Mineral potential mapping using artificial neural networks and GIS with advangeo® - Theoretical background and case studies

advangeo® Prediction Software

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ProMine Workshop on Mineral Resources Potential Maps
Nancy, March 13th, 2012

Agenda

- **Motivation**
- **Predictive Mapping with advangeo®**
  - Theoretical Background: Artificial Intelligence / Artificial Neural Networks
  - Short Presentation of Developed Software: advangeo®
  - Description of Work Methodology
  - Case Studies:
    - Ghana: Au – Deposits
    - Burkina Faso: Regolith Landforms
    - Pacific Ocean: Manganese Nodules Coverage Density
    - Kosovo: Pb/Zn, Au, Cr – Deposits
    - Europe: Top Soil Geochemistry
  - Further Case Studies
- **Outlook / Summary**
- **Website**

Motivation

Where are the deposits located ?

Where do forest pests spread ?

Where does coal burn ?

Where are karst caves located ?

Motivation

Where is soil contaminated ?

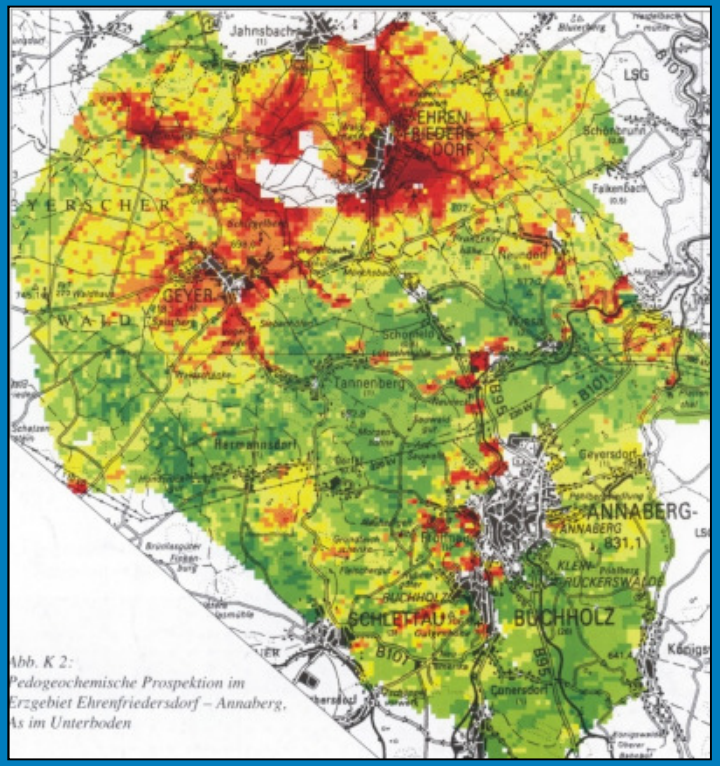
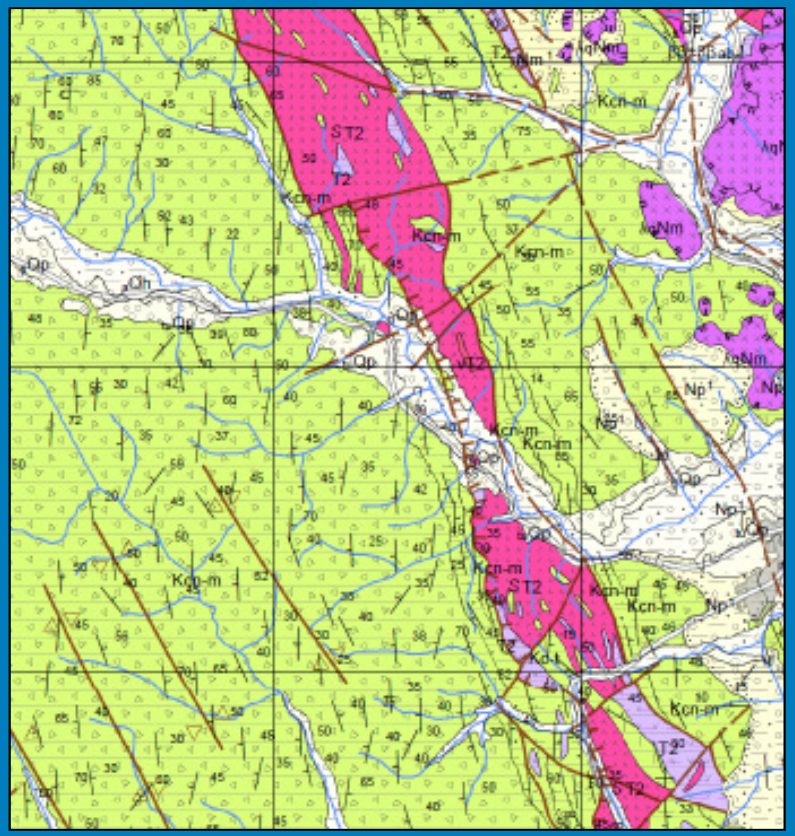


Abb. K 2:
Pedogeochemische Prospektion im Erzgebiet Ehrenfriedersdorf – Annaberg, As im Unterboden

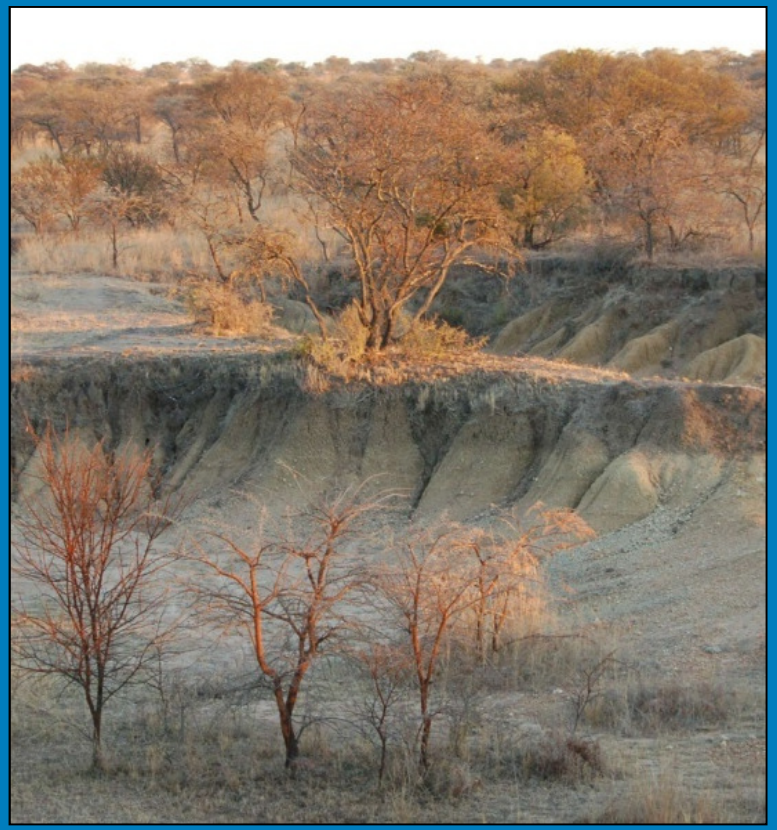
Where is a geological / pedological boundary?



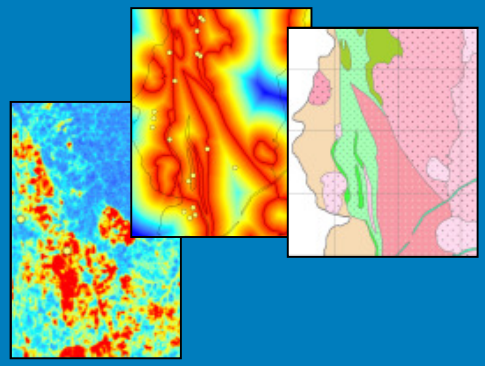
Motivation

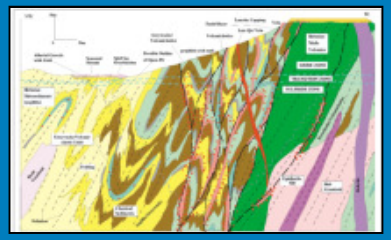
Where do hillside slides occur?

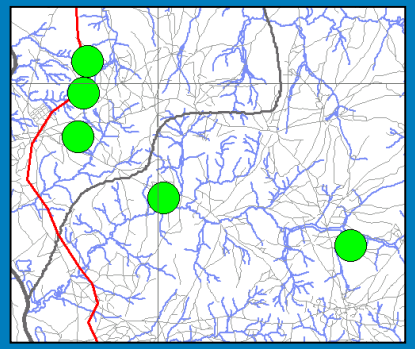
Where do erosion gullies form?

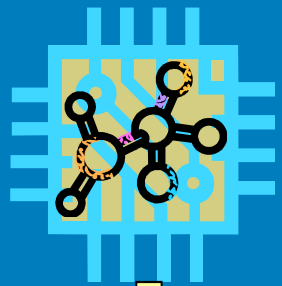


Modern Approach Using Artificial Intelligence







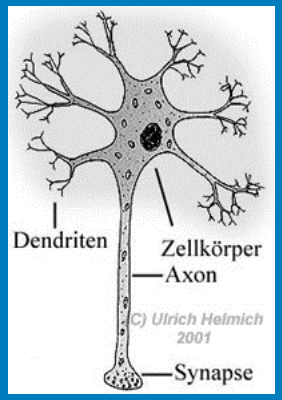


The artificial neuronal network "replaces" the experts empirical data analysis

Pre-Processing

Validation

Definition: Artificial Neural Networks

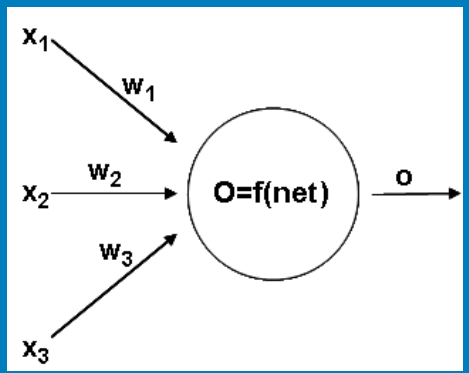


Model: Neuron Cell

- Functionality as a biological neural system
- Consists of artificial neuron cells
- Simulation of biological processes of neurons by use of suitable mathematical operations
- In most cases layer-like configuration of the neurons

The Neuron Cell as a Processor

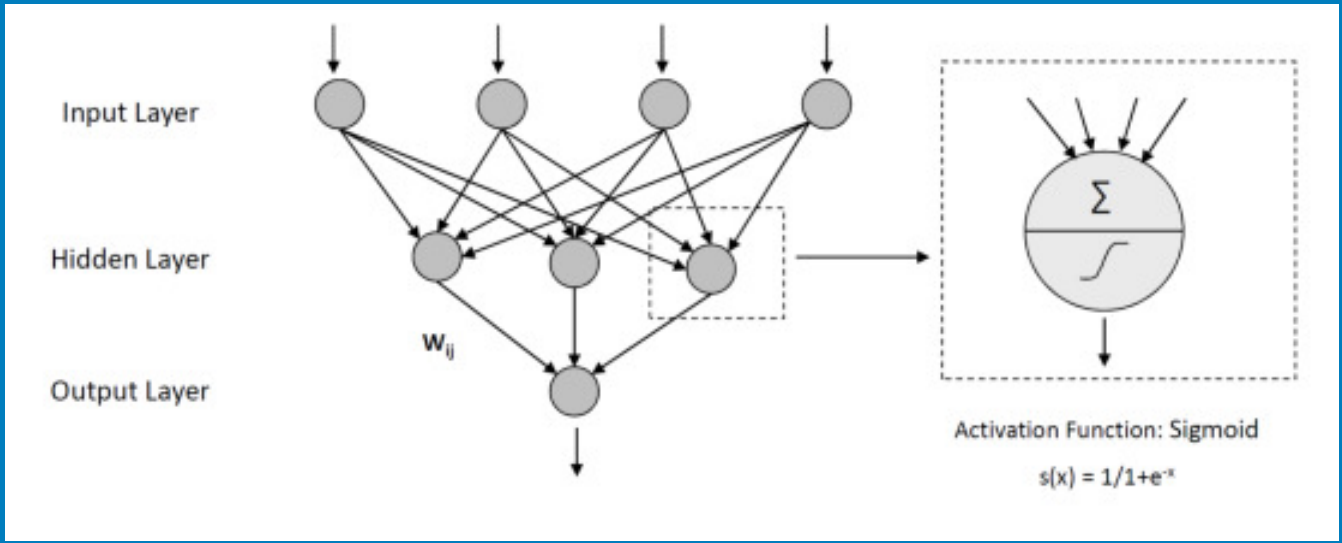
- **Connection between the neurons by weights w**
  - Enforce or reduce the level of the input information
  - Are directed, can be trained
- **Input signals**
  - Re-computed to a single input information: the propagation function
- **Output signals**
  - Activation function computes the output status of a neuron (often used: Sigmoid function)



Principle Setup of Artificial Neural Networks

Network Topology: MLP (Multi Layer Perceptron)

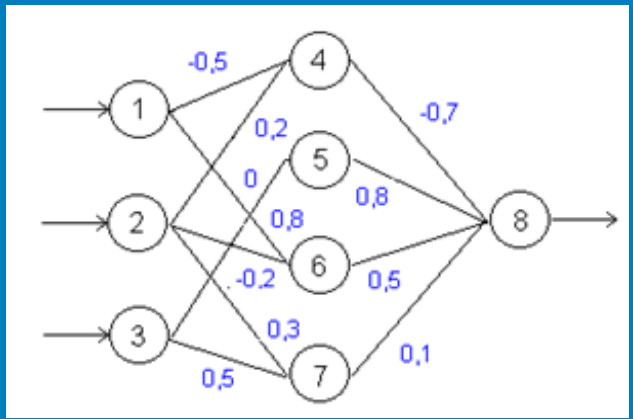
- Set-up of neurons in layers
- Direction and degree of connections
- Amount of hidden layers and neurons

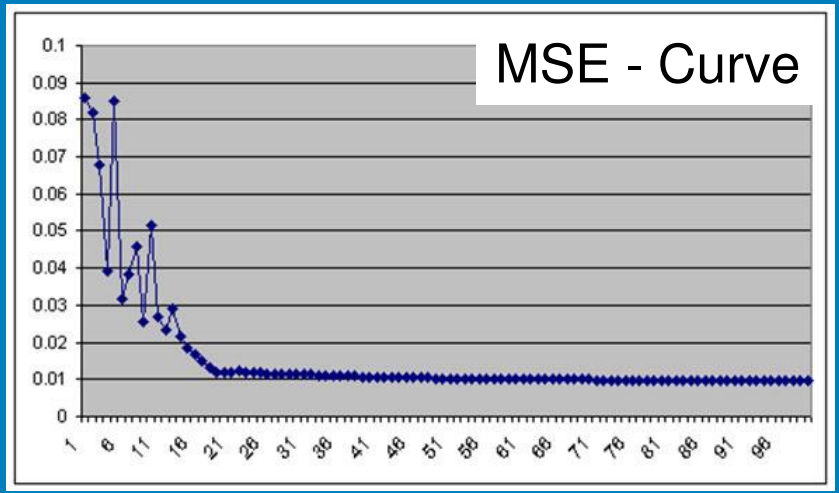


Training of Artificial Neural Networks

Learning Algorithm: Back-Propagation

- Repeated input of training data
- Modification of weights w
- Reduces error between expected and actual output of the network





Characteristics of Artificial Neural Networks

Advantages:

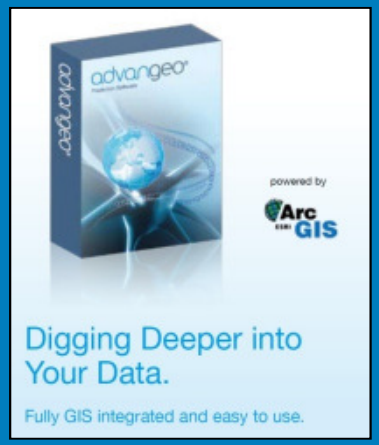
- ***learnable***: learning from examples
- ***generalization***: able to solve similar problems that have not been trained yet
- ***universal***: prediction, classification, pattern recognition
- able to analyze complex, ***non-linear*** relationships
- ***fault-tolerant*** against noisy data (e.g. face recognition)
- ***quick***

Additional characteristics:

- choice of ***topology*** and ***training algorithm***
- ***black box system***: evaluation of weight of parameters

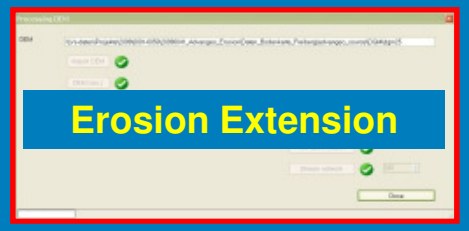
Software: advangeo

- **Easy Access** to Methods of Artificial Intelligence for Spatial Prediction
- **Documentation** of Working Steps
- Capture and Management of **Metadata** for Geodata
- **Tools** for Data Pre-Processing, Post-Processing and Cartographic Presentation
- **Integration** into Standard ESRI ArcGIS-Software



advangeo®
Prediction Software

Software Components



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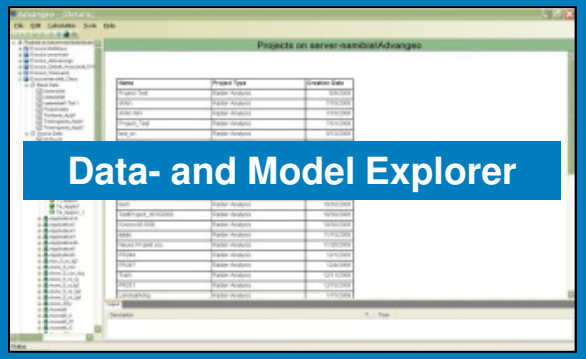
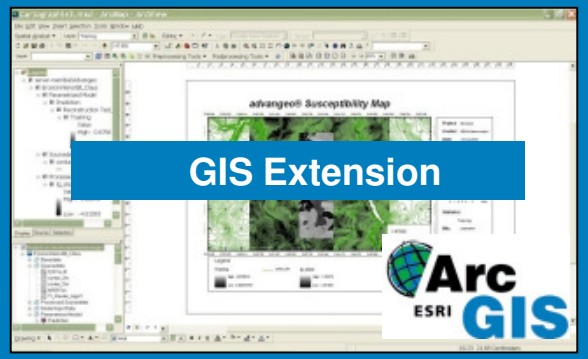
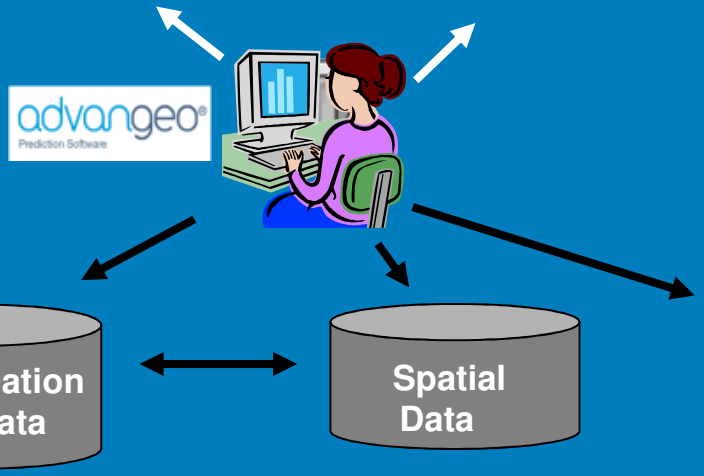
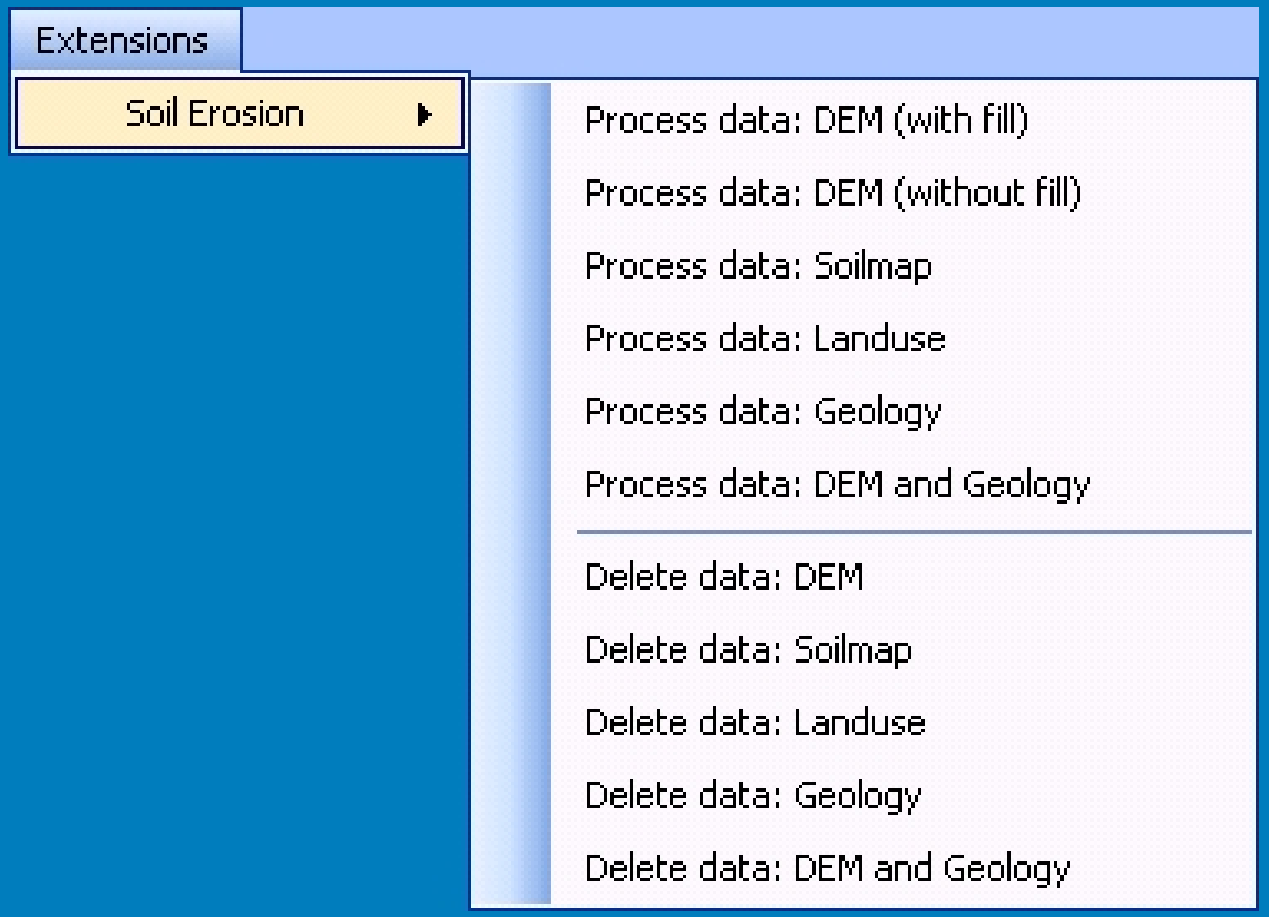






advangeo: Erosion Extension with Pre-Processing Tools

- **Soil Erosion Toolbar:** Overview



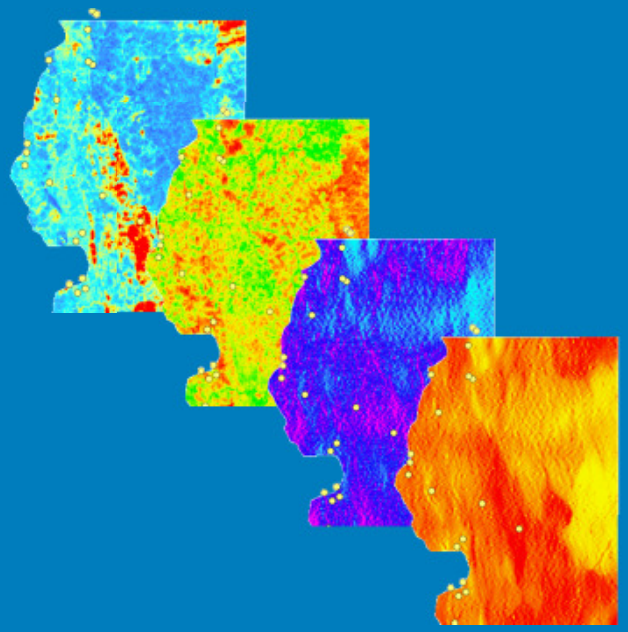
Case Study 1 - *Mineral Deposits*: Gold (Ghana)

Where are Au-Deposits located ?

Modelling by:
Solomon Anum

Case Study 1 - *Mineral Deposits*: Gold (Ghana)

Input Data:
Airborne Geophysics: U, Th, K, Total, Magnetics
Distance to Tectonic Structures
Intersections of Tectonic Structures
Rock Type from Geology
Important Rock Contacts



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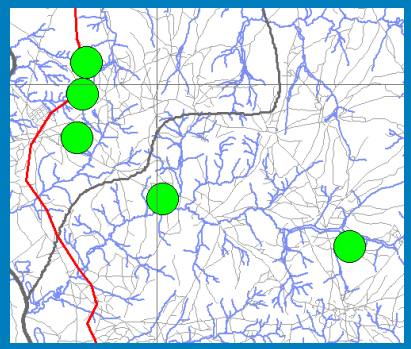
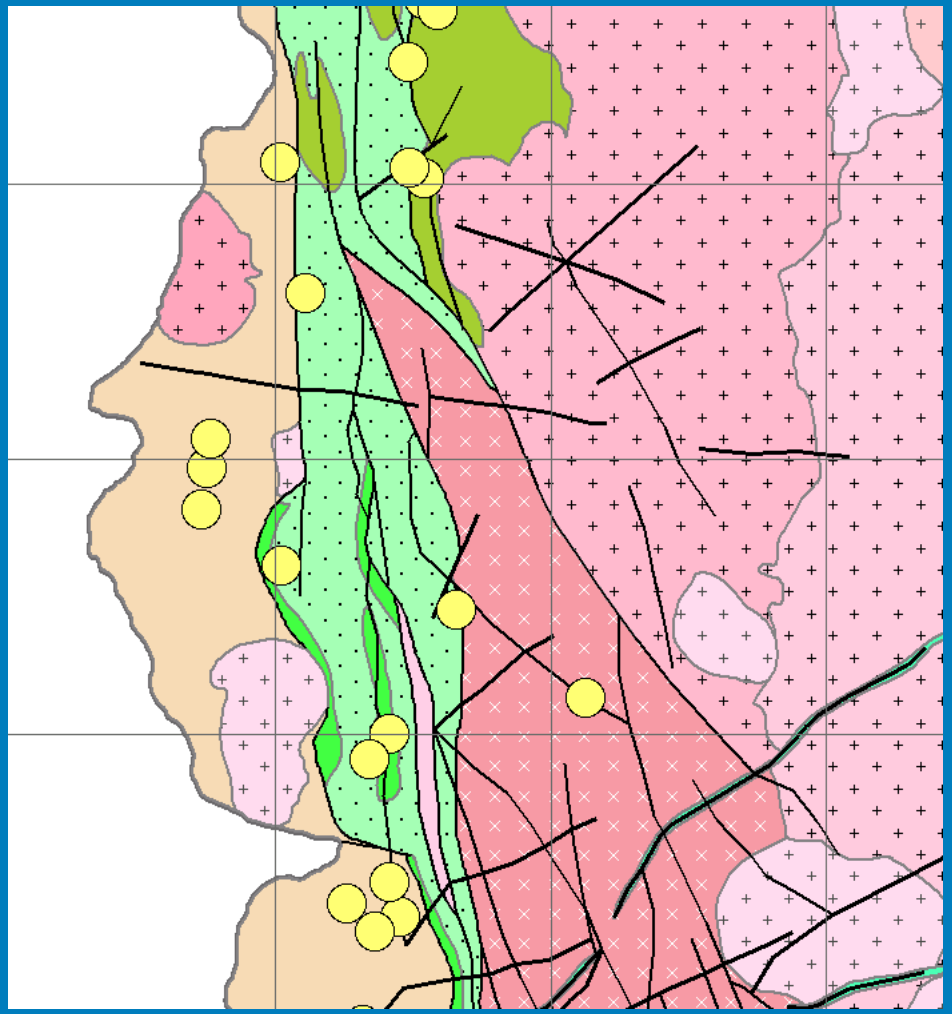
Prediction Software

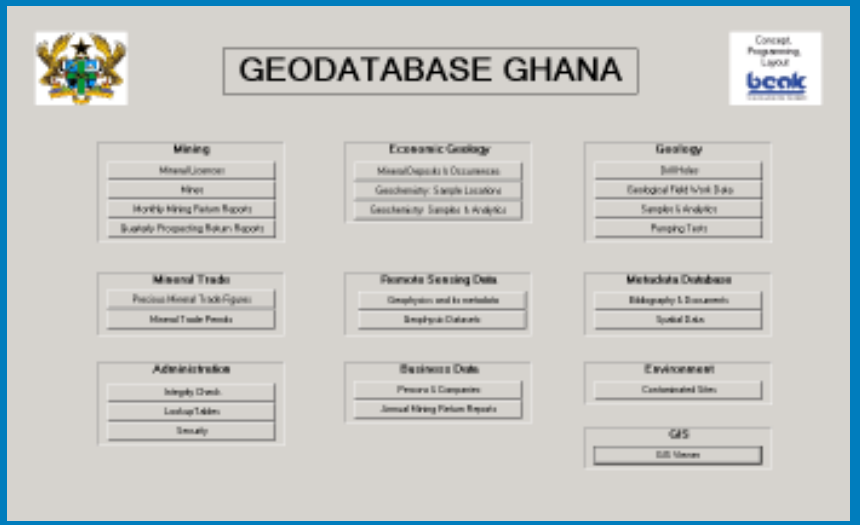
Trainings Data:
Known
Mineralisations



Case Study 1 - *Mineral Deposits*: Gold (Ghana)

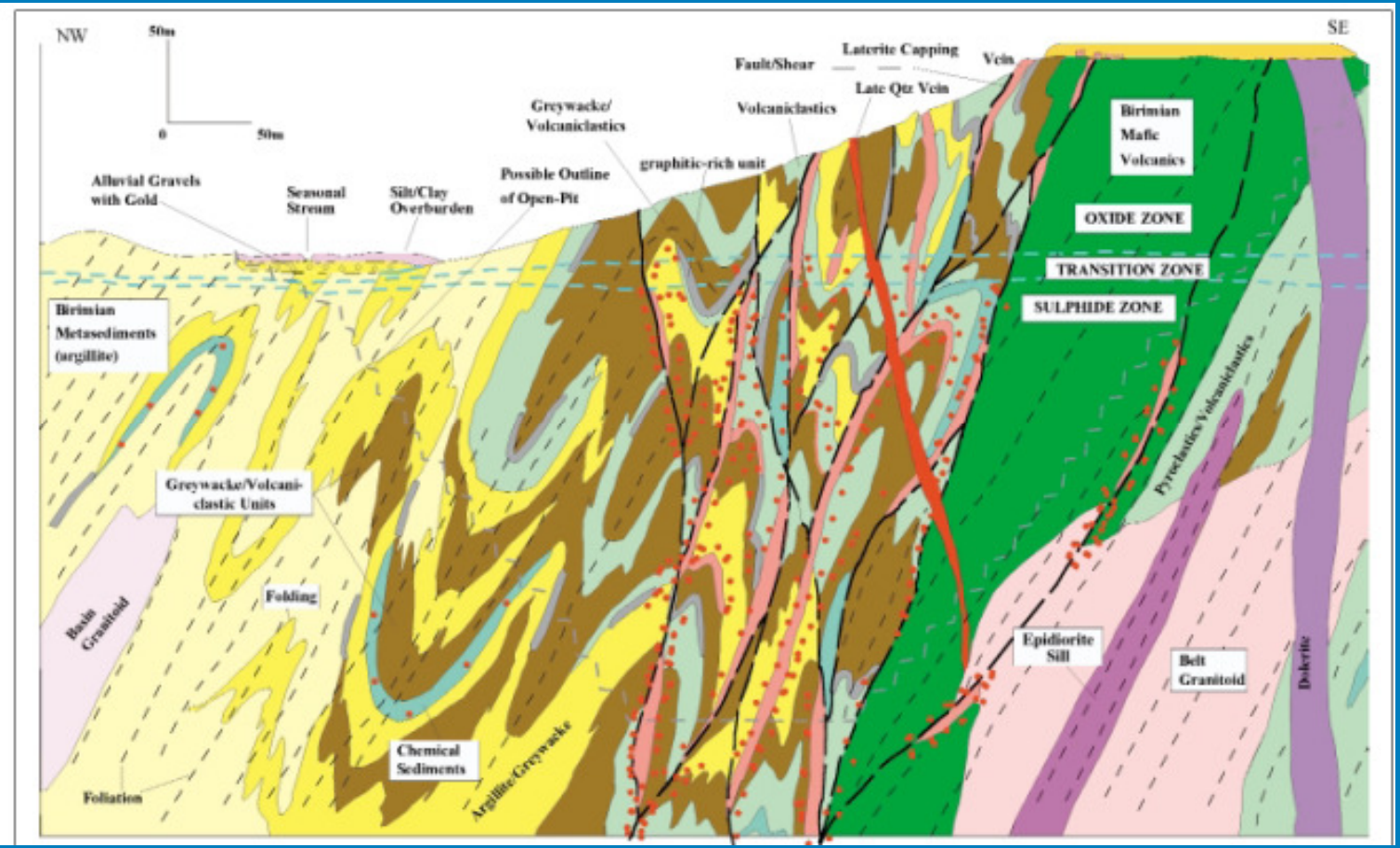


Training Data:
Known Deposits and Occurrence
From Geodatabase Ghana



Case Study 1 - *Mineral Deposits*: Gold (Ghana)

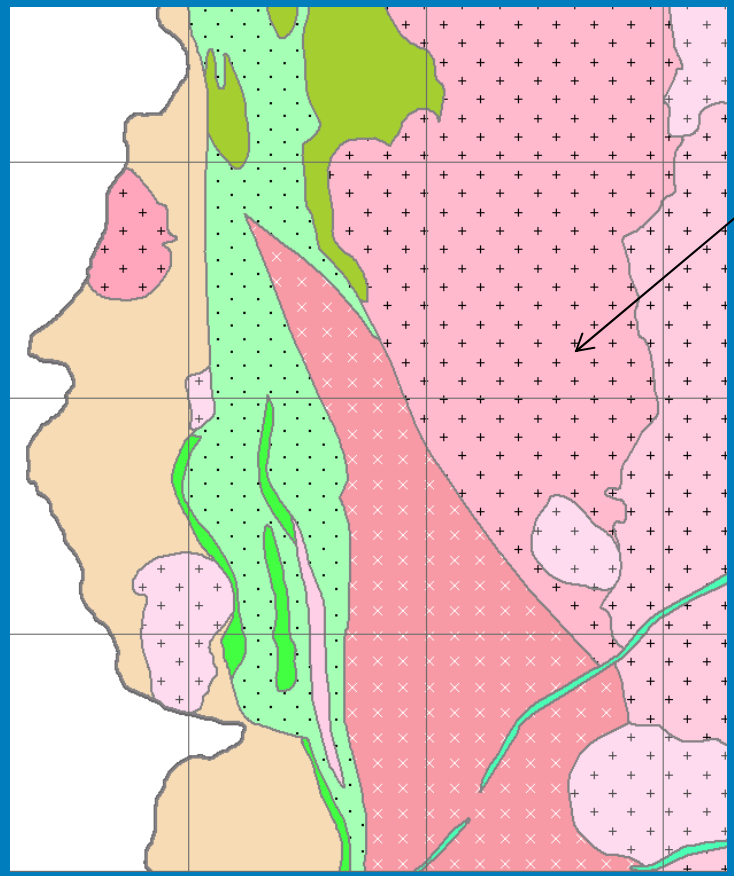
Knowledge: Existing Deposit Model

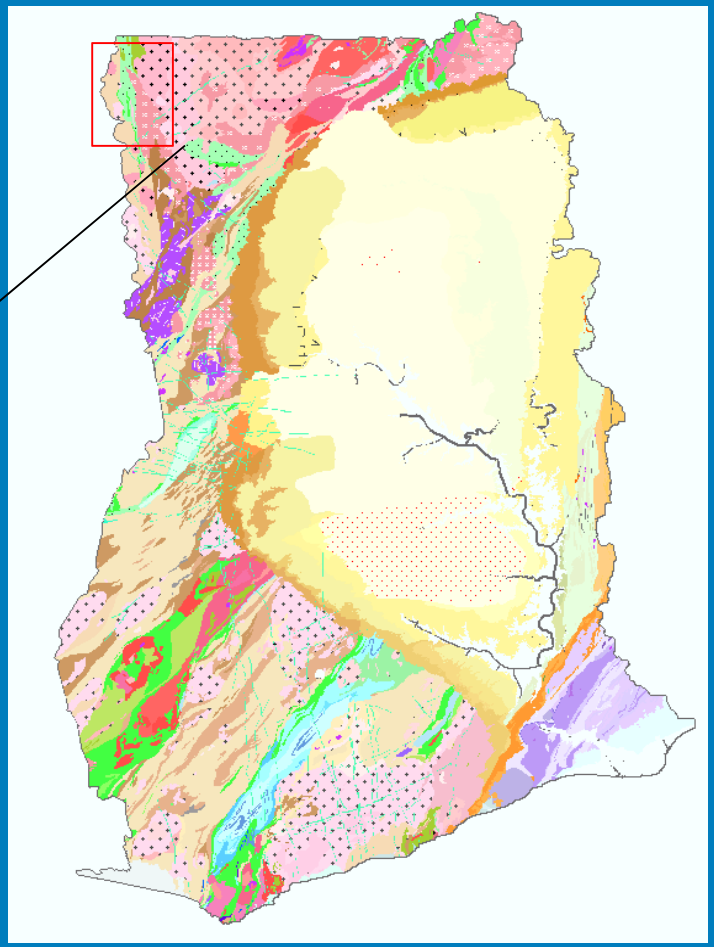


Source: Gold deposits of Ghana, Minerals Commission, Ghana, ROBERT J. GRIFFIS, KWASI BARNING, FRANCIS L. AGEZO, FRED K. AKOSAH, 2002

Case Study 1 - *Mineral Deposits*: Gold (Ghana)

Input Data:
Geological Map 1:1.000.000



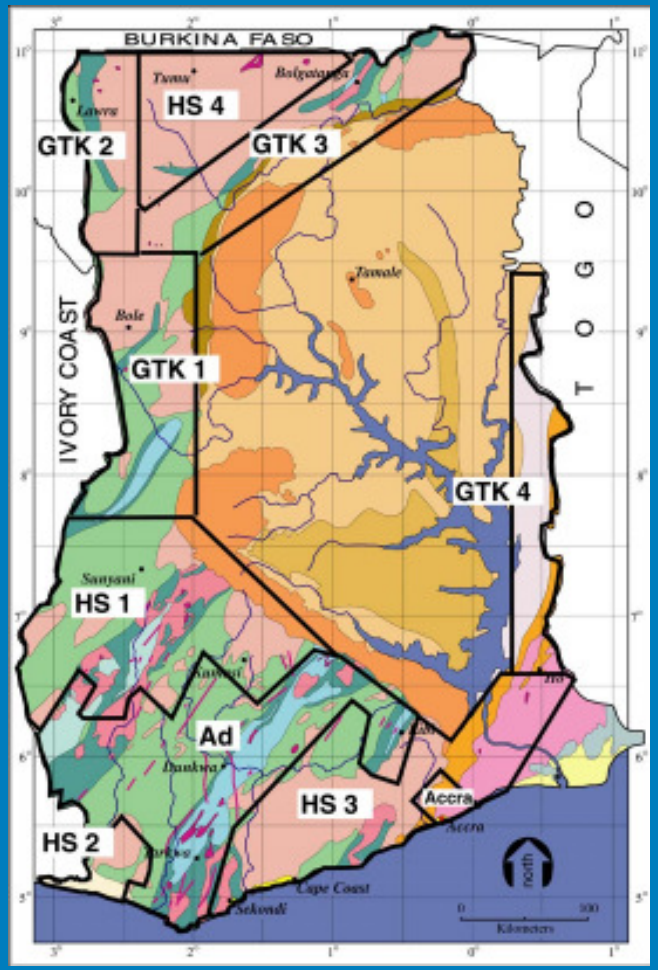


Source: Geological Map of Ghana, 2010
Geological Survey Department, Ghana
Bundesanstalt für Geowissenschaften und Rohstoffe, Germany

Case Study 1 - *Mineral Deposits*: Gold (Ghana)

Input Data:
Airborne Geophysical Data

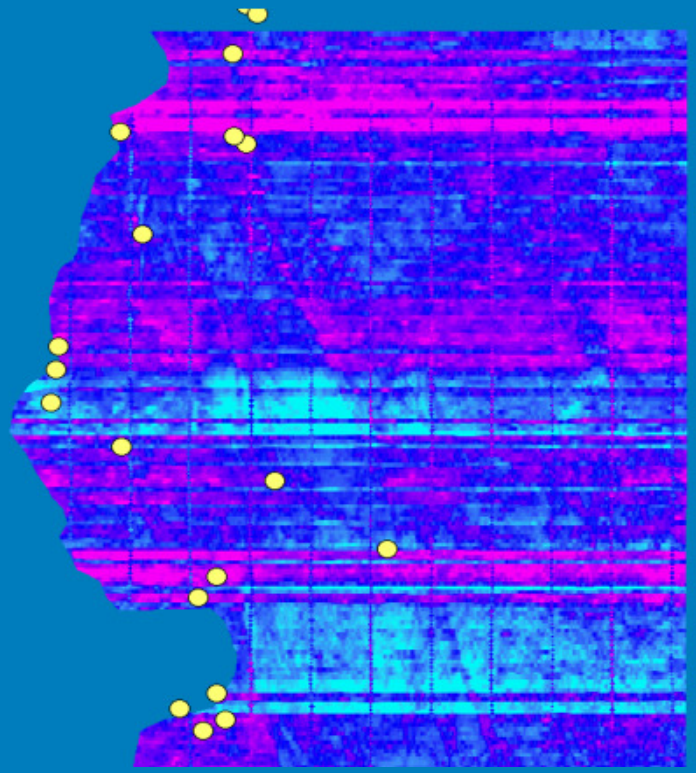
- Between 1996 and 1998, the World Bank/ Nordic Development Fund sponsored the Mining Sector Development and Environment Project.
- The EU funded MSSP has covered the Volta and Keta basins



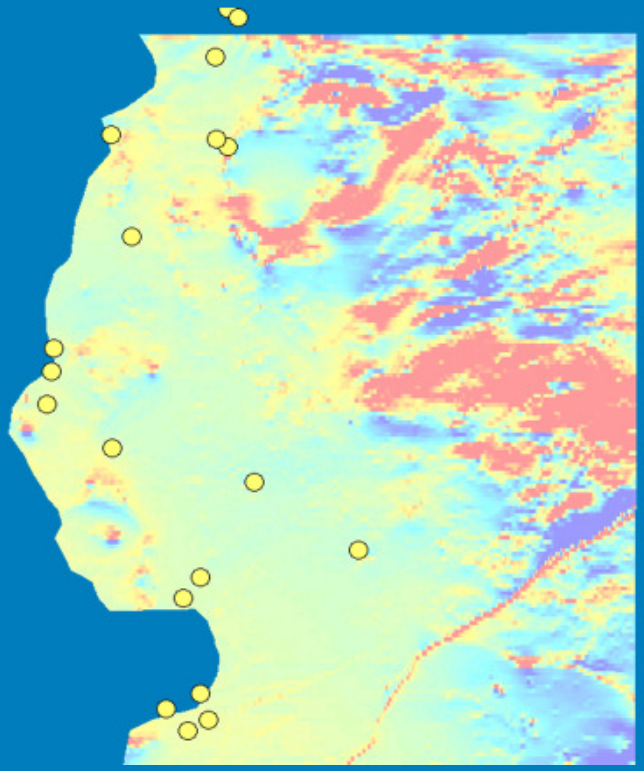
Source: Geological Survey Department of Ghana

Case Study 1 - *Mineral Deposits*: Gold (Ghana)

Input Data:
Airborne Geophysical Survey - Electromagnetic



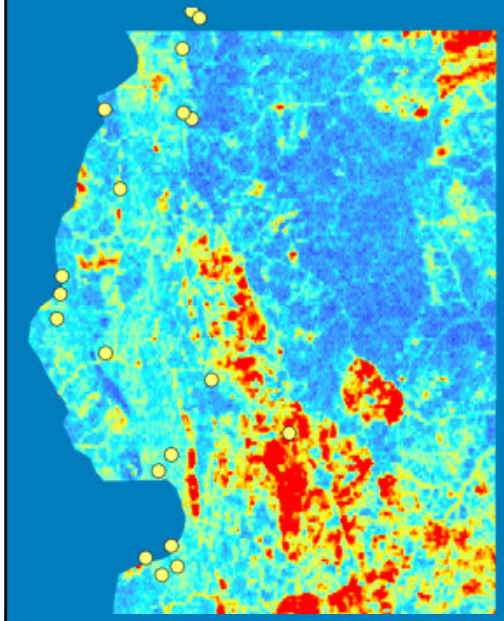
Input Data:
Airborne Geophysical Survey – Magnetic



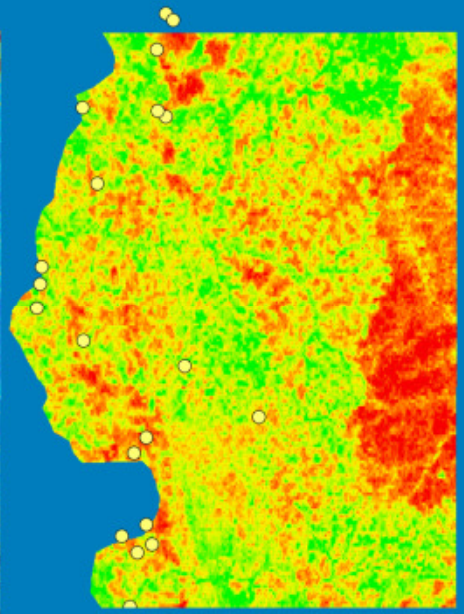
Source: Geological Survey Department of Ghana

Case Study 1 - *Mineral Deposits*: Gold (Ghana)

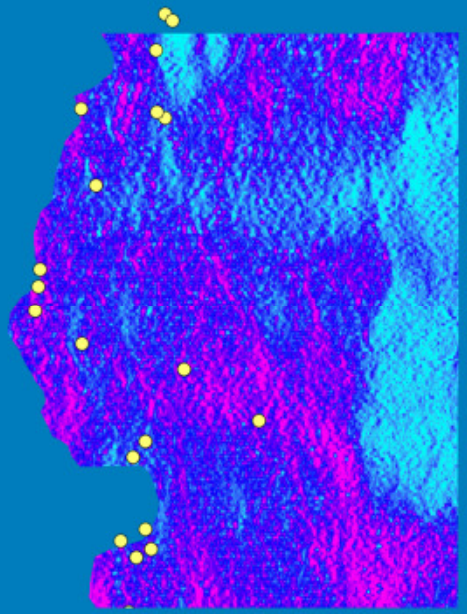
Input Data:
Airborne Geophysical Survey - Radiometric



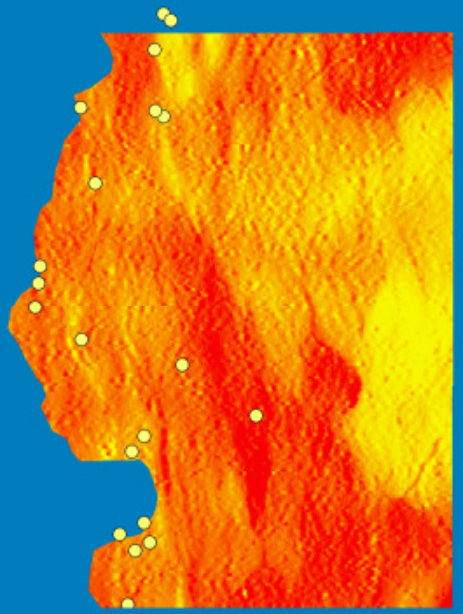
Potassium



Thorium



Uranium

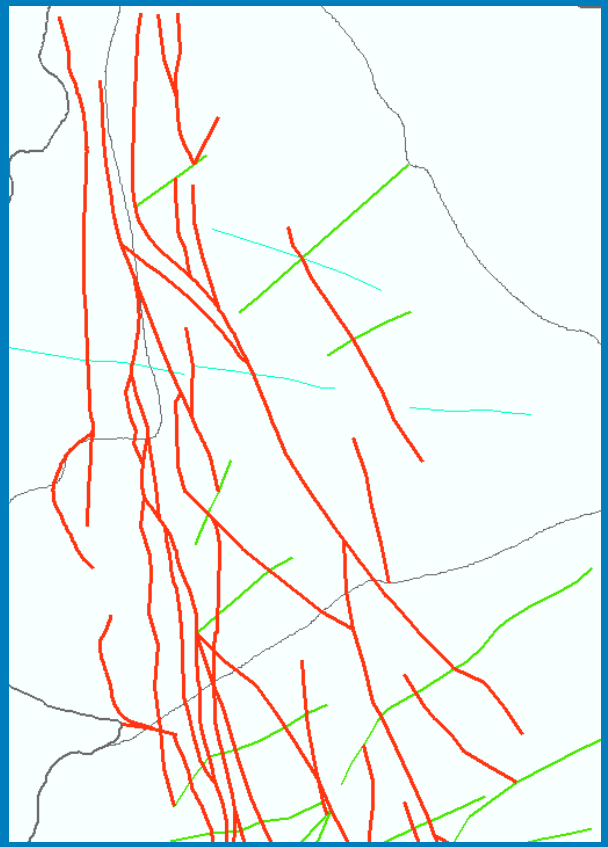


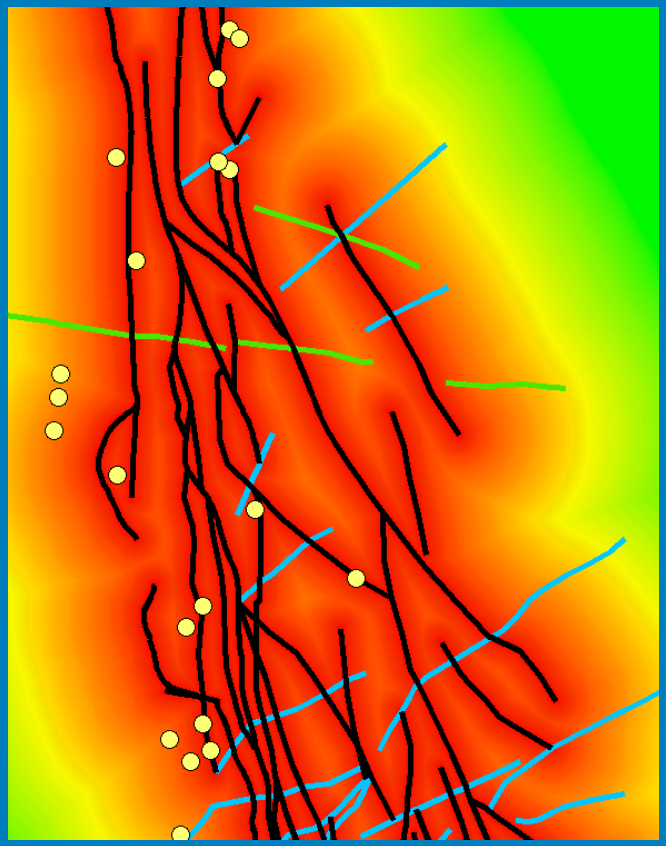
Total

Source: Geological Survey Department of Ghana

Case Study 1 - *Mineral Deposits*: Gold (Ghana)

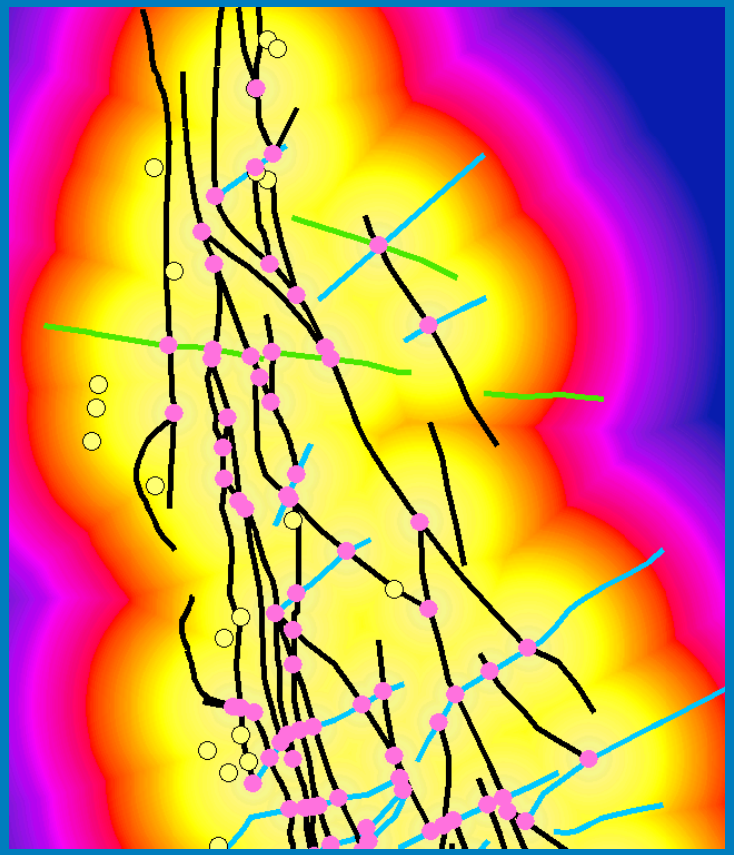
Input Data:
Euclidian Distance to Faults



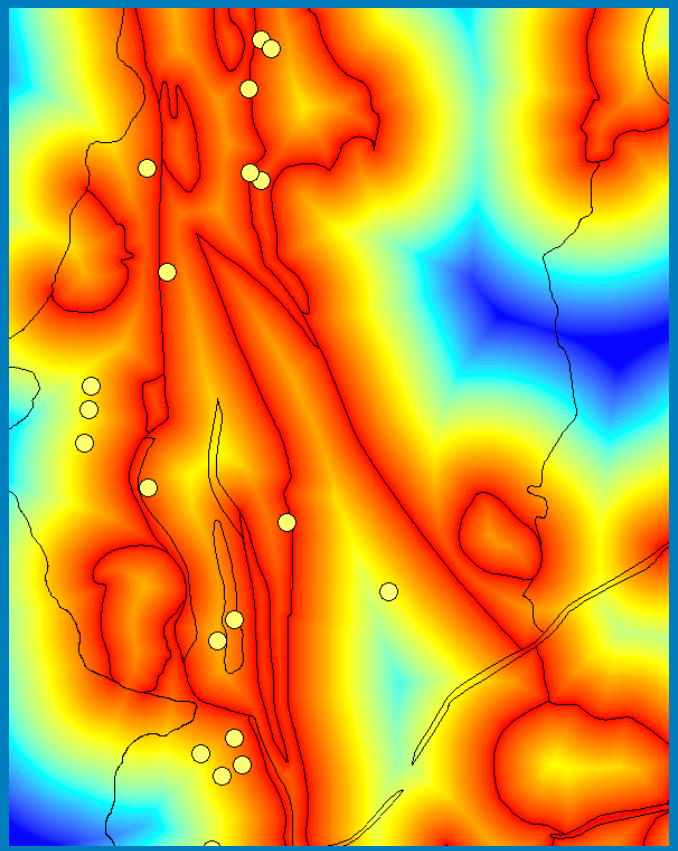


Case Study 1 - *Mineral Deposits*: Gold (Ghana)

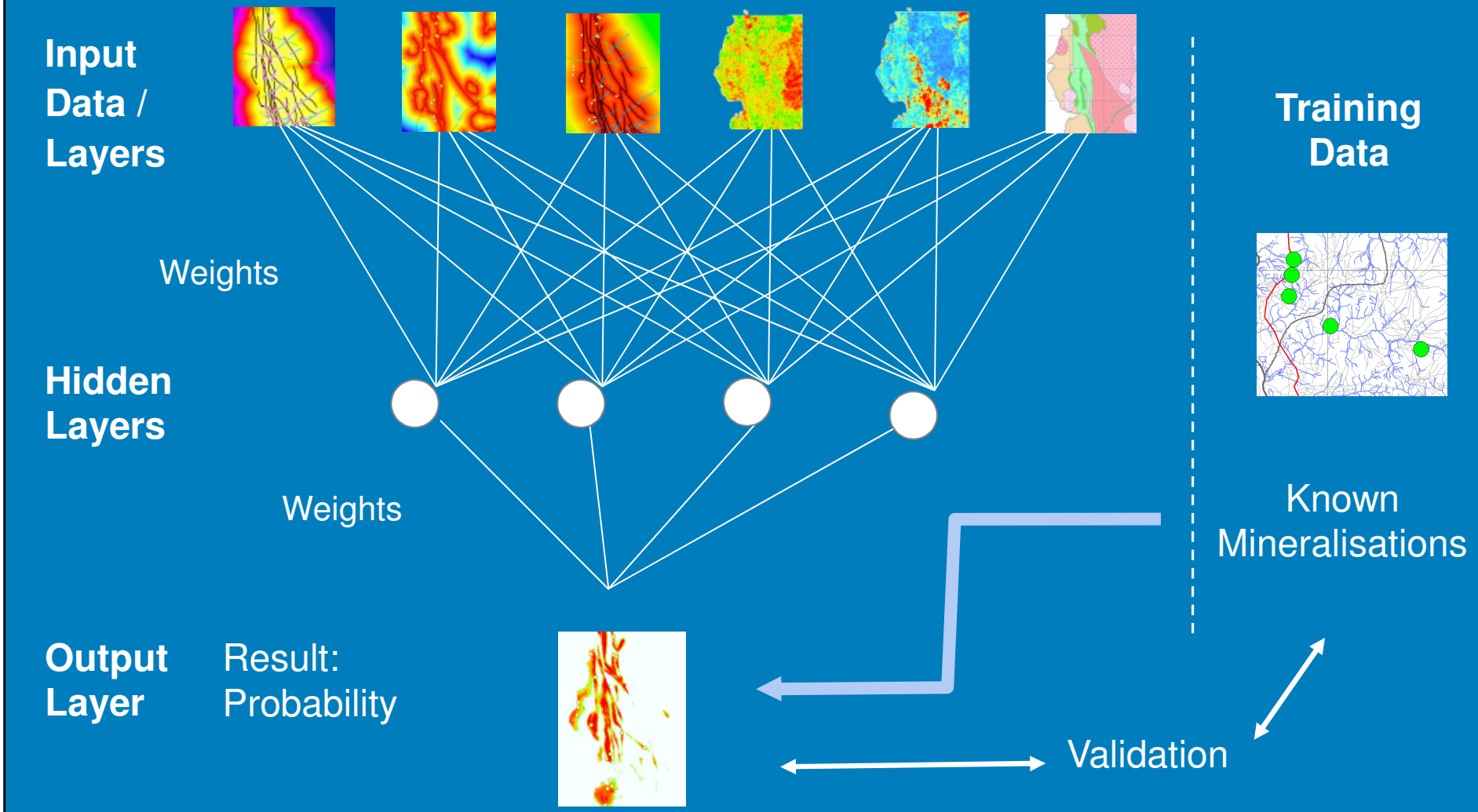
Input Data:
Euclidian distance to tectonic intersections



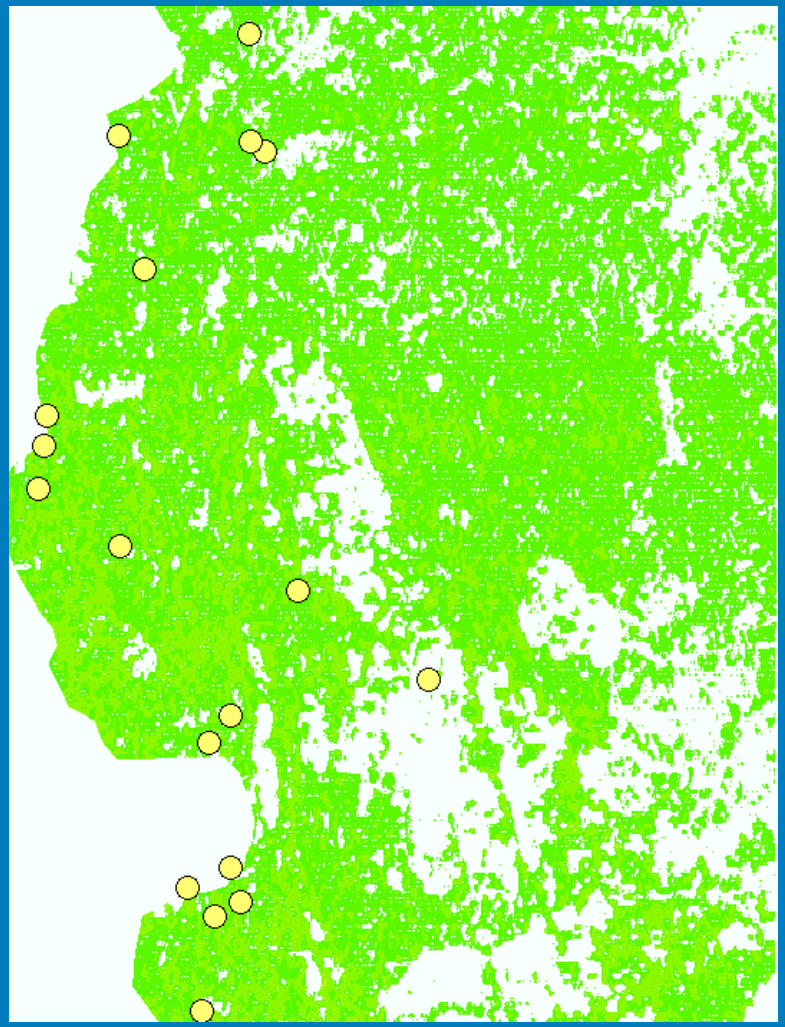
Input Data:
Euclidian distance to important rock contacts



Case Study 1 - *Mineral Deposits*: Gold (Ghana)



Case Study 1 - *Mineral Deposits*: Gold (Ghana)



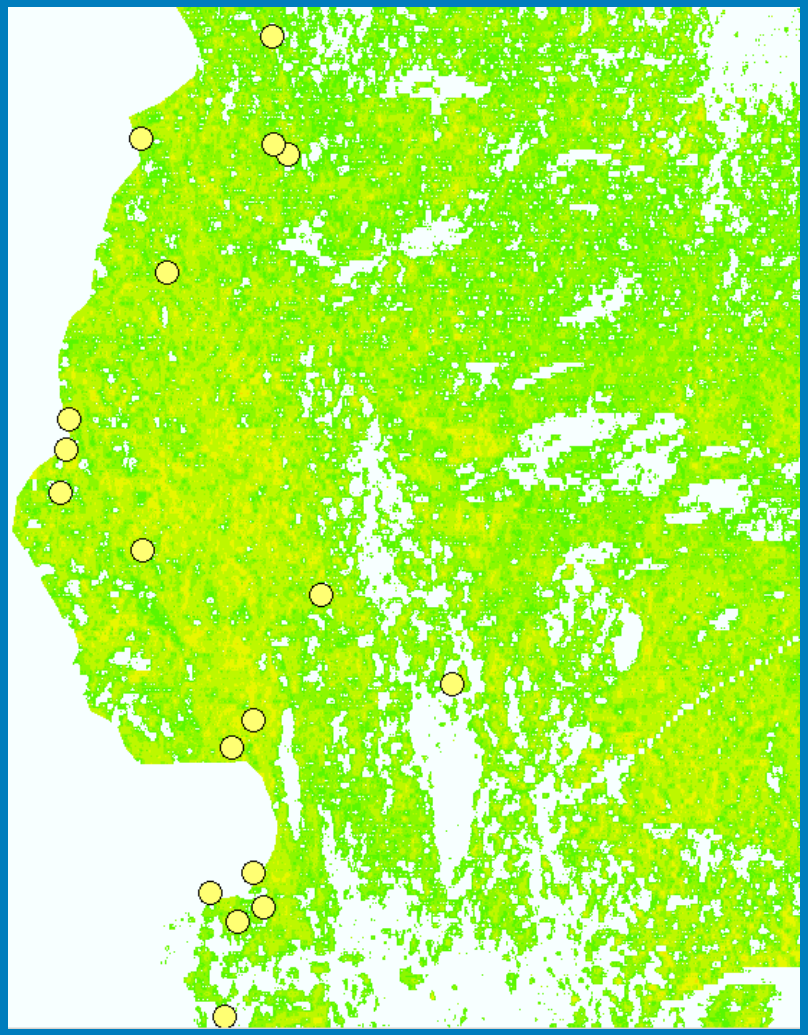
Model 1
Radiometric (U, Th, K, total)

Known Gold Occurrences

Probability for gold mineralisations

- 0.5 - 0.55
- 0.55 - 0.6
- 0.6 - 0.65
- 0.65 - 0.7
- 0.7 - 0.75
- 0.75 - 0.8
- 0.8 - 0.85
- 0.85 - 0.9
- 0.9 - 0.95

Case Study 1 - *Mineral Deposits*: Gold (Ghana)



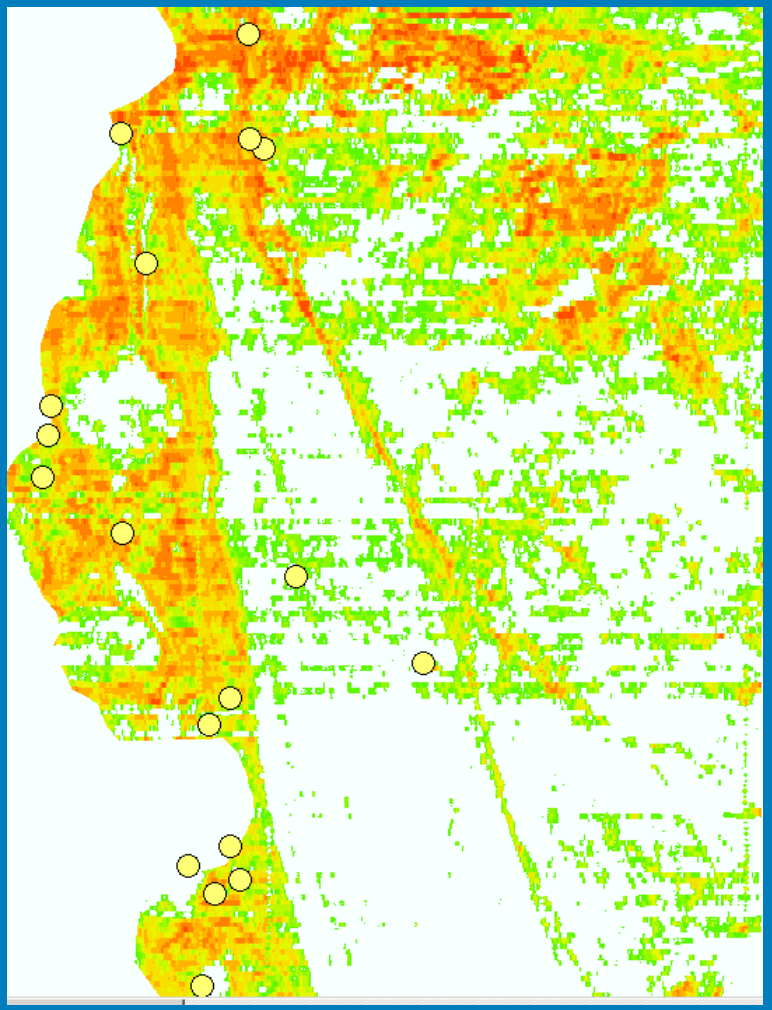
Model 2
Radiometric (U, Th, K, total)
Magnetics

Known Gold Occurrences

Probability for gold mineralisations

0.5 - 0.55	0.75 - 0.8
0.55 - 0.6	0.8 - 0.85
0.6 - 0.65	0.85 - 0.9
0.65 - 0.7	0.9 - 0.95
0.7 - 0.75	

Case Study 1 - *Mineral Deposits*: Gold (Ghana)



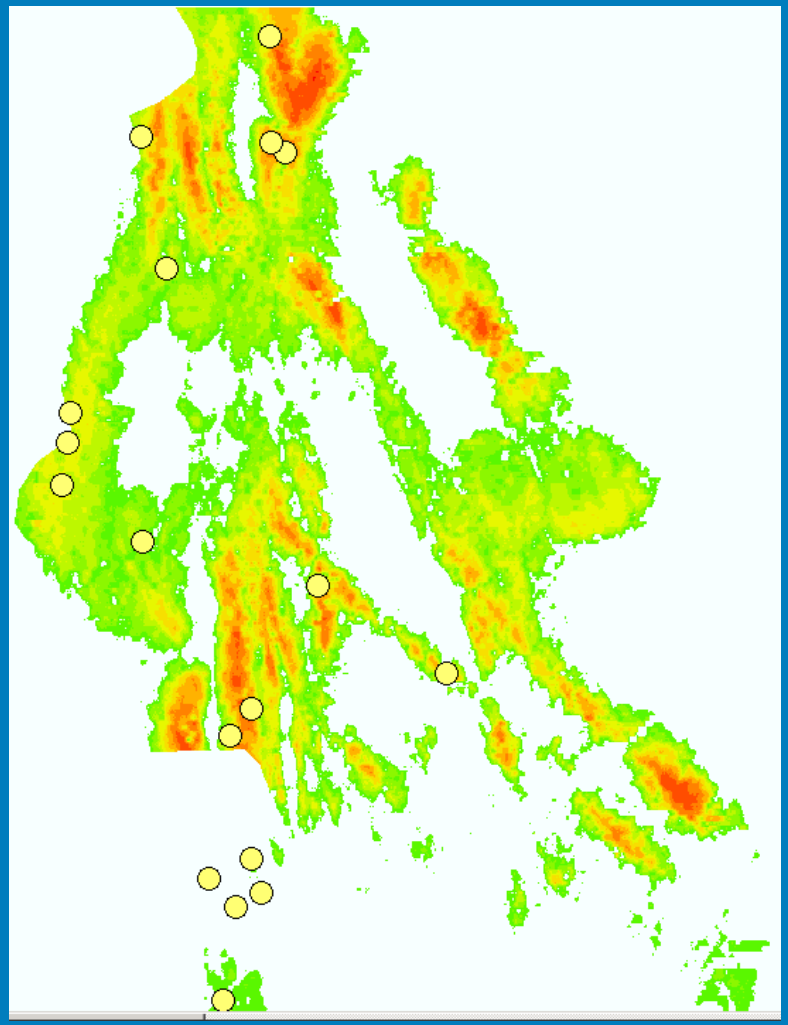
Model 3
Radiometric (U, Th, K, total)
Magnetics
Electromagnetics

Known Gold Occurrences

Probability for gold mineralisations

0.5 - 0.55	0.75 - 0.8
0.55 - 0.6	0.8 - 0.85
0.6 - 0.65	0.85 - 0.9
0.65 - 0.7	0.9 - 0.95
0.7 - 0.75	

Case Study 1 - *Mineral Deposits*: Gold (Ghana)



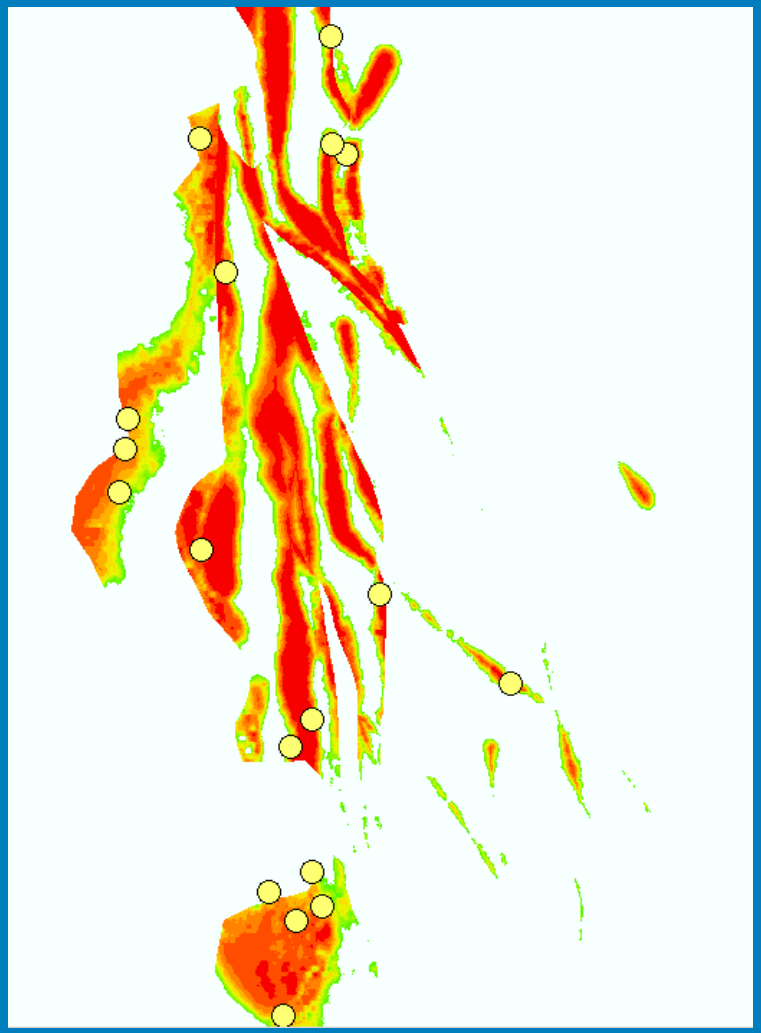
Model 4
Radiometric (U, Th, K, total)
Magnetics
Tectonic structures

Known Gold Occurrences

Probability for gold mineralisations

0.5 - 0.55	0.75 - 0.8
0.55 - 0.6	0.8 - 0.85
0.6 - 0.65	0.85 - 0.9
0.65 - 0.7	0.9 - 0.95
0.7 - 0.75	

Case Study 1 - *Mineral Deposits*: Gold (Ghana)



Model 5 - FINAL

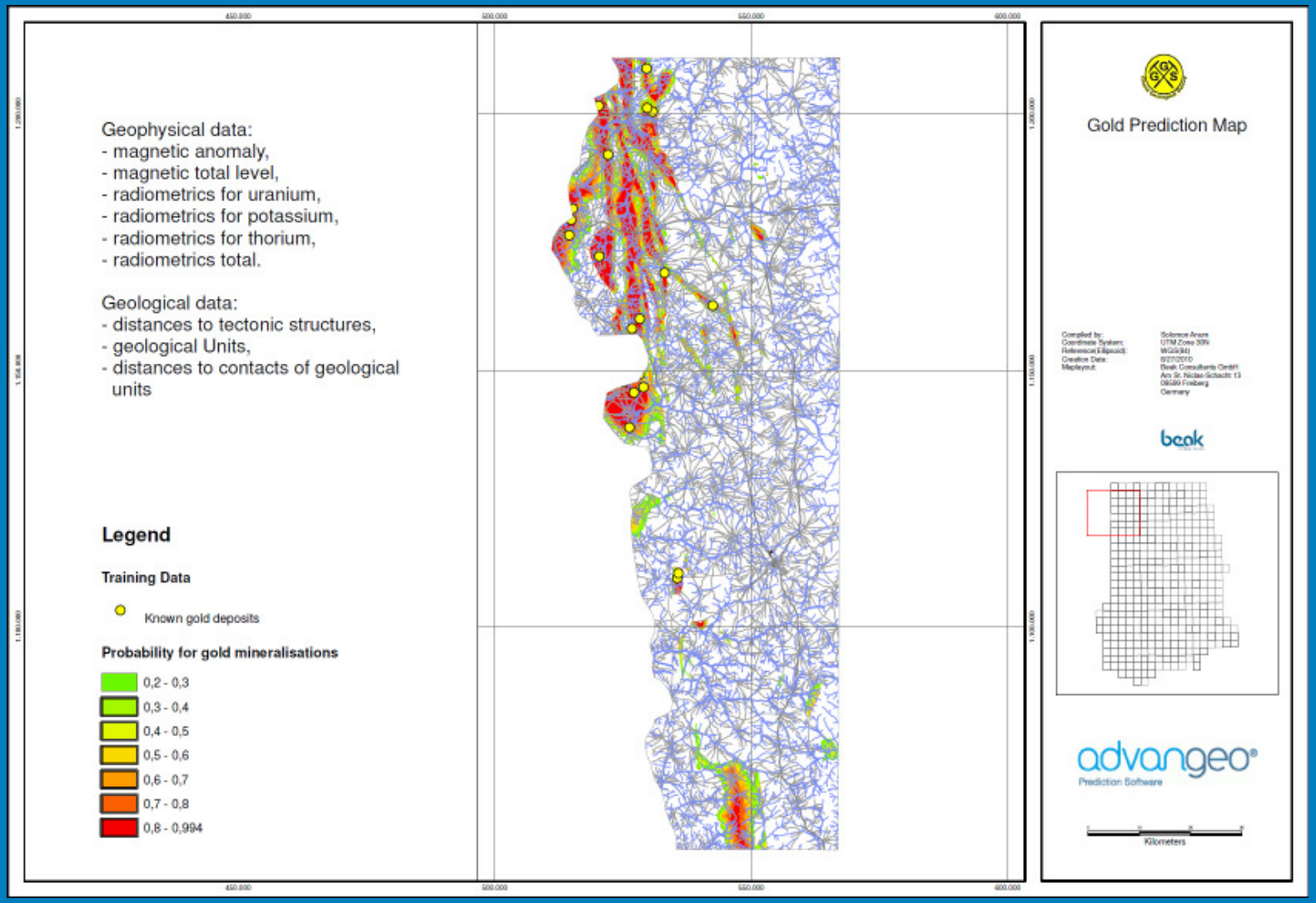
Radiometric (U, Th, K, total)
Magnetics
Tectonic structures
Rocks
Intersections of tectonic structures
Rock contacts

Known Gold Occurrences

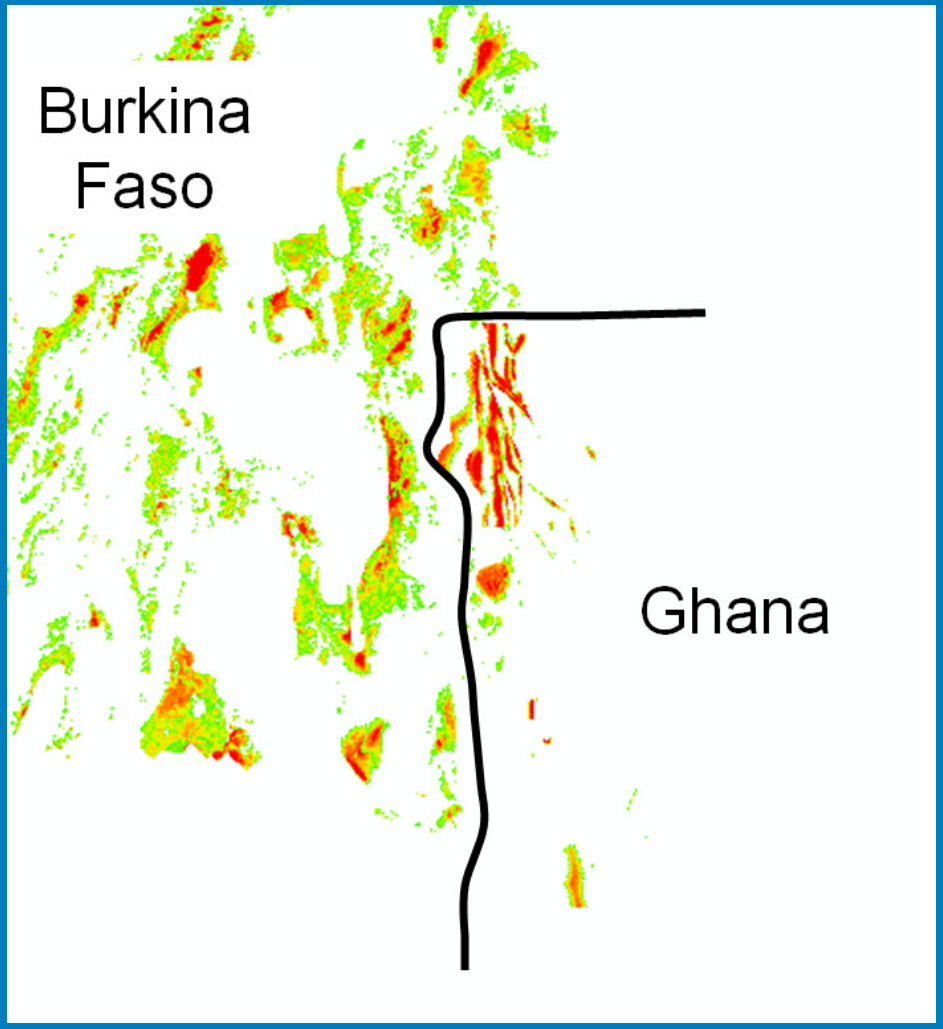
Probability for gold mineralisations

- 0.5 - 0.55
- 0.55 - 0.6
- 0.6 - 0.65
- 0.65 - 0.7
- 0.7 - 0.75
- 0.75 - 0.8
- 0.8 - 0.85
- 0.85 - 0.9
- 0.9 - 0.95

Case Study 1 - *Mineral Deposits*: Gold (Ghana)



Case Study 1 - *Mineral Deposits*: Gold (Ghana)



Burkina Faso prediction created by Vaclav Metelka

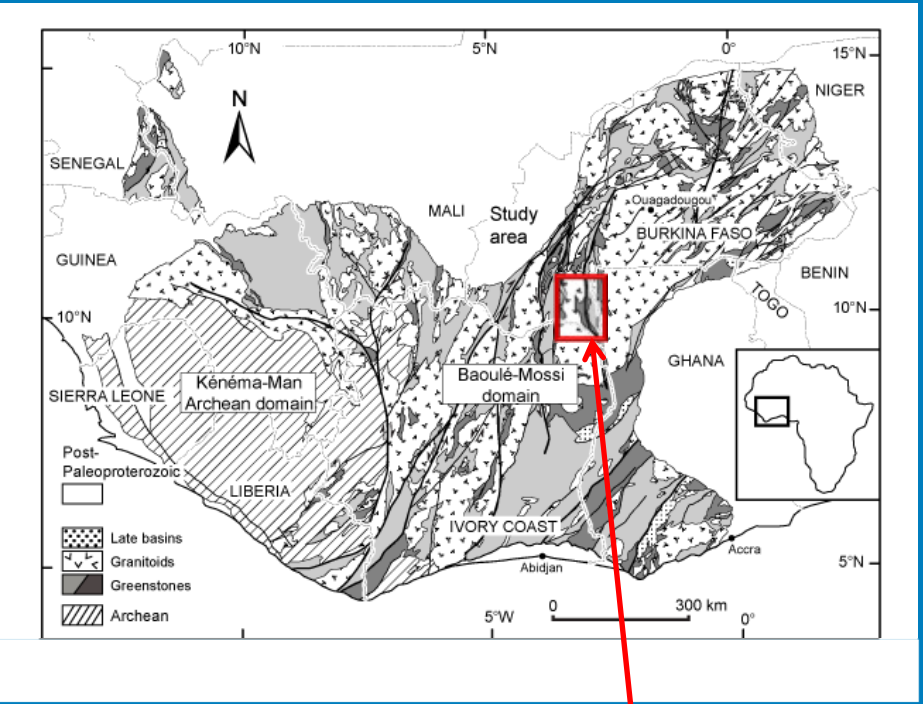
Case Study 2 – *Geological Mapping*: Regolith Landforms (Burkina Faso)

Regolith Landform Mapping

Modelling by:
Vaclav Metelka

Case Study 2 – *Geological Mapping*: Regolith Landforms (Burkina Faso)

Study Area: Western Burkina Faso



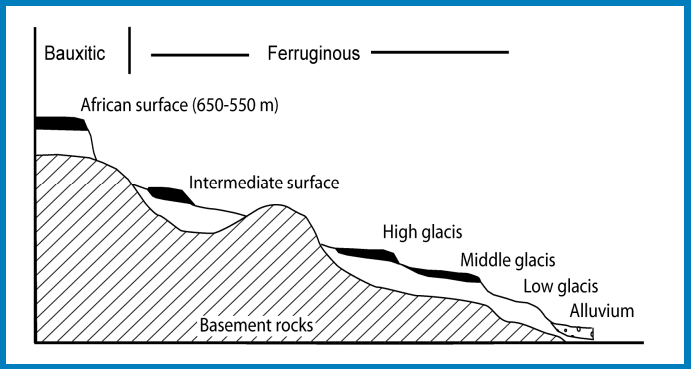
SIGAfrique (BRGM)

Gaoua area

Regolith Landform Units

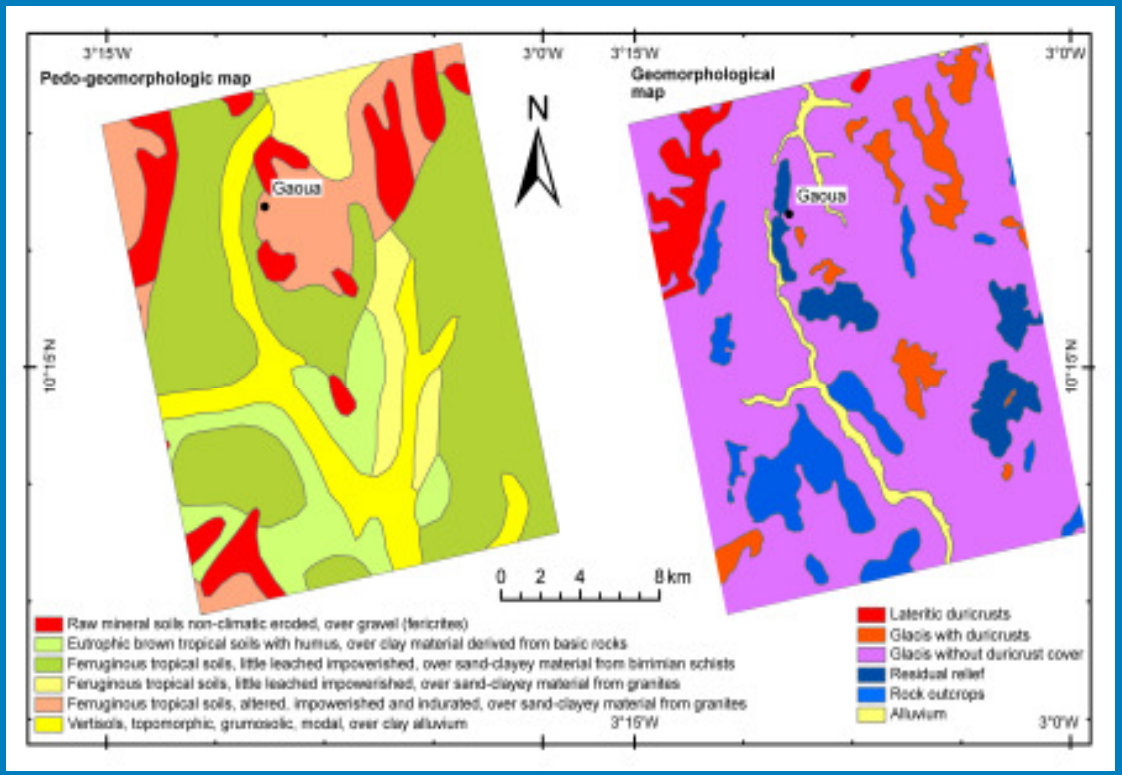
- High/Middle glacis
  → Ferruginous duricrusts
- Low glacis
  → without duricrust cover
- Residual relief
- Alluvial sediments

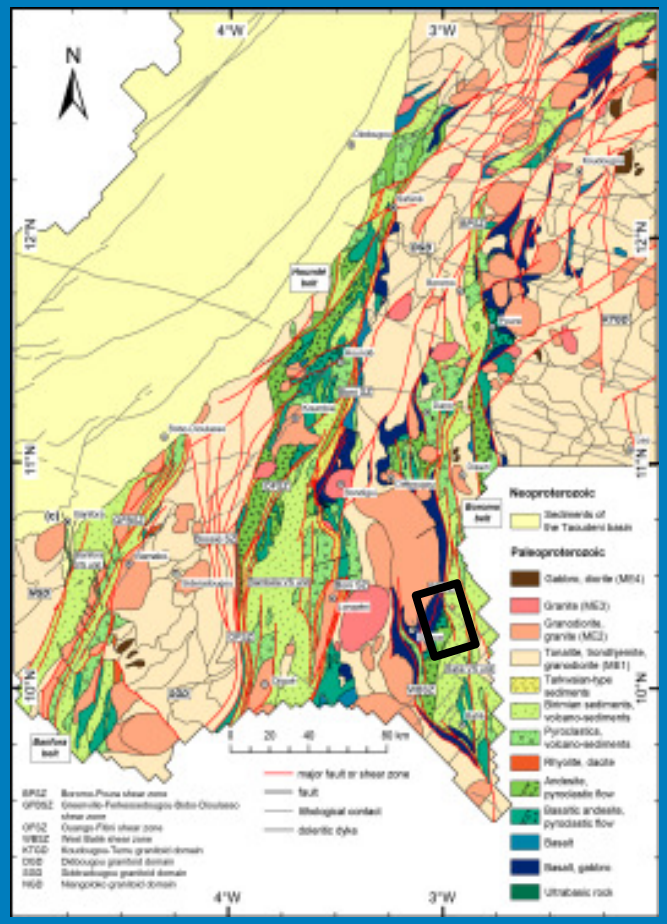
Regional Chronology of Laterites



Case Study 2 – *Geological Mapping*: Regolith Landforms (Burkina Faso)

Existing Maps:





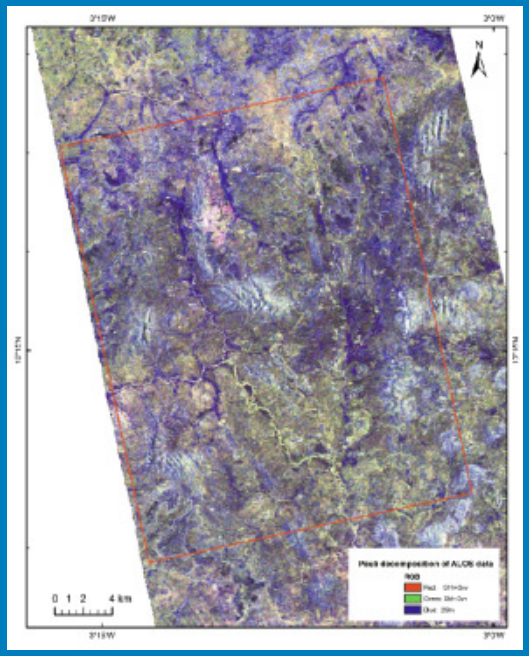
Geomorphological Map
1 : 500,000
IGB & IGN

Pedo-Geomorphological Map
1 : 500,000
IRD

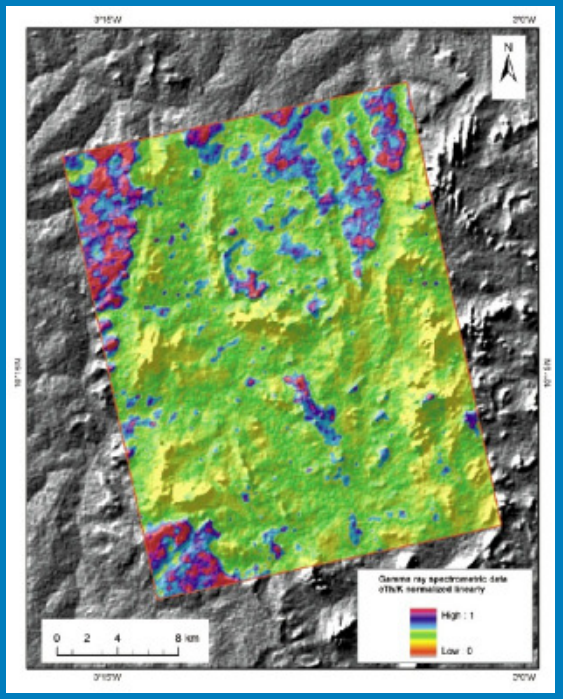
Case Study 2 – *Geological Mapping*: Regolith Landforms (Burkina Faso)

Input Data:

- Airborne geophysics: K, eTH, eU,
- Landsat 7 ETM+: 7 bands,
- ASTER: 14 bands,
- ALOS Palsar,
- Radarsat-2,
- SRTM-3: 90m DEM



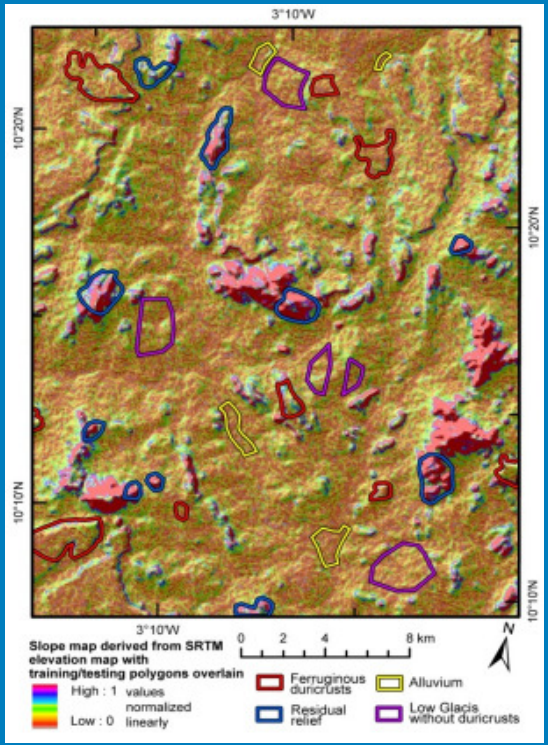
Gammaspektrometry & DEM



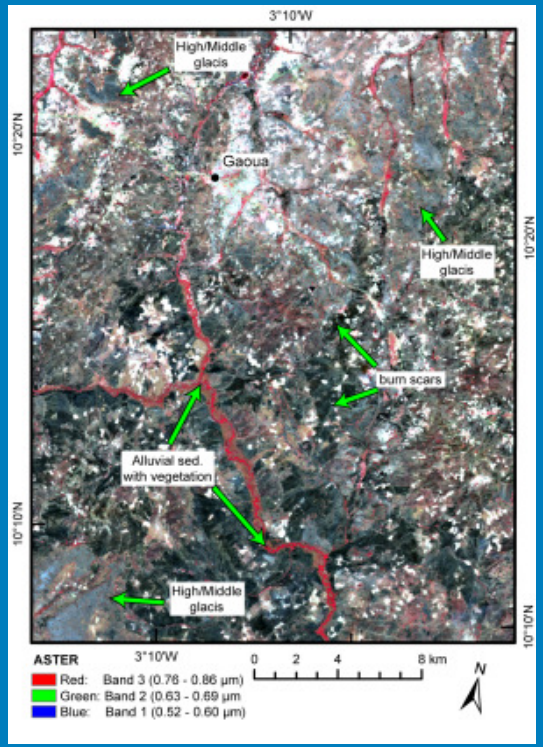
ALOS PALSAR – Pauli Dekomposition

Case Study 2 – *Geological Mapping*: Regolith Landforms (Burkina Faso)

Training Data:



Gamma-ray + DEM

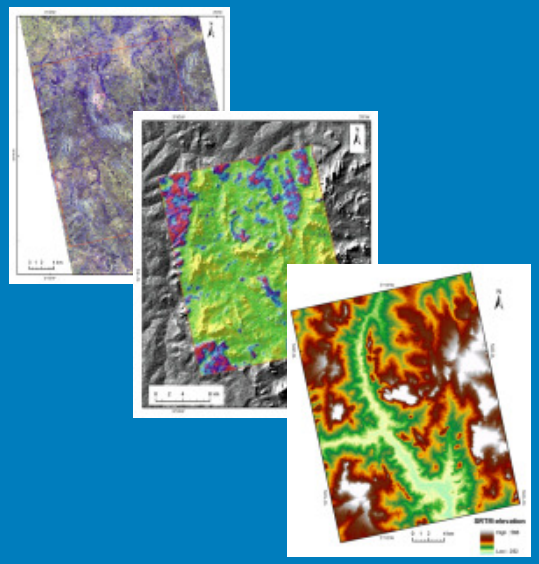


ASTER

Class	N. of Training pixels	N. of Testing pixels
High/Middle glacis	8665	8665
Residual relief	8447	8446
Alluvium	2719	2718
Low glacis	8395	8394

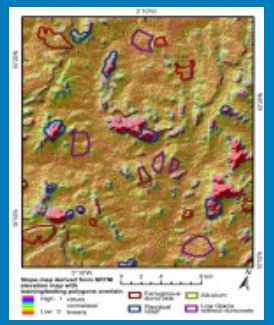
Case Study 2 – *Geological Mapping*: Regolith Landforms (Burkina Faso)

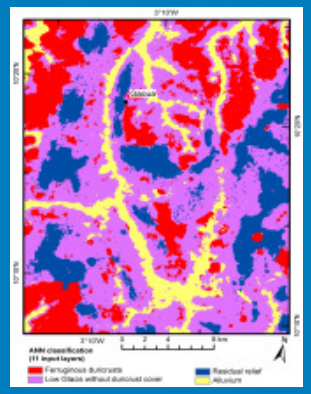
Input Data:
Geophysics: K, eU, eTh, eTh/K,
DEM: Elevation, Slope, Relief, Curvature
Pauli Decomposition: 6 bands
ALOS Palsar, Radarsat: 2 bands,
ASTER: 14 bands,
LANDSAT 7 bands



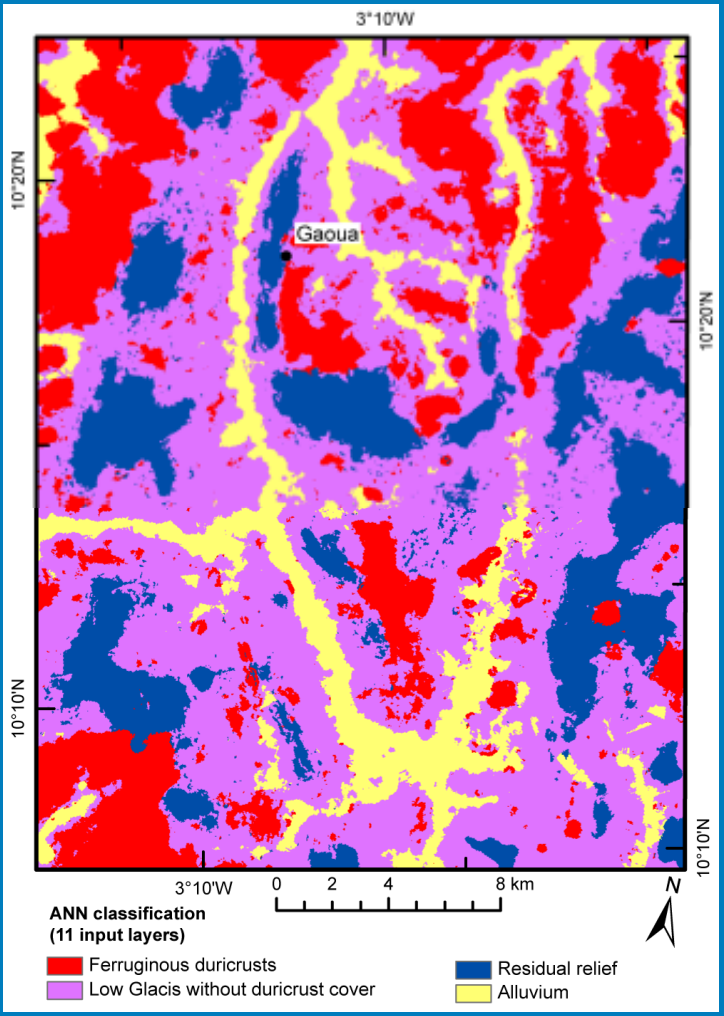
advangeo®
Prediction Software

Trainings Data:
Known Regolith
Landform Units





Case Study 2 – *Geological Mapping*: Regolith Landforms (Burkina Faso)



Results:
Confusion Matrix

Validation Class	Predicted class					
	High/ Mid. gl.	Res relief	Alluv.	Low glacis	Total	Prod. Acc. %
High/Mid. gl.	8377	17	17	254	8665	96.68
Res. relief	27	8138	0	281	8446	96.35
Alluvium	0	0	2650	68	2718	97.50
Low glacis	189	154	201	7850	8394	93.52
Total	8593	8309	2868	8453	28223	
User Acc. %	97.49	97.94	92.40	92.87		
Overall accuracy = 95.71 %, K = 0.94						

Ferruginous duricrusts (high/middle glacis)

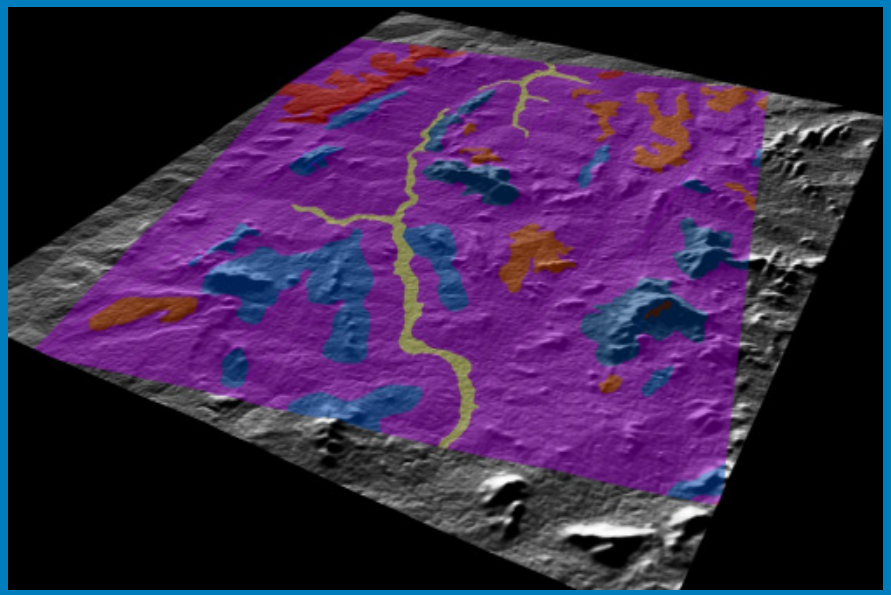
Low glacis without duricrust cover

Residual relief

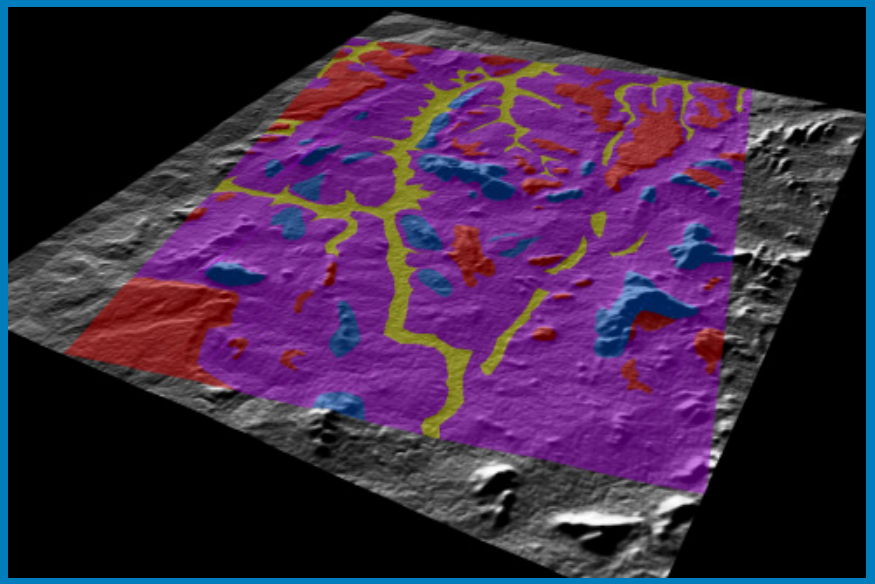
Alluvium

Case Study 2 – *Geological Mapping*: Regolith Landforms (Burkina Faso)

Result Comparison: Mapping vs. Modeling with ANN



Geomorphological Map 1 : 500,000
(IGB & IGN) with SRTM Elevation Model in the background



Vectorised Results of the advangeo Prediction Model with SRTM Elevation Model in the background

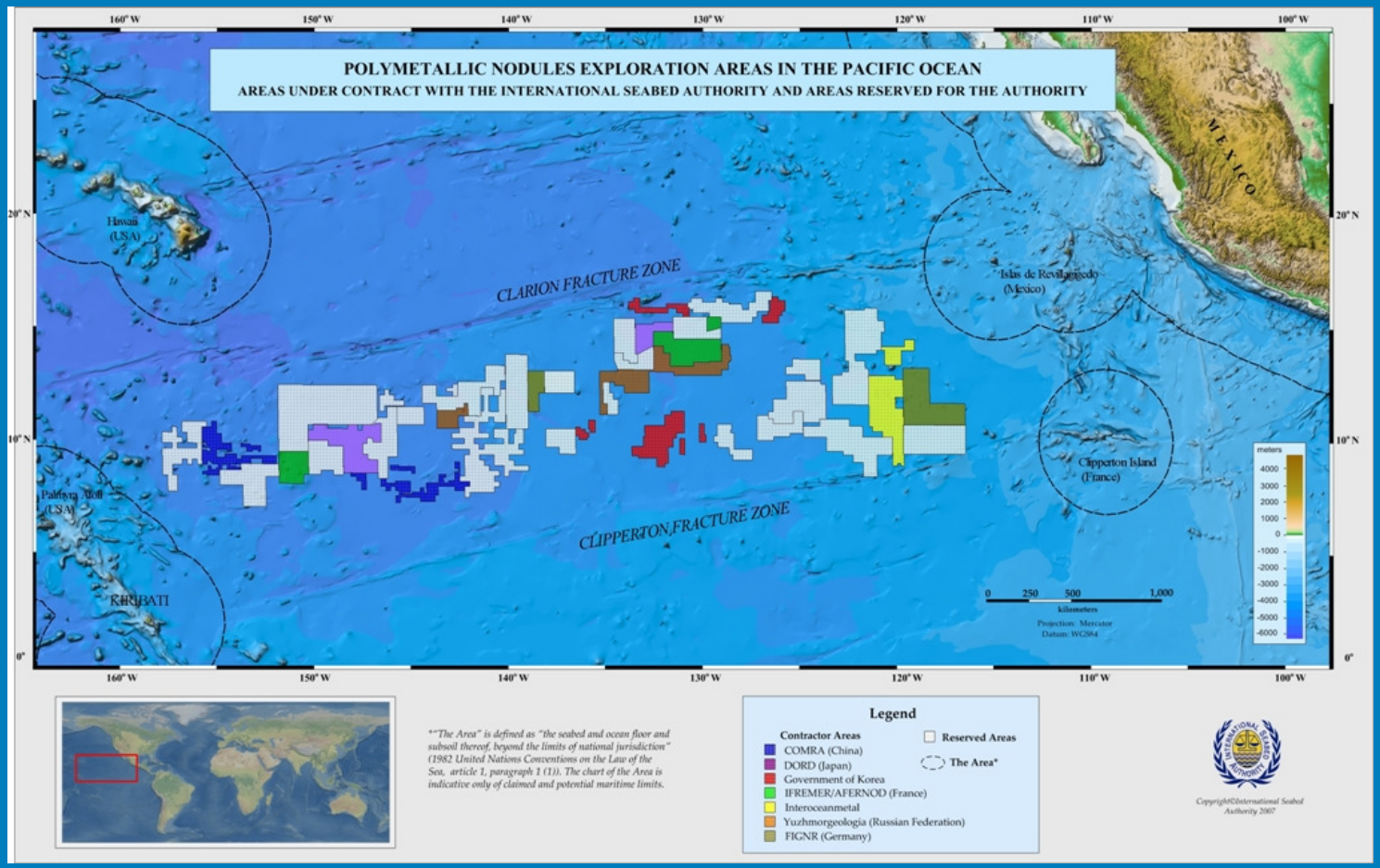
Case Study 3 - *Mineral Deposits*: Manganese Nodules (Pacific)

Where are Manganese nodules located?

What is their coverage density?

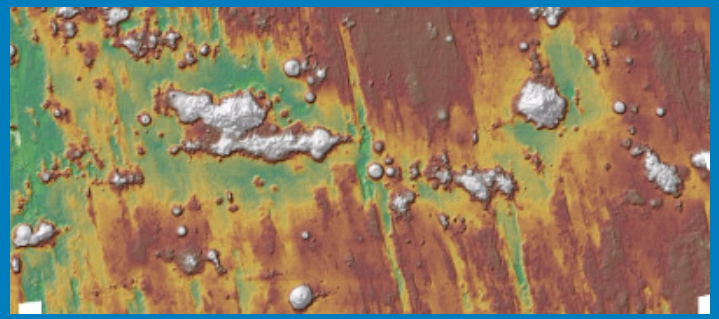
Case Study 3 - *Mineral Deposits*: Manganese Nodules (Pacific)

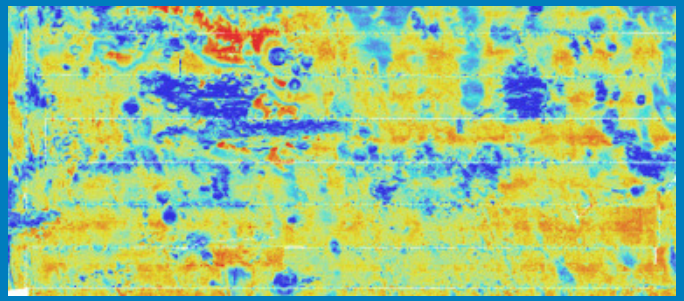
Working Area: Clarion-Clipperton-Fracture-Zone (CCFZ)



Case Study 3 - *Mineral Deposits*: Manganese Nodules (Pacific)

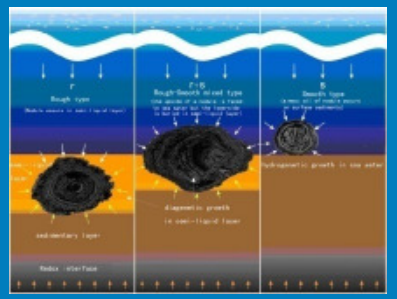
Existing Data & Knowledge





Data:
DGM / Bathymetry
Backscatter

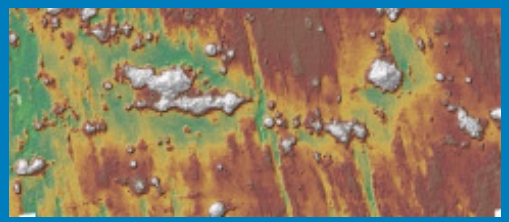
Sampling Points + Analysis



Genetic Models

Case Study 3 - *Mineral Deposits*: Manganese Nodules (Pacific)

Input Data:
Bathymetry and Derivates
Backscatter
Lineaments
Seamounts



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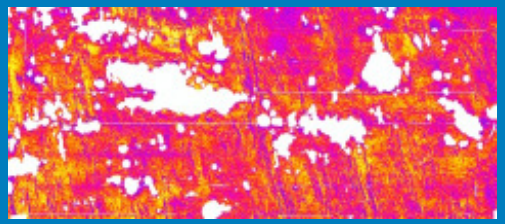
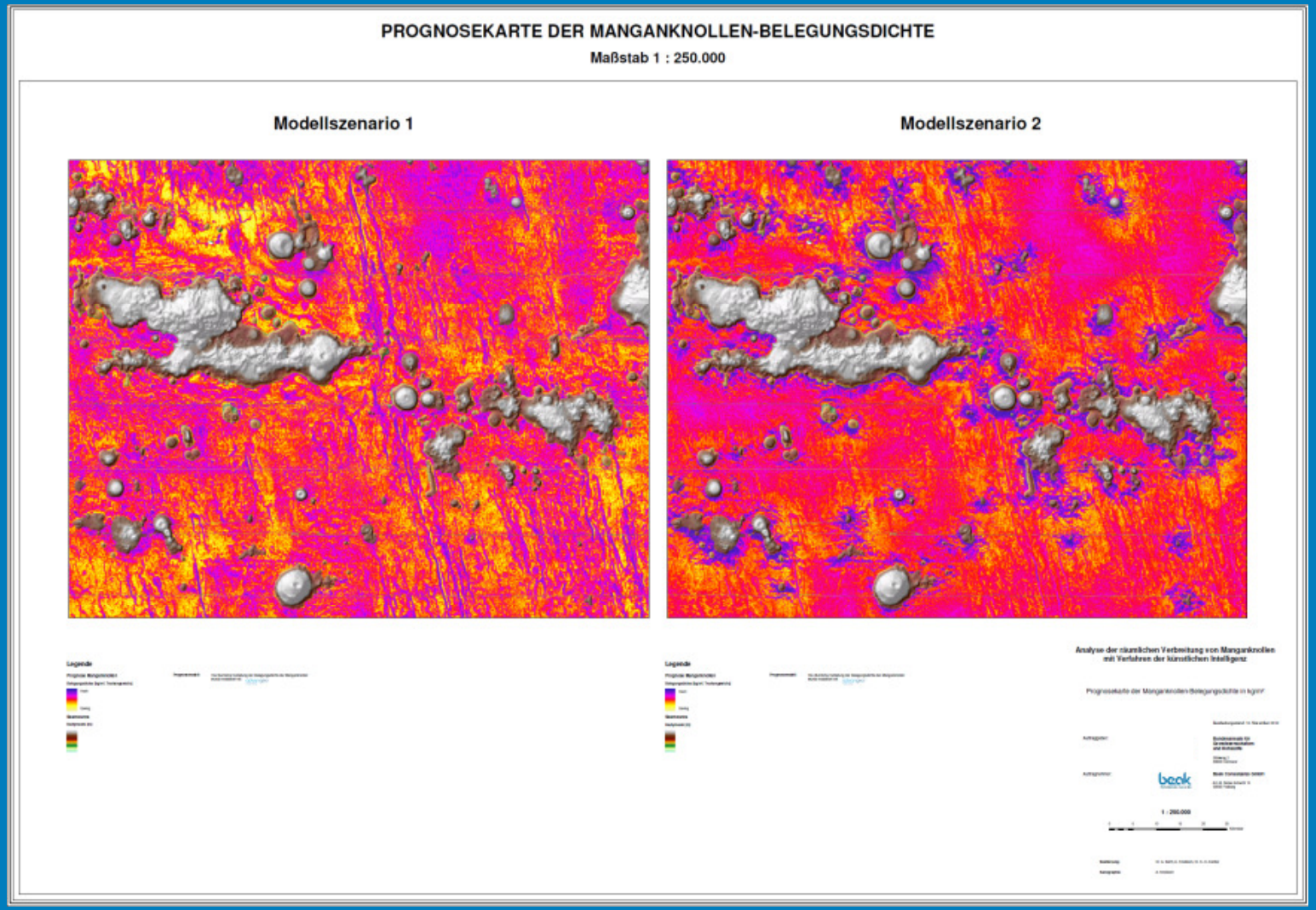
Prediction Software

Training Data:
Analysis Results
Sampling Points



Case Study 3 - *Mineral Deposits*: Manganese Nodules (Pacific)



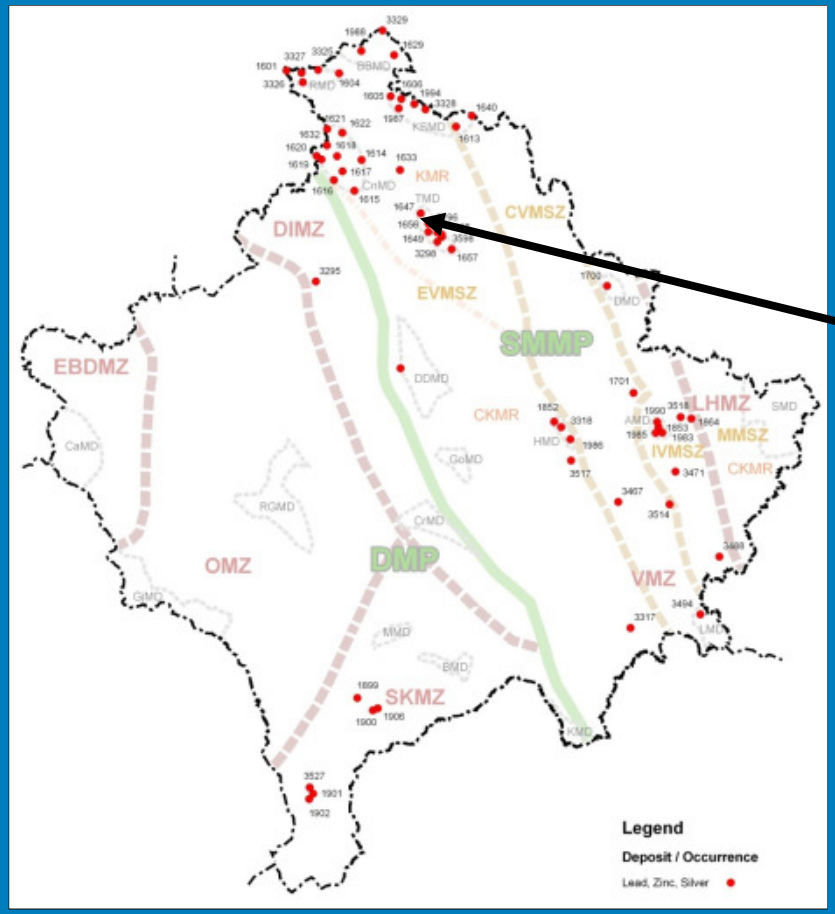
Case Study 4 - *Mineral Deposits*: Pb/Zn, Au, Cr (Kosovo)

Where are Pb/Zn, Au and Cr Deposits located?

Independent Commission for Mines and Minerals

Case Study 4 - *Mineral Deposits*: Pb/Zn, Au, Cr (Kosovo)

Training Data: Known Pb/Zn-Deposits and Occurrences



Trepca

Case Study 4 - *Mineral Deposits*: Pb/Zn, Au, Cr (Kosovo)

Deposit Model:

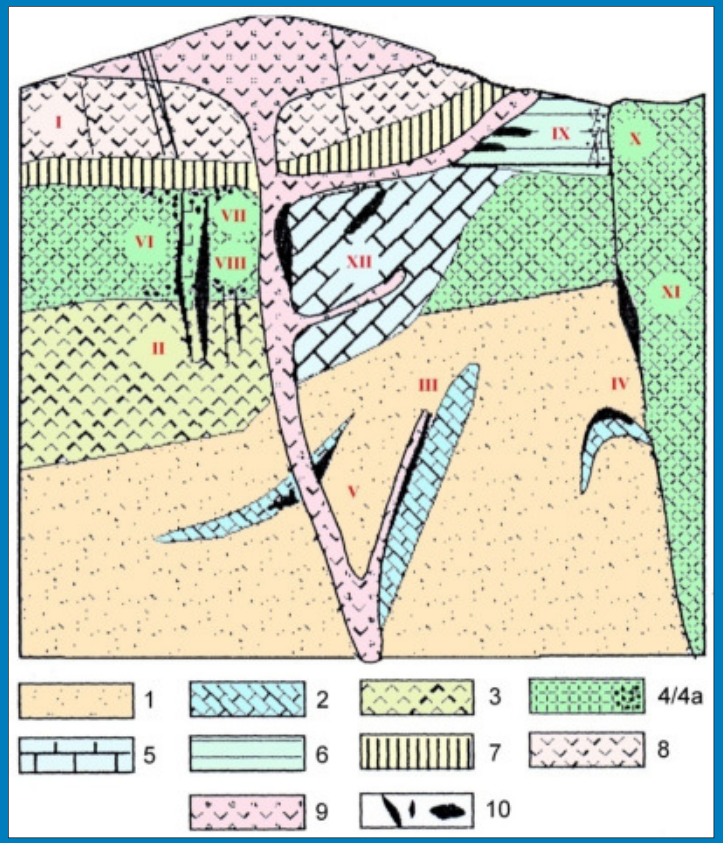
- **Lithological bound** (controlled) to heterogeneous sedimentary series with carbonatic intercalations and with other reactive rocks (e.g. serpentinite, partly graphitic schist) of Paleozoic and partly Mesozoic age, micro-tectonically per-marked with good cleavage, ruptures and joints
- **Tectonically bound** (controlled) to large structures of faults and thrusts,
- **Magmatic bound** to Oligocene to Miocene high potassium grade andesite-trachyte sub- and effusive volcanism, partly with extensive and intensive pyroclastic and breccious activities (pipe breccias)
- Main minerals: galena, sphalerite, pyrite; minor minerals: chalkopyrite, aresenoprite, pyrrhotine, rarely gold; main gangue minerals: quartz, calcite; minor gangue minerals: dolomite, Fe-Mn-carbonate

→ **Replacement deposit** of Pb/Zn sulphides in carbonatic rocks, sometimes as skarn, as veins and veinlets, as paleokarst fillings, massive, compact, lens-like, disseminated etc.

→ **Neogene hydrothermal mineralisation**, metal source uncertain

Case Study 4 - *Mineral Deposits*: Pb/Zn, Au, Cr (Kosovo)

Deposit Model: Controlled by NNW-SSE-Faults and Volcanic Centers



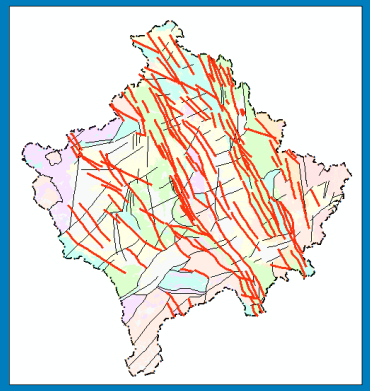
Simplified Schema of Genetic and Structural Types of Pb/Zn-Deposits in the Vardar Zone after ANKOVIC, JELENKOVIC, VIJUC (2003).

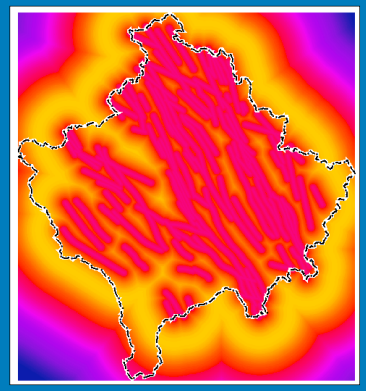
1 – Palaeozoic and Triassic Crystalline Schists, 2 – Upper Palaeozoic Marbles, 3 – Amphibolite and Amphibole schist, 4 – Serpentinite and 4a - Listvenite, 5 – Upper Cretaceous Limestones, 6 – Upper Cretaceous Carbonatic Flysch, 7 – Miocene "Red Series": Conglomerates, Sandstones, Slates and Marlstones, 8 – Andesitic Lavas and Pyroclastic Rocks, 9 – Subvolcanic and Volcanic Quartz Latite and Trachyte incl. Pipe Breccias, 10 – Pb-Zn Ore Bodies

I – Belo Bërdë / Belo Brdo, II – Crnac / Crnac, III – Staritërg / Stari Trg, IV – Hajvali / Ajvalija, V – Novo Bërdë / Nove Brdo, VI – Koporiç / Koporić, VII – Shuta Prlina / Žuta Prlina, VIII – Jelakse / Jelakce, IX – Shatoriza / Šatorica, X – Kishnicë / Kišhnica, XI – Badovc / Badovac, XII – Crepulja / Crepulja

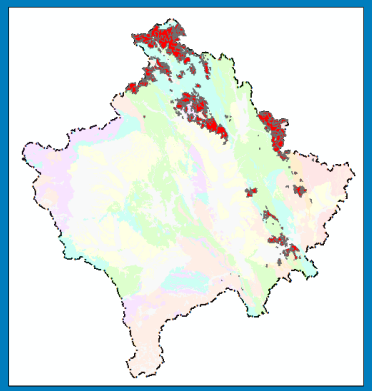
Case Study 4 - *Mineral Deposits*: Pb/Zn, Au, Cr (Kosovo)

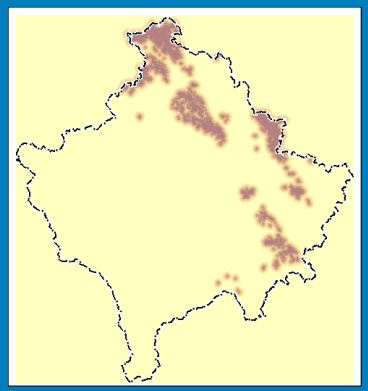
Input Data: Euclidian Distance to NNW-SSE Faults





Input Data: Euclidian Distance to Young Volcanic Centers

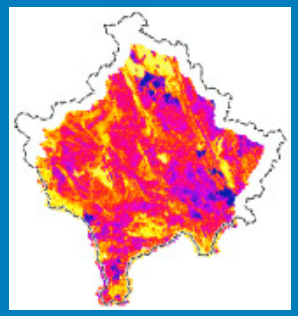




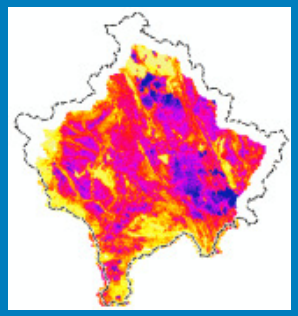
Case Study 4 - *Mineral Deposits*: Pb/Zn, Au, Cr (Kosovo)

Input Data: Airborne Geophysical Survey Data

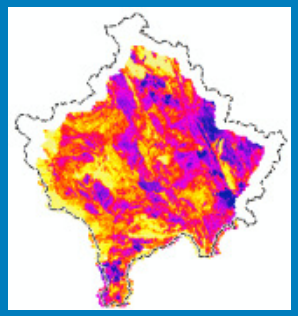
- Radiometrics



Uranium

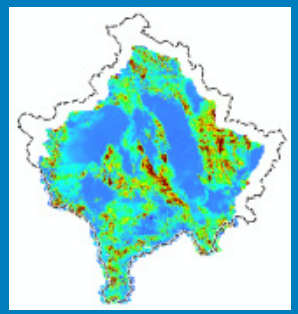


Thorium

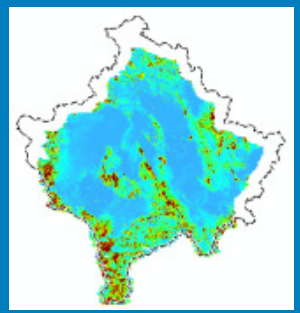


Potassium

- Electromagnetics

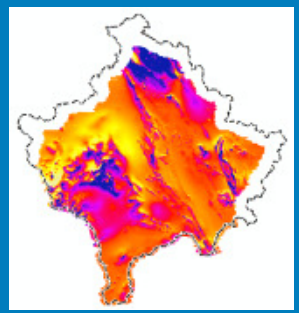


9 kHz



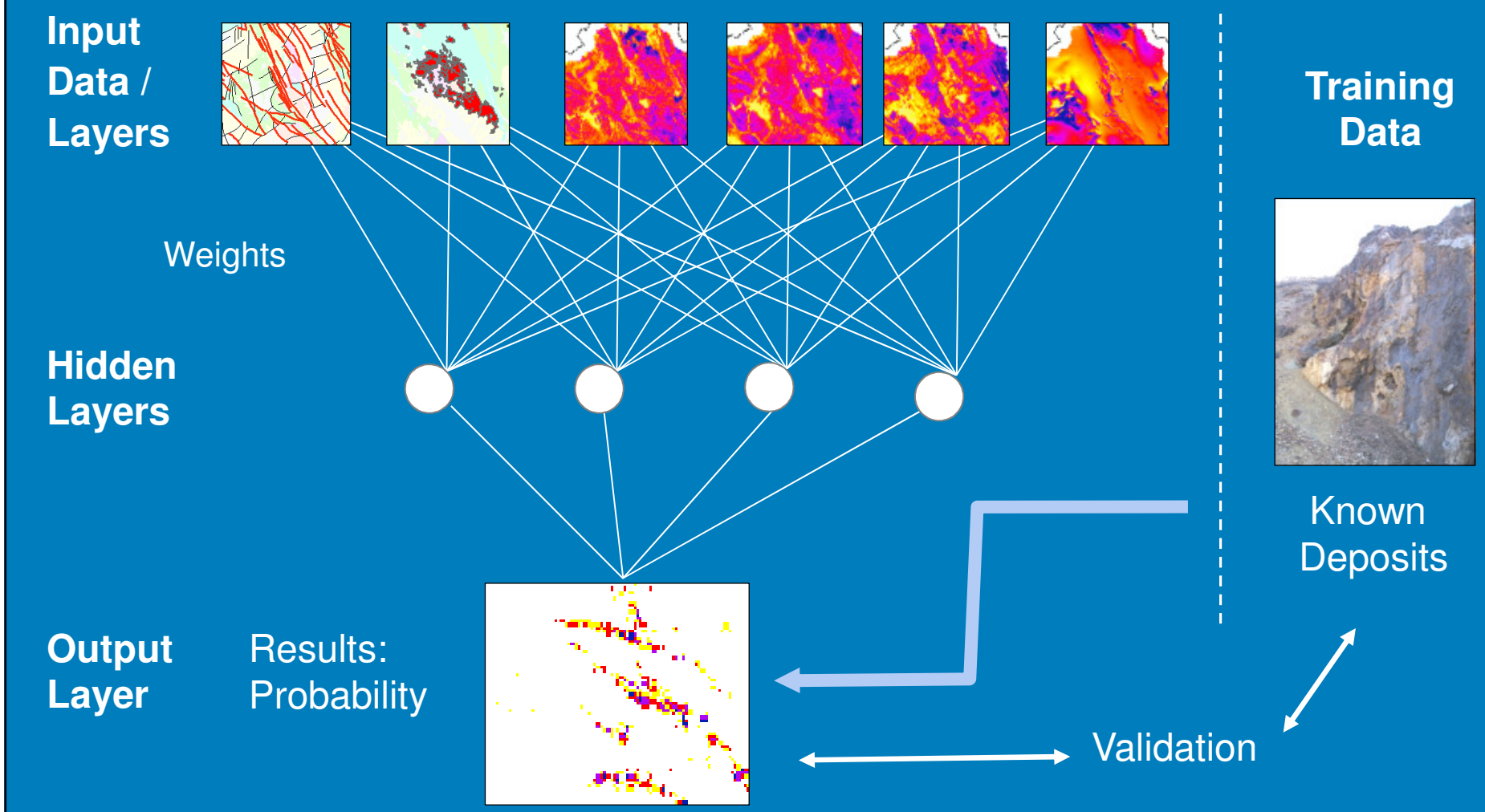
12 KHz

- Magnetics

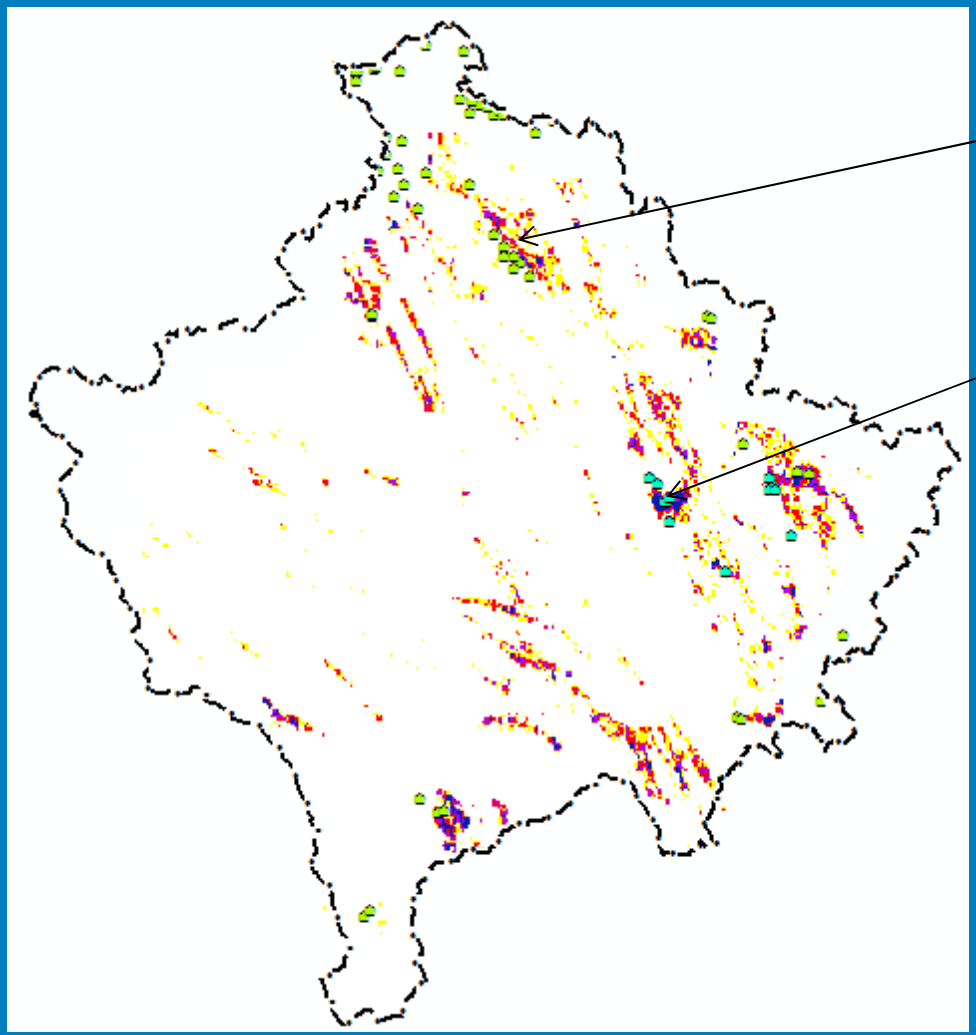


Total

Case Study 4 - *Mineral Deposits*: Pb/Zn, Au, Cr (Kosovo)



Case Study 4 - *Mineral Deposits*: Pb/Zn, Au, Cr (Kosovo)



Test Points

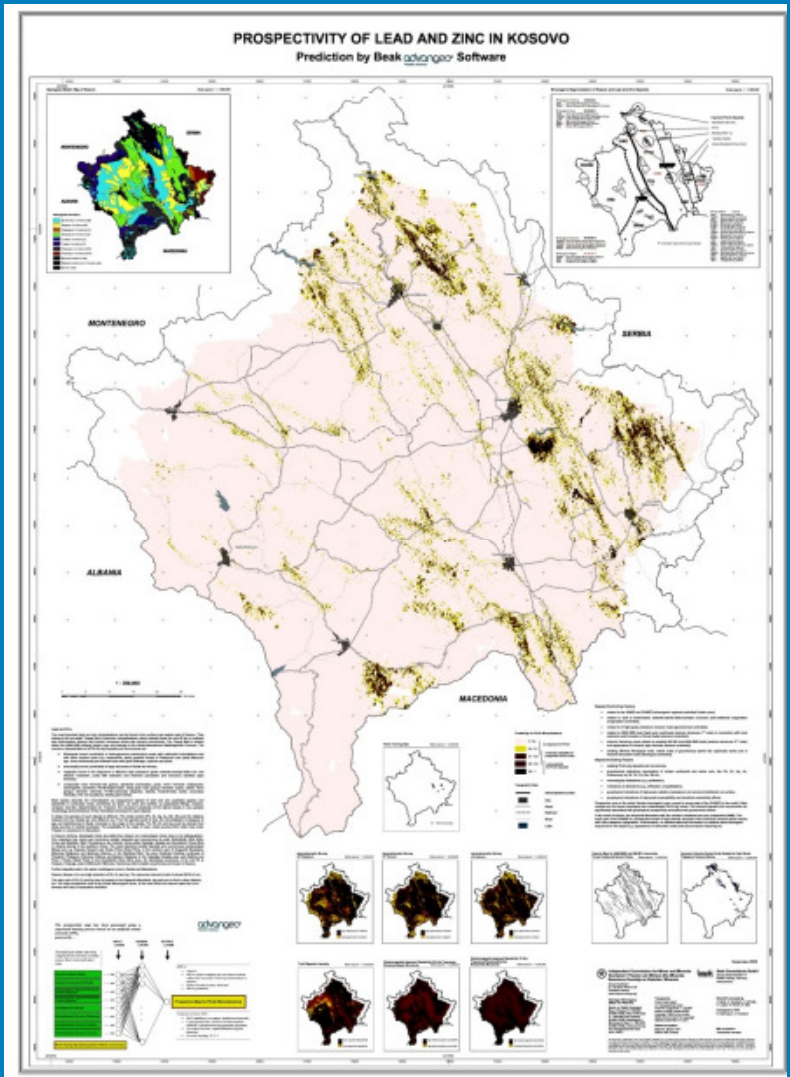
Training Data

Training Points

Probability for Pb-Zn Mineralisations

0 - 0,5	no response for Pb-Zn
0,5 - 0,7	moderate probability for prospective Pb-Zn areas
0,7 - 0,8	
0,8 - 0,9	most potential for Pb-Zn deposits
0,9 - 1	

Case Study 4 - *Mineral Deposits*: Pb/Zn, Au, Cr (Kosovo)

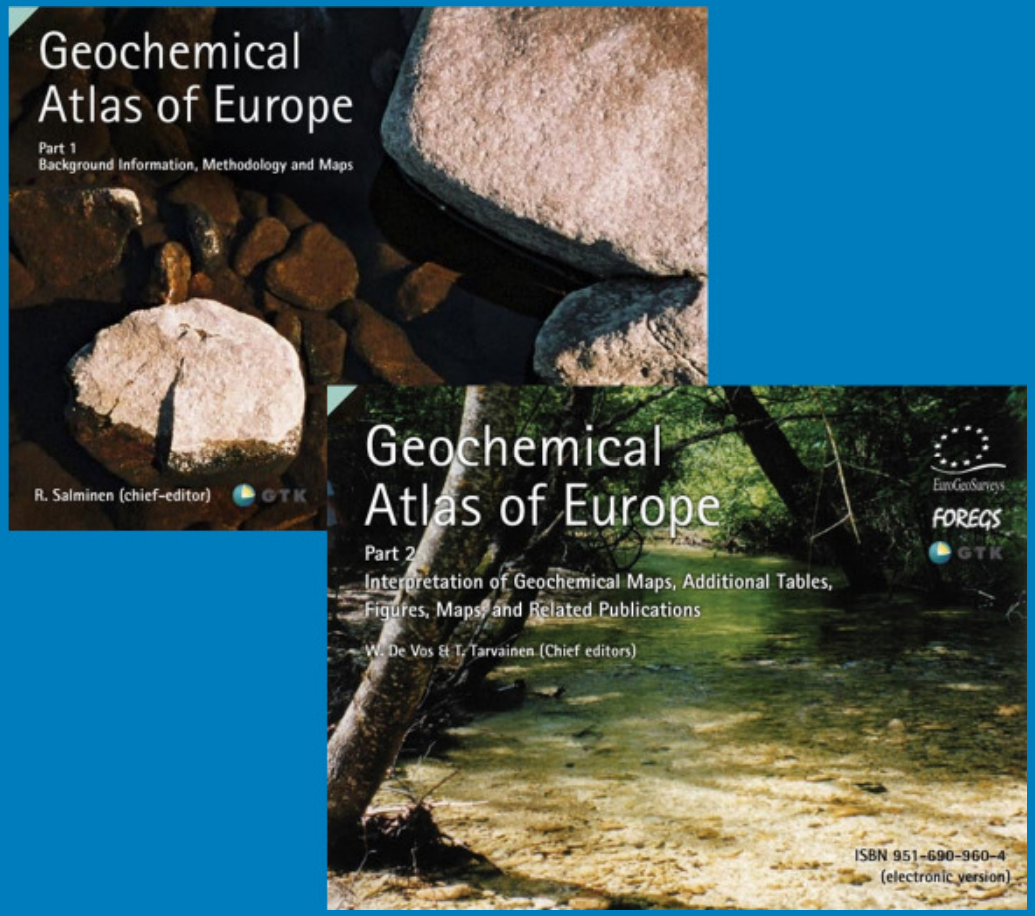


Prospectivity Maps 1:200,000 compiled / available for:

- Pb/Zn
- Au
- Cr

Case Study 5 – *Geochemistry*: Top Soil (Europe)

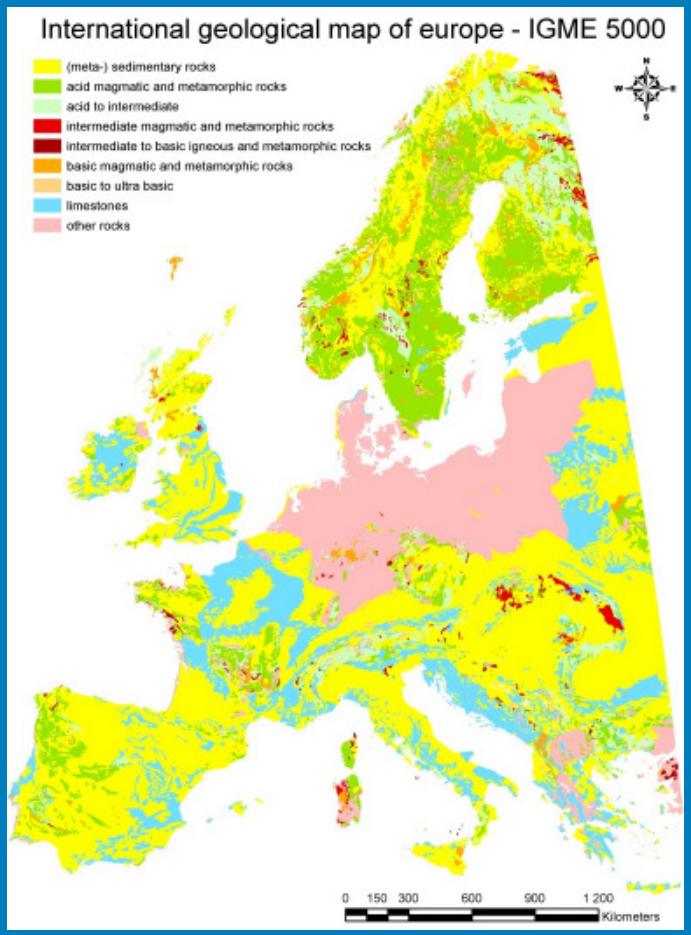
Regionalization of Geochemical Top Soil Parameters



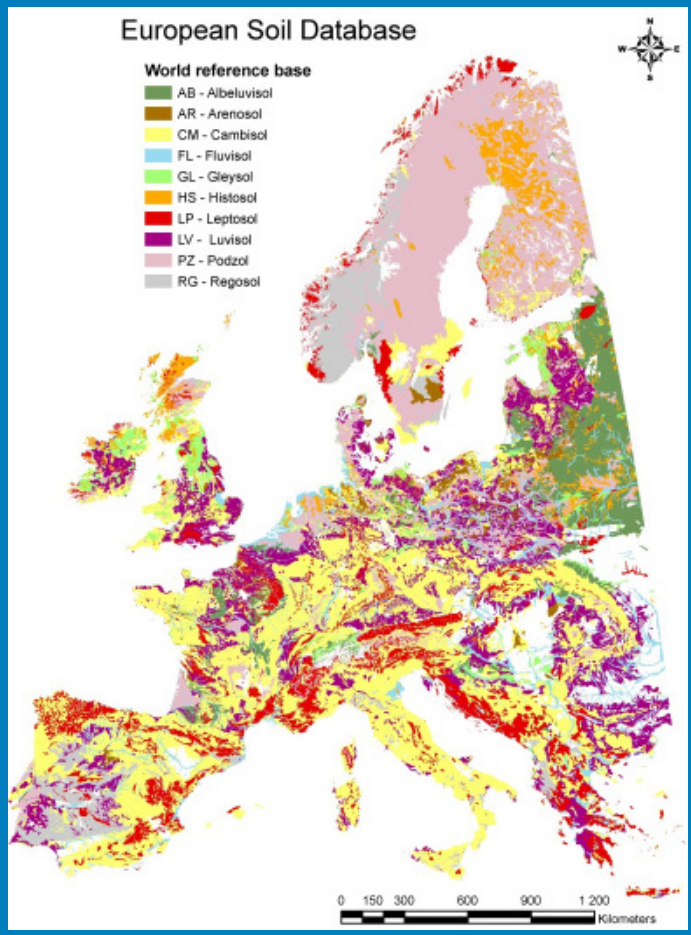
Modelling by:
Christian Scharpf
Master Thesis
(April 2012)

Case Study 5 – *Geochemistry*: Top Soil (Europe)

Input Data: Geology

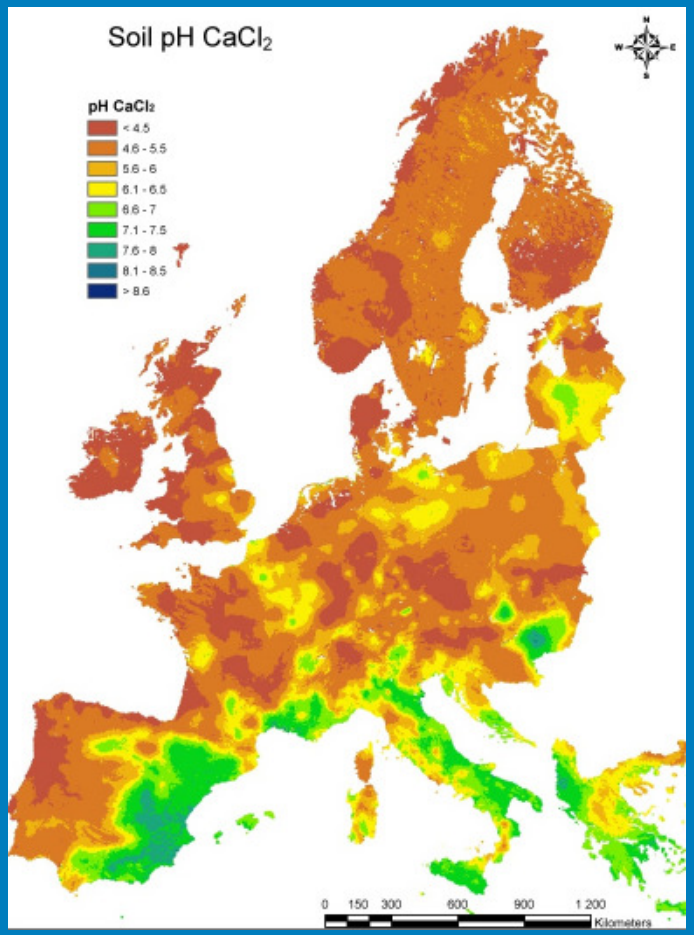


Input Data: Soils



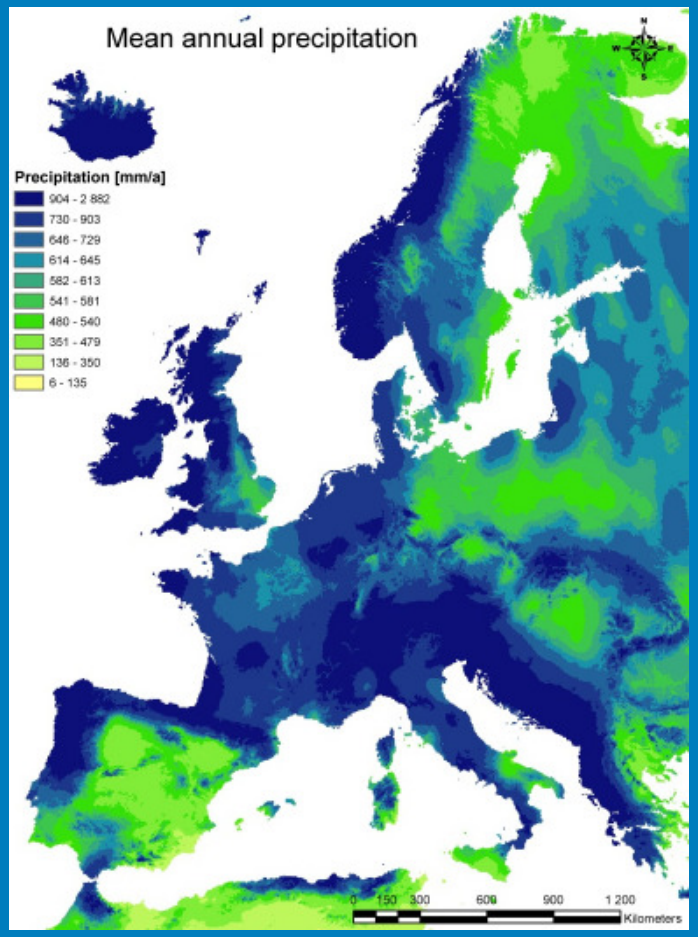
Case Study 5 – *Geochemistry*: Top Soil (Europe)

Input Data: Soil pH

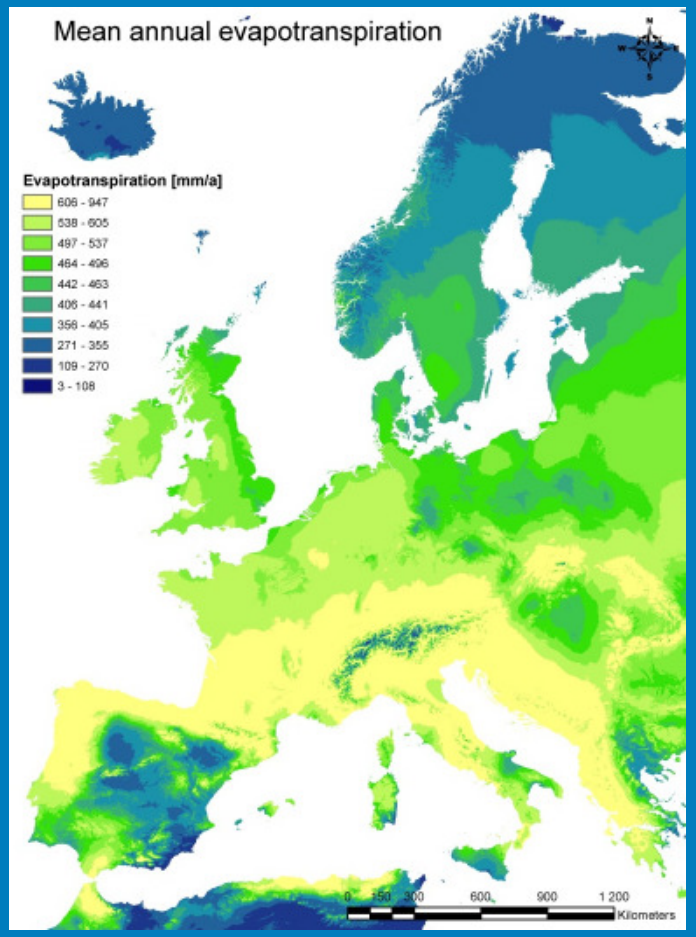


Case Study 5 – *Geochemistry*: Top Soil (Europe)

Input Data: Precipitation

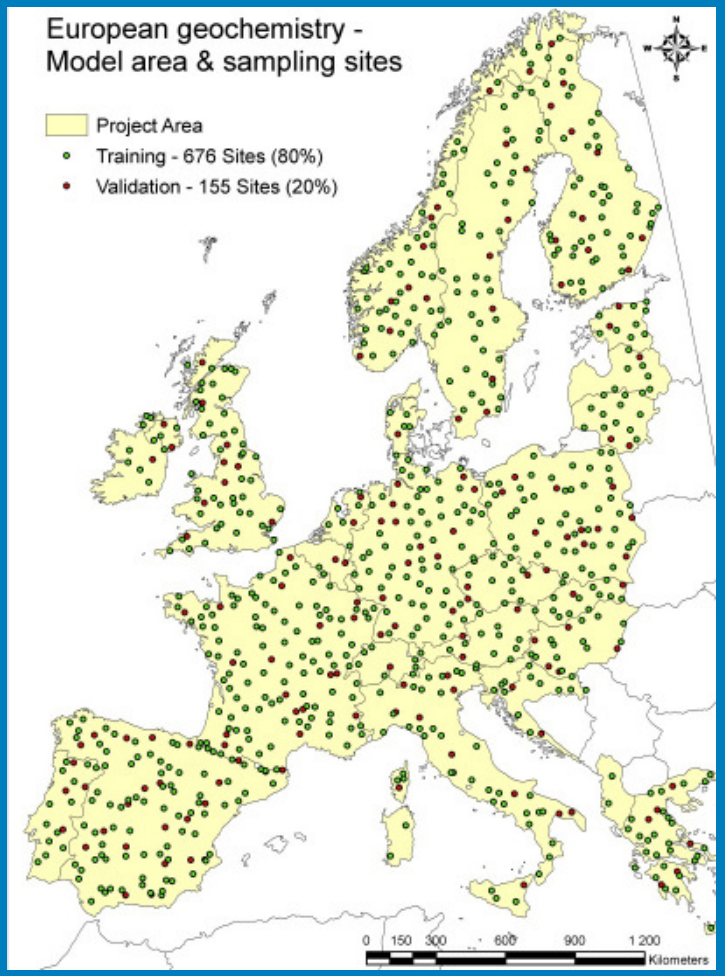


Input Data: Evapotranspiration



Case Study 5 – *Geochemistry*: Top Soil (Europe)

Training Data



FOREGS-EuroGeoSurveys
Geochemical Baseline Database

Number of samples: 831 Training: 676 Validation 155
Parameter: Geology, Soils, Soil-pH, Precipitation, Evaporation
Neurons 22-20-1, Rprop-algorithm, Sigmoid activation function, 250 Epochs

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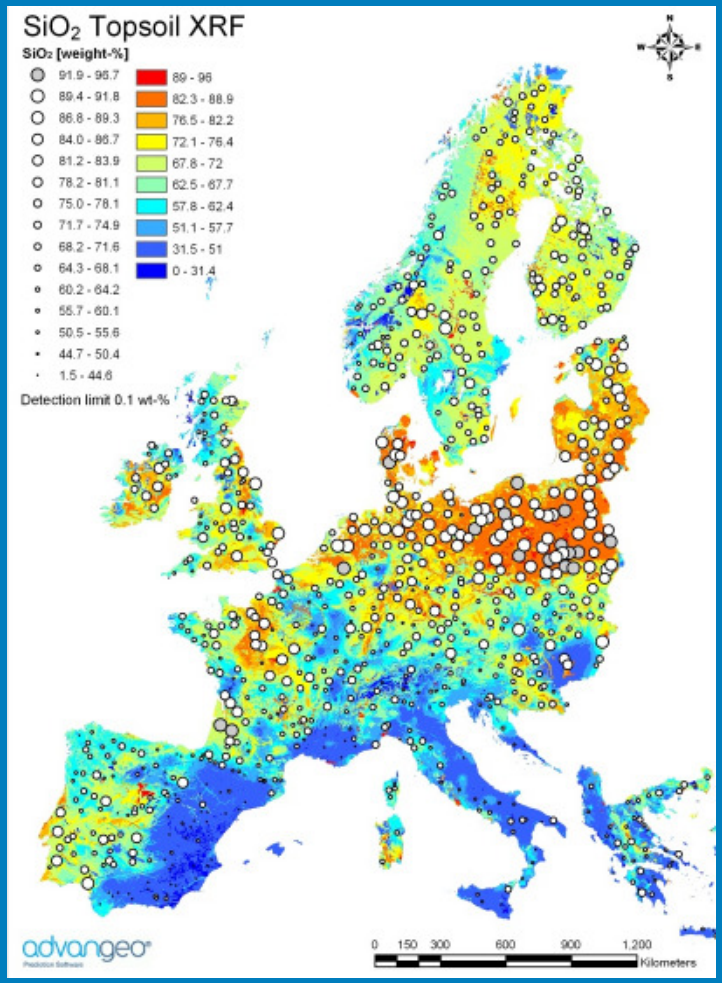
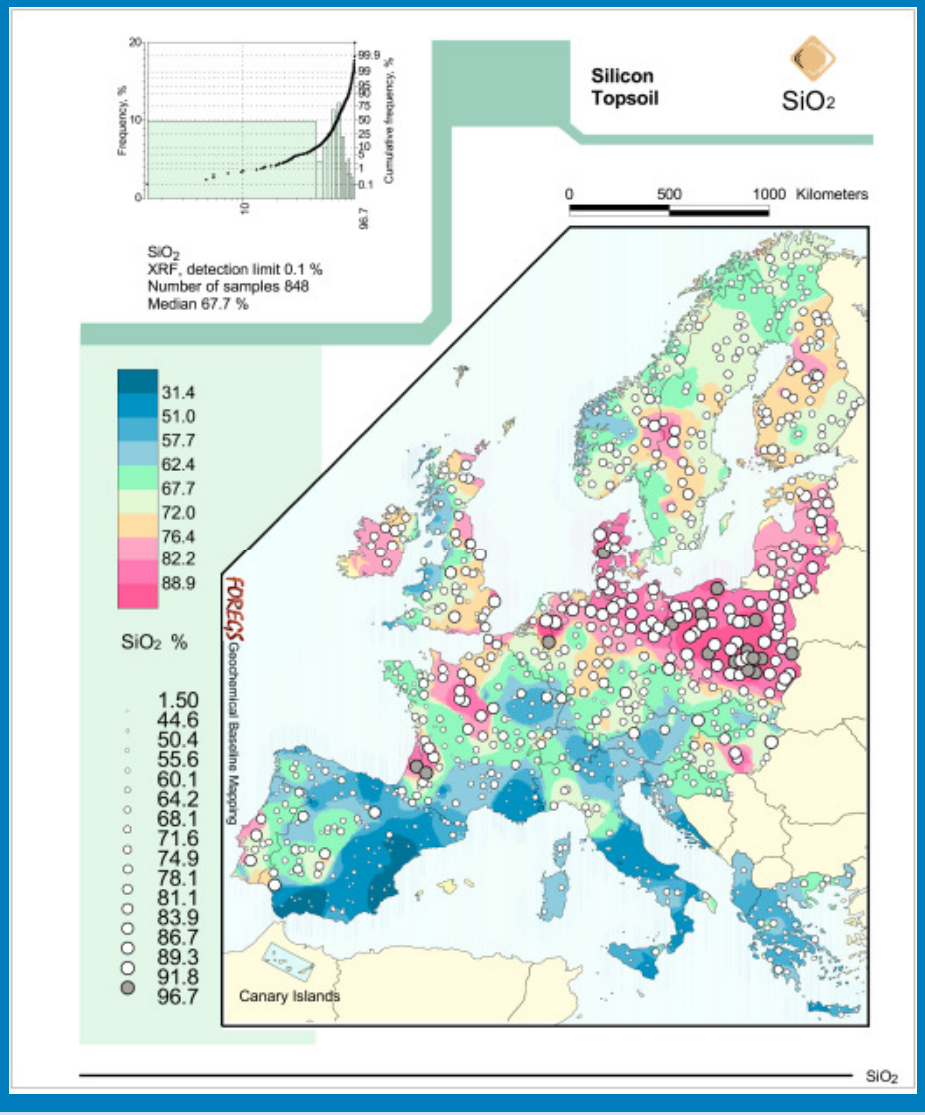
Results: SiO_2





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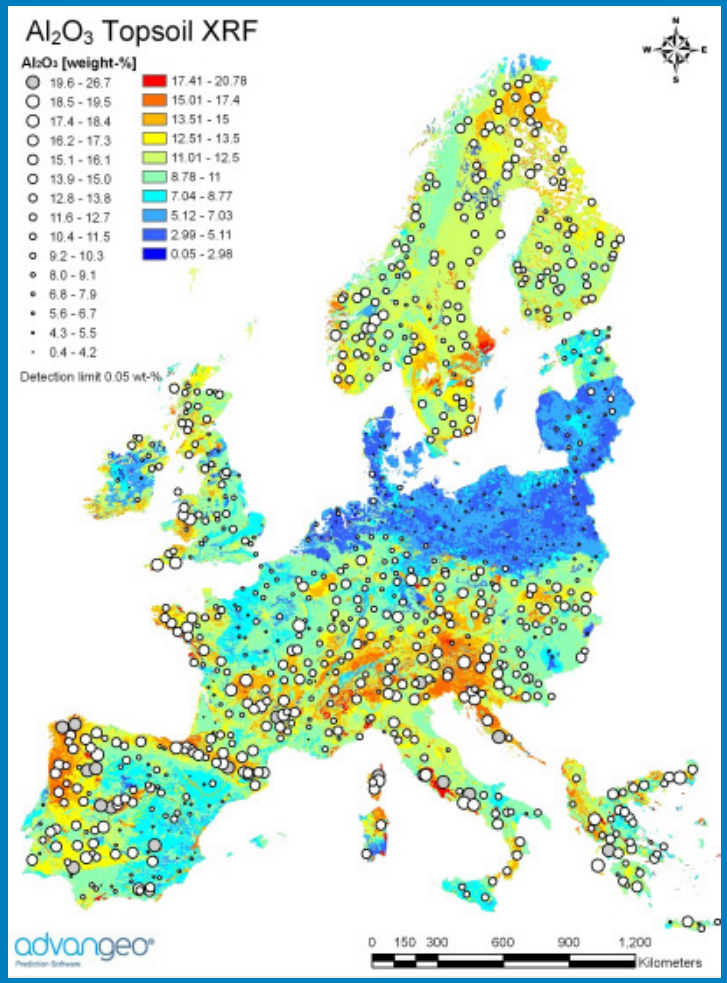
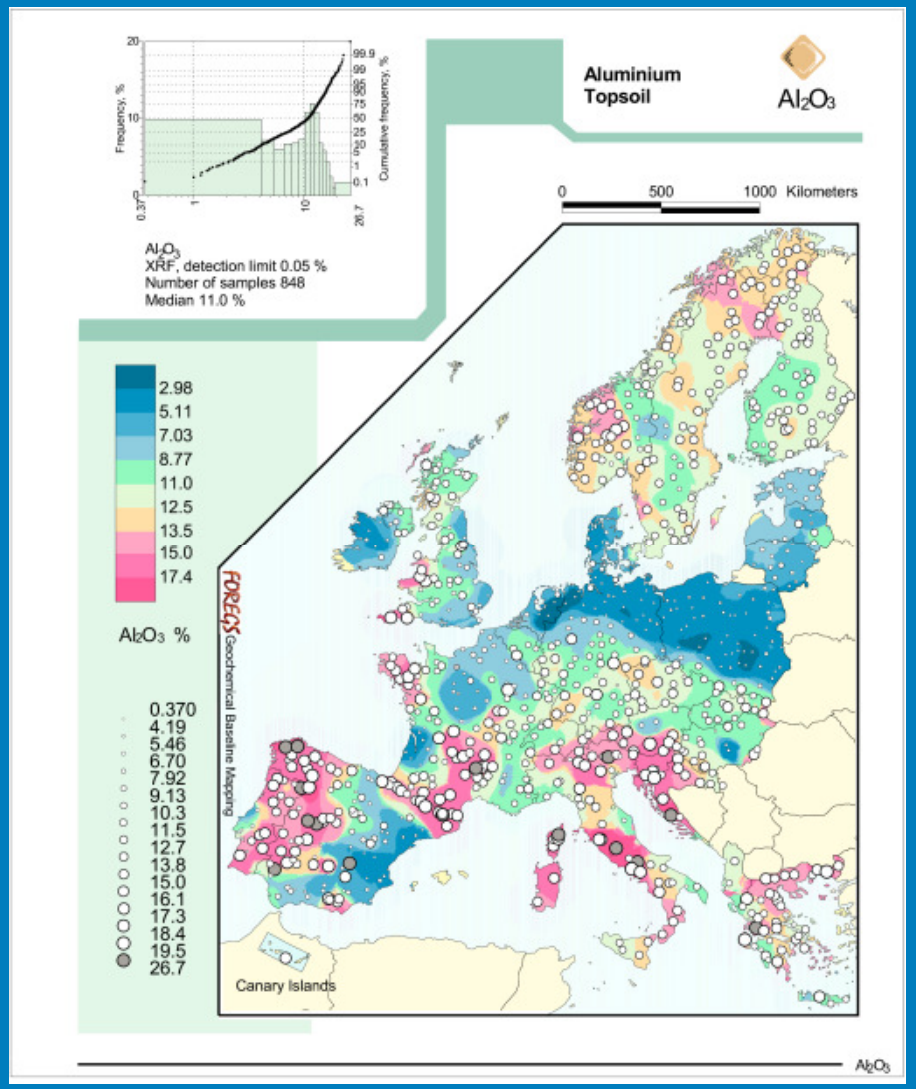
Results: Al_2O_3





Further Case Studies

FINALISED:

- **Soil Creeping, Formation of Erosion Gullies**: Freital / Germany (2009)
- **Extensive Soil Erosion**: Weißeritz Catchment (2008)
- **Erosion Gullies**: Limpopo Area / South Africa (2009)
- **Coal Fires**: China (TUBAF, 2010)
- **Soil Contaminations in Urban Areas**: Marienberg / Germany (LfULG, 2010)
- **Spread of Forest Pests**: Tharandter Wald, Sächsische Schweiz / Germany (Sachsenforst, 2009 / 2012)

IN PROGRESS:

- **Mineral Deposits / Occurrences – Sn, W**: Erzgebirge / Germany (TUBAF, 2012)
- **Mineral Deposits / Occurrences – Nb, Ta, Sn, etc.**: Rwanda (RNRA, 2012)
- **Mineral Deposits / Occurrences – Au**: Volta basin / Ghana (GSD, 2012)

Summary / Outlook

- Multiple applications of the developed methodology using artificial neural networks and GIS with advangeo® Prediction Software in geosciences:
  - Mineral exploration,
  - Soil protection,
  - Geo-hazard prediction,
  - Geological mapping,
  - Hydrology / water management.

→ **We look forward to your questions, suggestions and comments and hope for future knowledge sharing and collaboration!**

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