Predictive modelling for environmental management and mineral exploration – potential applications for the marine minerals industry.

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Abstract

Deep sea mineral exploration has progressed significantly in the past few years, however it remains a nascent industry when compared to terrestrial mineral exploration and mining and the offshore petroleum industry.

Given that in general marine exploration is more costly than terrestrial exploration the ability to focus exploration efforts and funds should be highly desirable to those companies involved. Similarly, the detailed understanding and distribution of species or habitats in the marine environment in many areas which coincide with prospective minerals deposits is often limited.

Predictive modelling could therefore be a valuable tool for aiding the management of both facets of a marine minerals project. Although a GIS is a perfect way of visualising data and producing maps from that data, GIS also allows you to create new data through using statistically based gridding techniques or predictive maps using spatial data modelling techniques. This modelling is where businesses can really add value, using their data more effectively rather than just passively using it to generate maps and figures.

Basic statistical gridding allows you to predict unknown values from within a single layer such as topography, bathymetry, geochemistry, vegetation, hydrology, water temperature or climate data. However the real power of GIS is when spatial modelling is applied to combine several layers to predict outcomes based on probability such as:

- Mineral prospectivity
- Agricultural sustainability
- Geotechnical risk
- Environmental risk
- Conservation planning

Adapting the technique for locating or ranking prospective seafloor massive sulphide or manganese nodule targets or for aiding baseline and detailed environmental planning are some of the possible applications for predictive modelling for the marine minerals industry.

Keywords: Geographical Information Systems (GIS), Predictive Modelling, Mineral Prospectivity, environmental planning

Introduction

As the worlds push for mineral resources continues to extend into the marine environment, an area of the minerals industry that has been growing steadily over the past decade, the challenges of operating in this area from an exploration and environmental perspective has become more apparent. Being at the forefront of a new industry, the level of knowledge, information or data is typically limited when compared with established industries.

Given that marine mineral exploration is a costly exercise, the ability to focus exploration efforts and project funding in a more effective manner should be desirable to the players involved.

Similar to all resources projects, managing the environmental effects of activities undertaken (exploration, extraction) is a critical factor for any project. Costs of marine research typically inhibit lengthy broad scale and regionally extensive programmes being undertaken. This can be problematic for those looking to evaluate the potential of marine mineral resources (exploration/mining companies and governments) that presently do not have the same volumes of data as terrestrial counterparts to evaluate the potential impacts of exploration or extraction on benthic habitats in a broader context than just the localised project area.

Predictive modelling is therefore a potentially valuable tool for evaluating this and aiding the management and decision making around the exploration and environmental facets of a project.

Predictive Modelling

Kenex is a New Zealand based company that focuses on data integration and digital knowledge transfer using spatial modelling techniques in Geographical Information Systems (GIS). This modelling is where business can really add value to their data rather than only using it passively to just generate maps.

Basic statistical gridding allows you to predict unknown values from within a single layer such as topography, bathymetry, geochemistry, vegetation and hydrology, water temperature or climate data. However, the real power of GIS is when spatial modelling is applied to combine several layers to predict outcomes based on probability such as mineral prospectivity, agricultural sustainability, geotechnical risk, environmental risk and conservation planning.

Spatial modelling uses multiple layers or themes related to the object or occurrence being searched for to statistically predict areas where it is most likely to be found (Refer Fig. 1). The key to success of spatial data modelling is related to the way it takes into account of how strongly a particular theme is related to the occurrences being modelled (i.e. what is the probability of an occurrence happening in the area of the theme) and then combines all the themes weighted accordingly to their importance to make a prediction.

Since the initial use of ‘Weights of Evidence’ modelling in medical diagnosis and research, spatial modelling has been applied successfully to mineral prospectivity, forestry, conservation and petroleum exploration for example.

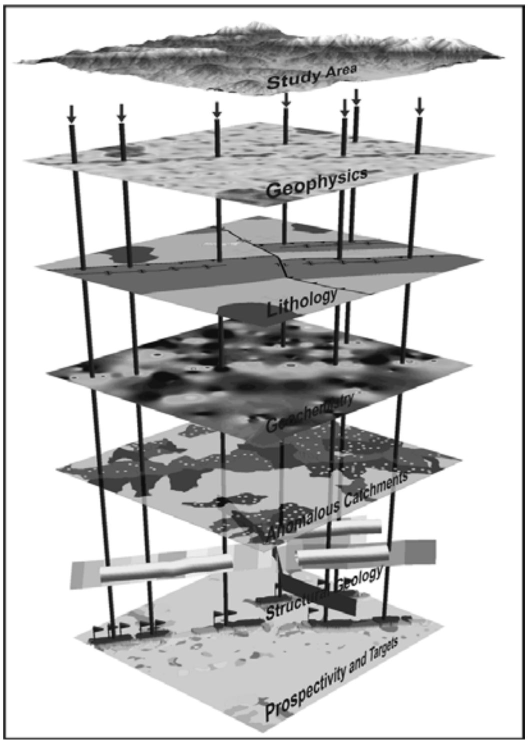


Figure 1. Example predictive layers for Mineral Prospectivity Modelling

A variety of new tools are available for use within a GIS for evaluating the distribution of data in a statistical framework. Using mineral exploration as an example, the creation of derivative spatial 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.

These derivative datasets must be reclassified in a manner that matches the mineralisation model being used. For example, the creation of geochemical anomaly maps from point data values or digital terrain 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 are also used to create the derivative themes. These themes can be used to calculate spatial correlation statistics between the data themes and a training dataset selected from historic areas of mineral production or known deposits.

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

Weights of Evidence modelling in contrast uses statistical analysis of the map layers being used with a training data set to make less subjective decisions on how the map layers in any model are combined. 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 minerals and mining fields. An estimate of the (prior) probability of the occurrence of a specific mineralisation style 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 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 map then defines the probability of finding the mineral at a point on a grid covering the area being explored.

The technique can equally be applied to other industries such as environmental or conservation management, where the number of features important to the habitat of a particular plant or animal can be evaluated.

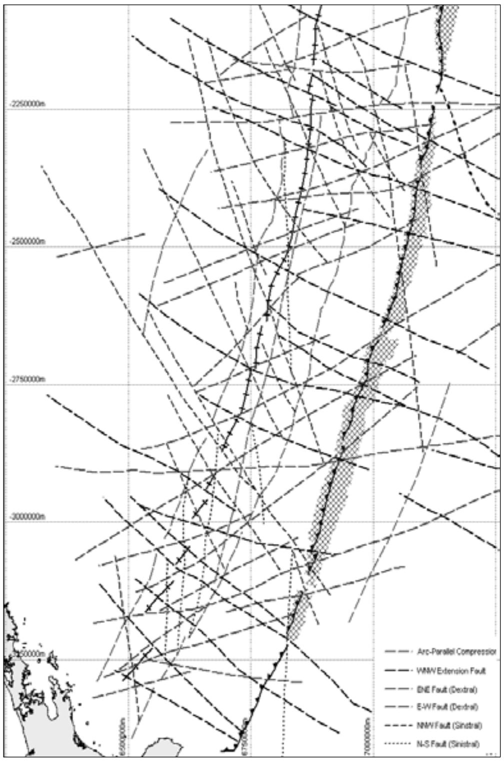
Predictive Modelling for Minerals

Identifying 'target' areas from existing information or post reconnaissance exploration is a key to ensuring effective direction of exploration and expenditure. Kenex has completed multiple modelling projects for clients over the past eight years, for a wide range of commodities, and a wide range of geological settings. Examples include granite related nickel mineralisation in eastern Australia, porphyry copper-gold mineralisation in Papua New Guinea, mafic nickel-copper-PGE and porphyry copper gold mineralisation in Southland, New Zealand and Volcanogenic Massive Sulphide mineralisation in Oman.

Recently Kenex has been giving consideration to how the modelling techniques might be applied to the marine minerals sector. New Zealand alone has several significant minerals opportunities in the marine environment including Seafloor Massive Sulphides (SMS), ironsand and rock phosphate. The level of research on these potential resources has been relatively high; however the work completed to date has yet to narrow down discrete areas where intensive exploration should be undertaken, or from extensive project areas - what target areas have the greatest probability of success.

The initial aim of any prospectivity model is to take a probabilistic approach to exploration targeting to develop a portfolio of targets that have an increased probability of discovery and development, and in doing so reduce the initial search area by several orders of magnitude.

An important aspect to predictive modelling is through the application of a 'mineral systems approach' (e.g. Wyborn et al, 1994), which defines those parts of a mineralisation system that are critical to the ore forming process. These ore forming processes are mapped spatially using GIS analysis and used to predict mineral potential. Evidence for appropriate sources of metal, fluid and energy to drive the mineral system mainly comes from regional scale geology, whole rock geochemistry, magnetic data and known mineral occurrences. Taking SMS as an example, predictive maps for possible sources of metals come from the rocks that are part of the upper crustal sequence at or near the seafloor at the time of mineralisation. The presence of volcanoes/seamounts is an important indicator of heat/energy. The source fluids and metals within a mineralisation system have to be able to migrate effectively to a site of deposition for economic quantities of metals to be present. Again with SMS in mind, fluid focussing structures could include caldera structures (particularly on rim faults) or localised extensional/dilational areas (Refer Fig. 2).



[1]**Figure 2.** Relevant regional structure relating to SMS mineralisation modelling in the Kermadec Arc area

The presence of hydrothermal fluid activity can also be confirmed by areas of low magnetic response in lithologies usually associated with a high magnetic mineral content, where the magnetite has been destroyed by the circulating fluids. SMS mineralisation forms when metal rich hydrothermal fluids meet cooler water or water rich rocks or sediments. Consequently, the main regional control (trap) on mineralisation is the seafloor. The trap is one of the most important variables in any mineral system as it will determine the size and continuity of any resulting orebody, and the type of trap present in a mineral system can be assessed using geological and geophysical data to look for structural controls on mineralisation. The size of the trap can be assessed using low level geochemical data to map the probable extent of the mineral system either by using the metal of interest or the pathfinder elements.

The value of the modelling from the exploration sense is that it enables better informed decision making on exploration effort and funds, acquisition or relinquishment and direction on what further detailed or new information needs collecting.

Environmental Management – The use of predictive tools

Like mineral exploration, the availability of funding to undertake conservation management or knowing where to focus environmental management is often limited. Predictive modelling is a tool that can aid in this process.

Kenex has recently undertaken an environmental project involving habitat modelling for the native powelliphanta land snails on the West Coast of the South Island. These snails are considered an endangered species and have received a large amount of media attention in the

[1] Figure created from information located in Crown Minerals technical reports MR4030, MR4353, MR4354, MR4498 & MR4500.

last few years. The aim of the modelling was to identify sites of ideal habitat conditions where they could possibly be living. The weights of evidence spatial modelling technique has been used to create a predictive map where possible locations of alpine powelliphanta could be. Climatic, soil, topographic and botanical data used in this model came from various organisations such as NIWA, GNS and Landcare Research. The model used known locations of five powelliphanta taxa that occur in high elevation, isolated alpine habitats to find other areas that might support similar powelliphanta populations.

The resulting predictive model for snail habitat locations showed that mountain ranges in north western parts of the South Island have the highest probability of finding powelliphanta land snails. It also showed that high altitude, low temperature and high rainfall conditions are favoured by the snails. The model was validated in the field and some areas not covered by known locations of snail populations that were classified as highly probable by the model have recorded sightings of snails (Wildman and Peters, 2009).

Habitat modelling in the marine setting is an area that Kenex views as having some potential to aid the marine minerals industry. As the marine mineral exploration and extraction industry develops, then so must its understanding of the environment where these projects will potentially take place also continue to evolve.

Currently, operators working or intending to work outside the 12 nautical mile limit in New Zealand's Exclusive Economic Zone are not subject to any environmental management legislation - it just does not exist at present. However this is not to say that companies operating in this legislative vacuum are not concerned about how they manage the effects of their activities on the marine environment, including marine habitats. All operators will be concerned with answering questions such as:

- What are the potential benthic impacts?

    - Direct impact - localised loss of individual organisms living on the area to be explored/mined;
    - Smothering or entombment of epifaunal, infaunal and slow moving or sessile benthic organisms;
    - Alteration of nutrient values;
    - Clogging of the filtering apparatus of suspension feeding organisms;
    - Possible toxic effects associated with release/agitation of deposit; and
    - Loss of brood stocks from restricted specialised habitats.

- What are the potential water column impacts?

    - Oxygen depletion by bacterial growth on suspended particles; and
    - Dissolution of minerals within the oxygen minimum zone and incorporation into the food chain.

- Potential Photic Zone Impacts

    - Effects of trace minerals on surface productivity; and
    - Effects on behaviour of marine mammals and seabirds due to reduced water clarity.

But can this be done effectively when often there is a lack of quantitative information? Can predictive modelling be an accepted tool in aiding the development of effective environmental management strategies and exploration plans?

Predictive modelling to map deep sea communities could be an alternative to 'traditional' methods such as direct sampling, remote sensing and acoustic survey which for often typically large expanses (e.g. prospecting licences) is neither cost nor time effective. The principle of this type of modelling is in the utilisation of combined key environmental parameters to produce criteria to understand species distribution and hence generate predictive maps.

Understanding the representiveness of a particular habitat or individual species is important in understanding its uniqueness in the area marked for extraction as an example is not only important to operators but decision makers.

Predictive models are not better than the data used to develop them, and with data typically being scarce in some areas (or widely spaced) then further refinements would need to focus on validation through obtaining new data, however in the absence of definitive data, predictive modelling could aid where data should be collected.

A variety of data in vector and/or raster format would be necessary for the effective modelling of marine habitats. In the marine environment this would likely include:

- Bathymetry – Bathymetric data is an important source of information for mapping and modelling benthic habitat as direct depth measurements and models of depth which can be used as a basis for calculation of the topography of the seabed (complexity, slope, aspect).

- Substrate – The type of substrate is one of the main factors affecting the distribution of organisms that live in, on or near the seafloor. The type of substrate will not explain all patterns of distribution, but it will be a key variable to be included as part of the process of mapping and modelling benthic habitats.

  Sediment core and grab samples could be used to create analogue sediment maps including using information on composition of sediment grain size.

  Evaluation of backscatter data from multibeam surveys could prove to be an efficient and cost effective method of achieving accurate and high resolution data on the spatial distribution of different substrate types.

- Oceanography – Oceanographic variables would be an important class of data for the modelling of marine habitats. Oceanographic parameters could include light exposure and the impact of current and/or wave exposure (in shallow marine environments). The quality of light on the seafloor is influenced primarily by solar influx, depth and water turbidity. These three parameters combined determines the light climate at a particular location which is considered to be a main factor in determining the vertical distribution of different algae species enabling the formation of different pelagic and benthic communities.

Ocean currents and/or exposure to waves are an important variable in structuring flora and fauna (particularly on hard substrate). Current and/or wave activity affects the phyto-benthic communities through the formation of substrate quality and direct physical disturbance.

- Chemistry – Salinity, temperature and oxygen are potentially important in the variability of benthic flora and fauna.

- Biological information – Empirical data on known locations of certain flora/fauna would be valuable as potential 'training points' in a modelling exercise.

(Dinesen, 2008)

Summary

Spatial data modelling techniques where the individual predictor themes of a mineral system or habitat are combined into a single predictive map could be particularly useful when targeting the varied array of marine mineral opportunities within New Zealand's EEZ as well as a management tool when dealing with the potential and/or anticipated effects on marine habitats proximal to the area of exploration or extraction.

From our view the opportunity certainly exists for predictive modelling to be a useful tool in developing baseline information of habitat over a wide extent and should therefore be a consideration as companies embark on marine mineral projects.

As with any modelling project, the quality of the data that is utilised will impact on the accuracy of the end result. As such, a project specific data discovery and evaluation process, and input from experts would be critical prior to the commencement of the development of positive spatial associations and development of a predictive model.

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