Mineral Potential Mapping for Land Management and Exploration Decision Making

A Case Study from the Southern New England Orogen

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Kenex
Creating opportunities in the spatial world

Mineral Potential Mapping – Why?

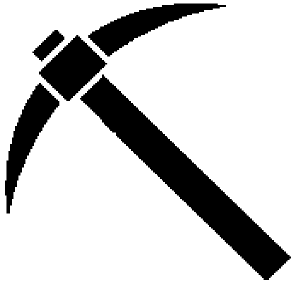
The practical implication of high discovery risk for strategic planning and exploration budgeting is a large difference between the average cost of exploration success and the level of funding required to ensure success (e.g. finding “World Class” deposits).

GOVERNMENT

- Broad-scale mapping
- Pre-competitive data
- Land management

- Broad-scale modelling

EXPLORATION COMPANIES



- Detailed mapping
- Area selection
- Exploration targeting

- Detailed modelling

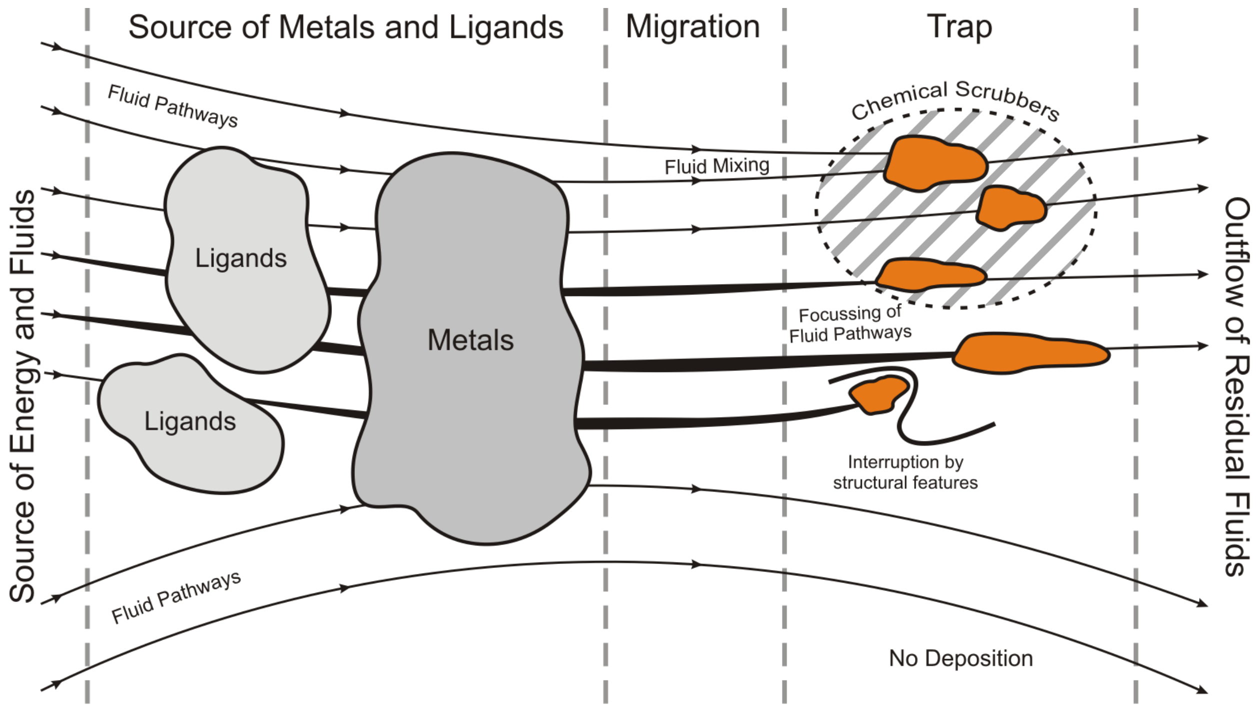
Mineral Potential Mapping

- Mineral systems analysis
- Data compilation and preparation
- Translating mineral systems processes to mappable criteria
- Mapping criteria from available GIS data
- Testing how useful the maps are for predicting mineralisation
- Producing mineral potential maps
- Assessing the results

Stakeholder Engagement

Mineral Systems Analysis – What is it?

- Requires critical parameters for ore formation to be identified:
  - Controls on generation and preservation of ore
  - Processes that cause metals to be mobilised from Source, Transport, and Deposition into Traps.
- Allows for multiple mineralisation styles to be realised in a single mineral system.

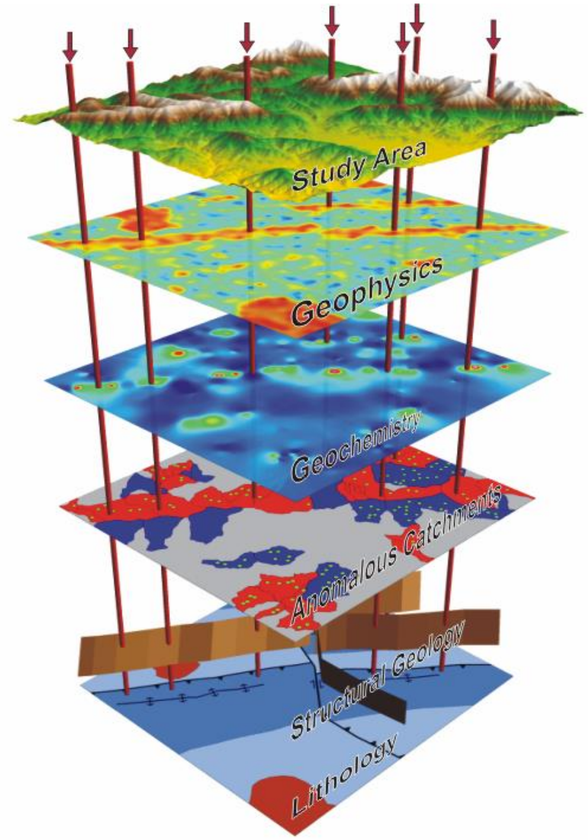


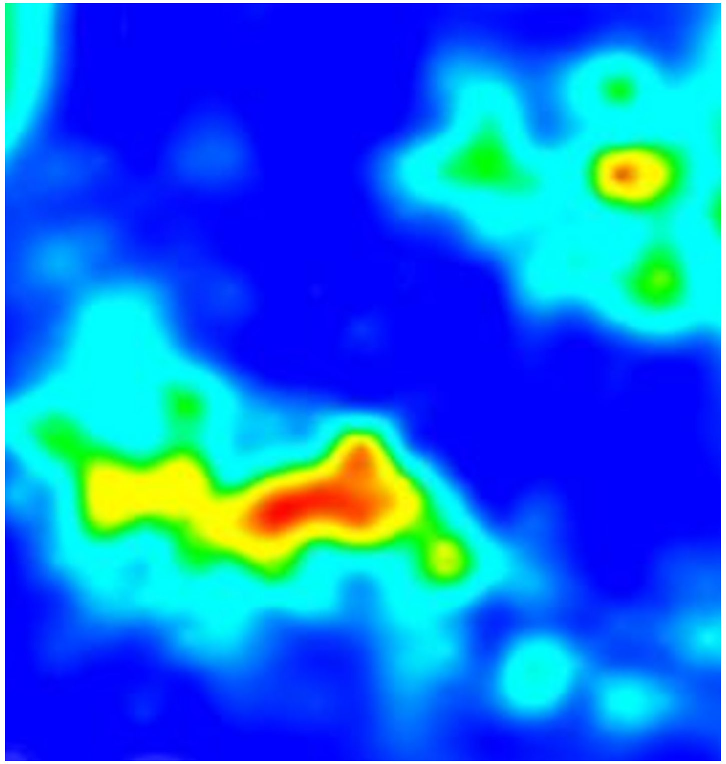
Mineral Systems Analysis – How to use it?

- Not ore deposit models
  - Economic geology traditionally focuses on differences between deposits
  - Mineral systems analysis aims to establish similarities
- Understanding the fundamental underlying processes
  - E.g. In a hydrothermal mineral system, what is the source of the heat driving the fluid flow? How is that fluid being transported through the crust? What causes the metals in the fluid to drop out?
- Stop worrying over the detail
  - Can test details later
  - Might find the results aren’t always what you expect!

Stakeholder Engagement

- What is being modelled?
- Why is it being modelled?
- Mineral systems expertise
- Data
- Deliverables





Mineral Systems Analysis – Review it…

	SOURCE	MIGRATION	TRAP	DEPOSITION
REGIONAL	CRITICAL • Mantle lithosphere • Magma series • Geodynamic setting, age	CRITICAL • Lithospheric architecture • Long-lived features • Paleocraton margins	LESS RELEVANT	LESS RELEVANT
CAMP	IMPORTANT • Mantle lithosphere • Magma series • Geodynamic setting, age	CRITICAL • 4D structural model • Upper crustal architecture • Large-scale damage zones	CRITICAL • Complexity • Competency contrasts • Permeability barriers	CRITICAL • Alteration • Geochemical anomalies • Geophysical anomalies
PROSPECT	LESS RELEVANT	IMPORTANT • Large-scale damage zones • Lower order structures	CRITICAL • Dilational zones • Reactivity contrasts • Alteration	CRITICAL • Alteration • Geochemical anomalies • Geophysical anomalies

Modified from McCuaig and Beresford, 2009

Data Compilation

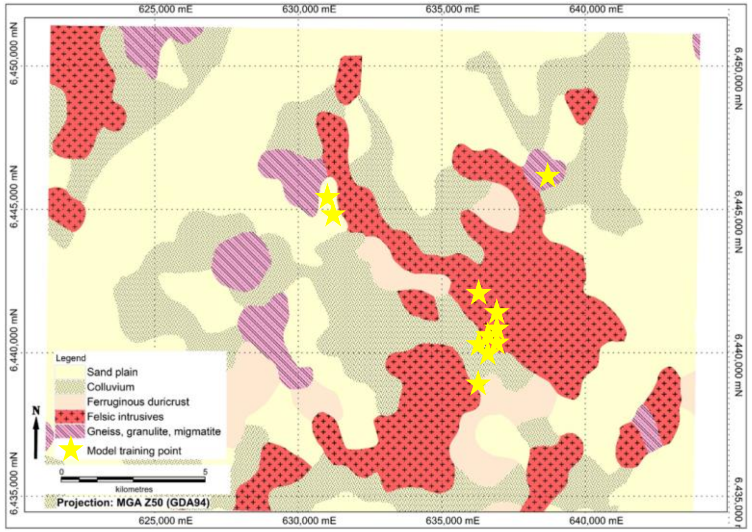
- Go back to your mineral systems model
  - What are your source, transport, and deposition to trap processes?
- Do you have the right type of data and the necessary attributes?
  - If you have an intrusion related mineral system, do you have a well attributed granite map?
  - If you are looking at a classic Archaean greenstone gold mineral system, do you have a well attributed fault map?
- Upgrading existing datasets
- Acquiring new data
- QA/QC – time consuming!

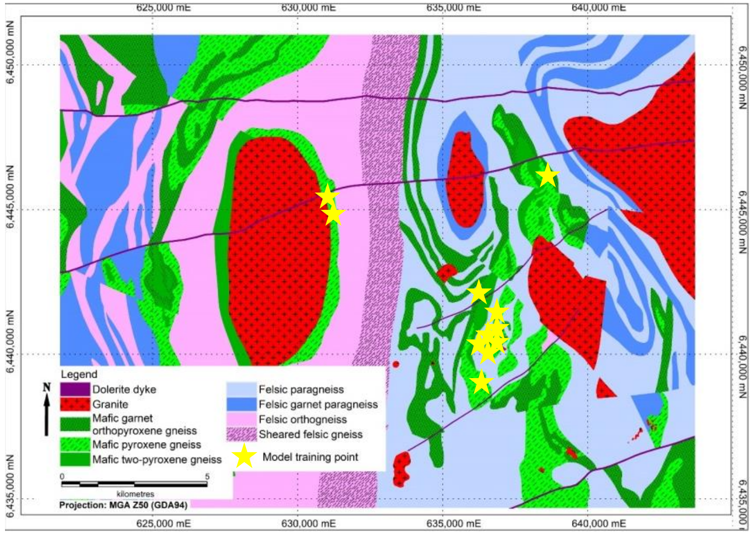
Stakeholder Engagement

Data Preparation

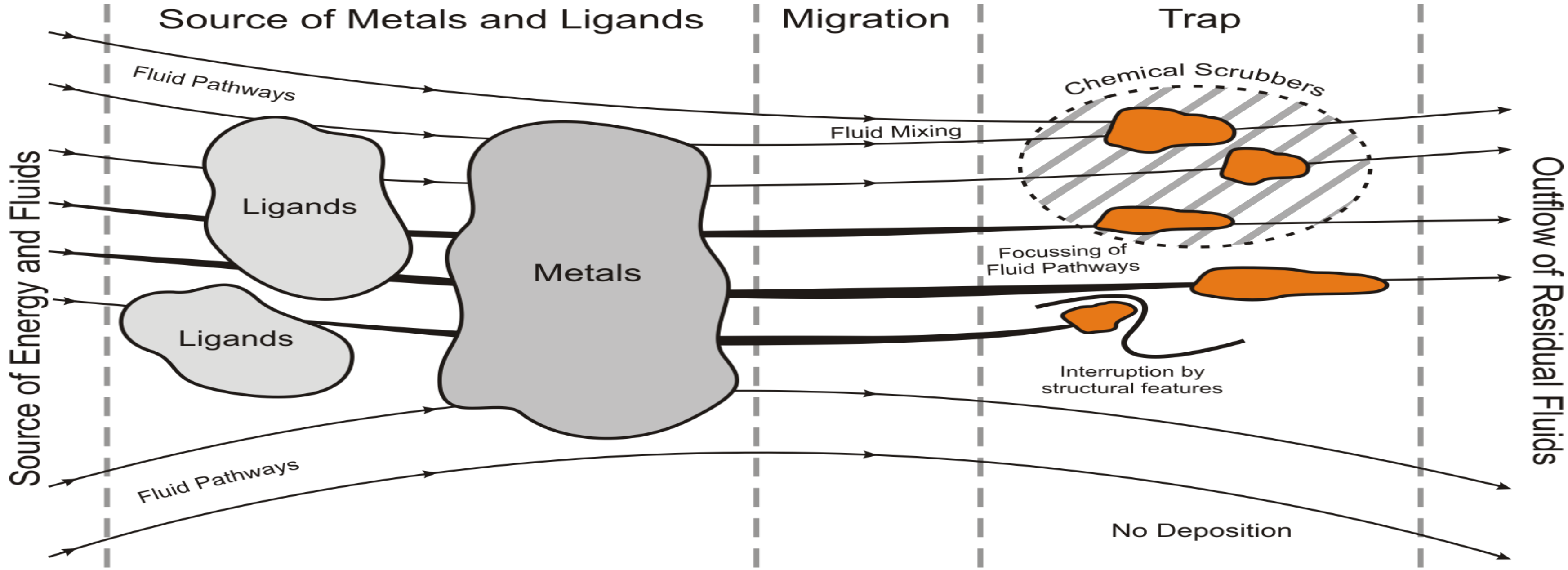
- Good quality datasets are key to a successful mineral potential mapping project
- Data should be reviewed and changes fed back to the original dataset and feedback provided to the client
- Critical to get the training points and geology right
  - Are training points correctly attributed and located?
  - Do the training points sit in the right lithology?

Stakeholder Engagement





Mapping Mineral System Processes



MAPPABLE CRITERIA	• Deformation • Metamorphism • Magmatism	• Connate brines • Magmatic fluids • Meteoric fluids	• Enriched source rocks • Magmatic fluids	• Structures • Permeable zones	• Structures • Chemical traps	• Structures • Aquifers
SPATIAL PROXIES	• Metamorphic grade • Igneous intrusions • Sedimentary thickness	• Evaporites • Organics • Isotopes	• Radiometric anomalies • Geochemical anomalies • Whole-rock geochemistry	• Fault/shear zones • Folds • Geophysical or geochemical anomalies • Alteration	• Dilational traps • Reactive rocks • Geophyiscal or geochemical anomalies • Alteration	• Geophysical or geochemical anomalies • Alteration • Structures

Mapping criteria from available GIS data

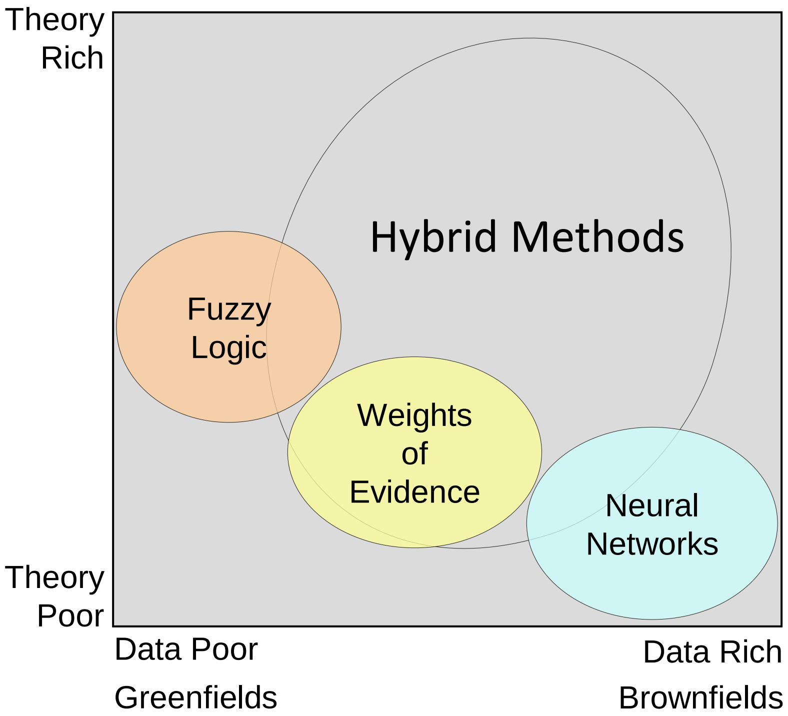
- Do you have the data available to map the targeting criteria?
- Do your datasets have the required attributes to select out the relevant features?
- Go back to your mineral system model
  - Check that the results of your queries are meaningful
- If you can't map something, make a note of why
  - Data availability?
  - Scaling?
  - Expertise?

Stakeholder Engagement

Testing Maps Using Spatial Analysis

- Selecting the spatial analysis technique to be used
  - Training data?
  - Mineral system expertise?
- Data-driven methods need known deposits
  - Useful for brownfields exploration
- Knowledge-driven methods use expert knowledge
  - Useful for greenfields exploration
- Kenex focuses on the use of Weights of Evidence
  - Statistically driven but user retains control over model
  - Use Logistic Regression as a complementary tool
  - Fuzzy Logic used if insufficient training data

Stakeholder Engagement



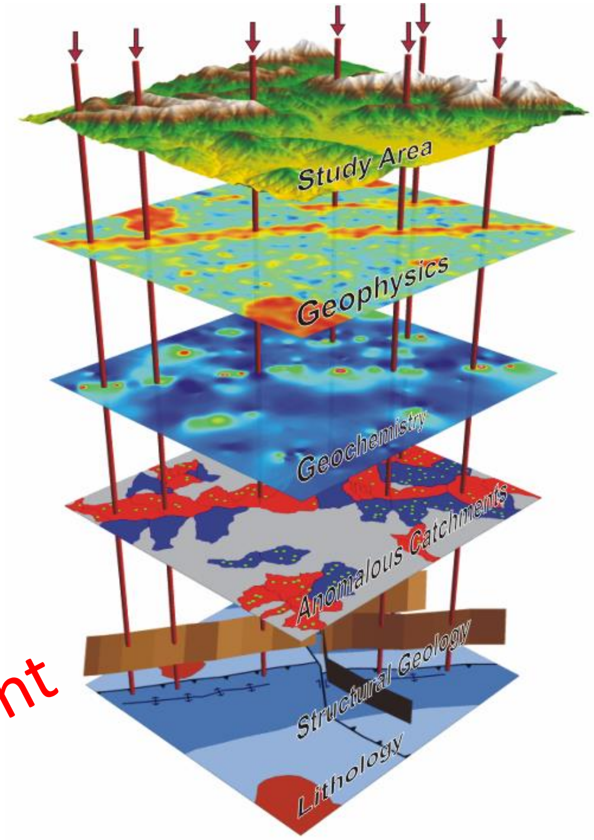
Producing mineral potential maps

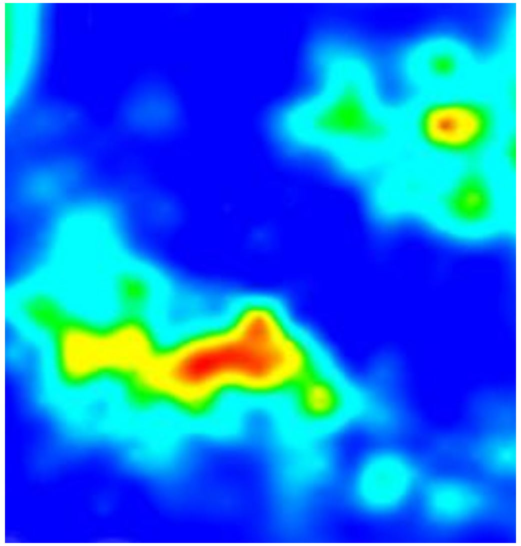
- Engage with stakeholders to select maps to go into mineral potential models
- Maps with best statistics might not be fit for purpose
- Go back to the mineral system model
  - Do you have a useful map to represent each mineral system process?
- Maps need to be geologically meaningful, statistically valid, and practically useful
- Select a method for integration

Mineral Potential Mapping

- Data-driven integration
  - Let the statistics decide which maps to include
- Knowledge-driven integration
  - Let an expert decide which maps to include
- Hybrid
  - Let the statistics guide an expert decision

Stakeholder Engagement





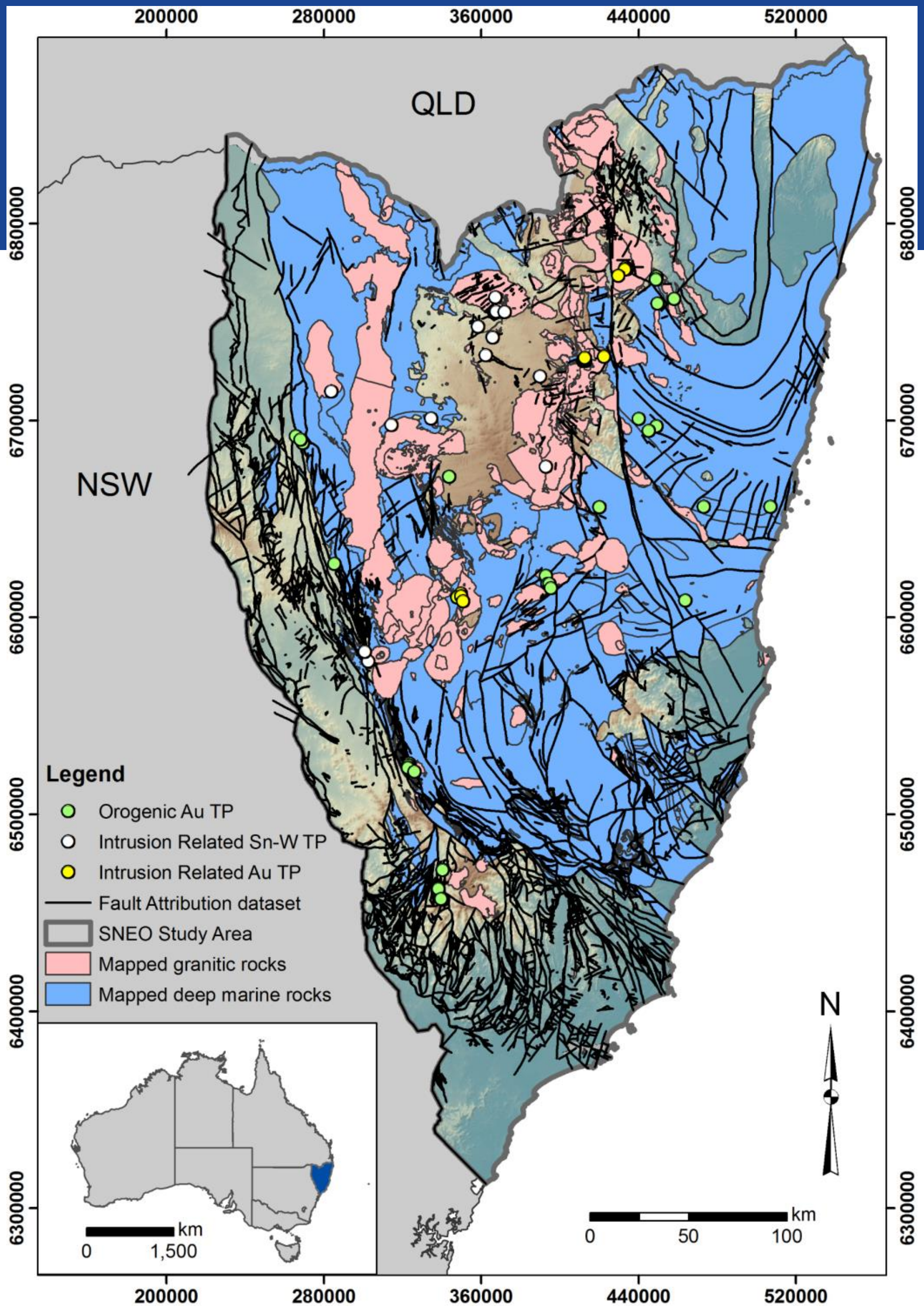
Assessing Mineral Potential Mapping Results

- How well does the mineral potential map predict known mineralisation?
- Field-checking prospective areas?
- What are the results going to be used for:
  - Delineating exploration targets?
  - Land use decision making?
- Revising mineral system model and subsequent analysis

Stakeholder Engagement

Southern New England Orogen Case Study

- Geological Survey of NSW (Australia) embarking on a statewide mineral potential project
- Approach utilises GS NSW mineral system expertise and high quality pre-competitive data
- Pilot study conducted in the Southern New England Orogen (SNEO), mapping mineral potential for intrusion-related Sn-W, intrusion-related Au, and orogenic Au-Sb
- Outputs being used for land planning and advice purposes, and for promoting exploration in the SNEO
- Data package released on the DIGS website: https://search.geoscience.nsw.gov.au/product/9222
- Project Report: GS2017/0624
- Current follow-up project in western NSW

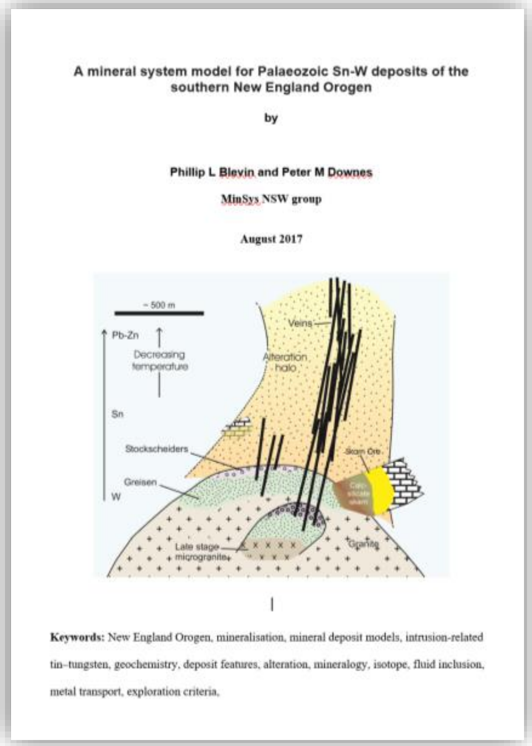


Workflow

- The key to the success of the project was the collaboration between Geological Survey of NSW and Kenex, utilising the expertise of both parties
- Project workflow involved the following stages:
  - Mineral system research (GS NSW)
  - Review and compilation of available data (GS NSW/Kenex)
  - Development of spatial data table and training data (GS NSW/Kenex)
  - Preparation of predictive maps (Kenex)
  - Spatial analysis to create weights and test correlations (Kenex)
  - Review of predictive maps and selections for the final models (GS NSW/Kenex)
  - Generation of models (GS NSW/Kenex)
  - Report and deliver (GS NSW/Kenex)

Mineral System Models

- Local mineral system models prepared by GS NSW staff.
  - Intrusion-related Sn-W GS2017/0617
  - Intrusion-related Au GS2017/0618
  - Orogenic Au-Sb GS2017/0619



A mineral system model for Palaeozoic Sn-W deposits of the southern New England Orogen

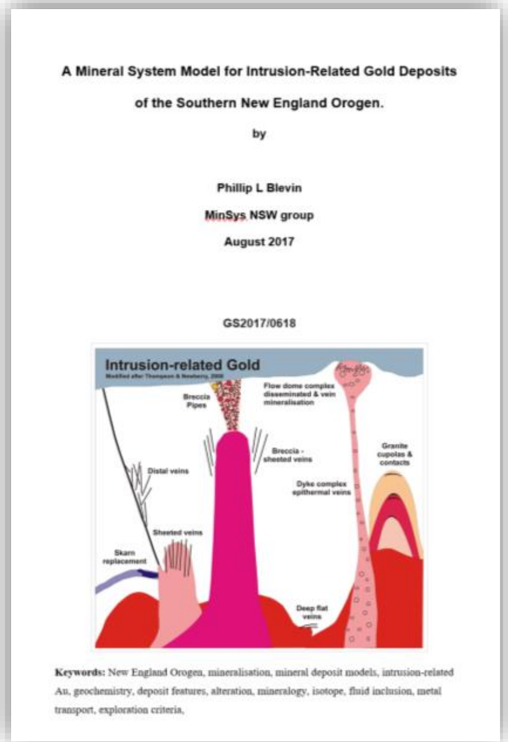
by

Phillip L Blevin and Peter M Downes

MinSys NSW group

August 2017

Keywords: New England Orogen, mineralisation, mineral deposit models, intrusion-related tin–tungsten, geochemistry, deposit features, alteration, mineralogy, isotope, fluid inclusion, metal transport, exploration criteria.



A Mineral System Model for Intrusion-Related Gold Deposits of the Southern New England Orogen.

by

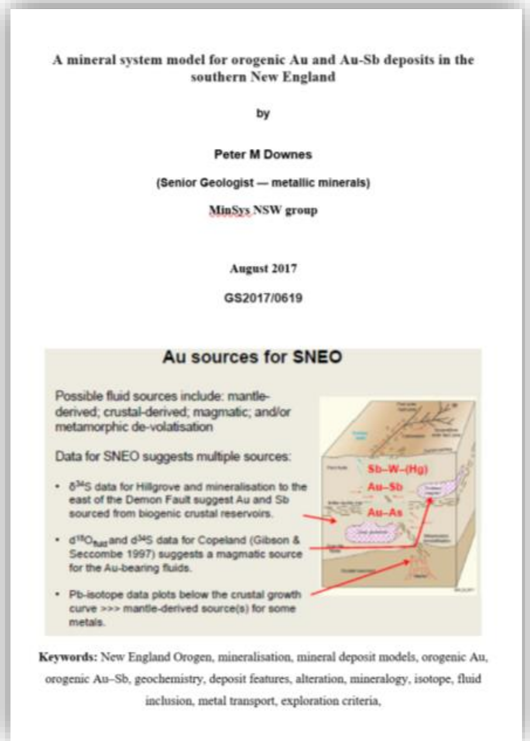
Phillip L Blevin

MinSys NSW group

August 2017

GS2017/0618

Keywords: New England Orogen, mineralisation, mineral deposit models, intrusion-related Au, geochemistry, deposit features, alteration, mineralogy, isotope, fluid inclusion, metal transport, exploration criteria.



A mineral system model for orogenic Au and Au-Sb deposits in the southern New England

by

Peter M Downes

(Senior Geologist — metallic minerals)

MinSys NSW group

August 2017

GS2017/0619

Keywords: New England Orogen, mineralisation, mineral deposit models, orogenic Au, orogenic Au–Sb, geochemistry, deposit features, alteration, mineralogy, isotope, fluid inclusion, metal transport, exploration criteria.

Spatial Data Table

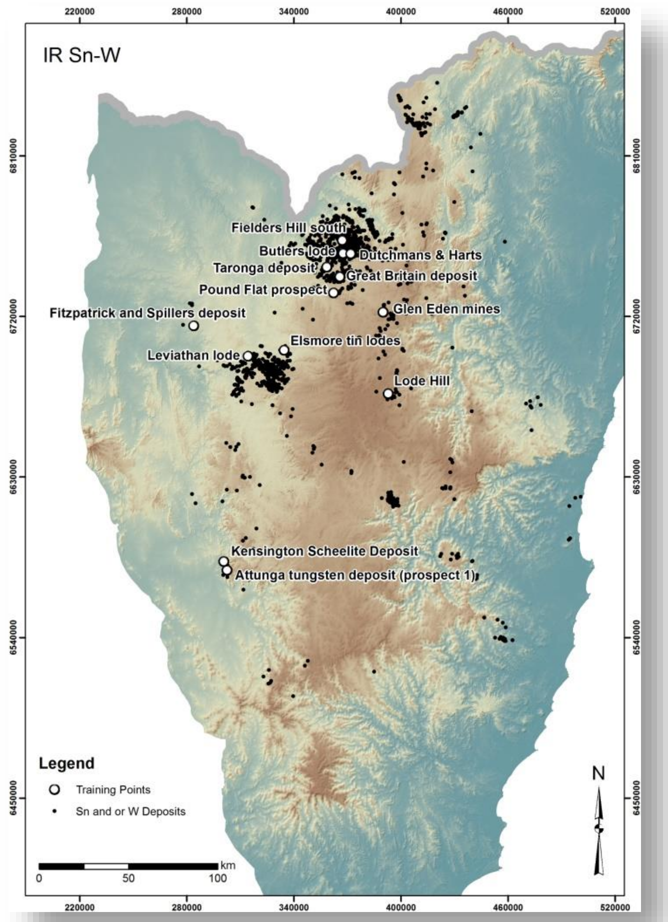
- Lists all mappable variables to be considered
- Details method used to map the variable
- Displays results of spatial data analysis
- Important document for managing data, derivative maps, and workflows

Spatial Variable	System	Measure	Source Data	Technique	Predictive Map	Set Up	Variable ID	Area	Units	# TP	W+	W+s	W-	W-s	C	Cs	StudC	Action
Lithological Association	P1: Sources of Metals and Fluids	Sources and host of metals and/or fluids	Seamless Geology: RockUnit	Use modlith2 attribute to test spatial association with a particular rock type. 1 = granite, 2 = cover, 3 = mafic igneous, 4 = sandstone, 5 = conglomerate, 6 = felsic igneous, 7 = mudstone, 8 = till, 9 = intermediate volcanic, 10 = limestone, 11 = volcanic breccia, 12 = chert, 13 = breccia, 14 = ultramafic	modlith_2	WoE Method, Study Area = sneosa, Unit Area = 1, Training Data = IntrusionRelatedSnWTP.shp, Missing Data = -99, PP = 0.000101, confidence = 0.5	1	16899.56	16899.56	6	1.176426	0.408321	-0.4655	0.377977	1.641931	0.556411	2.950933	Consider
Lithological Association	P1: Sources of Metals and Fluids	Sources and host of metals and/or fluids	Seamless Geology: RockUnit	Use modlith2 attribute to test spatial association with a particular rock type. 1 = granite, 2 = cover, 3 = mafic igneous, 4 = sandstone, 5 = conglomerate, 6 = felsic igneous, 7 = mudstone, 8 = till, 9 = intermediate volcanic, 10 = limestone, 11 = volcanic breccia, 12 = chert, 13 = breccia, 14 = ultramafic	modlith_2	WoE Method, Study Area = sneosa, Unit Area = 1, Training Data = IntrusionRelatedSnWTP.shp, Missing Data = -99, PP = 0.000101, confidence = 0.5	5	6930.415	6930.415	3	1.374724	0.577475	-0.20223	0.316242	1.576952	0.658397	2.395139	Consider
Lithological Association	P1: Sources of Metals and Fluids	Sources and host of metals and/or fluids	Seamless Geology: RockUnit	Use modlith2 attribute to test spatial association with a particular rock type. 1 = granite, 2 = cover, 3 = mafic igneous, 4 = sandstone, 5 = conglomerate, 6 = felsic igneous, 7 = mudstone, 8 = till, 9 = intermediate volcanic, 10 = limestone, 11 = volcanic breccia, 12 = chert, 13 = breccia, 14 = ultramafic	modlith_2	WoE Method, Study Area = sneosa, Unit Area = 1, Training Data = IntrusionRelatedSnWTP.shp, Missing Data = -99, PP = 0.000101, confidence = 0.5	6	8709.728	8709.728	3	1.146115	0.57745	-0.18618	0.316242	1.332295	0.658375	2.023612	Consider
Association with granites	P1: Sources of Metals and Fluids	Sources and host of metals and/or fluids	Seamless Geology: RockUnit	Select granites using rock type and lithological descriptions, buffer 10 km at 100 m intervals around granites using Spatial Analyst distance buffer tool. Test spatial correlation with training data.	grnbuf1600	WoE Method, Study Area = sneosa, Unit Area = 1, Training Data = IntrusionRelatedSnWTP.shp, Missing Data = -99, PP = 0.000101, confidence = 0.5	1600 m	26728.48	26728.48	10	1.228828	0.316287	-1.21131	0.57736	2.440139	0.658317	3.706631	Consider
Association with Felsic Igneous Rocks	P1: Sources of Metals and Fluids	Sources and host of metals and/or fluids	Igneous Fertility	Use the igneous fertility layer that includes felsic intrusive and extrusive rocks. Buffer all polygons 10 km at 100 m intervals using Spatial Analyst distance buffer tool. Test spatial correlation with training data.	grnall700	WoE Method, Study Area = sneosa, Unit Area = 1, Training Data = IntrusionRelatedSnWTP.shp, Missing Data = -99, PP = 0.000101, confidence = 0.5	700 m	25435.13	25435.13	11	1.373795	0.301577	-1.63075	0.707114	3.004545	0.768739	3.908409	Send to model

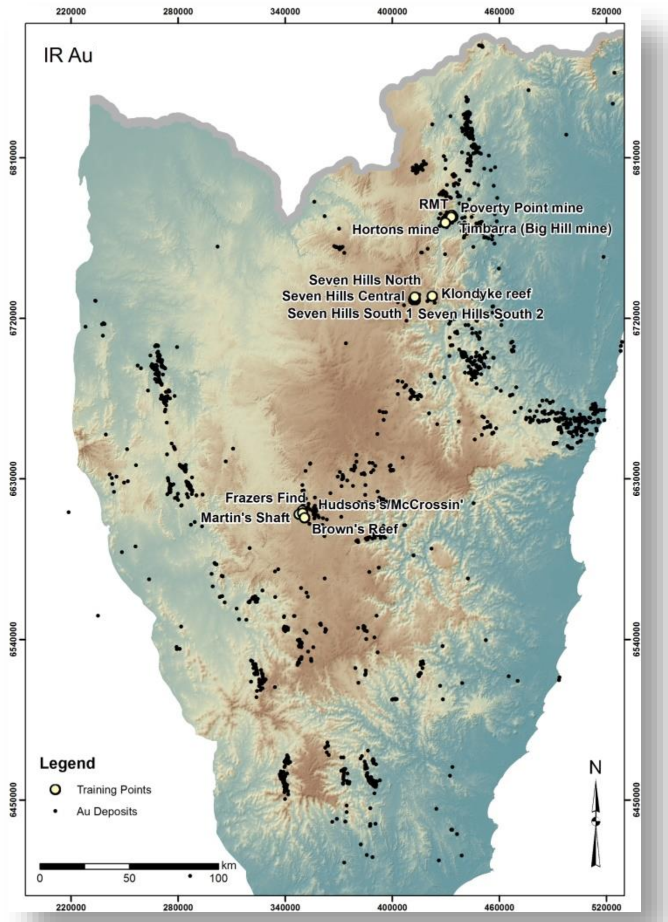
Weights of Evidence

- Create study area (extent of seamless geology): 50 x 50 m grid
- Select training data – chosen by GS NSW experts
- Select unit cell – 1 km^2 for all models
- Determine prior probability
- Create predictive maps and perform spatial analysis
- Select predictive maps for mineral potential map
- Run weights of evidence model
- Test model efficiency for classification

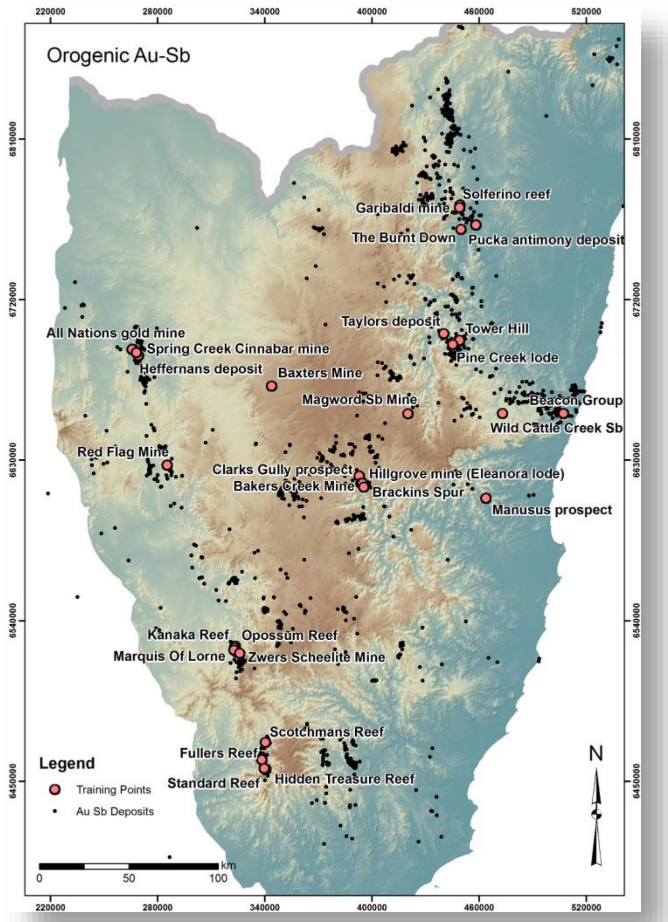
Training Data



IR Sn-W = 13 Points

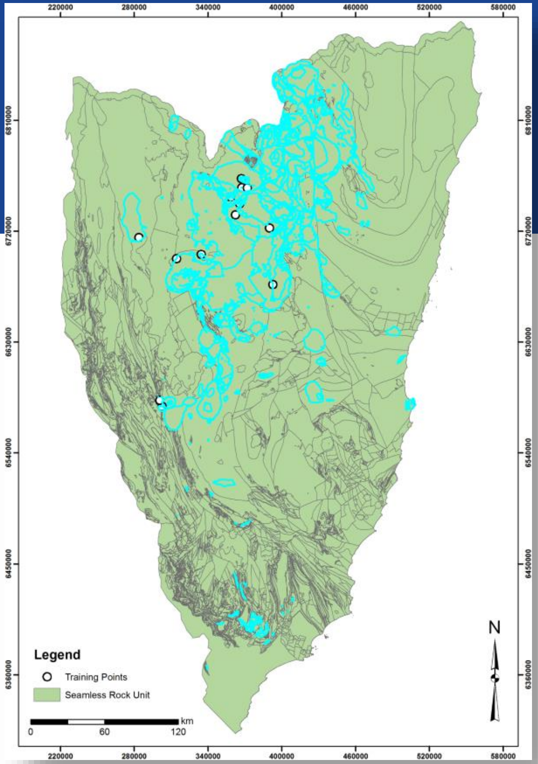


IR Au = 13 Points

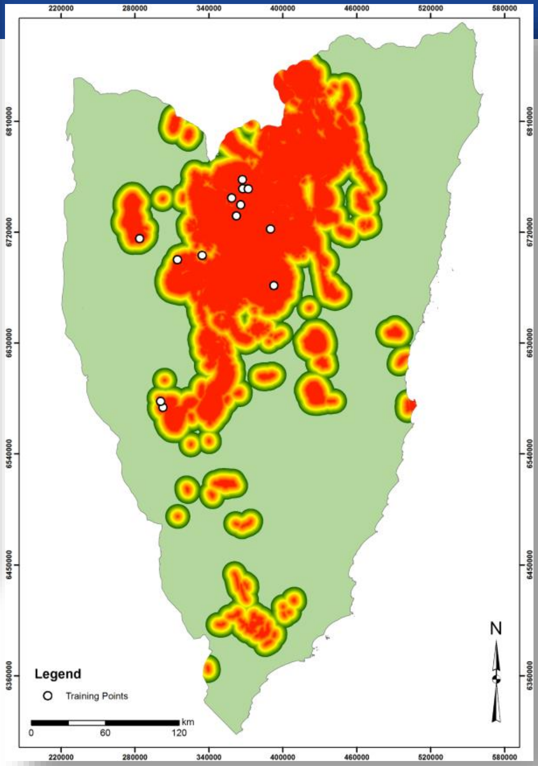


Orogenic Au-Sb = 28 Points

Spatial Analysis

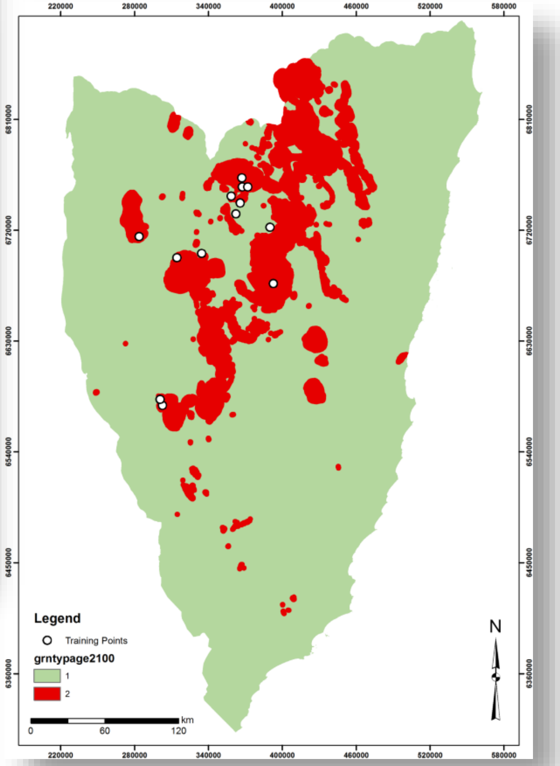


Select data



Distance buffer + ascending weights

Reclassify



- 88-99 spatial variables identified
- 71-101 predictive maps created and tested
- Spatial correlations mostly positive with 53-91 predictive maps having contrast values > 1

Calculate weights

Very strong correlation
C > 3.0; StudC > 4

Strong correlation
C 2.0-3.0; StudC > 3

Moderate correlation
C 1.0-2.0; StudC > 2

Weak correlations
C < 1.0; StudC < 2

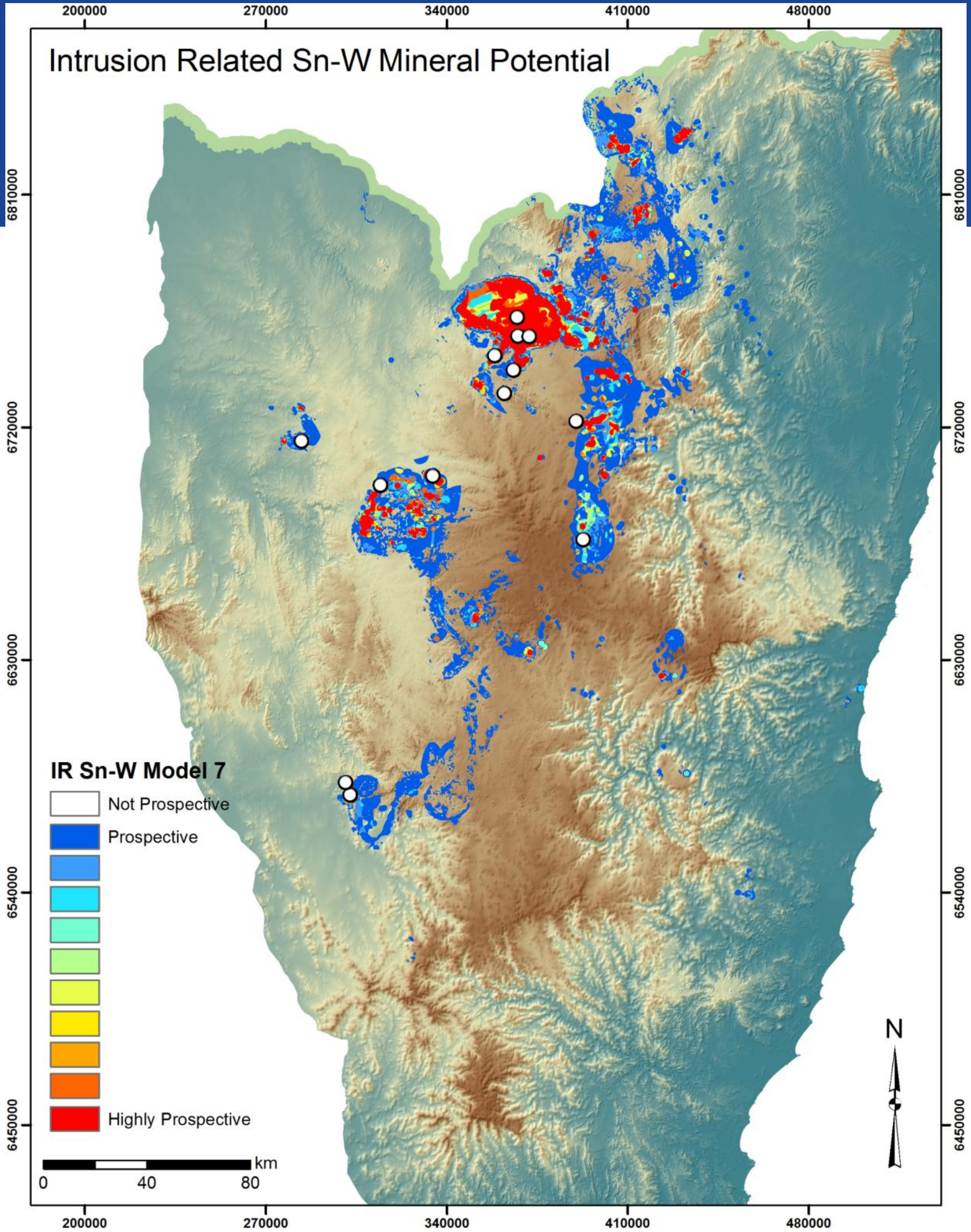
CLASS	AREA_SQ_KM	AREA_UNITS	NO_POINTS	WPLUS	S_WPLUS	WMINUS	S_WMINUS	CONTRAST	S_CONTRAST	STUD_CNT	GEN_CLASS	WEIGHT	W_STD
1	99598.1825	99598.1825	2	-1.6964	0.7071	1.6599	0.3016	-3.3563	0.7687	-4.3659	1	-1.6964	0.7071
2	19108.7350	19108.7350	11	1.6599	0.3016	-1.6964	0.7071	3.3563	0.7687	4.3659	2	1.6599	0.3016

Key Exploration Criteria

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)	N/A	N/A	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.	N/A
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.	N/A	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)	N/A	N/A	Lows; Slope; Lows along faults.
Radiometrics (Deposition/Source)	U, Th, and K radiometric highs.	U, Th, and K radiometric highs.	N/A
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.

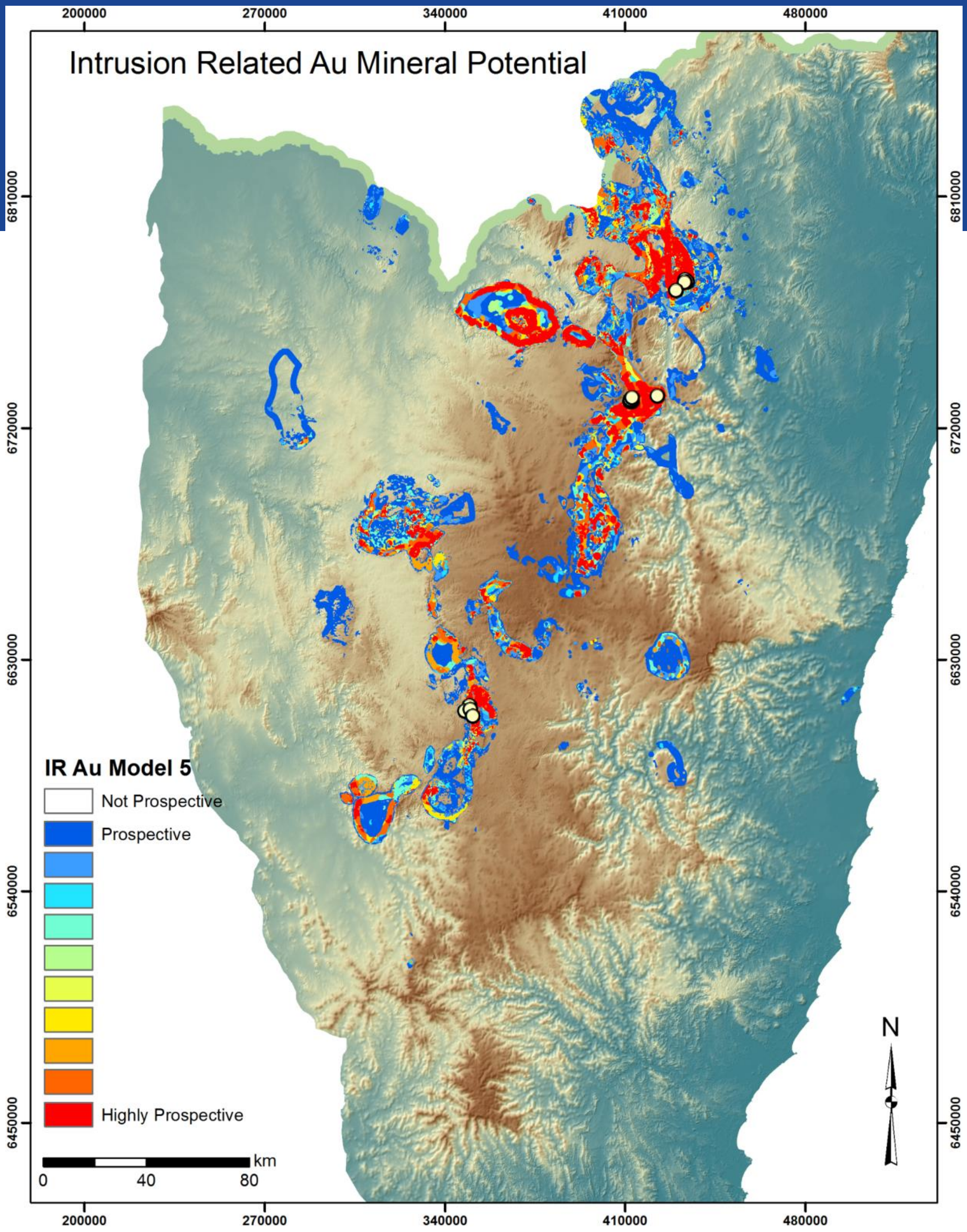
IR Sn-W Mineral Potential

- Prospective areas are defined as having a post probability higher than the prior probability (0.000101)
- Prospective area covers 6% of the study area
- Efficiency of classification = 99.5
- Training points all fall in the highly prospective area (lowest post probability is 0.736587)
- Highly prospective area (above 0.736587) covers 1.2% of the study area



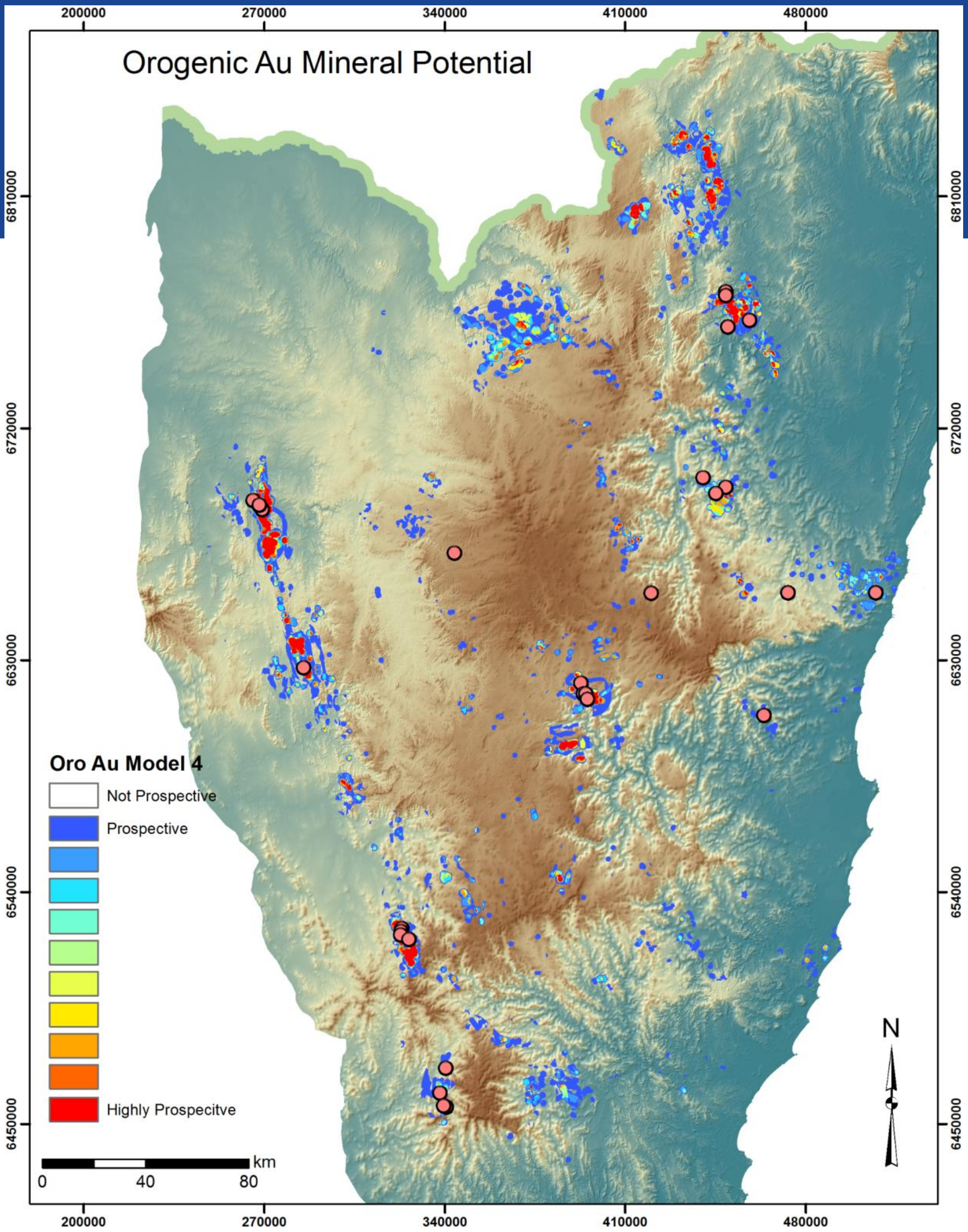
IR Au Mineral Potential

- Prospective areas are defined as having a post probability higher than the prior probability (0.00011)
- Prospective area covers 8% of the study area
- Efficiency of classification = 99.5
- Training points all fall above the prior probability (lowest post probability is 0.000723; next lowest is 0.999992)
- Highly prospective area (above 0.937254902) covers 1.4% of the study area



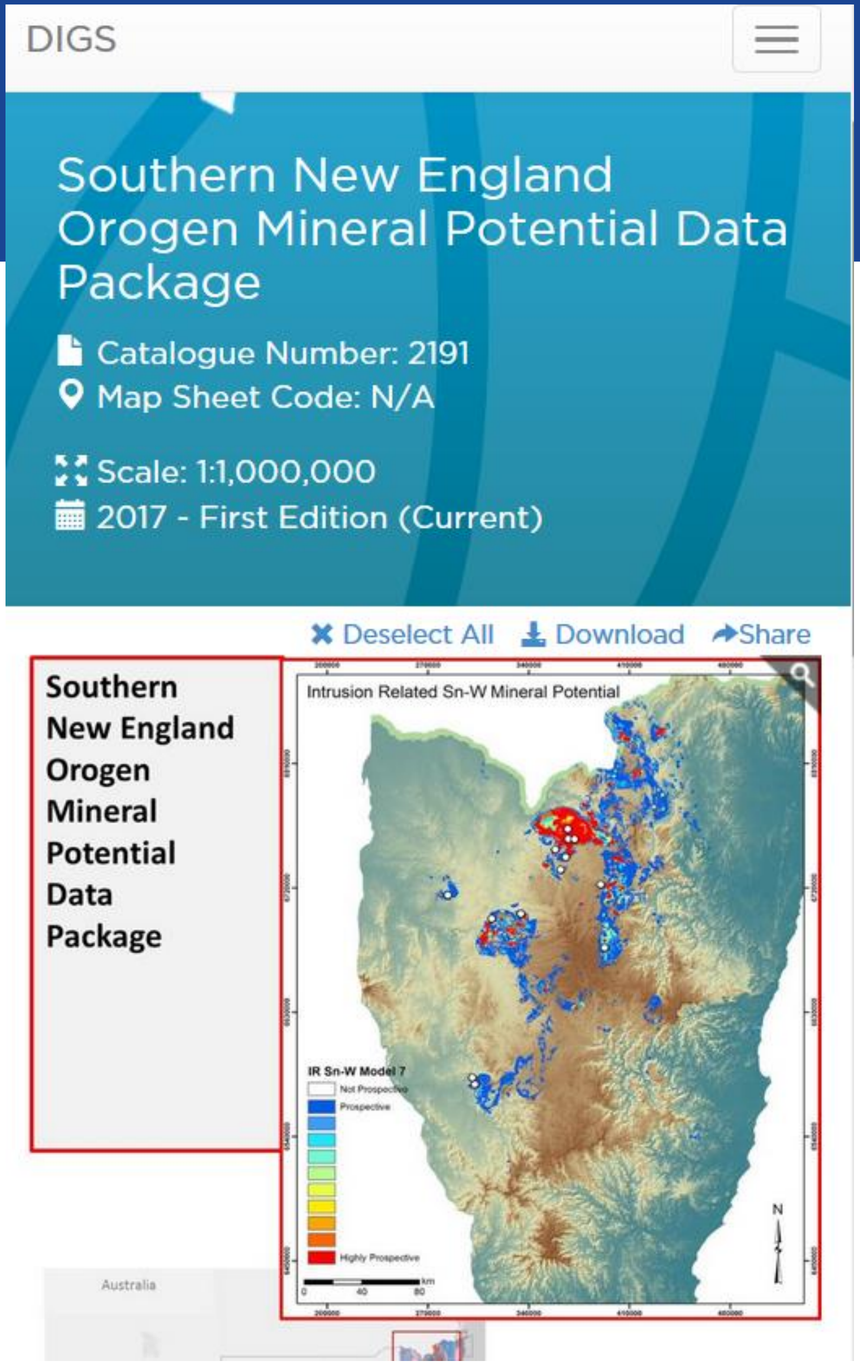
Orogenic Au Mineral Potential

- Prospective areas are defined as having a post probability higher than the prior probability (0.000236)
- Prospective area covers 4.5% of the study area
- Success rate = 97.6
- 2 training points are below the prior probability
- 26 training points fall above the prior probability (lowest post probability is 0.00073)
- 20 training points fall in the highly prospective area (above 0.94117671) that covers 0.5% of the study area



Project Outcomes

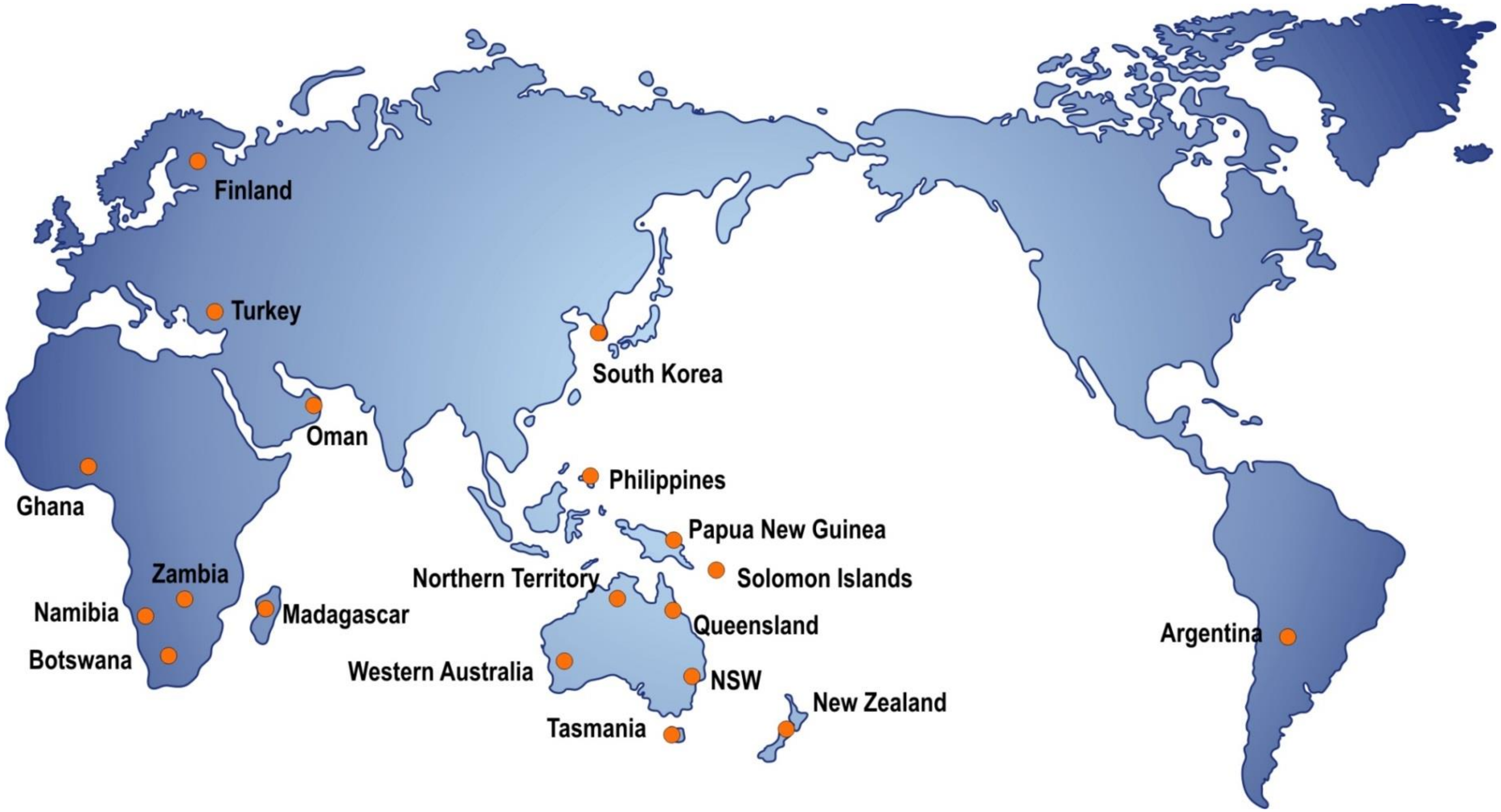
- Excellent quality datasets
- Robust mineral system descriptions for local area
- Detailed weights of evidence spatial analysis to test the mineral system models
- List of key predictive variables confirmed/determined by spatial analysis
- Data and mineral system knowledge synthesised into mineral potential maps for IR Sn-W, IR Au, and orogenic Au
- SNEO Mineral System Atlas released to the public, including training points, predictive maps, weights tables, mineral potential maps, spatial data table, and report
- Follow-up projects in other areas of NSW



Review

- Mineral potential mapping is more than raster calculations in GIS
- Essential to understand the mineral system
- Critical dependence on quality data – especially geology
- Requires both geological understanding and technical GIS skills
- Successful projects rely on collaboration between consultants and stakeholders

Our Business Is To Help Companies Discover New Opportunities



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