The Southern New England Orogen Mineral Potential Project

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Abstract

The Southern New England Orogen (SNEO) in the northeastern part of New South Wales (NSW) is prospective for intrusion-related tin-tungsten, intrusion-related gold-bismuth-molybdenum-silver and orogenic gold-antimony mineral systems. An initiative by the Geological Survey of NSW to conduct mineral potential modelling for these mineralisation styles in the SNEO has resulted in a comprehensive account of the mineral resource potential of the region.

The Geological Survey of NSW has a successful strategy of providing high quality pre-competitive data that has been complemented and enhanced by the mineral potential mapping approach. Datasets including seamless basement geology, detailed attribution of faults, and igneous fertility that were created by the survey prior to modelling enabled an extensive number of variables be tested for relevance to each mineral system. The feedback from the data processing and spatial analysis allowed improvements to be made to the data and provided information on the relevance of the datasets to mineral exploration in the region.

The outputs of the models are mineral potential maps that map the geological potential of the SNEO for each mineralisation style. The models will be used for land planning and advice purposes, technical resources for improved mineral system studies including global endowment estimations, and for promoting exploration in the SNEO through the generation of prospective targets.

Due to the richness of the geological datasets in NSW it is likely that the technique, including the creation of high-quality datasets combined with mineral potential modelling, can be successfully applied to other mineralised regions within NSW.

Keywords: Southern New England Orogen, intrusion-related tin-tungsten, intrusion-related gold, orogenic gold-antimony, pre-competitive data, predictive variables, mineral potential mapping

Introduction

The Southern New England Orogen (SNEO) Mineral Potential Project has been developed as a pilot study by the Geological Survey of NSW with the purpose of promoting the quality of their pre-competitive datasets and how these datasets can be used to determine the geological potential for the three main mineral systems within the region; intrusion-related Sn-W, intrusion-related Au and orogenic Au-Sb. The project was developed in collaboration with Kenex Pty Ltd (Kenex), using the mineral system expertise of the Geological Survey of NSW staff along with their newly developed geological datasets. The results of the project will be used primarily for land planning and advice purposes, but are also valuable for promoting and guiding exploration in the SNEO by highlighting prospective areas, providing an atlas of

predictive maps that map the various components of each mineral system and identifying the key predictive variables for each mineralisation style.

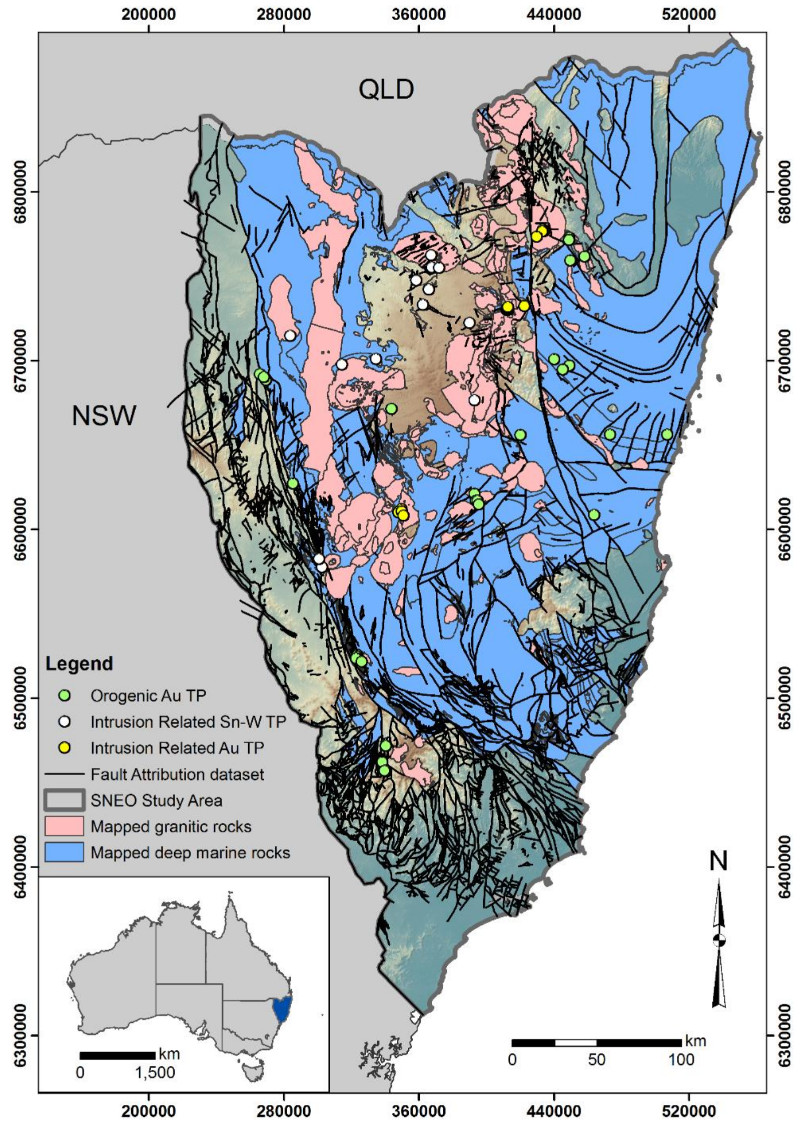

Figure 1. Location of the SNEO study area with key rock types extracted from the seamless geology, faults and training data

The SNEO, in the northeastern corner of NSW is a large Sn province with many large to very large intrusion-related Sn-W and related base metal vein systems. These include the Emmaville-Torrington district, which hosts the large Taronga Sn deposit, the Tingha district near Invernell and the Ruby Creek area near Stanthorpe. Compared to many other Sn-W systems in NSW most of the mineralisation in the SNEO is associated with I-type intrusions. Intrusion-related Au ± Bi-Mo-Ag deposits in the SNEO are also associated with I-type intrusions. Known deposits are less regionally extensive than the Sn-W systems and occur along a NNE to SSW trend including Timbarra and Seven Hills. Orogenic Au and Au-Sb mineralisation is widespread in the SNEO. Major deposits/districts occur adjacent to the Peel Fault, at Hillgrove and with many smaller zones located in the Coffs Harbour Block and the Nambucca Block to the east of Demon Fault. Most orogenic Au deposits in the SNEO are hosted by marine sedimentary rocks (Figure 1).

Mineral potential mapping 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 output mineral potential maps highlight areas with similar geological features as known mineral deposits. Mineral potential mapping is a versatile mapping 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). Importantly, these techniques can be applied to a wide range of mineralisation styles and are complementary to the recently adopted mineral systems approach (Wyborn et al., 1994; McCuaig et al., 2010). The commonly used weights of evidence technique is data driven and allows for a complete spatial analysis of the geological datasets with respect to the mineral system model being tested.

The SNEO Mineral Potential Project was undertaken using the following workflow:

- Review and compilation of available data
- Research and confirm mineral deposit model descriptions
- Determine the key predictive variables and development a spatial data table
- Select training data and define study area
- Prepare predictive maps
- Undertake weights of evidence spatial analysis to create weights and test correlations
- Select predictive maps for the final models
- Generate mineral potential maps
- Report and deliver

A significant outcome of the project is a SNEO Mineral System Atlas that contains all the GIS files generated for each model including: training points, study area, predictive maps, weights tables and mineral potential models as well as a detailed spatial data table. The spatial data table is an important document that explains the files and the processes undertaken to create them.

Data

Pre-Competitive Datasets

Data applied to mineral potential mapping need to be spatially extensive, describe components of the mineral system model as unambiguously as possible and fit into the temporal framework of the established mineral systems model. The most common datasets needed are geology, geochemistry, geophysics and mineral occurrences.

The datasets used for this project have been created and compiled by the Geological Survey of NSW in geodatabase (GDB), shapefile, raster format and include:

- Mineral occurrences (MetIndEx) including deposit locations, alteration descriptions, deposit types, and vein structural data
- Seamless Geology GDB including rock units, folds and structural data
- Fault Attribution GDB
- Geophysical data including magnetics (TMI datasets and processed magnetic worms), gravity and radiometrics

- Geochemical data including drill hole, stream and surface samples with assays
- Igneous Fertility GDB
- Reactive Rocks GDB
- Metamorphism GDB
- Field observations point file

Several of the SNEO datasets were compiled prior to the commencement of the mineral potential project and were designed specifically to increase the value of mineral potential mapping and increase understanding of mineral systems in the region.

For example, to create the Fault Attribution GDB, faults from the Seamless Geology GDB were individually attributed with information relating to fault grouping, fault architecture, fault geophysical character, and fault kinematics and event chronology. A full description of the attribution methodology and the structural framework of the SNEO can be found in the report (Phillips 2016, GS2016/0967). The level of attribution has allowed many fault-related predictive variables to be tested that are often left out or approximated due to a lack of detailed information.

The data were reviewed prior to modelling, but very little modification to the datasets was required. The review process enabled the Geological Survey of NSW to further improve the quality of their datasets.

Data Processing

The compiled datasets were analysed and reclassified in accordance with the mineral system models. Data processing included, classifying and attributing rock units, creating derivative point datasets from fault data, creating linear vein datasets from point data, determining anomalous thresholds for geochemical data relevant to the mineral system and creating geochemical anomaly grids.

The Mineral Systems Approach

Ore deposit models have been developed by the Geological Survey of NSW that describe the region-specific process factors of ore-formation, products of the mineralisation process, characteristics of the regional and local geology and structure, inferences about the tectonic setting and grade and tonnage data. These models provide important research and knowledge that is needed to guide the weights of evidence spatial analysis and development of mineral potential maps. Conversely the modelling process can identify variables important to mineralisation that weren’t considered in the ore deposit models.

For the mineral potential mapping process, it is important to step back from the deposit scale models and look at the entire mineral system. It has been recognised that mineral deposits are the focal points of much larger systems of energy and mass flux. The critical parameters of ore deposit formation can be reduced to those geological factors that control the generation and preservation of mineral deposits, and the processes that are involved in mobilising ore components from a source, transporting and accumulating them in more concentrated form and then preserving them throughout subsequent geological history (Figure 2). Ore deposit formation is precluded where a mineral system lacks one or more of these essential components.

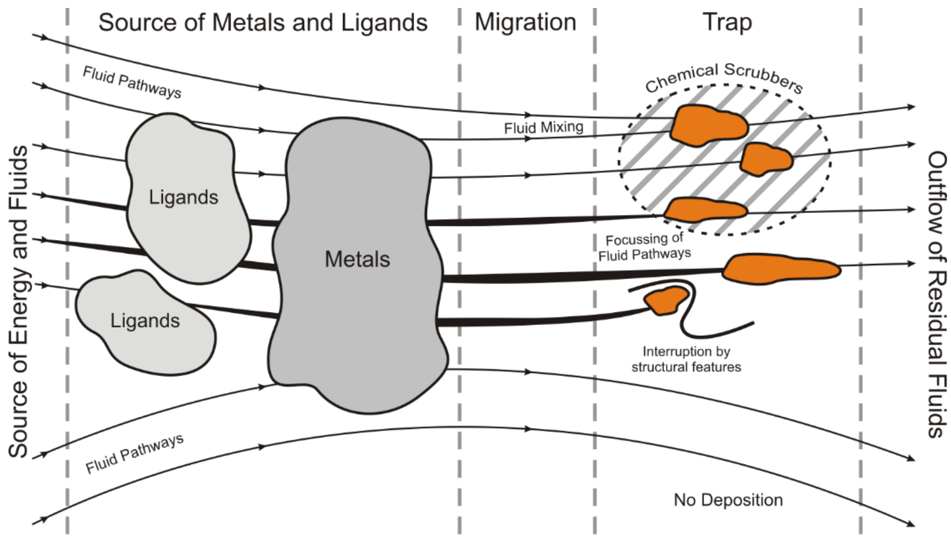

Figure 2. The essential geological components that define a mineral system include: A source of energy that drives the system; Sources of fluids, metals and ligands; Migration pathways allowing fluids to travel to trap zones; Physical throttles (i.e. narrow, effective pathways) that focus fluids and modify fluid composition; Chemical scrubbers that facilitates the conversion of ore from fluid to solid form; Outflow zones for discharge of residual fluids (modified from Knox-Robinson and Wyborn 1997).

The key geological features that characterise each mineralisation style as detailed in the deposit models have been extracted and grouped by the relevant mineral system component. Based on this review the Geological Survey of NSW provided additional attributes to some of the datasets including granite age and known presence/absence of a roof pendant, indicating a likely position in the mineralised roof zone of the magma chamber. The list of geological features guided the development of a comprehensive spatial data table that lists every possible predictive variable that could be tested for a relationship with mineralisation and records information on the relevance to the mineral system, the data required, methods used to turn the data into a predictive map, and eventual spatial correlation results.

Weights of Evidence Spatial Analysis

Model Parameters

The weights of evidence modelling technique has been used for this project to evaluate the mineral potential of the SNEO. Weights of evidence is a Bayesian statistical approach that allows the analysis and combination of various datasets to predict the location of the feature in question (Bonham-Carter, 1994). It is based on the presence or absence of a characteristic or pattern and the occurrence of an event. The spatial analysis process allows for a non-biased assessment of large numbers of predictive variables to determine their relevance to the mineral system. The spatial analysis and mineral potential modelling has been carried out using Arc-SDM.

Weights of evidence models require training data to determine spatial correlations and weights for each predictive map tested. Training data were chosen from the MetIndEx dataset for each mineralisation style by Geological Survey of NSW geologists. The training points that were selected for each model have sufficient regional spread, are the same style and age of mineralisation, and represent the range of mineral assemblages present within the mineral system. The intrusion-related Sn-W and intrusion-related Au models both have 13 training points and the orogenic Au-Sb model has 28 training points.

A study area was created that matches the extent of the Seamless Geology rock unit data for the SNEO. The study area was converted into a 50 m by 50m grid that represents the extent of the model and the cell distribution for all subsequent grids created during the modelling process. The size of the grid was chosen to represent the minimum scale that the data should be viewed.

A unit cell of 1 km^2 was used for the statistical calculations and is the area covered by each training point. Using the input parameters of the study area, unit cell and number of training points a prior probability was calculated for each model. The prior probability is the chance of randomly finding a deposit within the study area before any additional evidence for mineralisation is applied. The aim of weights of evidence modelling is to add evidence in support of a hypothesis to increase or decrease the prior probability of each grid cell in the study area. The prior probability is 0.000101 for the intrusion-related Sn-W model, 0.00011 for the intrusion-related Au model and 0.00236 for the orogenic Au-Sb model.

Spatial Analysis

The spatial correlation of a feature is calculated by using the relationship of the area covered by the feature being tested and the number of training data points that fall within that area compared with the number of points that fall in the remainder of the study area. This calculation produces a positive W+ value for features that correlate with the training data and a negative W+ value for the features that don’t correlate. The opposite applies for the W- value. Each feature gets a W+ and a W- value representing the positive and negative weight of the variable.

Other important values that are calculated are the contrast (C) and the studentised contrast (StudC). These are used to determine the strength and statistical validity of the correlation. The C value is calculated from the difference between W+ and W-. The StudC value is the ratio of the standard deviation of the contrast (Cs) to C. This provides an indication of the uncertainty in the C value; if the contrast is large compared with its standard deviation, it implies that the contrast is more likely to be real. The higher the values of C and StudC the stronger the spatial correlation of the feature being tested. In this study, a very strong correlation is inferred from C values > 3.0, and StudC values > 4. Strong correlations are inferred from C valued between 2.0 and 3.0, and StudC values > 3. Moderate correlations are inferred from C values between 1.0 and 2.0, and StudC values > 2. Weak correlations are inferred from C values < 1.0, and StudC values < 2.

The spatial analysis process results in the creation of between 71 and 101 predictive maps for each model that have been tested for a spatial correlation with the training data. The percentage of maps that correlated well with the training data (C value ≥ 1) was high, ranging from 74% to 93%. The spatial correlation results for each predictive map are stored in the SDT and are an important resource for understanding the relevance of each dataset to mineralisation in the SNEO.

The spatial analysis has identified the most important variables for predicting intrusion-related Sn-W, intrusion-related Au and orogenic Au-Sb mineralisation in the SNEO based on the data available for this study. These are summarised in Table 1. These variables should guide data collection and attribution in this region and potentially other regions with the same mineralisation styles.

Table 1. Key variables for each mineralisation style determined from weights of evidence spatial analysis.

Data Type (Mineral System Component)	**Intrusion-Related Sn-W Key Variables**	**Intrusion-Related Au Key Variables**	**Orogenic Au-Sb Key Variables**
Lithology/Igneous fertility (Source/Transport/Trap)	Granite characteristics: I-Type, 230-259 Ma, miarolitic cavities, aplite, pegmatite, microgranite, porphyritic, leucosyenogranite textures, high heat producing; Roof pendants; Granite contacts; Competency contrast.	Granite characteristics: I-Type, 230-259 Ma, miarolitic cavities, aplite, pegmatite, microgranite, porphyritic, leucosyenogranite textures, intermediate oxidation states, high heat producing; Roof pendants; Granite contacts; Competency contrast.	Marine metasediments with a mafic component; Mafic/ultramafic units; Deep marine depositional environment; Competency contrast; Breccias; Sheared margins of competent lithologies; <100 km^2 felsic intrusions; Iron rich rocks.
Metamorphic type (Source)	NA	NA	Sub-greenschist to greenschist facies
Mineral occurrences (Source/Deposition)	Occurrences of Pb, Zn and Ag, isolated occurrences of Sn and W, as well as chlorite, carbonate, and fluorite gangue minerals; Density of known Sn occurrences; Greisen and chlorite alteration.	Occurrences of Bi, Mo, W, Ag, Pb, and Zn, as well as chlorite, carbonate, and fluorite gangue minerals; Density of known Au occurrences; Placer Au deposits; Density of placer Au deposits.	Density of Au, Sb, stibnite, W and Hg occurrences; Placer Au deposits, density and source; Chloritic alteration.
Water bore data (Source)	Granite descriptions in water bore lithology to identify shallowly buried granites.	Granite descriptions in water bore lithology to identify shallowly buried granites.	NA
Faults (Transport/Trap)	Fault sub-sets: E-W trending, 4th order faults, active during the Hunter Bowen Contraction, combined 3rd and 4th order; Intersections and splays.	NA	Fault sub-sets: reactivated, thrust, NW-SE oriented, 4th order faults and veins, west dipping; Density; Bends; Intersections between faults and reactive rocks.
Veins (Transport/Trap)	Vein density and proximity to veins.	Proximity to veins	Vein density and proximity to veins.
Magnetic worms (Transport)	Magnetic worm heights of 11944 and 14333.	Magnetic worm heights of 4000 and 4800.	Magnetic worm heights of 9953 to 14333.
Magnetics (Deposition/Trap)	NA	NA	Lows; Slope; Lows along faults.
Radiometrics (Deposition/Source)	U, Th and K radiometric highs.	U, Th and K radiometric highs.	NA
Stream geochemistry (Deposition)	Stream catchments containing stream samples with anomalous Sn, W, Ag and As.	Stream catchments containing stream samples with anomalous Au, W, Ag, Bi, As, Sb, Te and Mo.	Stream catchments containing stream samples with anomalous Au.
Rock chip and drill hole geochemistry (Deposition)	Rock chip and drill holes with anomalous Sn, W, Ag, Zn, As and Pb.	Rock chip and drill holes with anomalous Au, W, Ag, Bi, As, Pb and Mo.	Rock chip and drill holes with anomalous Au, Ag, As, Sb, and W.

Mineral Potential Maps

A mineral potential map was developed for each mineral system, using a selection of 18 predictive maps that represent all stages of the mineral system model defined for each mineralisation style. Predictive maps for the models were chosen that have the best regional coverage, a significant spatial association with the mineral system model being considered and minimal duplication of predictive map patterns.

The output mineral potential maps are grids that map the geological potential for mineralisation for each grid cell. The output grid values range from 0-1 and map the post probability, which has either increased or decreased from the prior probability, depending on the combination of weighted predictive map variables. In Figure 3-Figure **4** below the areas that are coloured from blue to red have post probability values that are above the prior probability for that model with the red areas having the highest values. The models can be validated by calculating the efficiency of classification which is a measure of how well the training sites were classified by the model. If fewer than 10% are not well classified the model is considered acceptable.

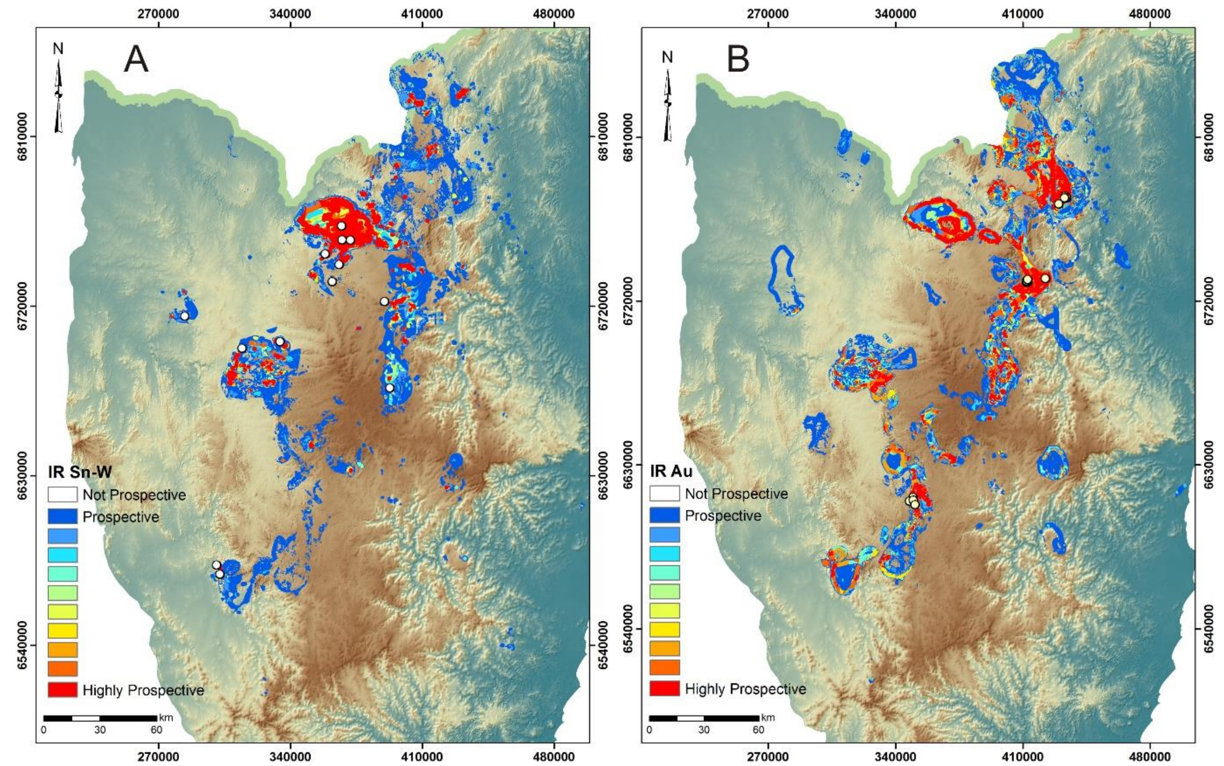

Figure 3. Mineral potential maps for intrusion-related Sn-W (A) and intrusion-related Au (B) mineralisation in the SNEO.

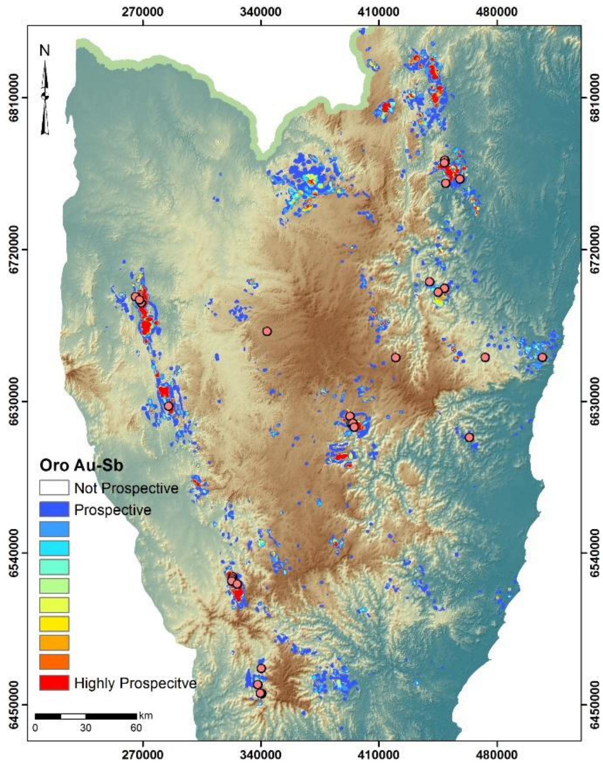

Figure 4. Mineral potential map for orogenic Au-Sb mineralisation in the SNEO.

For the intrusion-related Sn-W and intrusion-related Au mineral potential maps the area considered to be prospective covers only 6% and 8% of the study area respectively. For both models the training points all fall in the highly prospective area with all but one from the intrusion-related Au training points falling outside of the highly prospective areas classified in Figure 3. The efficiency of classification for both mineralisation styles is 99.5 % confirming the validity of the models.

For the orogenic Au-Sb mineral potential map the area considered to be prospective covers only 4.5% of the study area. Two training points fall outside of the prospective area and 20 of the 28 training points fall in the highly prospective area classified in Figure 4. The efficiency of classification is 97.6% confirming the validity of the model.

Discussion

The key outcome of the SNEO Mineral Potential Project is the creation of the SNEO Mineral Potential Atlas. The Atlas contains all the GIS files that were created to produce the mineral potential maps for each mineralisation style including, training data points, study area grids, predictive map grids, weights tables and mineral potential grids. The Atlas also contains a detailed spatial data table that is an important document containing information relating to the various GIS files including methods for creating predictive maps, model set up, spatial correlation statistics and predictive maps combinations used for the final mineral potential maps. The SNEO Mineral Potential Atlas has been released to the public through the Geological Survey of NSW website.

The main use for the SNEO Mineral Potential Project within the Geological Survey of NSW is to guide land planning and decision-making processes. The spatial analysis and resulting mineral potential maps can also be used for exploration planning. The Atlas has been

designed so that the predictive maps can be used as independent maps that provide information about the relationship of the data to mineralisation. The predictive maps can also be combined in different ways to create new mineral potential maps that highlight prospective areas for exploration purposes. The highly prospective areas can be converted into targets that can be attributed, ranked and filtered to aid ground acquisition and prioritisation of existing ground. New predictive maps and mineral potential models can easily be created when new data is updated or new datasets become available.

The spatial analysis process has confirmed existing ideas about the mineral systems based on the deposit models and relevant predictive variables that were previously not considered have been identified. This shows that it is important to have prior knowledge of the mineralisation style being mapped and to keep an open mind, testing all possible variables in case something unexpected shows up. The key predictive variables identified in Table 1 should be used as a guide to data collection and attribution in the SNEO.

The SNEO Mineral Potential Project, combining high-quality pre-competitive data with weights of evidence spatial modelling techniques, has successfully mapped the mineral potential of the SNEO for intrusion-related Sn-W, intrusion-related Au and orogenic Au-Sb mineralisation and produced a comprehensive Mineral Systems Atlas for the region. This methodology can be applied in other geological provinces of NSW with data compilation in some project areas already underway.

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