Machine Learning in Exploration Target Generation

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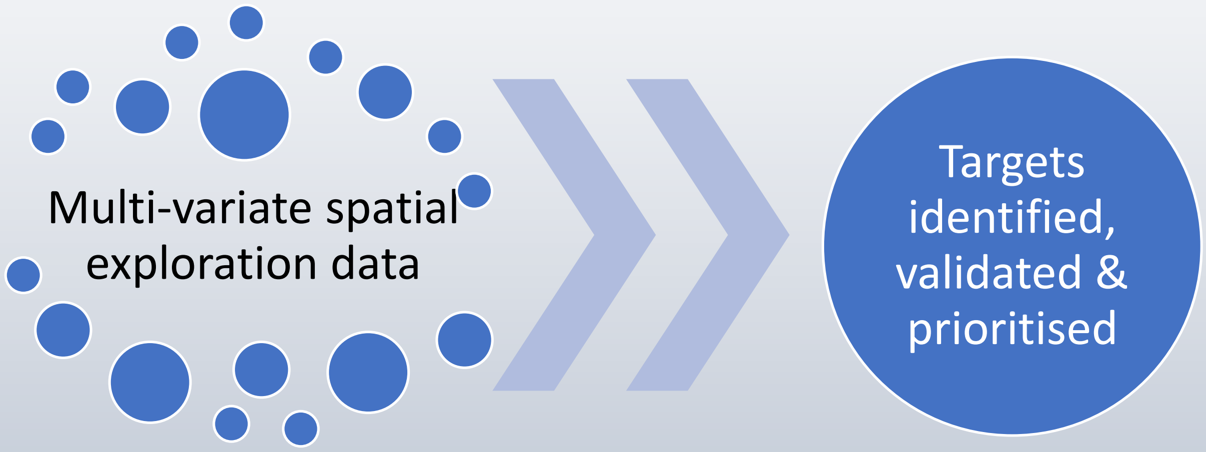
AUSTRALIAN INSTITUTE OF GEOSCIENTISTS

Supporting Geoscientists

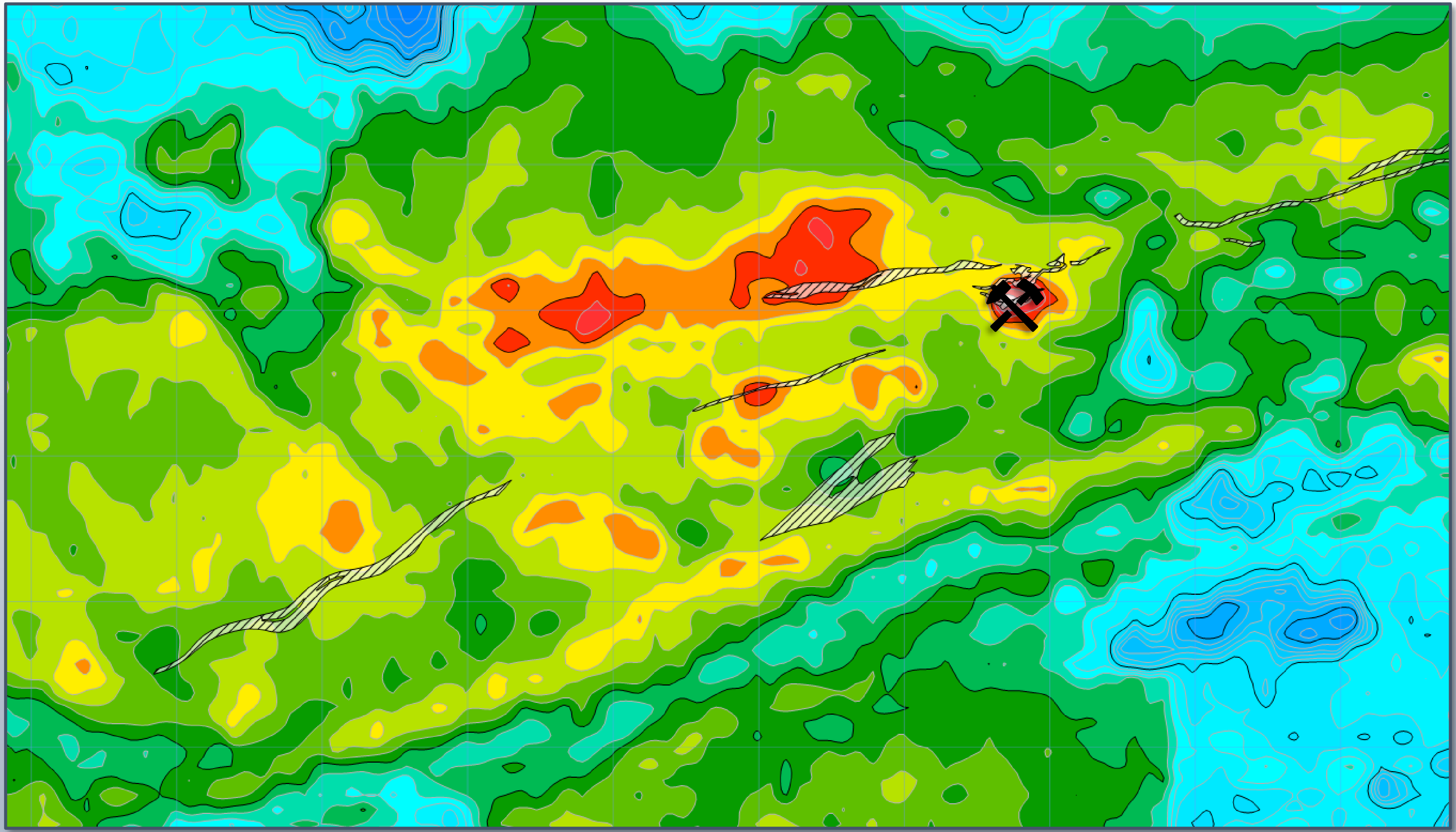
Paradigm



input

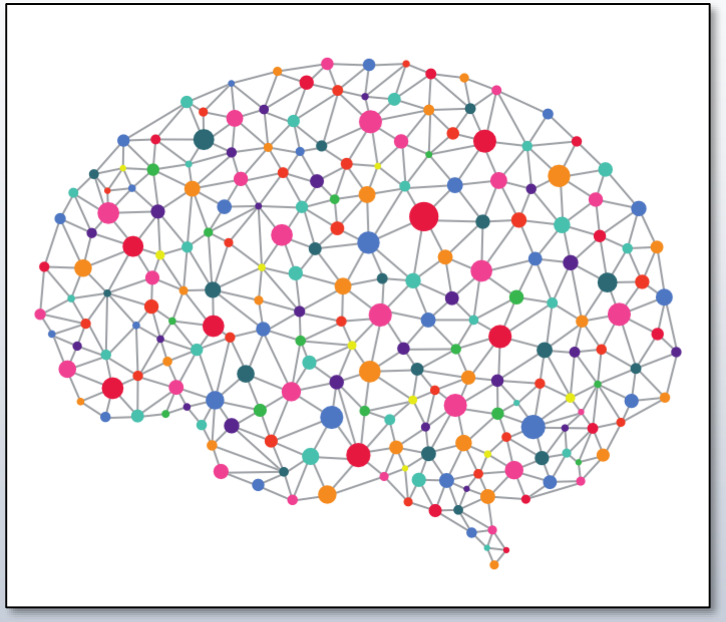
output

Degrussa brown-field prospectivity?



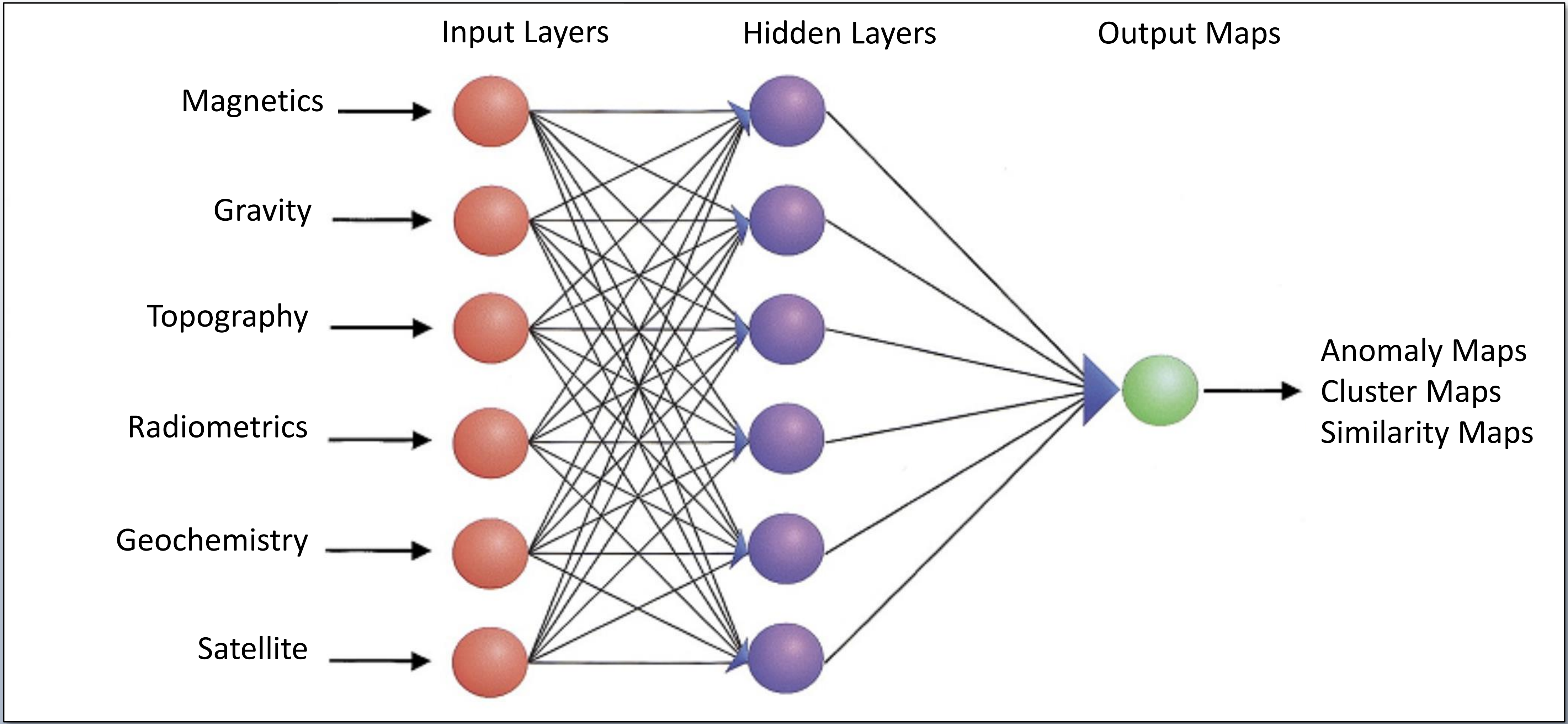
Artificial Neural Networks (ANNs)

- ANNs are one set of algorithms used in machine learning
- They are inspired by the biological processes of the brain
- ANNs are good at:
  - Analysing large amounts of complex data
  - Identifying relationships between data layers
  - Recognising patterns and associations
  - Making predictions automatically



- Powerful analysis tool that can explore the complete set of data layers
- Decision support for the Geologist
- Orders of magnitude more time efficient than conventional methods

Artificial Neural Networks



ANN Analysis Techniques

Five types of neural network analysis can be used for target generation in mineral exploration:

- Anomaly Detection
- Cluster Identification
- Correlation Analysis
- Relationship Analysis
- Fuzzy Searching

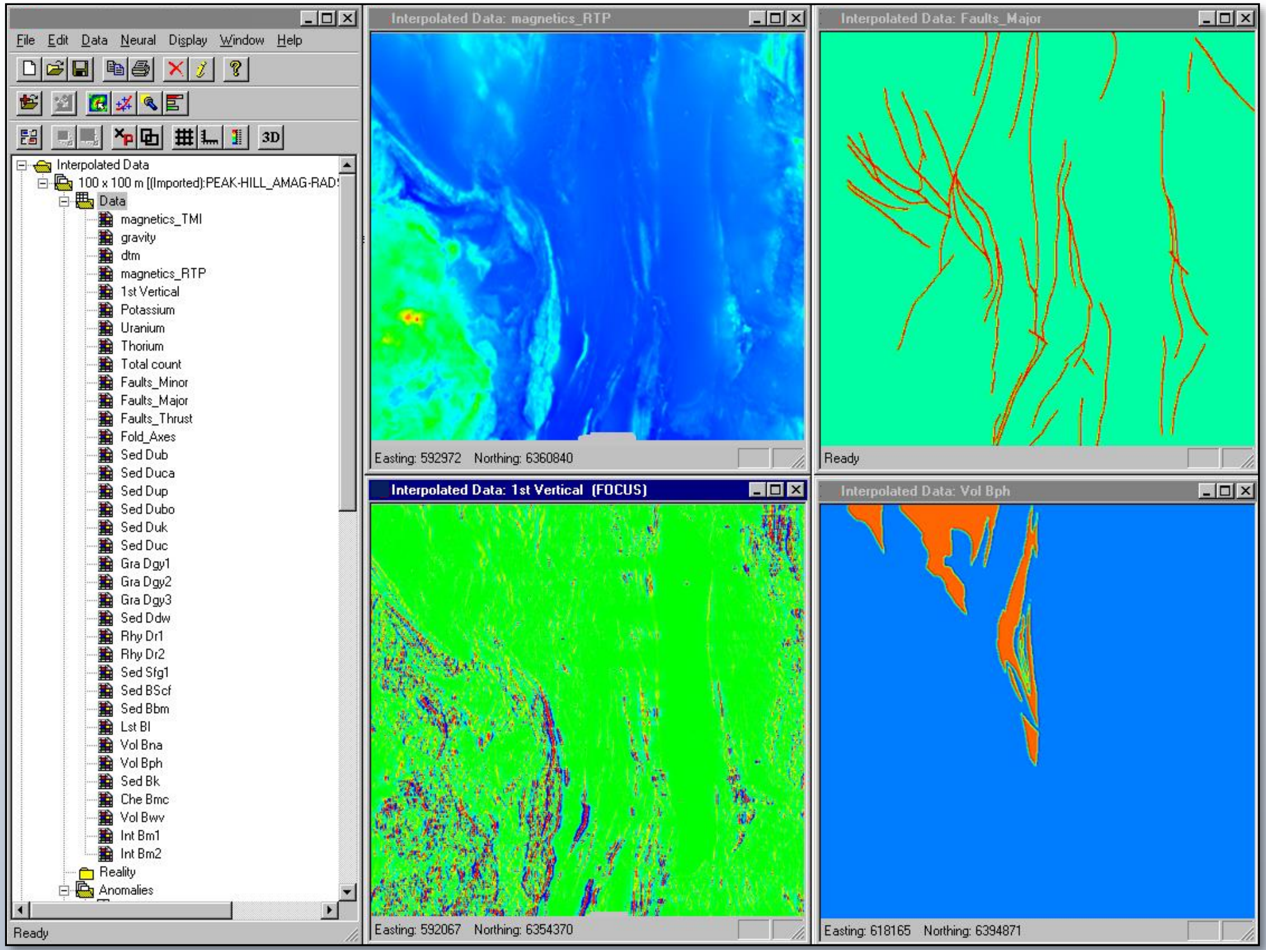
UNSUPERVISED

SUPERVISED

Data Input & Output

Analysis can be at any scale.

Can handle 2D or 3D data.

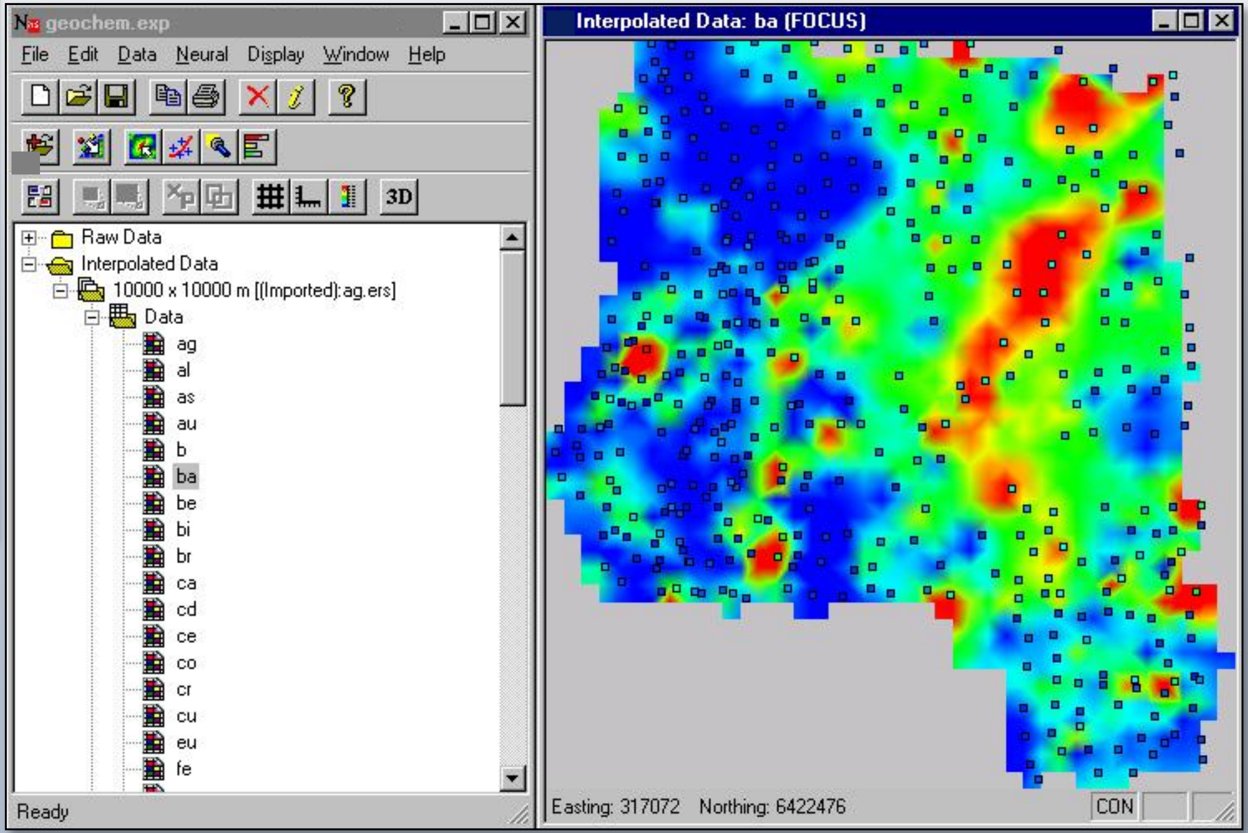


Regional scale data layers:

- Airborne magnetics
- Structural – 1st order faults,
- Processed magnetics - 1vd
- Geology layers

Prospect scale:

soil samples – 50 elements



ANN Anomaly Analysis

- Features:
  - Identifies regions that are anomalous
  - Evaluates *how* anomalous these regions are
  - Relates anomalies back to the data with the ability to interrogate each anomaly
  - Fully automatic operation

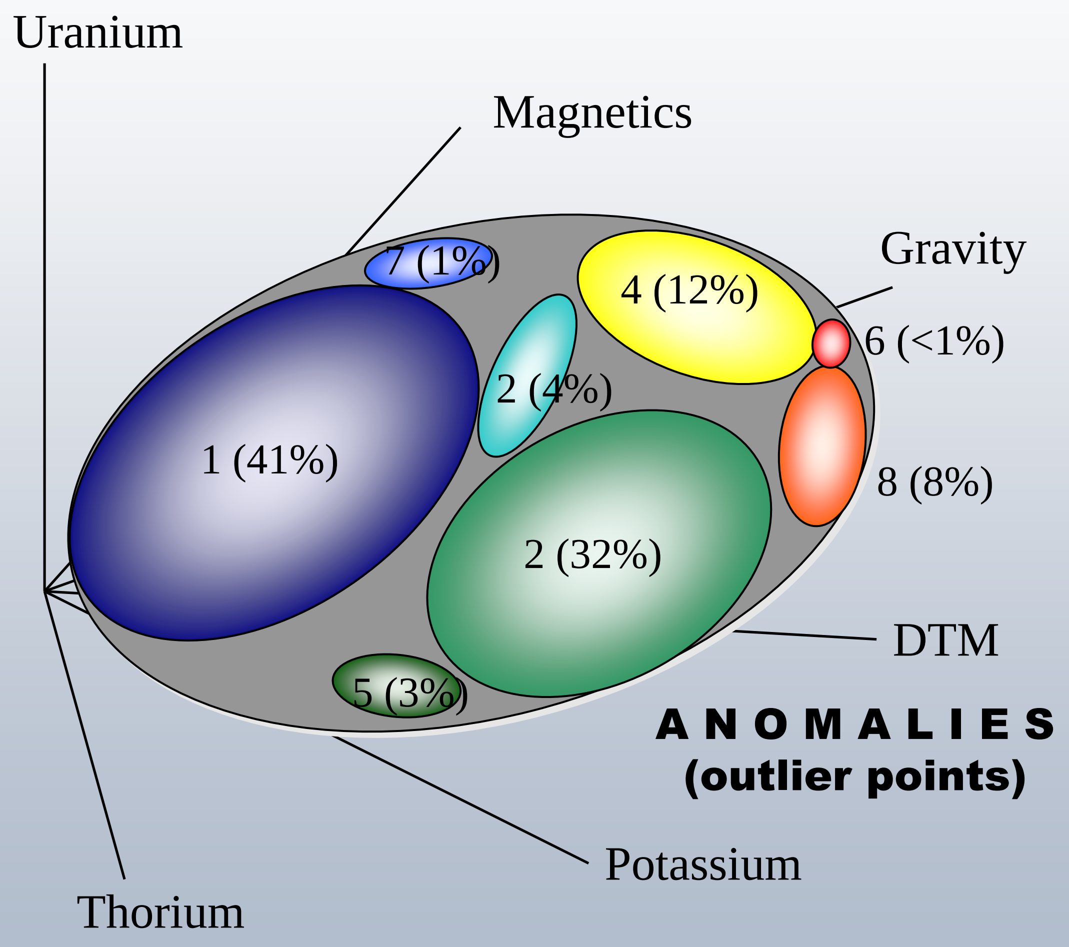
- Control by:
  - Selection of survey layers
  - Region of interest
  - Training duration

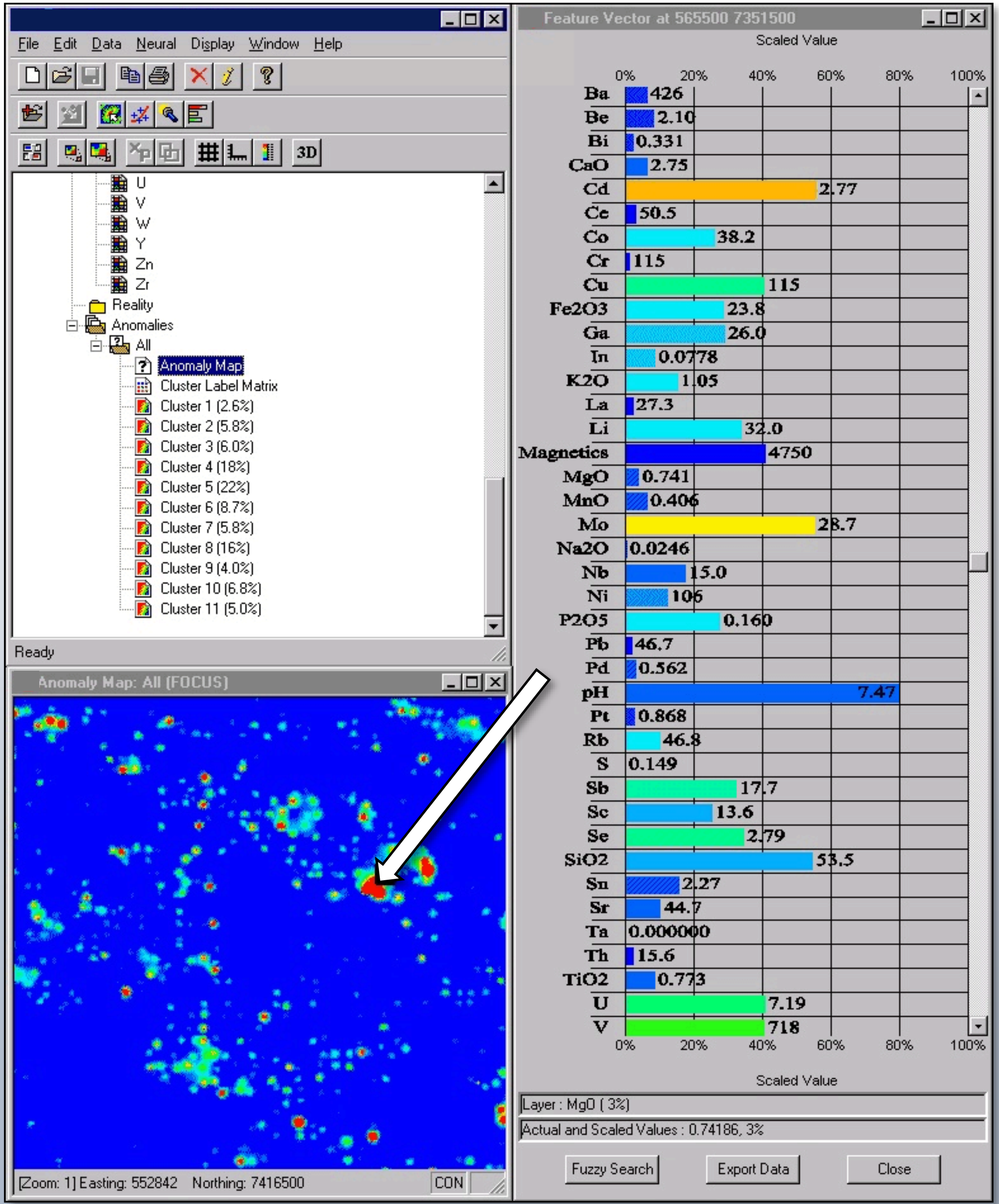
Anomaly & Cluster Identification

An unsupervised neural analysis search results in a map of anomalies highlighting instances where the data do not fit the range of values of common patterns (or clusters).

After identifying the anomalies, the unsupervised search defines areas of commonly recurring patterns and then groups these into clusters.

Essentially the group of anomalous points (defined by the anomaly map) are those points that fall outside the set of common patterns (or clusters) recognised by the unsupervised ANN.





Anomaly analysis

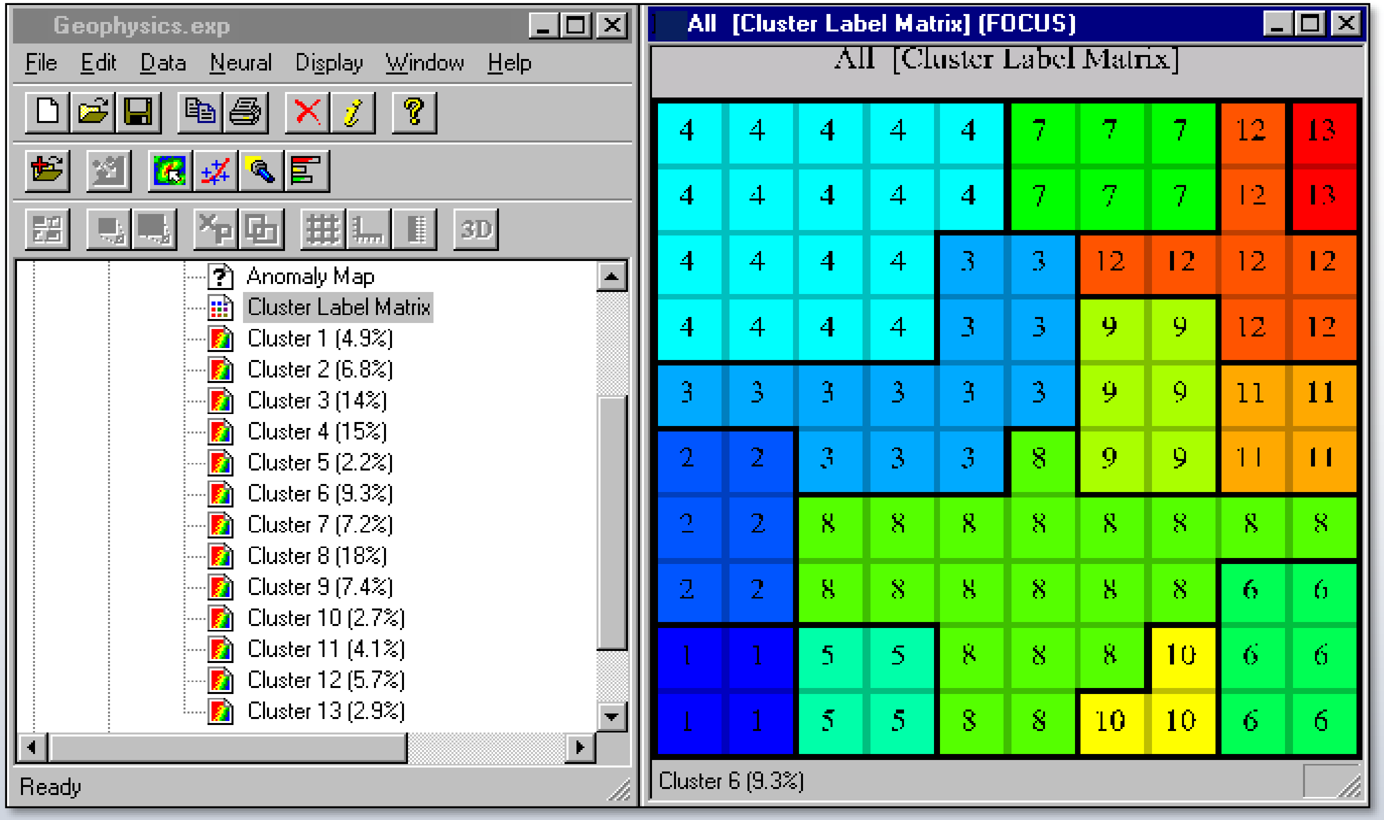
The Feature Vector Plot (FVP) shows the values at particular anomalies.

The colour of the histogram indicates the variability of that layer with its neighbours.

Moving the cursor over the anomaly map dynamically changes the FVP values.

Cluster Label Matrix

13 clusters have been identified in this example



The Cluster Label Matrix represents the association between individual clusters. Each cluster is represented by several coloured and numbered squares:

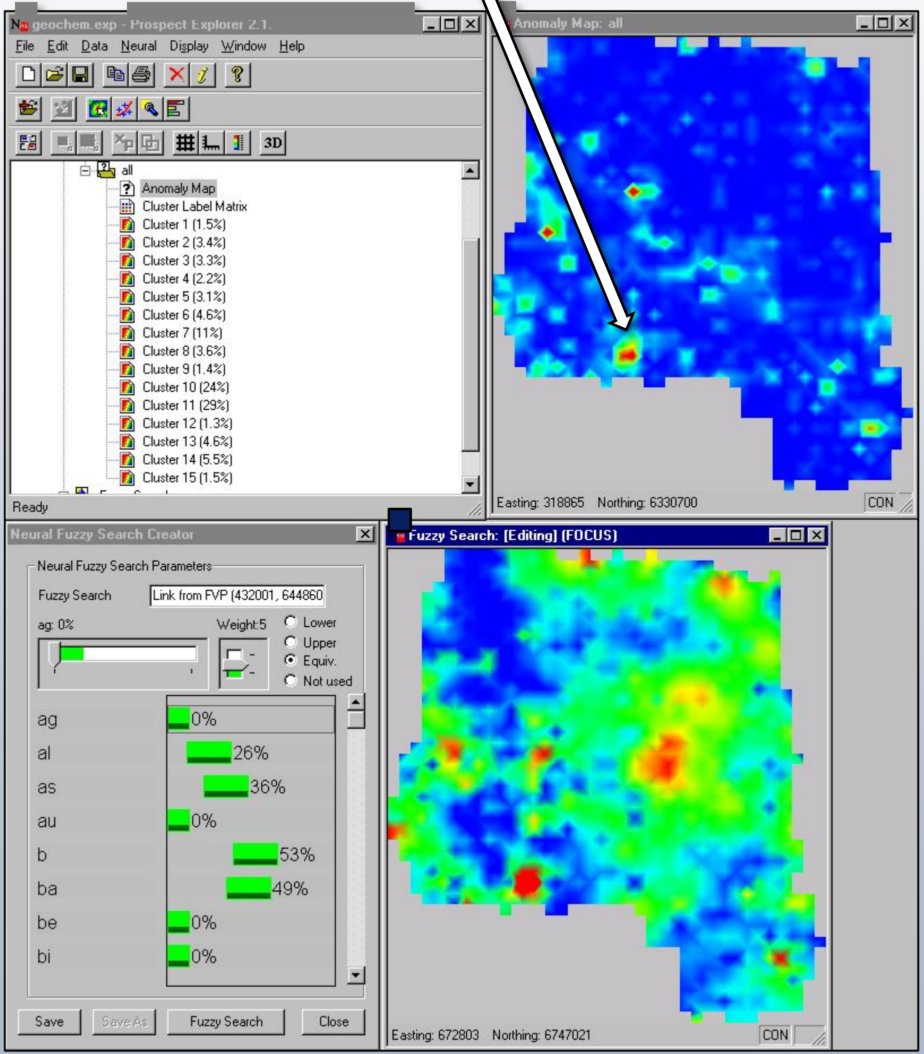
- The number of squares assigned to a cluster indicates its relative proportion of the total data coverage or area
- The proximity of two clusters indicate their similarity e.g. cluster 1 is similar to cluster 5 but dissimilar to cluster 4. A geological setting where this sort of association might occur is in a granitic terrain with minor basaltic flows. In this instance clusters 3 and 4 might represent the outcrops of the dominant granitic lithologies whereas clusters 1 and 5 might well represent the basaltic flows and their weathering products.

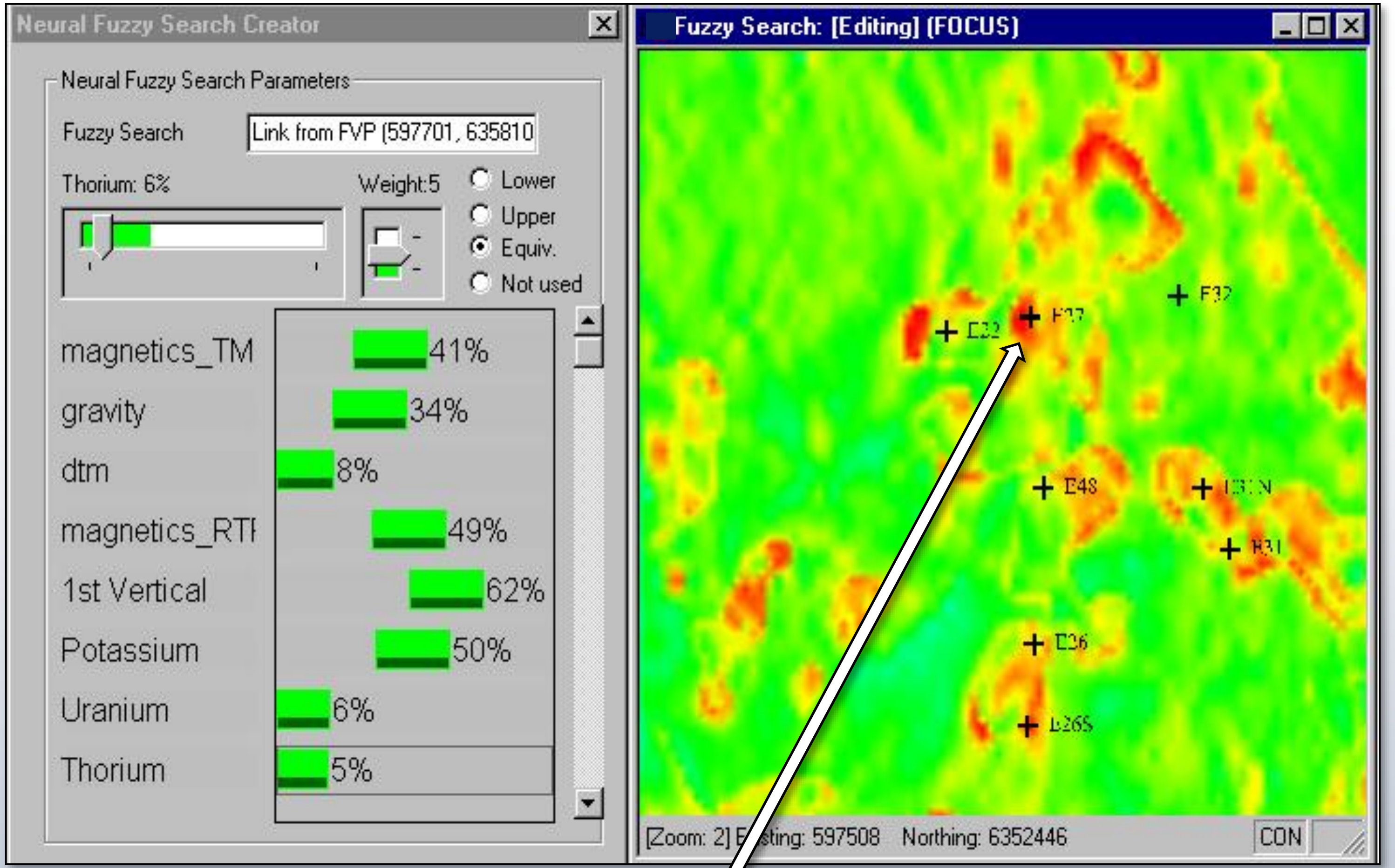
Neural Fuzzy Search

- Specify search items
  - search for a selected pattern eg. anomaly
  - search from a particular location eg. a known mineral deposit
  - search for a “created” pattern - look for a particular deposit type signature
  - searches for a correlation signature
- Control by:
  - choose data layers to include
  - set the data threshold for each layer
  - control the weighting of each layer

Neural Fuzzy Search

Neural Fuzzy Search - link from known mineral deposit to look for areas with a similar geochemical signature



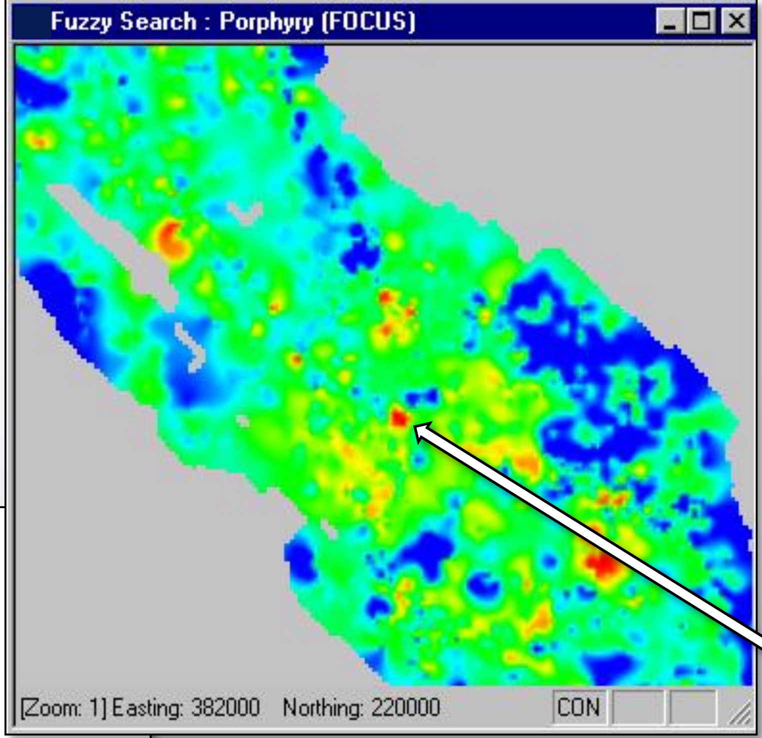


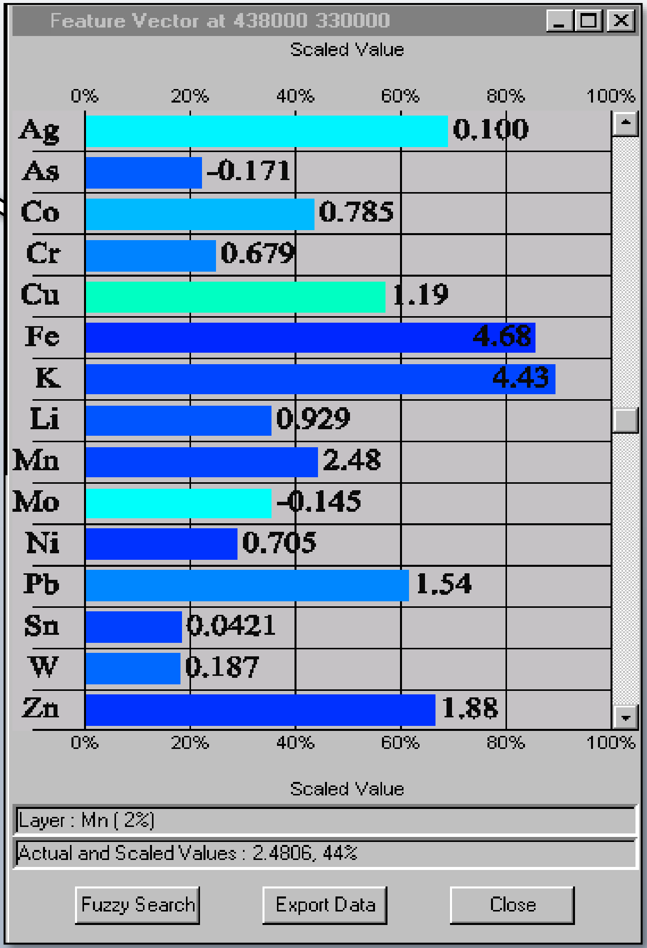
Neural Fuzzy Search using the North Parkes Endeavour 27 deposit as the search location

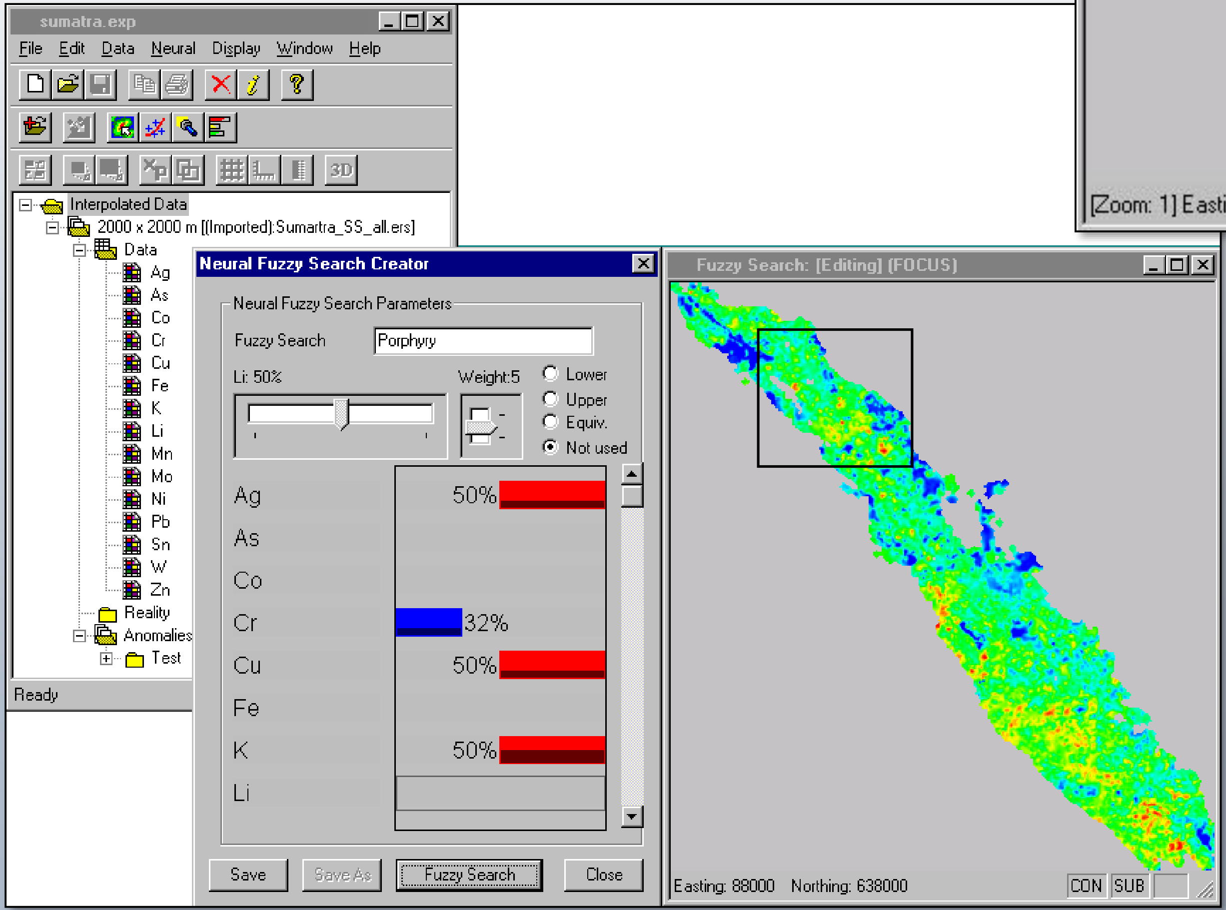
Neural Fuzzy Search

Customised (Porphyry) *Fuzzy Search*

- elevated Ag, Au, Cu, K, Mo
- low Cr, Ni

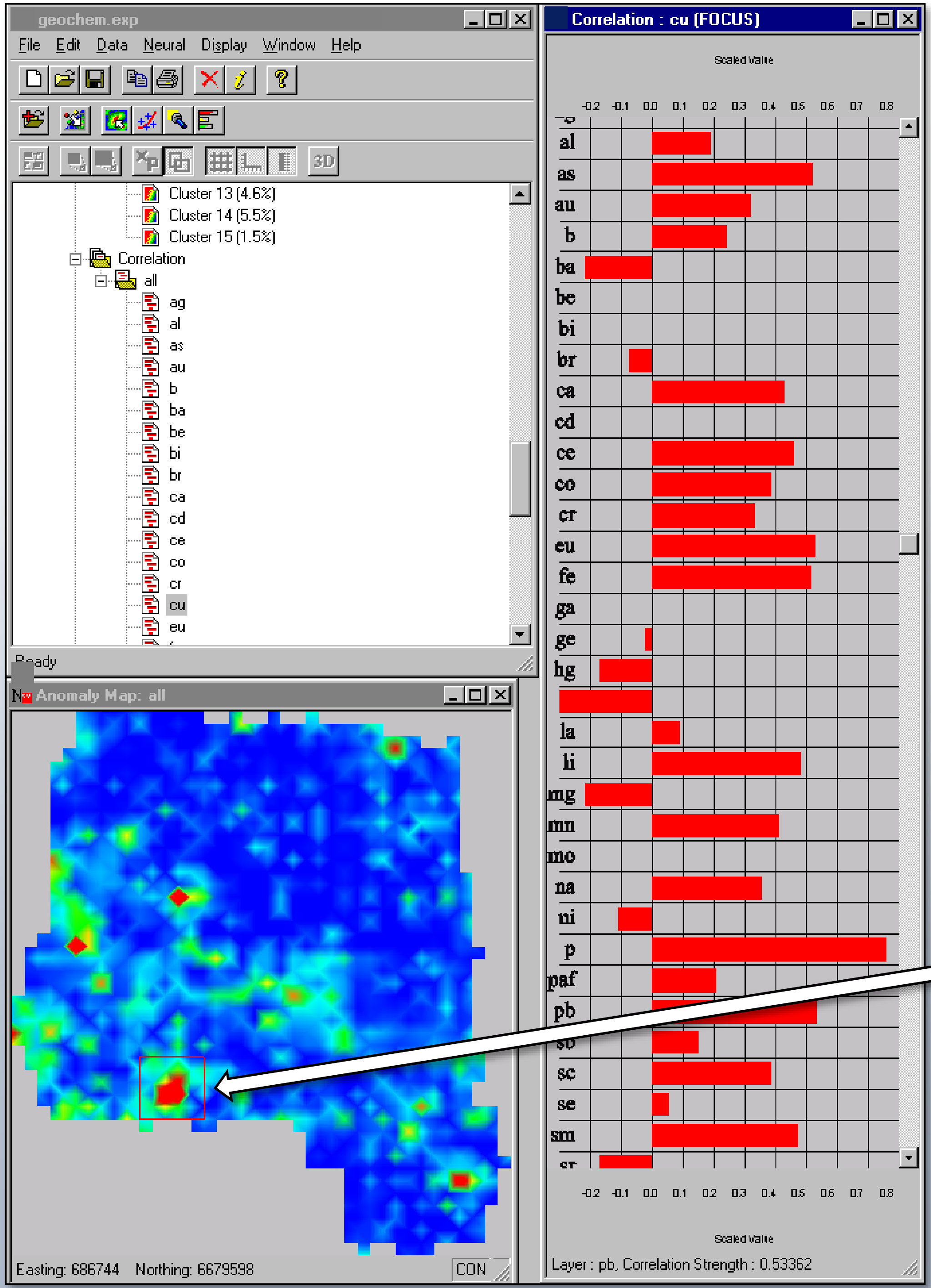




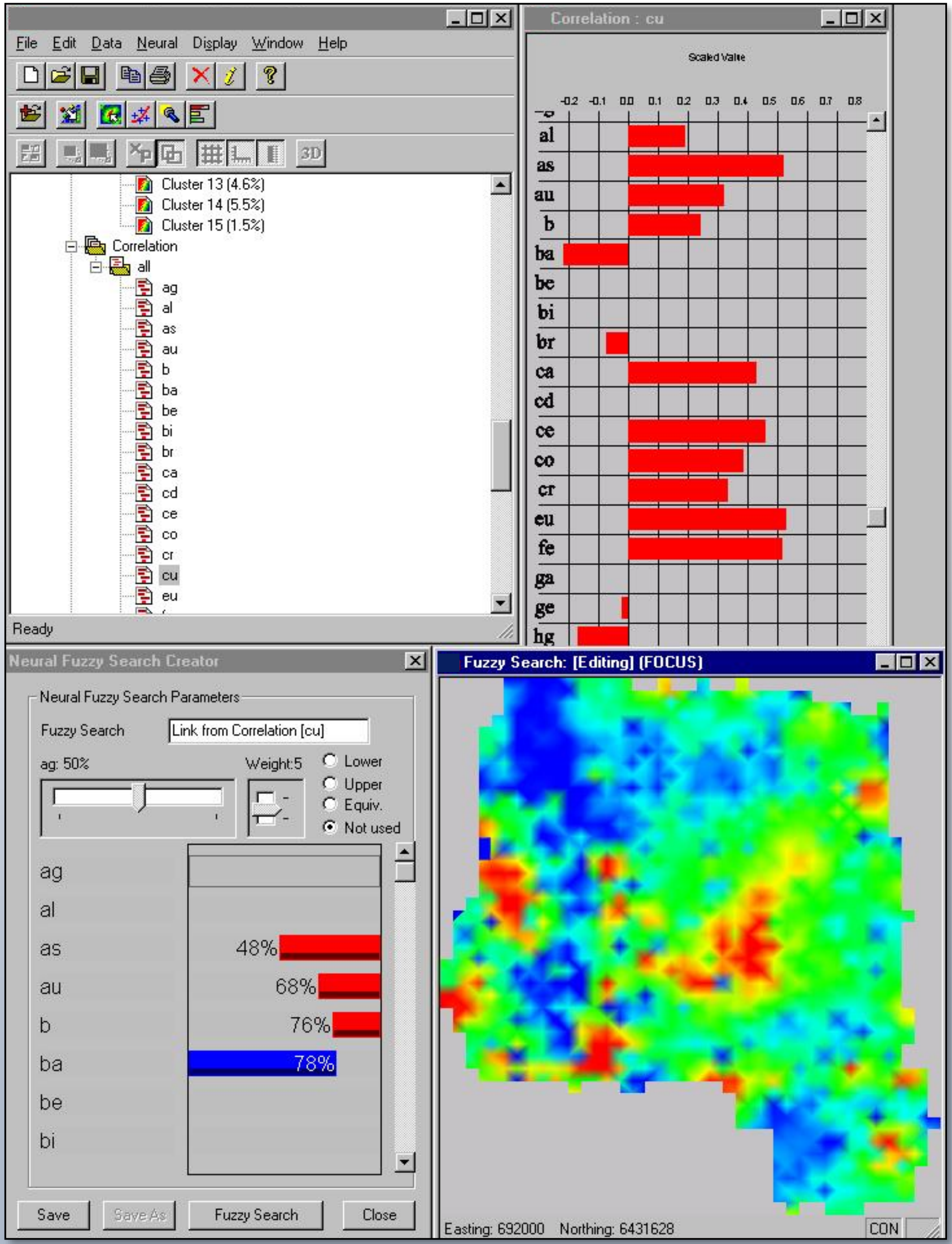


Neural Correlation Analysis

- Looks at the relationships between the data layers
- Relational Knowledge
- Correlation signatures can be determined
- Search for areas with similar correlation signature ie. search for similarities in relationships for population identification
- Correlation analysis provides a means of searching for signatures of the relationship between layers, independent of the amplitude values of the layers
- The subtle relationship between elements can be of more importance than the observed rank outlier values that are easily observed



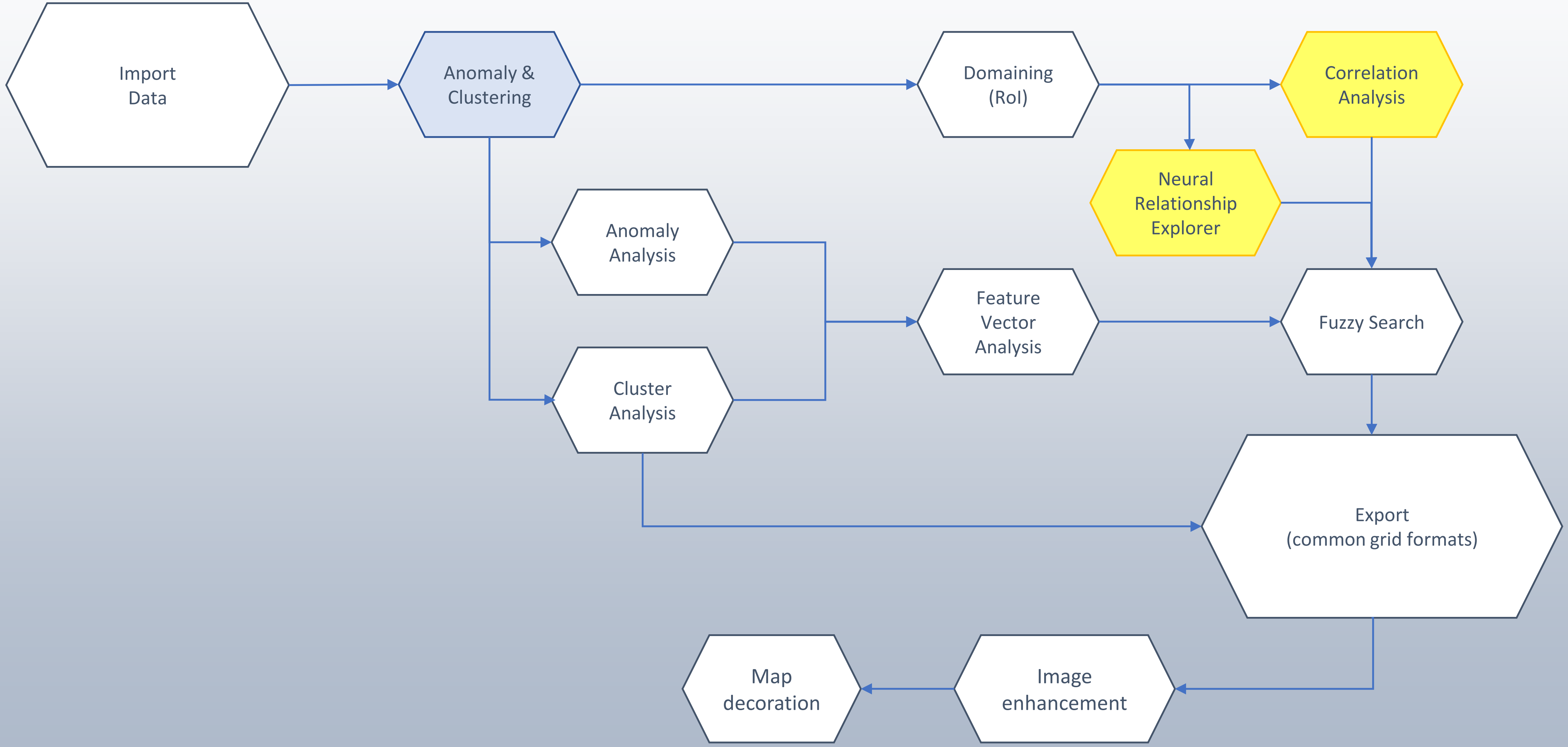
Correlation of each element with respect to Cu within a specified region of interest



Correlation link to fuzzy search

This searches for signatures of the relationships between layers, independent of the amplitude values of the layers and so may detect anomalies in areas where the raw values are close to the detection limit but the associations are the same as the higher values in the region of interest.

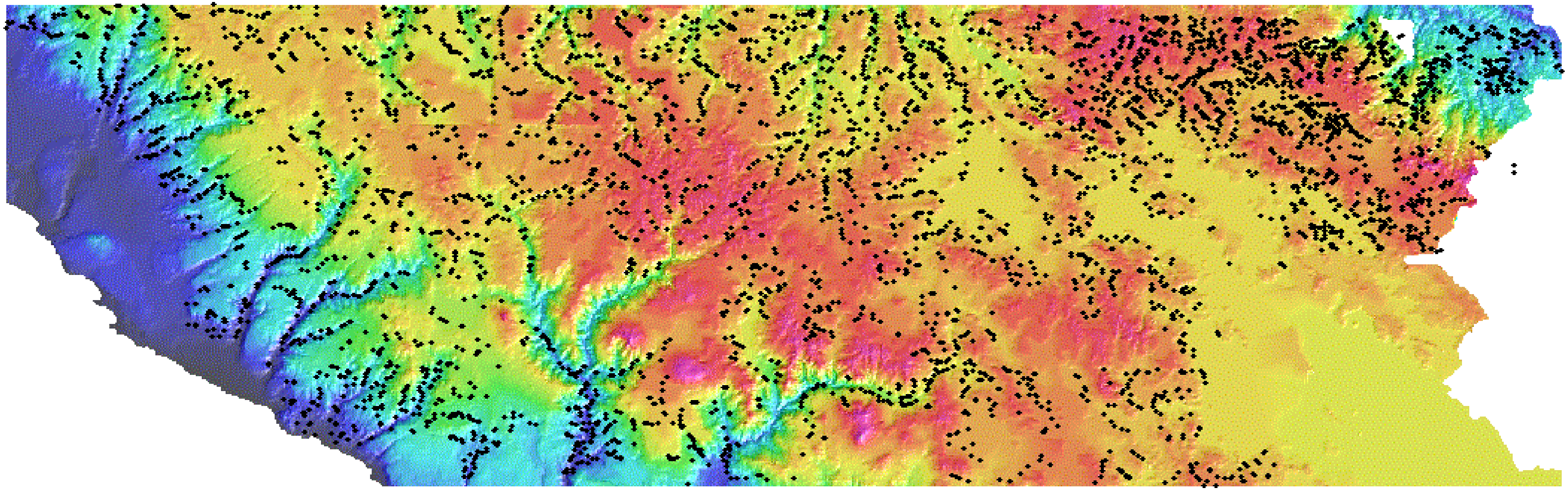
Workflow - Neural Network Analysis



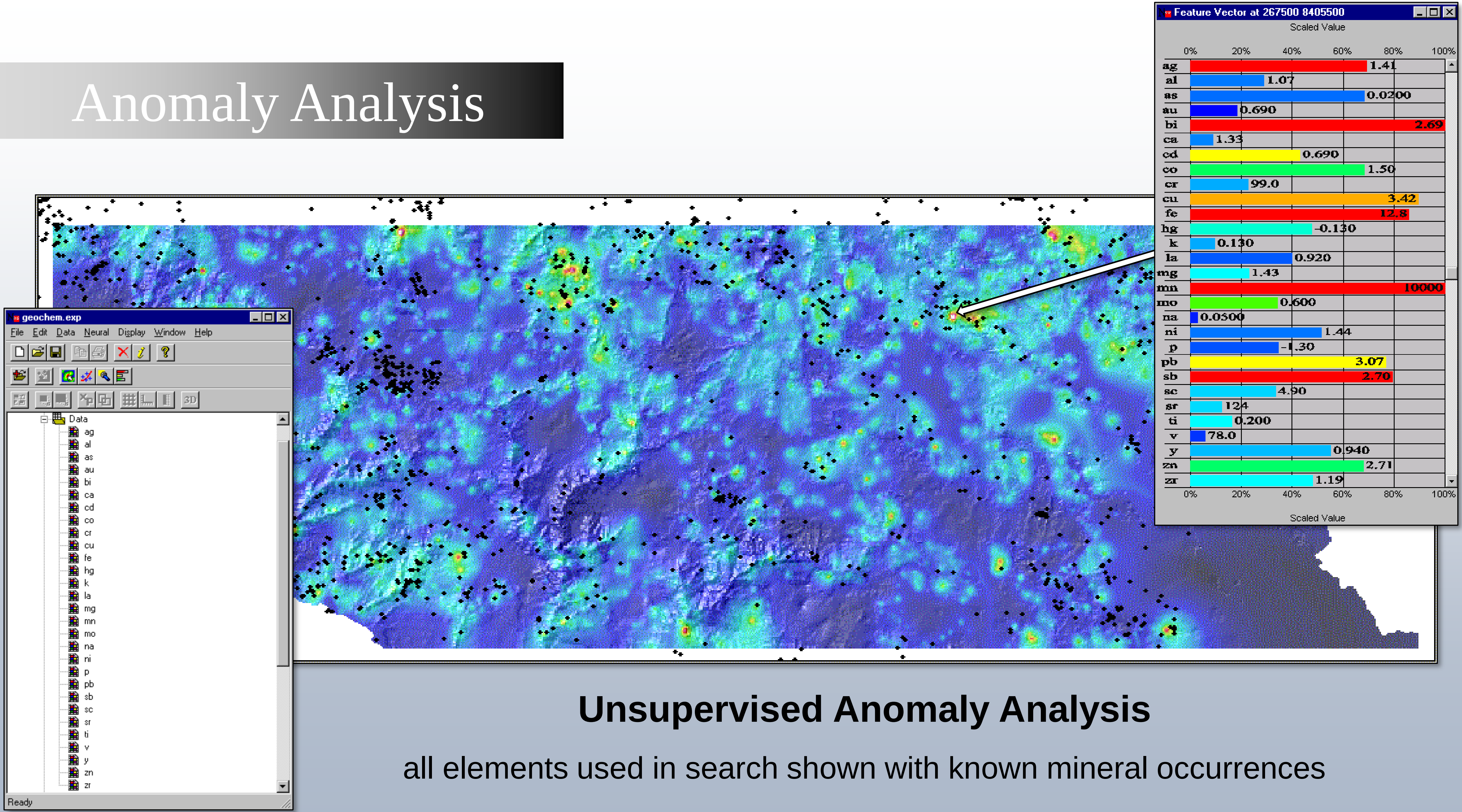
Rio Tinto – Southern Peru

- Peru Mines Department (Ingemet) Southern Peru Data Package
- Geochemistry - 30 layers of stream sediment geochemical samples
- Mineral Occurrences Database
- Surface geology
- Anomaly detection, cluster analysis, fuzzy search and correlation analysis tools used

Stream Sediment Sample Points



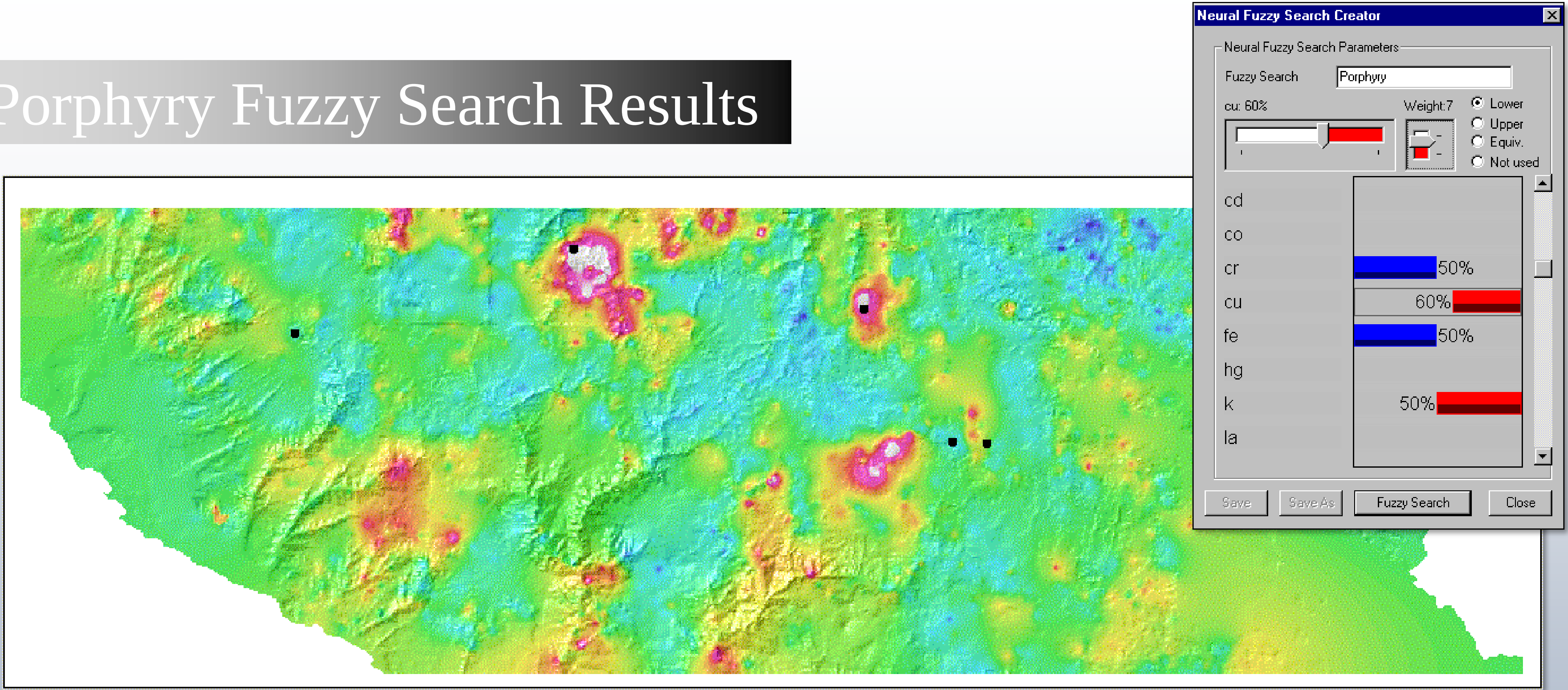
Anomaly Analysis



Unsupervised Anomaly Analysis

all elements used in search shown with known mineral occurrences

Porphyry Fuzzy Search Results



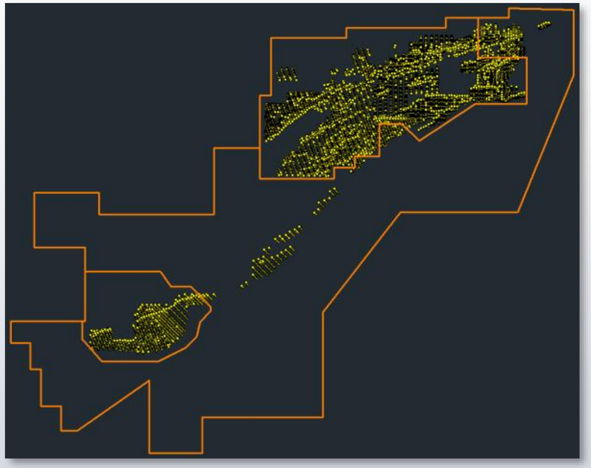
Porphyry search: > 50% Ag-Au-Cu-K-Mo-Pb-Zn

< 50% Cr-Fe-Ni

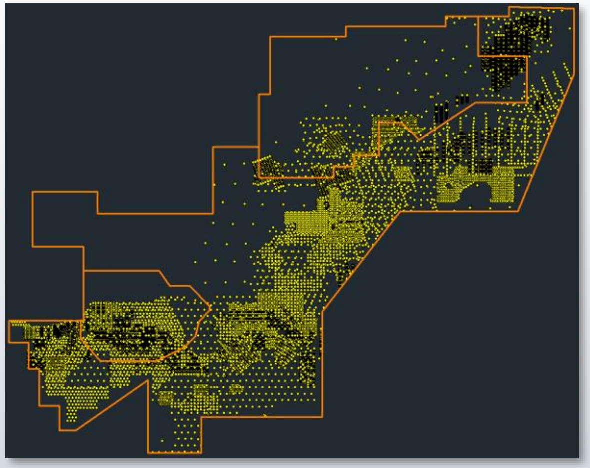
Known major porphyry mines and deposits

Degrussa VMS Deposit - WA

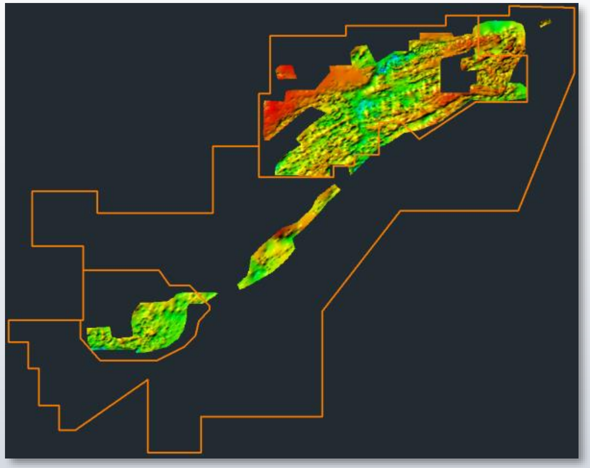
Boh geochem (83)



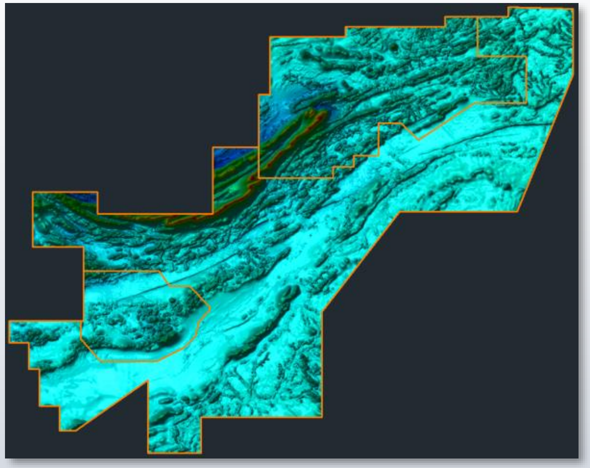
Soil geochem (67)



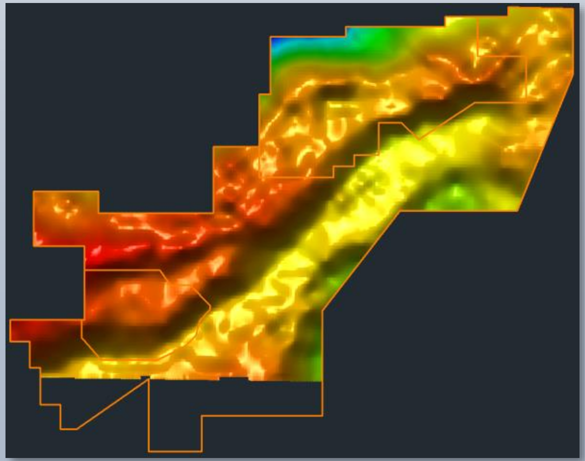
Depth to basement (1)



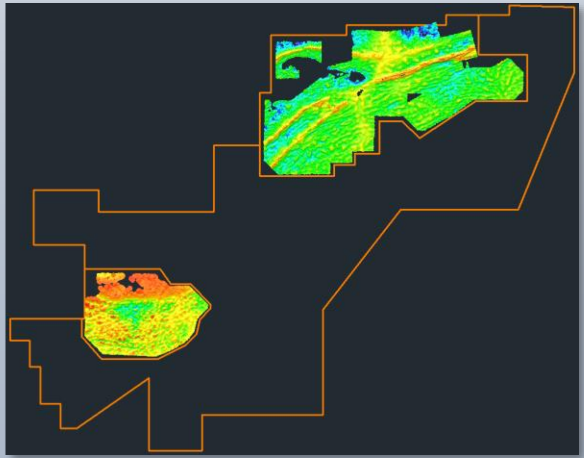
Aeromagnetics (1)



Gravity (1)

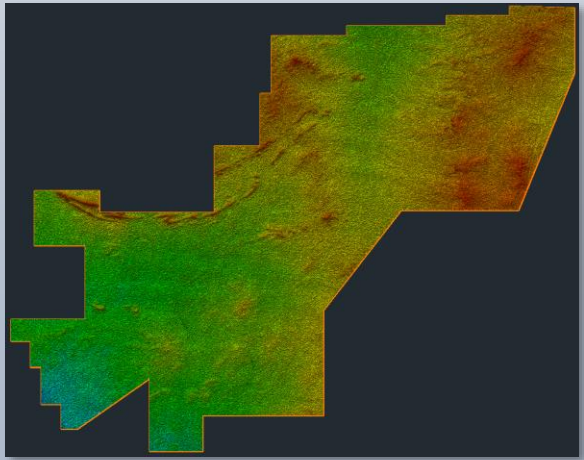


AEM (32)



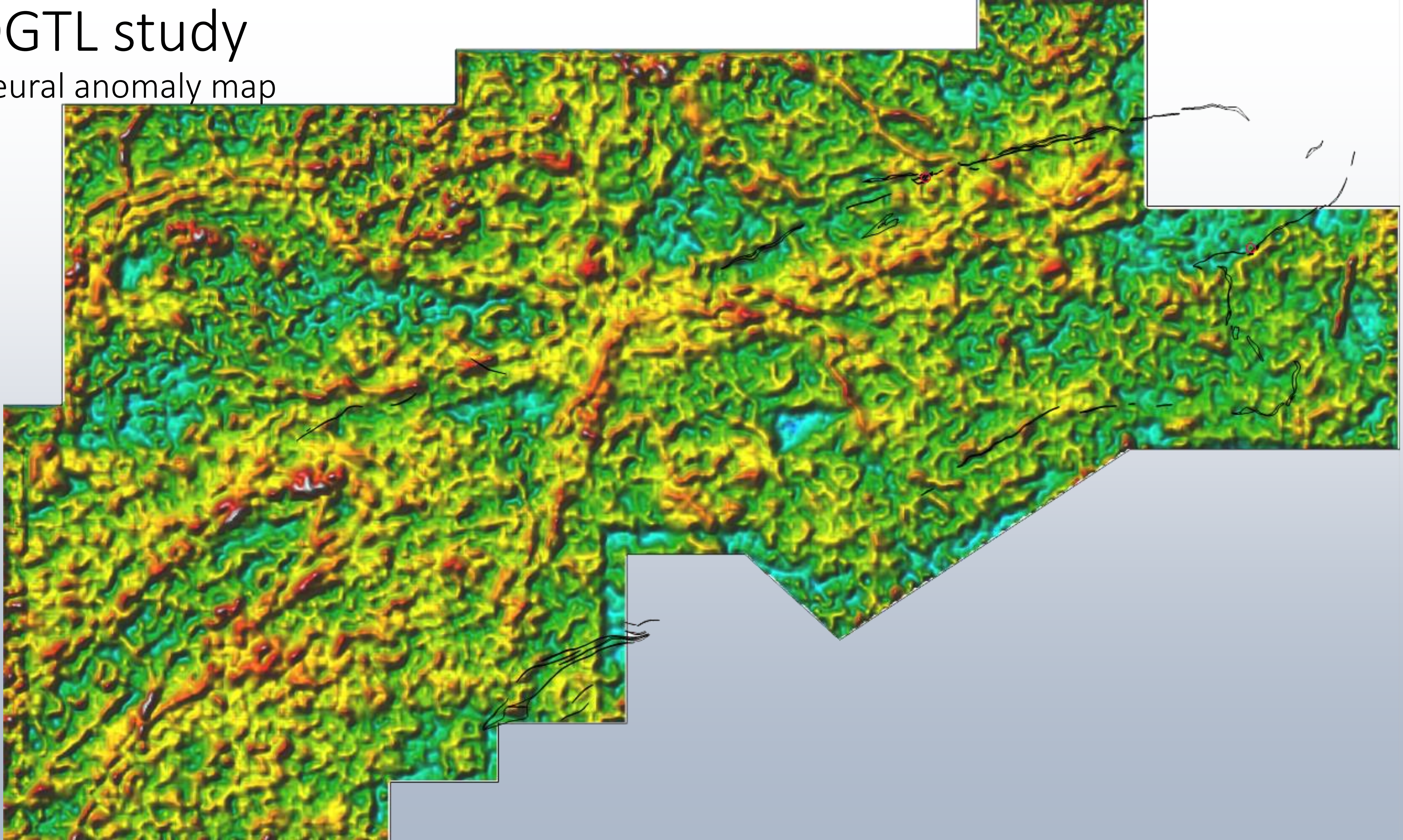
Satellite (24)

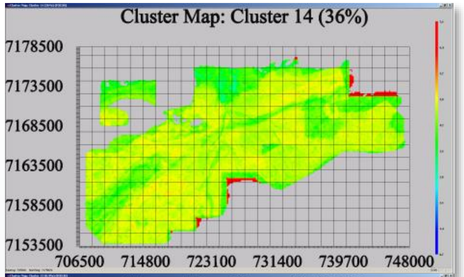
DEM (1)

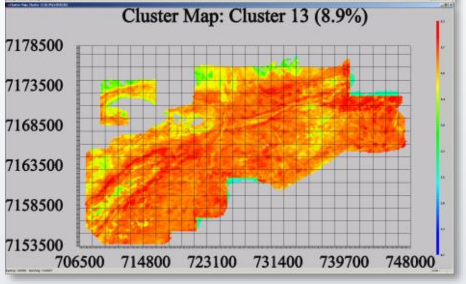


DGTL study

Neural anomaly map







DGTL Study- Cluster Label Matrix

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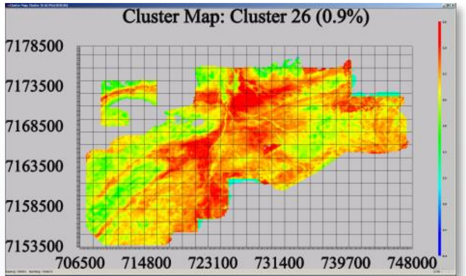
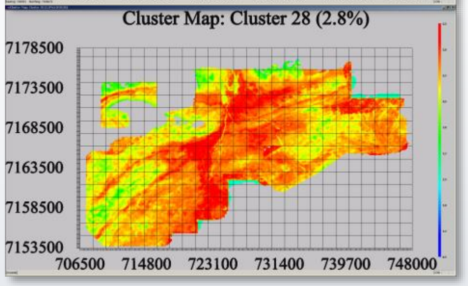
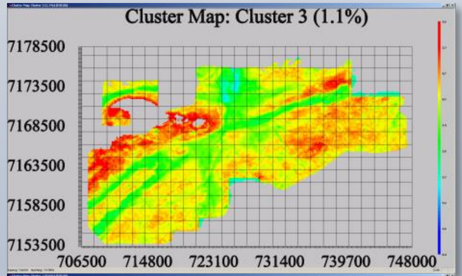
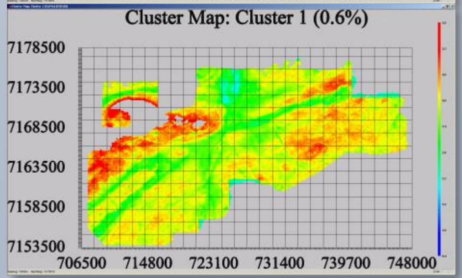
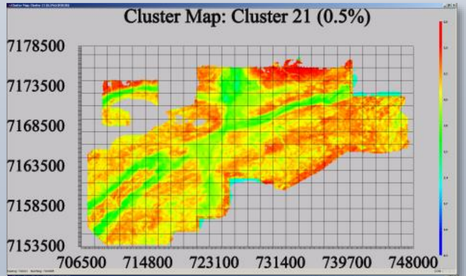
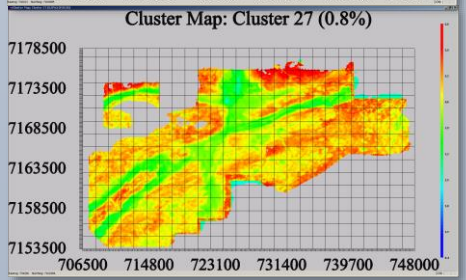


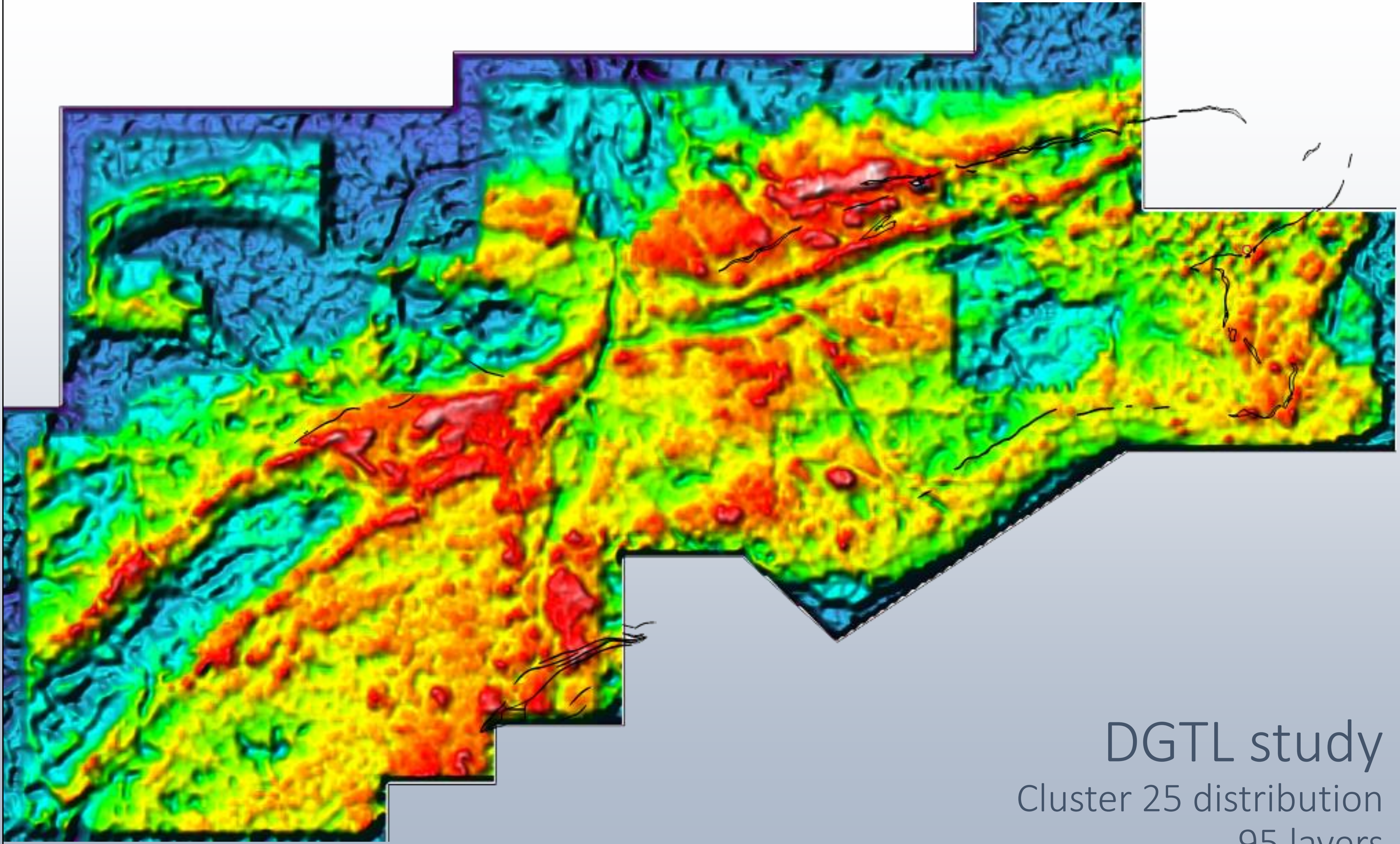








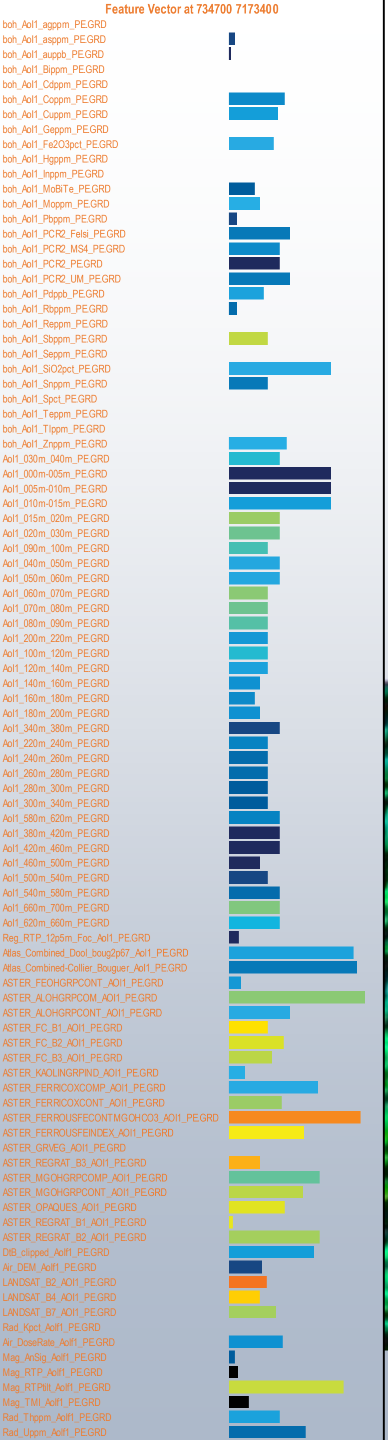


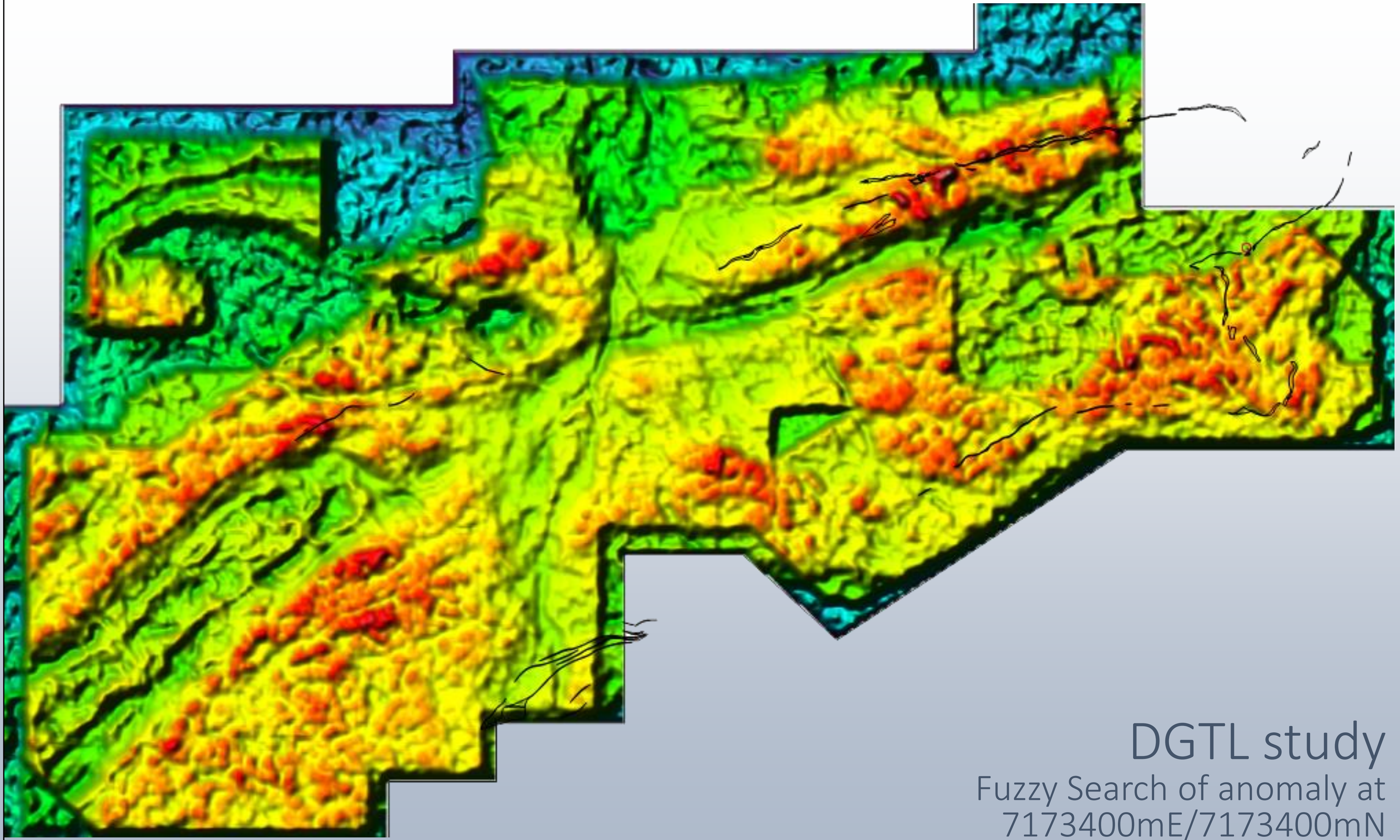


DGTL study

Cluster 25 distribution

95 layers





DGTL study

Fuzzy Search of anomaly at
7173400mE/7173400mN
95 layers

STARRA Hymap Analysis

Input layers:

Geophysics (2 layers)

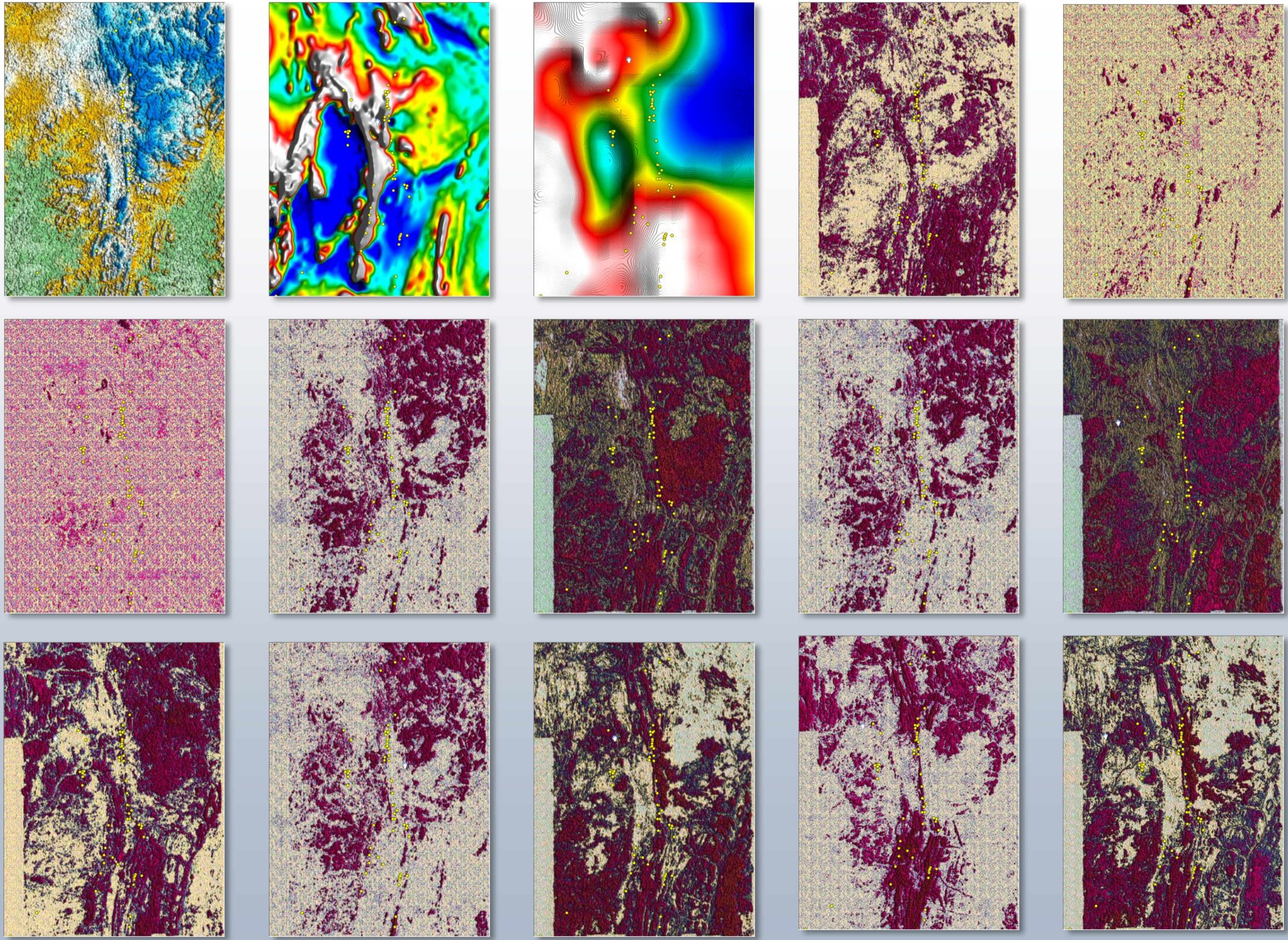
- Gravity
- Magnetics

Terrain (1 layer)

- DTM

Spectral (12 layers)

- Variety of modelled mineral abundance maps

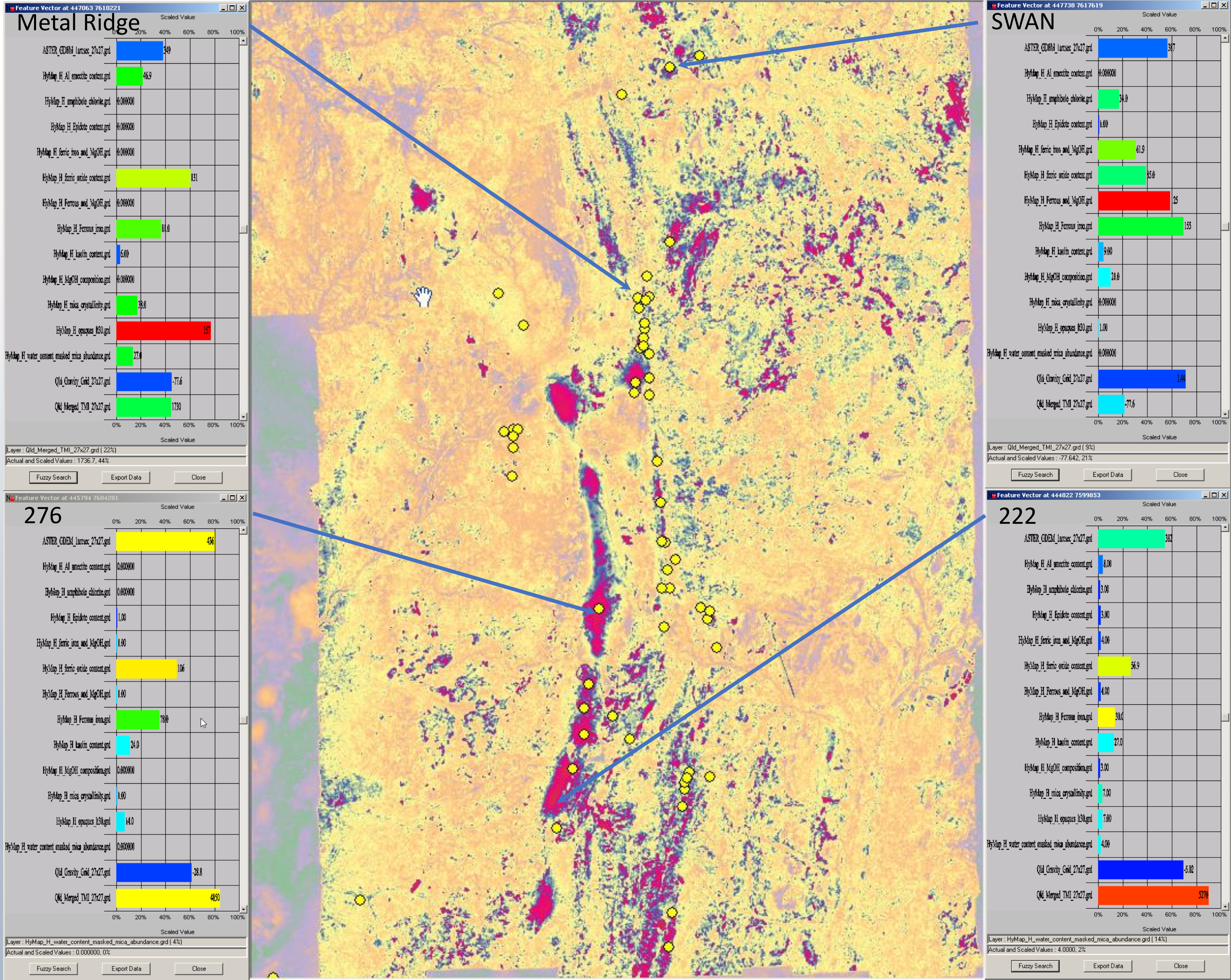


Anomaly Map Unsupervised ANN

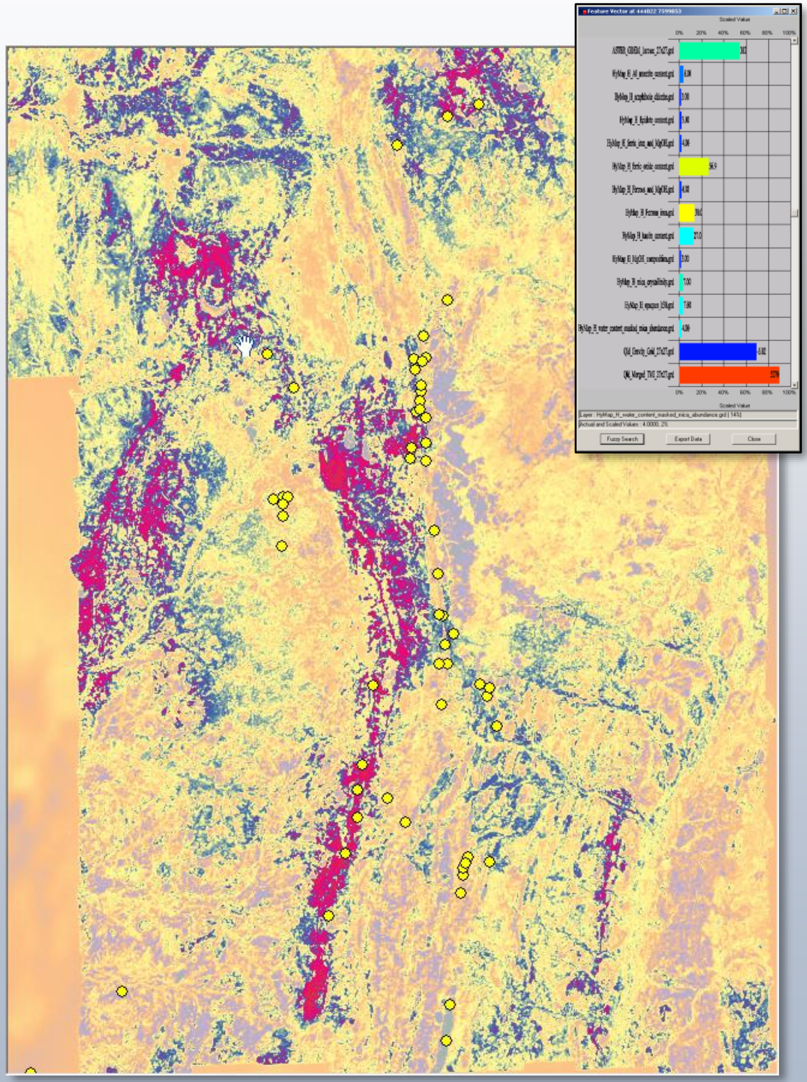
Highlighted colours signify cells having rare input layer associations

Mineralising systems:

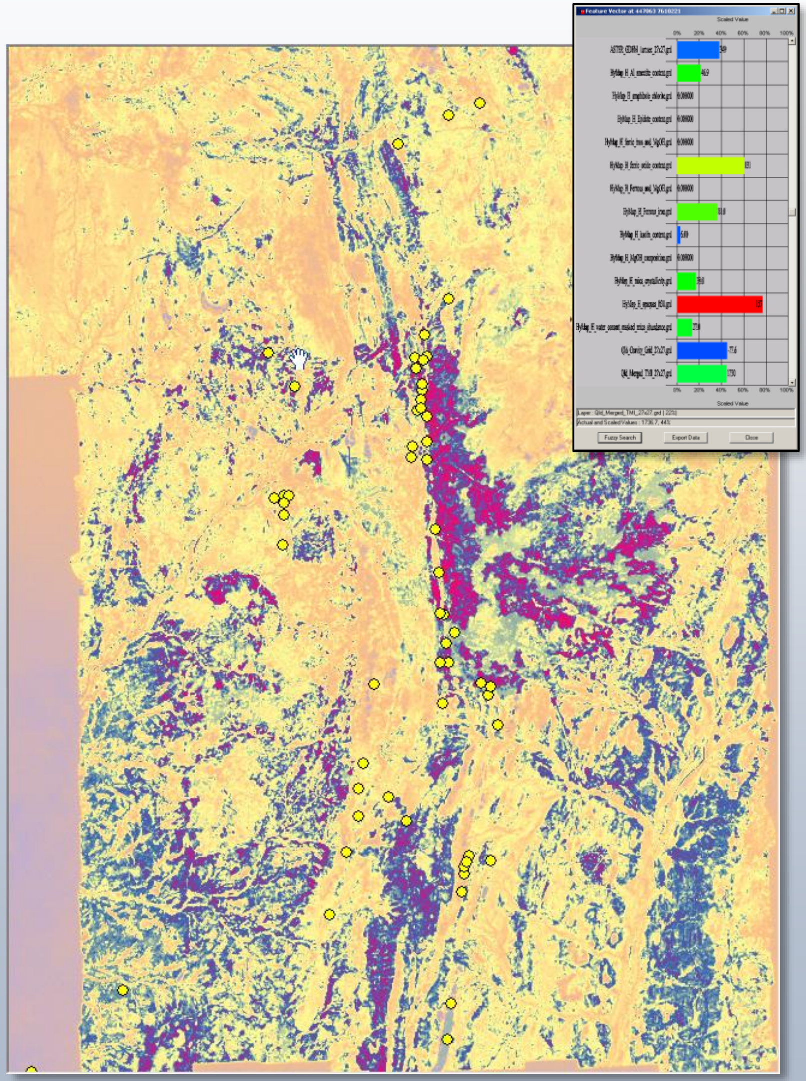
- generally have a much smaller footprint relative to geological & geomorphological regions
- Unusual physical metrics (geophysical, geochemical, spatial etc.) relative to region
- Unlikely to be defined by a cluster or class of more frequently occurring input layer associations



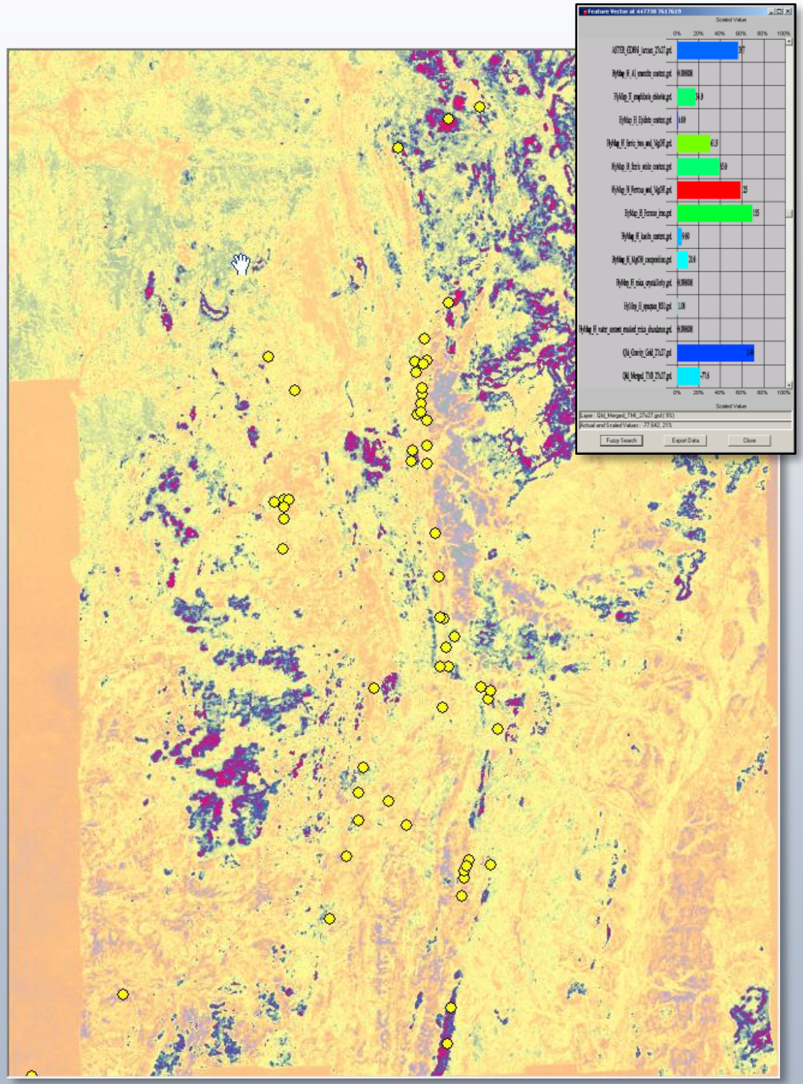
Starra 222 similarity map



Metal Ridge similarity map



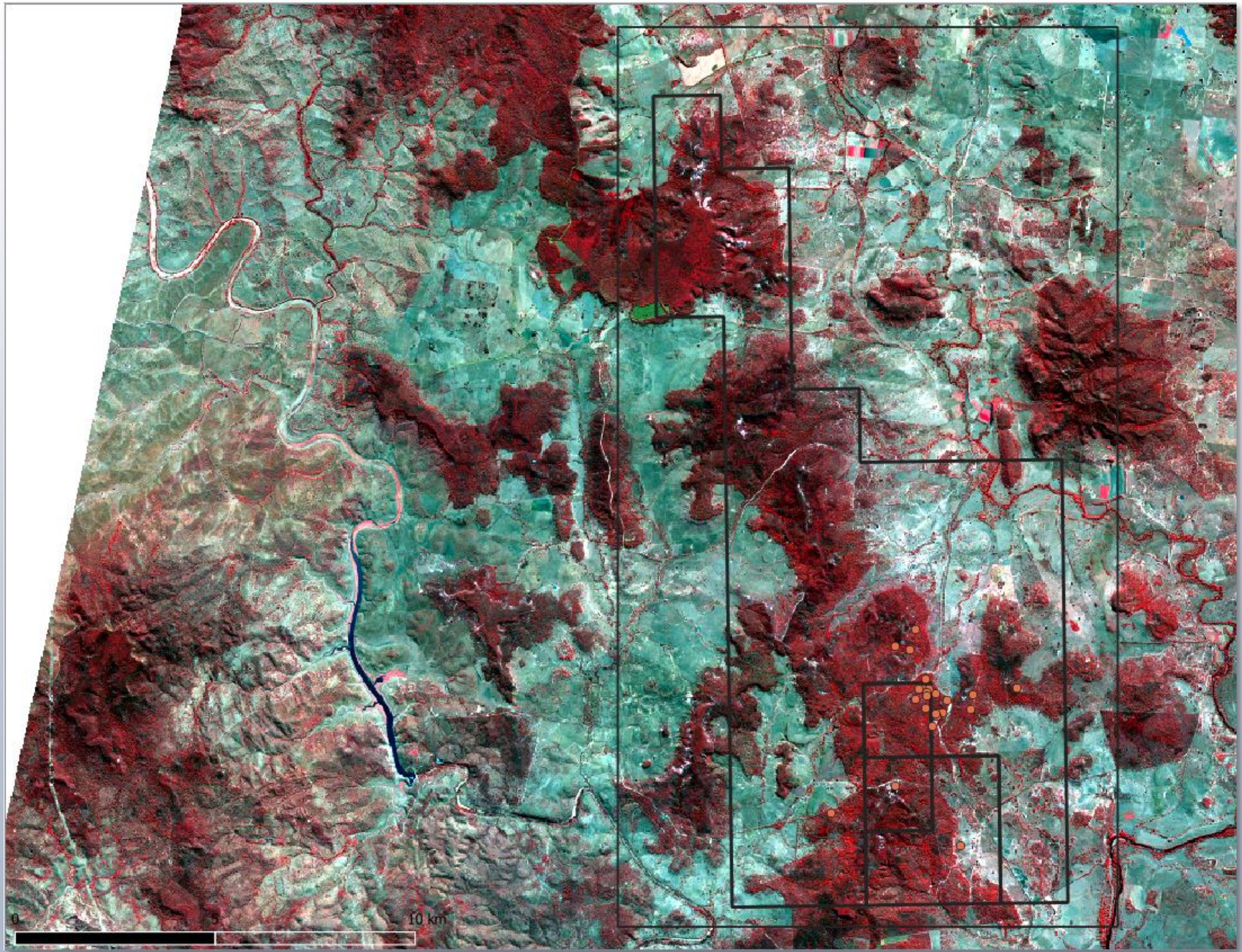
SWAN similarity map



Neural Analysis Project Using ASTER Data

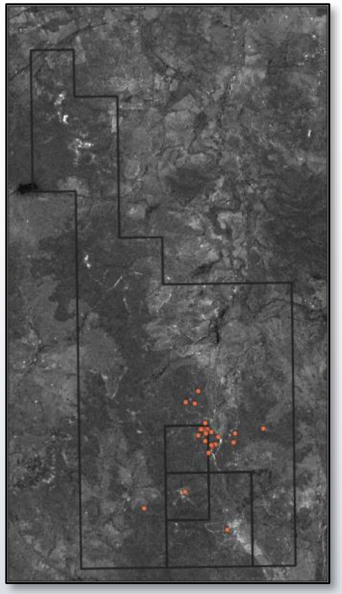
AREA OF INTEREST

UPPER LEFT X=302500.000
UPPER LEFT Y=7230000.000
LOWER RIGHT X=315000.000
LOWER RIGHT Y=7207500.000
WEST LONGITUDE=151° 02' 21.4472" E
NORTH LATITUDE=25° 01' 57.8340" S
EAST LONGITUDE=151° 09' 58.9343" E
SOUTH LATITUDE=25° 14' 14.6504" S
UL CORNER LONGITUDE=151° 02' 33.1153" E
UL CORNER LATITUDE=25° 01' 57.8340" S
UR CORNER LONGITUDE=151° 09' 58.9343" E
UR CORNER LATITUDE=25° 02' 03.5222" S
LR CORNER LONGITUDE=151° 09' 48.0034" E
LR CORNER LATITUDE=25° 14' 14.6504" S
LL CORNER LONGITUDE=151° 02' 21.4472" E
LL CORNER LATITUDE=25° 14' 08.9097" S
PROJ_DESC=UTM Zone -56 / WGS84 / meters
PROJ_DATUM=WGS84
PROJ_UNITS=meters
EPSG_CODE=EPSG:32756
COVERED AREA=281.25 sq km

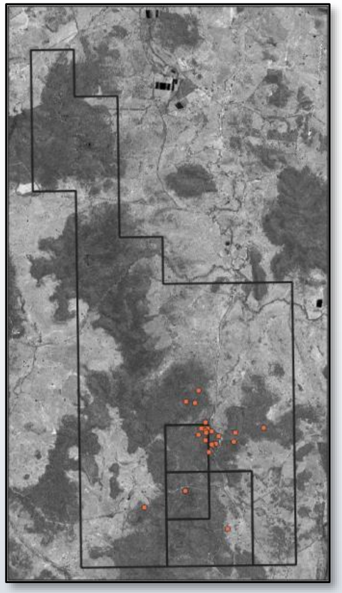


ASTER& DEM Layers Used In Analysis

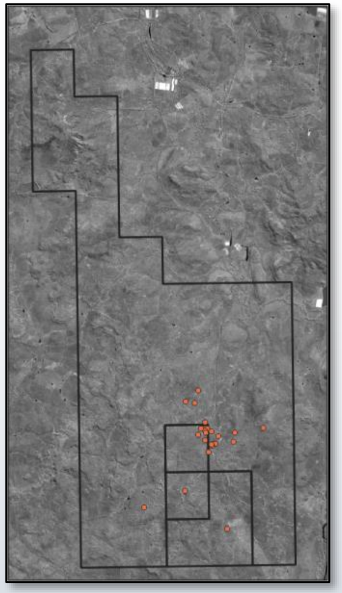
VNIR_Band_1_DS



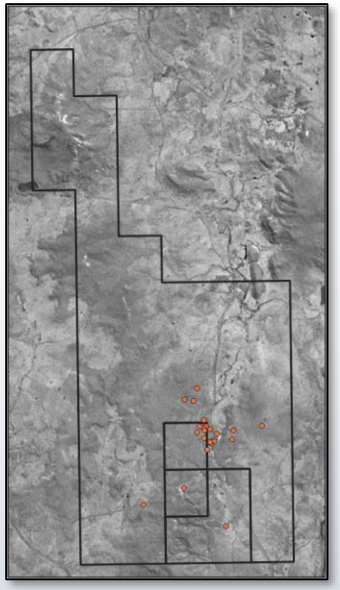
VNIR_Band_2_DS



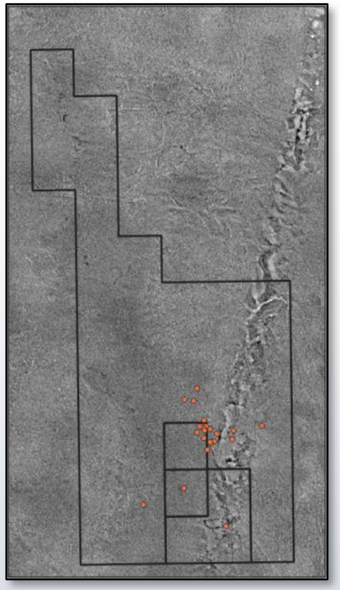
VNIR_Band_3_DS



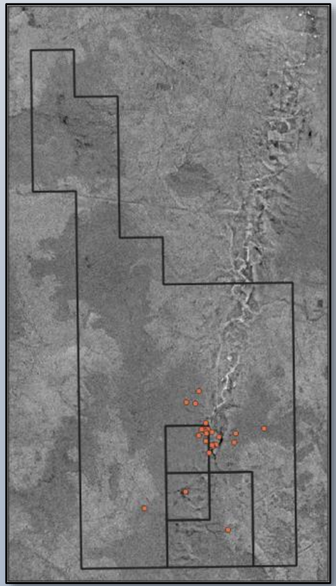
SWIR_Band_4_DS



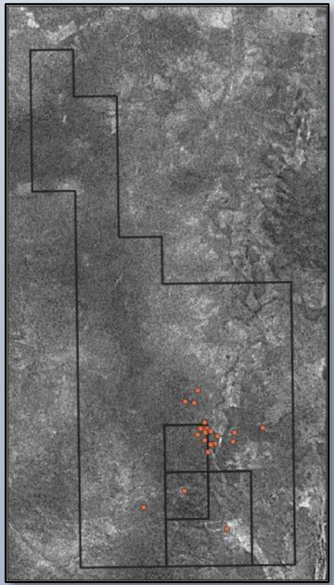
SWIR_Band_5_DS



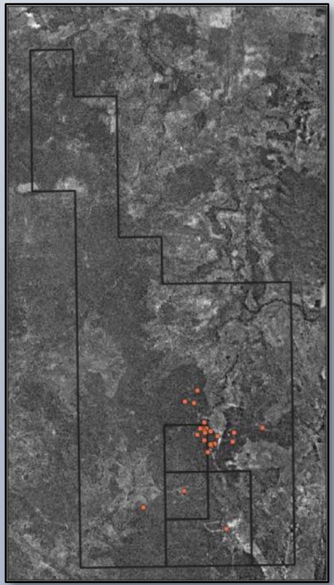
SWIR_Band_6_DS



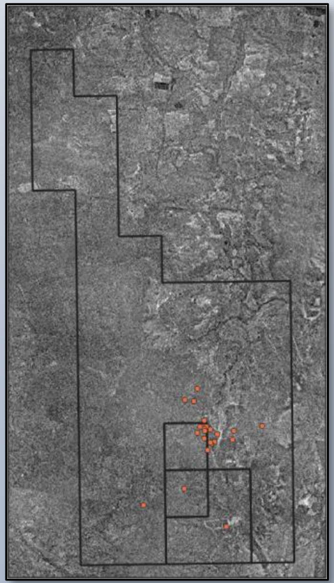
SWIR_Band_7_DS



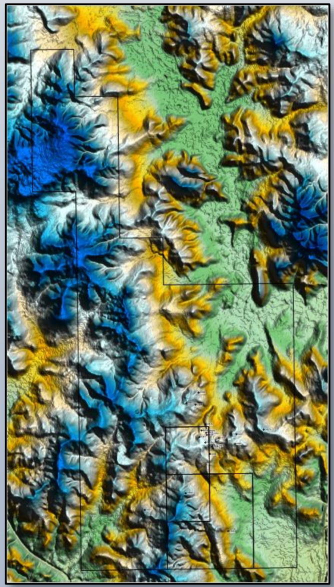
SWIR_Band_8_DS



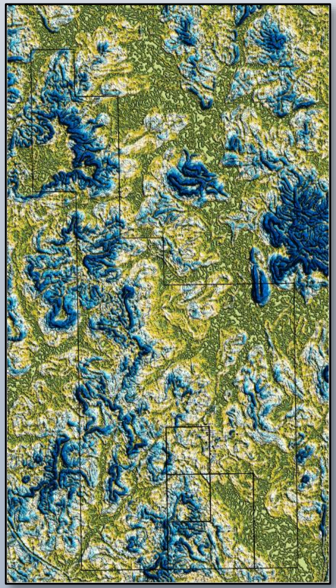
SWIR_Band_9_DS

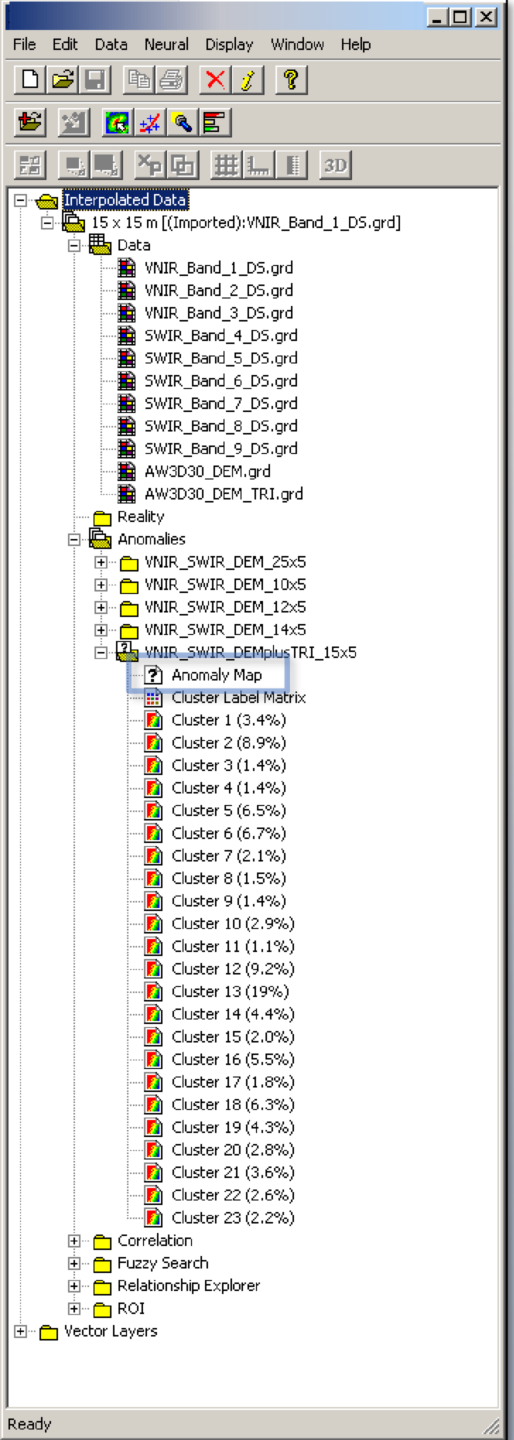


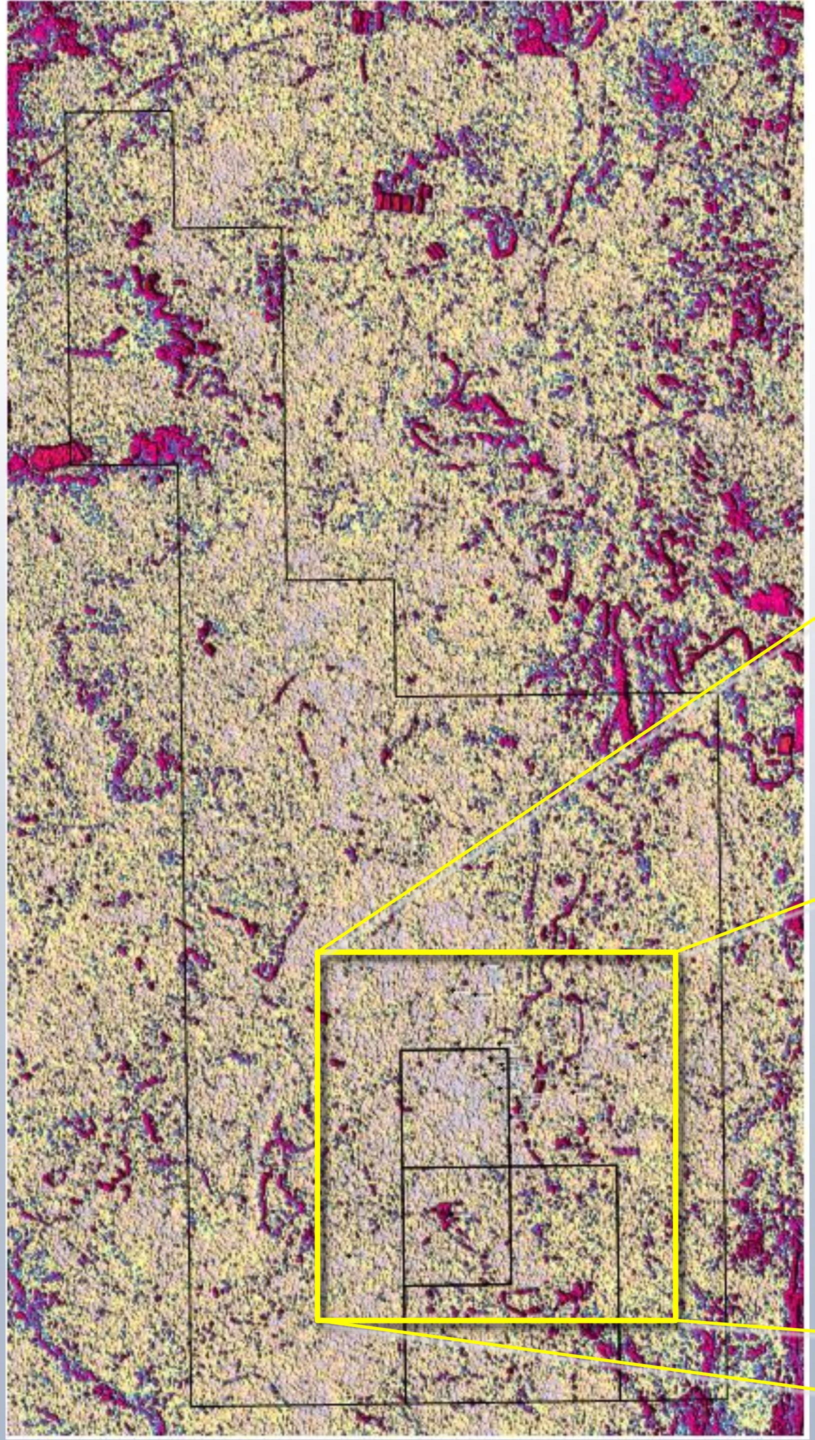
DEM



DEM – Terrain Ruggedness Index (TRI)



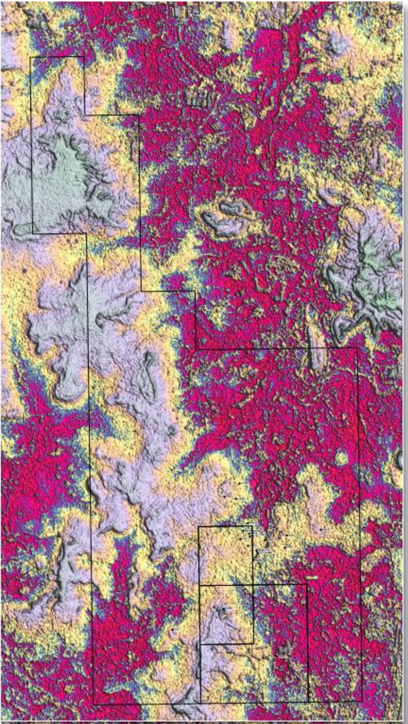




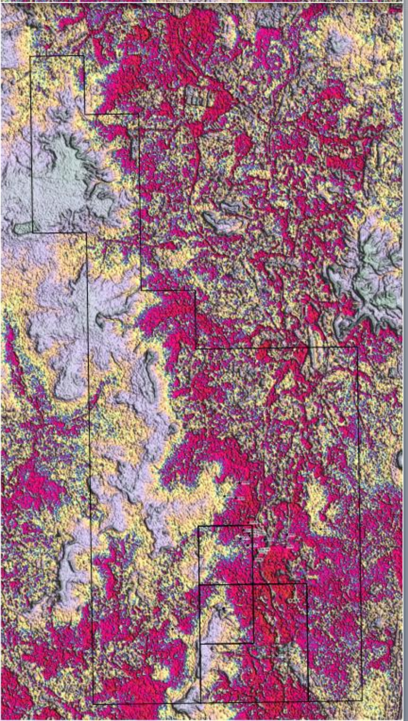
Anomaly Map

- Magenta colours signify points with unique input layer associations too rare to comprise a cluster
- Anomalous points may be unique for different reasons
- The only drill hole coinciding with an anomaly is CK003

Cluster 2



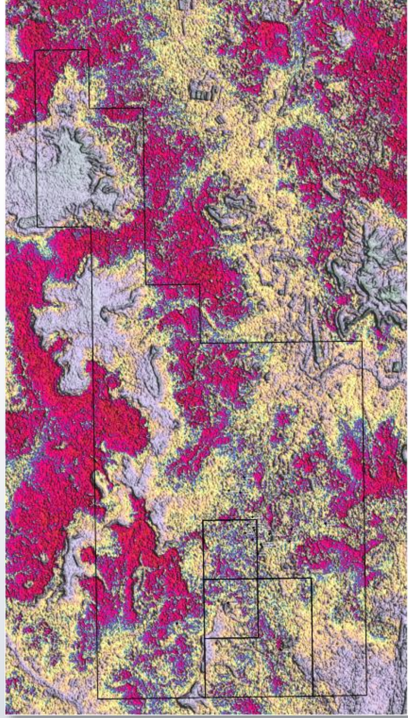
Cluster 3



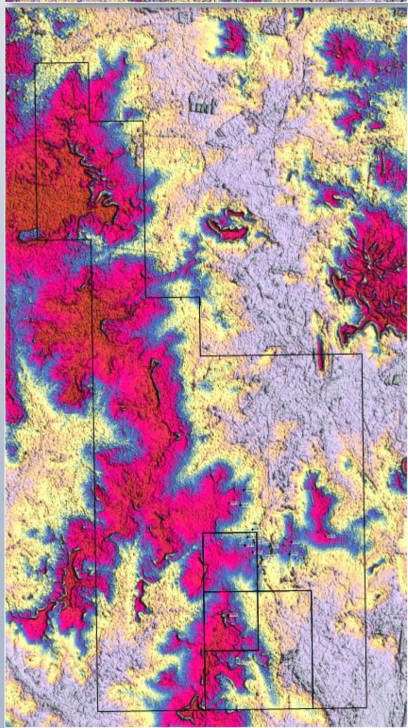
VNIR_SWIR_DEMplusTRI_15x5 [Cluster Label Matrix]

2	4	4	7	7	10	17	17	22	22	22	13	13	13	13
2	2	4	7	7	10	17	17	22	22	22	13	13	13	13
2	2	6	10	10	10	10	20	20	20	19	13	13	13	13
2	2	6	6	10	10	10	20	20	20	19	13	13	13	13
2	2	6	9	9	9	9	19	19	19	19	13	13	13	13
2	2	6	9	9	14	14	14	14	19	19	13	13	13	13
2	2	6	6	8	8	8	14	14	14	19	13	13	13	13
2	2	6	6	8	8	14	14	14	14	14	13	13	13	13
2	2	6	6	8	18	18	18	18	18	18	13	13	13	13
1	1	6	6	5	18	18	18	18	18	18	12	12	13	13
1	1	5	5	5	12	12	12	12	12	12	12	12	12	12
1	1	5	5	5	5	16	16	16	16	16	12	12	12	12
3	1	5	5	5	5	16	16	16	16	16	16	12	12	12
3	3	5	5	5	11	15	15	21	21	21	21	23	23	23
3	3	3	5	5	11	15	15	21	21	21	21	23	23	23

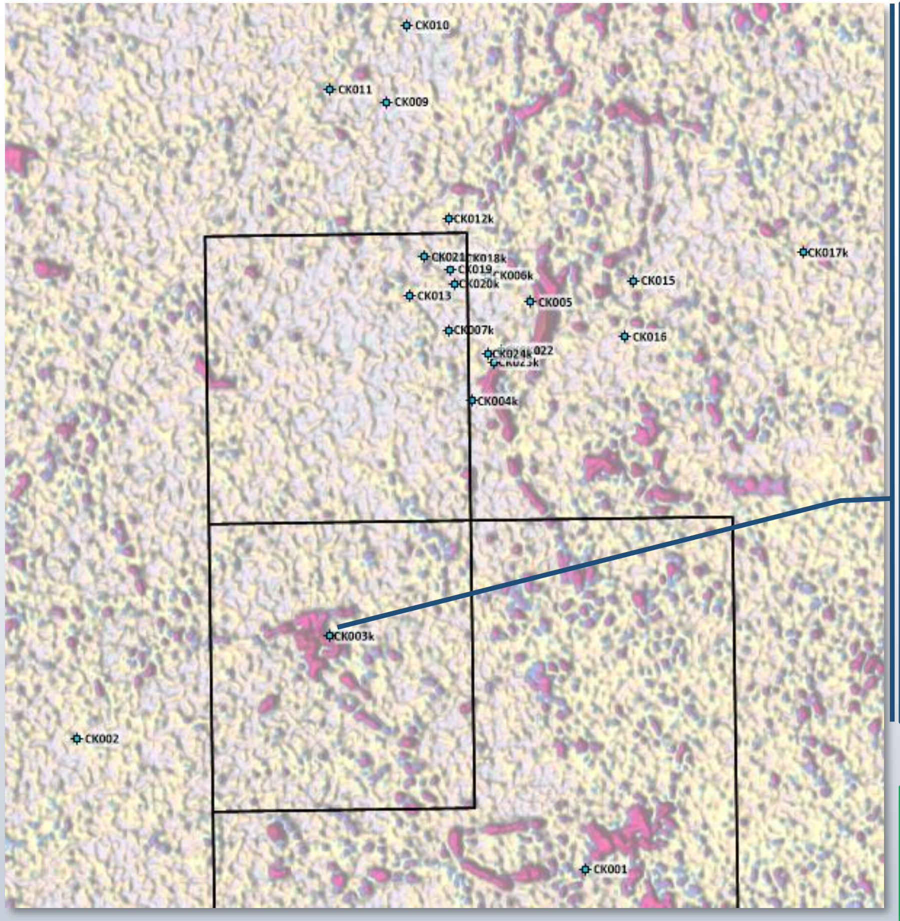
Cluster 13



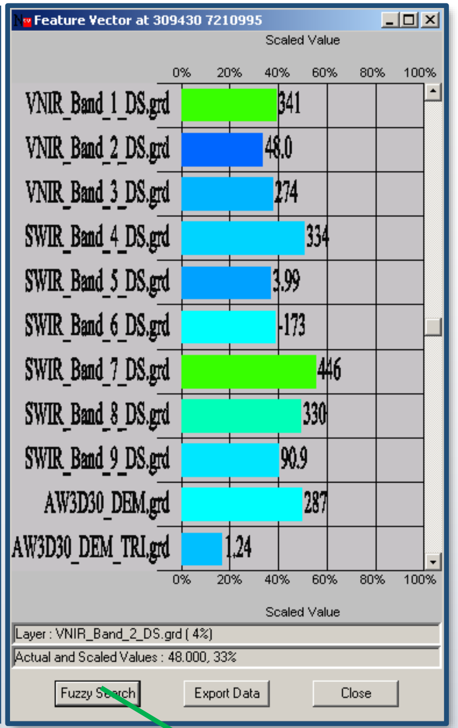
Cluster 23

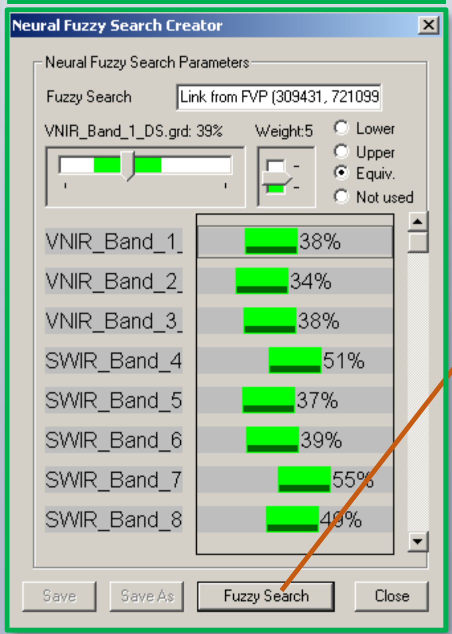


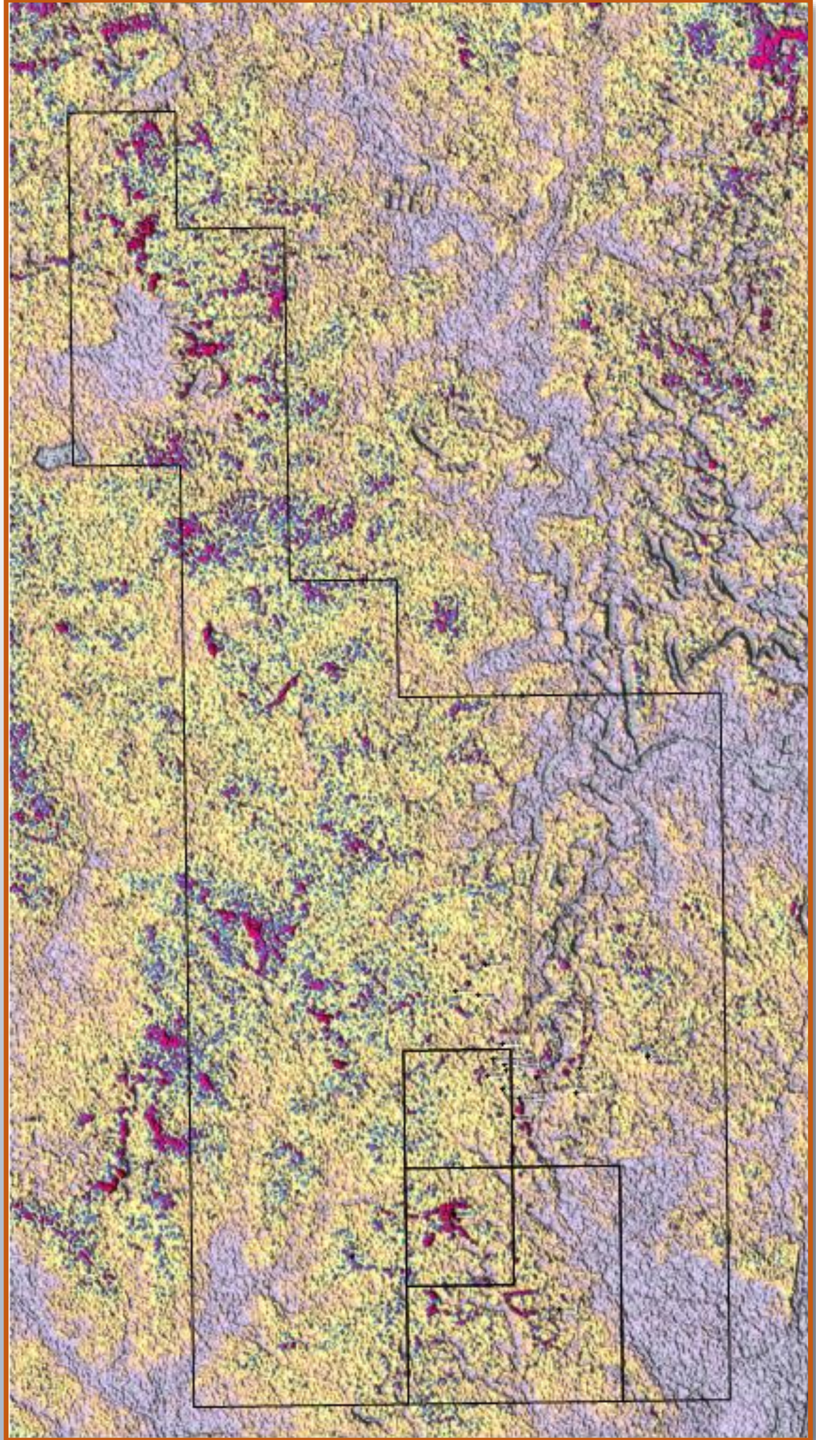
Cluster Label Matrix – neural matrix indicating the relationship between clusters defined by the unsupervised ANN



Drill hole Prospectivity Map



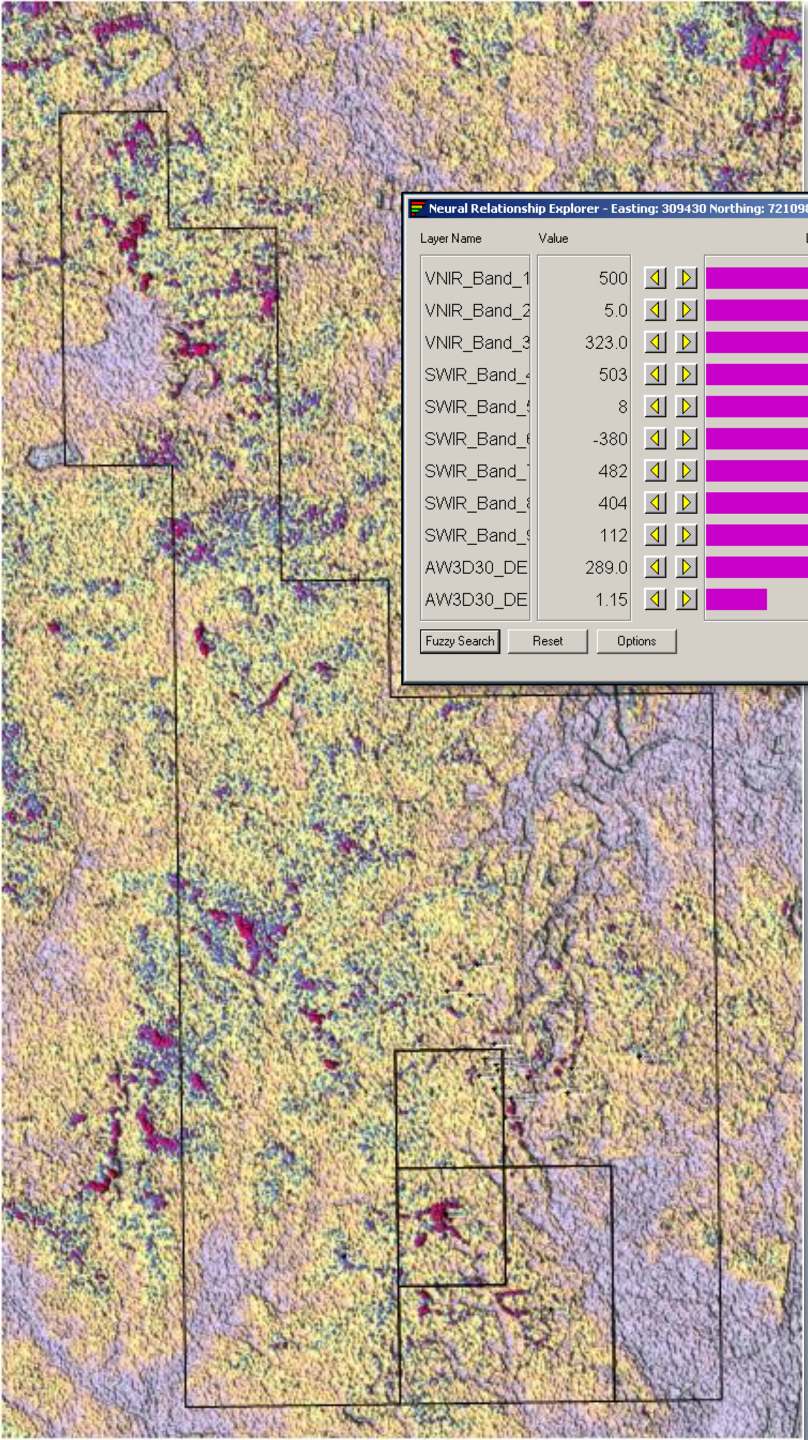




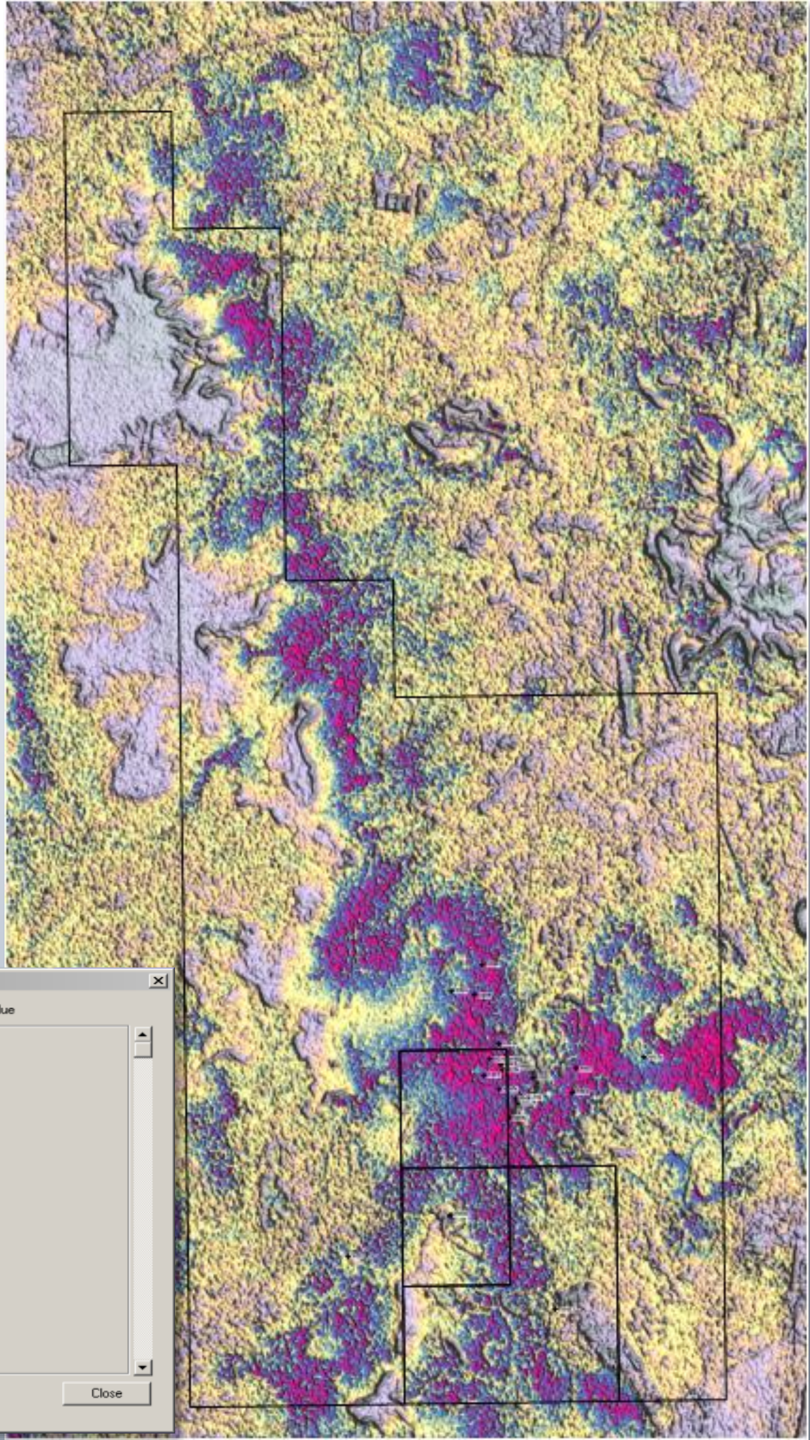
Workflow

1. Generate feature vector plot at point of interest (CK003)
2. Create a Neural Fuzzy Search profile. Form auto-populated by relevant search profile
3. Initiate a fuzzy search to generate a similarity map showing points more closely sharing the same input layer association as CK003 in magenta.

CK003
ROI supervised learning
NRE pattern & distribution



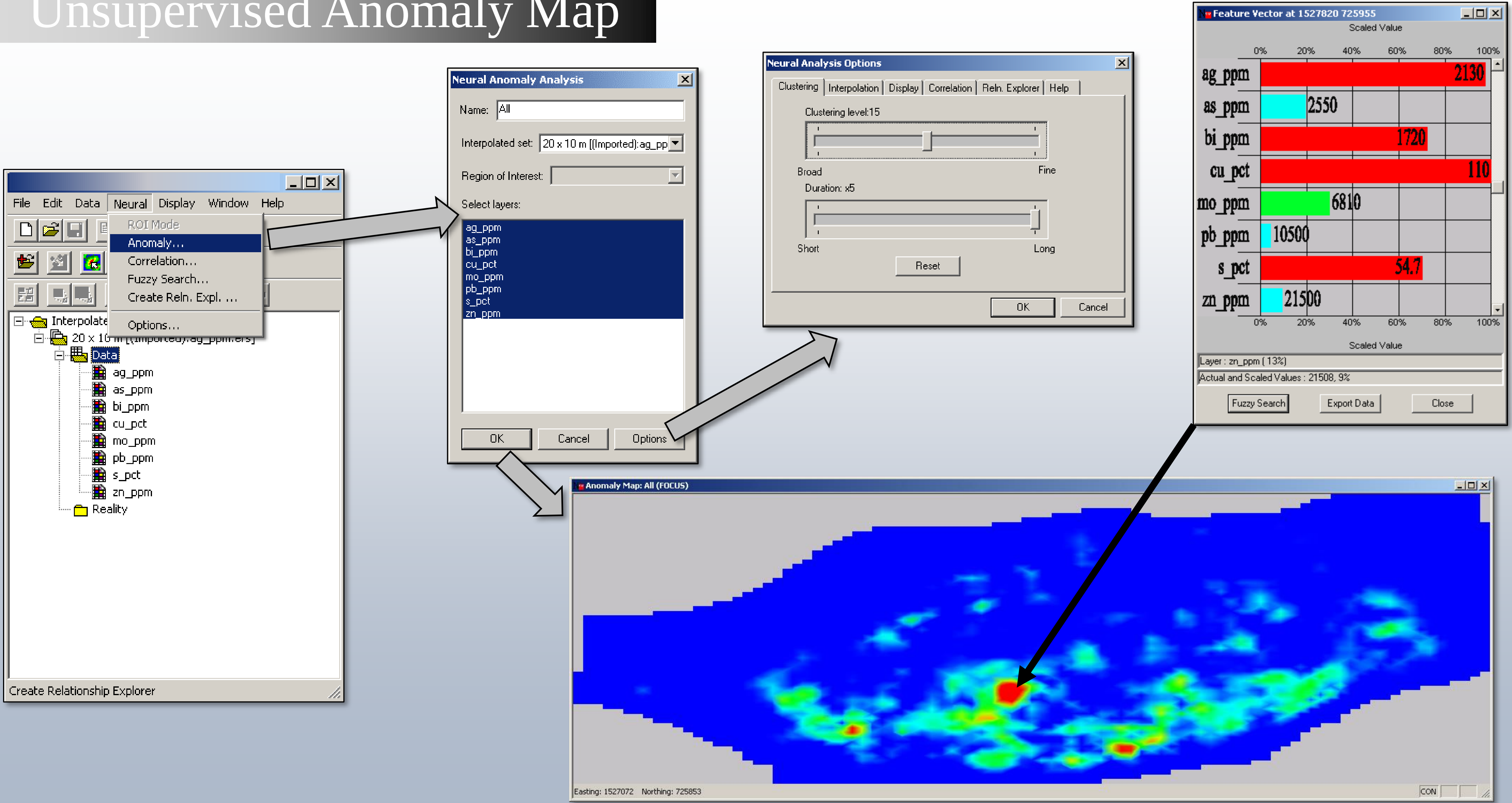
Densest drill location
ROI correlation search
NRE pattern & distribution



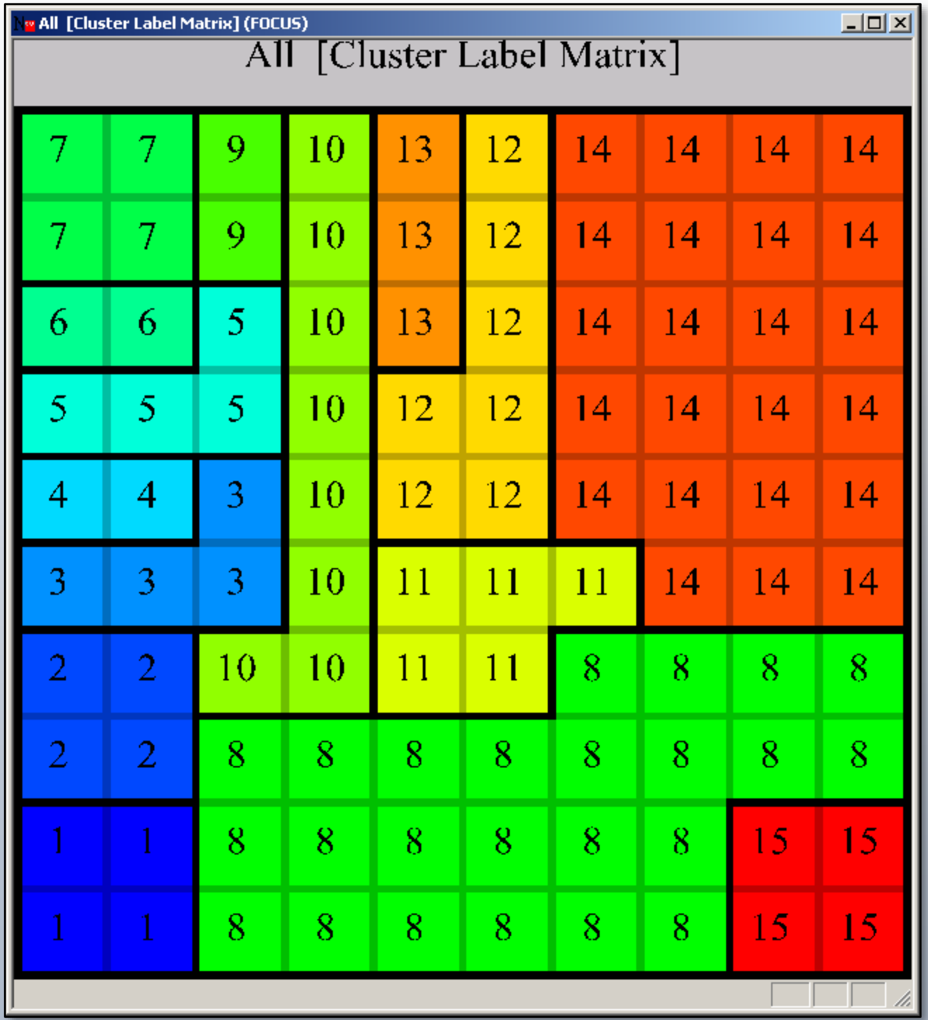
3D Neural Network Analysis Project

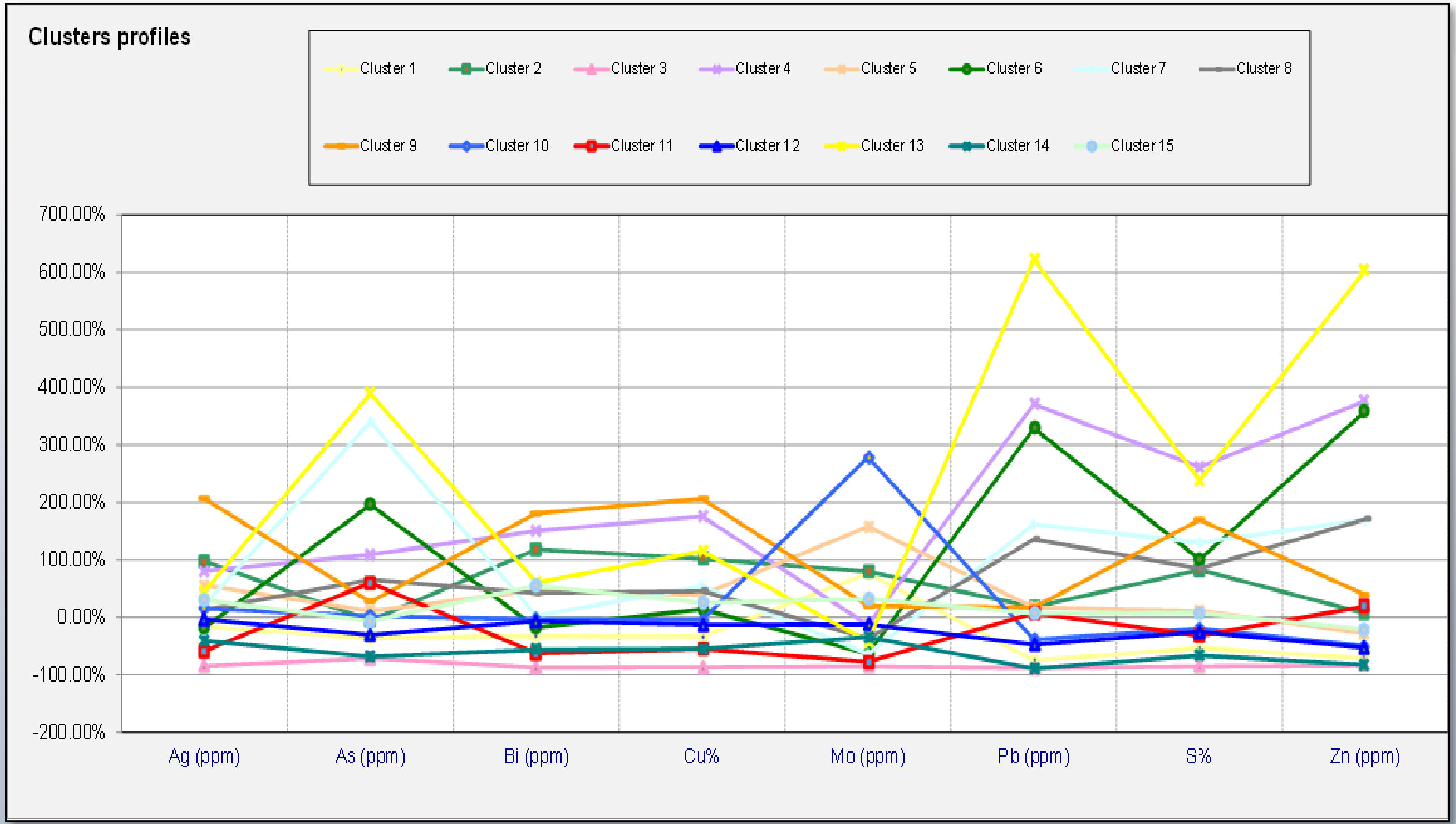
- Geochemical-geometallurgical domains can be identified using multivariate data analysis combined with machine learning pattern-recognition techniques (Keeney, 2010; Montoya et al. 2011).
- Geochemical domains can reflect mineralogy to a degree that might be difficult or impossible to produce using geological mapping, visual logging, or considering geochemical data in conventional ways (Berry et al., 2011; Cobeñas et al., 2015).
- Example project – 3D block model of a strata bound Cu deposit with 8 elements modelled: Ag, As, Bi, Cu, Mo, Pb, S, Zn
- Over 150 RC and diamond drill holes defining the resource

Unsupervised Anomaly Map

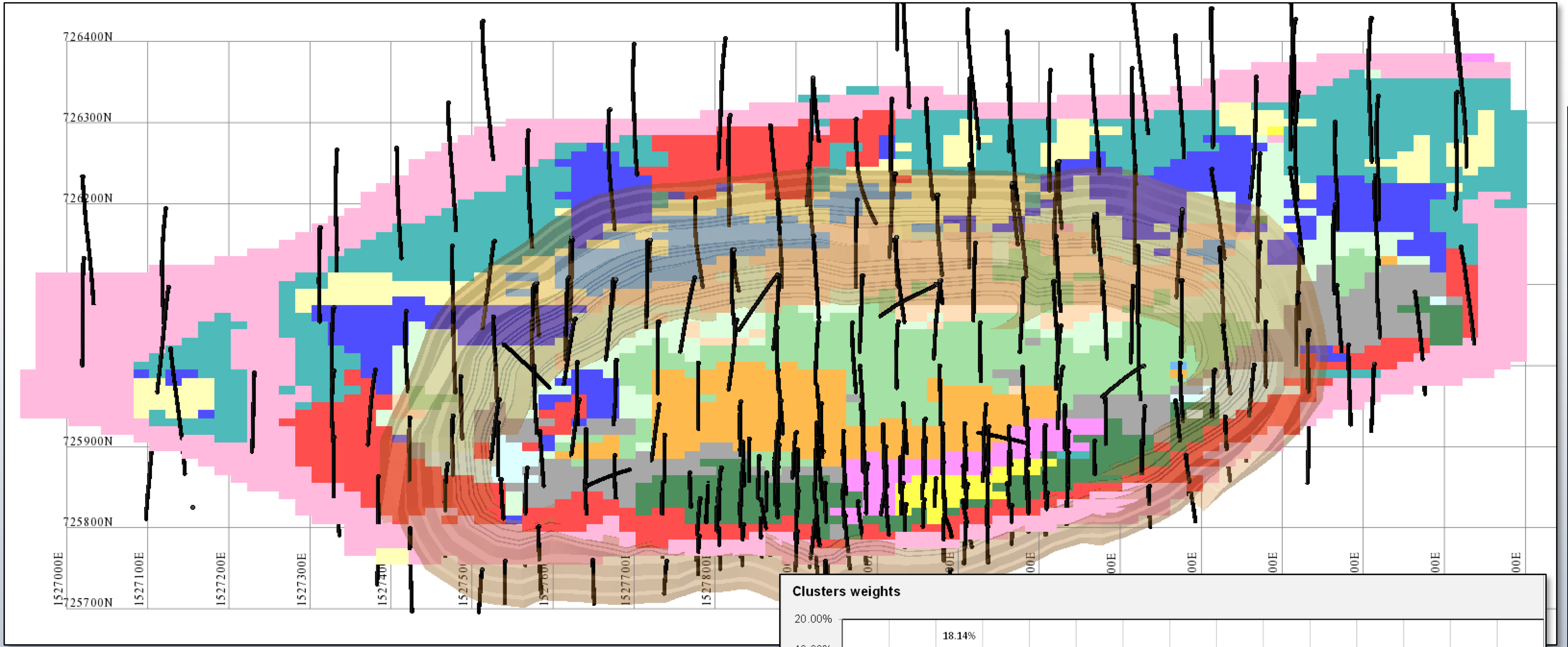


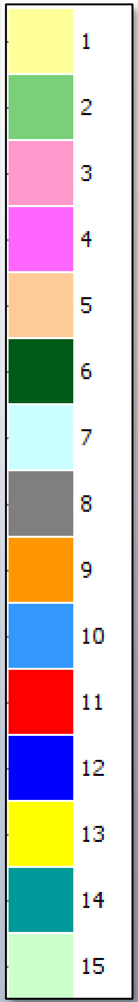
Unsupervised Cluster Identification

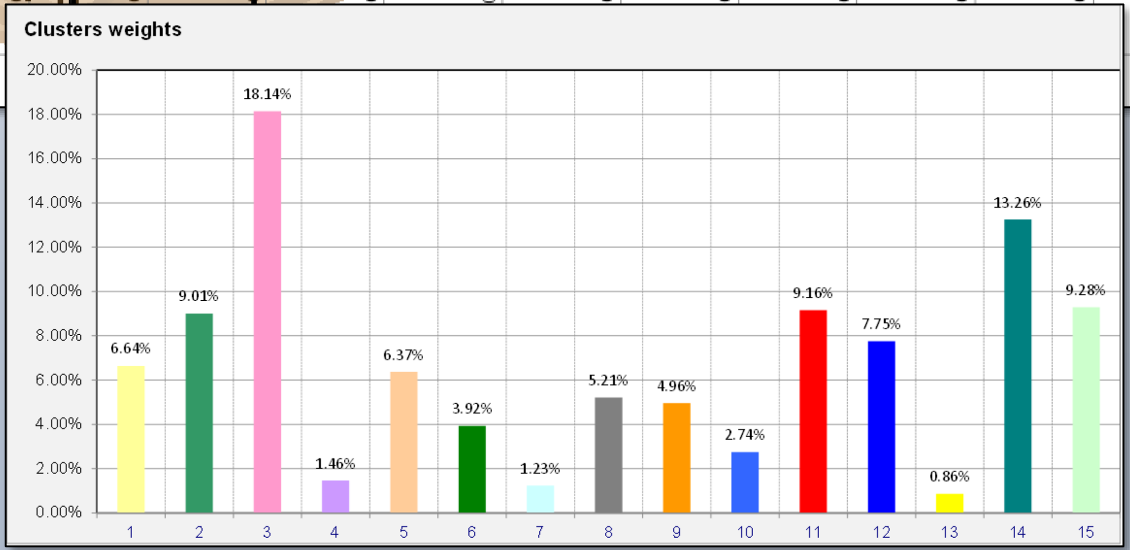




Cluster profiles for 15 clusters generated. The peaks represent the relative strength of their contribution of the element to the cluster in which they are associated.

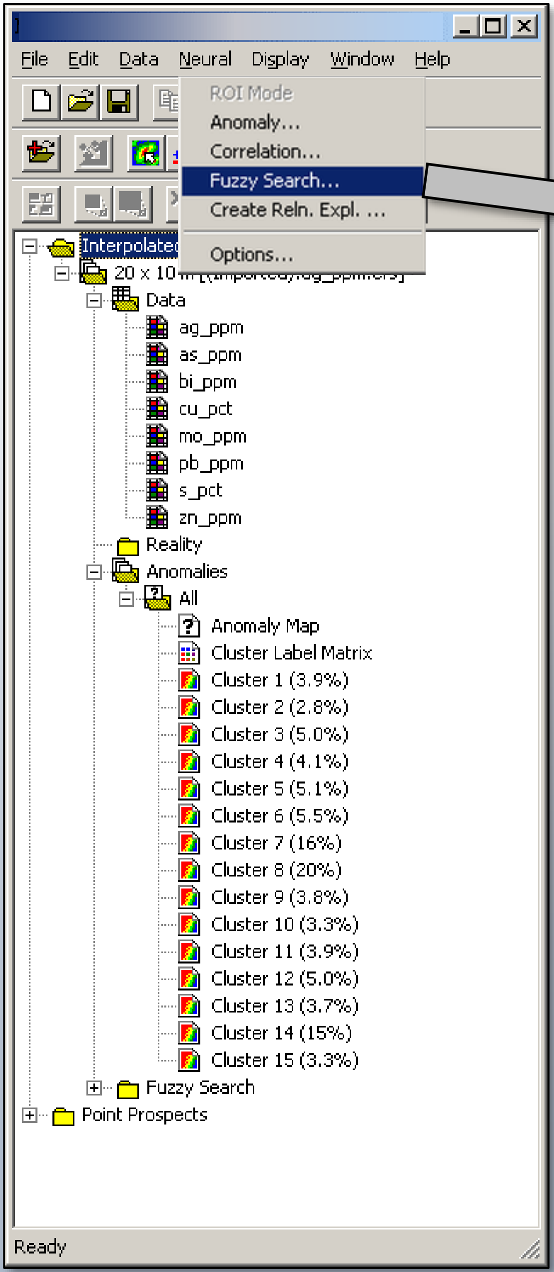


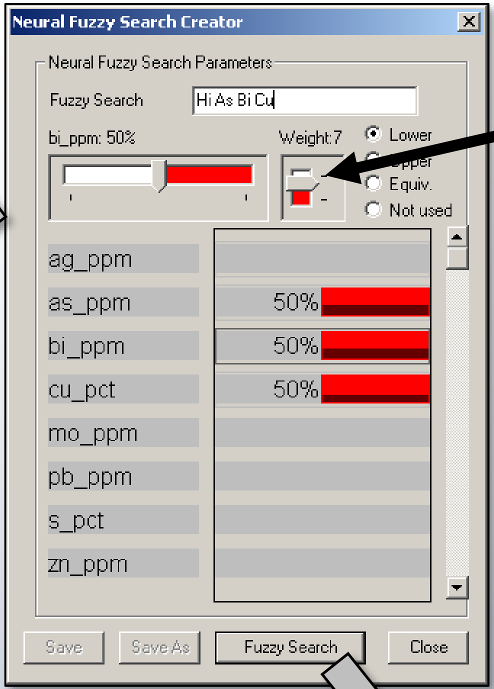




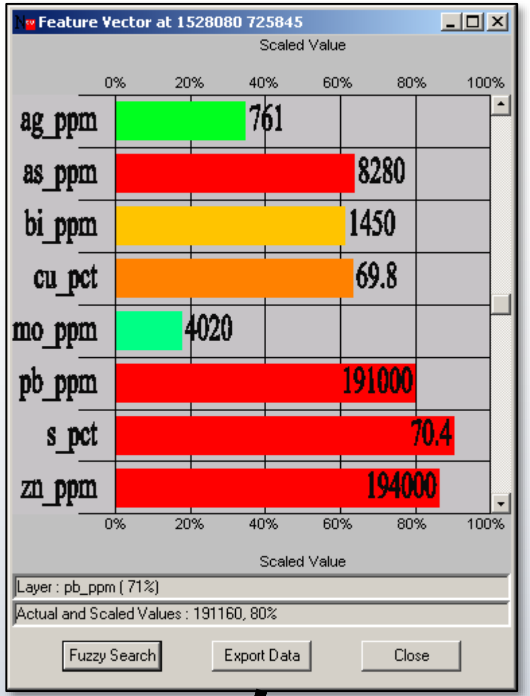
Clusters exist in spatially coincident groups suggesting that they have meaning in terms of the geological process.

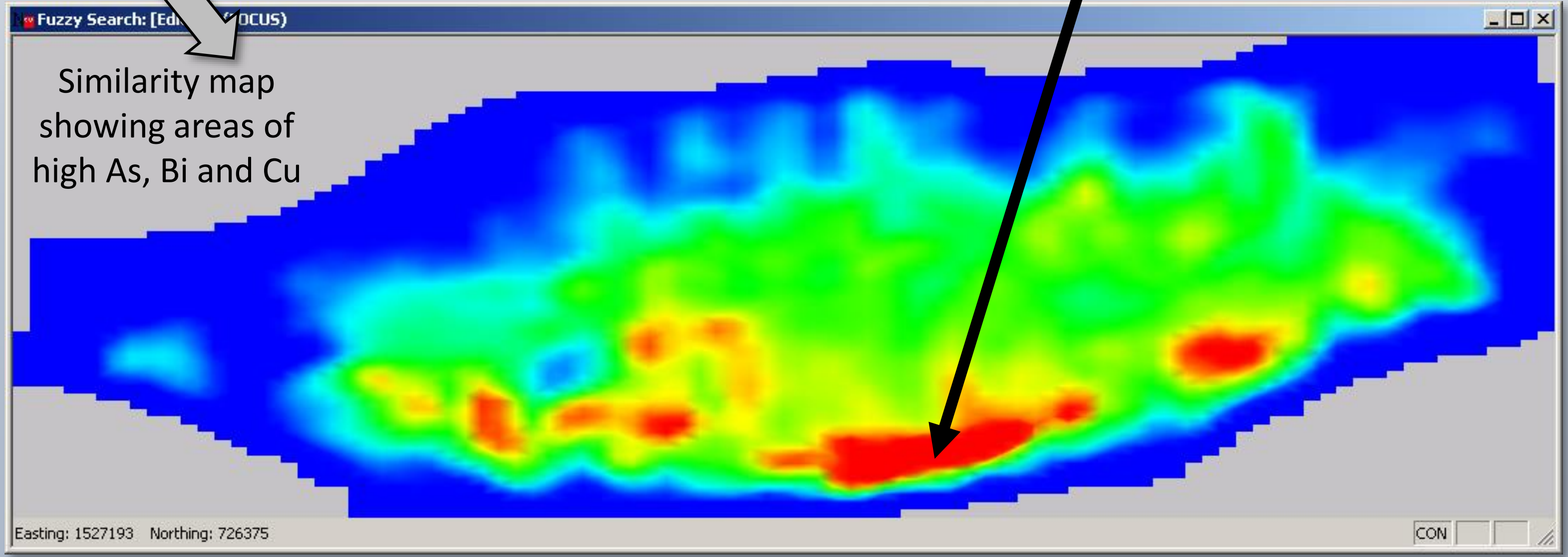
Fuzzy Search for High As, Bi and Cu

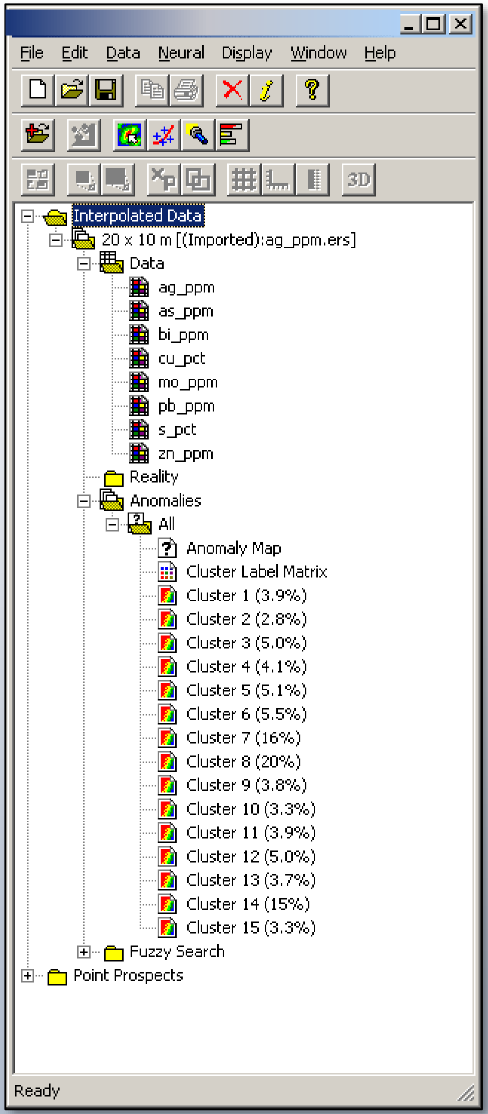


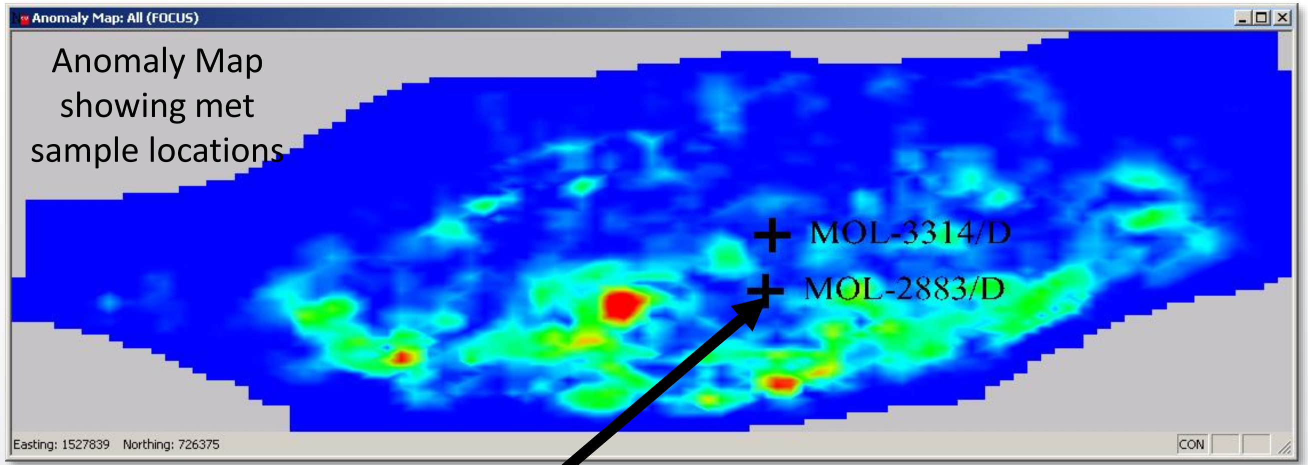


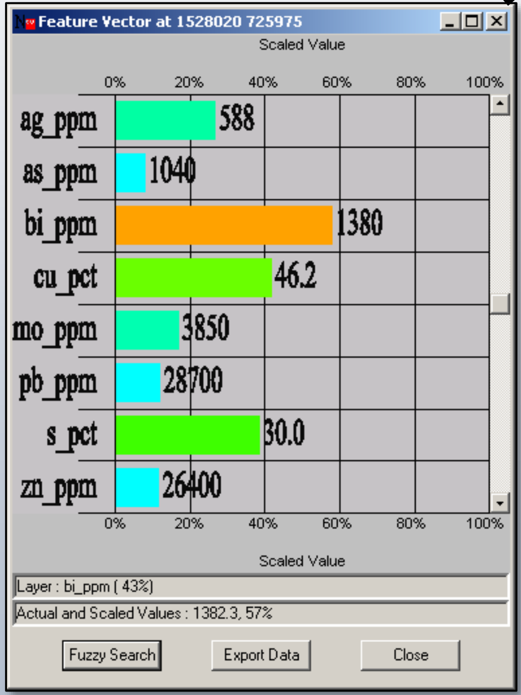
Increase As weighting





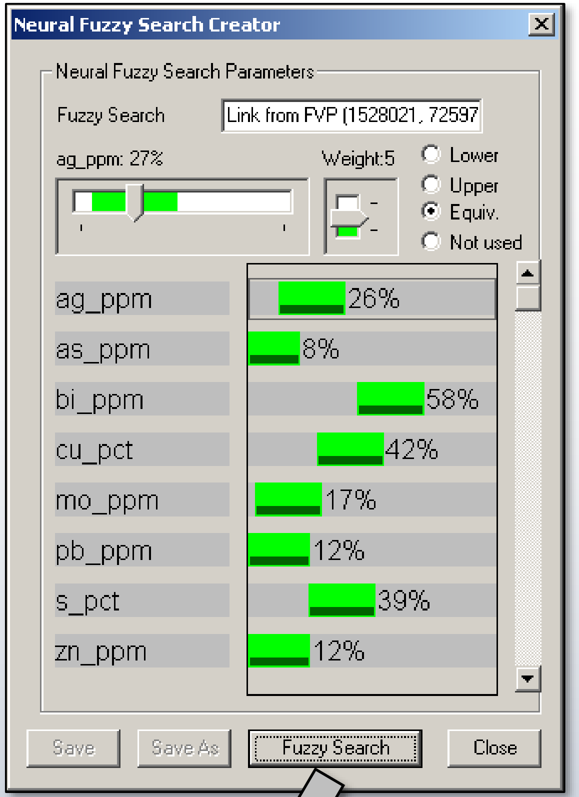


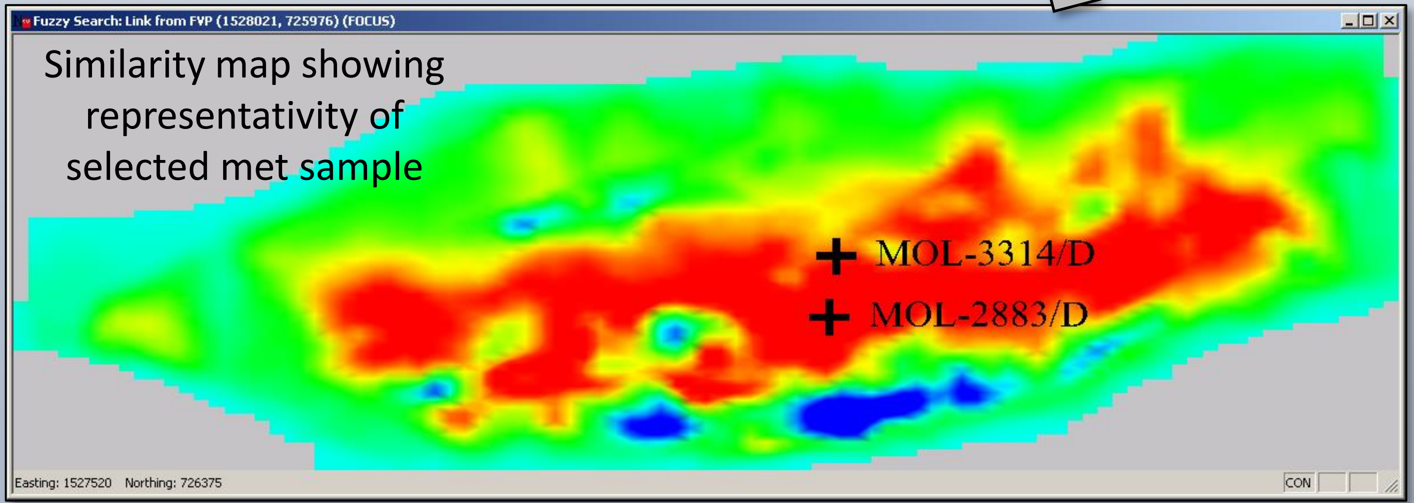




FVP showing geochemical characteristics of a particular met sample

Fuzzy Search Creator using met sample search criteria



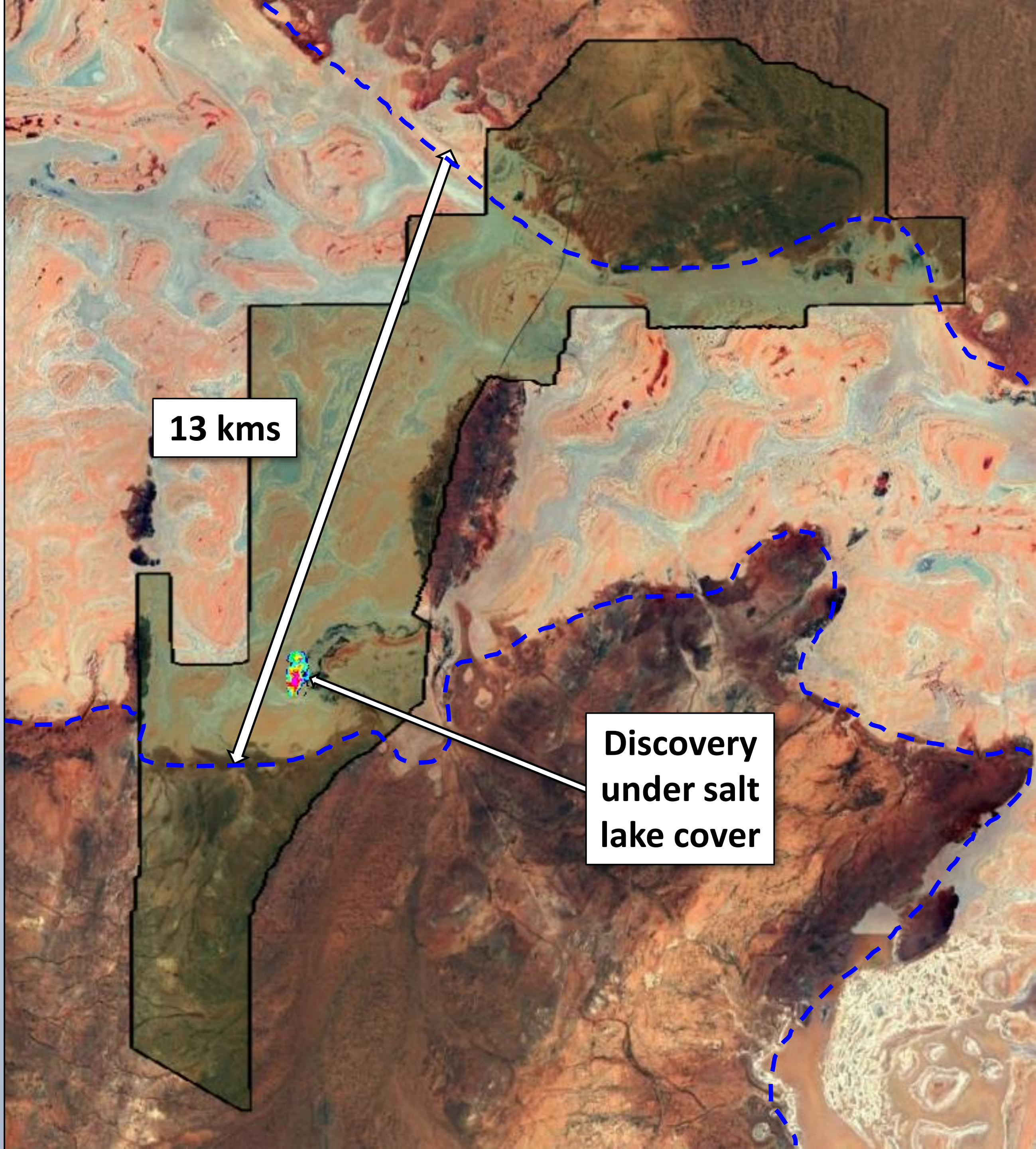


Under Cover Western Australian Archean Gold Project

This project was recently completed for a company exploring for gold beneath a salt lake in Western Australia.

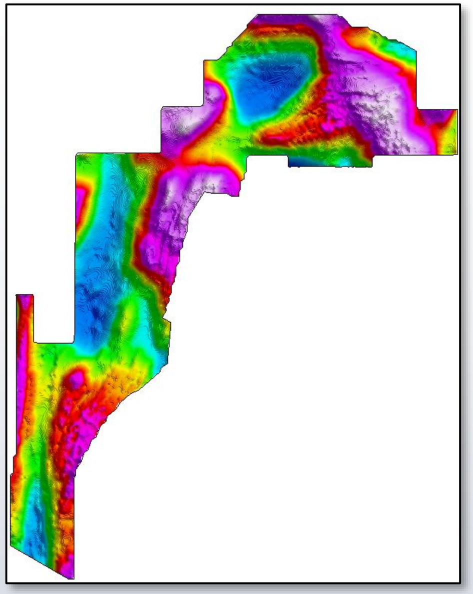
The company had made a significant discovery and had completed an initial drilling program with some outstanding intersections.

The cost of drilling on the lake was very high so they were looking for ways to minimize the drilling by locating targets under cover using machine learning.

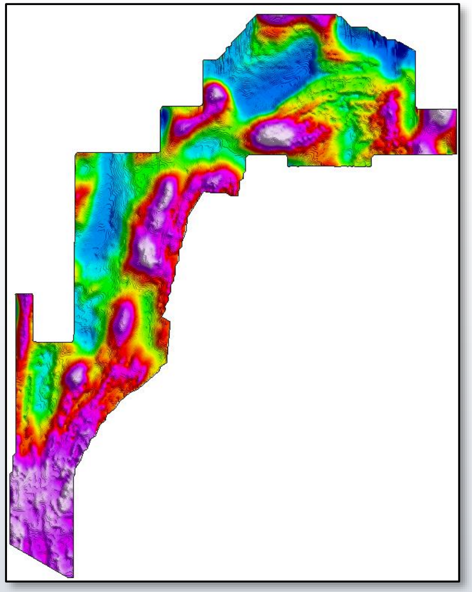


Gravity layers

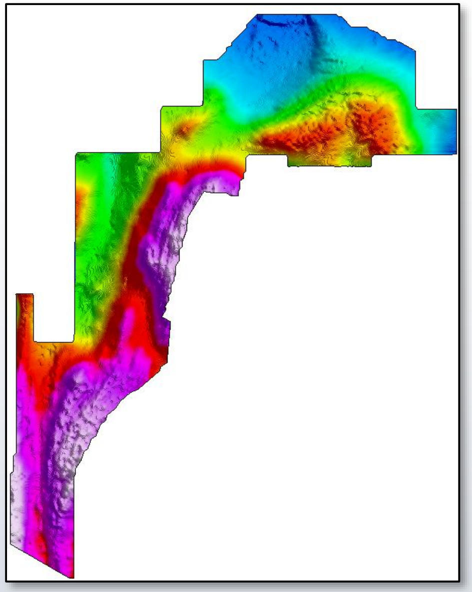
BA_3rd_Order_Res



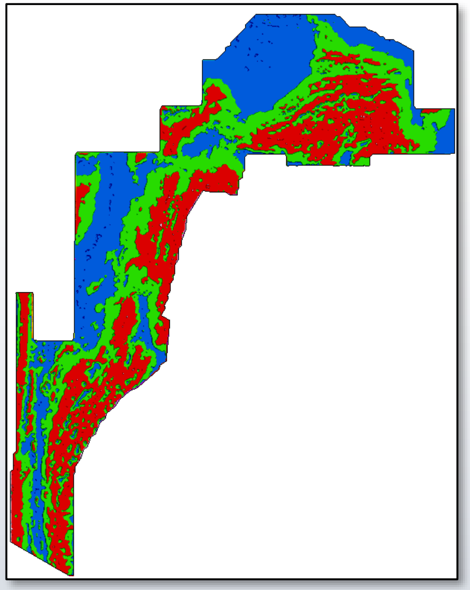
BA_Res_5km



SCBA267GU

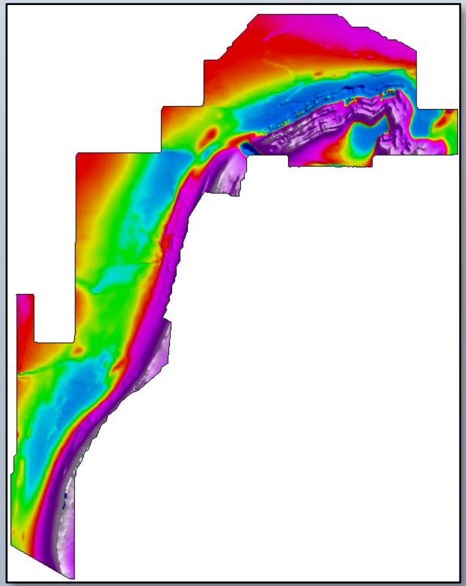


SCBA267GU-tilt

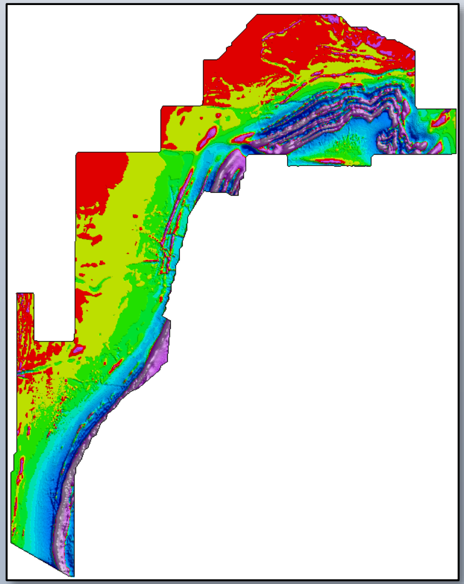


Magnetics layers

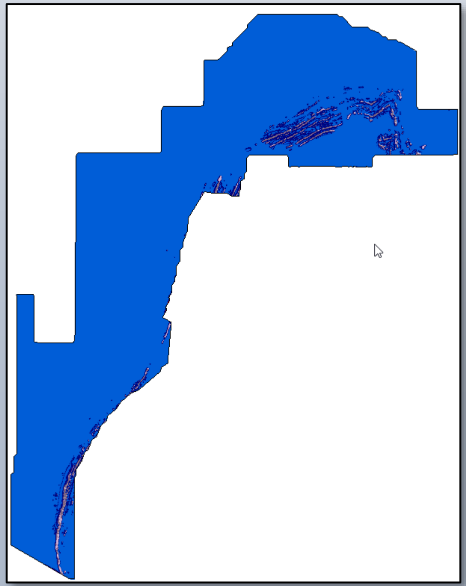
TMI_RTP



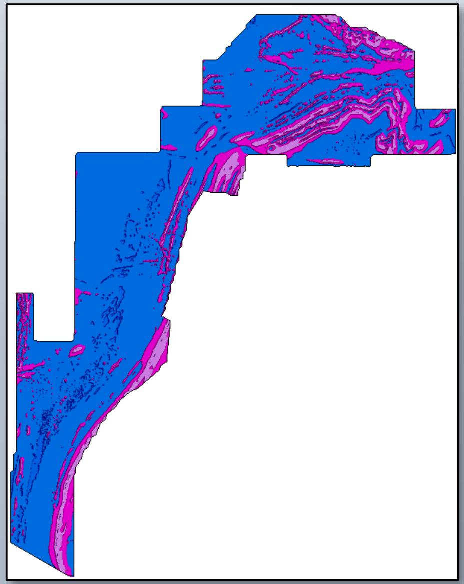
TMI_TRP-1VD



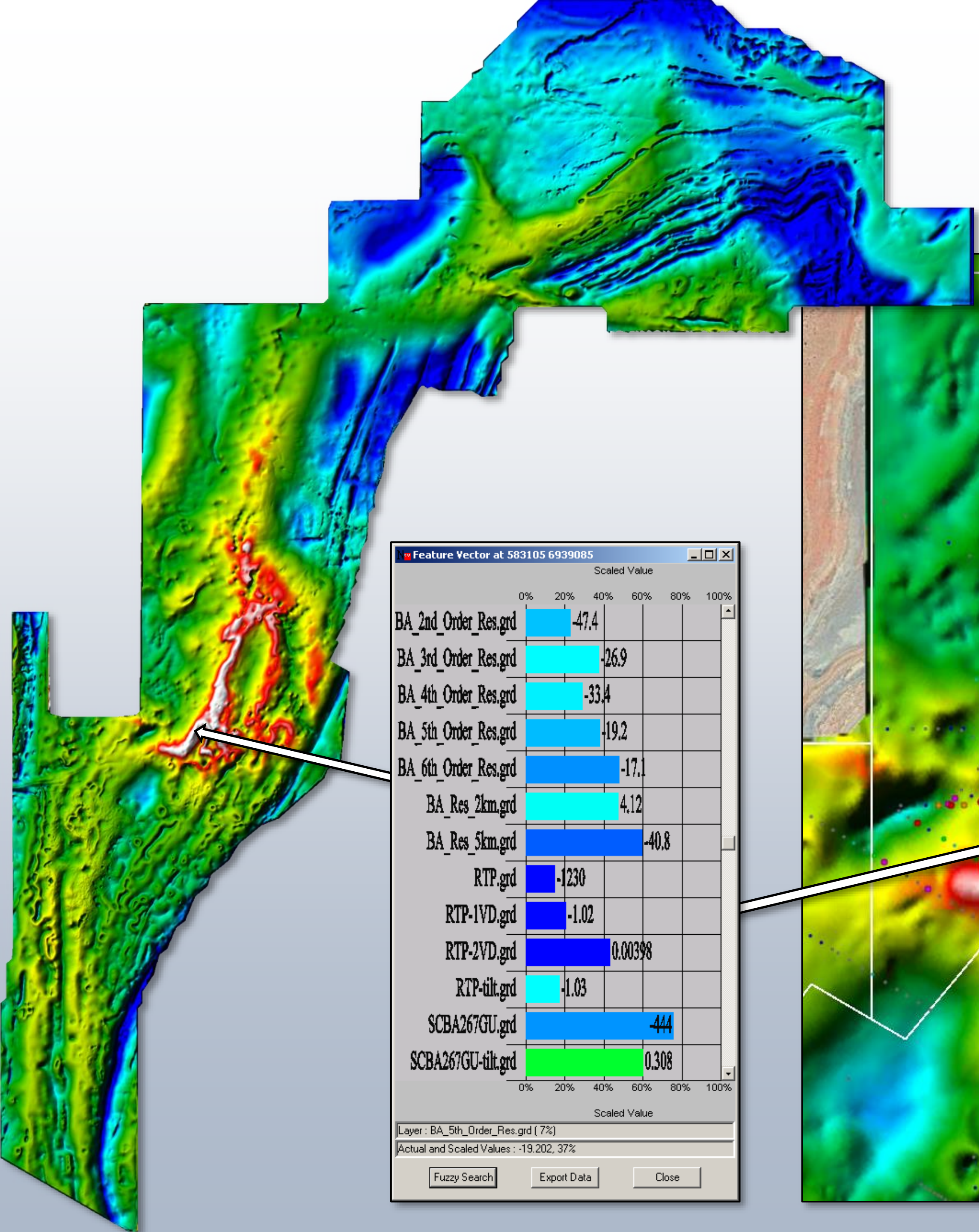
TMI_RTP-2VD

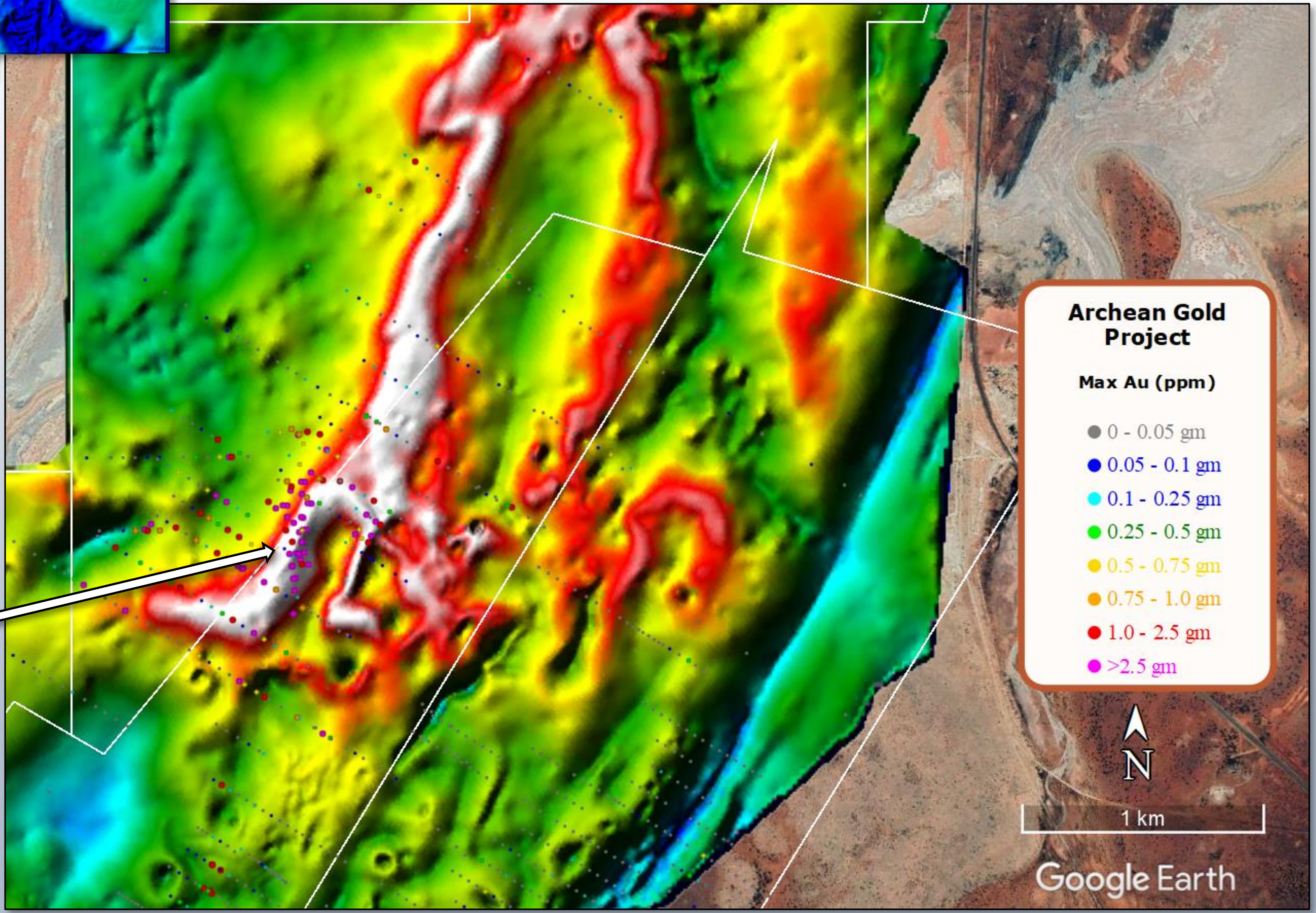


TMI_RTP-tilt

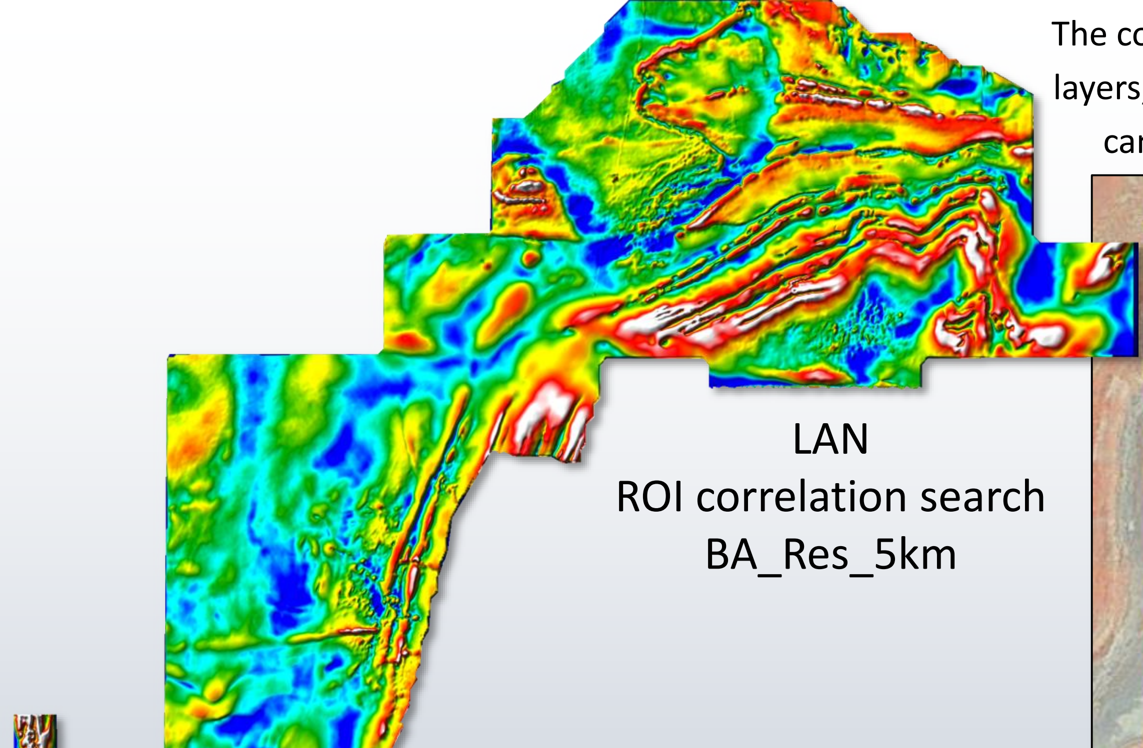


Fuzzy search similarity map using the gold discovery under cover location as the search point

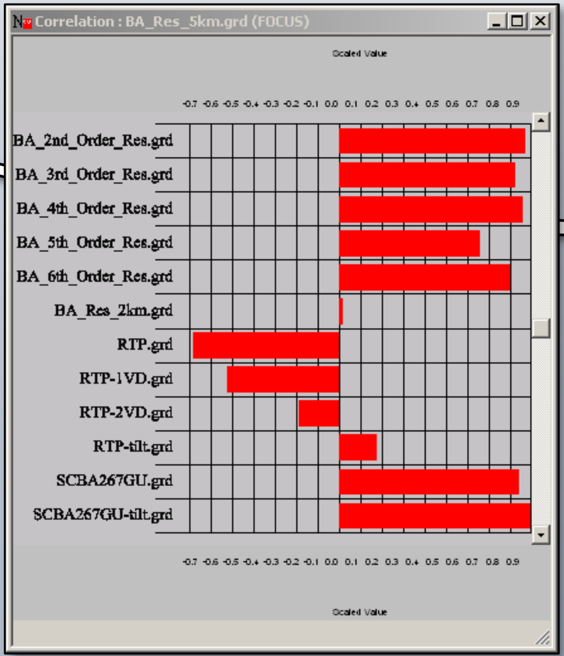


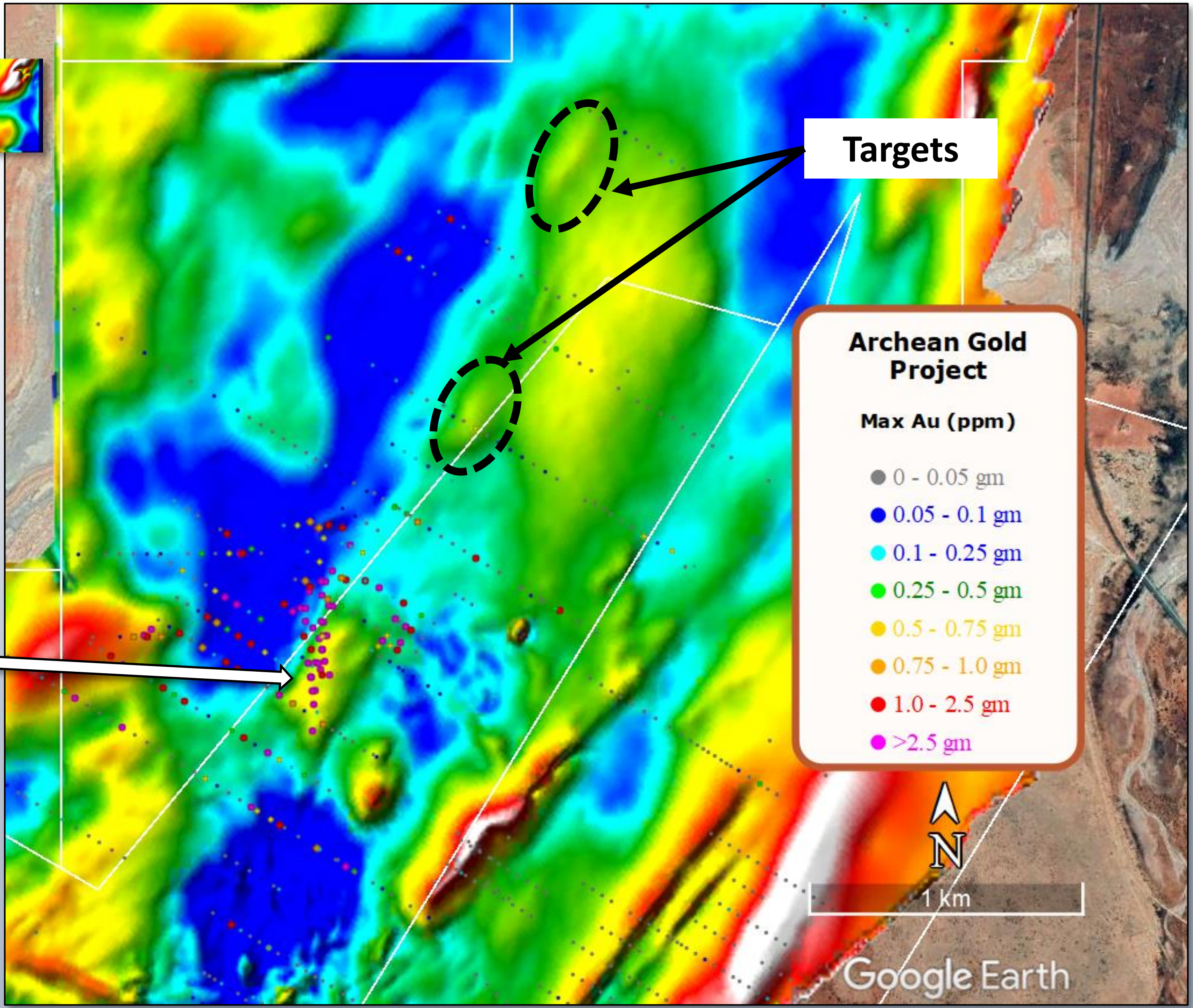


The correlation analysis provides a means of searching for signatures of the relationship between layers, independent of the amplitude values of the layers. The subtle relationship between layers can be of more importance than the observed rank outlier values that are easily observed.



LAN
ROI correlation search
BA_Res_5km





GeoWizards have utilized the exploration data supplied by Oz Minerals, as well as sourcing other data, to perform detailed Neural Network processing using unsupervised neural analysis tools to automatically identify anomalies, and supervised analysis tools using data relationships at known mineral deposits such as Olympic Dam and Prominent Hill to search for "lookalikes". The resulting anomaly and similarity maps have then been integrated with geology and drill hole data to develop a feature selection matrix that has been used to prioritise targets for further investigation.

Regional study Input Layers

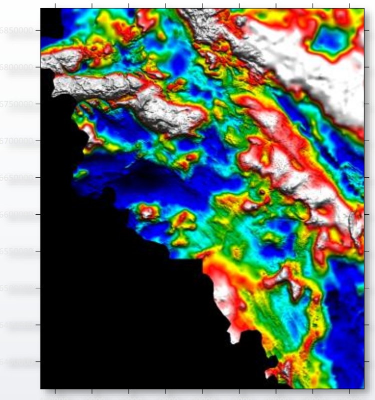
North Eastern Gawler IOCG Province

Machine Learning Analysis Input layers

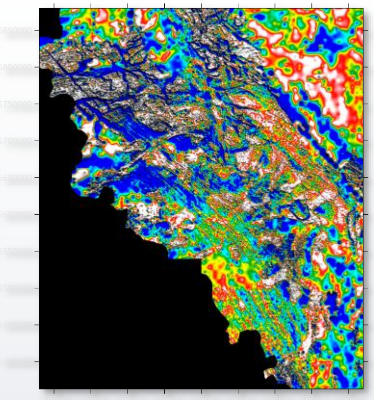
gridded to a common 200m x 200m

gravity

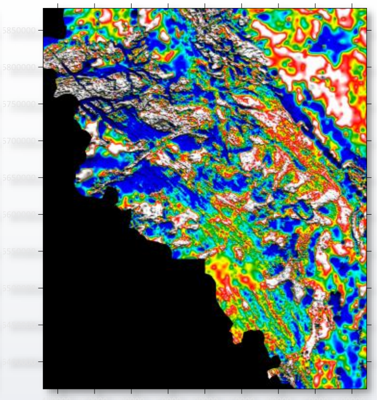
gravity



1VD

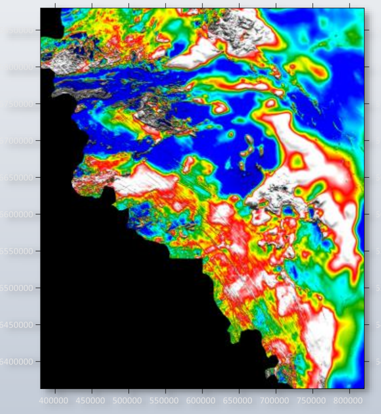


UC1000 residual

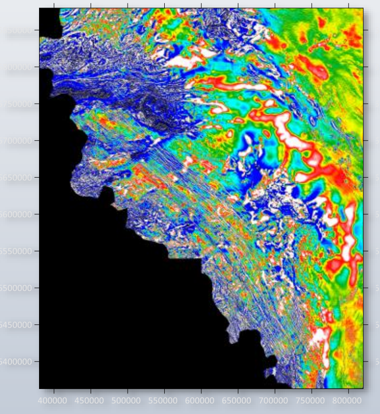


magnetics

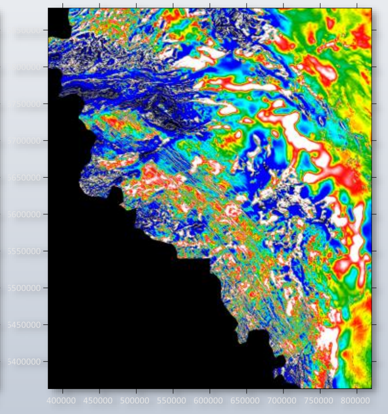
RTP



RTP 1VD

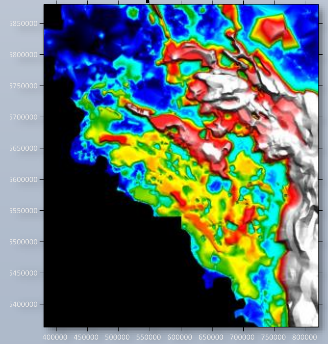


UC1000 residual

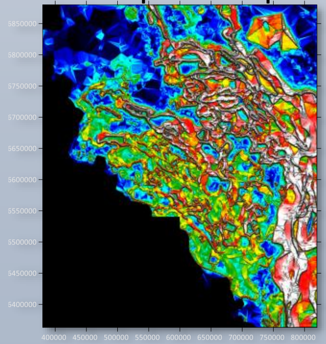


cover thickness

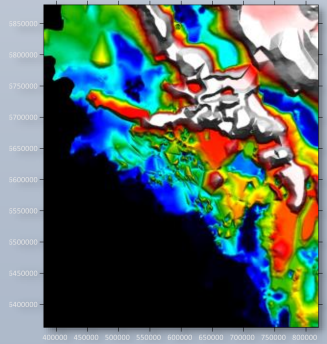
Neoproterozoic



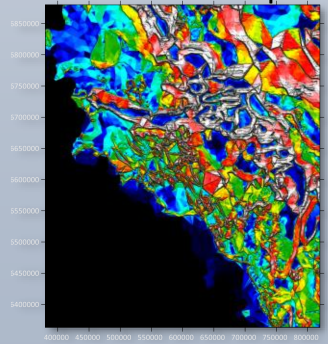
Neoprot. slope

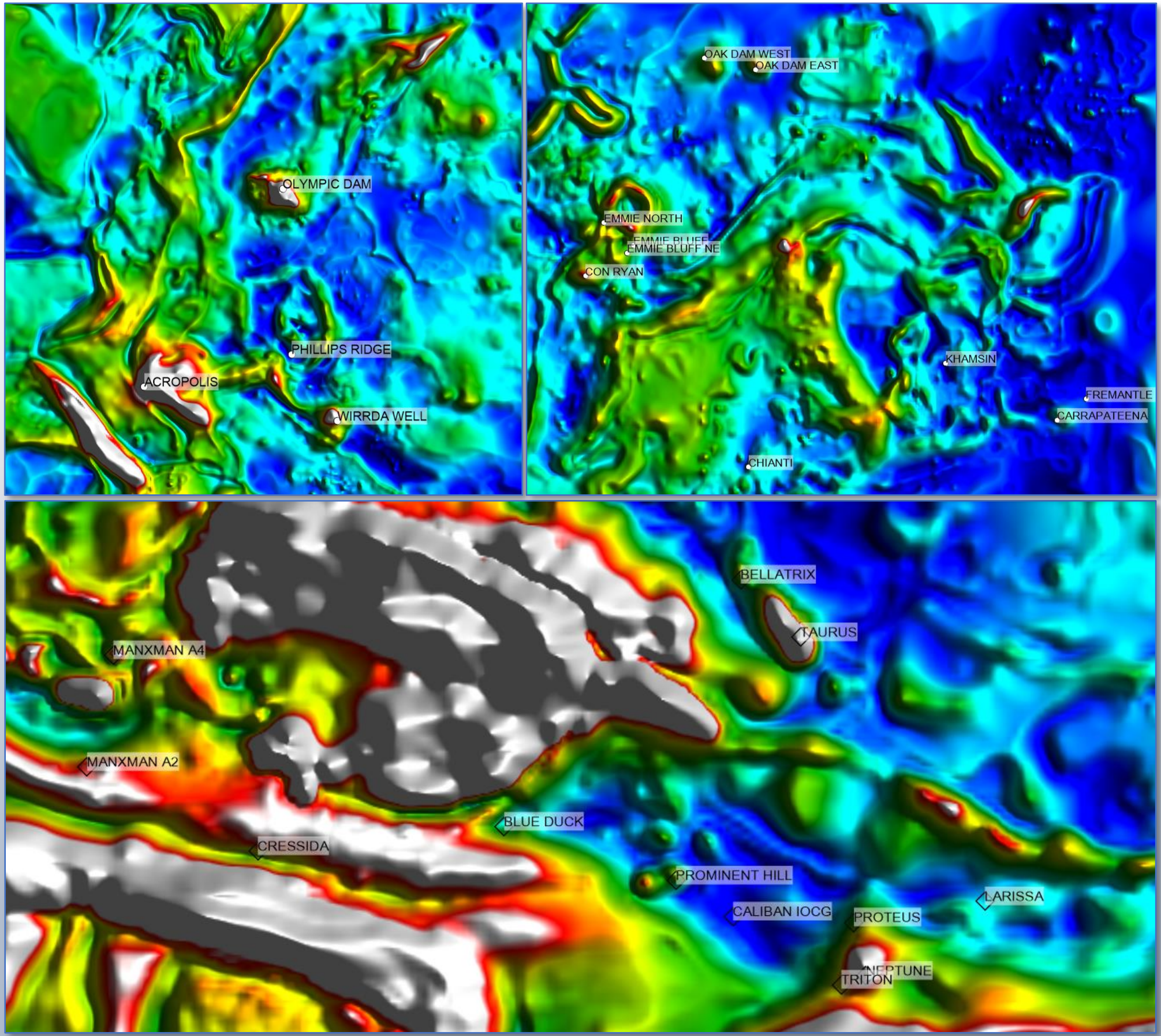


Phanerozoic



Phan. slope





Regional study Search Results

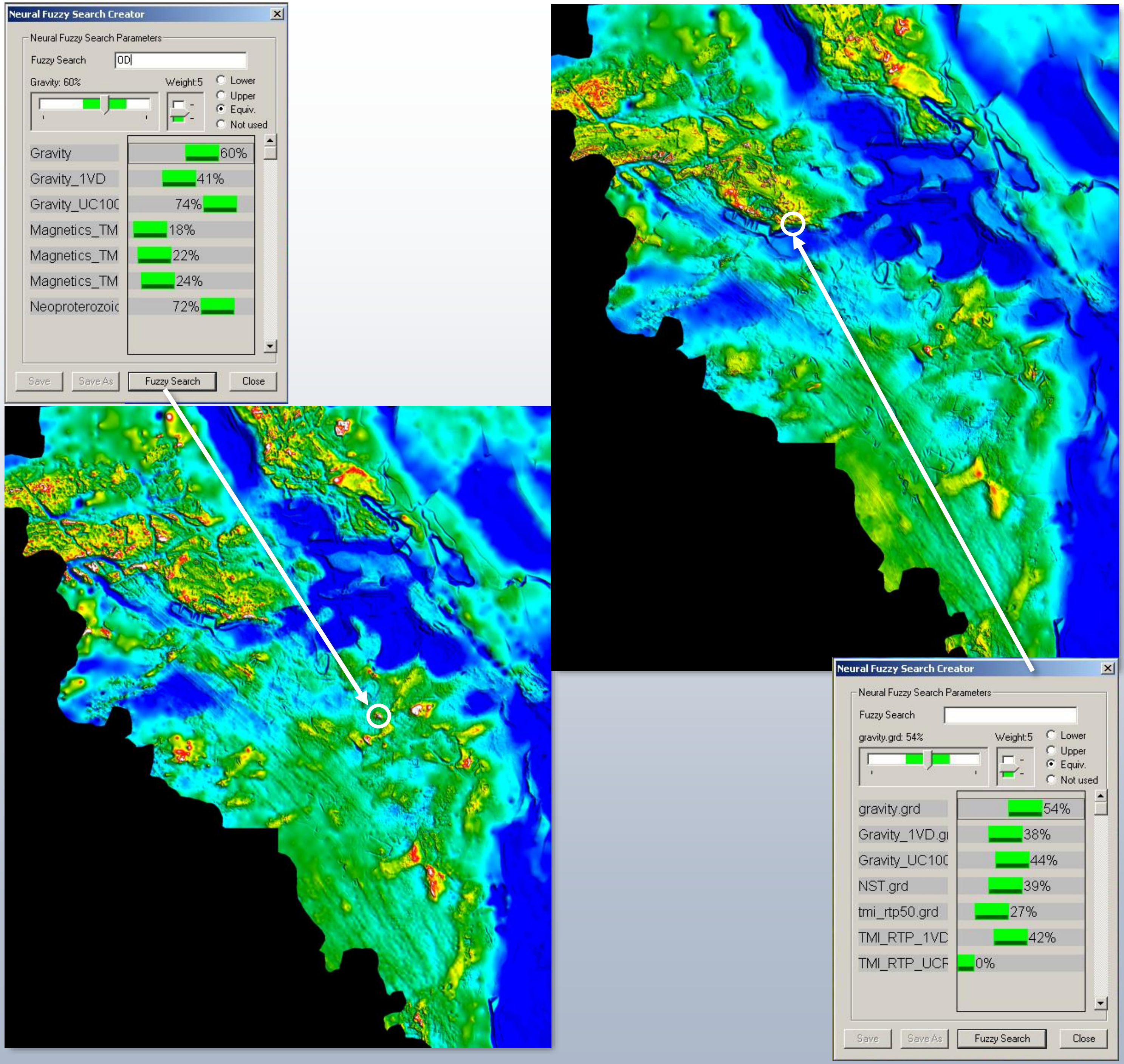
North Eastern Gawler IOCG Province

Unsupervised ANN

Detected relatively unique input-layer association (anomalies) over all major IOCG deposits and discoveries

Note:

warmer colours signify relative uniqueness and each feature is not unique for the same input-layer association



Regional Study Search Results

North Eastern Gawler IOCG Province

Unsupervised ANN

Numerous features sharing similar input-layer associations for Olympic Dam (Left) and Prominent Hill (Right) as highlighted by the auto-generated fuzzy search creator parameters for each deposit

Note:

1. warmer colours signify relative similarity and each feature highlighted shares similar input-layer association
2. "character" of Olympic Dam is not the same as for Prominent Hill

NUMEROUS MAJOR IOCG

TARGETS IDENTIFIED

Thank you

If you would like more info,
please contact us at:

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