Mineral prospectivity modelling in New Zealand: Review and future perspectives

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Abstract

Mineral prospectivity modelling using geographic information systems (GIS) has been used in New Zealand since 2002 both by the government, to promote mineral exploration in New Zealand, and industry, to inform project acquisition and increase the efficiency of exploration programmes. Over the last 15 years at least 38 mineral prospectivity models have been completed in New Zealand covering most of the hard rock mineralised regions onshore as well as nodular phosphate offshore on the Chatham Rise.

Analysis of highly prospective targets generated from the models already completed in New Zealand provides important information about the mineral potential of the country. Onshore, highly prospective targets over a range of commodities cover only 0.5 percent of the total land area of New Zealand, significantly narrowing the search area for new mineral deposits. 83 percent of the targets occur outside public conservation land, and 45 percent of the targets are unpermitted at the time of writing, suggesting there is potential for increased exploration investment and for new discoveries to be made.

Prospectivity modelling has had a measureable positive impact on exploration activity and project development in New Zealand over the last 15 years. Future work should include incorporating new data into existing models, modelling new areas when data becomes available, improving existing mineral occurrence datasets, 3D prospectivity modelling, modelling of other commodities such as coal, alluvial gold and ironsand, infrastructure modelling, and exploration effectiveness analysis.

Keywords: mineral prospectivity modelling, exploration targeting, GIS, spatial data, New Zealand.

Introduction

Spatial prospectivity modelling of mineralised systems using Geographic Information Systems (GIS) is used by geoscientists in industry, government and academia for appraising exploration areas and geological terrains and identifying targets for further investigation (Porwal and Kreuzer, 2010; Peters and Miller, 2013). The outputs of prospectivity models are mineral potential maps that highlight areas with similar geological features as known mineral deposits. Prospectivity modelling is a versatile exploration tool, which can be applied to both large-scale and small-scale areas and can utilise both detailed and sparse datasets (Ford et al., 2015; Miller et al., 2015). Importantly, these techniques can be applied to a wide range of mineralisation styles and are complementary to the recently adopted mineral systems approach explained below (Wyborn et al., 1994; Partington and Hill, 2008; McCuaig et al., 2010). With recent developments in software and computer processing capabilities, as well as increased data availability and accessibility, prospectivity modelling has expanded into the 3D domain (Greenwood and Dhnaram, 2013; Partington, 2013; Yuan et al., 2014; Nielsen et al., 2015a).

In New Zealand, prospectivity modelling has been used in the mineral exploration industry since the early 2000's when the Institute of Geological and Nuclear Sciences (IGNS; now GNS Science) assessed the mineral potential of the Reefton Goldfield on the West Coast (Partington, Christie and Cox, 2001) and collaborative projects between Crown Minerals (now New Zealand Petroleum & Minerals; NZP&M) and IGNS produced national coverage GIS and prospectivity models for orogenic gold mineralisation in 2002, and epithermal gold mineralisation in 2003 (Partington and Smillie, 2002; Rattenbury and Partington, 2003; Partington et al., 2006). These studies showed the mineral potential of New Zealand at a regional scale to support project targeting and to promote exploration investment in New Zealand to the international market. In the years since these government modelling projects were completed new models at various scales have been developed, largely by Kenex Ltd, a spatial data-focussed geoscience consultancy supporting the resource exploration industry and government but also by Geoinformatics as part of wider data-integration and prospecting work for Glass Earth NZ (Table 1).

In the last 15 years there have been a number of factors that have improved the quality of prospectivity models. The results of a prospectivity model are greatly influenced by the quality of the input data, the selection of training data if required by the modelling method, and the balance between the expert understanding of the mineralisation system being modelled and the statistical modelling technique applied. As more data becomes available in a digital format, models can be updated or new models can be created over areas that were previously data-poor. Tools for processing digital exploration data and performing prospectivity analyses are now included in GIS software packages such as ESRI's ArcGIS and the MISDM add-on to Pitney Bowes' MapInfo. A wide variety of prospectivity modelling statistical methods can be used from data-driven to expert systems (Bonham-Carter, 1994; Carranza, 2009). 3D software packages such as Paradigm's GOCAD, are now able to perform prospectivity analysis in 3D and thus enable exploration targeting in 3D (Partington, 2013; Cunningham et al., 2013). Another important development in the way prospectivity models are constrained is the now widely used mineral systems concept (Wyborn et al., 1994), which ensures that all elements and processes necessary to generate and preserve mineral deposits are represented in the prospectivity model (Partington and Hill, 2008; McCuaig et al., 2010).

This paper presents a summary of the prospectivity models that have been completed in New Zealand to date; looks at the way that prospectivity model results can be turned into highly prospective targets that can be ranked, analysed and used by government and industry to inform exploration activities; and presents a few recommendations to improve and expand the use of prospectivity modelling in New Zealand in the future.

Table 1. Two-dimensional mineral prospectivity models completed in New Zealand over the last 15 years.

No	Year	Model Type	Mineralisation Style	Region	Company[a]	References[b]
1	2001	WoE	Orogenic Au	West Coast	IGNS	Partington et al., 2001
2	2002	WoE	Orogenic Au	South Island	IGNS & Crown Minerals	MR4342
3	2003	WoE	Epithermal Au	Northland, Coromandel, TVZ	IGNS & Crown Minerals (Kenex)	MR4343
4	2003	WoE	Orogenic Au	Marlborough	HPD Exploration (Kenex)	MR4225
5	2003	WoE	Epithermal Au	Hauraki, Coromandel	HPD Exploration (Kenex)	MR4266
6	2003	WoE	Orogenic Au	Barewood, Otago	HPD Exploration (Kenex)	MR4081
7	2003	WoE	Orogenic Au	Bendigo, Otago	HPD Exploration (Kenex)	MR4065
8	2003	WoE	Orogenic Au	Skippers-Macetown, Otago	HPD Exploration (Kenex)	MR4086
9	2004	WoE	Orogenic Au	Garvie, Otago	HPD Exploration (Kenex)	MR4084
10	2004 - 2005	WoE	Epithermal Au	Southern Coromandel, TVZ	Glass Earth NZ (GENZ and Geoinformatics Exploration)	MR4214
11	2004	WoE	Epithermal Au	Muirs, Bay of Plenty	HPD Exploration (Kenex)	MR4088
12	2004	WoE	Orogenic Au	Ophir, Otago	HPD Exploration (Kenex)	MR4090
13	2004	WoE	Orogenic Au	Umbrella, Otago	HPD Exploration (Kenex)	NA
14	2004	WoE	Intrusion Related Au	Ross-Buller, West Coast	Auzex Resources (Kenex)	MR4072, MR4073
15	2004	WoE	Intrusion Related Au	Tasman, West Coast	Kenex	Closed file
16	2004	WoE	Epithermal Au	Hazelbrook, Northland	Aurora Minerals (Kenex)	MR4077
17	2004	WoE	Epithermal Au	Lanigans, Northland	Aurora Minerals (Kenex)	MR4076
18	2004	WoE	Orogenic Au	Macraes, Otago	Aurora Minerals (Kenex)	MR4074
19	2004	WoE	Porphyry Cu-Au	Rockville, Tasman	Aurora Minerals (Kenex)	MR4074
20	2005	WoE	Orogenic Au	Onslow, Otago	HPD Exploration (Kenex)	MR4089
21	2005	WoE	Orogenic Au	Nenthorn, Otago	HPD Exploration (Kenex)	MR4141
22	2005	WoE	Orogenic Au	Nenthorn North, Otago	HPD Exploration (Kenex)	NA
23	2005	WoE	Orogenic Au	Manorburn, Otago	HPD Exploration (Kenex)	NA
24	2005	WoE	Orogenic Au	Nicholsons, Otago	HPD Exploration (Kenex)	NA
25	2006	WoE	Orogenic Au	Otago	NZ Minerals Ltd (Kenex)	NA
26	2006	WoE	Orogenic W	Otago	NZ Minerals Ltd (Kenex)	NA
27	2007	WoE	Granite Related Ni	South Island	Accord Mining (Kenex)	NA
28	2007	Fuzzy Logic	Porphyry Cu-Au	Southland	Lodestar Resources, Paramount Platinum (Kenex)	MR4812
29	2007	Fuzzy Logic	Mafic PGE Ni-Cu	Southland	Lodestar Resources, Paramount Platinum (Kenex)	MR4812
30	2008	WoE	Orogenic Au	Wellington	Kenex	Hill and Peters, 2010
31	2011	WoE	Orogenic Au Mesozoic	South Island	NZP&M (Kenex)	MR4842
32	2011	WoE	Orogenic Au Paleozoic	South Island	NZP&M (Kenex)	MR4842
33	2012	WoE	Epithermal Au	Coromandel	Kenex	Closed file
34	2012	WoE	Epithermal Au	Northland	Kenex	Closed file
35	2013	WoE	Epithermal Au	TVZ	Kenex	Closed file
36	2014	Fuzzy Logic	Orogenic Au-W	Marlborough	Hawkeswood Resources (Kenex)	MR5118
37	2014	WoE	Phosphate	Chatham Rise	CRP (Kenex)	Closed file
38	2014	Fuzzy Logic	Phosphate	Chatham Rise	CRP (Kenex)	Closed file

a. Modeller is given in brackets if different to the company who the modelling was for;
b. MR number refers to minerals report available from the New Zealand Petroleum & Minerals website.

Prospectivity models completed in New Zealand

A total of 38 prospectivity models that we know of have been completed in New Zealand since 2002 (Table 1). The existing prospectivity models cover most of the known hard-rock mineralised areas of the country (Fig. 1), including epithermal gold-silver-mercury mineral systems in Northland, Coromandel and the Taupo Volcanic Zone (TVZ); Palaeozoic orogenic gold, intrusion-related gold and granite-related nickel mineral systems on the West Coast; porphyry copper-gold mineral systems in Northwest Nelson; Mesozoic orogenic gold and tungsten mineral systems in Wellington, Marlborough and Otago; and porphyry copper-gold and mafic nickel-copper-platinum group element mineral systems in Southland, as well as offshore models for nodular phosphate on the Chatham Rise.

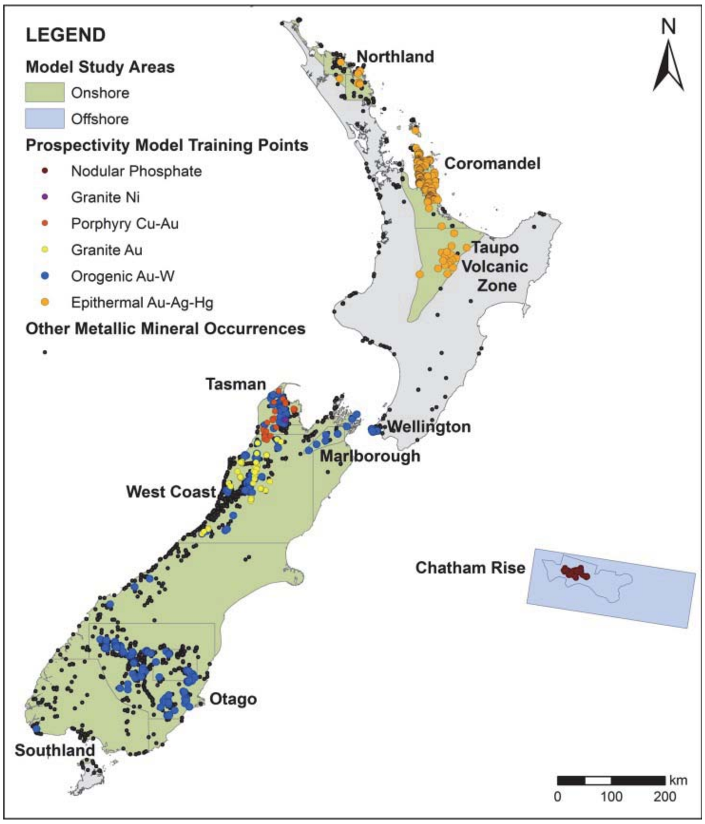

Figure 1. Distribution of mineralised regions and areas covered by prospectivity modelling in New Zealand.

Some mineralised regions have been covered by multiple generations of models. This has occurred due to individual requirement for modelling by different explorers over their permit areas, to incorporate more detailed data as it becomes available, or to take advantage of new modelling techniques. For example, the Otago area has been modelled for orogenic gold and/or tungsten in 2002 for Crown Minerals, in 2004 for Aurora Minerals, in 2005 for HPD Exploration, in 2006 for New Zealand Minerals Ltd, and in 2011 for NZP&M, incorporating newly available geophysics and more extensive geochemical databases.

The original Crown Minerals-IGNS prospectivity models in New Zealand were produced for the government with the aim of attracting explorers into the country. However, most of the subsequent models undertaken by Kenex have been undertaken to assist the exploration ventures of private companies (Table 1).

Analysis of prospectivity model targets

The way that explorers have been using the results of prospectivity models has evolved in the last 15 years. Using the results of a model in an effective way to enhance exploration is as important as what goes into the model and how it was created (Peters and Miller, 2013). The post-probability grid that is the output of a prospectivity model can be classified into highly prospective targets that can focus mineral exploration within existing permits. They can also guide project acquisition, and provide critical information on which types of exploration data are most useful to collect. In addition to this, the prospectivity model targets can be used by government for planning and land management purposes.

Exploration targets can be created from prospectivity model grids by reclassifying the probability values above a defined cut-off that may relate to a percentage area or to the post probability statistics of known deposits. Depending on the scale of the model and the detail of the input data, the targets may be larger areas for further exploration, or small and even 3D areas for drill targets. Targets can be ranked based on their relative post probabilities and assigned additional information from the model parameters, predictive maps, and other factors such as presence of anomalous geochemistry, distance to towns and infrastructure, current tenement status, and presence of restricted land (Fig. 2). Databases can be created to query and prioritise targets for exploration, or be used for economic evaluation studies (e.g. Kreuzer et al., 2015).

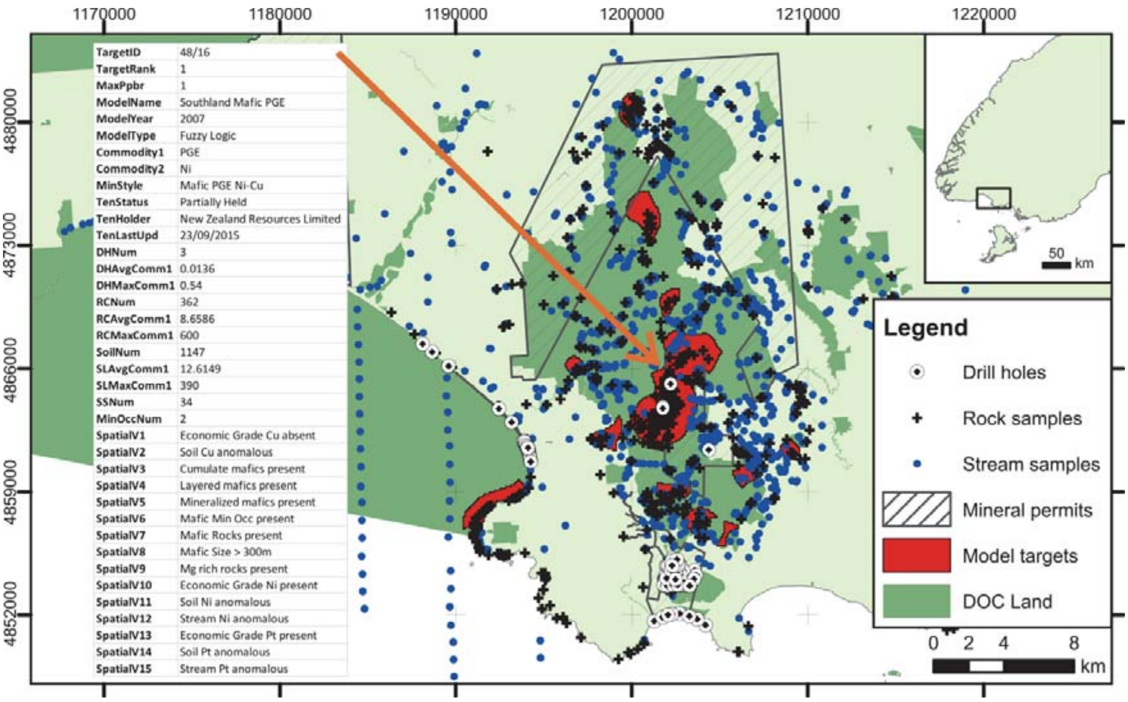

Figure 2. An example of prospectivity model variables and additional spatial data that can be attributed to prospective targets in order to filter, rank and prioritise a group of targets.

Kenex have performed a preliminary analysis on highly prospective targets that have been created from a compilation of prospectivity models completed in New Zealand, many of which are open file (Table 1). The prospectivity targets database contains 1226 targets, covering eight mineralisation styles over eight onshore regions (1102 targets) and offshore on the Chatham Rise (124 targets). Where areas have been remodelled at the same scale for the same mineralisation style, the targets from the superseded models have not been included in the database. The targets cover 1501 km^2 onshore and 9581 km^2 offshore. The onshore targets cover only 0.5 percent of the total land area of New Zealand. Therefore, the models completed to date have already considerably narrowed the potential focus of exploration, by highlighting the places most likely to host hard rock mineralisation onshore and phosphate offshore.

The examples below show how the current prospectivity targets in New Zealand can be analysed with respect to various types of spatial data, in order to inform permitting and land management, promote investment in mineral exploration, focus exploration programmes, and guide the collection of new exploration data by government and industry.

Conservation land

In New Zealand, the Department of Conservation (DOC) manages more than 80000 km^2 of land (approximately 30 percent of the total land mass of New Zealand) that is protected for conservation purposes. The DOC-managed land has various classifications and levels of conservation value. From a mineral exploration and mining perspective, knowing whether an exploration target contains public conservation land is important from the outset and the presence of this land does not necessarily preclude exploration or mining activities taking place. However, some of the DOC-managed conservation areas, including National Parks, are protected under Schedule 4 of the Crown Minerals Act 1991 and this land is restricted from mining, with only very low-impacting prospecting permitted. Only 182 of the 1102 onshore targets contain public conservation land with 99 of these completely covered. Of the 182 targets, 147 contain land protected under Schedule 4 and only 71 are completely covered by Schedule 4 land. 40 of the targets that intersect Schedule 4 land are ranked in the top 10 for prospectivity for that model showing that some of this land is highly prospective for hard rock mineralisation. Importantly, the prospectivity model targets can be used for land management purposes by government regulators. For example, knowing the location of highly prospective land, as indicted by the model targets, can help to inform the classification of DOC land ensuring that where possible prospective ground can remain accessible.

Tenement status

An analysis of the current permit status of the targets shows how much of the most prospective land is currently being prospected, explored, or mined. Importantly, the analysis also shows how much potential there is for new projects to be developed where targets are currently free of permits at the time of writing. As at June 2016, 454 of the 1102 onshore targets are completely covered by current permits and 151 are partially held. This leaves 497 targets, just under half of those onshore, which are currently not permitted. This indicates there remains potential for more prospective land to be explored in New Zealand and for new discoveries to be made. This type of prospectivity target analysis could be an important tool for marketing New Zealand as an exploration destination, to ensure investment in New Zealand’s mineral estate is maintained if not increased.

Geochemistry

An analysis of the historic surface and drill hole geochemical data that has been collected within each target indicates many of the targets in New Zealand have been poorly explored. 742 targets have no geochemical sampling of any kind and more importantly 1153 targets have no drill testing, suggesting that many of the targets are based on geological rather than geochemical factors. This analysis also confirmed that only 484 targets have one or more types of geochemical sampling. These targets may be more mature than indicated and suitable for explorers looking for drill targets or brownfield opportunities, or they may only require geochemical analyses to confirm historic results before more comprehensive and expensive exploration programmes commence. An important conclusion from this analysis is that there are a large number of targets that remain to be tested further by geochemical exploration techniques, particularly drilling. Future investment needs to prioritise developing these targets if New Zealand's mineral estate is to be efficiently and effectively managed. New Zealand remains under-explored in comparison to other countries with similar geological potential, and should be seen by the exploration sector as a high priority destination for their exploration investment.

Detailed geophysics

Between 2005 and 2013, detailed airborne geophysical surveys have been acquired over five regions in New Zealand by government and private companies (Fig. 3). These surveys provide detailed magnetic, ± gravity, ± radiometric data that can be used to interpret areas of alteration caused by mineralisation, and structures and lithological units that may not be mapped at the surface. These geophysical datasets are well suited to prospectivity modelling as they provide an even coverage of uniformly measured data. They are also less susceptible to spatial, methodological and interpretive bias, compared to data that is focussed around areas of past exploration, such as geochemistry or discrete geological data such as quartz vein mapping.

Of the 38 prospectivity models listed in Table 1, only 2 (Northland epithermal Au, 2012 and TVZ epithermal Au, 2013) were completed after newly-flown geophysical data was released over the study areas, allowing this data to be used in the modelling (Fig. 3). All of the Orogenic Au or W models over Otago were completed prior to the October 2011 release of the detailed geophysical surveys flown by Glass Earth Gold in 2005 and 2007. There are 584 targets from models that were completed prior to the release of geophysical data that now have this data available. These could potentially be improved by re-modelling and incorporation of predictive variables derived from geophysical interpretations. 159 targets fall in areas that are due to have airborne geophysical surveys flown by the government in 2016. These areas should be modelled using all available geological and geochemical data and can be re-modelled when the planned geophysical surveys are complete.

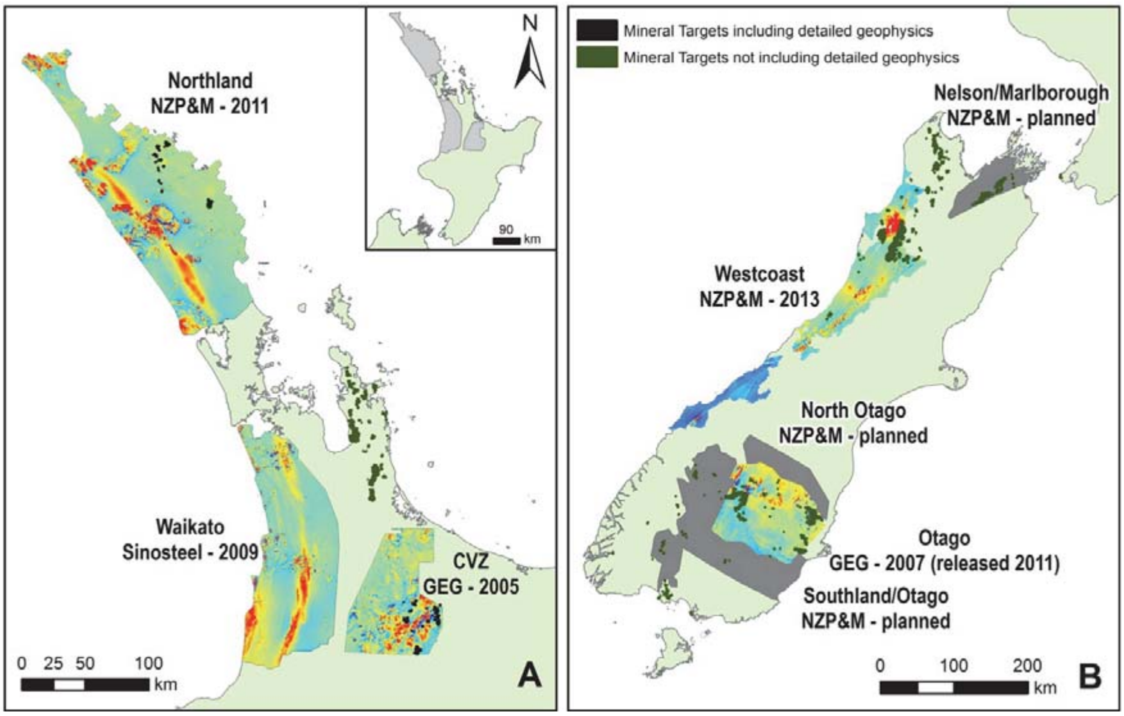

Figure 3. Coverage of completed (coloured reduced to pole grids of aeromagnetic data) and planned (grey areas) regional airborne geophysical surveys in the North Island (A) and the South Island (B) of New Zealand overlain by compiled highly prospective targets.

Future of prospectivity modelling in New Zealand

Many of the hard rock mineralised areas of New Zealand have been covered by prospectivity modelling. However, there is scope for re-modelling of known mineralised regions with more recent data or when new data becomes available in the future. Also, there is opportunity to test new mineral system concepts in regions of New Zealand that have been under-explored in the past. Nelson, Marlborough and Southland are examples of regions that would benefit from re-modelling. This can be done by incorporating new geological mapping, interpretations from planned geophysical surveys, data from new geochemical surveys, as well as recent data compilations of historic exploration.

Prospectivity modelling, and in particular the 'weights of evidence' technique, uses mineral occurrence data to undertake statistical spatial analysis of exploration data. Mineral occurrence datasets available in New Zealand have not undergone significant change in the last 15 years. The main datasets available are the Geological Resource Map of New Zealand Database (GERM) and the Regional Exploration Geochemistry Database (REGCHEM), both managed by GNS Science. The GERM database has not been updated since 1993 and has poor location precision (±1 km) and REGCHEM data is discontinuous. An investment in improving these datasets, including increasing the location precision and attribution of the data points, would greatly help to improve the accuracy of future models.

Prospectivity modelling using fuzzy logic and weights of evidence can now be undertaken in software packages such as GOCAD Mining Suite, allowing companies to carry out exploration targeting in 3D. Geological and prospectivity models in 3D make full use of down hole data, surface structural measurements and geophysical data. Prospectivity modelling in

3D has so far had limited application in New Zealand with one test model completed over the Ohakuri prospect (Fig. 4), a target from the 2013 TVZ epithermal gold model (Cunningham et al., 2013; Payne et al., 2015). Examples where 3D prospectivity modelling has been successfully implemented in other countries include modelling for IOCG mineralisation at Tennant Creek by Emmerson Resources, modelling for orogenic gold in the Marymia Inlier of Western Australia (Nielsen et al., 2015a) and modelling of the Quamby Region by the Geological Survey of Queensland (Greenwood and Dhnaram, 2013). Prospectivity modelling in 3D is a powerful tool that complements the wealth of new geological and geophysical data being provided by government groups in New Zealand.

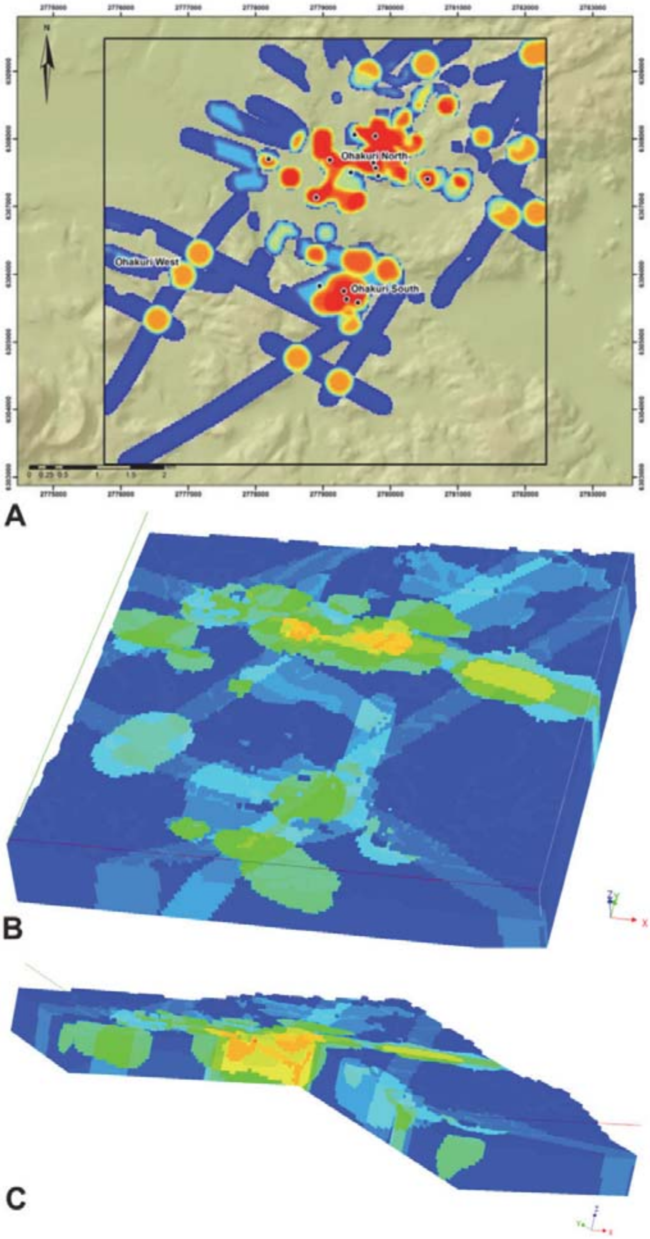

Figure 4. Prospectivity models of the Ohakuri Prospect, TVZ: A. Detailed 2D model (black circles are gold assay values greater than 0.25 ppm that were used as training data), B. 3D model and C. A cut-away of the 3D model showing extension of prospective areas into the subsurface (after Payne et al., 2015).

As well as the traditional hard rock mineral systems, prospectivity modelling could be applied to mineral studies for alluvial gold, garnet, or ironsand; exploration for coal, oil and gas; quarry site studies that incorporate infrastructure and regional development factors; product quality assessment at the scale of a mine or quarry, e.g. limestone, phosphate or weathering in aggregate; or any spatially related land management problem in New Zealand. The Canada National Infrastructure spatial analysis completed by Kenex (Wildman et al., 2015) looked at the spatial relationship between infrastructure deficient regions and the location of significant, undeveloped mineral deposits in Canada. This project was undertaken for the Prospectors and Developers Association of Canada (PDAC), but the method can also be applied in New Zealand to encourage development of mineral deposits and development of infrastructure. Analysis of exploration effectiveness similar to that done in the Lachlan Fold Belt of New South Wales (Kreuzer et al., 2015) could also be applied to the New Zealand minerals industry. This statistical and spatial analysis would give an understanding of the effectiveness of exploration activities currently undertaken on highly prospective land and how they could be improved.

Conclusions

Prospectivity modelling has been used successfully by government to promote mineral exploration in New Zealand and for land management purposes, and by industry to inform project acquisition and increase the efficiency of exploration programmes. Over the last 15 years, at least 38 prospectivity models have been completed in New Zealand that cover most of the regions that contain orogenic gold, epithermal gold, porphyry copper-gold, granite related nickel, granite related gold, mafic nickel-copper-platinum group element mineral systems, and offshore nodular phosphate. In this time there have been advances in prospectivity modelling techniques, software capabilities, and digital data availability. Exploration targeting, involving ranking and analysis of highly prospective targets from current and future prospectivity models, is a valuable tool for informing permitting and land management, promoting investment in mineral exploration, focusing exploration programmes, and guiding the collection of new exploration data by government and industry. Moving forward, modelling for other commodities such as coal and ironsand would provide a more complete picture of the status of mineral exploration and development in New Zealand. Future prospectivity modelling studies should focus on areas with recent compilations of digital data and more 3D models should be developed to get a complete understanding of the geological framework and prospectivity at depth.

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