3D Prospectivity Modelling – A new era in exploration targeting.

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Abstract

The use of computers in the mineral industry has dramatically changed the way exploration targeting is carried out over the last twenty years. This is especially true in the last five years where computer and GPS technology has developed to the stage where it is possible to digitally locate, accurately store, visualise and manipulate geological data in three dimensions (3D) at the scale of a mineral system. These tasks are commonly carried out using a Geographic Information System (GIS), which has become as an important tool to a geologist as his hammer. Most GIS store, manage and manipulate data in two dimensions (2D), with some having the ability to visualise information in 3D. However, there are now a number of packages that allow full GIS functionality including querying and modelling in 3Dgiving geologists a tool to carry out exploration targeting in 3D.

A regional scale weights of evidence 2D prospectivity model was developed for the Taupo Volcanic Zone in New Zealand to assess the potential for epithermal Au mineralisation. A number of prospective areas have been identified including the known Ohakuri hydrothermal deposit. While this model has been successful at identifying mineralised areas the 2D data that is used gives little understanding of what is happening below the surface. Because geology does not just operate in 2D, trying to visualise 3D geometries in 2D can be challenging in exploration targeting. The development of 3D GIS such as GoCad and Geomodeller now give us the tools and techniques to use fuzzy logic and weights of evidence techniques for targeting in mineral exploration in 3D. A prospectivity modelling exercise using the weights of evidence modelling technique (developed by Bonham-Carter of the Canadian Geological Survey), was completed over the Ohakuri epithermal gold deposit in both 2D and 3D.

***Key Words*; Ohakuri, Prospectivity Modelling, GIS.**

Ohakuri Epithermal Gold

The Ohakuri epithermal gold deposit is located near the western margin of the Taupo Volcanic Zone, approximately 35 km north of Taupo and 40 km southwest of Rotorua (Grieve et al., 2006). The deposit has been split into three prospects, Ohakuri North, Ohakuri West and Ohakui South. Ohakuri North is separated by the east-west flowing Waikato River. The river is dammed at Atiamuri and Ohakuri for the generation of hydro-electric power. Ohakuri lies within the Taupo Volcanic Zone (TVZ) which is a rifted volcanic arc interpreted to be the southern extension of the Lau Rift – Havre Trough system. The rift is 300 km long by up to 60 km wide on land and extends offshore to the NE. Rifting began in the TVZ around 4 – 5 Ma and early, predominantly andesitic, volcanism began ≈ 2 Ma (Grieve et al., 2006). Voluminous caldera-forming rhyolitic volcanism (with minor andesitic, dacitic, and basaltic volcanism) began ≈ 1.6 Ma. Greater than 10,000 km^3 of predominantly rhyolitic pyroclastics have been erupted filling the TVZ to depths of > 2.2 km. Modern day extension across the TVZ is estimated between 7 to 18 mm per annum (Wilson et al., 1995).

Exploration History

Detailed exploration began at Ohakuri in 1986 by Amoco Minerals NZ Ltd and BP Oil (NZ) Ltd. Exploration at Ohakuri has included geological mapping, stream sediment, rock chip and soil geochemistry sampling programmes, induced polarisation and gravity survey, aeromagnetic surveys, and drilling. A total of 33 drill holes were drilled by Cyprus Gold and Coeur Gold in Ohakuri North, BP drilled six holes in Ohakuri South (Maxwell, 1986) and Elders Resources drilled six holes in Ohakuri West. These exploration programs defined a large low-grade resource of 126 Mt at 0.38 g/t Au (1.54 Moz Au) at Ohakuri North and 42 MT at 0.41 g/t Au (0.54Moz) (Grieve et al., 2006) for Ohakuri South. Delta Gold NZ Ltd undertook a wacker sampling programme over Ohakuri North, defining a zone of vein hosted mineralisation within the low grade mineralisation. Follow up drilling of three target areas in

1998 totalling 2287 m over seven holes, intercepted high grade Au-Ag mineralisation. Based on drilling results, a revised resource estimate for Ohakuri North of 126 Mt at 0.38 g/t Au and 8.5 g/t Ag for a contained 2.22 Moz Au (Grieve et al., 2006) was recorded.

Mineralisation

The Ohakuri epithermal gold deposit is hosted in a sequence of fine to coarse grained ignimbrites. Alteration is characterised by a moderately intense quartz-adularia and minor zeolite overprint (Grieve et al., 2006). Delta Gold defined the Central Stream area of Ohakuri North as being more highly mineralised than other areas at Ohakuri. Two styles of mineralisation are present in the area: mineralisation associated with veining and brecciation, and mineralisation associated with fluid mixing within the highly permeable rhyolitic ignimbrite (Grieve et al., 2006). Mineralisation occurs within dark sulphide rich electrum bands/veins, associated with E-W orientated structures. These structures occur within a dilational environment, related to NE striking regional rift faulting (Grieve et al., 2006).

Prospectivity modelling of the Ohakuri deposit

Mineral Systems Approach

This study focuses on utilising the mineral systems approach in order to identify the critical parameters of ore deposit formation within the Ohakuri prospects. This approach concentrates on those factors that control the generation and preservation of epithermal mineralisation. The critical parameters of ore deposit formation are identified from existing literature about the mineral system 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 epithermal mineralisation within the prospect area, structures that could be used for fluid migration, and structures ideally suited to trap and host mineralisation.

Evidence for appropriate sources of metal, fluid and energy to drive a mineral system mainly comes from prospect scale mapping and regional scale aerial magnetic data. Felsic to intermediate composition intrusive rocks provide the main source of heat, fluids and metals in epithermal systems. Magnetic geophysical data has been used to interpret the location of buried intrusive rocks. In an epithermal system the metals are commonly deposited further from the source, however, a relationship with these rocks is still expected. This relationship highlights the importance of magnetic geophysical data in identifying the source rocks for epithermal mineralisation that may be buried under cover. The host rocks for epithermal mineralisation are commonly directly related to the source in the form of volcanic rocks that are the shallow/surface expression of the same magmatic system. Sinters and eruption breccia locations can also be an indication of the source of heat and fluids

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 from geological mapping at prospect scale and aerial magnetic data. Faults with NE-SW and E-W orientations are considered to be potential pathways for epithermal mineralisation at Ohakuri.

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 also 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 at Ohakuri have been modelled using lithology (ignimbrites) and structure to identify zones of dilatation (joints, faults and fault intersections).

2D Spatial Modelling Methodology

In order to determine the spatial relationships to be used in the 3D prospectivity modelling, a 2D model was initially completed. The surface data has more detail and density of data, allowing a thorough evaluation of the spatial relationships. The results of this exercise were used as a guide for the 3D model, which was produced using a Multi-Class Index Overlay model (MIO).

As a first step in the spatial correlation calculation, a 25 by 25 metre grid was generated over the project area. The size of the grid was chosen to represent the minimum scale that the data should be viewed at. A unit cell grid of 0.4 km^2 was used for the model calculations, which represents a reasonable surface target deposit size. Historic drill hole gold assay results that contained anomalous values greater than 5 g/t, were used as training data sets. For this study area the points give a prior probability of 0.016. The prior probability is the chance of randomly finding a deposit for each 0.4 km square of the grid before any additional evidence for mineralisation is applied.

3D Spatial Modelling Methodology

Spatial modelling in 3D was carried out in GoCAD 2009.4 based on the results of the 2D spatial correlations. The properties used in the 3D model are derived from the 2D model properties when these could be extended into to the third dimension. For the prospectivity modelling, two procedures were used: multiclass binary index targeting method, with weights assigned from the 2D modelling and adjusted when deemed necessary.

GoCAD Mining Suite creates a box-shaped model volume which is capable of being rotated, tilted and stretched in any dimension, while retaining corner angles at 90 degrees. The 3D model surface area was approximated to be similar to the 2D model area. The final model volume is 6.7 km long, 7.0 km wide and 500 m deep. The unit cell is 25 (X) by 25 (Y) by 25 (Z) metres, resulting in 1,500,800 unit cells for the model. Training points for the 3D model were the same as the 2D model, but the RL of the training point was determined where the high gold intercept was within the drill hole.

Spatial Analysis

The spatial analysis was carried out using the weights of evidence technique developed by Bonham-Carter of the Canadian Geological Survey (Bonham-Carter, 1994), using the Spatial Data Modeller extension developed for ESRI's ArcGIS 10.1 GIS software for the 2D modelling, as well as the targeting workflow of the GoCAD Mining Suite 2009.4 for the 3D model. The spatial correlation 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 that fall within that area. This produces a W+ result when the feature is present and a W- result when the feature is absent (Table 1). A contrast value C is then calculated from the difference between W+ and W-. Most of the data types were reclassified to produce classified predictive maps, which in the case of continuous data like geochemical data were further reclassified using the posterior probability values into binary predictive maps. Predictive themes like geology were reclassified into broad groups and as multi-class predictive maps

The standard deviations of W and C (Ws and Cs) are also calculated as part of the contrast calculation. This provides a Studentised value of the contrast (StudC), which is 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 exceeding ± 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, for the 2D modelling, a strong correlation is inferred from C values > 2.0, 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 StudC value cut-offs differ in the case of 3D modelling, but generally follow the same pattern of higher values equal stronger correlations.

Table 1: Glossary of modelling terminology.

W+	spatial correlation - prior probability of a (training set) feature being present
Ws+	standard deviation of W+
W-	spatial correlation - prior probability of a (training set) feature being absent
Ws-	standard deviation of W
Contrast (C)	difference between W+ and W
Cs	standard deviation of the Contrast
studC	studentised Contrast: the contrast divided by its standard deviation

2D Spatial Correlation Results.

Following detailed spatial analysis five predictive maps that represent each part of the mineral system for epithermal Au-Ag and that have good spatial correlations with the training data were chosen to create the final prospectivity model (Table 2). Sinters and intrusive rocks were mapped and used as potential sources of energy and fluids, NE and E-W oriented structures were used as potential variables for transport, fault intersections were mapped as potential trap sites and Au rock and drillhole geochemistry were used as indicators for gold deposition (Table 2).

Table 2: Spatial correlation results of predictive maps used in the 2D prospectivity model.

System Variable	Mapped Layer	W+	W-	C	StudC
Source	Sinters and Intrusive rocks	0.7868	-0.447	1.434	3.341
Transport	Northeast & east-west orientated structures	0.7506	-1.135	0.6537	2.884
Trap	Fault intersections	1.7868	-0.547	2.334	4.241

Deposition	Rock chip and drill hole Au geochemistry	1.4006	-3.149	3.545	5.213

Modelling Results

Spatial modelling of the Ohakuri epithermal gold deposit has successfully identified exploration targets within the deposit area for epithermal mineralisation (Fig. 1). The model highlights the existing epithermal gold prospects (Ohakuri North, Ohakuri South and Ohakuri West) which highlight how successful the model is. The model has found new prospective areas that have not been drill tested and also identifies areas where key data sets are missing and if data is collected new areas can become prospective or could be eliminated.

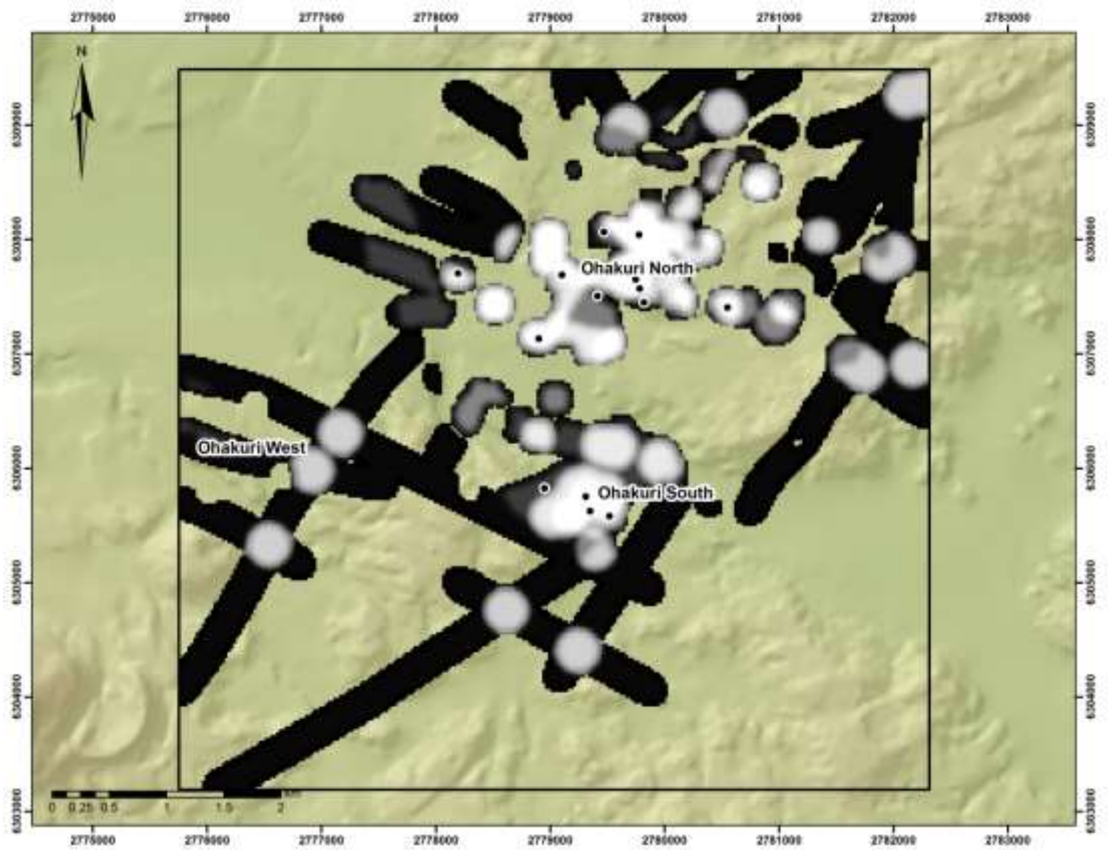

Figure 1. Prospectivity results over the Ohakuri North, Ohakuri South and Ohakuri West prospects. The model results shown range from prospective in blue to highly prospective in red. The remaining area is below the prior probability and is not considered to be prospective for epithermal mineralisation. Black box shows the extent of the study area and black dots are training points.

2D Vs 3D Prospectivity Modelling

Even through 2D prospectivity modelling is still a very powerful tool for exploration targeting, trying to visualise 3D geometries in a 2D plane can cause problems when it comes to exploration planning. With new drill hole planning programmes in 3D GIS software, drill hole collar locations and information can be projected onto the surface. The future is slowly heading towards a 3D GIS world but there are some things that need to be developed before this can happen. For example:

- Digital geology maps need to be improved, i.e. structural information needs to be added to lithological contacts and fault data.
- Mineral occurrence data needs to be developed into 3D shapes that represent the size of the deposit. At the moment they are currently treated as points.
- 3D modelling software needs to become more user friendly, more comprehensive and less expensive.
- There needs to be more seismic data in hard rock terranes allowing more accurate representation of geological relationships at depth.

Conclusions

The weights of evidence modelling technique provides a way for large quantities of historical and new exploration data to be integrated and viewed as a single predictive map. The 2D prospectivity model identified the best predictive map layers that predict epithermal mineralisation in the Ohakuri area following the mineral systems approach. These predictive maps and their spatial correlations with the training points can be used to guide the inputs of a 3D prospectivity model. This study has demonstrated the value of 3D prospectivity modelling and has provided a valuable tool to further define and possibly increase the estimate of the gold resource at Ohakuri.

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