Commercial Application of Spatial Data Modelling with Examples from North Queensland

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Introduction

Most major mining companies, even during the minerals boom, reduced investment in mineral exploration, preferring to depend on acquisitions to replace ore reserves and grow their companies. Consequently, few significant new mineral resource discoveries have been made in the last few years (Hronsky and Groves, 2008). Current mineral deposits are rapidly being depleted and without new discoveries in the coming years metal prices will increase in the near future back to the levels seen during the minerals boom. Now is the time for exploration companies to develop new innovative techniques to allow them to survive and grow into the future to be ready when metal prices recover.

The discovery of new mineral resources is based on probability of about 1 in 3000, which makes the discovery of new mineral resources a rare event (e.g., Henley, 1997; Hronsky and Groves, 2008). Therefore, for any company to be successful in exploration they have to be able to increase their chances of success. One way of doing this is by measuring the probability of occurrence of a commodity in a region using mineral system models and Spatial Data Modelling techniques (e.g., Bonham-Carter 1994). This allows the explorer to develop a prioritised list of targets for follow up exploration. The economic return from each target can then be modelled to determine the likely return on investment at the exploration stage (e.g., Kreuzer et al., 2008).

The commercial application of using mineral system models in conjunction with national scale geological databases and Spatial Data Modelling for exploration targeting is presented. The mineral system model used is described and the results of the Spatial Data Modelling are presented. Finally the commercial implications of these results are discussed with reference to economic modelling and follow-up field work on targets in North Queensland.

Granite Related Mineral System Model

In the last ten years a new, globally widespread, economically important class of Intrusion Related Gold Deposit has been recently recognised (Thompson et al., 1999; Lang et al., 2000). Historically, granites related to these deposits have been recognised for their potential to host tin and tungsten mineralisation, but now have been shown to be prospective for gold mineralisation. Examples of deposits that belong to the intrusion-related deposit class include: Donlin Creek (10.4 M Oz Au), Vasilkovskoe (9.5 M Oz Au), Pogo (4.9 M Oz Au), Kidston (4.5 M Oz Au), and Fort Knox (4.1 M Oz Au). Recent rises in metal prices mean that these deposits now have the advantage that they have other high value metals associated with gold mineralisation, such as molybdenum, bismuth, silver, tungsten and tin, which can significantly add to the economic value of the deposit.

The mineralisation targeted by the Spatial Data Modelling are associated with granite intrusions that occur in a continental tectonic setting well inboard of inferred or recognised convergent plate boundaries. Importantly, the deposits exhibit a distinctive metallogenic signature, namely Au, Bi, Sn, W, Mo, As, Te, Sb ± (Pb, Cu), with a strong relationship between economic mineralisation such as Au, Sn and W and Bi and a negative correlation with basemetal mineralisation (Mustard, 2001; Mustard, 2004). A systematic relationship between degree of fractionation, oxidation state and ore element ratios in granite-related ore deposits is evidence of a magmatic origin. The relationship between the degree of fractionation, oxidation state and ore element ratios in these granite systems can be used to assess the prospectivity for Ag-Au-Bi-Mo-Sn-W mineralisation. Associated plutons are typically granodiorite to granite in composition and the metals of interest are generally associated with the more evolved phases of these igneous suites, specifically late stage vein-dykes, aplites and pegmatites. Also, associated plutons commonly contain textures indicative of the transition from magmatic to hydrothermal conditions (e.g. miarolitic cavities, interconnected miarolitic cavities, unidirectional solidification textures, aplite-pegmatite layers and vein-dykes). The deposits can form over a range of crustal depths (1 to 10 km) and at various proximities to the source intrusion (0 to 3 km). As a result the mineral system model that has been developed must take into account this vertical and lateral variation (Figure 1).

Spatial Data Modelling

It was recognised that past exploration may have overlooked the potential for intrusion related mineralisation in Eastern Australia and New Zealand and rather than carrying out the usual literature searches of known mineral deposits it was decided to develop a prospectivity model from a GIS database of known mineral occurrences, regional geology and geochemistry for both Eastern Australia and New Zealand. A GIS database containing a total of 79,000 mineral occurrences, 9,324,000 rock geochemical data analyses, 21,912,000 stream sediment geochemical data analyses, 26,360,592 soil geochemical data analyses, 109,000 drill holes and 2,537,522 km^2 of geological and geophysical data in Eastern Australia and the West Coast of New Zealand was compiled so that Spatial Data Modelling using the Weights of Evidence technique could be carried out. Most of these data were obtained inexpensively from local geological survey organisations or from freely available data downloadable from the Internet.

Weights of Evidence modelling requires the creation of a variety of predictive maps for a particular deposit type, based on the relevant mineral system model. These predictive maps are then statistically analysed using training data to test their predictive capacity, which allows the calculation of a spatial correlation value or weight (e.g., Bonham-Carter, 1994; Partington and Sale, 2004). In this case, the training data were drawn from mineral deposit locations for hard rock Bi-W-Mo-U-Au mineralisation held in the relevant Geological Survey mineral resource databases. These include the Kidston Au-Mo-Bi deposit in North Queensland and the Au-Mo-W deposit Timbarra in New South Wales (Baker and Tullemans, 1990; Mustard, 2001). The predictive maps are then combined using the weights to calculate the probability of undiscovered mineral resources (e.g., Bonham-Carter 1994). The model was developed using Arc-SDM software through Spatial Analyst in ArcGIS 9.2 (Sawatzky et al., 2008).

Sixty-seven different predictive maps were developed and tested for their spatial correlation with the training data (e.g., Sawatzky et al., 2008). A unit area of 4 km^2 was used in all calculations, assuming the area was representative of the probable extent that would be covered by an economically viable mineral deposit of this type. Most of the data were reclassified to produce binary predictive maps, but data like geology were reclassified into multi-class predictive maps. The predictive maps used in the final Spatial Data Model were chosen from those with the highest positive weights and were drawn from a mixture of geological and geochemical maps, including density of Au, Bi, Mo and W mineral occurrences, granites with gold in rock chips, granites with anomalous Bi, W and Mo, fractionated granites as defined by Rb/Sr ratios and SiO_2 composition and granite type (Table 1). Some of the predictive maps with high weights had similar map patterns, for example granite age and granite type. In this case only one predictive map was used in the model to attempt to reduce potential conditional dependence.

The resulting prospectivity model consisted of a raster grid containing the intersection of all of the input maps as a single integer raster. Each row of the raster attribute table contains a unique row of input map values, the number of training points, area in unit cells, sum of weights, posterior logit, posterior probability, and the measures of uncertainty. Importantly, the raster grid can be mapped by any of the fields in the attribute table, giving important information on the data influencing the result and missing information. This type of analysis usually cannot be done with other Spatial Data Modelling techniques like Fuzzy Logic or Neural Network Systems. The final stage of the modelling was to reclassify the model grid to map high priority exploration targets for intrusion related mineralisation. This was done by using the prior probability as the lower cutoff and the post probability values calculated for mines such as Timbarra and Kidston as an upper threshold. Target areas above the lower threshold were considered for tenement acquisition and targets with post probability values greater than known mines were prioritised for immediate follow-up exploration.

Economic Modelling

The Spatial Data Modelling provides a measure of the geological potential of a variety of exploration targets, but does not take into account financial cost and return on any follow-up exploration or development. Consequently, the full risk of exploring is unknown. It is possible to calculate the exploration risk by combining the geological probability of success with the cost of exploration and reward from development (c.f.., Kreuzer et al., 2008). This can be done for each target defined by the prospectivity modelling or any targeting methodology to develop a district wide exploration risk profile for each target. The probability of geological success has been calculated by the Weights of Evidence modelling, the probability of discovering a target tonnes and grade can be calculated from grade and tonnage data from grade tonnage curves and cost and revenue data can be derived from historic information updated for current costs and metal prices. The exploration risk can be calculated by multiplying the cost of exploration and development by the probability of failure and subtracting this from the NPV value of the project times the probability of success (Kreuzer et al., 2008). This allows the identification of the highly prospective targets that have the best returns in an exploration portfolio. It is these targets that should be given the highest priority for exploration investment.

A database of exploration targets was developed from the prospectivity model that lists the geological predictive variables and geological potential for each target. A list of economic parameters were developed for each target, including potential resource, metal prices, operating costs, production rate, exploration costs and capital costs. These were then combined with the geological probability values to calculate mine life, margin, NPV and the exploration risk for each target (c.f., Kreuzer et al., 2008). The economic risk analysis assumes minimum, likely and maximum input variables which when simulated allow the calculation of the uncertainty of the outcome, which in this case is NPV and Exploration Risk. The economic and geological data were then simulated using Monte Carlo simulation to calculate the probability of a positive NPV and positive exploration risk for each target.

Target Follow-up and Implications for North Queensland

The prospectivity modelling identified a large number of high priority targets in Eastern Australia and the West Coast of New Zealand. The target areas not covered by pre-existing tenements were acquired leading to the development of three new project areas in North Queensland, New England and the West Coast of New Zealand (Figure 2). These project areas contained a total of 113 targets, which were prioritised by their post probability values and economic risk values. Four of these targets were ready for immediate drilling. Some of these targets proved to have better potential for the other metals associated with intrusion relate gold mineralisation such as molybdenum, tungsten and tin than gold. Consequently, these metals were added to the economic factors used in the economic analysis. The final target database consists of a prioritised list of exploration targets that, although they contain different metals, can be compared economically. Those with the best potential economic returns have been targeted for follow-up exploration.

The North Queensland project areas are situated between Cairns and Mount Surprise and contain 29 high priority targets for intrusion related mineralisation including gold, molybdenum, tungsten and tin. They consist of the Lyndbrook, Khartoum and West Tinaroo group of tenements (Figure 2), which are all solely held by Auzex. The three highest priority targets based on exploration risk are the Khartoum, Galala and Runningbrook prospects, which are described below.

The tungsten-bismuth-gold-molybdenum Galala Range prospect, which is located north of Mt Surprise (Figure 2), produced a small amount of tungsten from alluvial sources in the early 1900s. The prospect occurs within a large alteration system forming a north east trending zone of sericite-silica alteration measuring 6km by 4km. Mineralisation consists of 0.1m to 1.5m wide sub-horizontal quartz veins within a sericite-silica altered biotite-muscovite granite. Geochemical sampling defined 13 separate combined soil and rock chip geochemical anomalies that have been targeted for drilling. Soil results from the prospect highlight the multi-element character of mineralisation at Galala, which has a central core of molybdenum mineralisation, surrounded by tungsten and an outer margin of gold. Drilling of the central molybdenum core returned significant molybdenum assays from a 600m by 400m area that suggest the potential for a sizeable molybdenum resource at shallow depth. Drilling of two of the gold soil anomalies intersected stacked narrow sub horizontal gold and tungsten bearing veins.

The Running Brook prospect is also located north of Mt Surprise (Figure 2), with initial soil sampling identifying anomalous gold and copper over a 1,000m by 300m area. Results from follow-up sampling confirm the prospectivity of the region with coherent gold and copper anomalies defined over 900m by 200m and 1,700m by 800m areas respectively. The anomalies overlap but are offset from each other. A series of costeans intersected wide zones of low grade gold mineralisation over 150m wide and up to 0.3 g/t Au. Drilling that targeted the costean results returned similar results, with the grade of gold mineralisation increasing towards a granite contact. Gold mineralisation appears to be associated with minor quartz, bismuth, arsenopyrite and pyrite veins in weakly altered gneiss.

Khartoum was identified by the prospectivity modelling as highly prospective for tin and tungsten mineralisation and moderately prospective for gold mineralisation and is located approximately 100km south-west of Cairns (Figure 2). The geology of the Khartoum tenement is dominated by highly fractionated coarse-grained Late Carboniferous-Early Permian granites (the Elizabeth Creek Granite), containing over fifty tin, tungsten, molybdenum and gold occurrences. Historic production is estimated to be 15,000t tin. Outcropping tin mineralisation is associated with 107 greisen zones covering a combined area exceeding 50km^2. Regional mapping and soil sampling initially identified a 9km by 3km zone of highly anomalous tin geochemistry with 15 key areas that have soil values up to 1.8% tin. The soil anomalies are derived from sub-horizontal and steeply dipping greisen zones that can be mapped over a 1km strike length. Channel Sampling gave very encouraging results with six of the ten greisens sampled averaging greater than 0.1% Sn. Follow-up scout drilling intersected wide intervals of tin mineralisation from surface to a depth of 132m, with grades between 0.13% and 0.26% tin. Narrow zones of higher grade tin were also intersected.

Conclusions

The lack of alteration, veining and sulphides makes detection by conventional prospecting for granite related mineral systems very difficult, and many explorers have walked over ore-bodies of this type and dismissed the host rocks as unprospective. Spatial Data Modelling techniques, where individual predictor maps of geology, geochemistry and geophysical data are combined into a single predictive map, are particularly useful when targeting this deposit type. Geological data have proved to be fundamental predictors of mineral occurrences in all predictive maps developed to date. An understanding of the structure and temporal development of the geology of an area is critical, especially at a prospect scale. The benefits of carrying out this type of analysis also include effective data compilation, QC of digital data, understanding of critical geological factors to be used in follow-up exploration, ranking of prospects, prioritising exploration, exploration budgeting and management, understanding of risk and cost reduction.

The prospectivity modelling successfully reduced the initial search to areas with similar combinations of geological, geophysical and geochemical predictive data. The targets could be quickly tested in the field and used to plan the acquisition of new exploration data. The modelling reduced the time taken to acquire tenements and identify drill targets, which has reduced risk and costs of investment. The Weights of Evidence technique is particularly useful for exploration, especially as it is possible to derive the data and weights that contribute to any target from the predictive map. This allows the exploration manager to identify those data that are the best predictors of mineralisation. More importantly it allows the identification of missing data in areas of lower probabilities that if collected could increase the prospectivity of the area. Not all historic exploration data were available in digital formats for the modelling and many areas lacked good geochemical coverage. However, the model highlighted significant areas of interest where all remaining historic data should now be compiled and new geochemical data collected in the field. The prospectivity model was also used to identify other gaps in the exploration database, for example detailed alteration and structural geological information. This analysis helped to develop focussed and appropriate exploration programs for specific area of interest.

The aim of using Spatial Data Modelling techniques was to shorten the exploration cycle and reduce the cost of assessment and future discovery. Work to date confirms that Spatial Modelling Techniques can help find new exploration targets in a part of the world that is considered to be a mature exploration area, confirming the prospectivity of North Queensland and that more investment in exploration is warranted in the region.

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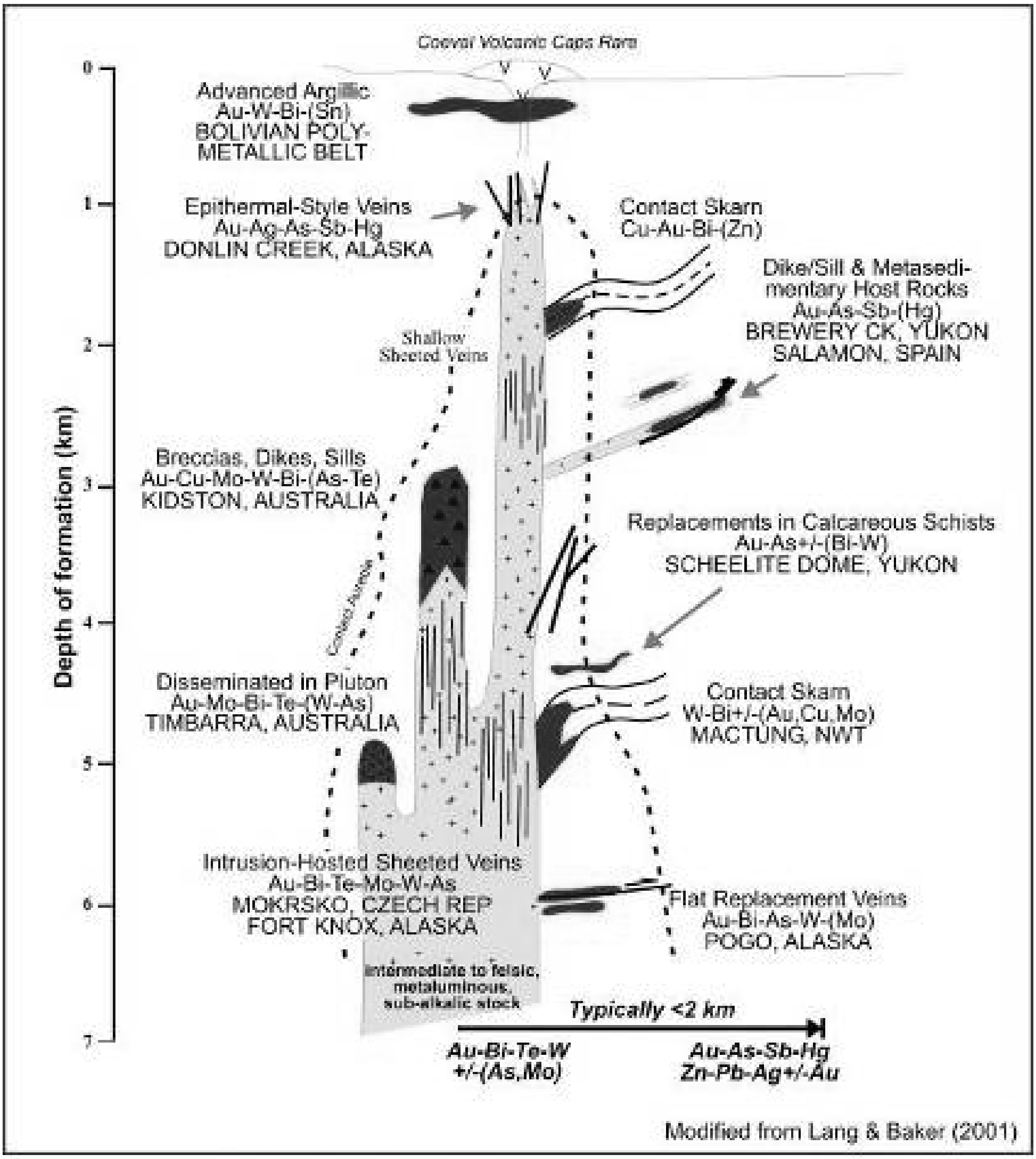
Map	Contrast	StudentC
Density of Bi mineral occurrences	5.7100	23.5402
Density of Mo mineral occurrences	5.4795	22.7676
Catchments with 10x anomalous Au	2.6423	5.6244
Catchments with anomalous U > 14 ppm	2.5832	9.1171
Catchments with anomalous W > 11 ppm	0.4830	1.8075
Cu in granites < 58 ppm	1.7493	3.7046
Radiogenic content of granites > 5	3.0114	6.9412
East faults buffered to 2,800m	1.9285	7.6805
Presence of I-type granites	9.8810	0.9880
Presence of leucogranite or adamellite	12.6997	1.2666
Mid range magnetic signature.	3.8650	12.5000

Table 1 Predictive derivative data maps used in the regional scale prospectivity model.



Geological Model for Intrusion-Related Gold Systems (IRGS).

Figure 1 Modified granite related mineral occurrence model, showing granite related mineral targets in relation to depth of formation.

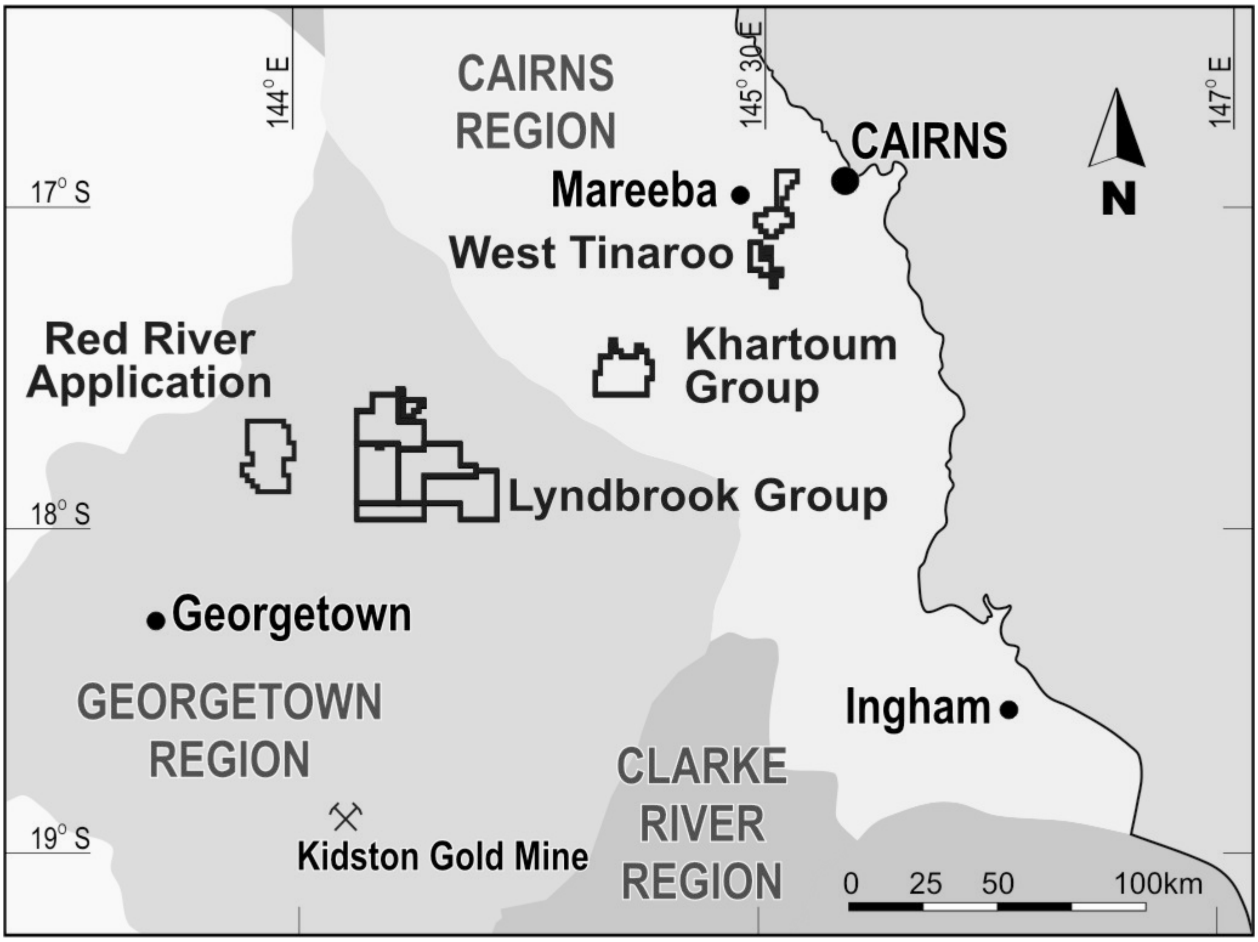


Figure 2 Location of Auzex North Queensland Projects.