

Geochemistry in prospectivity modelling: investigating gold mineralisation in the Taupo Volcanic Zone, New Zealand

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Outline

- Prospectivity Modelling
- Weights of Evidence modelling
- Taupo Volcanic Zone (TVZ)
- Data Available
- Modelling the TVZ
- Geochemistry in the TVZ
- Predictive Maps
- TVZ prospectivity model
- Conclusions

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Prospectivity modelling

- Goal
  - To predict where there is a high probability of finding mineral deposition
- Basic method
  - Compile digital data into GIS and develop maps related to the mineral system being modelled
  - Use training data to weight mapped data (weights of evidence)
  - Or expert defined values to weight important mapped data (fuzzy logic)
  - Combine predictive maps using weights of evidence or fuzzy logic to produce prospectivity map

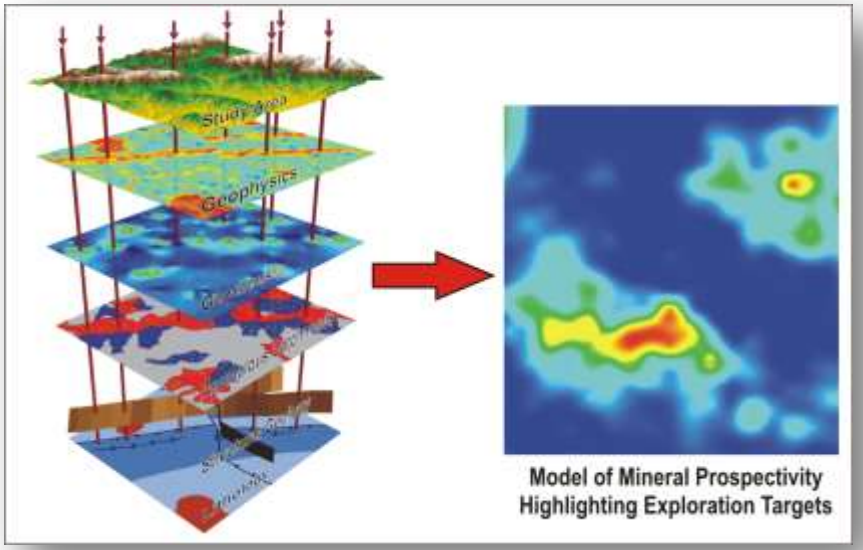
Weights of Evidence Modelling

- Developed from medical industry for use in mineral exploration
  - Graham Bonham-Carter at Geological Survey of Canada
- Used to predict a disease given a list of symptoms
- Applied to a number of different industries
- WoE is a probability based method
  - Bayesian statistical approach
- Used WoE to create a prospectivity model for epithermal gold mineralisation in the TVZ superseding one done in 2003

Weights of Evidence Modelling

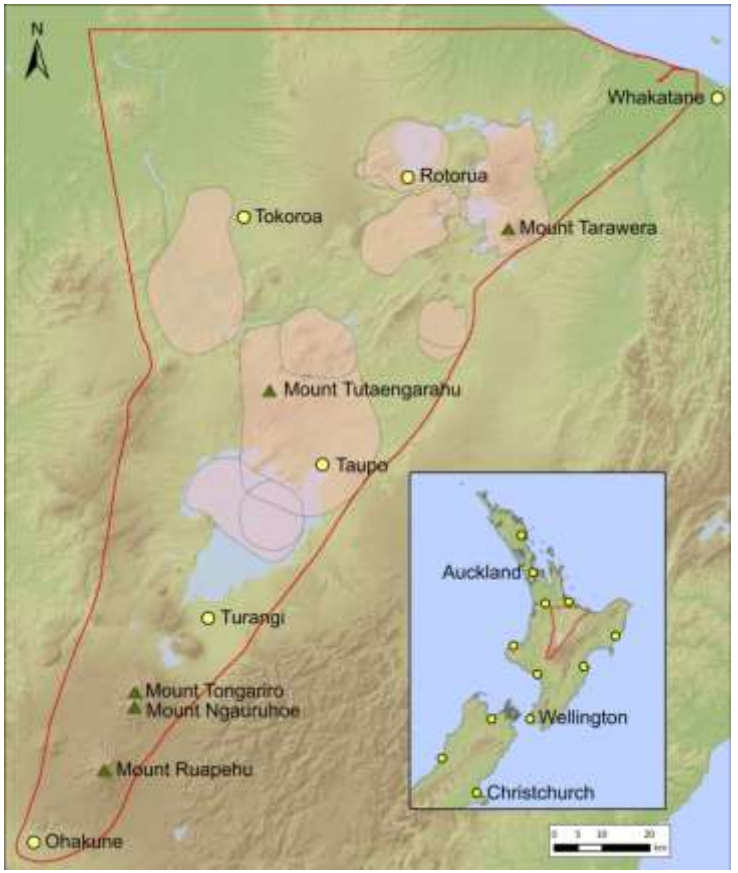
Basic Method

- Develop binary or multiclass predictive maps of data relevant to mineralisation style being modelled
- Use training data to test maps for spatial correlation
- Combine selected maps together using weights of evidence statistics producing a map of probabilities – the Prospectivity Map



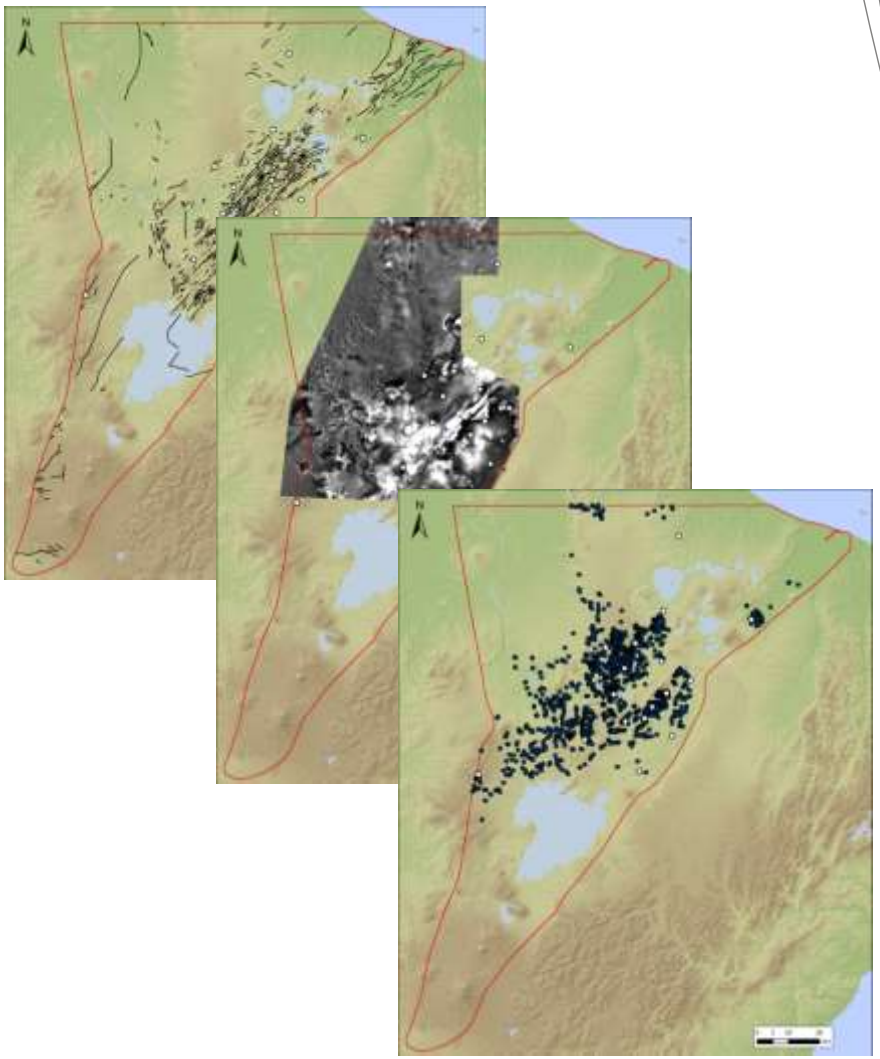
Taupo Volcanic Zone

- Volcanic rocks and associated hydrothermal systems generated by subduction of oceanic Pacific Plate beneath continental Australian
- Belt of andesite-dacite volcanoes along SE side of extensional volcano-tectonic depression
- Depression filled by and is source of ignimbrites and rhyolites from a number of centres
- The TVZ is representative of a modern day analogue for epithermal ore deposition



Data available

- Mineral occurrence data
- Geological data from Rotorua QMAP project (full coverage)
  - Alteration
  - Calderas
  - Lithology
  - Structural
- Glass Earth Gold geophysics data (limited coverage)
  - Gravity
  - Magnetics
  - Radiometrics
- Abundant rock chip and stream geochemistry data (limited coverage)



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Modelling the TVZ

- Mineral Systems Model

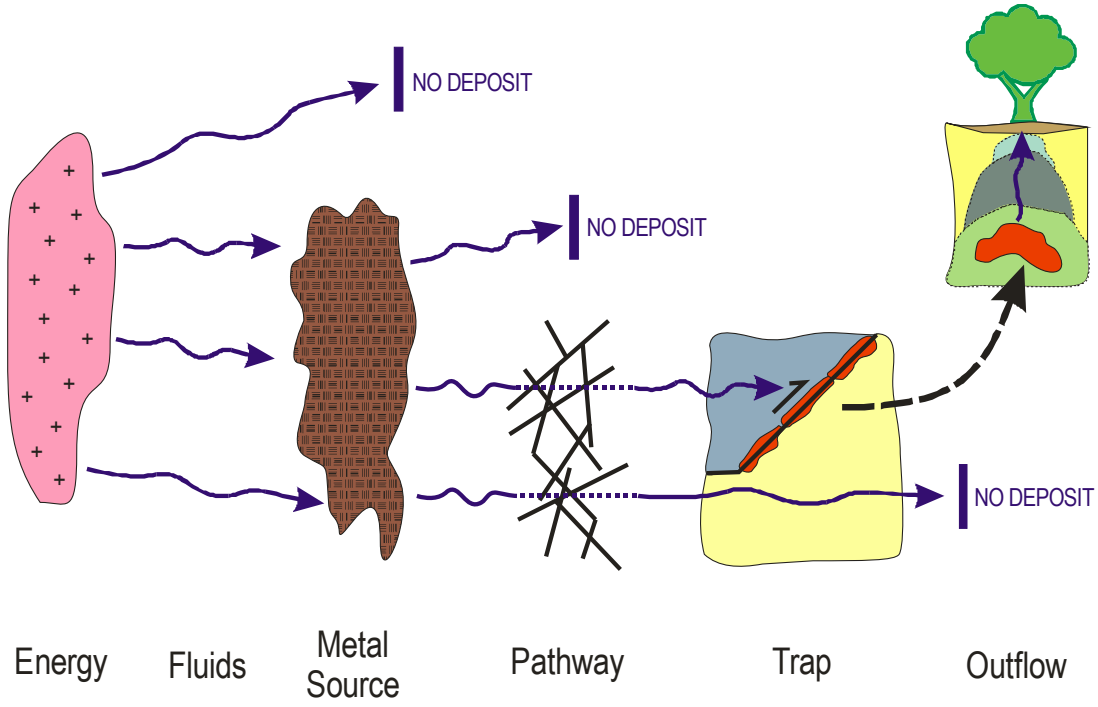
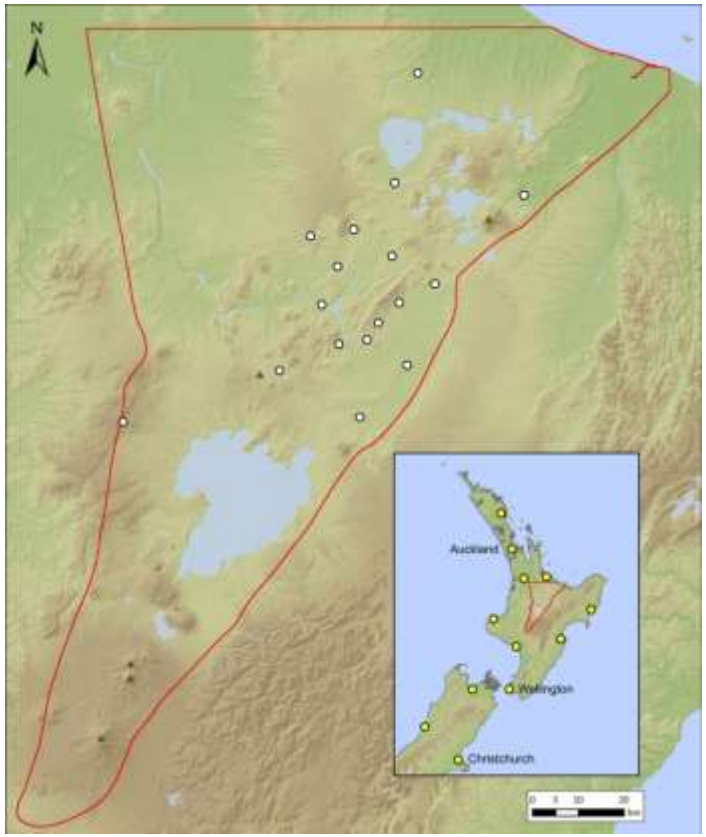


Figure demonstrates source of energy and fluids, migration pathways and the deposition of metal and outflow of fluids

Modelling the TVZ

-Study Area

- The TVZ has been modelled for epithermal gold mineralisation
- Used known epithermal gold occurrences as gold training points (white circles)
- The study area is outlined in red



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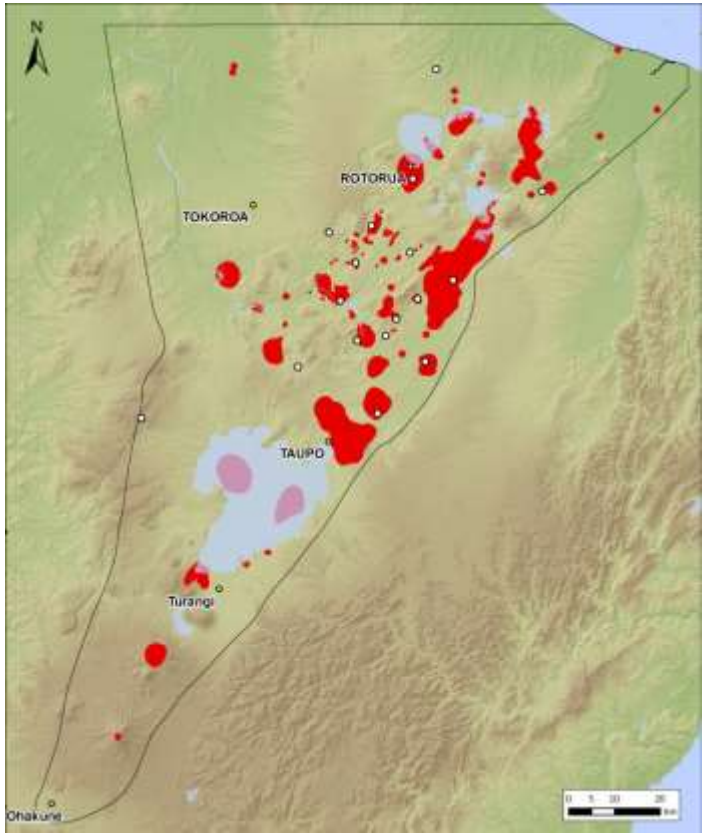
Geochemistry in the TVZ

- Number of processes
  - Changes in state
  - Redox
  - Rock-water interactions
- Geochemical enrichments
  - Envelope related to host rock alteration by fluids
  - Secondary pattern from erosion of deposit
- Maps created from
  - Hydrothermal Alteration
  - Rock and stream geochemistry



Active and inactive hydrothermal alteration buffered to 300 m in red. White circles are epithermal gold training points

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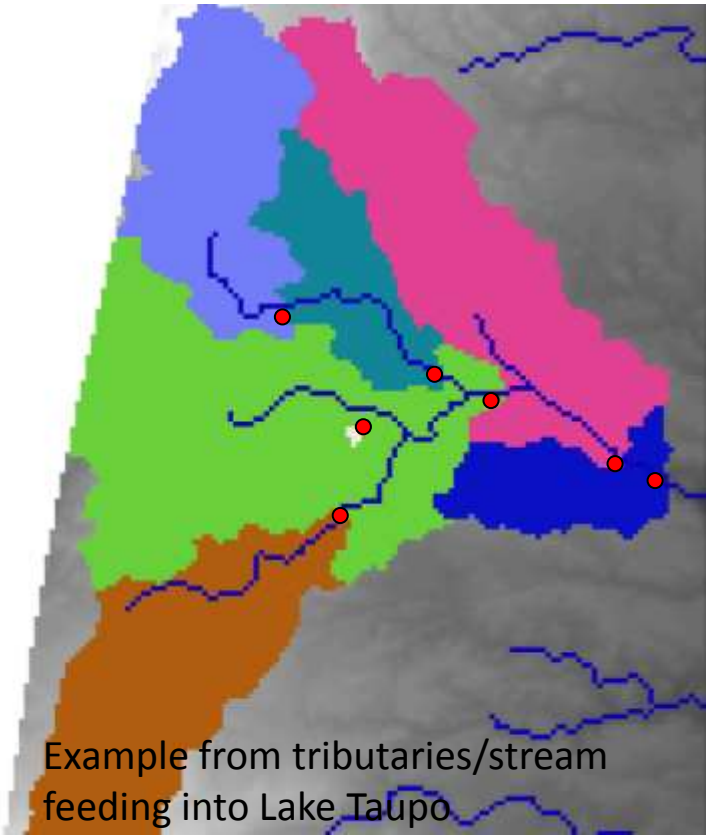
Creating Predictive maps

Streams

- Stream geochemical point used as a pour point to create a catchment
- Value applied to catchment based on pour point defined
- Anomalous thresholds were defined using probability plots and compared to those defined for the model in 2003

Pour points and Catchments



Example from tributaries/stream feeding into Lake Taupo

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Creating Predictive maps

Streams

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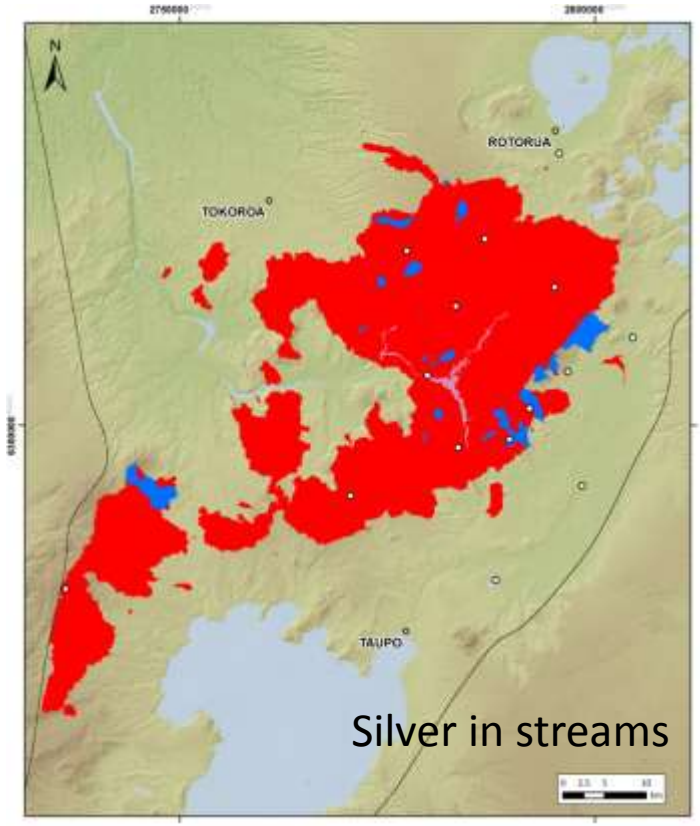
Binary Predictive Map



Red indicates anomalous, blue non-anomalous.
White circles are epithermal gold training points

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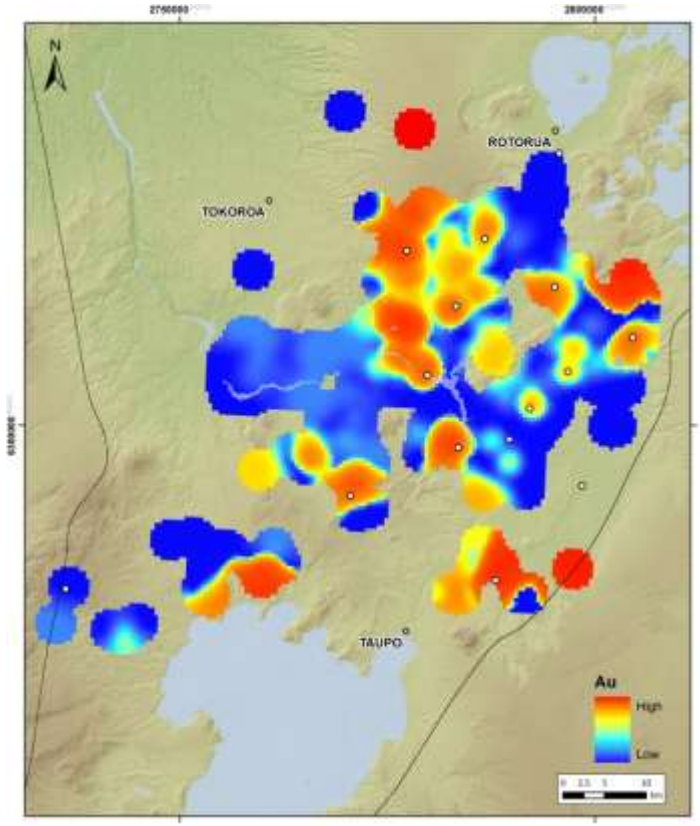
Creating Predictive maps

Rocks

- Used ioGAS to create map for each element with sphere of influence around all data points
- Defined a range of acceptable anomalous thresholds using probability plots in IOGas
- Anomalous thresholds were refined statistically by optimising spatial correlation with training points in ArcGIS

ioGAS produced GRID



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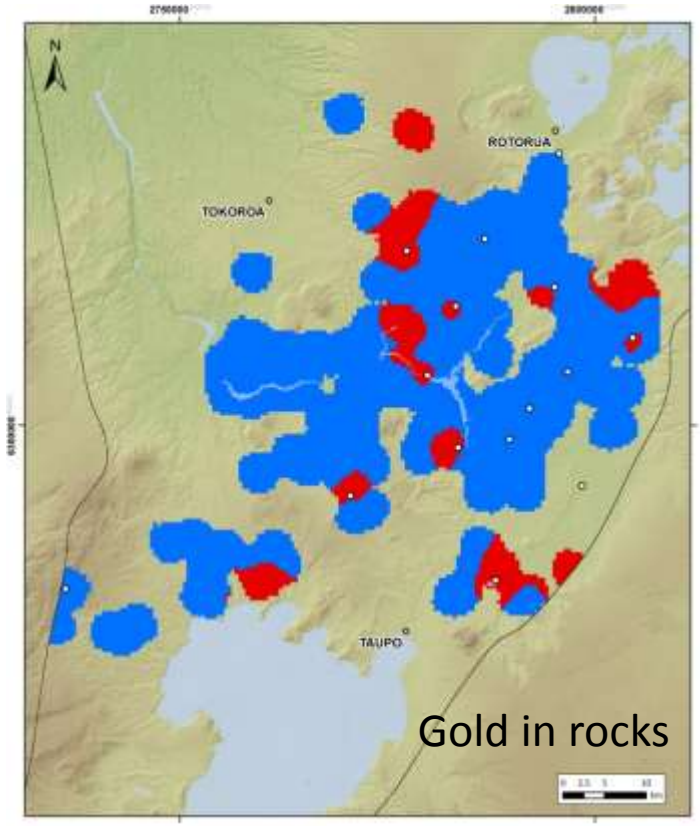
Binary Predictive Map



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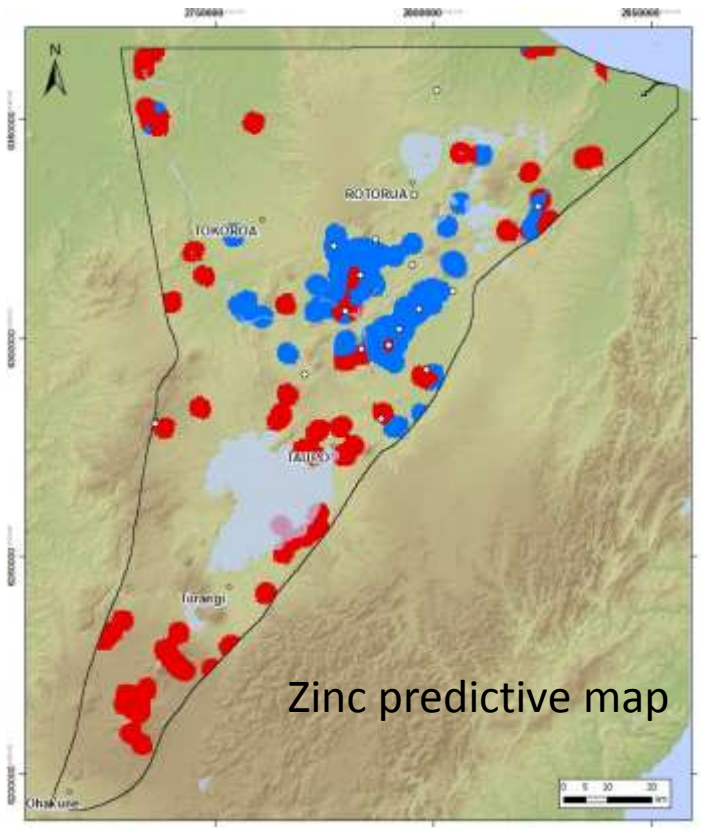
Predictive Maps

- Rock Geochemistry

Rock Geochemistry

Element	Threshold	C	StudC
Ag	8 ppm	0.7	1.1
As	**150 ppm**	**2.4**	**4.6**
Au	**0.25 ppm**	**1.9**	**3.6**
Cu	4 ppm	0.6	0.8
Hg	**6 ppm**	**1.7**	**2.2**
Pb	10 ppm	0.5	0.7
Sb	25 ppm	1.5	2.6
Zn	50 ppm	0.3	0.5

C > 3.0 Strong ; 1.0 < C < 3.0 Moderate ; C < 1.0 Poor



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Layers included in the model

Mineral System	Layer	Description	C	StudC
Source of energy and fluids	Calderas	Mapped active and inactive calderas buffered to 1400 m	1.1	2.3
	Gravity Slope	Gravitational interpretations – high slope relates to boundaries of fluid host igneous intrusive and resultant hydrothermally altered rock buffered by 100 m	2.1	2.6
Migration pathways	Faults NE-SW	NE-SW orientated faults buffered to 500 m	1.4	2.8
Deposition of metal and outflow of fluids	Alteration	Mapped active and inactive alteration buffered to 300 m	3.4	6.4
	Magnetic Lows	Magnetic interpretation – representing areas of large scale hydrothermal demagnetisation	2.3	4.1
	As > 150 ppm	Anomalous arsenic in rock samples	0.7	1.1
	Au > 0.25 ppm	Anomalous gold in rock samples	1.9	3.6
	Hg > 6 ppm	Anomalous mercury in rock samples	1.7	2.2

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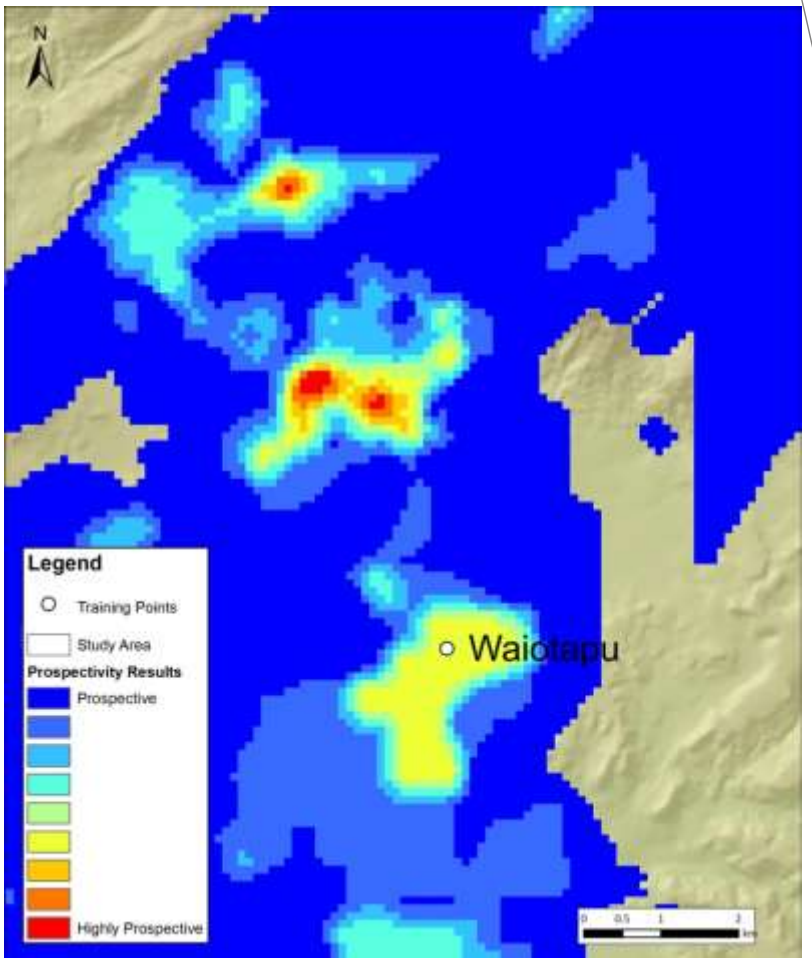
TVZ Prospectivity Model Results

- Waiotapu

- Up to 115 ppm, 360 ppb Au has been recorded in precipitates and fluids respectively of Champagne Pool (Renaut et al. 1999, Pope et al. 2005)
- Model highlights Waiotapu as very prospective area
- North of Waiotapu has also been identified as very prospective, perhaps more so than Waiotapu

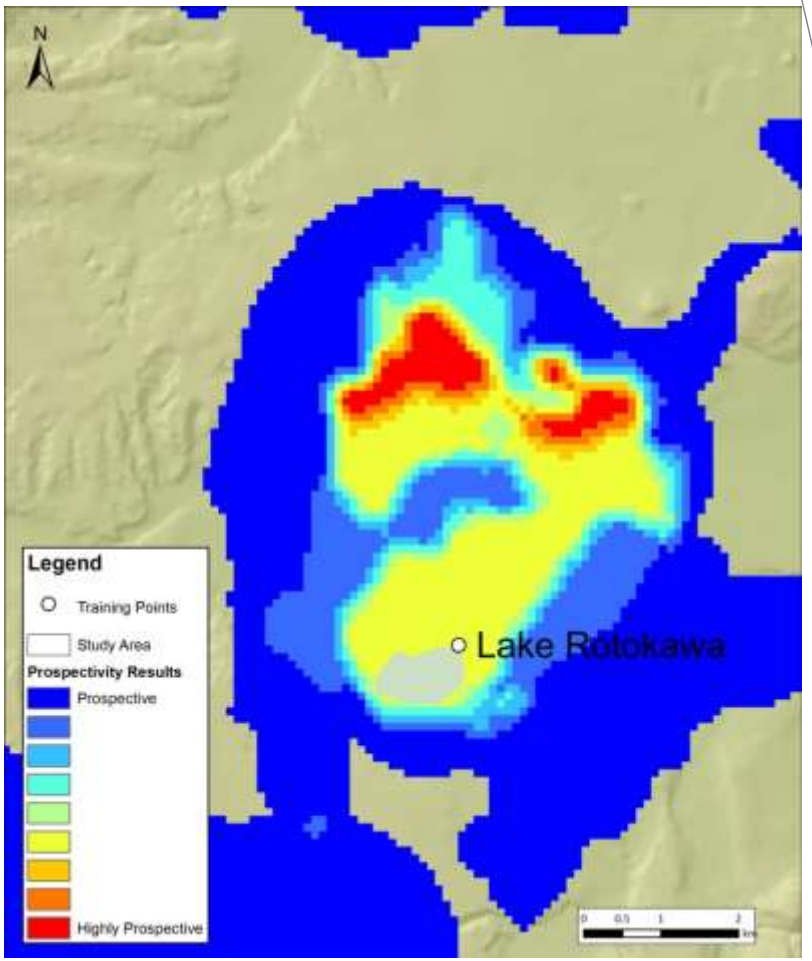


Renaut, R.W. et al., 1999, Geo. Soc. of America 1999 Ann. Meeting, p. 392
Pope, J.G. et al., 2005, Econ. Geol., p. 677

TVZ Prospectivity Model Results

- Rotokawa

- Rotokawa has also been identified as very prospective
- There is also known gold deposition up to 50 ppm on the sinter flat (Krupp and Seward 1987)
- Identification of these active geothermal areas gives evidence as these being analogues for epithermal gold deposition



Krupp, R.E. & T.M. Seward, 1987, Econ. Geol., p. 1109

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Conclusions

- Used WoE modelling for TVZ
- Prospective areas despite lack of coverage of some data sets
- Geochemistry is important in identifying areas of high prospectivity
- Areas such as Rotokawa and Waiotapu are highlighted in the prospectivity map
  - Evidence as modern day analogues for epithermal gold deposition – such as those deposits in Coromandel and Northland

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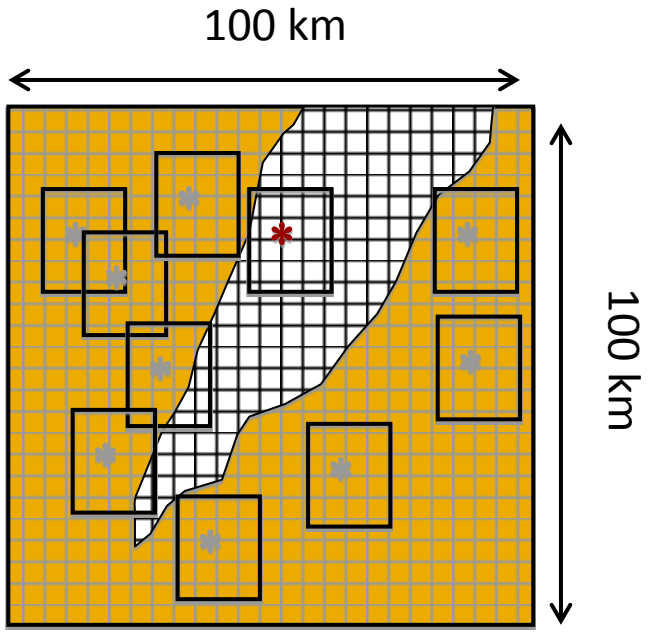


a = total study area (e.g. 10,000 km)
A = Unit Cell = 1 km^2 cell
N(D) = number of deposits
P(D) = prior probability
N(T) = total area of study region
N(B) = area of binary theme
N(B) = area of binary theme not present
N(T) = N(B) + N(B) (as long as no missing data)

When unit cell inf. small

$$W+ = \ln \frac{N(B \cap D)/N(D)}{N(B)/N(T)}$$

$$W+ = \ln \frac{P(B \mid D)}{P(B \mid \bar{D})}$$

$$W- = \ln \frac{P(\bar{B} \mid D)}{P(\bar{B} \mid \bar{D})}$$

$$W- = \ln \frac{N(\bar{B} \cap D)/N(D)}{N(\bar{B})/N(T)}$$

$$Ws+ = \frac{1}{N(B \cap D)} + \frac{1}{N(B)}$$

$$Ws- = \frac{1}{N(\bar{B} \cap D)} + \frac{1}{N(\bar{B})}$$

$$C = (W+) - (W-)$$

$$Cs = \sqrt{(Ws+) + (Ws-)}$$

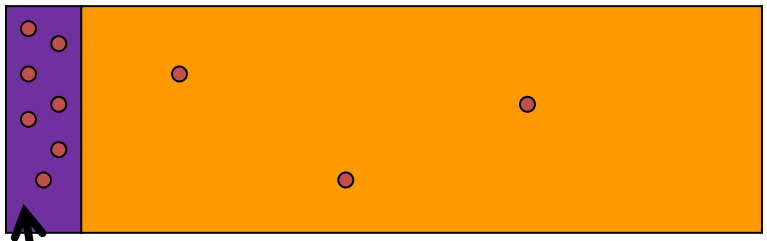
$$StudC = C / Cs$$

From: Bonham-Carter, G.F. (1994)
"Geographic information systems for geoscientists".

Weights of Evidence Modelling

- Correlation of Themes

Good Spatial Correlation

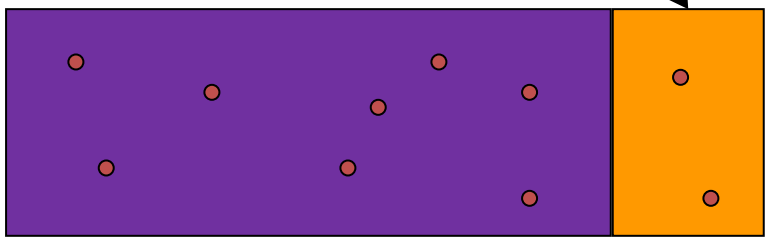


W+ = 3.0 | W- = -1.2 | C = 4.2

Mapped predictive area
e.g. Fault buffer

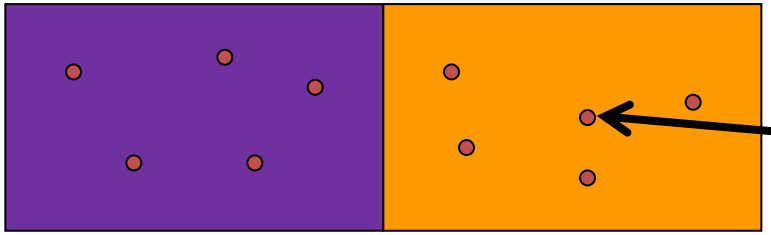
Non-theme area

Poor Spatial Correlation



W+ = 0.15 | W- = -0.44 | C = 0.59

No Spatial Correlation



W+ = 0 | W- = 0 | C = 0

Training sites
e.g. mines, known
mineral occurences

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Weights of Evidence Modelling

- Important Spatial Indicators

$$W+ = \text{natural log} \frac{\text{Proportion of deposits on theme}}{\text{Proportion of total area occupied by theme}}$$

$$W- = \text{natural log} \frac{\text{Proportion of deposits not on theme}}{\text{Proportion of total area not occupied by theme}}$$

$W+ > 0$ indicates positive association with theme

$W- < 0$ indicates negative association with non-theme

$C > 3.0$ Strong correlation

$1.0 < C < 3.0$ Moderate correlation

$C < 1.0$ Weak to poor correlation

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