Mineral Potential Mapping as a Strategic Planning Tool in the Eastern Lachlan Orogen, NSW

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Project Background

- Produce mineral potential maps that can be used for strategic land-use planning by NSW government, and to promote mineral exploration through the delivery of value-added pre-competitive geoscience data to industry.
- Five mineral system models were developed for the eastern Lachlan Orogen
  - Macquarie Arc: Porphyry Cu-Au
  - Eastern Lachlan Orogen: Polymetallic Skarn, Kanimblan Orogenic Au, Tabberabberan Orogenic Au, VAMS
- Development of the models included
  - Review and compilation of available data (GSNSW and Kenex)
  - Mineral system research (GSNSW)
  - Development of spatial data table and training data (GSNSW and Kenex)
  - Preparation of predictive maps (Kenex)
  - Spatial analysis to create weights and test correlations (Kenex)
  - Selection of maps for final models (GSNSW and Kenex)
  - Mineral potential maps created for each mineral system (Kenex)
  - Validation of mineral potential maps (Kenex)
  - Reporting and delivery (Kenex)

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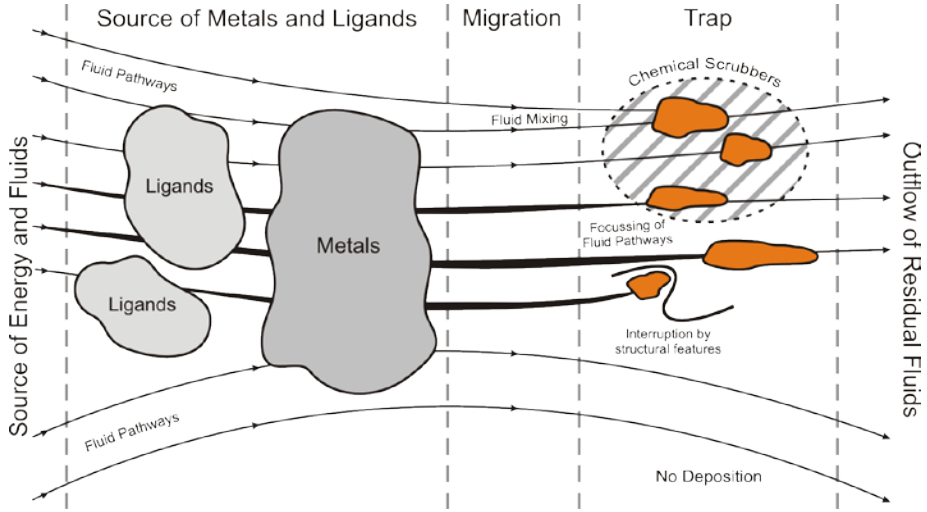
Data

- All of the datasets for the project were provided by GSNSW
- Review of data undertaken by Kenex and any noted issues discussed with GSNSW and changes made where appropriate

Data type	GSNSW source database	Zone 55E (ELO)
Radiometric ages	Geobank radiogenic isotopes	1727 analyses
Whole-rock geochemistry	Geobank whole rock geochemistry	6133 analyses
Mineral occurrences	Geobank MetIndex	12169 observations
Petrographic observations	Geobank petrology	56126 observations
Field observations	Geobank field observations	94548 observations
Structure points	Geobank field observations, MetIndex and seamless geology	37945 compass readings
Fold axes	Geobank field observations and seamless geology	2864 recorded
Drillholes (including lithology logs)	Geobank drillholes and wells	45448 logged
Drillhole assays	Geobank assay results	2903474 analyses
Surface major element analyses (pXRF)	Geobank assay results	12763 analyses
Surface trace element analyses (soil, stream sed, pXRF)	Geobank assay results	62367 analyses
Reactive rocks layer	Seamless geology	Complete
Igneous metal fertility	Seamless geology, whole rock geochemistry	Calculated and complete
Fault attribution	Seamless geology	50740 mapped
Metamorphic map	Seamless geology	Complete
Geology	Seamless Geology	Complete
Geophysics	Statewide 50m grid magnetics, gravity, radiometrics, mag and grav worms	Surveyed and complete

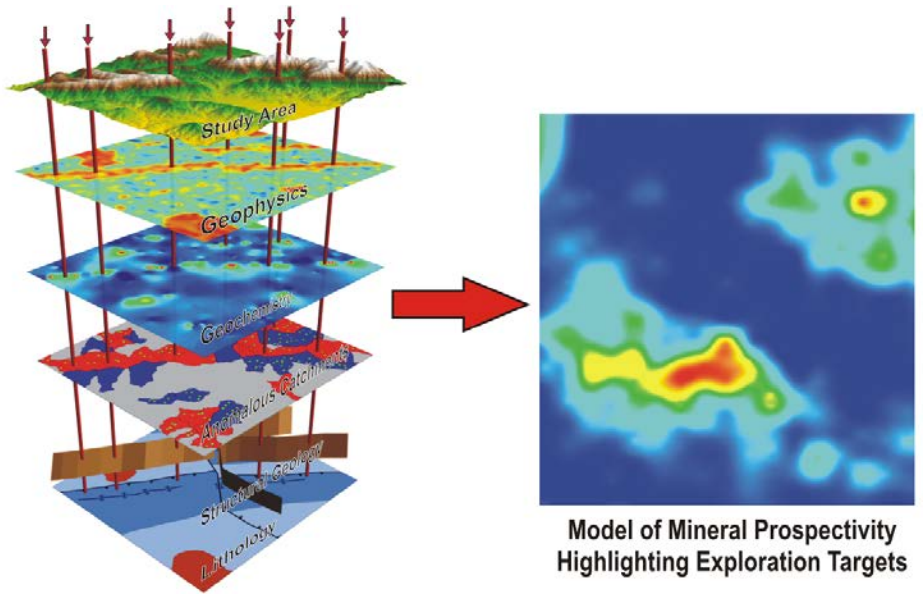
Mineral System Models

- Mineral system models for porphyry Cu-Au, polymetallic skarn, orogenic Au (Kanimblan and Tabberabberan), and VAMS mineralisation were prepared by GSNSW staff.
- Models used as a basis for determining the key predictive variables for each style of mineralisation in the eastern Lachlan Orogen.
- Key predictive variables were grouped by mineral system component: source, transport, trap, or deposition/preservation.



Mineral Potential Mapping

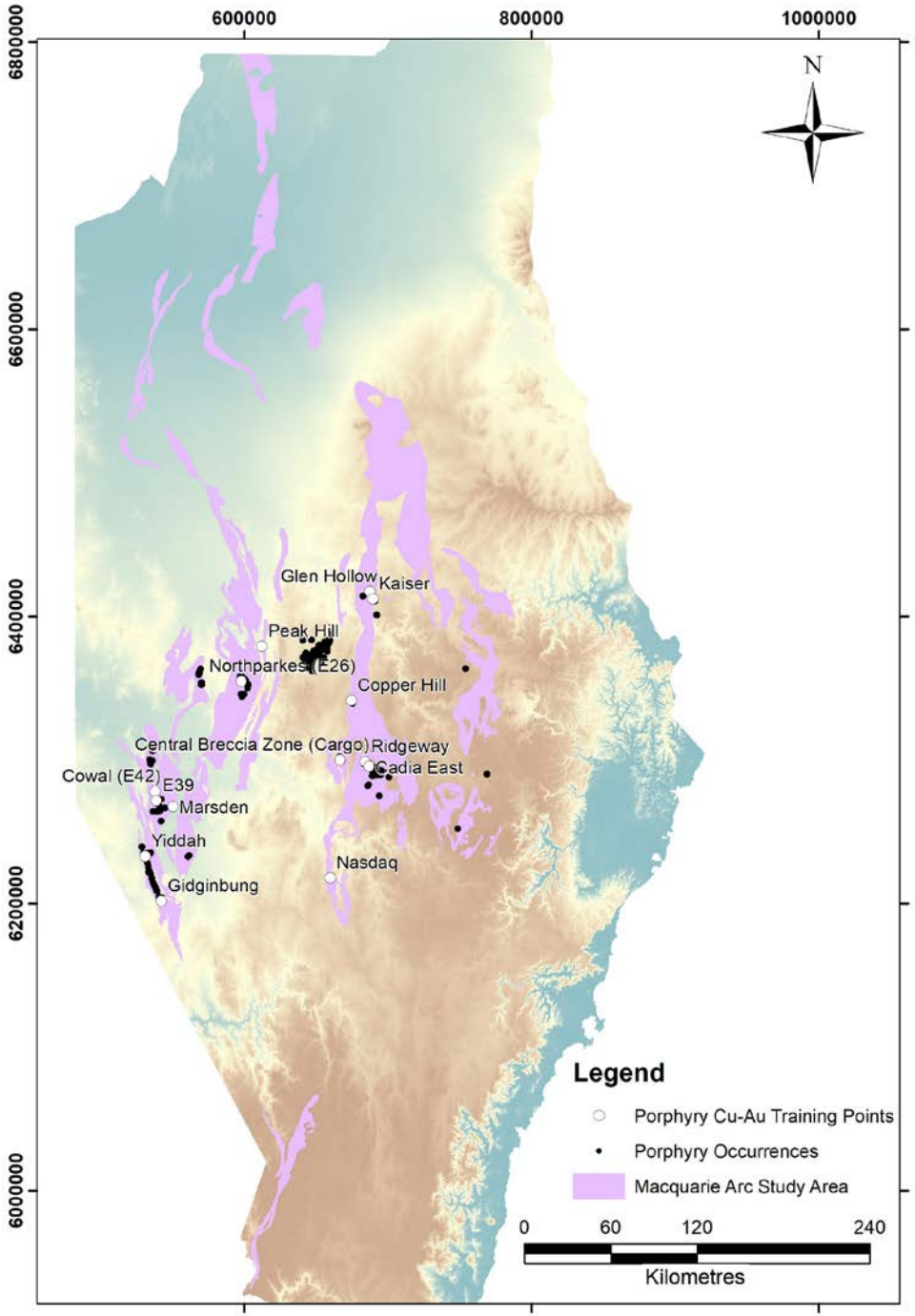
- Weights of evidence (WofE) approach was used:
  - Statistically-driven, but user retains control over model.
  - Quantifies spatial association between training points (known mineral occurrences) and predictive maps (e.g. distance to felsic intrusion, fault density).
- Training data selected by GSNSW experts for each mineral system.
- Predictive maps generated and WofE used to quantify spatial association with training points for each mineral system.
- Selection of predictive maps for inclusion in mineral potential maps and running models for each mineral system:
  - Maps need to be statistically valid, geologically meaningful, and practically useful.
- Testing efficiency of classification for each mineral potential map produced.



Porphyry Cu-Au Mineral System

- Ordovician to early Silurian porphyry Cu-Au mineralisation associated with fertile magmas within the Macquarie Arc.
- The mineral systems knowledge tested using spatial analysis:
  - 215 spatial variables tested
  - 164 produced a statistically valid result
  - 80 correlated well with the training points

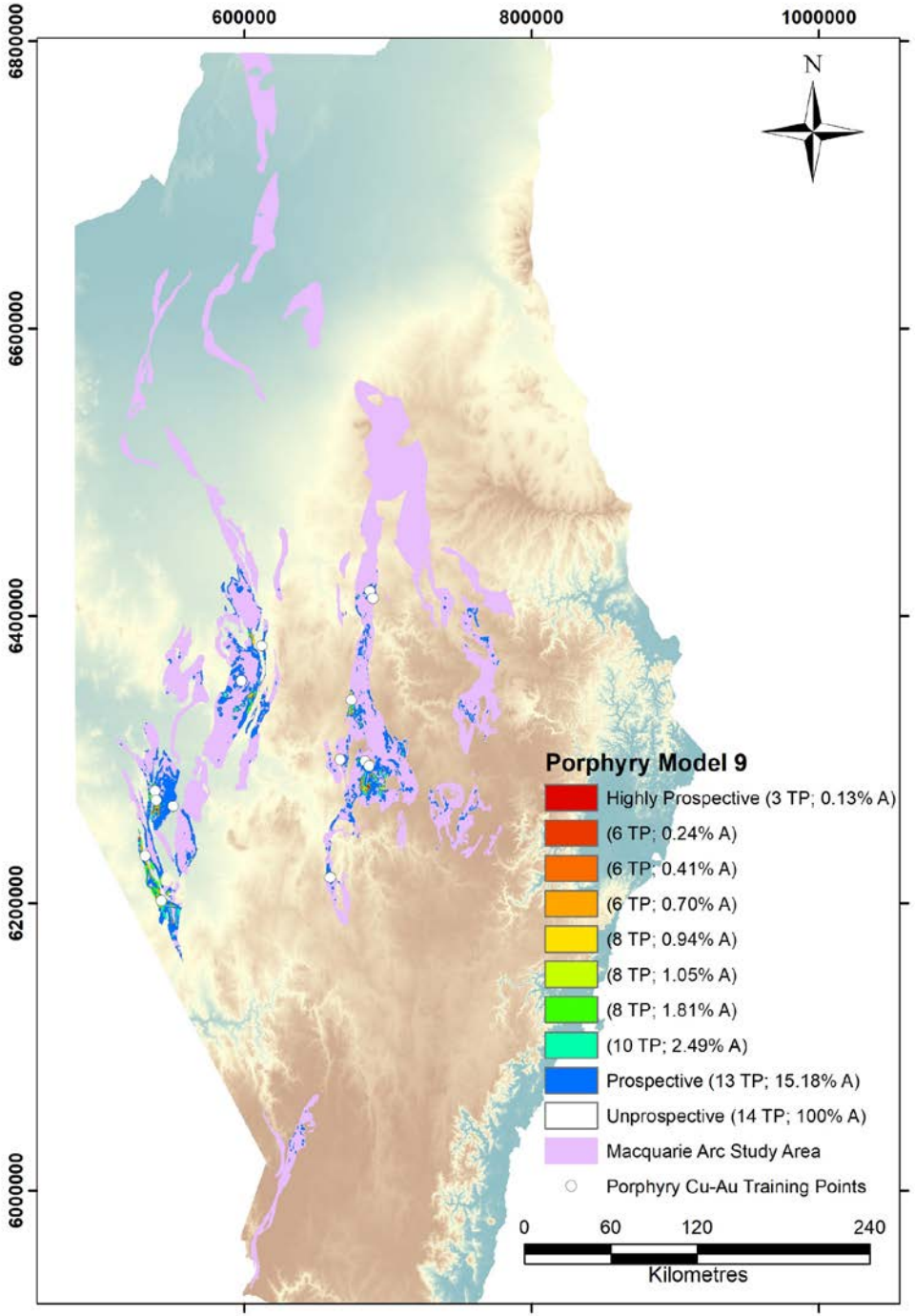
Data Type	Mineral System Component	Key Variables
Lithology/Stratigraphy	Source/Transport/Trap	Ordovician-Silurian (Benambran Cycle) geology in the Macquarie Arc: fertile magma, oxidised and K-enriched magma, shoshonitic/high-K subaqueous volcanics, reactive rocks.
Mineral occurrences	Source/Deposition	Known occurrences of associated epithermal or skarn mineralisation; clustering of Au, Cu, Ag, or Zn occurrences.
Petrology	Source/Transport/Trap	Magnetite and sericite alteration.
Faults	Transport/Trap	Fault subsets including: Benambran contraction faults and 4th order faults; point datasets derived from the fault dataset, particularly fault intersections, jogs, and bends; fault and vein density.
Magnetics/Gravity	Source/Trap/Deposition	Magnetic RTP high.
Magnetic/Gravity worms	Transport	Gravity worms with a height of 17916 m. More value could potentially be extracted from the worm data with further processing.
Rock chip and drillhole geochemistry	Deposition	Rock chip and drillhole assays with anomalous Ag, As, Au, Cu, Mo, Pb, Sb, or Zn.



Porphyry Cu-Au Mineral Potential Map

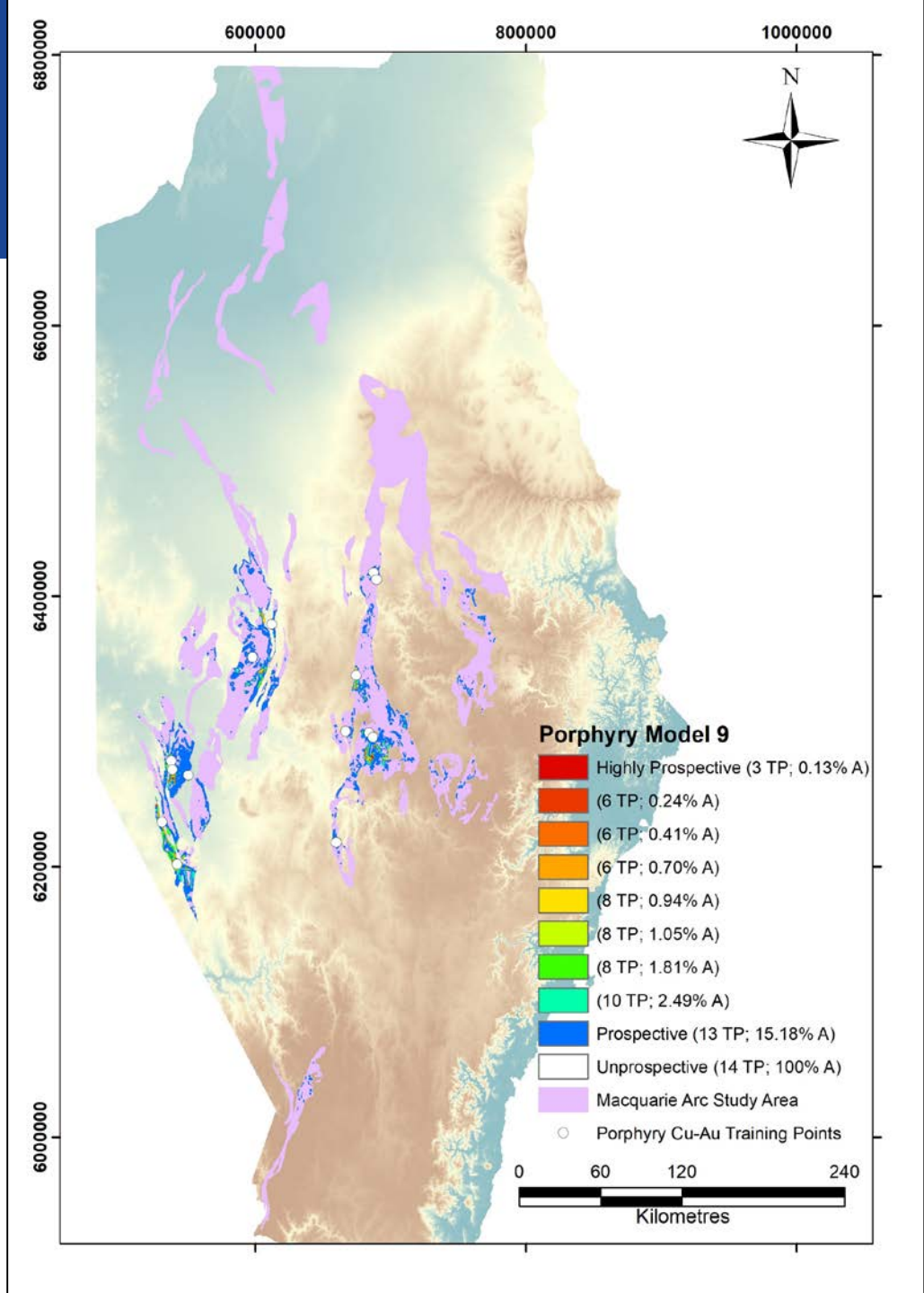
Mineral System	Spatial Variable	Variable ID	TP (N=14)	C	StudC
Source	Association with Ordovician-Silurian intrusions (Benambran)	800 m	9	2.59	4.64
	Association with fertile magma (oxidised and K-rich)	Moderately to very strongly oxidised AND med- to ultra high-K	10	1.45	2.44
	Shoshonitic/high K subaqueous volcanics	4600 m	10	2.48	4.19
Transport	Fault age (Benambran Contraction)	1400 m	8	2.01	3.71
Trap	Reactivity Contrast – All	850 m	8	1.42	2.63
	Fault Bends-Jogs-Splays	1550 m	12	2.36	3.09
	Magnetics (RTP high)	Class>=6 (mag high)	9	1.94	3.48
Deposition	Drillhole-Rock-MinOcc Cu-Au anomaly	Combined drillhole-rock Au>=0.04 ppm and Cu>=1260 ppm	14	3.88	3.72
	Au, Cu, Ag, Zn occurrence density (constrain by age)	Class>=2 (high density)	10	2.17	3.67

- Prior probability: 0.000606
- Prospective area (post prob > prior prob): 15.2% of Macquarie Arc study area
- Highly prospective area: 0.13% of study area
- 13/14 training points in prospective area
  - 1 training point (Kaiser) falls below the prior probability
- Efficiency of classification: 96.0%



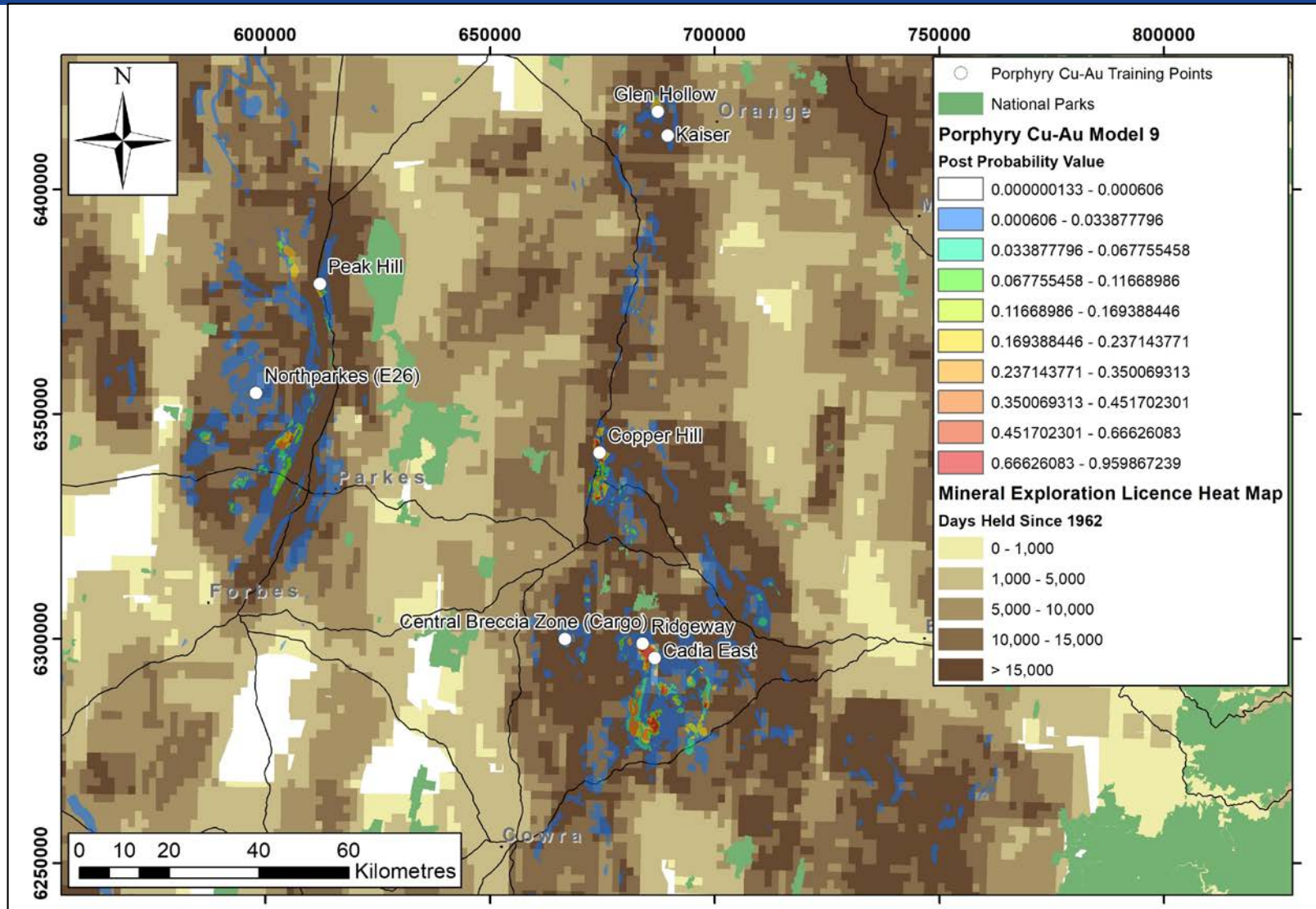
Porphyry Cu-Au Mineral Potential

- Most highly prospective areas around the Cadia and Cowal districts.
  - Cadia East, Ridgeway, Copper Hill, Cowal, E39, Gidginbung in highly to very highly prospective area
  - Cargo, Combella, Peak Hill, Marsden, Yiddah in moderately prospective area
- Other highly prospective areas are located around Gidginbung, Copper Hill, and Glendale.
- Northparkes highlighted as weakly prospective.
  - Lack of faults mapped in the district
  - Deposit geometry at E26
- Kaiser is in an unprospective area
  - Absence of mapped intrusions and structures.
  - Seamless is being updated to resolve this.



Porphyry Cu-Au Mineral Potential

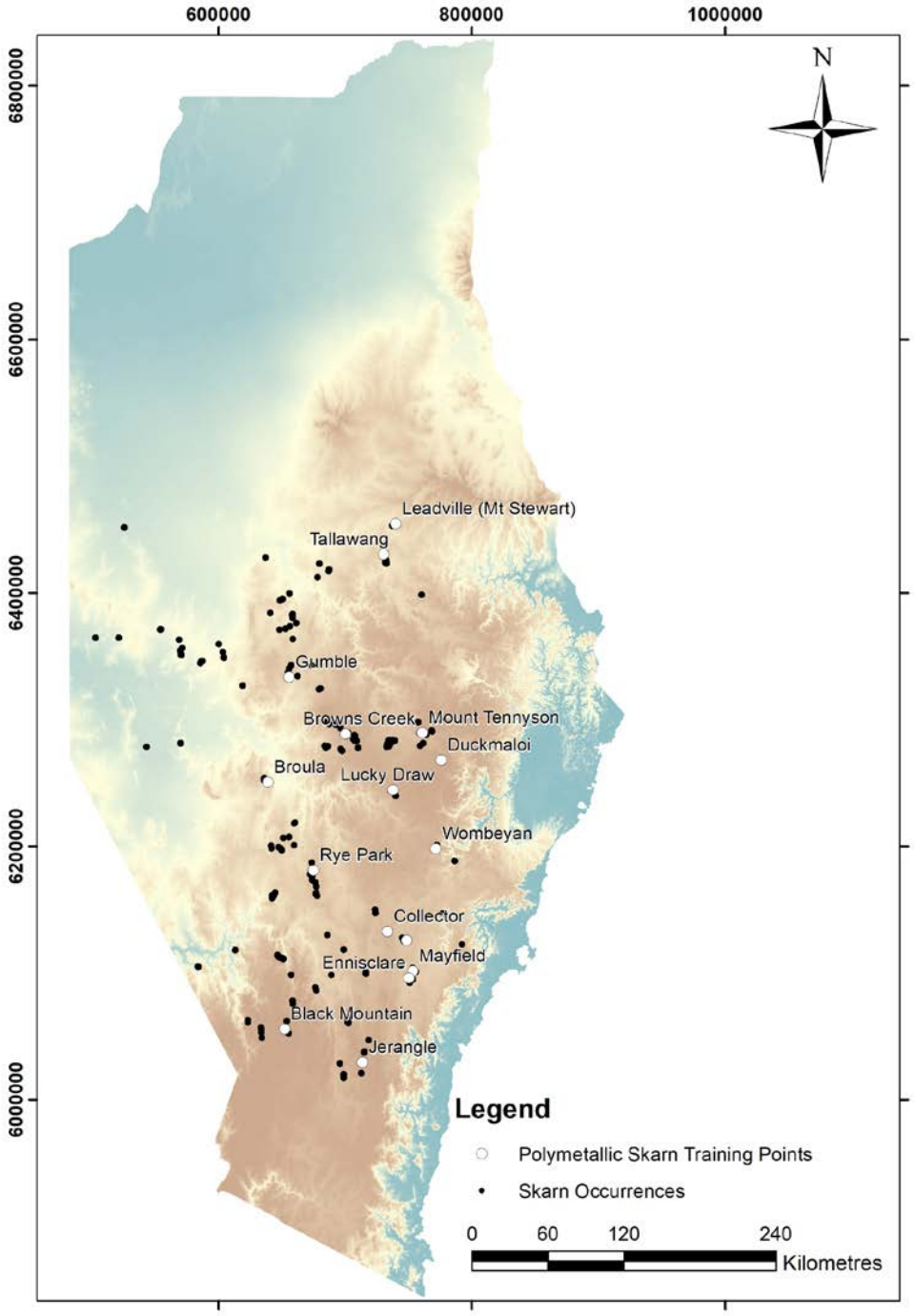
- Tested 33 different magma fertility parameters
  - Modelling results emphasise importance of moderately to very strongly oxidised magmas that were also K-enriched.
- Regional-scale faults showed only moderate correlation with training points.
- Some areas haven't had the same intensity of historic exploration and may represent opportunities.



Polymetallic Skarn Mineral System

- Mid-Silurian to mid-Carboniferous polymetallic skarn mineralisation associated with Tabberabberan and Kanimblan Cycle intrusions.
  - Skarns related to Benambran Cycle intrusions(e.g. Big Cadia) and metamorphic reaction skarns (e.g. Red Hill) were excluded.
- The mineral systems knowledge was tested using spatial analysis:
  - 228 spatial variables evaluated
  - 153 produced a valid predictive map
  - 89 correlated well with the training points

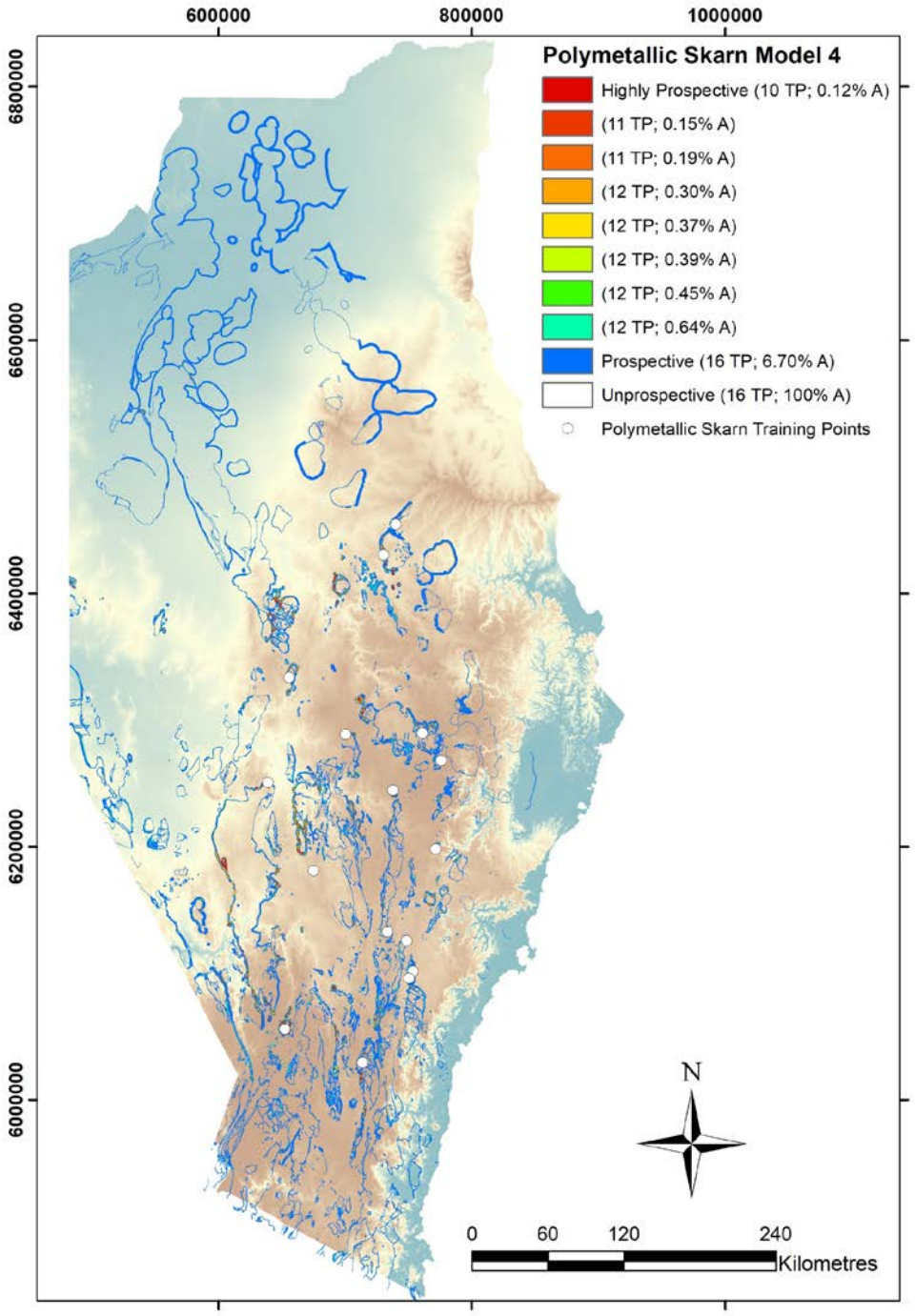
Data Type	Mineral System Component	Key Variables
Lithology/Stratigraphy	Source/Transport/Trap	Silurian-Carboniferous (Tabberabberan-Kanimblan Cycle) geology: metamorphic aureoles, fertile magma, I-type intrusions, lithological contacts, reactive (calcareous) rocks.
Faults	Transport/Trap	Fault subsets including: reactivated faults, thrust faults, Tabberabberan contraction faults, Kanimblan contraction faults, NNW oriented faults, 4th order faults and veins; point datasets derived from the faults (i.e. intersections, jogs, bends, and splays); fault and vein density.
Petrology	Source/Transport/Trap	Carbonate-chlorite-epidote alteration; sulfides.
Radiometrics	Deposition/Source	Th radiometric highs.
Stream sediment geochemistry	Deposition	Catchments containing stream sediment samples with anomalous Pb and Zn.
Rock chip and drillhole geochemistry	Deposition	Rock chip and drillhole assays with anomalous Ag, As, Au, Bi, Cu, Fe, Mo, Pb, S, Sn, W, and Zn.



Polymetallic Skarn Mineral Potential Map

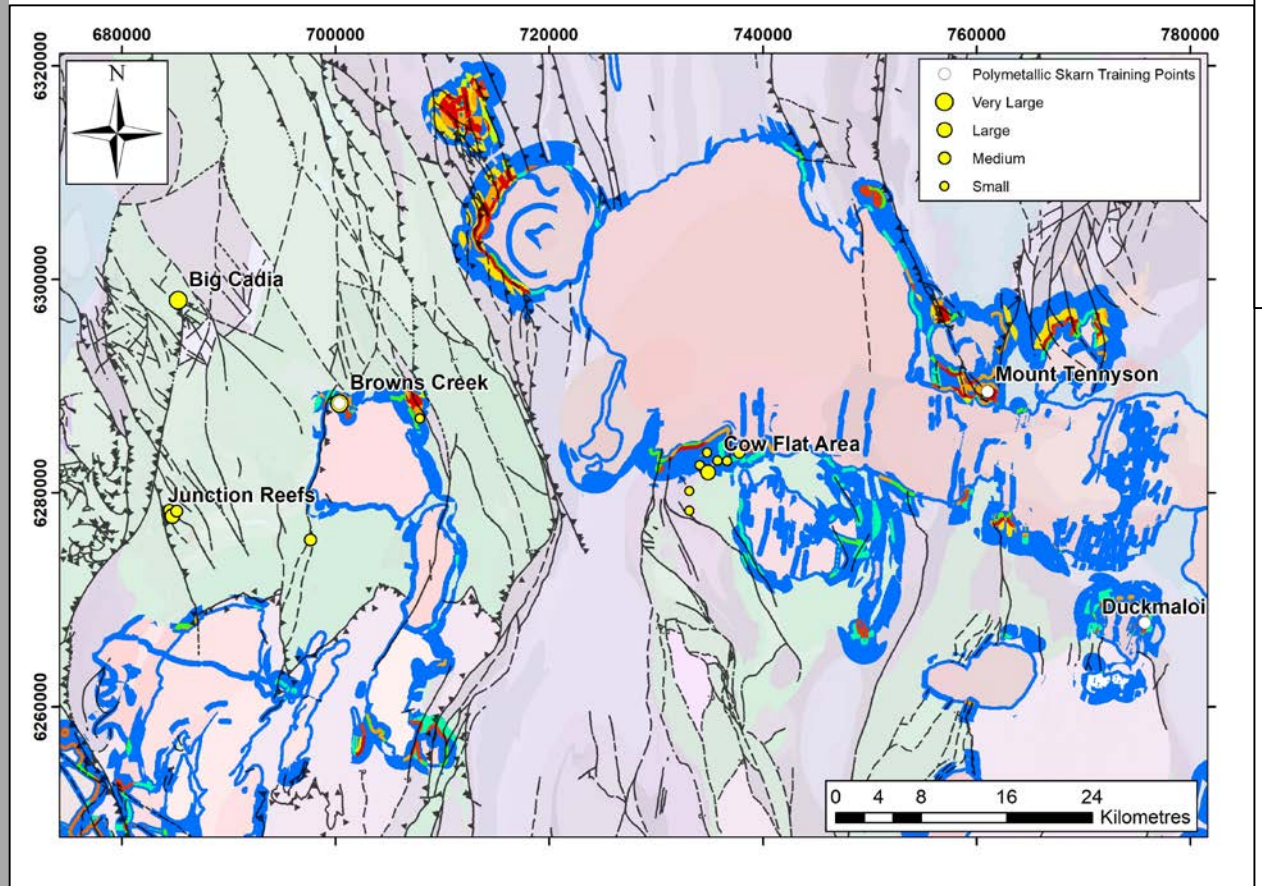
Mineral System	Spatial Variable	Variable ID	TP (N=16)	C	StudC
Source	Metamorphic aureoles	50m	14	4.21	5.56
	Association with gabbro, diorite, granodiorite, granite	1050 m	14	3.16	4.18
	Association with metamorphic aureole intersecting limestone units	650 m	14	5.04	6.66
Transport	NNW oriented Tabberabberan and Kanimblan contraction faults	2050 m	10	2.58	4.99
	Intrusion contacts (age constrained)	250 m	10	3.35	6.49
Trap	Combined Fault and Vein Density	Class>=4 (high density)	11	2.75	5.16
	Reactivity Contrast	250 m	16	5.35	14.39
Deposition	Drillhole-Rock-MinOcc Pb-Zn or Cu-Au or Cu-As or Sn-W anomaly	Drillhole-rock (Pb>=334ppm and Zn>=550ppm) OR (Cu>=372ppm and Au>=0.04ppm) OR (Cu>=372ppm and As>=500ppm) OR (Sn>=13.9 ppm and W>=12ppm)	15	2.74	2.63

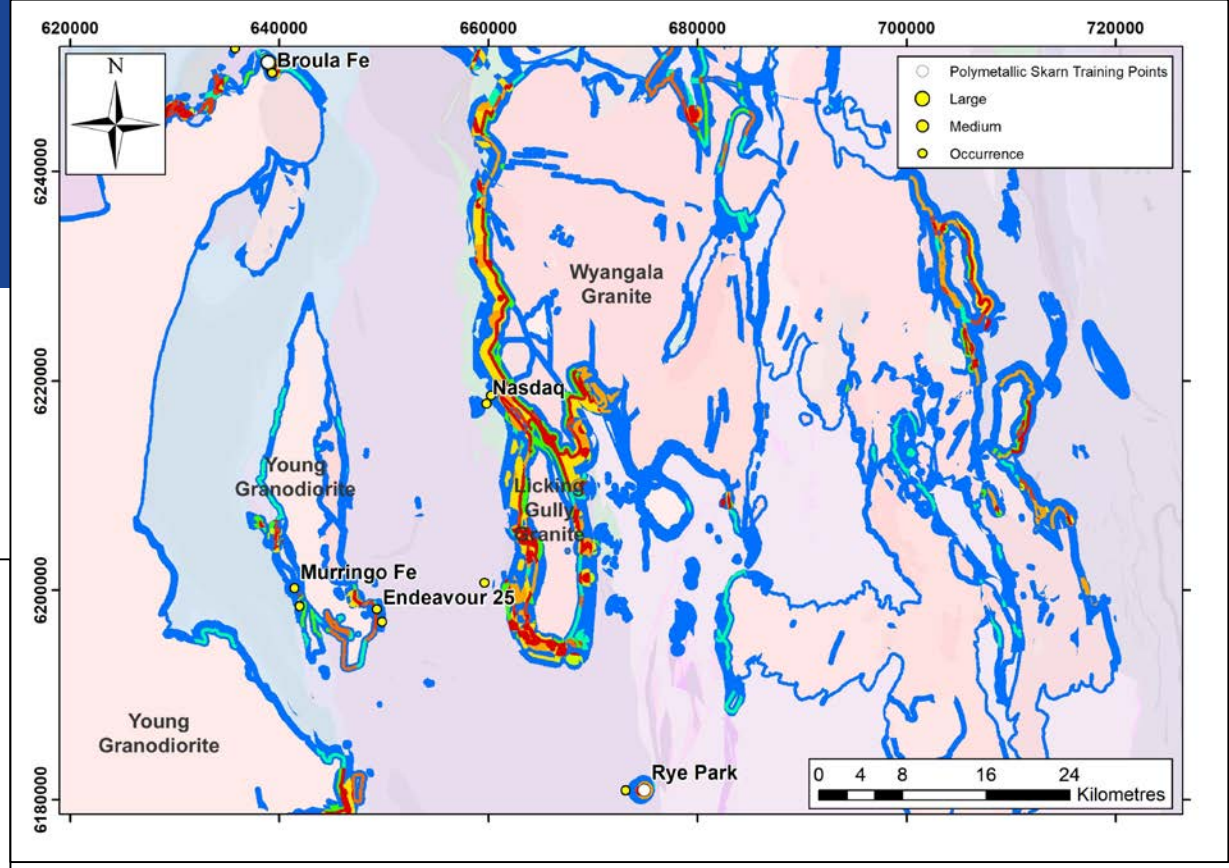
- Prior probability: 0.000055
- Prospective area (post prob > prior prob): 6.7% of eastern Lachlan Orogen study area
- Highly prospective area: 0.12% of study area
- All training points in prospective area
- 10/16 training points in highly prospective area
- Efficiency of classification: 99.4%



Polymetallic Skarn Mineral Potential

- Highly prospective area around Cow Flat area and Young Granodiorite.

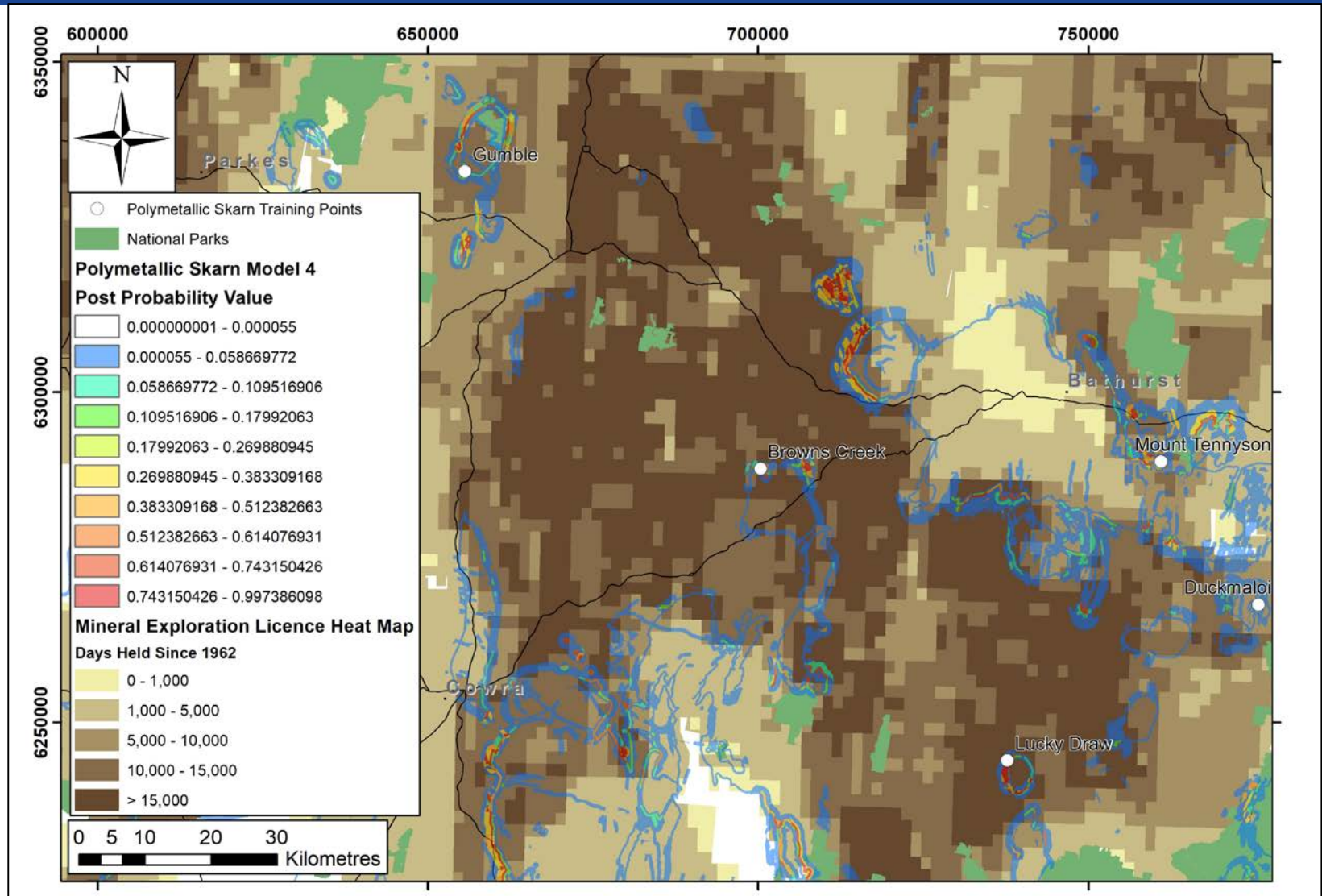




- Prospective area is typically within 1km of causative intrusion and within the pluton's contact metamorphic aureole.

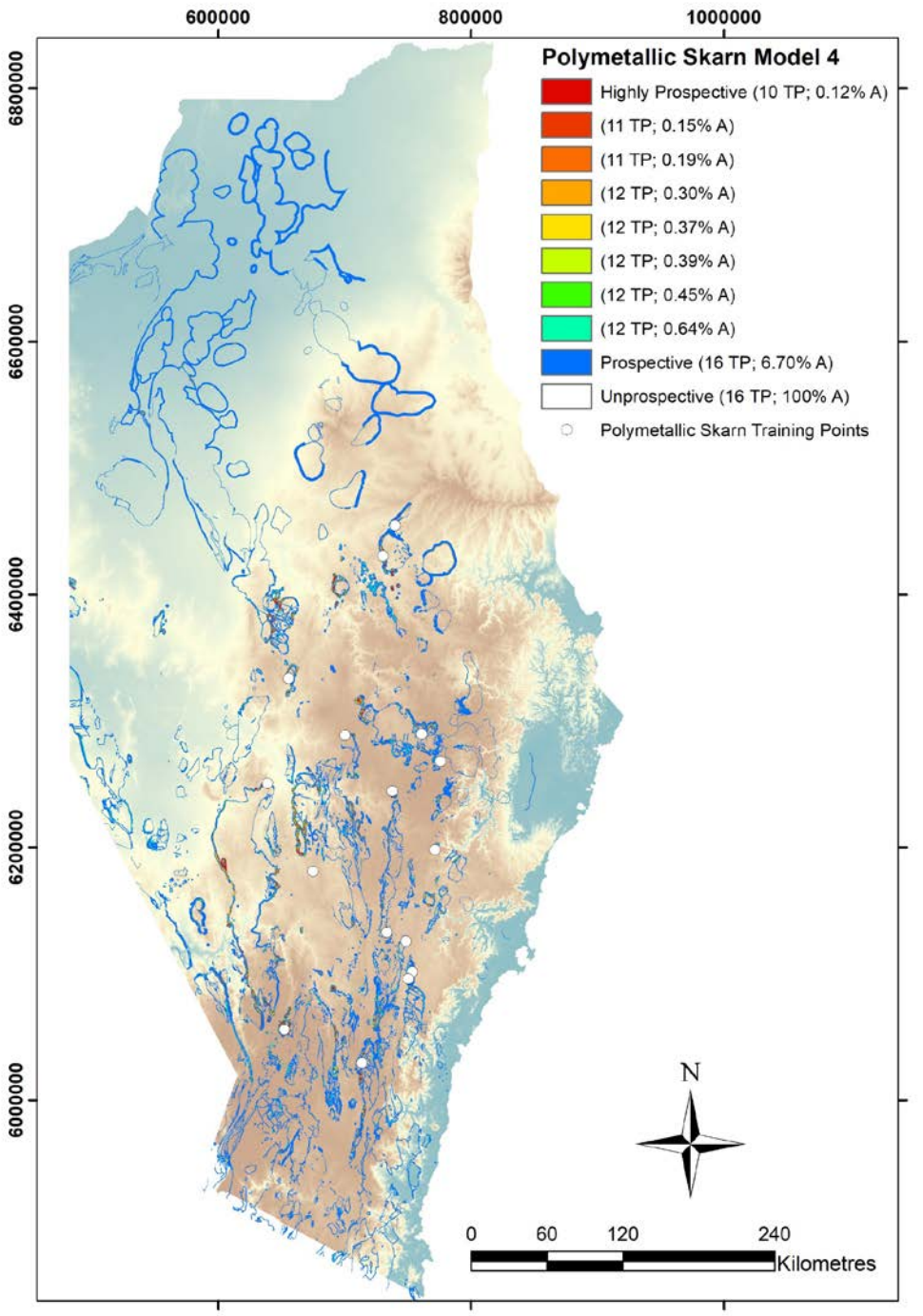
Polymetallic Skarn Mineral Potential

- Exploration heat map indicates areas of high prospectivity which are underexplored (relatively) for skarn-type mineralisation.
- Represents exploration opportunities.



Polymetallic Skarn Mineral Potential

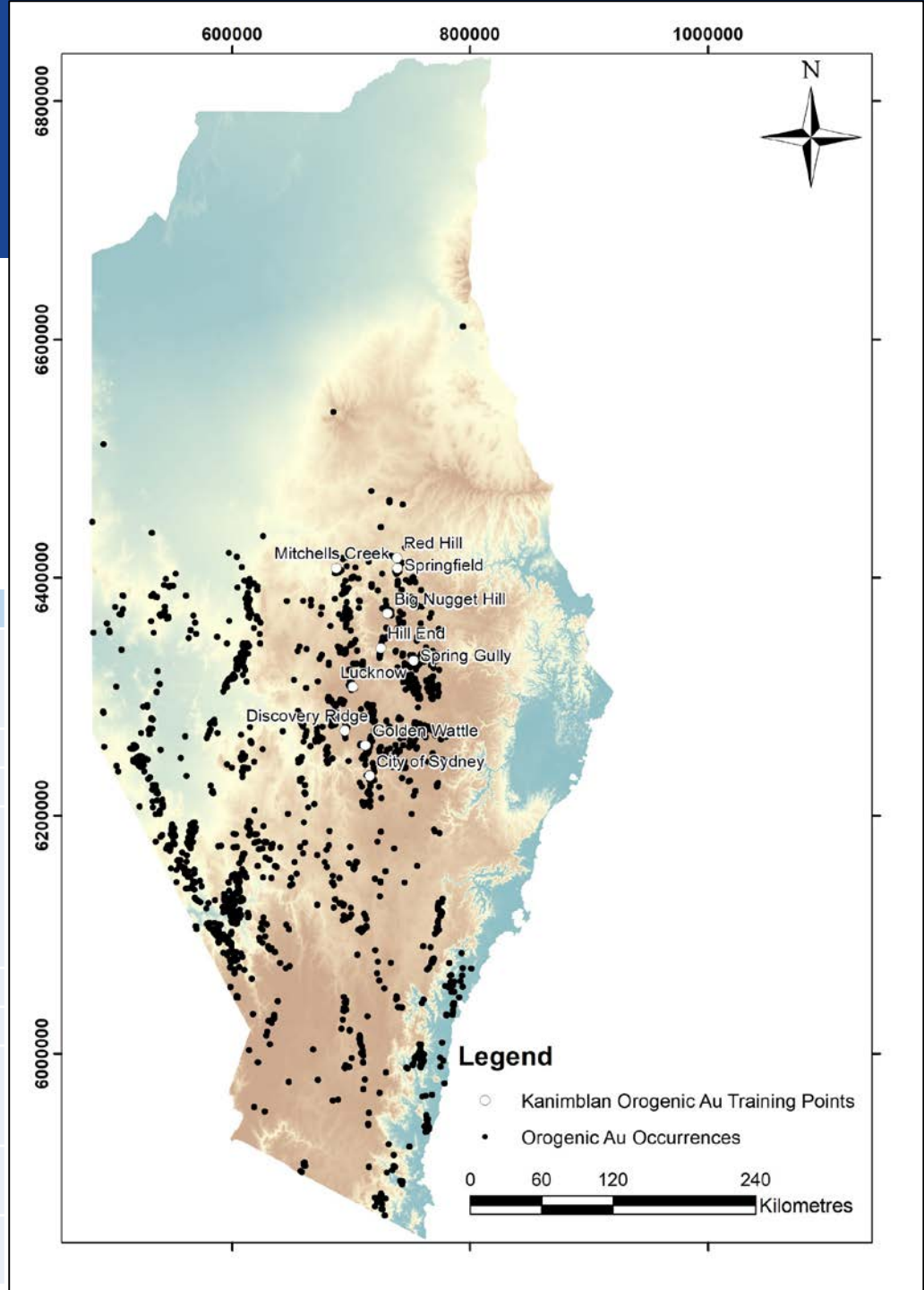
- Identifies skarns at Leadville, Ryans, and Collector
  - Skarns laterally distal to causative plutons
- Mineral system model specific to Tabberabberan and Kanimblan Cycle magmatism
  - Skarns related to Benambran Cycle magmatism are not highlighted
  - Metamorphic reaction skarns are not highlighted
- Modelling does not highlight Hawkins Volcanics or probable skarns under Sydney Basin
  - Improved mapping of limestone lenses and metamorphic aureoles critical
- Challenge with range of skarn types in model
  - Magma fertility parameters are different
  - Geochemical signatures are different



Kanimblan Orogenic Au Mineral System

- Low sulfide structurally controlled quartz veins related to Early Carboniferous Kanimblan Orogeny within/adjacent to Hill End Trough.
- The mineral systems knowledge was tested using spatial analysis:
  - 174 spatial variables tested
  - 126 produced a statistically valid result
  - 90 correlated well with the training points

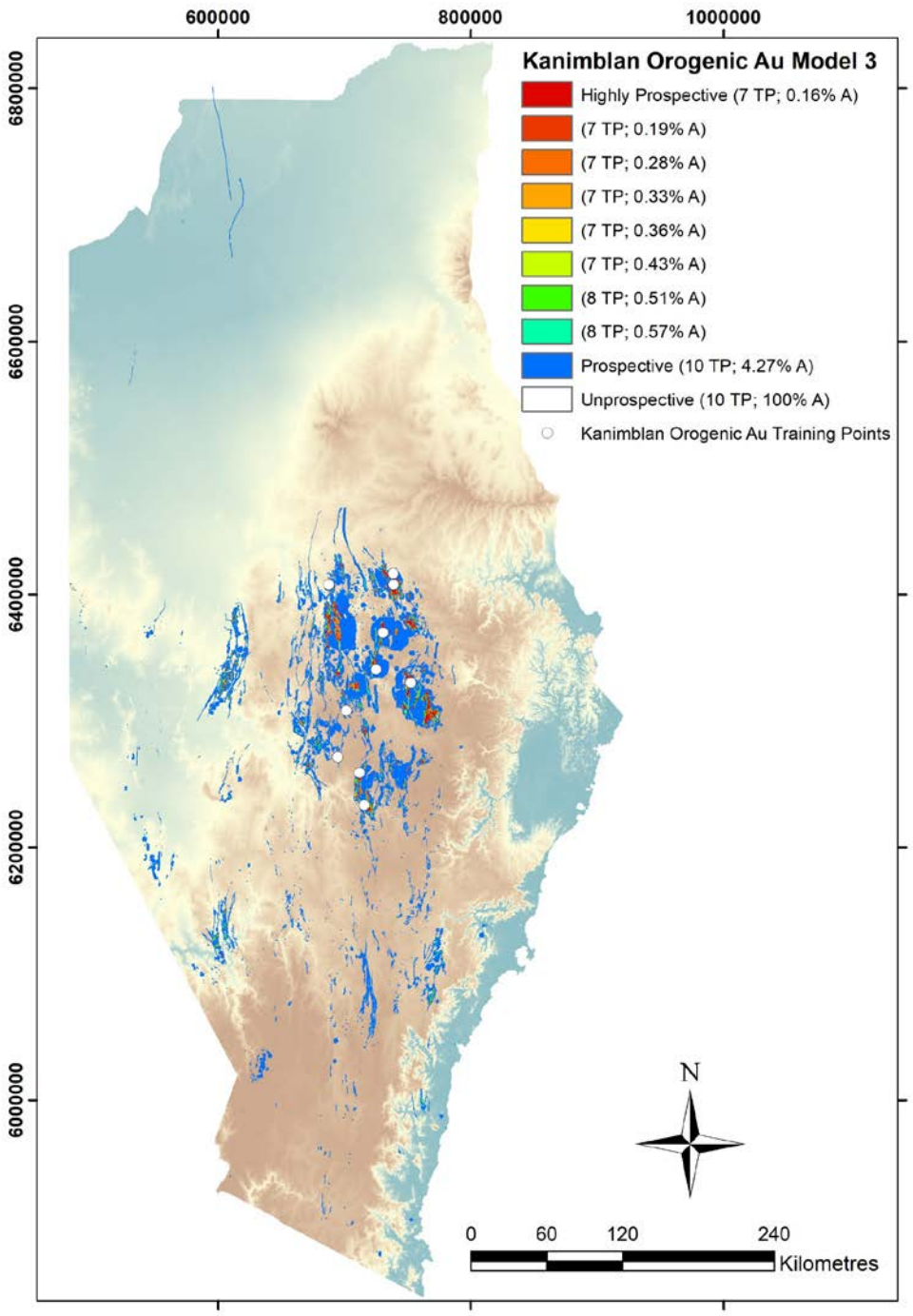
Data Type	Mineral System Component	Key Variables
Lithology/Stratigraphy	Source/Transport/Trap	Kanimblan Cycle geology: mafic and ultramafic rocks, deep marine units, pyritic rocks, breccias; pre-existing Macquarie Arc; Fe reactive rocks; reactivity and competency contrasts.
Metamorphic type	Source	Kanimblan age contact metamorphism.
Mineral occurrences	Deposition	Density of known Au mineral occurrences; Placer Au deposits.
Faults/Folds	Transport/Trap	Fault subsets including: reverse and thrust faults, reactivated faults, N-S trending faults; lower order faults; fault density; point datasets derived from the fault dataset, particularly fault intersections, bends, jogs, and splays; folds and fold density; fault and vein density.
Veins	Transport/Trap	Vein density and proximity to mapped veins.
Petrology	Source/Transport/Trap	Carbonate-sericite; white mica; pyrite; chlorite; phengite.
Magnetic/Gravity worms	Transport	Magnetic and gravity worms at mid- to deeper crustal levels. More value could potentially be extracted from the worm data with further processing.
Stream sediment geochemistry	Deposition	Stream sediment samples with anomalous Au in a regolith carbonate unit.
Rock chip and drillhole geochemistry	Deposition	Rock chip and drillhole assays with anomalous Au and As.



Kanimblan Orogenic Au Mineral Potential Map

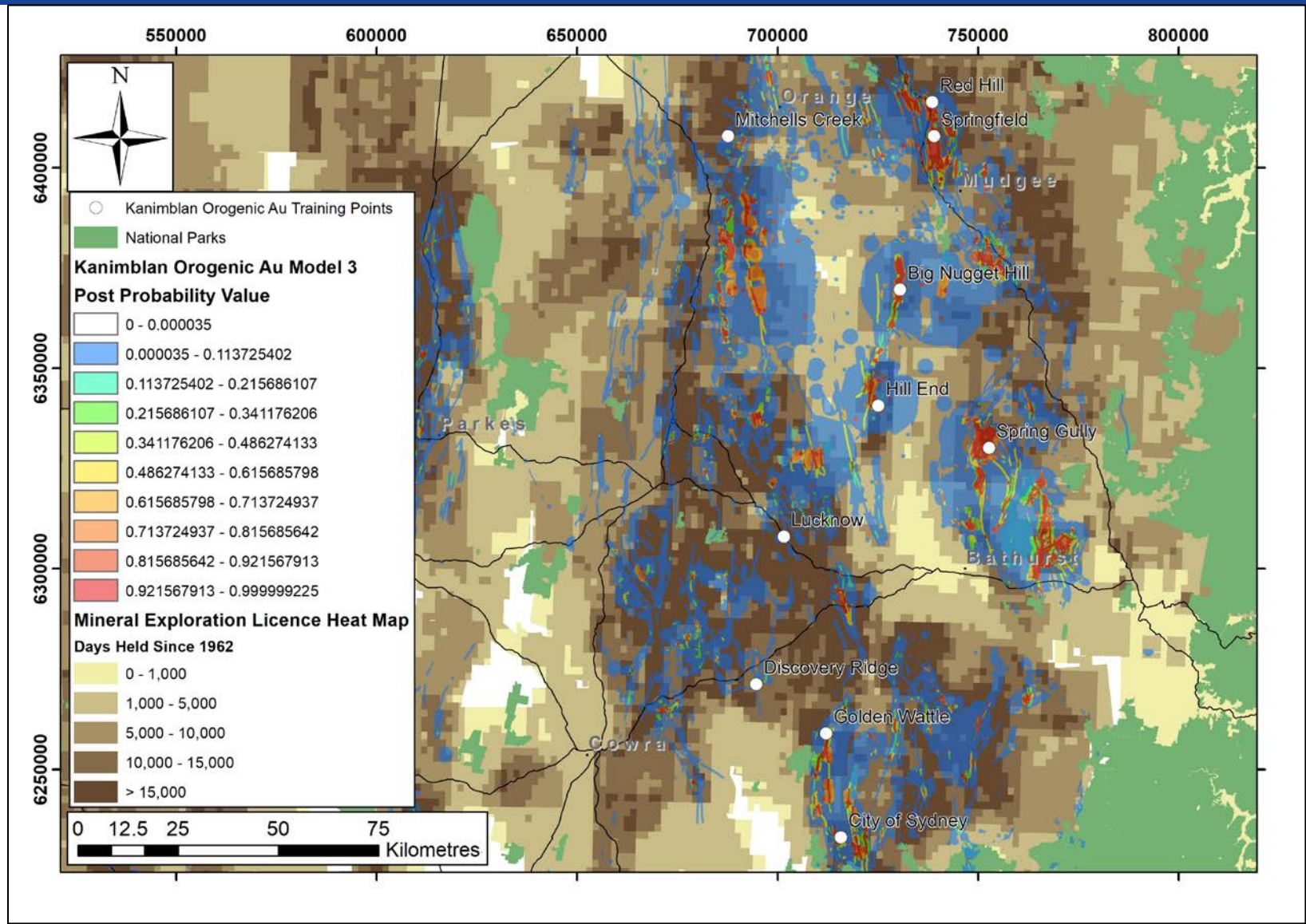
Mineral System	Spatial Variable	Variable ID	# TP (N=10)	C	StudC
Source	Association with Macquarie Arc and deep marine units	50 m	10	3.56	3.37
	Kanimblan greenschist metamorphism	3950 m	7	3.99	5.78
Transport	Reverse and thrust faults of Kanimblan age	250 m	7	4.01	5.82
	N-S Orientated Faults	1200 m	8	3.58	4.53
Trap	Fault Order - 3rd order Kanimblan (also possible transport)	900 m	6	3.37	5.22
	Folds	2950 m	8	3.55	4.49
Deposition	Au mineral occurrence density (excludes any intrusion related)	Class>=2 (high density)	9	4.73	4.49
	Placer Au deposits (excludes any intrusion related)	2000 m	8	4.95	6.26
	Drillhole-Rock-MinOcc Au anomaly	Drillhole-rock Au>=0.04 ppm	10	1.79	1.69
	Narrow phengite-chlorite-pyrite-carbonate halo around quartz veins	500 m	7	5.44	7.87

- Prior probability: 0.000035
- Prospective area: 4.3% of study area
- Highly prospective area: 0.16% of study area
- All training points in prospective area
- 7/10 training points fall in highly prospective area
- Efficiency of classification: 99.8%



Kanimblan Orogenic Au Mineral Potential

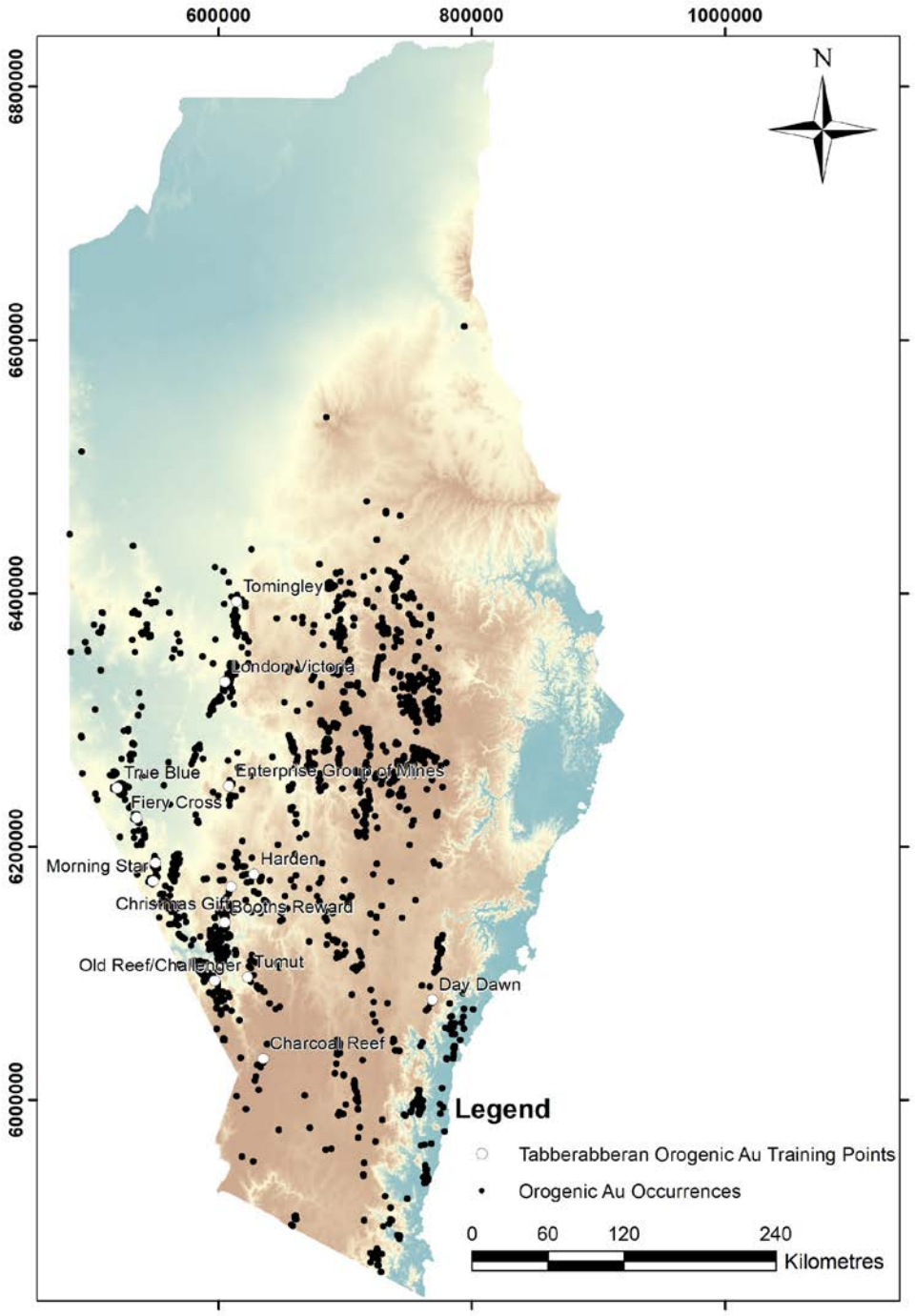
- Highly prospective area around training points and known past producers.
- Exploration heat map indicates some moderate to highly prospective areas are relatively underexplored.
- Other highly prospective area highlighted with no known Au occurrences.
- Model limits prospective area to the west.
  - Differentiates between Kanimblan and Tabberabberan systems.



Tabberabberan Orogenic Au Mineral System

- Low sulfide structurally controlled quartz veins related to Middle Devonian Tabberabberan Orogeny, predominantly near the Gilmore and Parkes thrust systems.
- The mineral systems knowledge was tested using spatial analysis:
  - 168 spatial variables tested
  - 112 produced a statistically valid result
  - 64 correlated well with the training points

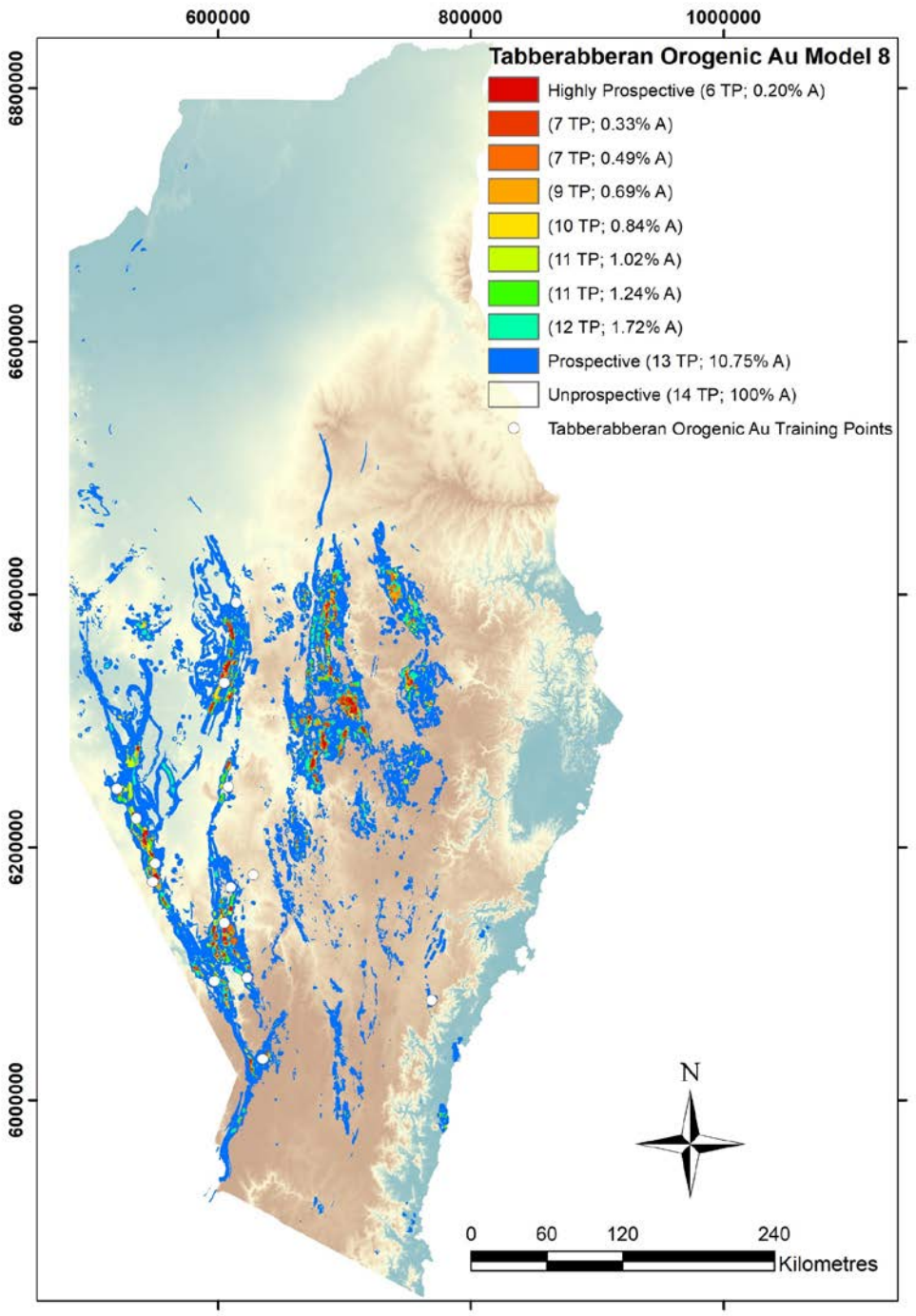
Data Type	Mineral System Component	Key Variables
Lithology/Stratigraphy	Source/Transport/Trap	Tabberabberan Cycle geology: intermediate to mafic composition rocks, deep marine units, syn-metamorphic intrusions; pre-existing Benambran Cycle units; competency and reactivity contrast; reactivity contrast; Fe reactive rocks.
Metamorphism	Source	Tabberabberan greenschist facies metamorphism
Mineral occurrences	Deposition	Density of known Au mineral occurrences; Placer Au deposits.
Faults/Folds	Transport/Trap	Fault subsets including: strike slip faults, Benambran contraction faults, Bindian contraction or Tabberabberan extension faults, higher order faults; dip variance along strike; fault density; point datasets derived from the fault dataset (i.e. intersections, bends, and splays).
Veins	Transport/Trap	Vein density and proximity to mapped veins.
Petrology	Source/Transport/Trap	White mica-carbonate-pyrite; muscovite-pyrite; chlorite; sericite/white mica; phengite.
Magnetics/Gravity	Deposition/Trap	Spatially coincident magnetic and gravity highs at depth.
Magnetic/Gravity worms	Transport	Magnetic worms with upward continuation of 33376 m.
Stream sediment geochemistry	Deposition	Catchments containing stream sediment samples with anomalous Au.
Rock chip and drillhole geochemistry	Deposition	Rock chip and drillhole assays with anomalous Au.



Tabberabberan Orogenic Au Mineral Potential Map

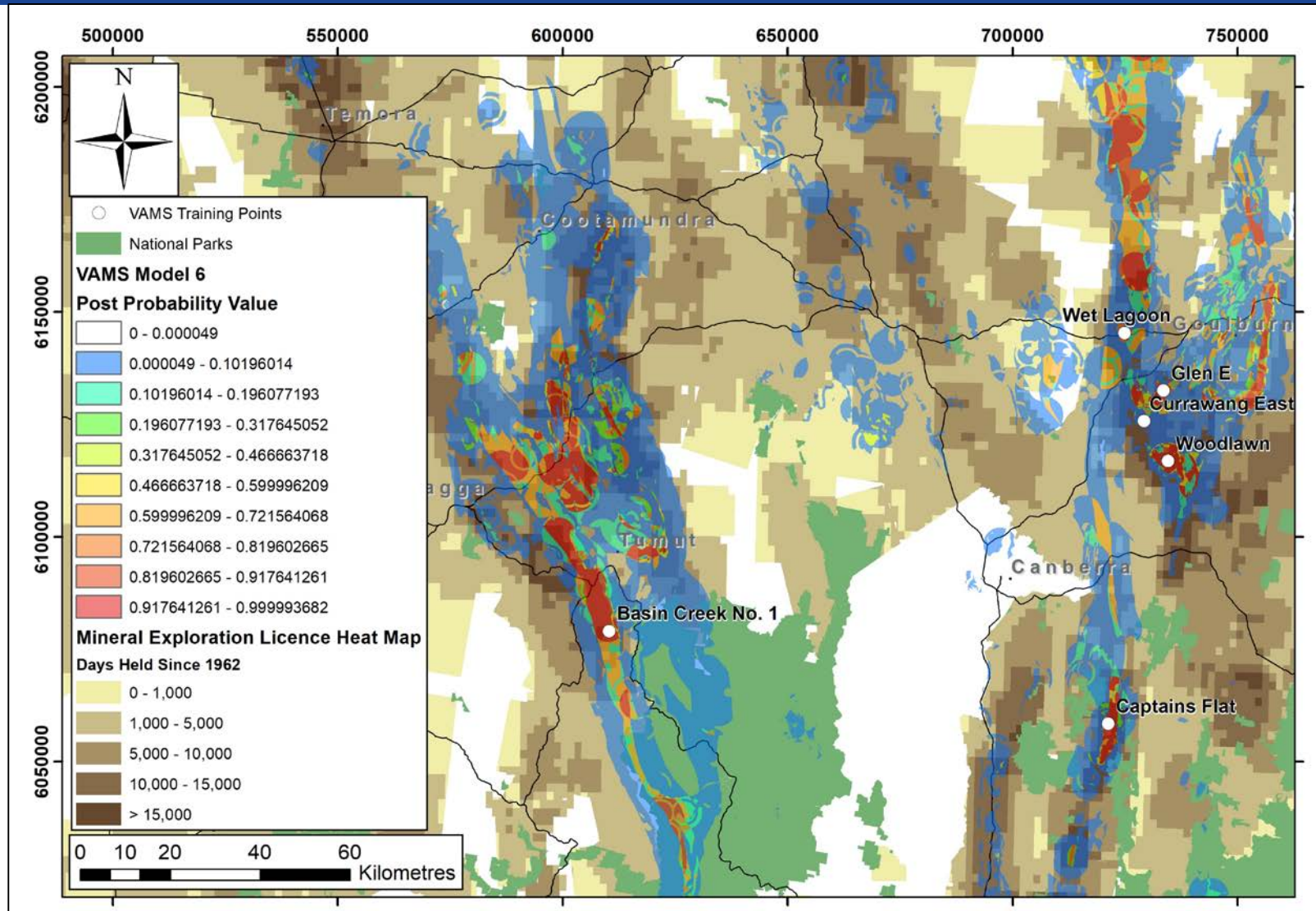
Mineral System	Spatial Variable	Variable ID	TP (N=14)	C	StudC
Source	Association with Benambran Cycle units with intermediate to mafic composition.	6000 m	12	3.08	4.03
	Spatially coincident magnetic and gravity highs at depth	11300 m	6	1.47	2.72
	Greenschist facies metamorphism	50m	13	2.54	2.45
Transport	4th order faults and veins (also possible trap)	500 m	14	5.70	5.46
	1st and 2nd order fault of Benambran or Bindian age	2500 m	10	3.21	5.42
	NNW oriented faults	4350 m	7	1.84	3.45
Trap	Reactivity Contrast - Iron	1150 m	9	2.61	4.68
	Lineation/1st-2nd order fault dip variance	1350 m	7	2.84	5.31
Deposition	Au mineral occurrence density (excludes any intrusion related)	Class>=2 (high density)	11	3.84	5.89
	Drillhole-Rock-MinOcc Au anomaly	Drillhole-rock Au>=0.04ppm	14	2.16	2.07
	Narrow phengite-chlorite-pyrite-carbonate halo around quartz veins	1950 m	11	3.58	5.49

- Prior probability: 0.000049
- Prospective area: 10.7% of study area
- Highly prospective area: 0.2% of study area
- 13/14 training points are in prospective area
  - 1 training point (Harden) falls below the prior probability
- 10/14 training points fall in highly prospective area
- Efficiency of classification: 98.6%



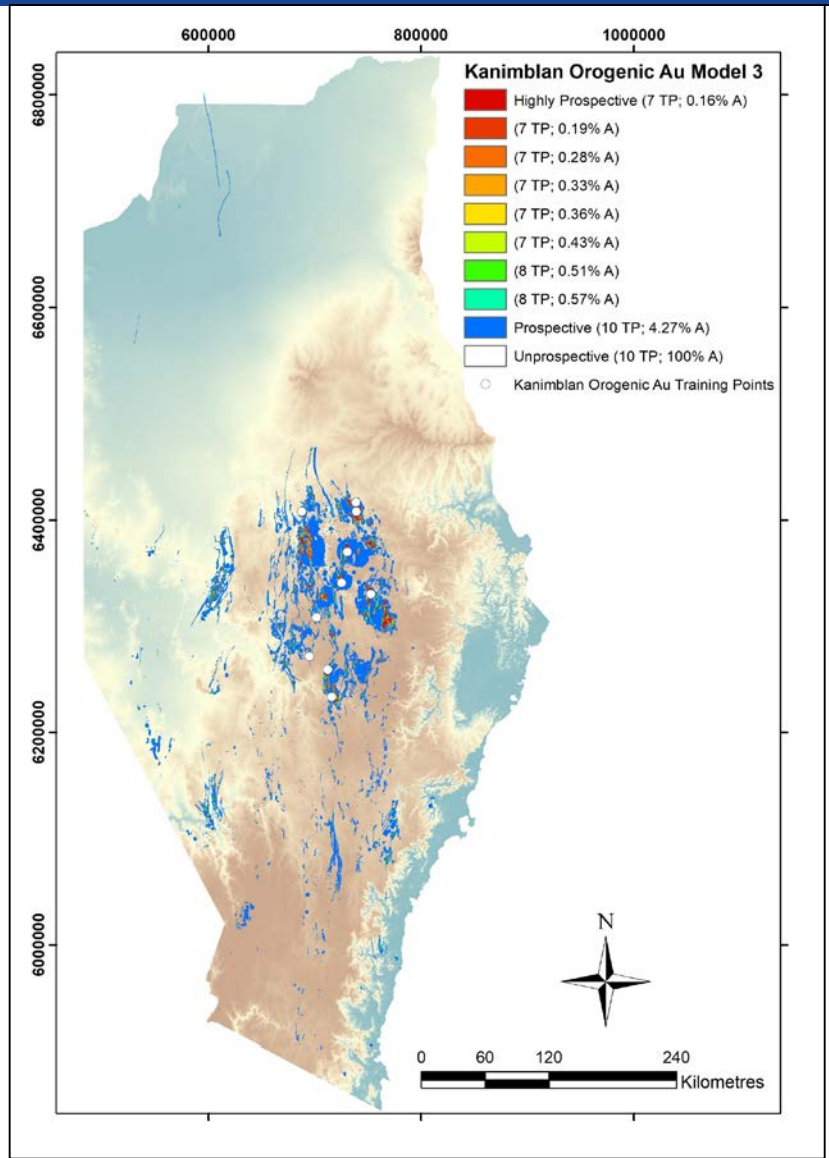
Tabberabberan Orogenic Au Mineral Potential

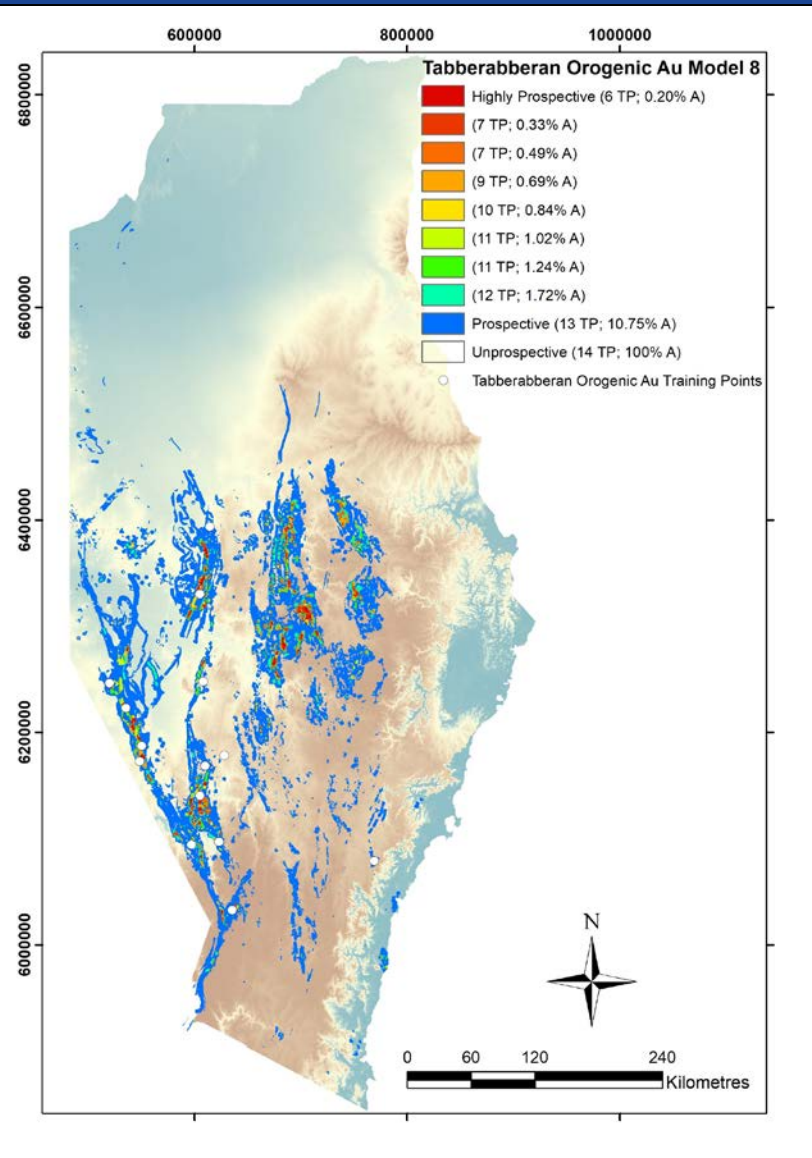
- Highly prospective area around Tomingley, Adelong, Parkes, and Wyalong.
- Other highly prospective area around Cowarra.
- Almost all moderately to highly prospective area is covered by known Au occurrences.
- Limited moderate to highly prospective area that is not already well explored.
- Model highlights areas under cover.
- Harden is located in an unprospective area
  - Different structural setting to other training points



Kanimblan vs. Tabberabberan Orogenic Au Potential

- Similar source maps used in each model
- Both mineral systems relate to greenschist facies metamorphism
  - Higher grade during Tabberabberan, making it difficult to map for Kanimblan
- Kanimblan system uses pre-existing structures from Tabberabberan
- Both models use the same exploration geochemistry data
- Use of placer occurrences for Kanimblan model can differentiate due to lack of topographic relief in areas where most of the Tabberabberan age mineralisation is.
- Parts of Hill End Trough prospective for Tabberabberan orogenic Au despite dominant event being Kanimblan in the area.
- Timing of many occurrences is not well constrained there is some uncertainty about which system some training points belong to.

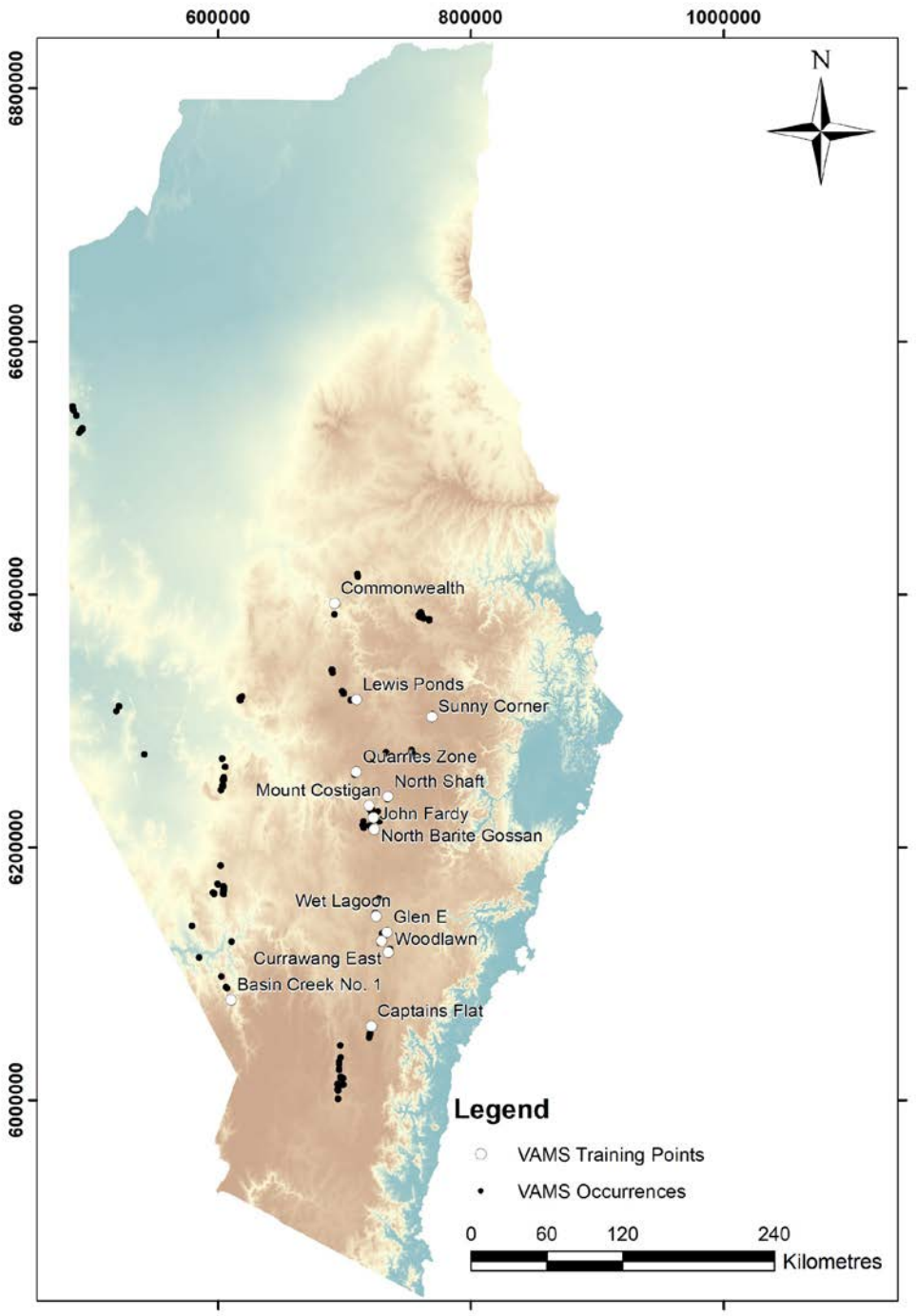




VAMS Mineral System

- Stratabound accumulations of sulfide minerals hosted in deep-water extensional basins that formed in the Middle Silurian (Tabberabberan Cycle).
- The mineral systems knowledge was tested using spatial analysis:
  - 138 spatial variables tested
  - 101 produced a statistically valid result
  - 89 correlated well with the training points

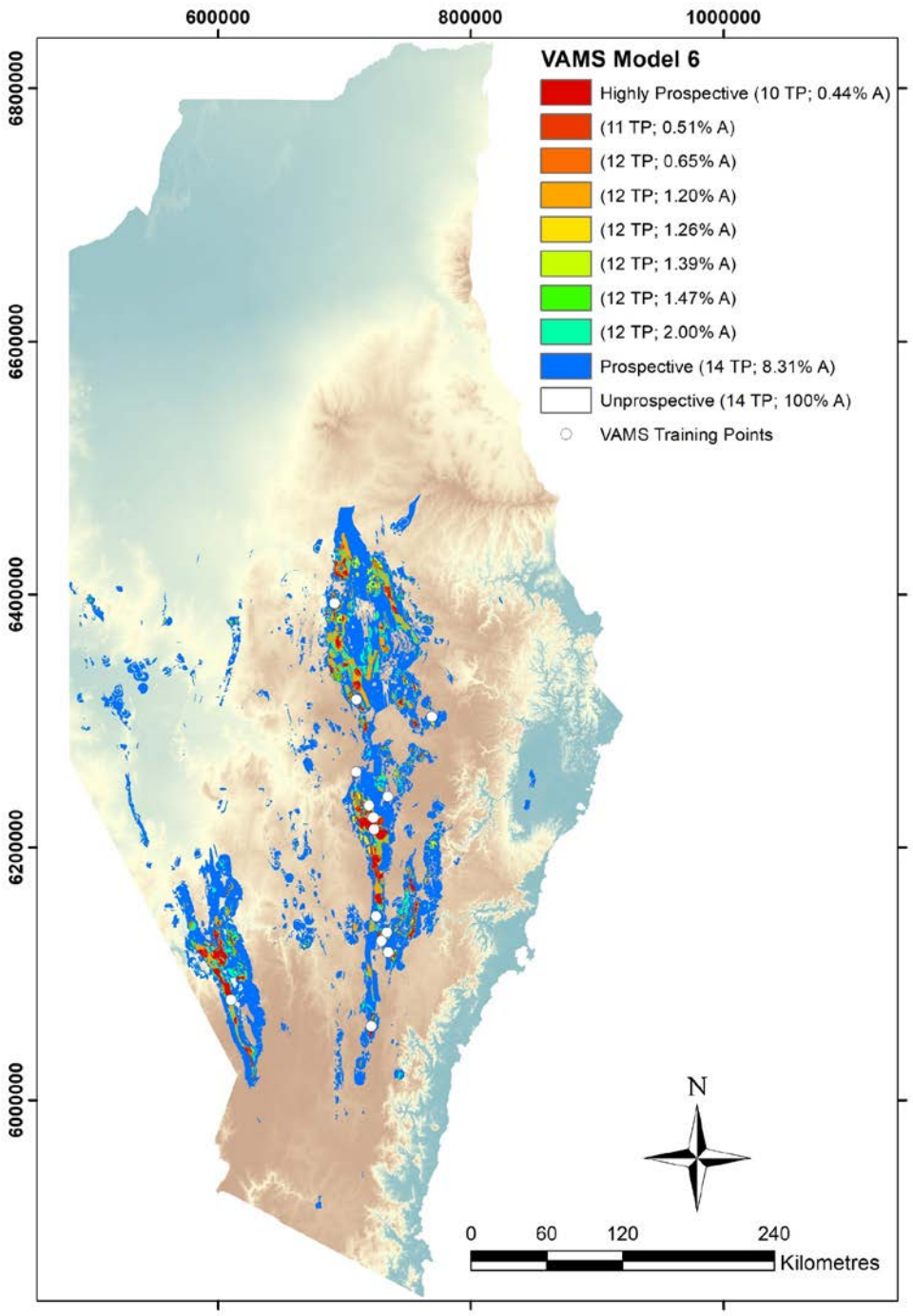
Data Type	Mineral System Component	Key Variables
Lithology/Stratigraphy	Source/Transport/Trap	Tabberabberan Cycle geology: stratigraphy, volcano-sedimentary basins, deep marine sediments, calc-alkaline volcanics, breccias; sediment-volcanic contacts; reactivity and competency contrasts; N-S trending linear stratigraphic units.
Mineral occurrences	Deposition	Density of known metallic mineral occurrences.
Petrology	Source/Trap/Deposition	Chlorite-epidote; silicification, cherts, jasper; Fe, Mn, and siliceous exhalates; sulphides (using pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, tennantite, arsenopyrite, pyrrhotite).
Faults	Transport/Trap	Faults sub-sets including: N-S and NNW oriented faults, basin bounding faults, extensional faults within the basins; fault density; point datasets derived from the fault dataset, including fault intersections, bends, jogs, and splays; structural complexity.
Magnetics/Gravity	Deposition/Trap	Magnetic RTP lows along early fault zones; high magnetic RTP gradient in volcanic rocks.
Radiometrics	Deposition/Source	U, Th, and K radiometric highs.
Stream sediment geochemistry	Deposition	Stream catchments containing stream sediment samples with anomalous Ag, Au, As, Ba, Bi, Cu, Hg, Pb, Sb, and Zn.
Rock chip and drillhole geochemistry	Deposition	Rock chip and drillhole assays with anomalous with anomalous Ag, As, Au, Ba, Bi, Cd, Co, Cu, Fe, Hg, Mo, Pb, S, Sb, Tl, and Zn.



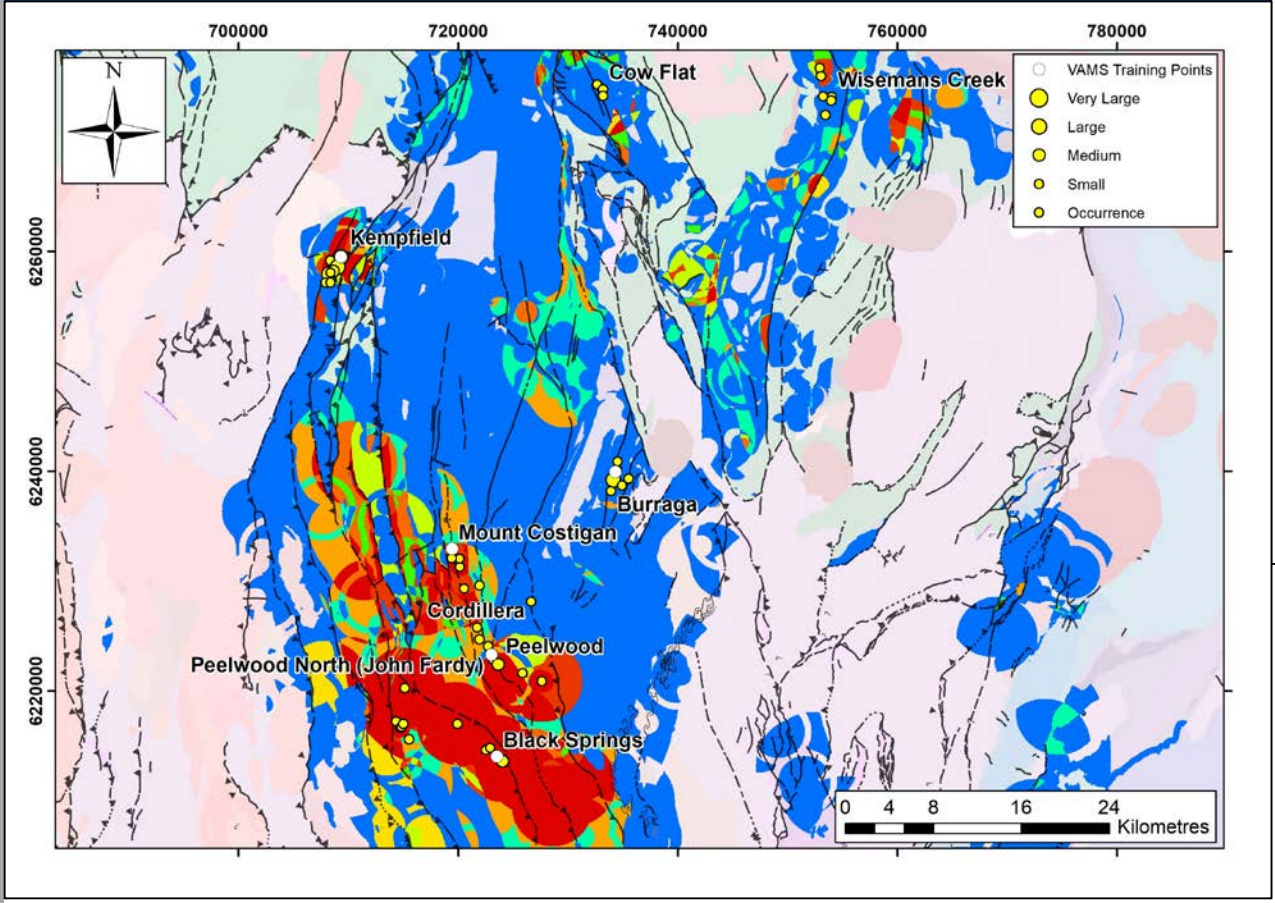
VAMS Mineral Potential Map

Mineral System	Spatial Variable	Variable ID	TP (N=14)	C	StudC
Source	Hill End Trough and Goulburn Basin, Tumut Trough volcano-sedimentary units (Tabberabberan Cycle units)	50 m	14	5.34	5.12
Transport	NNW Oriented Faults	3050 m	10	3.14	5.31
	Extensional faults within the basins	5900 m	11	3.66	5.62
	Basin bounding faults	4100 m	14	5.09	4.88
Trap	Relationship to syn-volcanic sediments	50 m	13	4.28	4.12
	Fe-rich, Mn rich and siliceous exhalites	3700 m	9	4.53	8.11
	Sulfide-bearing epiclastic units	550 m	14	3.82	3.66
	Presence of silicification or cherts, jasper*	3900 m	10	3.10	5.24
Deposition	Drillhole-Rock-MinOcc Cu anomaly	Drillhole-rock Cu>=372 ppm	9	2.22	3.70
	Drillhole-Rock-MinOcc Pb-Zn anomaly	Drillhole-rock Pb>=334 ppm and Zn>550 ppm	10	3.59	5.44
	Sulphide Mineralogy	2400 m	13	1.63	1.57

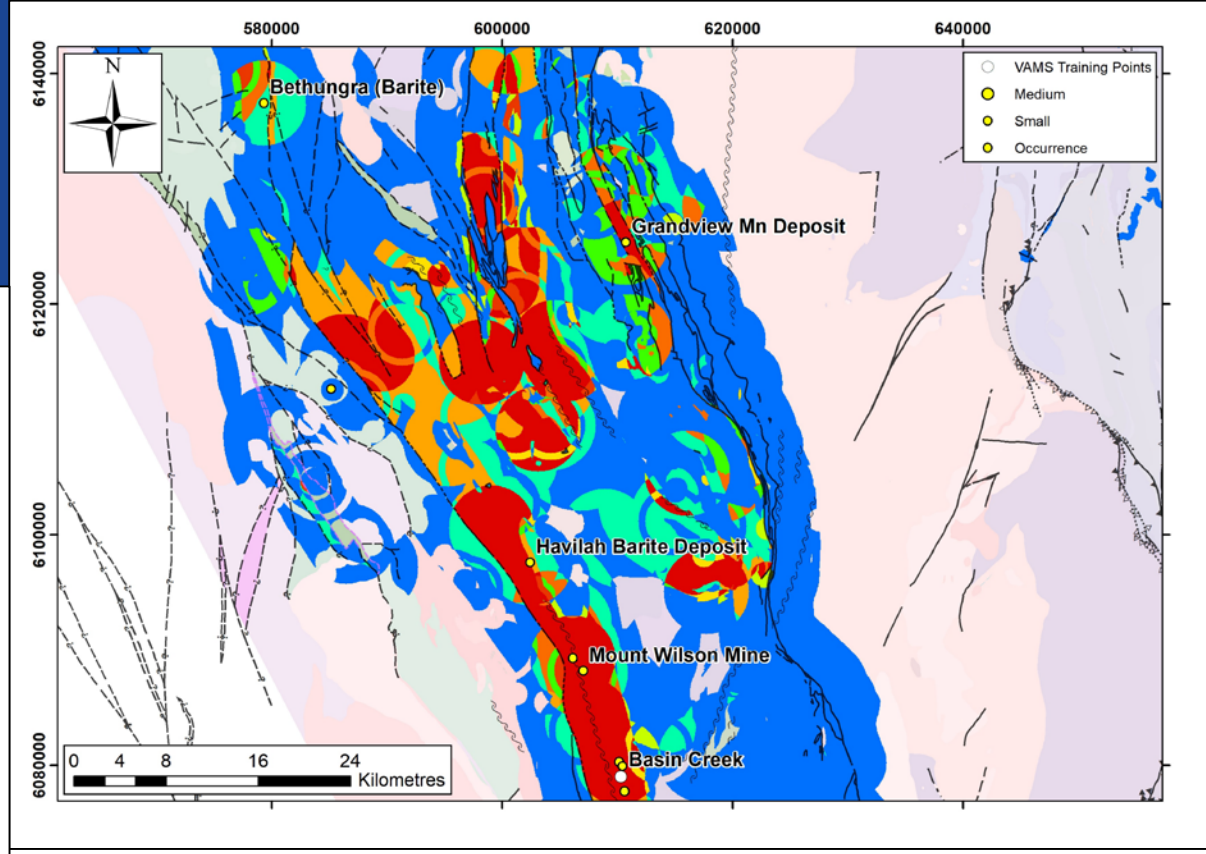
- Prior probability: 0.000049
- Prospective area: 8.31%
- Highly prospective area: 0.44%
- All training points in prospective area
- 10/14 training points in highly prospective area
- Efficiency of classification: 99.5%



VAMS Mineral Potential



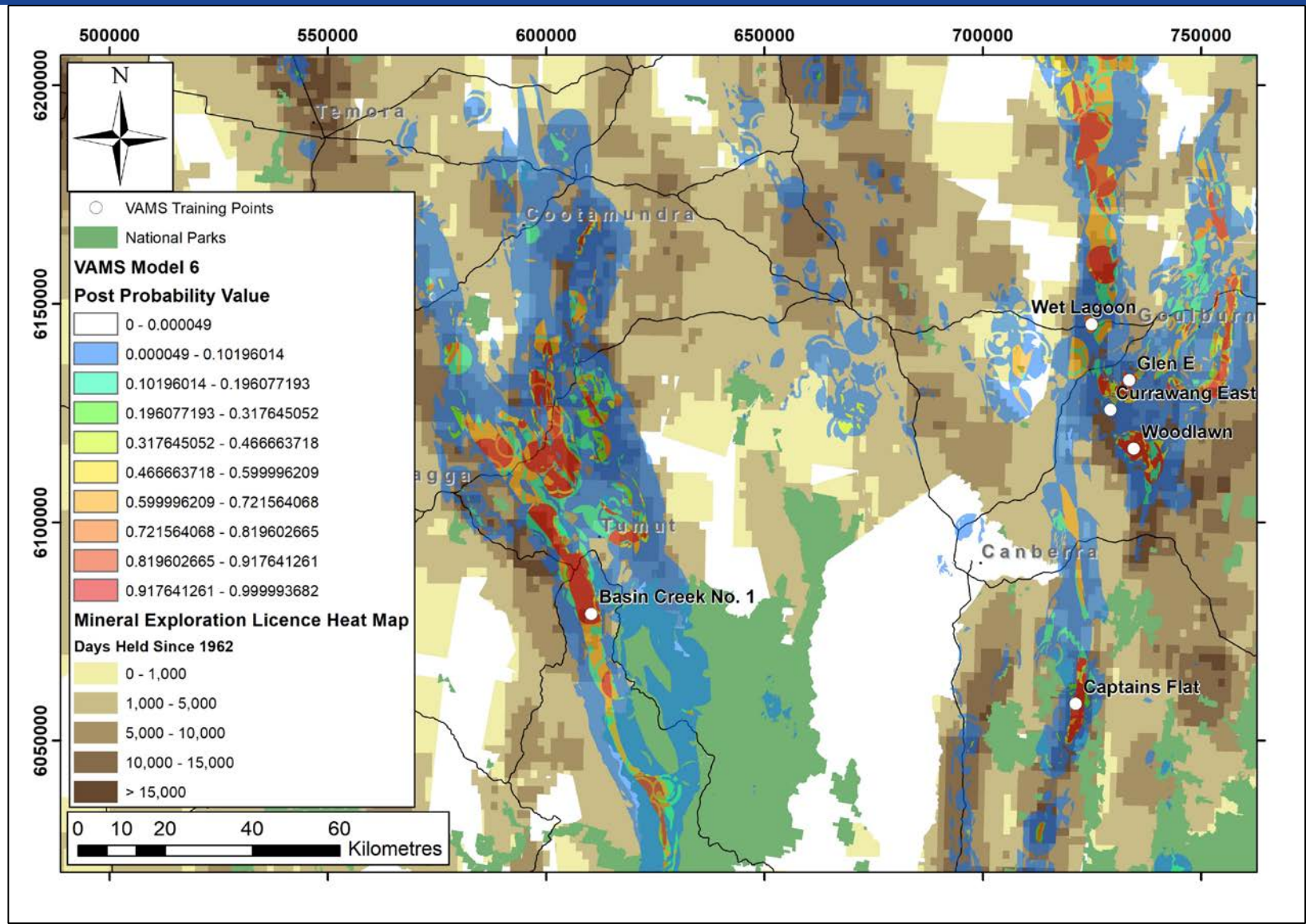
- Highly prospective area around Mount Costigan to Wet Lagoon.
- Low to moderate prospectivity to south of Bathurst Batholith



- Elevated prospectivity in the Tumut Trough highlights untapped potential.
- Modelling confirms key ideas about basin bounding and extensional faults, exhalative horizons, and syn-volcaniclastic sedimentary rocks.
- Challenge to map the causative heat sources/intrusions for the mineral system.

VAMS Mineral Potential

- Exploration heat map indicates there are still some relatively underexplored areas with moderate to high VAMS potential.
- May represent exploration opportunities for industry.



Results Summary

- Excellent quality datasets
- Mineral system descriptions for five key mineral systems in the eastern Lachlan Orogen
- Predictive variables linked to the mineral systems
- Detailed statistics from spatial analysis recorded in a spatial data table
  - 923 spatial variables tested
  - 656 maps with valid statistics
  - 412 maps correlate well with training points
- List of key predictive variables determined from spatial analysis
- Mineral potential mapped for each of the five key mineral systems
  - Assessment of statistical confidence due to “missing data areas” in the inputs used to produce each mineral potential map – increases confidence that we aren’t just mapping data availability
- Mineral System Atlas for eastern Lachlan Orogen delivered as a digital data package, which includes: predictive maps, weights tables, mineral potential models, unique conditions and data confidence maps, spatial data tables, and a summary report

Conclusions

- A Mineral System Atlas for the eastern Lachlan Orogen has been delivered and is downloadable as a digital data package from DIGS:
  - https://search.geoscience.nsw.gov.au/product/9253
- The mineral potential maps and a selection of predictive maps are also available to view on MinView
- A wide range of predictive maps for the porphyry Cu-Au, polymetallic skarn, Kanimblan and Tabberabberan orogenic Au, and VAMS mineral systems have been created and many have not been used for the final mineral potential models.
- New models can be created by choosing different combinations of the predictive maps listed in the spatial data table and combining them using the ArcSDM weights of evidence tools.
- New and/or improved datasets can easily be incorporated into the models.
- Mineral potential maps in this project are being used for strategic land-use planning, however industry can utilise the results for exploration targeting or to produce their own mineral potential maps using the files in the Mineral System Atlas.

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