfels sediments that host the main porphyry copper, silver and gold mineralization around the Bundarra pluton in the background.

The results from the regional MPM provided the confidence to invest in making tenement applications over the target area that was freely available and the subsequent raising of capital to support follow up exploration. This was despite the geology being much younger than accepted by current exploration models.

Follow up exploration culminated in field mapping and data compilation that were used to map the local scale prospectivity of the Bundarra pluton using MPM for porphyry copper-silver-gold mineralization (Luketina 2019). A 64 km^2 area surrounding the perimeter of the Bundarra pluton was mapped as prospective. Targets were generated from the MPM, which represent the areas with the greatest geological potential for hosting porphyry copper-silver-gold mineralization. The MPM targeting reduced the prospective exploration search space from 466 km^2 (size of study area), to 63.6 km^2 (area of prospective area), to 10.86 km^2 (area of targets), to 3.44 km^2 (area of highly prospective targets). Within the areas of highest prospectivity, new areas with no historic exploration were mapped. 45% of the target area contains known mineral occurrences. 20% of the target area contains no mineral occurrences, rock chips or soil samples, and are completely unexplored to date.

The results were used to plan diamond and resource drilling at the Mt Flora prospect, which was mapped as the highest priority target (Fig. 1). The first phase of drilling was successful and an Inferred JORC Code (2012) resource of 16 Mt at an average grade of 0.5% Cu and 6.9 ppm, Ag at a 0.2% Cu cut-off grade, which equates to 78,000 tonnes of copper and 3.6 million ounces of silver, was reported six months after listing by Duke Exploration on the ASX. There are currently five other target areas with similar development potential on the Bundarra project as mapped by MPM (Luketina 2019), giving confidence the metal resources at the project are large enough for a mining operation to be established.

The continuing use of MPM has helped provide confidence in the decisions and investment in the exploration that discovered a new resource of copper and silver in an area that has been considered as only prospective for coal resources. The workflow, techniques and targeting methodologies used are an example of the type of Decision Support System described by Yousefi et al. (2019), but applied using a variety of software tools in a relatively manual way rather than in a centralised system.

Is this really a new discovery, given copper was mined from the area in the 1880s? Maybe not, but the rediscovery of a new modern resource of copper and silver would not have been made without the use of MPM and the associated targeting systems initially at a regional Greenfields scale. The Bundarra pluton case study is an example of the rediscovery of an opportunity that to some extent has been hidden in clear sight for hundreds of years.

3 Using MPM for resource development of the Tampia gold deposit at a mine scale

The Tampia gold deposit case study is from an opportunity at the other end of the exploration value chain to the Bundarra pluton case study and is an example of how MPM can be used to support decision making that is less well understood by the Exploration and Mining Industry. This work was carried out to support resource development at the Tampia Gold Project in Western Australia (Nielsen et al. 2019). The aims of the study were to help constrain resource estimation, understand the distribution of gold grades from the resource estimation techniques with respect to geological and physiochemical continuity, and predict the location of new gold mineralization for future exploration drilling to expand the gold resource at the Tampia gold deposit (Nielsen et al. 2019). Details of the study and the resultant resource development and mining, with maps, sections, diagrams and photographs are available at http://kenex.com.au/Projects/tampia.asp.

Because the target is at the mine scale the resolution required to map the mineral system requires MPM to be implemented in 3D, using data from pattern resource drilling and mine scale geophysical 3D inversions, and constrained by a local sale granulite-facies orogenic gold mineral system model (Nielsen et al. 2019). The data included lithology, structure, rock property data and geochemical data. There were 44 individual maps created in 3D that were tested for their spatial correlation with training data from high grade gold drill intersections, using the Weights of Evidence technique (Nielsen et al. 2019). Of these, 11 were chosen for the MPM that had the highest spatial correlation with the training data and did not duplicate map patterns.

A 10 m by 10 m spaced infill drilling programme was subsequently undertaken over the area where the post probability results from the 3D MPM indicated high and continuous probability for gold mineralization, while the resource model estimated less continuous and lower grade gold mineralization (Nielsen et al. 2019). This infill drilling aimed to compare the gold continuity at a closer drill spacing with the resource estimate gold grades and post probability distribution of the 3D MPM.

Results from the first phase of infill drilling, which only covers 4% of the total model area, confirm the continuity of the post probability values and suggests that the mineral potential model predicts the location and distribution of gold mineralization within the area drilled (Nielsen et. al. 2019). The results were also better and more continuous than predicted by the resource estimate. Importantly, these results confirm that geological and physiochemical controls on gold mineralization at a mine scale can be numerically measured and mapped at the scale of an orebody. This allows MPM to be considered as an option to constrain and help inform the results of geostatistical techniques used in resource estimation (Nielsen et al. 2019).

Figure 2. Resource drilling in the barley paddock at the Tampia Gold project with drill core of the gold bearing arsenopyrite, pyrite and löllingite sulfide mineralization hosted in mafic granulite from an intersection of 21 m at 6.32 g/t Au from 42 m.

4 Future of MPM in mineral exploration and development

It is clear from the advances now being made in machine learning systems that these should become important tools to help exploration and mining into the future. Current research has advanced the capabilities of the techniques needed and quality of data available is improving rapidly. The availability and quality of data remains critical as emphasized by Ford (2019), that no matter how good the MPM techniques are they require high quality data and maps to work successfully. More importantly, for industry to start routinely using MPM, is access to the type of systems described by Yousefi et al. (2019), with the main algorithms and tools available in one software system, including decision support workflows. The final piece of the jigsaw is availability of trained professionals to manage, maintain and run these systems, which needs to be considered as part of university degrees in geology, particularly those institutions that teach economic geology.

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