

# Prospectivity Modelling of Mineralisation Systems in Papua New Guinea Using Weights of Evidence Techniques

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## ABSTRACT

*A regional scale prospectivity model was developed for Papua New Guinea (PNG) to identify areas of porphyry Cu-Au mineralisation. Weights of evidence modelling techniques were used to determine spatial correlations between porphyry Cu-Au mines and predictive maps created from available spatial data. These predictive maps were then combined into a final prospectivity map. Despite limited regional scale data the model has successfully identified areas of known porphyry mineralisation as prospective and has also identified areas where new mineralised systems may be discovered with further exploration.*

## INTRODUCTION

The weights of evidence technique for predictive modelling was originally developed for use in medical diagnostics and has been adapted to the mineral exploration industry by Bonham-Carter of the Canadian Geological Survey (Bonham-Carter, 1994). The technique provides a way for large quantities of exploration data to be integrated and viewed as a single predictive map. This map can be used as a tool to significantly reduce the target area for exploration and therefore greatly increase the chances of finding an economic deposit in a particular study area. This study applies the weights of evidence spatial modelling technique to PNG, an area that is known for its richness in mineral deposits (Williamson and Hancock, 2005). The aims of this study are twofold:

- to test the spatial modelling technique in an area where the results are for the most part already known and in doing so refine the location and extent of known mineralised regions, and
- to identify new areas of mineralisation that are worthy of follow up exploration.

There is potential in PNG for many undiscovered or under explored deposits to be identified using this modelling method.

## MINERALISATION STYLES AND DEPOSIT MODELS

Porphyry Cu-Au is one of the most common mineralisation styles in PNG along with epithermal Au-Ag and is represented by many well known deposits and producing mines (eg Ok Tedi and Frieda River on the PNG Mainland, and Panguna on Bougainville Island; Figure 1). Genetic deposit models for porphyry Cu-Au were used to map factors that are most likely to indicate the presence of this particular style of mineralisation (Seedorff *et al*, 2005). Porphyry-related metal deposits are large-tonnage, generally low-grade, hydrothermal mineralisation related to igneous intrusions emplaced at high crustal levels. Geologically, the deposits occur close to, or in, felsic intrusive rocks that are porphyritic in texture. The host rocks can be any kind of lithology, and often there are wide zones of

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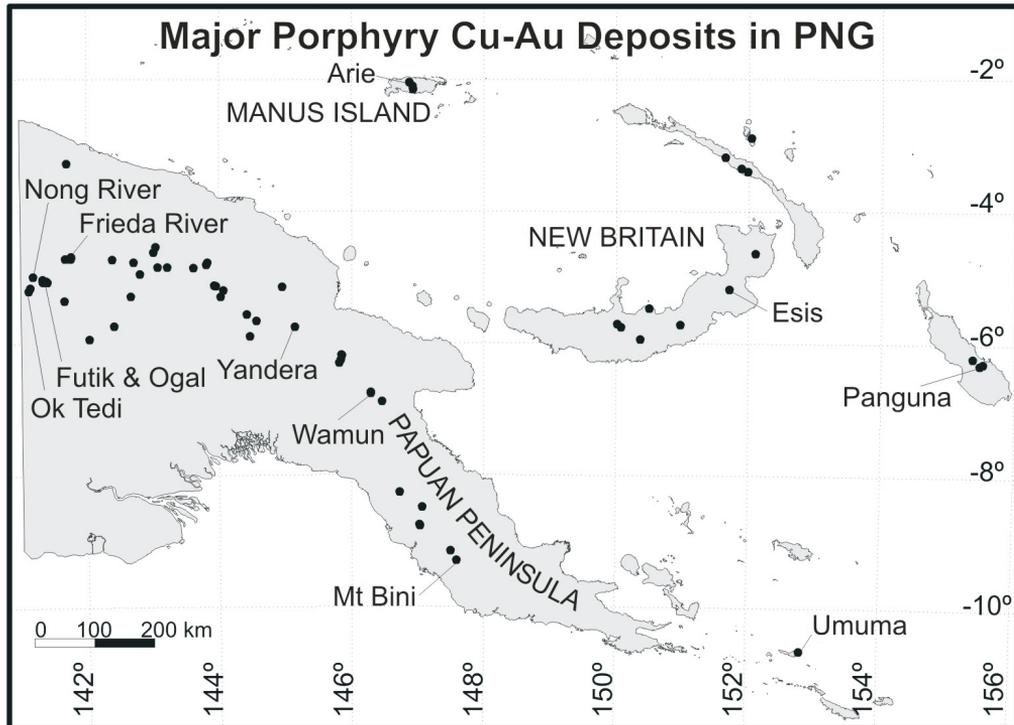


FIG 1 - Map of the Papua New Guinea study area with porphyry Cu-Au deposits and mines as black circles. Productive mines used as training data are labelled.

closely fractured and altered rock surrounding the intrusions as a result of widespread hydrothermal activity. Mineralisation may be confined to pluton-hosted disseminations, stockworks, vein sets and breccias, or occur in skarns, replacements, veins and disseminated deposits peripheral to the inferred source pluton. This spectrum of deposit types includes many of the world's largest accumulations of Cu, Mo, Au, Ag, Sn and W. As such the deposits represent critical economic resources and important exploration targets.

The model was further constrained by using a mineral systems approach, which identifies the mappable variables within a mineralisation system that are critical to the ore forming process: the source, fluid migration pathways, metal transport mechanisms, and controls on metal deposition, including outflow (Candela and Piccoli, 2005). This concept can be useful in aiding selection of relevant predictive mappable themes for inclusion in a model. The main geological features that are used in this study to determine the prospectivity of PNG for porphyry Cu-Au style mineralisation include:

- intrusions with syenite, monzonite, diorite and granodiorite compositions (source/trap);
- regional scale faults (transport/trap);
- comagmatic mafic volcanic rocks (trap);
- Au, Cu and Mo mineralisation (deposition); and
- distal As, Pb and Ag mineralisation (deposition).

## SPATIAL ANALYSIS AND PROSPECTIVITY MODELLING

The prospectivity model was created using open file data acquired freely from the Geological Survey of Papua New Guinea (Papua New Guinea Department of Mining, 2008). This data set includes nationwide mineral occurrences, geology (eg lithology and faults) and geochemistry (rock chip, stream sediment, drill hole and soil sample assays). Although there is good regional coverage of faults, lithology and geochemical data, there is no alteration or vein mapping and no available geophysical data of use to this study. Stream sediment sampling provides the best regional coverage of all the geochemical techniques used for exploration in PNG, followed closely by rock chip sampling. Soil sampling coverage is too localised to be used as a predictive theme in a country scale model. All geochemical techniques have poor coverage in the western half of the mainland and on Bougainville Island and sample density is a problem for the less commonly analysed elements such as Bi and Sb, which are good indicators for porphyry Cu-Au mineralisation. All geochemical data have been reviewed statistically at a regional scale to derive anomaly levels for Au, Ag, Cu, As, and Mo in rock and stream sediment samples.

As a first step in the spatial correlation calculation, a grid with a 200 m cell size was generated over the Papua New Guinea study area (Figure 1). The cell size of the grid is chosen to represent the minimum scale at which the data should be viewed. Sixty-eight porphyry Cu-Au deposits were selected from the mineral occurrences database. Of these deposits 13 productive porphyry Cu-Au mines were selected to use as the training data set for the model. The porphyry Cu-Au unit cell size was set at 4 km<sup>2</sup> in area, and was intended to represent the approximate size of a porphyry mineral system. The training data and unit cell give a prior probability of 0.00011, ie there is a 0.00011 chance of finding a productive porphyry Cu-Au deposit in any 4 km<sup>2</sup> block of the study area before any knowledge about the geology or geochemistry is applied.

The weights of evidence technique (Bonham-Carter, 1994) was used to determine spatial correlations between the training data and predictive maps created from the geological and geochemical data. This was done using the Spatial Data Modeller extension (ArcSDM) developed for ESRI's ArcGIS software (Sawatzky *et al*, 2004) but could also have been performed using the MapInfo extension (MI-SDM, see Avantara Geosystems, 2007). The modelling technique 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 spatial correlation of a theme in the model can be calculated by using the relationship of the area covered by the theme 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 theme and a W- result based on training points falling where the theme is absent. A W+ value greater than zero indicates a positive correlation with the theme, whereas a W- less than zero indicates a negative association with the non-theme area. The contrast, which is the difference between W+ and W-, gets higher with an increase in the correlation between the theme and the training data (ie a theme that correlates well with known porphyry Cu-Au locations will have a high contrast value).

The best themes for the models are selected based on their correlation (C) and their level of uncertainty (studentised contrast). 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. Ideally, a StudC value larger than (-) 1.5 can be considered as a positive or negative correlation. 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  $>3.0$ , StudC values  $>1.5$ , moderate correlations inferred from C values between 1.0 and 2.0, StudC values  $>1.5$ , weak correlations inferred from C values between 0.5 and 1.0, StudC values between 1.0 and 1.5, and poor correlations inferred from C values  $<0.5$  or StudC values  $<1.5$ .

The training data has a strong spatial correlation with intermediate intrusive rocks, anomalous gold and copper rock chips, and anomalous copper and molybdenum stream catchments, and a moderate correlation with tertiary mafic volcanic rocks, northwest trending faults and anomalous gold stream catchments. To create the prospectivity model, the predictive maps listed in Table 1 were added after the map values for each cell were weighted by their spatial correlation. The predictive maps were chosen as having the best regional coverage, a significant spatial association with the mineralisation model being considered and where possible not to duplicate predictive map patterns (to reduce the effects of conditional independence). The result of this predictive modelling is a map grid that can be reclassified to show the location of areas with the highest probability of containing the conceptual mineral system model for porphyry Cu-Au mineralisation.

**TABLE 1**

*Table of predictive maps used in the porphyry Cu-Au prospectivity model for PNG. See text for explanation of spatial correlation and confidence values.*

<b>Predictive map</b>	<b>Theme</b>	<b>Spatial correlation</b>	<b>Confidence</b>
Rock Au	Anomalous Au in rock samples	9.26	0.93
Lithology	Association with intermediate intrusive rocks	4.99	7.72
Stream Cu	Anomalous Cu in stream catchments	3.97	3.63
Rock Cu	Anomalous Cu in rock samples	3.87	3.35
Stream Mo	Anomalous Mo in stream catchments	2.71	2.34
NW faults	Distance from north-west trending faults	2.29	3.82
Stream Au	Anomalous Au in stream catchments	2	1.73
Lithology	Association with Tertiary mafic volcanic rocks	1.04	1.58

## PROSPECTIVITY REVIEW

Despite the limited nature of some of the regional scale data sets, the model has successfully identified areas of known porphyry mineralisation as prospective and has also identified areas where new mineralised systems may be discovered with further exploration. Targeting in exploration is all about a process of area reduction starting at regional kilometre scales that have to be reduced to metre scales to allow drill targeting. Therefore any prospectivity model has to reduce the target areas by several orders of magnitude. The most obvious way of mapping target areas is to choose all probability values that are greater than the prior probability as prospective. However this usually does not reduce the search area sufficiently. Another way of selecting target areas is to choose the probability value that reduces the search area by the desired order(s) of magnitude. In this study exploration targets were selected by assigning the post-probability values from the prospectivity model grid to the productive porphyry Cu-Au mines in the study area. It is assumed that any post-probability value that is of the same order as the probability values of the productive mines is likely to host economic mineralisation and can then be used as a cut-off to define other areas that have equal or greater prospectivity. For this model the least prospective mine was an order of magnitude lower than the next lowest mine and was considered too low to identify realistic exploration targets, therefore the second lowest mine was used as the cut-off. Areas of the model that have an equal or higher post-probability value to that identified

above are considered highly prospective for an economic porphyry Cu-Au deposit to occur. The selection of exploration targets has reduced the search area (the PNG study area) for porphyry Cu-Au style mineralisation by 99.5 per cent and identified 334 prospective targets.

The model also provides important information on the prospective targets that can greatly aid in the planning of follow up exploration programs. Firstly, the post-probability value can be used to rank the targets from most prospective to least prospective, allowing the more favourable targets to be prioritised for follow-up work. Secondly, it is possible to identify the predictive maps that contributed to the post-probability value at each target location. As an example the ten most prospective targets, located on Manus Island, New Britain and on the Papuan Peninsula (Figure 1), are listed in Table 2 with their post-probability value and contributing predictive maps. This information can be used to see which predictive variables have the most influence on identifying a porphyry Cu-Au deposit in PNG and also to identify where data is missing so that field checks can be done and more data collected over the target areas.

**TABLE 2**

*Table of the ten most prospective porphyry Cu-Au exploration targets identified from the spatial modelling results. The post-probability, a value between zero and one, is a measure of the likelihood of a porphyry Cu-Au deposit occurring. The remaining columns show the predictive variables that contributed to the post-probability for each target. F = fault; NF = no fault; II = intermediate intrusive; TMV = Tertiary mafic volcanic; a dash indicates missing data; 0 = non-anomalous concentrations of that element.*

Target	POST PROB	Fault NW	Litho	Rock Au	Rock Cu	Strm Au	Strm Cu	Strm Mo
Manus 1	0.996	F	II	Au	Cu	Au	Cu	Mo
Manus 2	0.984	F	II	Au	Cu	Au	Cu	-
Manus 3	0.974	F	II	Au	Cu	0	Cu	Mo
Manus 4	0.949	F	II	Au	Cu	Au	Cu	0
Tolukuma1	0.932	F	TMV	Au	Cu	Au	Cu	Mo
Manus 5	0.710	F	II	-	-	Au	Cu	Mo
Tolukuma2	0.710	F	II	-	-	Au	Cu	Mo
NB North	0.578	NF	TMV	Au	Cu	Au	Cu	Mo
NB Central	0.578	NF	TMV	Au	Cu	Au	Cu	Mo
Tolukuma3	0.578	NF	TMV	Au	Cu	Au	Cu	Mo

Of the 334 identified targets 270 lie mostly within current, application, or renewal ELs (as at December 2007) and 64 targets lie outside the ELs. This type of modelling provides a competitive advantage to companies wanting to acquire new ground in PNG or could help existing permit holders to refine their targets, identify the most prospective areas within their permits and help plan cost effective follow up exploration. Using the existing spatial data the weights of evidence technique could also be used to model other styles of mineralisation to provide a quantifiable objective understanding of the mineral prospectivity of PNG.

## REFERENCES

- Avantra Geosystems, 2007. Avantra Geosystems web site. Available from: <<http://www.avantra.com.au/mi-sdm.htm>>.
- Bonham-Carter, G F, 1994. *Geographic Information Systems for Geoscientists; Modelling with GIS* (Pergamon: United Kingdom).

- Candela, P A and Piccoli, P M, 2005. Magmatic processes in the development of porphyry-type ore systems, in *Economic Geology 100th Anniversary Volume* (eds: J W Hedenquist, J F H Thompson, R J Goldfarb and J P Richards), pp 25-37 (Society of Economic Geologists: Littleton).
- Papua New Guinea Department of Mining, 2008. Department of Mining web site. Available from: <<http://www.mineral.gov.pg/>>.
- Sawatzky, D L, Raines, G L, Bonham-Carter, G F and Looney, C G, 2004. ARCSDM3.1: ArcMAP extension for spatial data modelling using weights of evidence, logistic regression, fuzzy logic and neural network analysis [online]. Available from: <<http://www.ige.unicamp.br/sdm/ArcSDM31/>> [Accessed: 16 June 2008].
- Seedorff, E, Dilles, J H, Proffett Jr, J M, Einaudi, M T, Zurcher, L, Stavast, W J A, Johnson, D A and Barton, M D, 2005. Porphyry deposits: Characteristics and origin of hypogene features, in *Economic Geology 100th Anniversary Volume* (eds: J W Hedenquist, J F H Thompson, R J Goldfarb and J P Richards), pp 251-298 (Society of Economic Geologists: Littleton).
- Williamson, A and Hancock, G (eds), 2005. *The Geology and Mineral Potential of Papua New Guinea* (Papua New Guinea Department of Mining: Port Moresby).