# Prospectivity Mapping Using GIS With Publicly Available Earth Science Data — A New Targeting Tool Being Successfully Used for Exploration in New Zealand

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## ABSTRACT

The Epithermal and Mesothermal Gold Prospectivity Modelling Projects recently completed by Crown Minerals provided explorers in New Zealand with a new compilation of historical exploration data combined with new geological information from the GNS QMap 1:250 000 scale mapping project. These data were used to produce predictive mineral potential maps for gold mineralisation in New Zealand. The aim of these projects, which was to stimulate mineral exploration and investment in exploration, has been successful with new companies acquiring new tenements and committing significant exploration expenditure to exploring in New Zealand in the coming years.

The projects were undertaken at a national scale and consequently not all exploration data were compiled into the prospectivity models. HPD New Zealand Ltd recognised the value of the prospectivity modelling work and committed exploration funds to continue the modelling process started by the projects. They recognised the need to compile the remaining data and run the models again to allow detailed exploration targeting.

Detailed data compilations including digitising historic exploration stream sediment sample, rock chip sample, soil sample and drilling data has been completed. New models have been completed in Otago for mesothermal gold mineralisation and in the Coromandel for epithermal gold. The new models have been compared with the original regional scale models and used to target prospect scale exploration. This work has allowed exploration models for epithermal and mesothermal mineralisation in New Zealand to be refined. More importantly this work has identified significant areas with potential to host gold mineralisation with little or no systematic geochemical data including soil sampling or drilling. Exploration work programs have been designed to acquire these missing data and exploration funds have now been committed to test the areas highlighted by the prospectivity modelling.

In summary, the Epithermal and Mesothermal Gold Prospectivity Modelling Projects commissioned by Crown Minerals have successfully attracted new investment and ideas to the exploration scene in New Zealand. The projects cost an estimated $NZ 250 000 and could in the next two years, just through exploration expenditure, attract more than $NZ 10 M in investment. If a mine is discovered the return on investment will be considerably greater.

## INTRODUCTION

The completion of the Epithermal and Mesothermal Gold Prospectivity Modelling Projects by Crown Minerals (the New Zealand Department of Mines) provided explorers in New Zealand with a new compilation of historical exploration data (Partington and Smillie, 2002; Rattenbury and Partington, 2003), which has been combined with new geological information from the GNS (the New Zealand Geological Survey) QMap 1:250 000 scale mapping project (Nathan 1994; Nathan 1998). These data were used to produce predictive mineral potential maps for gold mineralisation in New Zealand (Partington and Smillie, 2002; Partington *et al*, 2002; Rattenbury and Partington, 2003). The aim of these projects was to stimulate mineral exploration and investment in exploration in New Zealand, which has been successful, with new companies acquiring tenement positions and committing significant exploration expenditure to exploring in New Zealand.

Both the Mesothermal and Epithermal Gold Projects were compiled at a national scale and consequently not all historic exploration data were included in the regional prospectivity models. HPD New Zealand Ltd (HPD NZ), who has a significant exploration permit holding in New Zealand, recognised the value of the prospectivity modelling techniques and committed exploration funds to continue the modelling process started by the government projects. All remaining historic exploration data were compiled and new prospect scale geological and geochemical data collected in the field. These data were integrated with the data from Crown Minerals in a Geographic Information System (GIS) and detailed prospectivity models created for both epithermal gold in the Coromandel and mesothermal gold in Otago. These models were used the for prospect scale exploration targeting and the development of ongoing exploration work programs and budgets. This work has now been completed, allowing HPD NZ to move rapidly from the reconnaissance stage to prospect scale exploration, so reducing costs and risk at the earliest stage of exploration.

This paper presents a summary of the results of the follow-up work carried out on the HPD NZ Otago permit areas and compares the new detailed Otago prospectivity model with the original regional Otago prospectivity model over the same area (Partington and Smillie, 2002). This has allowed the exploration model for mesothermal gold mineralisation in Otago to be refined. More importantly, new exploration targets have been developed using the mineral potential maps and prospective areas that require follow-up geochemical sampling and drilling identified. The value and use of mineral potential maps for exploration targeting and exploration management are also discussed.

## MESOTHERMAL GOLD MINERALISATION IN OTAGO

Mesothermal gold deposits in New Zealand are restricted to the South Island of New Zealand (Figure 1) and occur in greywacke rocks of Palaeozoic age located in the Greymouth and Nelson districts (eg Reefton, including the Globe-Progress deposit, which is greater than two million ounces of gold), and also in Mesozoic age schists of the Marlborough and Otago districts (eg the Macraes Flat deposit, which is greater than five million ounces of gold) and in schists and greywackes of the Southern Alps (Christie and Braithwaite, 1999; Christie, 2002). A summary of the characteristics of the two styles of mesothermal gold mineralisation in New Zealand is given in Table 1.

The schist belts in the South Island of New Zealand are one of the high priority exploration targets for exploration companies in New Zealand, and comprise psammitic, pelitic and interlayered psammitic-pelitic schist, with local metavolcanic and quartzite units (Mortimer, 1993). The rocks have been assigned to three tectonostratigraphic units: Caples Terrane, Torlesse Terrane and Aspiring Lithologic Association (Mortimer 1993; Mortimer 2000), which were metamorphosed in the Mesozoic as a result of collision between the Torlesse and Caples Terranes. The

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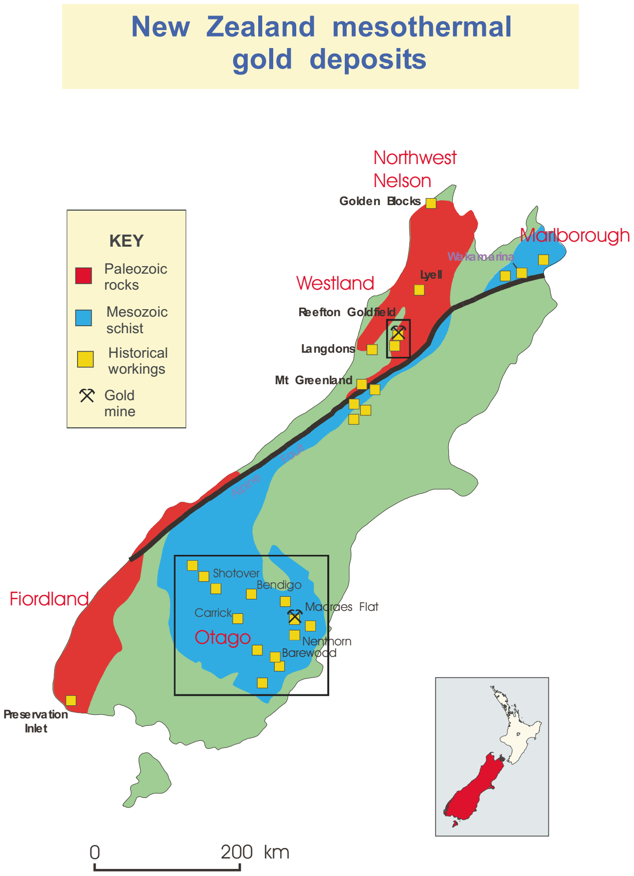


FIG 1 - Location of mesothermal gold mineralisation in New Zealand (Christie, 2002).

metamorphic grade is mostly greenschist facies (chlorite zone and garnet-biotite-albite zone), but rises to amphibolite facies near the Alpine Fault (Craw 1998; Mortimer 2000; Mortimer 2001; Foster and Lister 2003). The abundance of mesoscopic folds with different styles is generally taken as evidence for syn- and post-metamorphic recumbent and nappe folding (MacKenzie and Craw, 2001). More brittle features are associated with regional uplift, including low-angle thrust zones and steeper north west and north east trending normal faults (Mortimer, 1993). Forster and Lister (2003) concluded that central belt of schist in the Torlesse Terrane, adjacent to the Caples-Torlesse boundary was exhumed as the result of the operation of large-scale extensional ductile shear zones. These shear zones now mark the lateral extent of the higher grade parts of the schist and the structural arch in which the Otago Schist is now exposed. The location and development of these structures appears to have played an important role in the formation of mesothermal gold deposits in Otago.

Gold mining on the South Island of New Zealand was historically from small quartz lode deposits, but recent exploration and mining in Otago has identified the importance of lower grade disseminated regional shear zone deposits (eg Macraes Flat, Carrick and Bullendale). Mesozoic schist quartz lode deposits typically dip steeply and are discordant to the foliation in the host schist. The Otago lodes tend to strike north west, parallel to the antiformal axis of the schist belt (Christie, 2002). Regional shear zone (Macraes type) deposits occur as gold-bearing quartz veins and alteration zones within large regional-scale shear zones. The Macraes Flat deposit on the Hyde-Macraes Shear Zone is the type example, although it was formerly mined as a quartz lode deposit. The Hyde-Macraes Shear Zone consists of a 30 km long shallow dipping shear zone that is semi-concordant to the foliation in the host schist. The shear zone is up to 160 m thick, and consists of brecciated and sheared graphitic, pelitic schist separated from the host psammitic schist by well-defined upper and lower bounding

**TABLE 1**

*Characteristic features of New Zealand Palaeozoic and Mesozoic mesothermal gold deposits (Christie, 2002).*

| | Palaeozoic deposits | Mesozoic deposits |
|---|---|---|
| Geographic occurrence | West Coast, Nelson and Fjiordland | Marlborough, Southern Alps and Otago |
| Mineralisation style | Quartz lode and disseminated Au in shear zones | Quartz lode and disseminated Au in shear zones |
| Operating mines | Globe-Progress in development | Macraes Flat |
| Maximum known resource in one deposit | greater than 2 M oz Au | greater than 5 M oz Au |
| Lode dimensions L × D × W | 1070 m × 1000 m × 14 m | 1800 m × 150 m × 21 m |
| Host rock | Greywacke | Schist |
| Age of host rocks | Cambrian-Ordovician | Permian-Triassic |
| Age of metamorphism | Silurian-Devonian | Jurassic to Cretaceous |
| Age of mineralisation | Silurian-Devonian | Early Cretaceous |
| Geologic terranes | Buller | Haast, Caples, Torlesse |
| Metamorphism | Lower greenschist facies, weakly cleaved | Greenschist facies, strongly foliated |
| Structural controls | Faults, shears and folds. Lodes parallel strike of fold axes. Density of quartz veining | Faults and shears. Lodes parallel axis of schist belt |
| Hydrothermal alteration | Sericite, carbonate, arsenopyrite and pyrite | Sericite, arsenopyrite and pyrite. (Graphite at Macraes) |
| Lithological controls | Sandstone/mudstone, and bedding | Psammitic/pelitic/interlayered schist, and bedding |
| Potential source influences | Nearby granites | Greenschists and metacherts |
| Main metallic minerals | Gold, arsenopyrite, pyrite | Gold, arsenopyrite, pyrite |
| Minor metallic minerals | Local stibnite | Local stibnite and scheelite |
| Main non-metallic minerals | Quartz and carbonate | Quartz and carbonate |
| Minor non-metallic minerals | Feldspar and chlorite | Graphite at Macraes |
| Geochemical signature | Au, As, ±Sb | Au, As, ±Sb, ±W |

thrusts. The gold is generally fine grained and closely associated with quartz, pyrite and arsenopyrite. Quartz lode K-Ar and Rb-Sr age determinations from Bendigo, Oturehua, Bendigo and Glenorchy suggest mineralisation was formed in the Early Cretaceous (ca. 100 - 145 Ma), after regional metamorphism, at a late stage in the uplift and cooling history of the schist. Skippers, Macetown and Carrick are inferred to be Miocene in age and Macraes Flat mineralisation has been dated at about 140 - 150 Ma by Ar-Ar, and K-Ar and Rb-Sr methods (Christie, 2002).

Most researchers working on the genesis of the Mesozoic schist gold deposits consider that the ore fluid for the quartz vein and regional shear zone deposits was metamorphic, generated by dehydration reactions within the sedimentary pile at the greenschist to amphibolite facies transition (Craw and Norris, 1991). In contrast, some workers, based on micro-analytical studies of fluid inclusions, suggest that the ore fluids were a mixture of magmatic and meteoric rather than metamorphic fluids (De Ronde *et al*, 2000). Graphite in the host rock sequence may have played an important chemical role in the deposition of gold.

The Mesothermal Gold Prospectivity Project completed by GNS and Crown Minerals has helped define a regional exploration model for Mesozoic Gold mineralisation in Otago by identifying the most important geological spatial correlations with gold mineralisation as discussed below. Table 1 highlights the most important exploration parameters at a regional exploration scale that were used as a basis for the Otago prospectivity modelling.

## SPATIAL DATA MODELLING METHODOLOGIES

Most exploration targeting is currently performed by searching prospect information from mineral occurrence databases. While this type of analysis has been effective in the past, many areas have now been well explored and this type of approach will not find new or buried mineral deposits. Effective targeting can only be done if all data are compiled and integrated in a way that matches the mineralisation model being sought. The data available to assess the potential of an area for mineralisation come from various modern day exploration campaigns, research organisations and government surveys. These data are not only diverse but voluminous, including regional geology, geochemistry, remote sensing and geophysical data, and make the task of interpretation difficult. It is critical for exploration targeting that effective analysis of the available datasets is carried out with respect to each other and that only the relevant factors to the exploration model being used are extracted and combined into a single mineral potential map by using spatial data modelling techniques.

Spatial data modelling is a rapidly developing technique that is increasingly being used in geology (Bonham-Carter *et al*, 1988; Bonham-Carter, 1997; Agterberg *et al*, 1993; Partington, 1999, Raines, 1999; Partington, 2000a; Partington 2000b; Partington *et al*, 2002, Rattenbury and Partington, 2003; Tangestani and Moore, 2003), other spatially based sciences such as Archaeology (Mensing *et al*, 2000) and by government organisations such as Crown Minerals; the New Zealand Department of Mines (Partington *et al*, 2001; Partington *et al*, 2002; Partington and Smillie, 2003; Rattenbury and Partington, 2003), United States Geological Survey (Boleneus *et al*, 2001; Mihalasky, 2001) and the Canadian Geological Survey for resource assessment (Bonham-Carter *et al*, 1988). Government agencies use these techniques to make land-use decisions in relation to competing land-uses. These techniques are also increasingly being used by leading exploration and mining companies, but not to the same level as government agencies. It is not clear why the industry lags behind as these techniques are ideally suited for synthesising large spatial data sets for reconnaissance exploration so allowing more focussed targeting and risk reduction at an early stage of exploration (eg Henley, 1997).

A variety of new tools are available for use with computer aided geographic data management systems or Geographic Information Systems (GIS) for evaluating the distribution of spatial data in a statistical framework (Atterberg *et al*, 1993; Bonham-Carter, 1997; Looney, 1997; Kemp *et al*, 2001; Tangestani and Moore, 2003). The creation of derivative spatial data maps that can be used by the modelling software from base geological, geochemical and geophysical data is the key to creating successful mineral potential maps (Partington *et al*, 2001; Partington and Smillie, 2002; Rattenbury and Partington, 2003). These derivative datasets must be reclassified in a way that matches the mineralisation model being used; in this case Mesothermal or Orogenic Gold (Cox and Singer, 1986; Kerrich and Cassidy, 1994; Groves *et al*, 1998; Partington and Williams, 2000). For example, the creation of geochemical anomaly maps from point data values (eg Figure 2 and Figure 3) or digital terrane models from elevation point or contour data. GIS techniques such as buffering, density grid interpolation, grid extrapolation, grid interpolation, and the use of expert-assigned attributes of genetic significance were also used to create the derivative themes (eg Figure 4 and Figure 5). These themes were then used to calculate spatial correlation statistics between the data themes and a training data set selected from historic areas of gold production. A more detailed description of some of the derivative data themes, their spatial correlation results and implications of these to exploration models used to explore for gold in Otago is given below and by Partington and Smillie (2002).

The simplest type of predictive spatial analysis is where maps, with the chosen input variable(s) represented by a series of integer values, are combined together using arithmetic operators. For example differing lithologies can be reclassified into numeric values or geochemical data can be interpolated into a raster grid. This type of analysis takes no account of the relative importance of the variables being used and is based on expert opinion. Fuzzy Logic techniques address the problem of the relative importance of data being used, but this technique still relies on expert opinion to derive weights that rank the relative importance of the variable for the map combination. An example of the use of this technique in mineral exploration is given by Tangestani and Moore (2003). Weights of Evidence, in contrast uses statistical analysis of the map layers being used with a training data to make less subjective decisions on how the map layers in any model are combined. Bonham-Carter (1997) gives a good summary of the maths and algorithms used in Weights of Evidence and Partington (2000), Partington and Smillie (2002) and Rattenbury and Partington (2003) give examples of how this technique can be applied to geological datasets. Weights of Evidence is a Bayesian statistical approach that allows the analysis and combination of data to predict the occurrence of events. It is based on the presence or absence of a characteristic or pattern and the occurrence of an event. The technique was initially developed as a diagnostic tool in medicine. In spatial analysis, it has been used extensively in the mineral and mining fields. An estimate of the (prior) probability of the occurrence of granite gold mineralisation can be calculated from the total number of known deposits distributed over the region being targeted divided by the area of that region. A unit area is chosen that represents the potential areal extent of known mineralisation and is used as a grid for the spatial calculations. A probability or statistical value of importance can then be calculated for all geological features that are part of the exploration model. This probability is based on the prior probability and the presence or absence of the geological feature in question. The odds of occurrence (logits) are then used to combine the various statistically valid geological layers that represent the mineralisation model to produce a probability map. This map then defines the probability of finding the mineral at a point on a grid covering the area being explored.

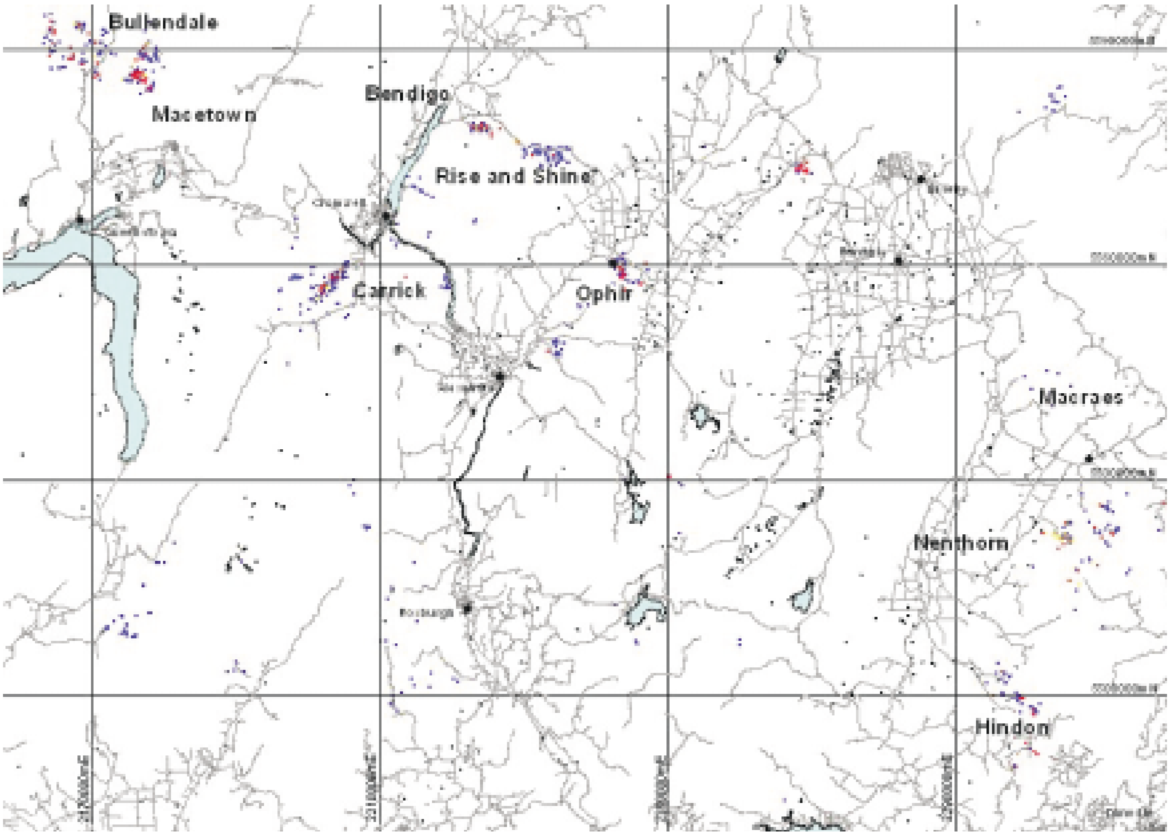


FIG 2 - Geochemical anomaly map for rock chip gold in Otago. Blue is <0.1 ppm Au. Yellow 0.1 - 1 ppm Au and red is >1 ppm Au. Note the lack of data over the Macraes deposit due to data being held in closed-file.

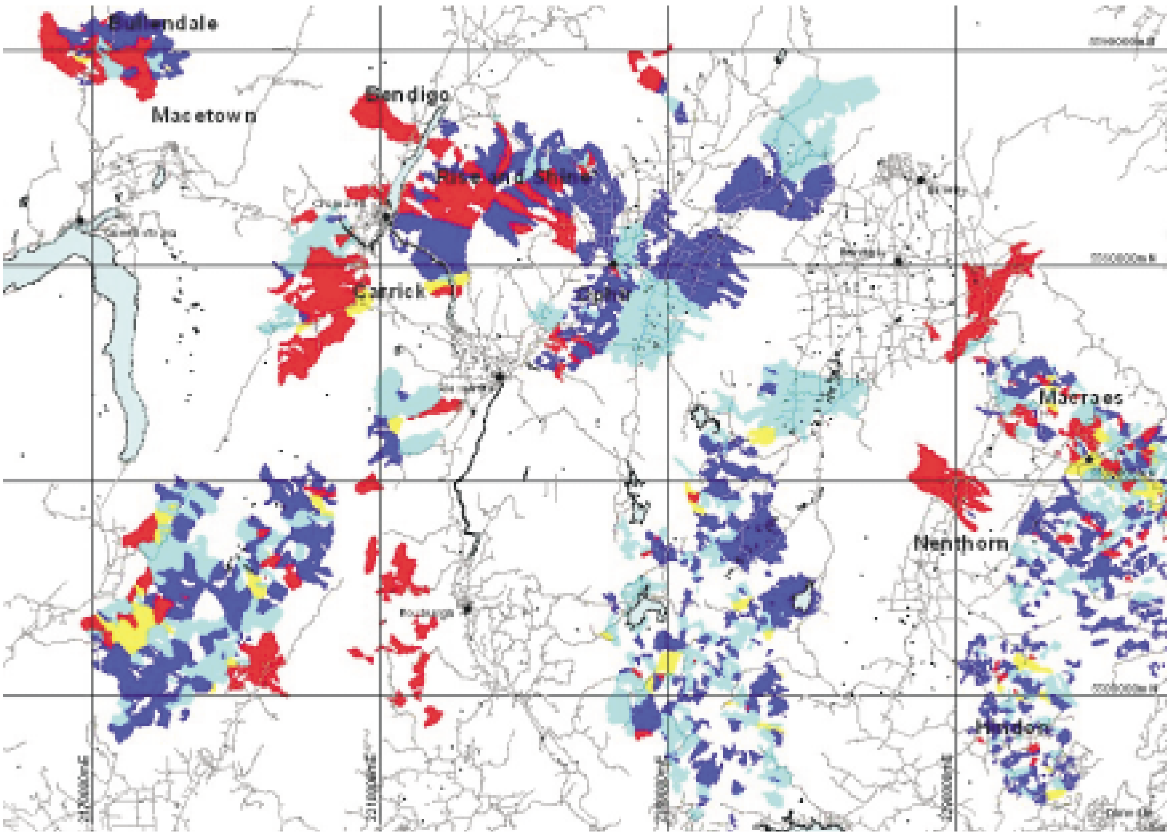


FIG 3 - Gold in stream sediment samples averaged into stream catchment areas in Otago with blue less than 3 ppb Au, light blue 3 - 17 ppb Au, yellow 17 - 33 ppb Au and red >33 ppb Au.

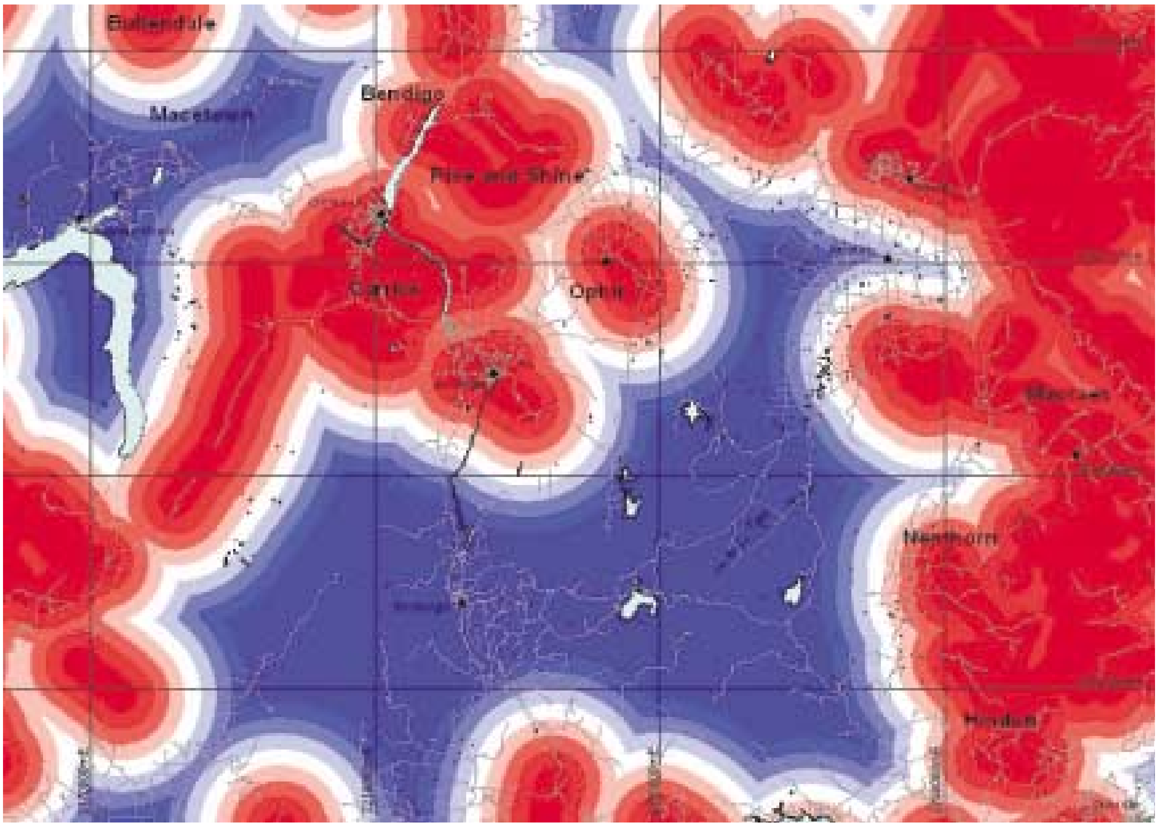


FIG 4 - Faults that were formed pre to syn mineralisation, buffered at 100 m intervals in Otago. The buffers were used to test the spatial relationships between various orientations of faults, fault movement sense and subtle variations in fault orientation with gold mineralisation.

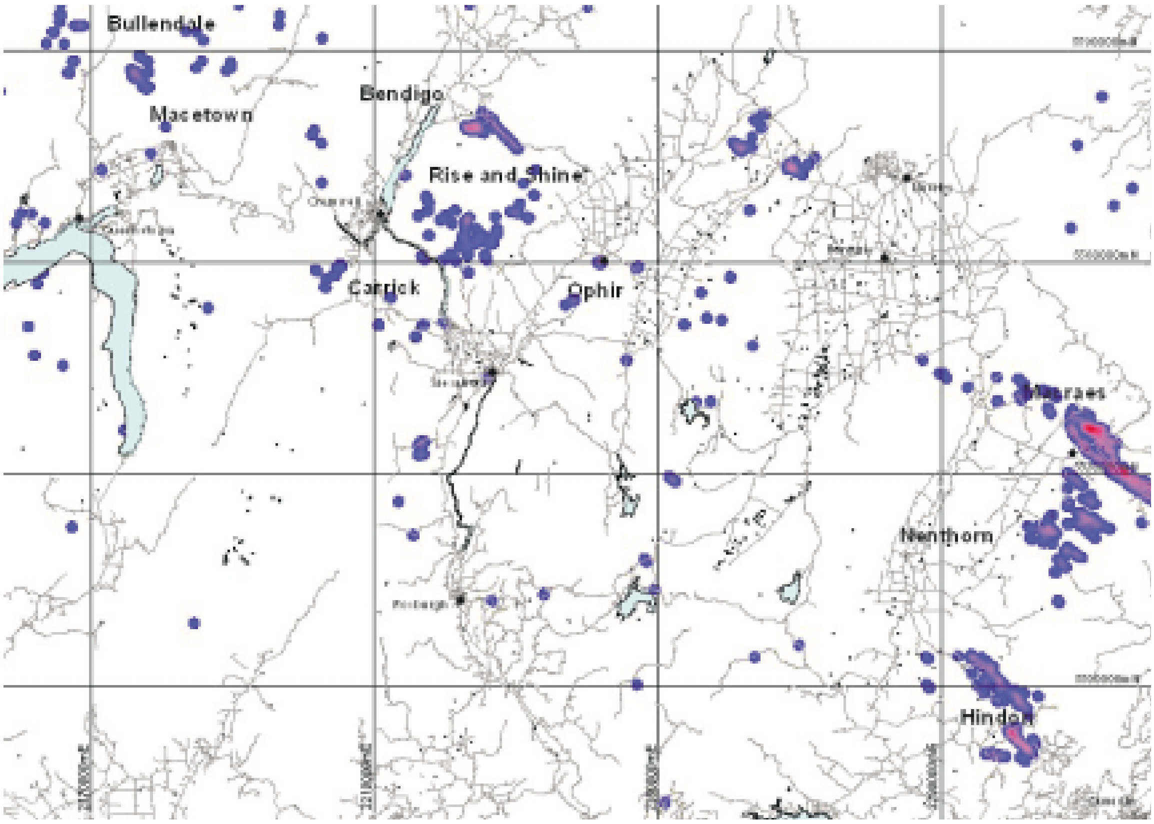


FIG 5 - Quartz vein density maps of mineralised veins in Otago. These maps were used to test the spatial relationship of the density of quartz veining in an area to economic mineralisation. The areas of a high density of quartz veining should represent areas of high fluid flow in the crust during the mineralising event.

## SPATIAL DATA CORRELATIONS IMPLICATIONS FOR CURRENT EXPLORATION MODELS

Data compiled prior to the modelling stage for both the regional Otago prospectivity model and detailed Otago prospectivity model were reclassified in accordance with the mineralisation models described by Christie (2002), and as discussed above and in Partington and (Smillie, 2002). These data were used to calculate spatial relationships between the exploration model data layers and the data layer containing the spatial data to be modelled; in this case historic occurrences of hard rock gold mineralisation with significant production or historic drill hole intersections of gold mineralisation. These mineral deposit locations for hard rock gold mineralisation were extracted from a national mineral deposit database held by GNS. Following data validation, the prospect database was then reviewed, checking data and excluding all prospects that were classified as alluvial or unrelated younger gold mineralisation. A training data set was then subset for the regional Otago prospectivity model from this database by selecting those prospects with historic production recorded in the database (Partington and Smillie, 2002). This training data-set accounts for 60 per cent of the total number of hard rock mesothermal gold deposits in the database and gave 182 training sites for the regional Otago prospectivity model. These training data were further subset according to production greater than 10 000 ounces, rechecked in the field with a GPS and locations modified for the detailed Otago prospectivity model. The 182 training sites for the regional Otago prospectivity model and 22 training data sites selected for the detailed Otago prospectivity model are shown on Figure 6.

The key derivative exploration data that were tested for geological spatial association with known mineralisation in both studies were the same and included:

- host rock and terrain preference of known deposits;
- proximity to macroscopic fold hinges;
- proximity to concentrations of mesoscopic folds;
- lithofacies (eg sandstone:mudstone occurrences, greenschist horizons);
- correlation with density of quartz veins;
- the relative structural depth of Mesozoic deposits, particularly in relation to the textural zones, isograds and the foliation thickness and mica grain size work of Mortimer (2001);
- metamorphic grade discontinuities as shown in Mortimer (2000);
- relationship to mesoscopically ‘folded’ versus ‘platy’ schist;
- relationship to the dip of foliation; and
- geochemistry of host rocks.

As a first step in the spatial correlation calculation, a 200 by 200 metre grid was generated over the regional Otago area and a 40 by 40 metre grid over the detailed Otago area. The size of the grids were chosen as the minimum scale that the models should be used at. The spatial correlations were calculated assuming the known deposits have a 0.7 $km^2$ sphere of influence, which was assumed to be the smallest footprint for economic mineralisation in the Otago area.

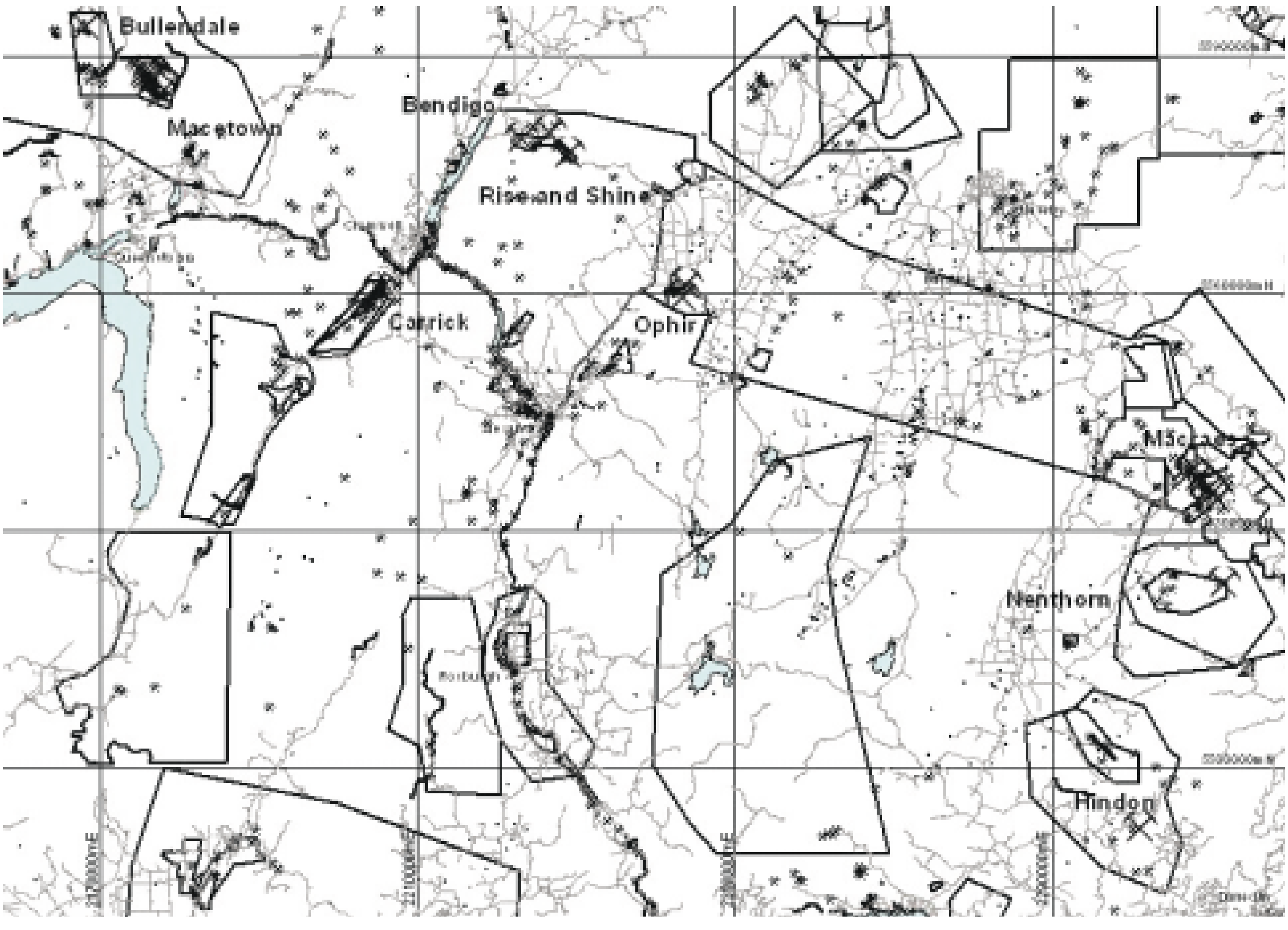


FIG 6 - Location of mines used as training data as black crosses for the regional Otago model. Mines with significant production are shown as larger crosses, which were used to choose the training data for the detailed Otago model. Exploration permit outlines are shown as black lines.

As described by Bonham-Carter (1997), the spatial correlation (prior probability) of a feature can be calculated by using the relationship of the area covered by the data variable being tested and the number of training data points (Weights of Evidence technique). This produces a W+ result for when the feature is present and a W- result when the feature is absent. A contrast value C is then calculated from the difference (Table 2). The standard deviations of W (Ws and Cs) are calculated, 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 (Table 2). Ideally a StudC value larger than (-)1.5 can be considered as a positive or negative correlation (Bonham-Carter, 1997). 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 StudC values >3.0, moderate correlations inferred from StudC values between 3.0 - 1.5, weak correlations inferred from StudC values between 1.5 - 0.5 and poor correlations inferred from StudC values <0.5.

A more detailed discussion of the methodologies used to develop the various data themes for the spatial correlation analysis are given in Partington (2000) and Partington and Smillie (2002). Table 2 summarises the results of the analysis, provides a summary of the methodology used to create the map theme and compares the spatial correlations results for each model.

The most important exploration parameters derived from the spatial analysis that should be considered when exploring for gold mineralisation in Otago are given in Table 3. The exploration parameters place the genetic model for mesothermal gold mineralisation in Otago into an exploration context. These results can therefore be used to develop realistic models for targeting during more detailed scale exploration. Interestingly, the main predictors of mineralisation in Otago are geological and can be derived from geological maps or collected in more detail in the field during prospect scale mapping. With the advent of more sophisticated geophysical techniques good field based geological mapping has become less fashionable. However, the spatial correlation data from both Otago prospectivity models demonstrate the value contained in geological maps when assessing an areas potential for hosting mineralisation.

**TABLE 2**

*Summary of derivative data maps created and analysed for spatial correlations with known gold mineralisation in Otago.*

| Spatial variable | Measure | Technique | Variable ID | Reg C | Reg StudC | Pros C | Pros StudC |
|---|---|---|---|---|---|---|---|
| Foliation style | Foliation style as a proxy for metamorphism | Interpretation of field mapping of rock structure. | S2 Foliation (2) | 2.2 | 11.3 | 2.80 | 3.77 |
| Fold style | Fold style as a proxy for deformation | Interpretation of field mapping of rock structure. | F2 (2) | 2 | 11.4 | 2.00 | 4.60 |
| Foliation Thickness | Mapped metamorphic and structural grade, association with metamorphism | Zones interpreted from petrographic analysis. | "-5.5*(4)" | | | 3.07 | 6.0034 |
| Distance From Crustal Faults | Crustal scale structural control 1 Order faults chosen only. Young faults excluded. | Buffered faults 20 000 m at 200 m intervals around faults. | 3800 (1) | 1.2 | 7 | 1.11 | 2.59 |
| 2nd Order Faults | Structural control at a local level. 2nd Order Faults Chosen. Young faults excluded. | Buffered faults 20 000 m at 200 m intervals around faults. | 2000 (1) | 0.2 | 0.8 | 2.89 | 6.73 |
| Fault Orientation | Structural control by preferred fault orientation. Young faults excluded. | Used Linanal USGS tool to subdivide faults into statistically valid subsets. | NNW Trend (1) | 0.6 | 2.7 | 1.77 | 2.29 |
| Shear Zones | Correlation with ductile stuctures subdivided from faults database. Young faults excluded. | Buffered shear zones 20 000 m at 200 m intervals, using SDM buffer tool. | 3000 (1) | | | 2.8 | 6.5 |
| Fault Intensity | Structural control at a regional scale as determined by intensity of faulting. Young faults excluded. | Density modelled in Arcmap, using density modelling tool in spatial analyst. | High Density (2) | 1.6 | 9.6 | 3.65 | 8.38 |
| Fault Intersections | Mineralisation controlled by intersecting faults. Young faults excluded. | Used Linanal USGS tool to subdivide faults into NE and NW trending faults then analysed these for intersections along the faults every 100 m. | NW-NE intersections (1) | 0.6 | 1.7 | 2.21 | 2.80 |
| NNW Fault Jogs | Variation in average azimuth, which should define fault jogs. Young faults excluded. | Used Linanal USGS tool to subdivide faults into NW trending faults then analysed these for deviations in trend along the faults every 100 m. | Jog (1) | | | 3.43 | 4.85 |
| Fold - Fault Intersections | Mineralisation controlled by intersection of folds and faults. Young faults excluded. | Used intersection lines tool to identify fault-fold intersections then buffered 100 × 100 m to test correlation. | 800 | 3.3 | 9.2 | 4.13 | 6.56 |
| Folds | Structural control at a local level. | Buffered folds 10 000 m at 200 m intervals around folds within 2500 metres of known workings using ESRI buffer tool. | 1300 | 0.7 | 1.6 | 2.32 | 5.23 |
| NNW Folds | Structural control at a local level. | Buffered folds 10 000 m at 200 m intervals around folds within 2500 metres of known workings using ESRI buffer tool. | 1300 | | | 2.77 | 6.49 |

**TABLE 2 (continued)**

*Summary of derivative data maps created and analysed for spatial correlations with known gold mineralisation in Otago.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rock type and stratigraphy combined | Rock composition. | Qmap geology. | Pelitic Schist | 2.8 | 16.1 | 1.99 | 4.35 |
| Rock type and stratigraphy combined | Rock composition. | Qmap geology. | Schist | 2.5 | 16.3 | 0.89 | 2.01 |
| Depth | Depth of burial | Interpretation of field mapping of rock structure | Mid Crust | 3.2 | 6.3 | | |
| Metamorphic Textural Grade | Mapped metamorphic and structural grade, association with metamorphism | Zones interpreted from field mapping. | IV | 0.6 | 4 | 0.67 | 1.5602 |
| Qtz Vein Density | Density of quartz veining representing possible centres of fluid flow. | Create point theme from linear quartz vein theme. Then create density map from points. | High (2) | 4.3 | 27 | 6.07 | 13.79 |
| All Quartz Veins | Relationship of mapped quartz veins to economic mineralisation. | Buffered out from mapped veins. | 300 (1) | | | 6.66 | 10.67 |
| Rock As | Geochemical pathfinder for gold, which has a larger geochemical signature within alteration halos around gold deposits. | Calculate anomalous values using 90 percentile to cut the data and then the 90 percentile for anomalous threshold. Use nearest neighbourhood gridding tool with 400 m search to create grid. | > 2500 ppm As (2) | 3.6 | 14.1 | 2.8761 | 4.4244 |
| Rock Au | Rock chip samples for gold | Calculate anomalous values using 90 percentile to cut the data and then the 90 percentile for anomalous threshold. Use nearest neighbourhood gridding tool with 400 m search to create grid. | >0.6 ppm Au (2) | 3.9 | 14.6 | 4.076 | 3.8583 |
| SS As | Geochemical pathfinder for gold, which has a larger geochemical signature within alteration halos around gold deposits, especially with dispersion down rivers and streams. | Use probability graphs to estimate anomalous populations. Use point averaging tool to calculate max and average values for relevant catchment areas. Develop grid using anomalous threshold values. | SS As> 20 ppm (2) | 3.1 | 15.2 | 3.3556 | 3.2312 |
| SS Au | BLEG and ordinary sieved stream sediment samples analysed for gold. Both BLEG and Sieved stream sediment samples have similar statistical distributions. | Use probability graphs to estimate anomalous populations for each collection methodology. Normalise the data using threshold values. Use point averaging tool to calculate max and average values for relevant catchment areas. Develop grid using anomalous threshold values. | 2>20 x Anomalous (2) | 1.2 | 4.7 | | |
| Soil As | Geochemical pathfinder for gold, which has a larger geochemical signature within alteration halos around gold deposits. | Use probability graphs to estimate anomalous populations for each collection methodology. Grid soil data using the Local Polynomial Interpolation algorithm in Arcmap. Use anomalous thresholds to develop anomaly grid. | >40 ppm As (2) | | | 2.5251 | 5.071 |
| Soil Au | Rock chip samples for gold | Use probability graphs to estimate anomalous populations for each collection methodology. Grid soil data using the Local Polynomial Interpolation algorithm in Arcmap. Use anomalous thresholds to develop anomaly grid. | >=35 ppb Au (2) | | | 2.9735 | 5.9346 |

## PROSPECTIVITY MODELLING RESULTS

Once the prior probabilities for each data layer are calculated, it is then possible to calculate a post probability model by combining the various data layers. These are calculated by weighting the values of each cell in the data layer according to their prior probabilities and then adding the weighted values of each data layer together (Bonham-Carter, 1997). A model for the prospectivity of gold mineralisation was constructed using the grid themes listed in Table 4 for the regional Otago prospectivity model (Partington and Smillie, 2002) and Table 5 for the regional Otago prospectivity model. The model was developed using ARC SDM software through spatial analyst in ArcView. The themes were all converted into binary grid themes where possible to speed up the processing time. The number of variables used was also kept to a minimum to reduce the potential for conditional dependence between the selected themes as discussed by (Bonham-Carter, 1997). The model consists of a grid response theme containing the intersection of all of the input themes in a single integer theme. Each row of the attribute table contains a unique row of input theme values, the number of training points, area in unit cells, sum of weights, posterior logit,

**TABLE 3**

*Key geological and geochemical criteria for exploration for Mesozoic mesothermal gold mineralisation in order of greatest spatial correlation.*

| Exploration Data | Comment |
|---|---|
| Presence of quartz veins | Simple and effective exploration tool to be collected during geological mapping. |
| Fold-fault intersections | Requires good geological mapping that identifies those structures that were pre to syn mineralisation. |
| Au and As geochemistry of rocks, stream sediments and soils | Mesozoic mineral systems geochemically complex. Therefore multi-element geochemical techniques appropriate. |
| Textural grade and foliation thickness | Suggests a metamorphic control at a broad scale (Mortimer, 2001). |
| NW trending faults | Well developed structural control that can be mapped in the field. |
| Second order faults | Similar control to other styles of mesothermal gold mineralisation. |
| Local variations in fault orientation | Requires more detailed geological mapping in the field. |
| Shear zones | What if the difference between the brittle and ductile structures? |
| Stratigraphy | Good geological mapping critical. |
| Rock type | Strong host rock control, geochemical or mechanical? |
| Structural intensity | Suggests a structural control at a regional scale. Detailed structural mapping and analysis in GIS critical. |
| Regional fault intensity | There appears to be a regional structural control along deep-seated faults. |
| Fold style | Relates to degree and style of deformation. Possible depth relationship. More detailed mapping. |
| Foliation style | Suggests a relationship to metamorphism. Studies on metamorphism important. |

**TABLE 4**

*Grid themes used in the regional Otago prospectivity model based on the mineral deposit model described by Christie (2002).*

| Grid theme | Description | Variables | C | StudC |
|---|---|---|---|---|
| Qvdenrc | Quartz vein density | 5 | 6.95 | 16.74 |
| Ssas | As stream sediment anomalies | 2 | 2.80 | 7.86 |
| Rkau | Au rock chip anomalies | 2 | 3.43 | 6.44 |
| Qstrain | Deformation intensity | 3 | 2.50 | 13.32 |
| Rkas | As rock chip samples | 2 | 2.58 | 8.68 |
| Fltauden | Density of faulting related to mineralisation | 2 | 3.80 | 22.68 |
| Texmet | Textural zones | 4 | 3.41 | 3.39 |
| Fltmzne | NE trending faults | 2 | 3.62 | 22.67 |
| Fltmznw | NW trending faults | 2 | 5.13 | 34.02 |
| Ssau | Au stream sediment anomalies | 2 | 1.58 | 4.65 |

**TABLE 5**

*Grid themes used in the detailed Otago prospectivity model based on the mineral deposit model described by Christie (2002).*

| Grid theme | Description | Variables | C | StudC |
|---|---|---|---|---|
| Qtzdenrc | Quartz vein density | 2 | 6.0654 | 13.7933 |
| Ssasrc | As catchment anomaly map | 2 | 3.3556 | 3.2312 |
| Rkaurc | Au rock chip anomaly map | 2 | 4.0760 | 3.8583 |
| Fltdenrc | Fault density map | 2 | 3.6493 | 8.3801 |
| Rkasrc | As rock chip anomaly map | 2 | 2.8761 | 4.4244 |
| Schist | Schist metamorphic subdivision map | 5 | 6.1185 | 0.6116 |
| Fltazrc | Fault trend variation map | 4 | 5.7362 | 0.5733 |
| Ssaurc | Au catchment anomaly map | 2 | 7.1486 | 0.7145 |

posterior probability, and the measures of uncertainty. The variances of the weights and variance due to missing data are summed to give the total variance of the posterior probability. The response theme can be mapped by any of the fields in the attribute table. Various measures to test the conditional independence assumption were also calculated. Conditional dependence as described by Bonham-Carter (1997) is a significant problem in most geological models, especially between geochemical themes, which if they correlate will have similar spatial patterns. Hence the posterior probabilities, which will be overestimated, should be thought of as relative favourabilities rather than true probability values. The normalised probability attribute gives a much better measure of probability.

The results of the modelling are shown in Figure 7 and Figure 8. The models represent a typical exploration program starting with regional data acquisition, especially geological mapping, moving to district scale geological mapping and regional geochemical data acquisition such as stream sediment sampling. The regional Otago prospectivity model identifies all the historic areas of gold mineralisation, but because of the scale of the model it over-estimates prospectivity around the areas most likely to host gold mineralisation. This type of analysis is appropriate for project acquisition and permit or tenement acquisition where the area acquired tends to be larger than the target area. The detailed prospectivity model reduces the potential prospective areas significantly, although the original map pattern is similar. A statistical correlation between both maps gives a Spearman Rank Correlation of 0.766. This suggests the exploration model and data used for the regional Otago prospectivity model are an adequate predictor of mineralisation at a regional scale, but the acquisition of district scale data, mainly geochemistry has significantly improved the mineral potential map.

Any follow-up exploration programs should be designed to further reduce the search area and hence any prospectivity map should provide a more focussed map pattern. As is the case when more detailed geochemical data are added to the model (cf Figure 7 and Figure 8). Statistical map correlation appears to be a powerful technique for testing the effectiveness of any data acquisition program.

The benefits for HPD NZ are that several of the prospective areas are now at a stage where new detailed data are required to make a difference to the prospectivity. The modelling has helped define the most important datasets. In this case, many of the prospective areas are lacking detailed geological and structural mapping and soil sampling, and the most important dataset not used in either study as a predictor of mineralisation, drilling. The most obvious conclusion that comes from this analysis is that the Otago area has a large number of areas that could host gold mineralisation that have not been tested with detailed geochemical sampling including drilling. The probability values derived from the model also allow a ranking of each prospect area, which allows efficient exploration programs to be developed that have the best chance for success.

## CONCLUSIONS

The regional Otago prospectivity model developed by Crown Minerals successfully reduced the initial search area at a regional scale, allowing HPD NZ to effectively prioritise its exploration effort, and acquire additional prospective areas. The model focuses on the areas with similar combinations of geological and geochemical variables that have recorded gold production in the past. The detailed Otago prospectivity modelling has further refined these search areas allowing HPD NZ Ltd to add value to their properties in the most cost efficient way.

More case studies need to be developed to test the analysis and interpretation of mineral potential maps as they, along with spatial correlation analysis have the potential to change how exploration project generation is done and allow better and more objective exploration management decisions to be made. This must lead inevitably to reduced costs and increased chances of discovery.

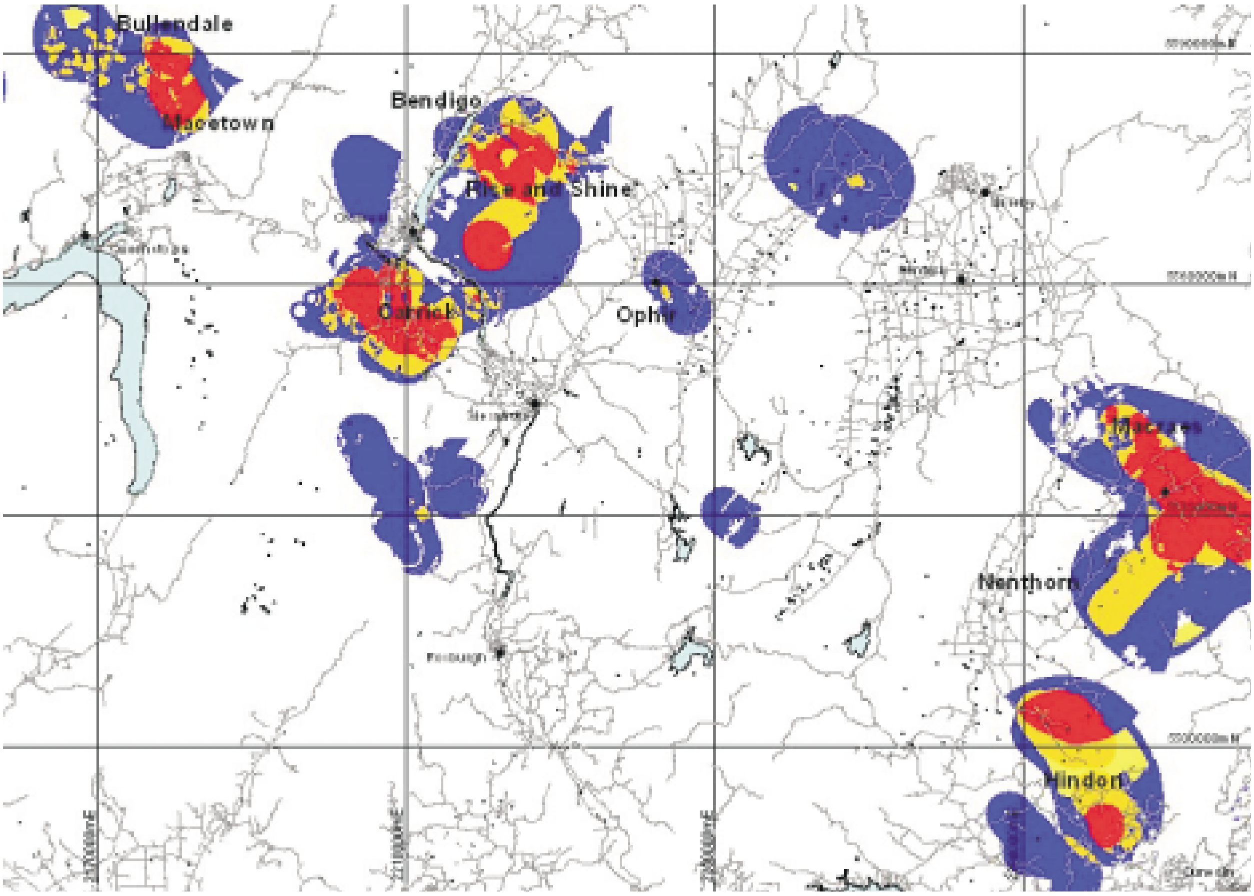


FIG 7 - Regional Otago prospectivity map showing areas above prior probability in blue, greater than 0.1 post probability in yellow and greater than 0.7 post probability in red. Permit outlines are in black. This map was used to help HPD NZ prioritise its regional permits in Otago for exploration.

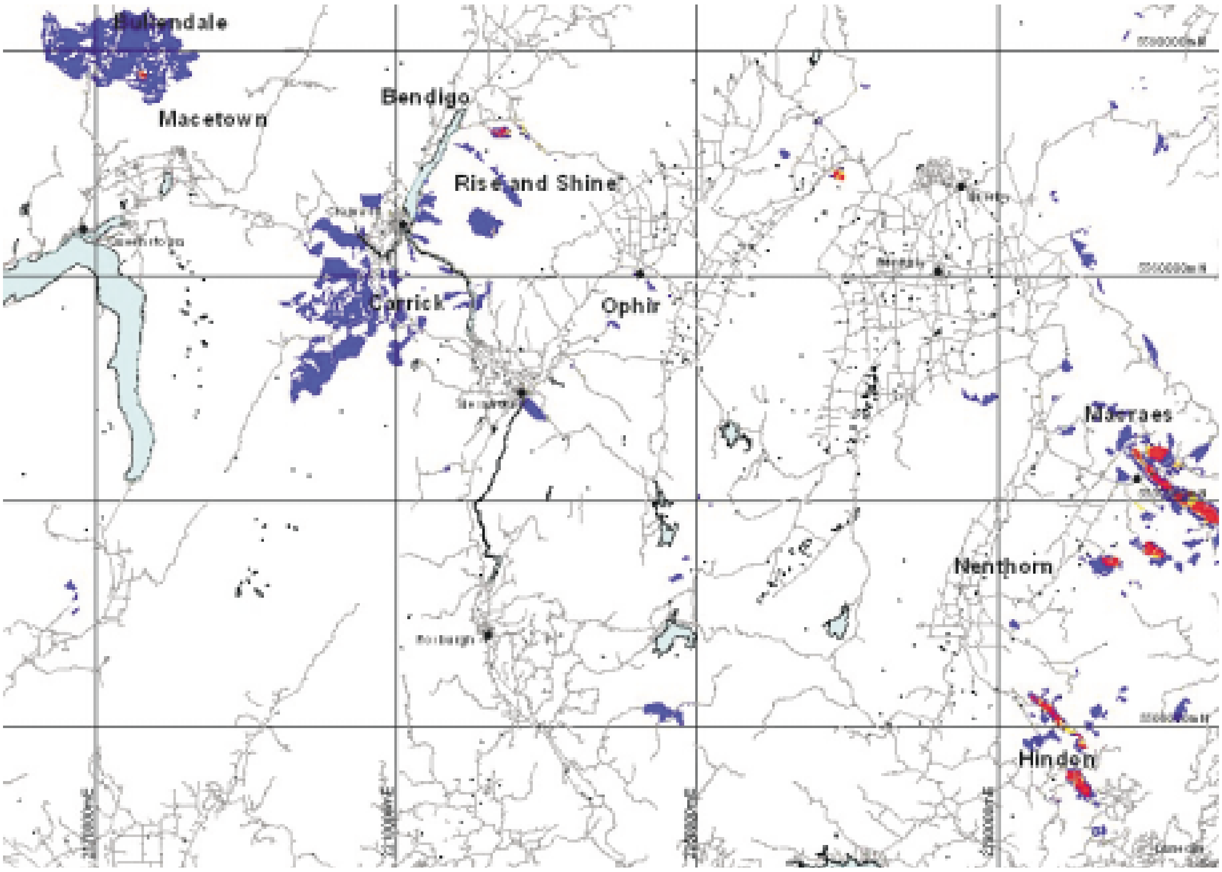


FIG 8 - Detailed Otago prospectivity map showing areas above prior probability in blue, greater than 0.1 post probability in yellow and greater than 0.7 post probability in red. This map was initially was developed using the same map themes as in Figure 7. The difference between Figure 7 and Figure 8 is the scale of modelling and use of more detailed data, especially geology.

In summary, Epithermal and Mesothermal Gold Prospectivity modelling work has successfully attracted new investment and ideas to the exploration scene in New Zealand. The project had an estimated cost of $NZ 250 000 and will in the next two years, just through grass roots exploration, attract more than $NZ 10 M in exploration investment. If a mine is discovered the return on investment will be considerably greater.

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