Resource assessment using GIS modelling of orogenic gold mineralisation potential in New Zealand

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Prospectivity modelling of orogenic gold mineralisation has been completed over New Zealand using the GIS based weights of evidence modelling technique. New Zealand orogenic gold deposits are restricted to the South Island and lower North Island and are divided into two groups (Paleozoic and Mesozoic) based on their age and host rock association. Modelling of Paleozoic and Mesozoic orogenic gold deposits was undertaken to illustrate the power of GIS modelling in regional and nationwide resource evaluation and how it can be used to quickly identify and rank in terms of prospectivity areas of land where new orogenic gold deposits might exist. The mineral deposit modelling was constrained by the mineral systems concept which defines those parts of a mineralisation system that are critical to the ore-forming process. Both of the New Zealand gold models identified possible sources of metals in the region, structures that could be used for fluid migration, mineral trap zones ideally suited to host a mineral deposit, and outflow zones that may indicate a subsurface deposit. The models were validated against known areas of historical gold mining such as the Reefton deposits (Paleozoic) and Macraes Flat (Mesozoic). Two prospectivity maps showing areas favourable for Paleozoic and Mesozoic orogenic gold formation were produced. The prospectivity modelling successfully identified known areas for both types of orogenic gold mineralisation as well as several new localities not currently covered by existing tenements. The spatial modelling techniques used here can be applied elsewhere to evaluate resource potential, whether for gold, or any other land based resource, and can help planners and land owners manage future developments and their assets more effectively. Both models supersede those undertaken in 2002 by Crown Minerals and GNS Science under the purview of Dr Greg Partington (now Director of Kenex Ltd.). The new models were re-run due to the addition of new data and new modelling techniques and appear to have much better definition and are better for targeting at a prospect scale.

Keywords: orogenic gold, gold exploration, GIS, prospectivity modelling.

Introduction

Spatial modelling in a geographic information system (GIS) is a powerful tool for analysing digital data. Prospectivity modelling of both Paleozoic and Mesozoic orogenic gold mineralisation has been completed over New Zealand using the weights of evidence modelling technique (Bonham-Carter, 1994). The technique provides a way for large quantities of historical exploration data to be integrated and viewed as a single predictive map. This modelling has been conducted to optimise exploration and target selection throughout New Zealand and illustrates the potential for the discovery of economic gold mineralisation. Both models supersede those undertaken in 2002 by Crown Minerals and GNS Science, due to the addition of new data, including 88273 km^2 of new QMAP geological mapping (Cox and Barrell, 2007; Forsyth et al., 2008; Rattenbury et al., 2006). Additionally, new geochemical data, including 23430 rock chip samples, 42999 soil samples, 15242 stream sediment samples, 1901 drill holes and 20094 whole rock samples digitised from open-source Crown Minerals reports and research thesis's from the University of Otago are incorporated (see Hill et al., 2006). Furthermore, the development of new modelling techniques is included that consists of a work flow that is constrained by the recently developed mineral system concept. The results from the spatial modelling allows explorers to undertake fast assessment of regional prospectivity and gives them the opportunity to prioritise spending, undertake economic modelling, and focus on regions which are most likely to yield successful results.

New Zealand Orogenic Gold

Gold deposits in the South Island and lower North Island of New Zealand are thought to have originated from orogenic hydrothermal systems (Christie, 2002). These deposits are typically associated with multiple quartz veins formed in fault and shear zone systems at depths of 3 - 12 km and are hosted in greenschist facies and lower grade metamorphic rocks (Fig. 1). These orogenic deposits are divided into two subgroups (Paleozoic and Mesozoic) based on their age and host rock association. The Palaeozoic orogenic gold deposits occur in greywacke rocks of Palaeozoic age and are located in western South Island (e.g. Reefton deposits, including Globe-Progress and Blackwater). This mineralisation occurs on steep faults and cleavage planes, with fluids potentially sourced from nearby granites (e.g. the Globe-Progress deposits in Reefton) (Partington et al. 2001). The Mesozoic orogenic gold occurs in schists of Mesozoic age in the Marlborough, Wellington, Otago and the Southern Alps (Christie, 2002). This mineralisation occurs on moderate dipping shear zones (e.g. Hyde-Macraes Shear Zone), faults, and schist cleavage and is sourced from greenschists and metacherts (e.g. Macraes Flat).

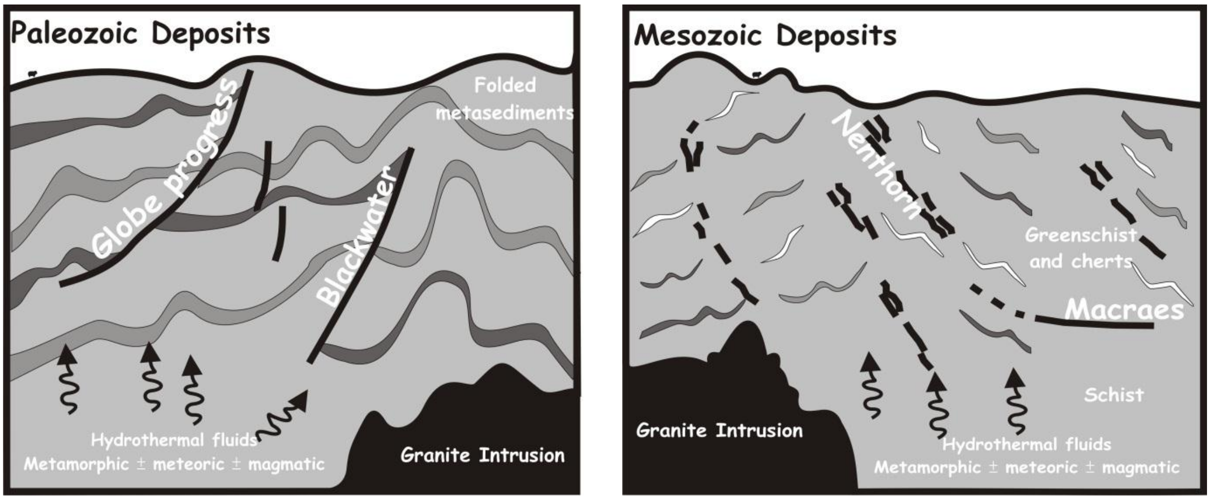

Figure 1. Cartoon of Paleozoic and Mesozoic orogenic gold mineralisation for New Zealand. Adapted from Christie (2002).

This study, unlike the previous study in 2002, focuses on utilising the mineral systems approach in order to identify the critical parameters of ore deposit formation. This approach concentrates on those factors that control the generation and preservation of mineral deposits, and the processes that are involved in mobilising ore components from a source, transporting and accumulating them in more concentrated form and then preserving them throughout subsequent geological history (Wyborn et al., 1994). The critical parameters of ore deposit formation are identified from existing literature about the mineral system (Christie, 2002; Groves et al., 2003; Pitcairn et al., 2006; Mortensen et al., 2010) and mapped spatially using GIS analysis to predict mineral potential in the study region (e.g. Partington et al., 2002; Partington and Sale, 2004). This modelling has mapped possible sources of metals in the region, structures that could be used for fluid migration, structures ideally suited to host a mineral deposit and outflow zones which indicate a subsurface deposit.

Evidence for appropriate sources of metal, fluid and energy to drive the mineral system in both models is derived from regional scale geological mapping (Bishop and Turbull, 1996; Rattenbury et al., 1998; Begg and Johnston, 2000; Turnbull, 2000; Forsyth, 2001; Nathan et al., 2001; Turnbull and Allibone, 2003; Rattenbury et al., 2006; Cox and Barrell, 2007; Forsyth et al., 2008). Greywacke and argillite turbidite rocks of Paleozoic age are identified as the preferred host rock lithology for Paleozoic gold. Nearby granites may have played a role as a potential source of energy and fluids for Paleozoic age gold (e.g. Partington et al. 2001); however, this is somewhat controversial. The mapping of schists deformed during the Mesozoic and their associated textural zones (Mortimer et al., 2001; Turnbull et al., 2001) are used to identify the source of energy and fluids for Mesozoic age gold. Regional strain intensity that represents a proxy for areas that have undergone deformational events (metamorphism, faulting, folding etc.) provides an additional source of fluid and energy.

The source of fluids and metals within a mineral system has to be able to migrate effectively to a site of deposition for economic quantities of metals to be present. The evidence for migration of fluids comes entirely from geological mapping at regional and prospect scales. For both models, structural pathways including fold hinges and first order fault planes are responsible for channelling fluids to higher crustal levels. These fluids then precipitate as vein material or wall rock replacement in second and third order structures. Areas with mapped quartz veins were used as a proxy in both orogenic systems for where fluid flow and vein precipitation may have occurred.

The formation and type of trap is one of the most important variables in any mineral system as the trap will determine the size and continuity of any resulting ore body. The trap may influence depositional processes, therefore grade continuity, and the type of trap present in a mineral system can be assessed using geological data to look for lithological or structural controls on mineralisation. The size of the trap can be assessed using low level geochemical data to map the probable extent of the mineralising system, either by using the metal of interest or pathfinder elements. The distribution of alteration zones may also provide information on the scale of the mineral system. Potential trap sites for both styles of orogenic gold mineralisation have been modelled using lithology (i.e. Paleozoic: greywacke and argillite turbidites; Mesozoic: schist) and structure to identify zones of dilatation (fault bends, jogs, intersections and splays). The possible scale of both styles of orogenic mineralisation was assessed using anomalous pathfinder element geochemistry (Ag, As, Au, Cu, Pb, Sb, W and Zn) in rock chip, stream sediment and soil samples.

Spatial data modelling of orogenic gold

Spatial data modelling requires a digital GIS database from which predictive evidence for a particular resource can be developed based on a process based model and ideally training data sets based on successful economic resource areas, which in this case are historic gold mines. The New Zealand area contains 379 mapped hard rock gold mineral occurrences (GNS Science GERM database) making it an ideal region for a weights of evidence spatial model using the known gold occurrences as training points.

The weights of evidence spatial data modelling technique (Bonham-Carter, 1994) was used in the New Zealand orogenic gold study to evaluate the wealth of geological data. This technique requires an understanding of the deposit mineral system, uses digital databases of geological information that include lithological mapping, structural interpretations, geochemistry, and importantly includes known economic deposits as training data to weight the model inputs. The main geological features from the orogenic gold mineral system model have been used to develop predictive maps from the available digital data using spatial modelling techniques such as buffering, intersections, interpolation, density algorithms, or from expert assigned attributes of genetic significance. The weights of evidence modelling technique combines these weighted predictive maps to create two prospectivity maps showing areas favourable for Paleozoic and Mesozoic orogenic gold deposits in New Zealand.

As a first step in the spatial correlation calculation, a 200 by 200 metre grid was generated over the study area which represents the minimum scale that the data should be viewed at. The modelling used a unit cell size of 0.7 km^2, which is intended to represent the approximate size of the mineral system. 138 Paleozoic and 183 Mesozoic deposit locations for hard rock gold mineralisation were extracted from the mineral occurrence databases (Begg and Johnston, 2000) as training data sets. These occurrences were chosen to have a suitable distribution throughout the study area and not overlap. The training data and unit cell give prior probabilities of 0.000361 for Paleozoic deposits and 0.000489 for Mesozoic deposits; i.e. there is a 0.000361 chance of finding a Paleozoic orogenic gold deposit in any 0.7 km^2 block before any knowledge about the mineral system is applied. 123 predictive themes were developed from the available digital data for the New Zealand orogenic gold model. From these, ten Paleozoic and eleven Mesozoic maps were chosen as having the best regional coverage, a significant spatial association with the mineralisation model, and where possible not to duplicate predictive map patterns to reduce the effects of conditional dependence (Table 1 and 2). The resulting predictive maps were classified into areas of relative prospectivity and used to target regions in New Zealand for follow-up investigations.

Table 1. Predictive maps used in the weights of evidence Paleozoic orogenic gold model.

Min. Sys.	**Layer**	**Description**	**C**	**StudC**
Source energy & fluids	greenland	Greenland Group lithologies (also Trap)	5.5	31.7
Pathways	faultden8	High regional fault density	2.8	14.2
	faultau800	Lower order faults buffered to 800 m	3.4	17.0
	faultn1000	North orientated faults buffered to 1000 m.	4.0	20.1
Traps	fold1500	Folds buffered to 1500 m.	4.4	24.4
	foldden6	Med-high fold density	6.7	37.3
Outflow	ssau01	Anomalous Au in stream samples (ss Au > 20 ppb, PC Au > 5000 ppb, BCL Au > 25 ppb	2.1	6.0
	ssas40	Anomalous As in stream samples (As > 40 ppm)	3.1	4.2
	rockau01	Anomalous Au in rock and drill samples (Au > 0.1 ppm)	2.6	5.7
	rockas200	Anomalous As in rock and drill samples (As > 200 ppm)	2.0	5.6

Table 2. Predictive maps used in the weights of evidence Mesozoic orogenic gold model.

Min. Sys.	**Layer**	**Description**	**C**	**StudC**
Source energy & fluids	permschist	Mesozoic age schist (also Trap)	3.1	21.0
	strucint178	High regional structural intensity (also Pathway)	2.9	19.8
	txtgrade4	Schist of textural grade 4	3.2	21.5
Pathways	faultne1900	North-east orientated faults buffered to 1900 m.	3.8	20.8
	qvden6	Med-high quartz vein density	4.9	20.8
Traps	foldstylef2	Fold style F2	3.7	21.6
	faultjog3800	Fault jogs buffered to 3800 m.	2.0	11.3
Outflow	ssau01	Anomalous Au in stream samples (ss Au > 20 ppb, PC Au > 5000 ppb, BCL Au > 25 ppb	1.7	8.2
	rockau01	Anomalous Au in rock and drill samples (Au > 0.1 ppm)	3.5	11.8
	rockas200	Anomalous As in rock and drill samples (As > 200 ppm)	4.1	13.8
	rocksb40	Anomalous Sb in rock and drill samples (Sb > 40 ppm)	1.5	6.8

Spatial correlations between the training data and individual predictive maps were calculated using weights of evidence spatial modelling techniques in the ArcSDM spatial data modeller extension developed for Arc GIS software. The modelling technique is a Bayesian statistical approach which allows the analysis and combination of data to predict the occurrence of deposits. It is based on the presence or absence of a characteristic or pattern and the occurrence of a deposit. The spatial correlation of mapped data in the model can be calculated by using the relationship of the area covered by the predictive feature being tested and the number of training data points that fall onto it. This produces a W+ result based on training points falling on the predictive feature and a W- result based on training points falling where the feature is absent. A W+ value greater than zero indicates a positive correlation with the mapped data, whereas a W- less than zero indicates a negative association with a non-mapped area. The contrast, which is the difference between W+ and W-, gets higher with an increase in the correlation between the predictive features and the training data (i.e. a map that correlates well with the selected training data for orogenic gold will have a high contrast value). The spatial association of each predictive theme is based on the contrast (C) and the level of uncertainty (StudC). The uncertainty is calculated from the standard deviations of W and C (Ws and Cs), from which the studentised value of the contrast (StudC) can then be calculated (the ratio of the standard deviation of the contrast (Cs) to the contrast (C)). StudC gives an informal test of the hypothesis that C=0 and as long as the ratio is relatively large, implying the contrast is large compared with the standard deviation, then the contrast is more likely to be real. This ratio is best used as a relative indicator of spatial correlation, rather than an absolute sense. In this study a strong correlation is inferred from C values > 3.0 and StudC values >1.5. The final weighted geological predictor themes were combined and a gridded response was generated representing the intersection of all the input themes in a single integer grid.

Modelling results

Spatial modelling of Paleozoic and Mesozoic orogenic gold using weights of evidence techniques highlights the importance of geology and geochemical data sets as predictors of mineralisation. The model identifies several regions that are highly prospective for both types of mineralisation (Fig. 2 and Fig. 3). This model clearly shows the importance of lithology as well as structural controls such as faults and folds, which act as pathways and traps for both mineralisation styles. The model successfully identifies most known occurrences of gold in the study area, particularly the Reefton deposit (Paleozoic) and Macraes Flat in Otago (Mesozoic), supporting the validity of this model as a predictor for orogenic gold mineralisation.

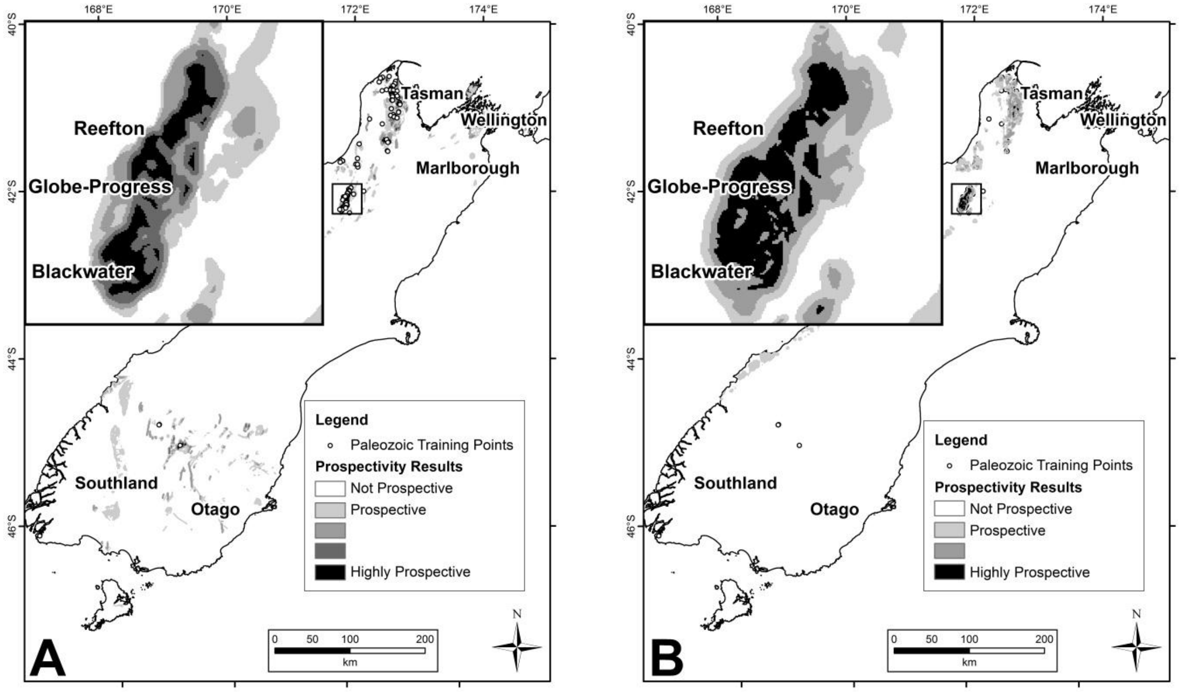

Figure 2. Prospectivity modelling results for Paleozoic orogenic gold mineralisation. A. Map of 2011 prospectivity model. B. Map of 2002 prospectivity model from Partington et al. (2002).

The model confirms that 4% of the New Zealand study area (267,707 km^2) is prospective for Paleozoic orogenic gold and that 10% is prospective for Mesozoic orogenic gold mineralisation. Through appropriate target ranking techniques, 28 highly prospective Paleozoic gold targets and 29 highly prospective Mesozoic gold targets larger than 1 km^2 in size are identified over New Zealand. The identified targets require follow-up field checking in order to verify their prospectivity, and collection of missing data that may further increase the chances of finding a deposit.

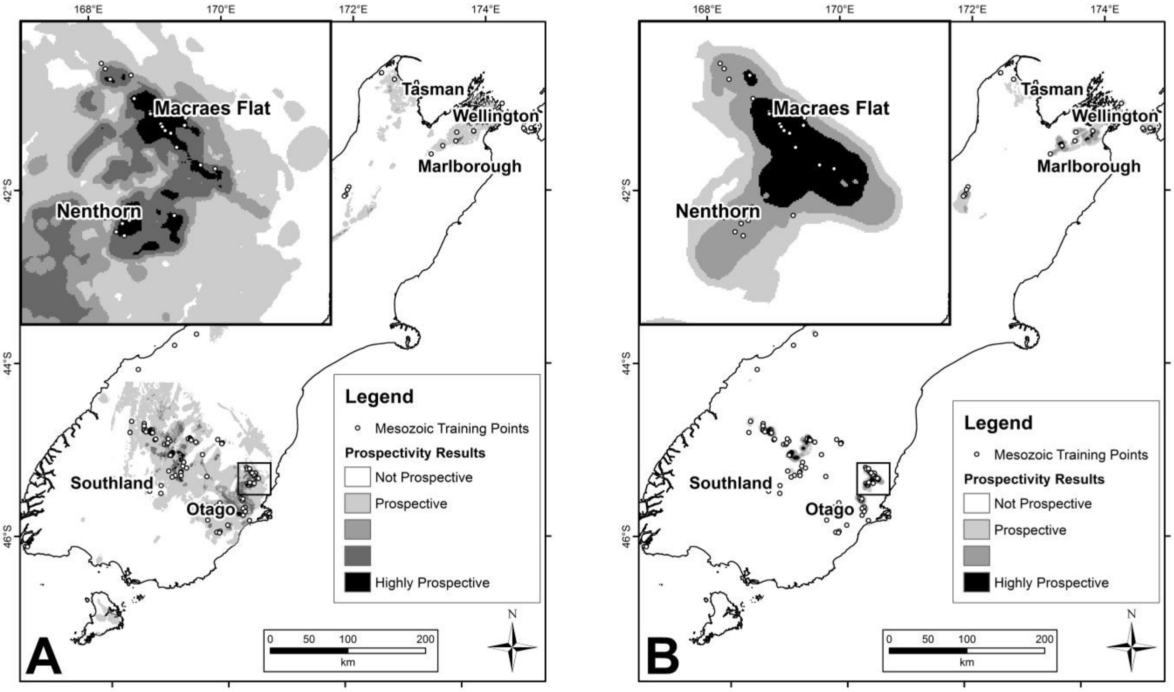

Figure 3. Prospectivity modelling results for Mesozoic orogenic gold mineralisation. A. Map of 2011 prospectivity model. B. Map of 2002 prospectivity model from Partington et al. (2002).

This model supersedes a similar modelling study carried out in 2002 by Crown Minerals and GNS Science (Partington et al., 2002). Both the 2002 model and this model make use of similar training data points, as this enables a meaningful comparison to be made. Similarities between the close-ups of the old and new model can be seen in Figs. 2 and 3. This is because these areas are well research and thoroughly sampled, with not much in the way of new data being added since 2002. However, there are some large regional differences between the 2002 and 2011 models, in that numerous new areas have become prospective that were previously not prospective as well as some areas experiencing an increase in their relative prospectivity. This is due to the addition of more geochemical data and far more detailed geological and structural mapping (QMAP by GNS Science), especially over the Marlborough and Otago regions. Overall, it appears that the new models produced are at a spatial definition ideal for targeting at a prospect scale compared to the more regionally based 2002 models.

These prospectivity models are relevant for a typical regional scale exploration program, or at the project generation and permit or tenement acquisition stage, where the area acquired tends to be larger than the target area. Any follow-up exploration programs should be designed to further reduce the target area. The probability values derived from the model also allow a ranking of any prospect area, which allows efficient exploration programs to be developed that have the best chance for success.

Conclusions

The prospectivity models derived from the weights of evidence technique place the genetic models of orogenic gold mineralisation in New Zealand into an exploration context. The spatial correlation data from both prospectivity models demonstrate the value contained in traditional geological maps organised in a GIS. The regional prospectivity models developed for orogenic gold mineralisation in New Zealand indicate considerable potential exists in under-explored areas, allowing new local and international companies to effectively prioritise their exploration efforts, and acquire additional prospective areas for these types of mineralisation.

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