# The QMAP dataset and an example of its application in modelling gold prospectivity in New Zealand

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## ABSTRACT

The 1:250,000 QMAP Geological Map of New Zealand is being built by GNS Science utilising an ArcInfo® geographic information system (GIS). The project has involved the staggered completion of 21 map sheets since 1994 and much of the country has now been completed. Available GIS data are already being used for a wide range of geological resource and natural hazard research. Its application to derivative research is best suited at regional scales, comparable at which the data were captured (1:50,000) and simplified for production of hard-copy maps (1:250,000). There is increasing demand to use and improve the data for site-specific hazard and resource applications. This paper introduces the QMAP dataset and presents an example of its application using weights of evidence spatial modelling to determine gold prospectivity in New Zealand. The spatial modelling showcases available geoscientific data and a method of adding value to create derivative products to market New Zealand's mineral estate internationally. Scale, conditional dependence and continuity of datasets are key factors in the quality of the spatial modelling and the conversion of geological GIS data into client-focussed derivative information.

***Keywords and phrases*:** QMAP, GIS, geological map, weights of evidence, gold, prospectivity, natural hazards

## 1.0 INTRODUCTION

Geological maps are scaled interpretations of geological formations and structures that occur at or very close to present-day topography. The production of geological maps was the primary task of the original NZ Geological Survey and remains a central focus for research effort its successor organisation GNS Science. Original geological maps were hard-copy sheets, commonly hand-drawn or printed and published using plates. Geological mapping since the early 1990's has been increasing carried out using computer software and hardware, now typically involving geographic information systems and large-format plotters. One of the key geological datasets of national significance is the QMAP Geological Map of New Zealand being built by GNS Science. The programme started in 1994, and as data has become available it has been applied in a variety of ways, principally for geological resource and natural hazard research. This paper introduces the QMAP dataset, its use and application, and outlines some of the issues associated with turning this GIS data into useful client-focussed derivative information.

## 2.0 QMAP GEOLOGICAL MAP OF NEW ZEALAND

### 2.1 Geological maps

The QMAP (**Q**uarter-million-scale **MAP**; Nathan 1993, GNS 2006) Geological Map of New Zealand is currently being produced by GNS Science. It supersedes the previous national 1:250,000 Geological Map of New Zealand ("four miles to the inch") series that was published during the 1960s. The programme is compiling the considerable amount of new geological research that has been completed since the original maps were published, including detailed geological mapping at 1:50,000 or larger scale, commercial investigations, university theses and other research. In addition, new fieldwork has been carried out specifically for QMAP in areas that were still poorly known or remained contentious. Major advances in all areas of geological research, including fundamental geological understanding of fault motion and plate tectonics, have occurred since the previous 1:250,000 scale maps were published. New fieldwork has added considerably to the state of knowledge, so there are significant differences between the old and new geological maps.

New Zealand has been divided into 21 QMAP sheets (Fig. 1). Twelve QMAPs have been completed since the programme began in 1994, and the remaining nine maps and accompanying texts will be published by 2010. Each completed QMAP is available as a 1:250,000 scale, high quality geological map folded into the back of an explanatory book. Each map differentiates rocks primarily in terms of their age of deposition, eruption or intrusion. Digital raster images of the maps and PDF versions of the books on are available on CD. In addition vector GIS data is being made available on CD.

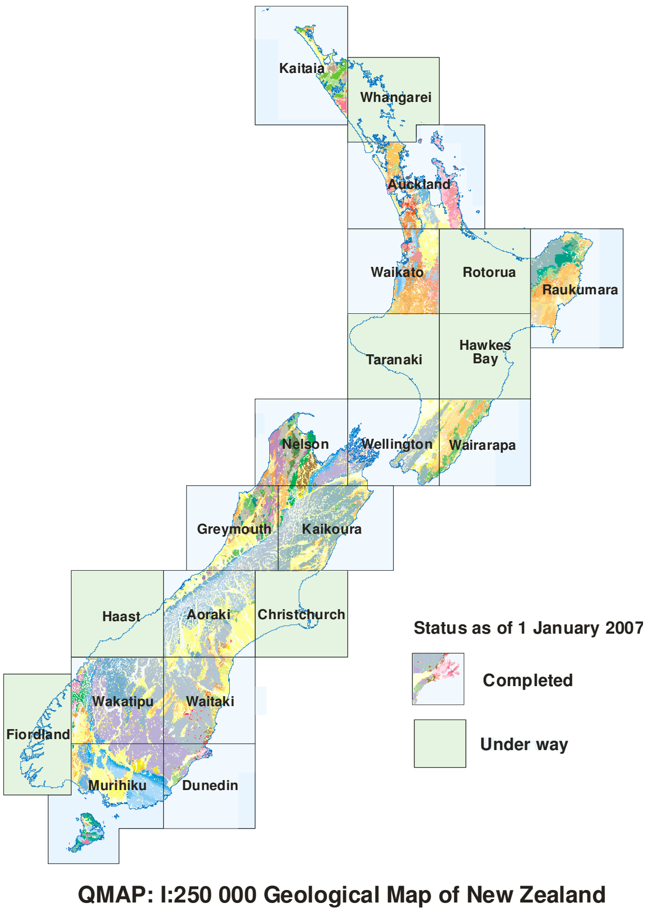


*Figure 1: The QMAP geological map of New Zealand and GIS dataset, showing sheet boundaries and expected progress as at 1 January 2007.*

## 2.2 The QMAP geographic information system

The QMAP series uses computer methods to store, manipulate and present geological information. Each map is drawn from data stored in the QMAP geographic information system (GIS) (Rattenbury et al., 1994; Rattenbury & Heron, 1997). The primary software used is ArcInfo®. The QMAP series and database are based on detailed geological information plotted by hand on 1:50,000 topographic base maps. The 1:50,000 data have been simplified for digitising during a compilation stage, with the line work smoothed, and geological units amalgamated to a standard national system based on age and rock type. Point data (e.g. structural measurements) have not been simplified. All point data are stored in the GIS but only selected representative structural observations are shown on the map. Procedures for map compilation, and details of data storage and manipulation techniques are given by Rattenbury & Heron (1997).

Geological data from each published QMAP sheet are being made available as ArcGIS coverages and shapefiles on CD. These data can be used in mainstream GIS software such as ArcInfo, ArcMap, ArcView and MapInfo, and included with each CD is the free GIS viewing software ArcReader which allows zooming, theme selection, searching and printing data. The data have rich attributes describing various parameters of each geological features e.g. rock types, age, stratigraphic affiliation for geological map units and movement sense, age and activity of faults. These attributes are searchable and enable customized selection and presentation of the data. The CDs contain the QMAP Data Dictionary and QMAP Metadata (GNS 2006). The GIS database behind each individual geological map will ultimately be integrated into a seamless national geological database. The completed QMAP geological GIS will be accessible to the New Zealand public in vector and raster formats, and will be maintained and updated as a Nationally Significant Database.

## 2.3 End users

The QMAP programme compiles, interprets and disseminates underpinning research relevant to a wide range of geological disciplines. A major goal is to contribute to a better understanding of natural hazards and earth resources such as mineral, groundwater and petroleum. QMAP data are an essential foundation for other science programmes. Data have recently been used for classifying earthquake ground shaking and liquefaction, seismic hazard models, and regional landslide susceptibility. Key end users include central, regional and local government, mineral and petroleum exploration companies, insurance and utility companies, universities, consultants and the general public. QMAP is also undertaking research specifically relevant to and involving Māori including identification of resource potential and geological hazard, and transfer of GIS and mapping skills to wānanga and rūnanga.

QMAP data has been successfully applied in a wide range of end uses is due to its:

- National coverage
- Pragmatic, multi-purpose design
- Systematic approach
- Consistency in scale and capture of information
- Consistency and completeness in its attributes

## 2.4 Reliability and limitations

QMAP began with early-1990's government science funding to generate new editions of 1:250,000 geological maps of New Zealand (Nathan, 1993). GNS Science (then the Institute of Geological & Nuclear Sciences) realised the potential of GIS for meeting the government's hard-copy publication requirements, at the same time as developing a significant digital dataset that could be used for other purposes. The accuracy of the geological contacts, faults and folds is constrained by the publication scale at 1:250,000. These data have been simplified from unpublished 1:50,000 compilation maps that have a greater precision of detail and accuracy. However, QMAP is a regional scale map. It should not be used in isolation for any activities that require geological site investigations, such as land development, planning and design of engineering projects, or detailed geological hazard assessments. There have been increasing requests for site-specific information, and some misuse of the dataset, as GIS software becomes more widely used. Future projects are likely to look towards improving the scale of data compilation and capture.

## 2.5 Geological maps are models!

Geological maps portray the spatial distribution of discrete rock units that differ in one or more of age, fossil assemblage, mineral composition, textural characteristics, inferred environment of deposition, and chemistry. Geological maps can be thought of as scaled and generalised models of the composition of the earth's surface, and their final forms are heavily influenced by the process of geological correlation and the choice of what to portray.

*Geological Correlation*

Geological maps are based on observational data from many locations but also require a lot of interpretation to correlate between data. For example a geological unit such as a granite pluton has characteristics that are similar over a certain area yet continuous exposure of the rock over large areas is very unusual in New Zealand. Defining the areal extent of the granite map unit relies on correlating isolated observation points, either visited in the field or interpreted from remote techniques such as aerial photographs. The correlation process relies on the experience of the geologist who must assess the original mineralogical and textural variation within the granite, after taking into account superimposed effects such as differential weathering and deformation. The correlation inevitably has a degree of subjectivity and can fall out of favour, particularly when new observational data are acquired.

*What to portray?*

QMAP, like many traditional geological maps, portrays a 2-D representation of major rock units that occur at the surface. QMAP aims to meet the needs of a wide range of end-user interests, such as mineral, petroleum and groundwater exploration, environmental and geological hazard evaluation, and educational and science research requirements. In doing so compromises are made that limit its effectiveness for some users. For example, young veneers of river alluvium or volcanic ash commonly overlie older mineralised rock. The portrayal of these deposits on a geological map results in an under-representation of the extent of potentially mineralised terrain and has some implications for the spatial prospective modelling discussed in the next section.

# 3.0 SPATIAL MODELLING APPLICATION

## 3.1 Mineral exploration companies

Mineral prospecting and exploration is a high-risk high-return business. Commonly quoted figures are that for every 1000 prospects identified, 100 will make it to detailed investigation, 10 will have major drill programmes and 1 will contain an economic deposit worth mining. Many small companies exist with little expectation of making an economic discovery, but aim to increase their shareholder wealth by improving the chances for other companies further down the exploration chain. Maintaining access rights, ensuring tenement ownership, selecting ground and understanding mineral potential are important to company success.

Mineral companies typically have a good understanding of areas where minerals have been found in the past and have general indicators of the types of rocks and geological situations where they should focus their efforts. Prospecting and exploration follow a geochemical and drilling-focussed methodology that has evolved into a reasonably standard set of procedures for shareholder reporting (e.g. JORC, 2004), but these risk-savvy companies also invest widely in new technology and methods. Their approach follows an empirical, inductive scientific process, which commonly involves considerable amounts of subjective assessment and personal experience. By way of contrast, concept driven or model-deductive science common in academic institutions does not sit as comfortably with their corporate strategies.

## 3.2 Spatial data modelling of mineral prospectivity

Spatial data modelling is increasingly being used in geological applications for research (Bonham-Carter, 1994; Kemp et al., 2001; Knox-Robinson, 2000; Raines, 1999). GNS Science began applying spatial data modelling to mineral exploration and resource assessment in 2001, an initiative with Crown Minerals (Ministry of Economic Development). The project aimed to improve the accessibility of relevant geoscience information and increase

the level of understanding of New Zealand's mineral resources at a national level, promote mineral development, and encourage the return of mineral explorers to the country (Smillie et al., 2002).

The project gathered a comprehensive set of geoscientific data, based primarily around available QMAP data (GNS, 2006), a point dataset of mineral occurrences in New Zealand (GERM – Christie, 1988), and mineral exploration company data available on open file (Crown Minerals, 2006). The first stage involved building a comprehensive digital data package, GIS project and mineralisation models of two of New Zealand's more productive gold-producing regions. Then, in order to distinguish New Zealand minerals information from that of other nations competing for mineral investment, spatial data modelling was carried out to describe the relative potential of different areas for the presence of hard rock (mesothermal and epithermal) gold. CDs containing the dataset, models and mineral reports were given away freely to all interested exploration companies and other organisations worldwide (Anon, 2002; Anon, 2003).

Techniques for spatial modelling vary in their degree of subjectivity and statistical quantification ranging from expert-driven to data-driven. Modelling of the gold prospectivity for this project used the more objective and statistically quantifiable data-driven approach. Here the degree of spatial coincidence between known gold occurrences or deposits (training data) and features within various geological and other datasets (evidential themes) has been quantified using weights of evidence modelling. The technique uses Bayes rule of probability to establish conditional probabilities of gold occurrences being present of absent with respect to a number of geological and other mineral-related themes. The GIS dataset is then searched, using ArcSDM extension to ESRI ArcView software (Kemp et al. 2001), for spatial coincidences of the higher-weighted themes and probability values calculated in the analysis are used to generate maps of mineral potential or 'prospectivity' (Fig. 2). Areas of higher probability reflect the spatial coincidence of several of the higher-weighted evidential themes. A correlation matrix also generated in the process shows relationships and degrees of association between the evidential themes. This has, in some cases, highlighted spatial associations that not been recognised before, and can be used to test mineral genesis models.

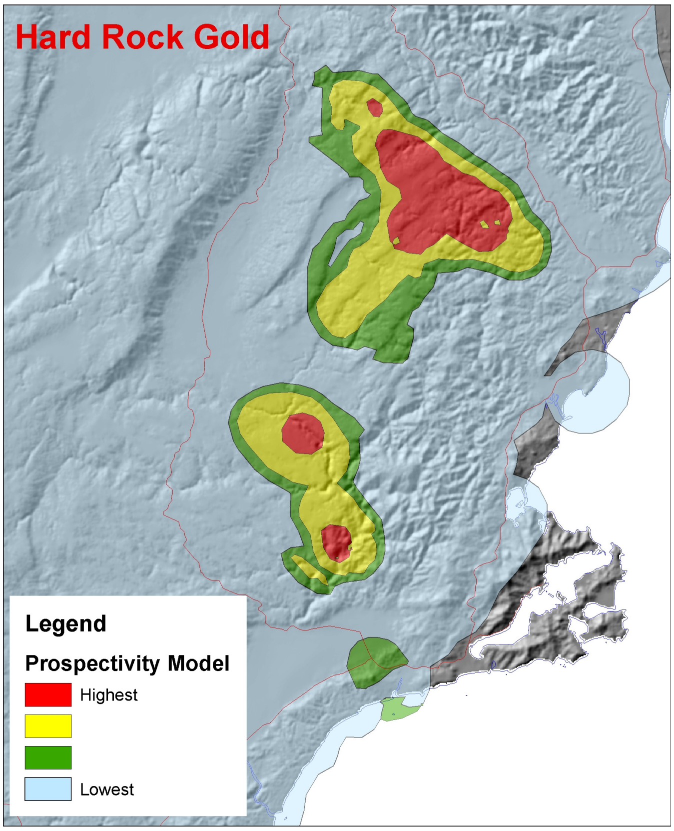


*Figure 2: Example map showing relative prospectivity ranking of different parts of east Otago for the occurrence of hard-rock (mesothermal) Macraes-style gold deposits (after Anon 2002).*

## 3.3 Application and caveat

The prospectivity modelling is an entirely empirical approach, applying the correlations and "experience" from areas where training data occur to areas where training data are absent. The maps and methods have proved very popular with both local and international mineral exploration companies, but their veracity is very dependent on the quality of the evidential theme data. The quality, scale and style of the geological mapping influences the resulting model and in the example above of Quaternary veneer deposits masking mineralised rock there are two effects. Firstly if training data (gold deposits) occur where there are mapped veneers then the prior probability for these masking deposits is artificially elevated at the expense of that of the mineralised rock. Secondly areas where mineralised rock occurs below surface (and does not outcrop) are downgraded. Artificial variations in the density of features, resulting from limited outcrop, or differing scales of mapping can also skew the prior probabilities.

The prospectivity models are generally able to reproduce high values in areas of known mineralisation outside of the training area, and generate other targets where follow-up investigation is warranted. However they are unlikely to discover new deposit types or styles for which evidential training data does not exist. Conditional dependence (see Bonham-Carter 1994) is a significant problem in most models because many of the geological, geophysical and geochemical themes are interrelated. The effect of conditional dependence is to overestimate the probabilities of occurrence, so the results are best thought of as relative favourabilities rather than true probability values.

The scale of input data used in the project was for the most-part insufficient for direct discovery of minerals. Rather, this project provided information at a regional-scale that can be used for tenement acquisition and land management. Significantly, the project highlighted significantly large areas of New Zealand that have potential to host hard-rock gold mineralisation that have never been tested with detailed geochemical sampling and drilling. The project has helped focus several new major exploration programmes in Otago and central North Island, and encouraged overseas investment in the New Zealand mineral estate.

GNS Science has also used spatial data modelling in larger-scale, smaller area investigations for companies with varying degrees of success. Many of the detailed company exploration datasets are highly variable in density and quality, commonly based around point data. The methods work best where datasets are relatively continuous, such as geophysical measurements captured by aircraft, or from geological maps generated at a constant scale. One useful process for both GNS Science and their clients has been to compare traditional **subjective** ranking of prospect areas, based on detailed field knowledge and geologist experience, directly against the more **objective** ranking of these areas by spatial data modelling. This can highlight observer bias, test paradigms, find inconsistencies in the datasets, and show where conditional dependence occurs in the models. Unlike subjective assessment, the prospectivity model values per unit area can provide an objective measurable value that can change as new information comes to hand and, in addition to highlighting targets, can be used to measure the impact of increased exploration expenditure and assess the effectiveness of exploration investment (see Partington et al., 2001).

## 4.0 SUMMARY

The QMAP Geological Map of New Zealand, currently nearing completion, provides a national, consistent scale, consistently attributed GIS dataset of New Zealand geology. Layers in the GIS are being used to make derivative maps for natural hazard assessment and geological resource research, as well as underpinning other geological science. QMAP was used in a spatial data modelling exercise with other datasets to market the mineral potential of New Zealand, specifically for 'mesothermal' and 'epithermal' hard rock gold deposits. Spatial data models were developed using weights of evidence Bayesian approach using ArcSDM. Key limitations in models completed to date are the regional scale of data capture, conditional dependence of interrelated geological datasets, and a lack of good continuous datasets. Nonetheless, the spatial modelling was an important marketing exercise for New Zealand, distinguishing our geoscience information and geological prospectivity from other nations competing for international mineral investment.

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2001) and these authors are thanked for making their software readily available. Crown Minerals are commended for their foresight to commit to new technologies for marketing New Zealand to the exploration industry. Phil Glassey is thanked for reviewing the paper.

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