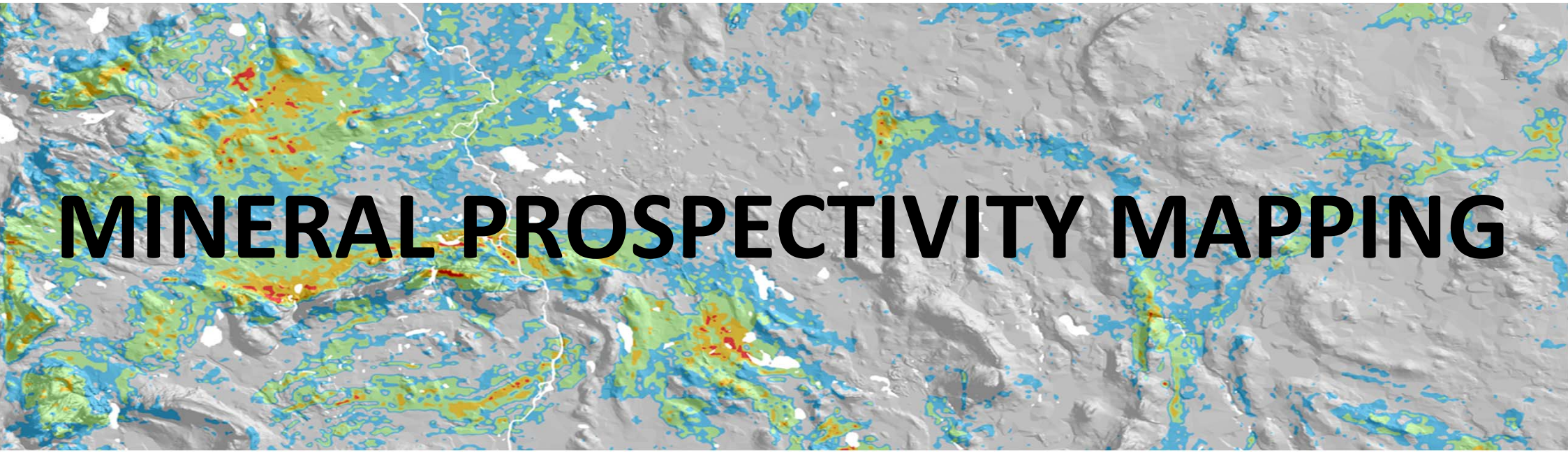


MINERAL PROSPECTIVITY MAPPING

Vesa Nykänen

Research Professor

Geoinformatics, Information Solutions

Geological Survey of Finland GTK

P.O. Box 77, FI-96101 Rovaniemi, Finland

This project is funded by the European Union

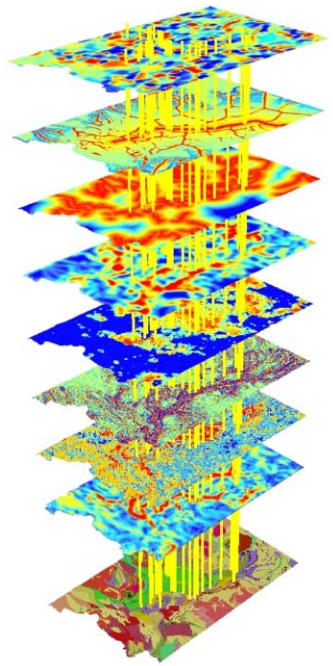
March 9th 2021

NEXT

GTK

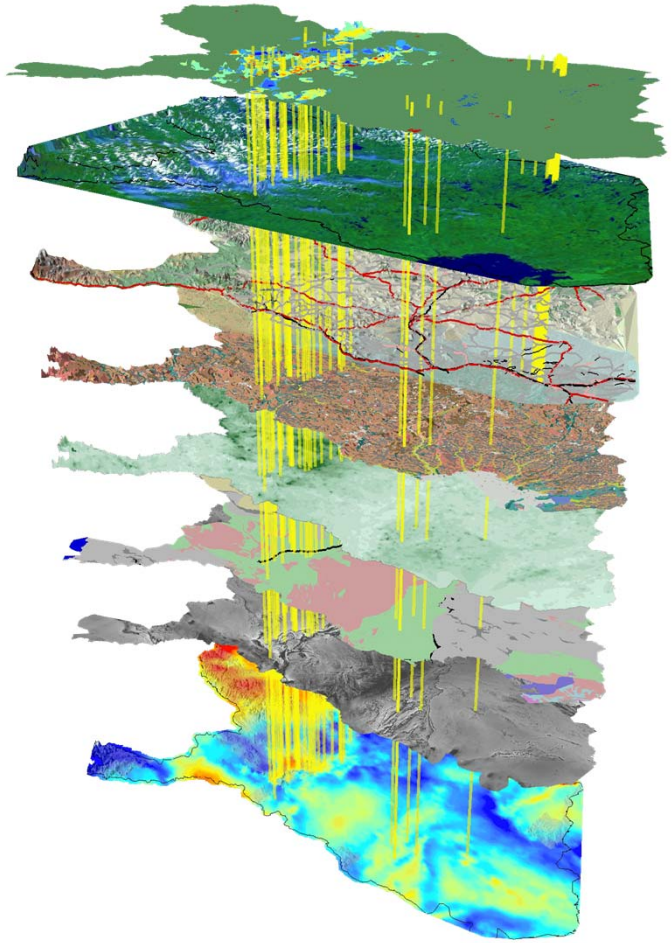
CONTENT

- GTK public geodata
- Prospectivity mapping
- Available tools
- Practical examples
  - *Orogenic gold prospectivity*
  - *IOCG prospectivity*
  - *Ni-Cu prospectivity*
- Summary



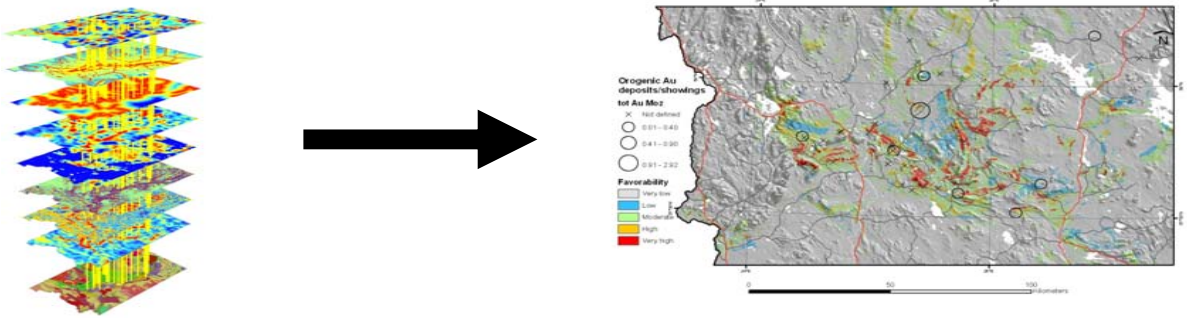
GTK SPATIAL DATA

- Geological maps
- Mineral resources
  - *Mineral deposits*
  - *Metallogenic belts*
- Airborne and ground geophysics
  - *Gravity*
  - *Magnetics*
  - *Electromagnetics*
  - *Radiometrics*
- Geochemistry
  - *Till*
  - *Bedrock*
  - *Boulder samples*
  - *Drilling data*
  - *Ore showings*
- All this data is publicly available (https://hakku.gtk.fi/en)



EXPLORATION POTENTIAL MAPPING / MINERAL PROSPECTIVITY MAPPING

- Traditionally based on expert opinions on potential areas for a certain deposit type
- Digital maps allow quantitative analysis of data and numerical modeling for mineral prospectivity mapping (also known as **mineral potential mapping**) -> Vast exploration data requires GIS based data-analysis and spatial data mining techniques
- Aim is to delineate areas favorable for mineral exploration, being time-saving, cost effective and environmentally neutral exploration technique



DYNAMIC PROSPECTIVITY MAPPING METHODOLOGY

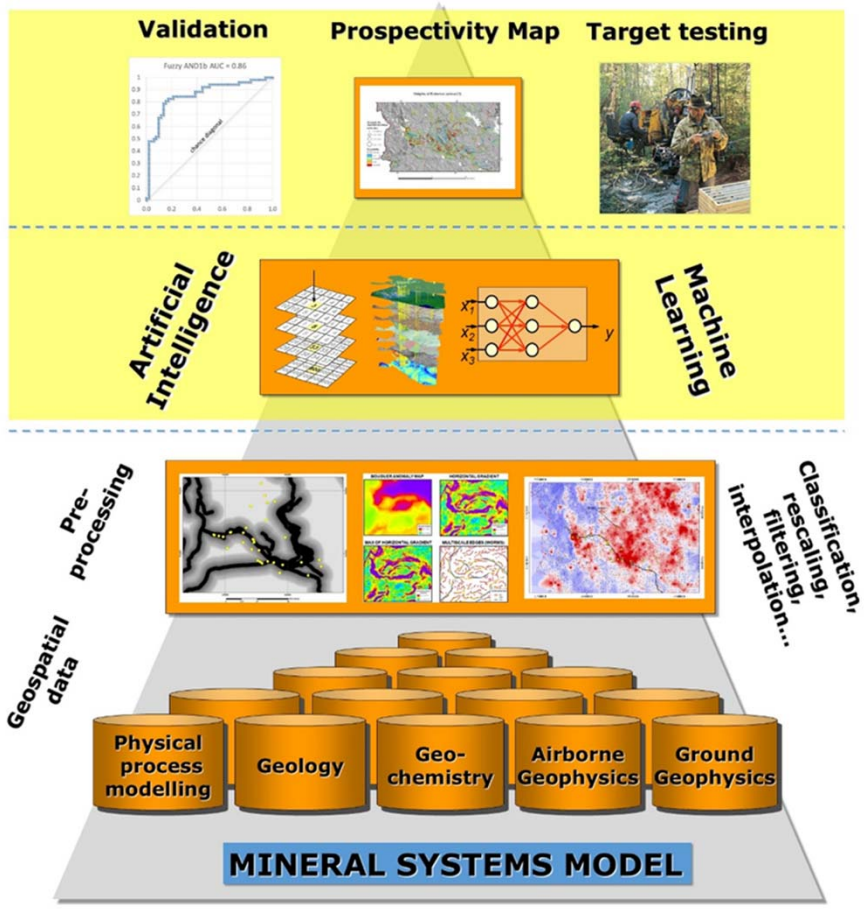
Dynamic loop and iteration

4. Validation:
Statistical and field validation

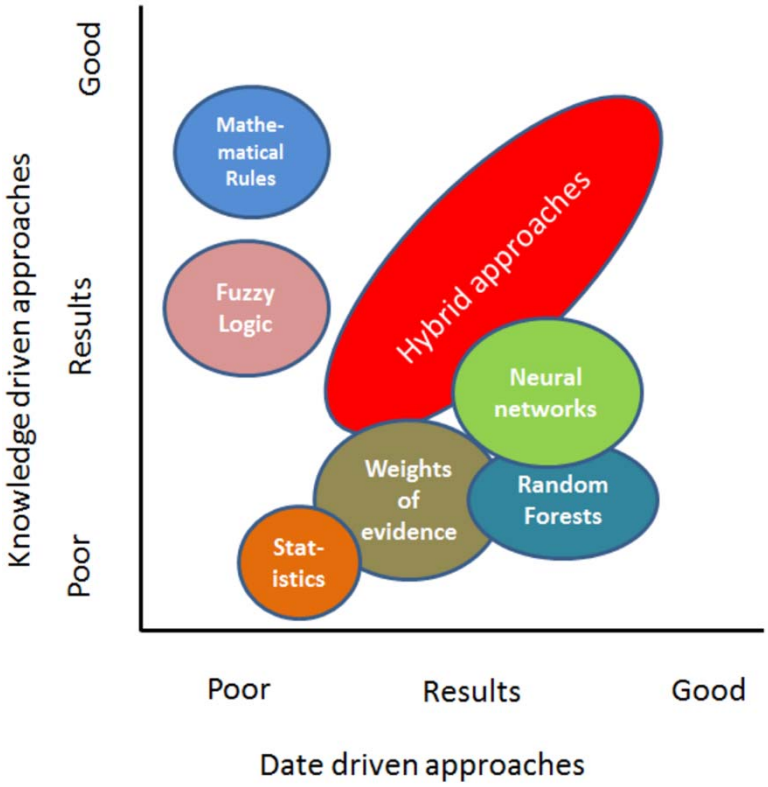
3. Spatial analysis:
Machine learning and AI

2. Input pattern generation – proxies for critical parameters

1. Selection of the relevant data based on a mineral system model – critical parameters



METHODS FOR MINERAL PREDICTIVE MAPPING (MPM) – *KNOWLEDGE VS. DATA DRIVEN*

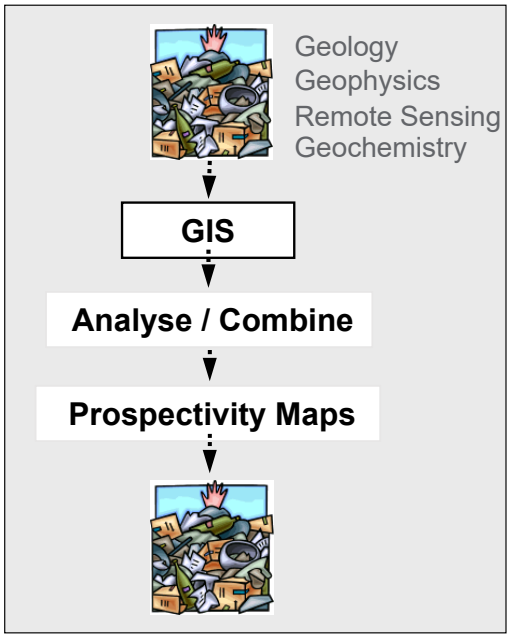


- **Knowledge driven approaches**
  - *We know controlling factors and use that knowledge*
  - *We can find only what we know*
  - *We do not need training points*
  - *Fuzzy logic, mathematical rules*
- **Data driven approaches**
  - *The algorithm finds the dependencies by itself*
  - *We need training points*
  - *Weights of evidence, artificial neural networks, random forests, regression*
- **Hybrid approaches**
  - *Combinations of the above*
  - *Neuro-fuzzy system (NFS)*

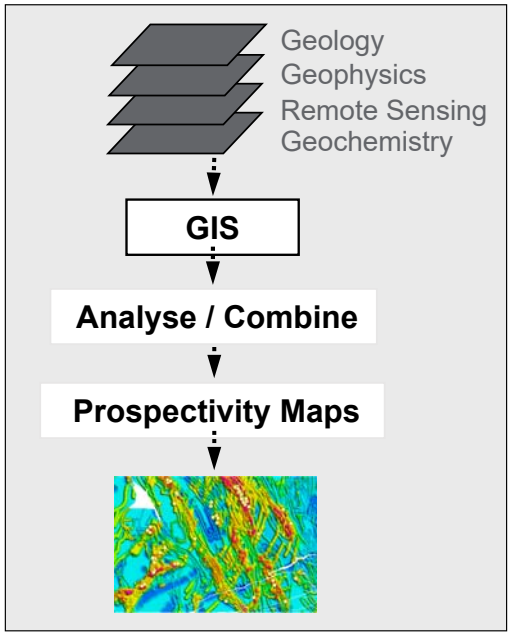
Source: Andreas Knobloch, Beak Consultants

DATA PREPROCESSING PHILOSOPHY

Garbage In, Garbage Out



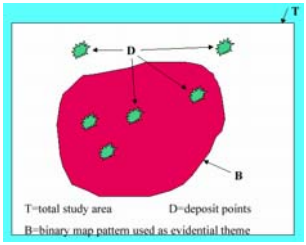
Good Data In, Good Resource Appraisal Out

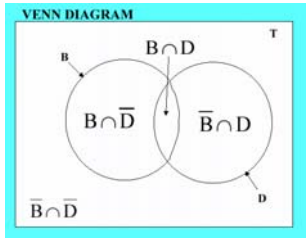


Courtesy of Dr. Stephen Gardoll

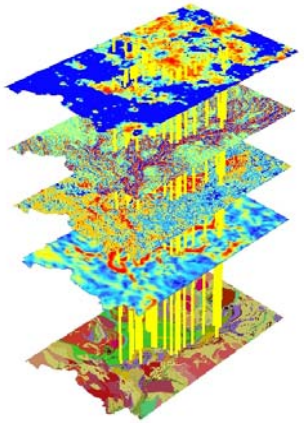
DATA DRIVEN (EMPIRICAL) APPROACH

Weights of evidence, logistic regression





Evidence layers



Combined till geochemistry: As, Au, Cu, Fe, Ni and Te

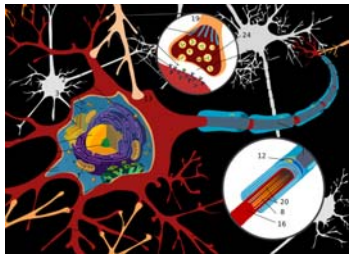
Airborne magnetics: magnetic field total intensity

Airborne electromagnetics: apparent resistivity

Gravity: horizontal gradient

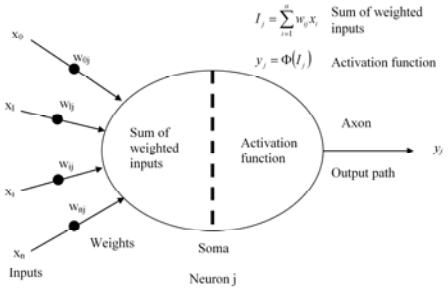
Bedrock geology

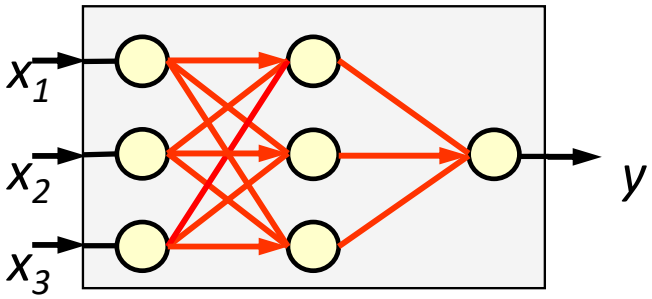
Artificial Neural Networks



Supervised:
RBFLN, PNN, Fuzzy NN

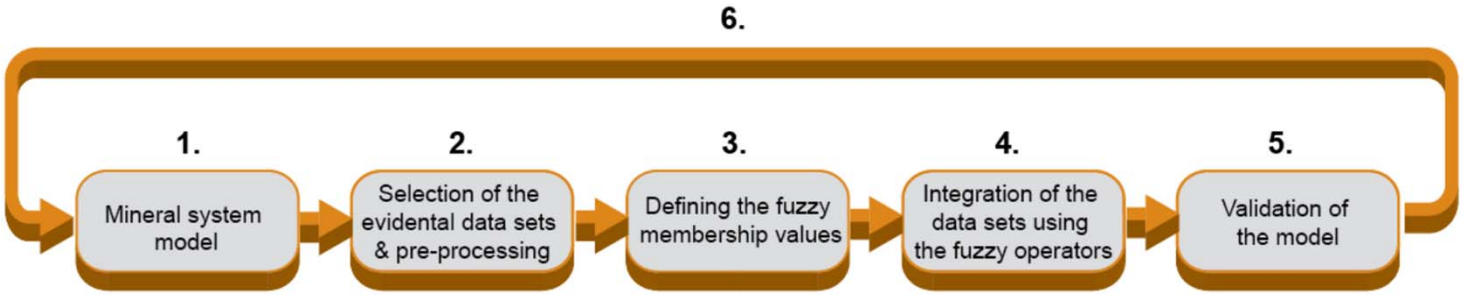
Unsupervised:
SOM





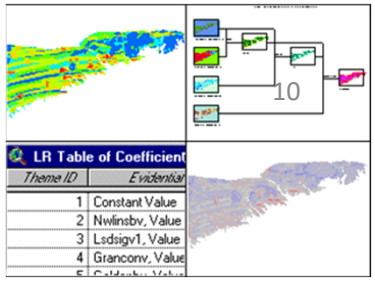
KNOWLEDGE DRIVEN (CONCEPTUAL) APPROACH

Fuzzy logic

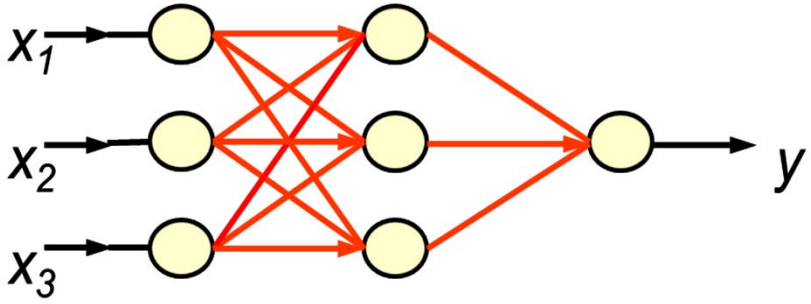


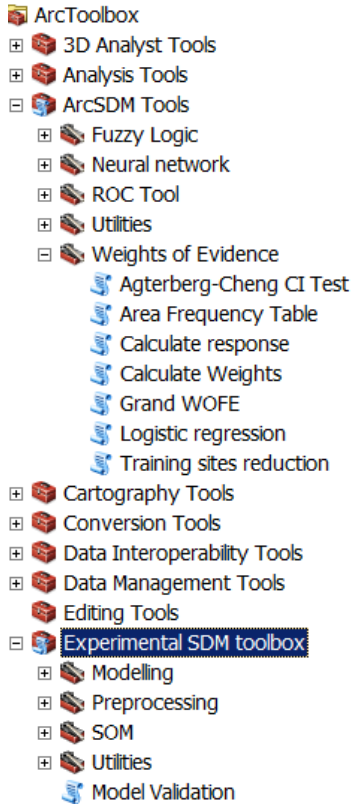
- Step 1: Definition of the mineral system model/Exploration model
- Step 2: Select data sets based on the mineral system/exploration model and data available
- Step 3: Assign fuzzy membership values e.g., rescale all data into a common scale from 0 -> 1 (e.g., not favorable -> favorable) using Fuzzy membership tool
- Step 4: Combine all the evidence data by using various fuzzy operators (Fuzzy OR, Fuzzy AND, Fuzzy Sum, Fuzzy Product, Fuzzy Gamma)
- Step 5: Validate your model (statistical or empirical methods)
- Step 6: Refine your model and repeat if needed !

ARCSDM 5
TOOLBOX FOR PROSPECTIVITY MAPPING



- ArcSDM was originally developed by Gary Raines (USGS) and Graeme Bonham-Carter (GSC) and was coded by Don Sawatzky (USGS)
- ArcSDM has been maintained by Prof. Carlos Roberto de Souza Filho, University of Campinas, Sao Paolo, Brazil, http://www.ige.unicamp.br/sdm/
- GTK has recoded the tools into ArcGIS 10.4 and ArcGIS Pro platforms and also implemented some new tools in 2017-2018. Tools available from: https://github.com/gtkfi/ArcSDM
- Download ZIP file to your computer and add toolbox(es) into your ArcGIS map document

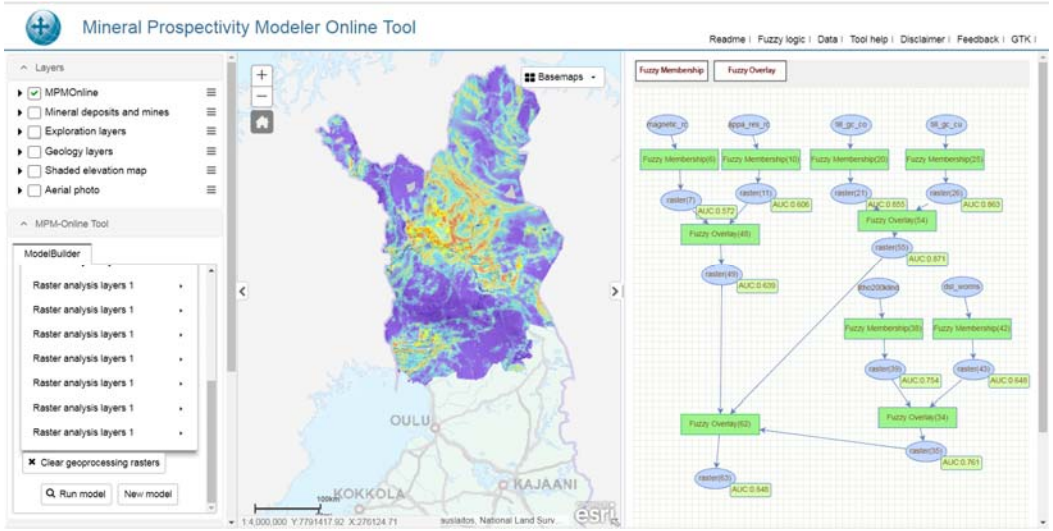




March 9th 2021

MPM ONLINE TOOL

- Conceptual fuzzy logic prospectivity modelling tools using the geological, geophysical and geochemical data provided by web map applications -> http://gtkdata.gtk.fi/mpm/



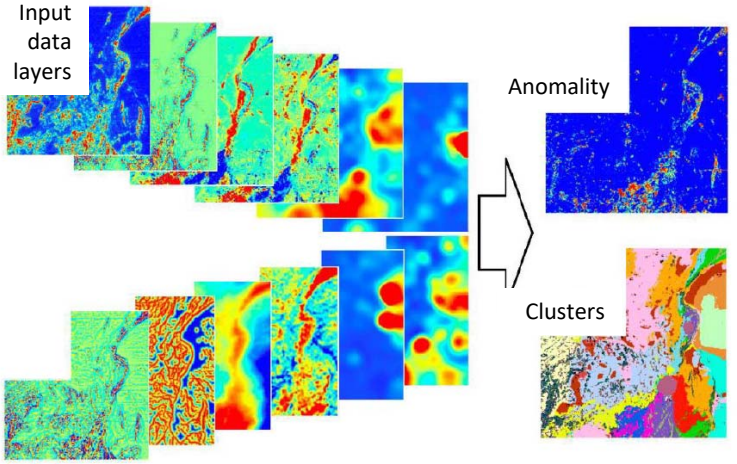
The NEXT Project

New Exploration Technologies for a More Efficient, Economic and Environmentally Friendly Ore Exploration

Development of data integration methodology and workflows for the different study areas and deposit types

⇒ NEXT has developed a reliable, easy-to-use **self-organizing map (SOM) software tool** devoted to data integration and spatial data analysis

⇒ We aim to create **predictive maps** for the investigated study areas and the different deposit types based on the developed data integration techniques of **SOM** and the available technique of the **ANN**



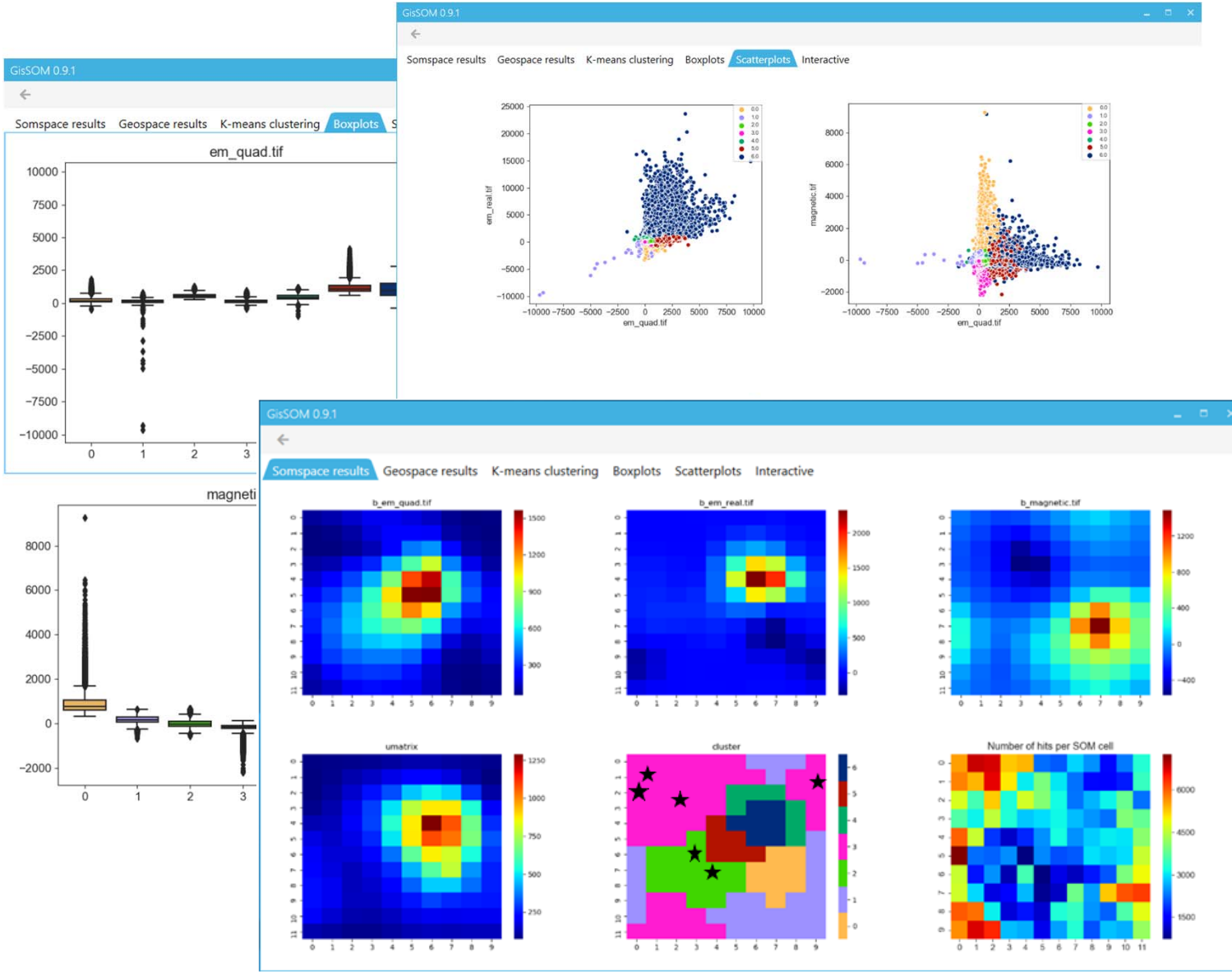
Example of data integration: multiple input data layers from geophysics and geochemistry are combined to produce maps showing either the level of anomality of each pixel or the areas with similar properties.

Source: Torppa J., Middleton M., Hyvönen E., Lerssi J. and Fraser S., 2015

This project is funded by the European Union

GISSOM

- GisSOM performs SOM clustering and optionally also k-means clustering.
- Displays the results in SOM and geospaces.
- Visualizes the data distribution in k-means clusters as box and scatter plots.
- In SOM space, labelled data (e.g. locations of known deposits) can be shown on the cluster map indicating which clusters are prospective.
- Tool available at GitHUB: https://github.com/gtkfi/GisSOM

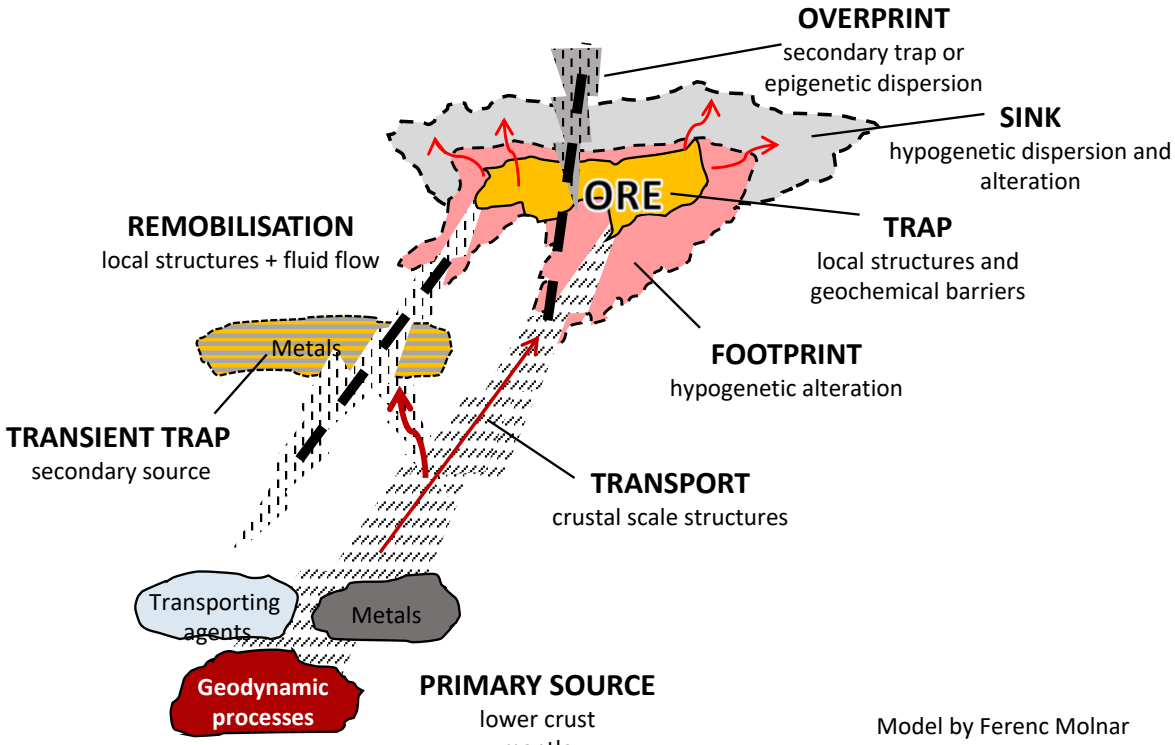


March 9th 2021

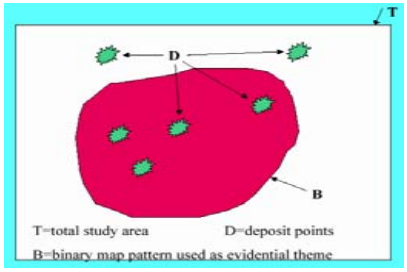
PROSPECTIVITY MODEL CAN BE BASED ON A THEORETHICAL **MINERAL SYSTEM MODEL** OR ALTERNATIVELY ON A PRACTICAL EXPLORATION MODEL

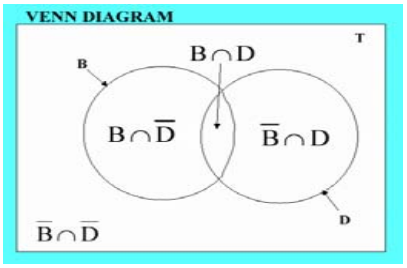
GENETIC MODEL:

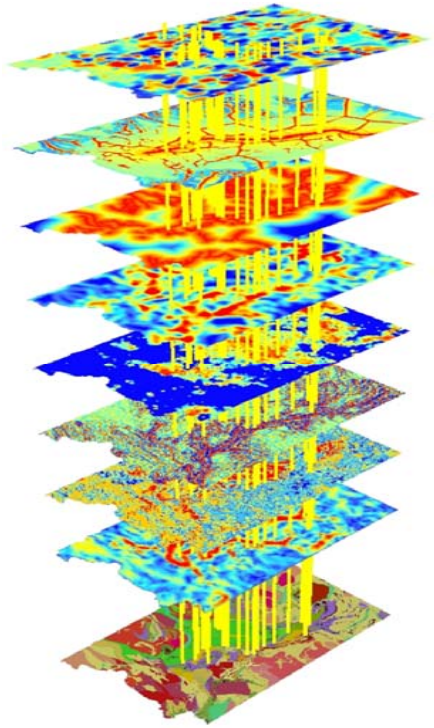
- **Source** of metals & fluids: rocks undergoing metamorphism in depth
- **Pathway**: (transcrustal) shear/thrust zones (during active seismic phase(s))
- **Trap**: reactive rocks, contrasting rheologies, structural traps (jogs, low permeability seals, folds)
- Formation of orogenic-Au deposits is *essentially a metamorphic process* – intrusives may contribute, but are not neccesary for the process!



INPUT LAYERS FOR OROGENIC GOLD PROSPECTIVITY MODELS







Paleostress model: zones of dilation

Distance from granitoid midpoints: zones of convergent/divergent flow

Proximity to greenstone/sedimentary contact: rheology contact/seal

Density of contacts: lithodiversity

Combined till geochemistry:
As, Au, Cu, Fe, Ni and Te

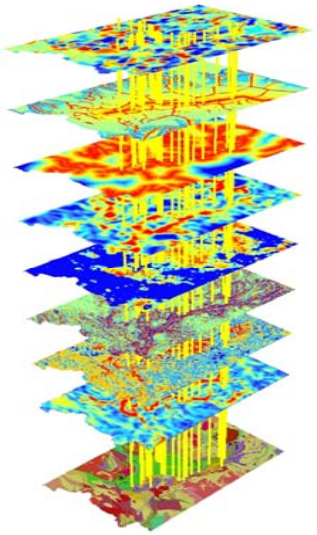
Airborne magnetics:
magnetic field total intensity: alteration zones

Airborne electromagnetics:
apparent resistivity: alteration zones

Gravity: horizontal gradient: faults, structural complexities

Bedrock geology: lithologies, faults etc.

DATA DRIVEN (WEIGHTS OF EVIDENCE) OROGENIC GOLD PROSPECTIVITY MODEL



Paleostress model: zones of dilation

Distance from granitoid midpoints: zones of convergent/divergent flow

Proximity to greenstone/sedimentary contact: rheology contact/seal

Density of contacts: lithodiversity

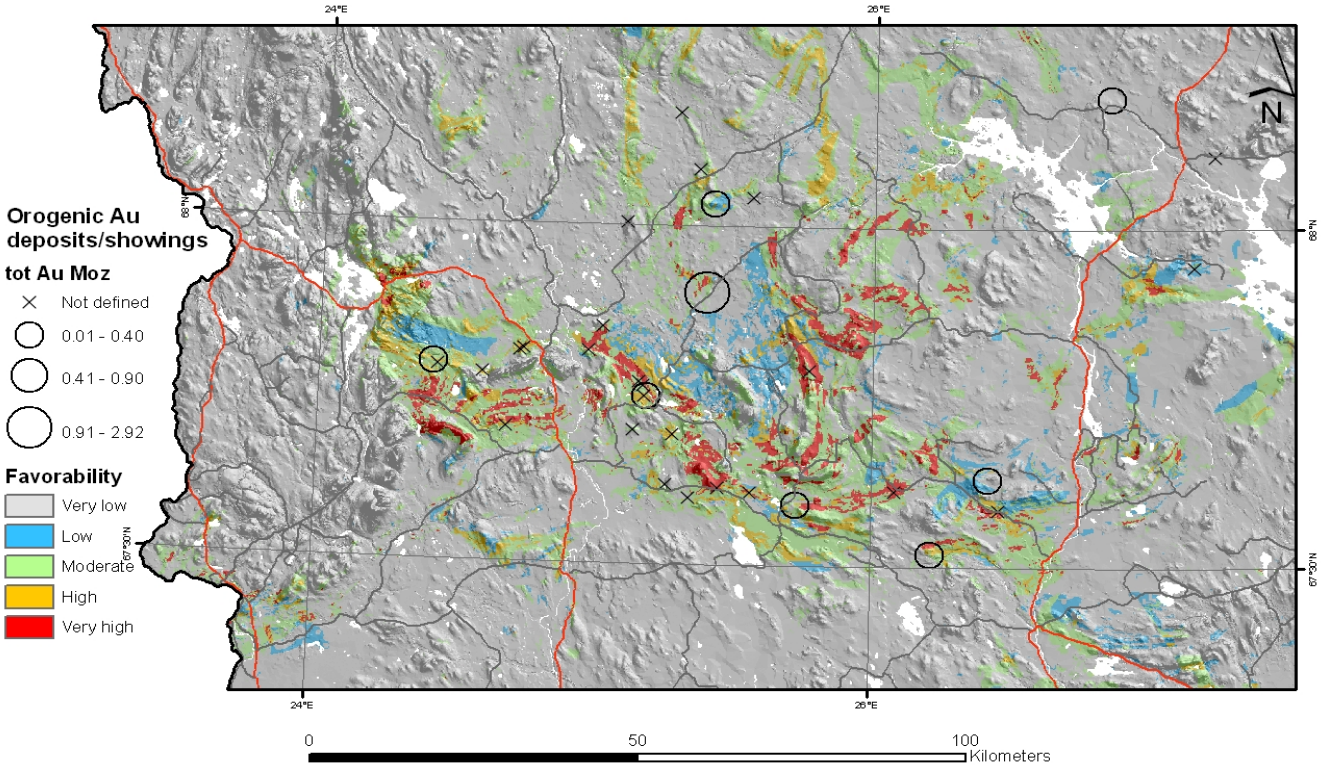
Combined till geochemistry: As, Au, Cu, Fe, Ni and Te

Airborne magnetics: magnetic field total intensity: alteration zones

Airborne electromagnetics: apparent resistivity: alteration zones

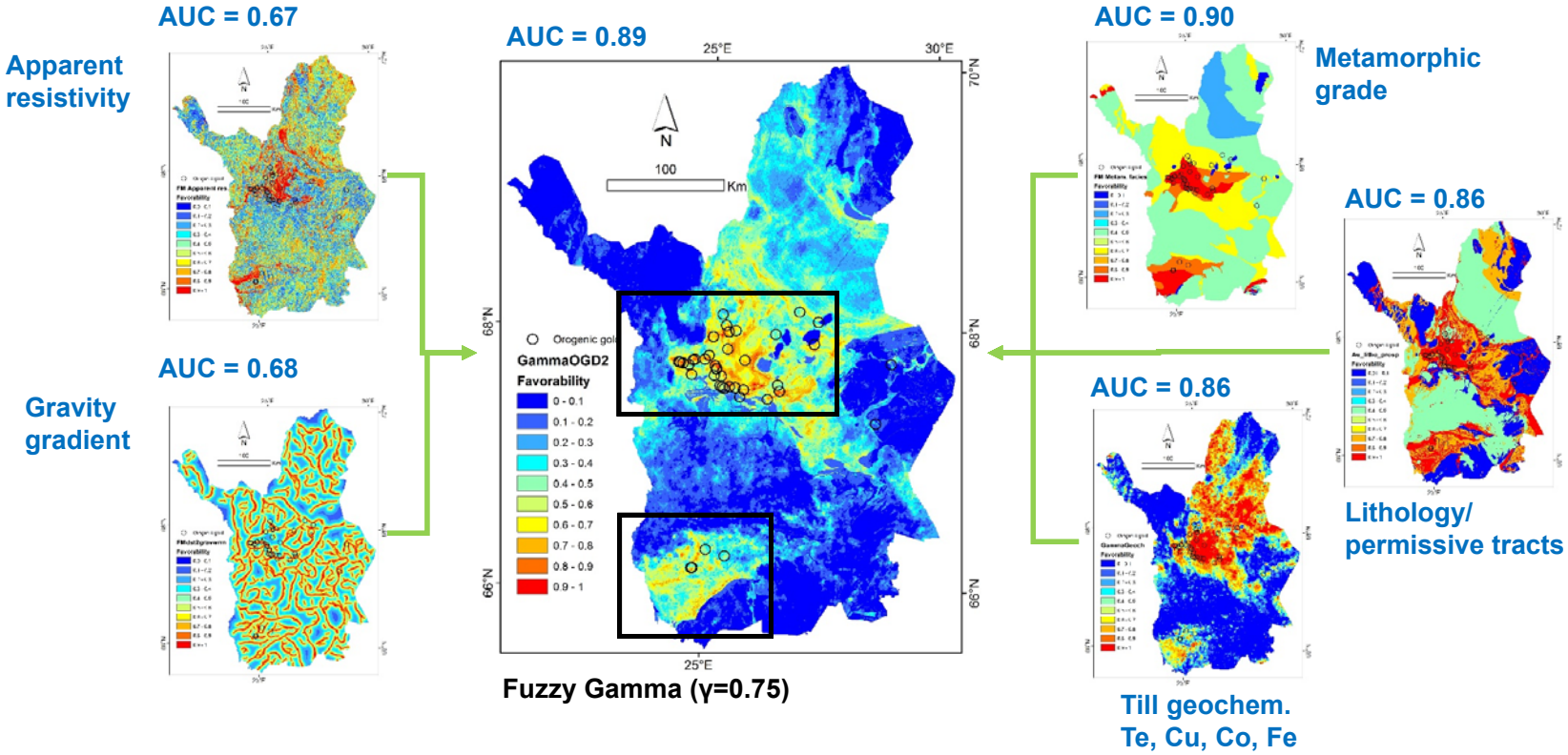
Gravity: horizontal gradient: faults, structural complexities

Bedrock geology: lithologies, faults etc.



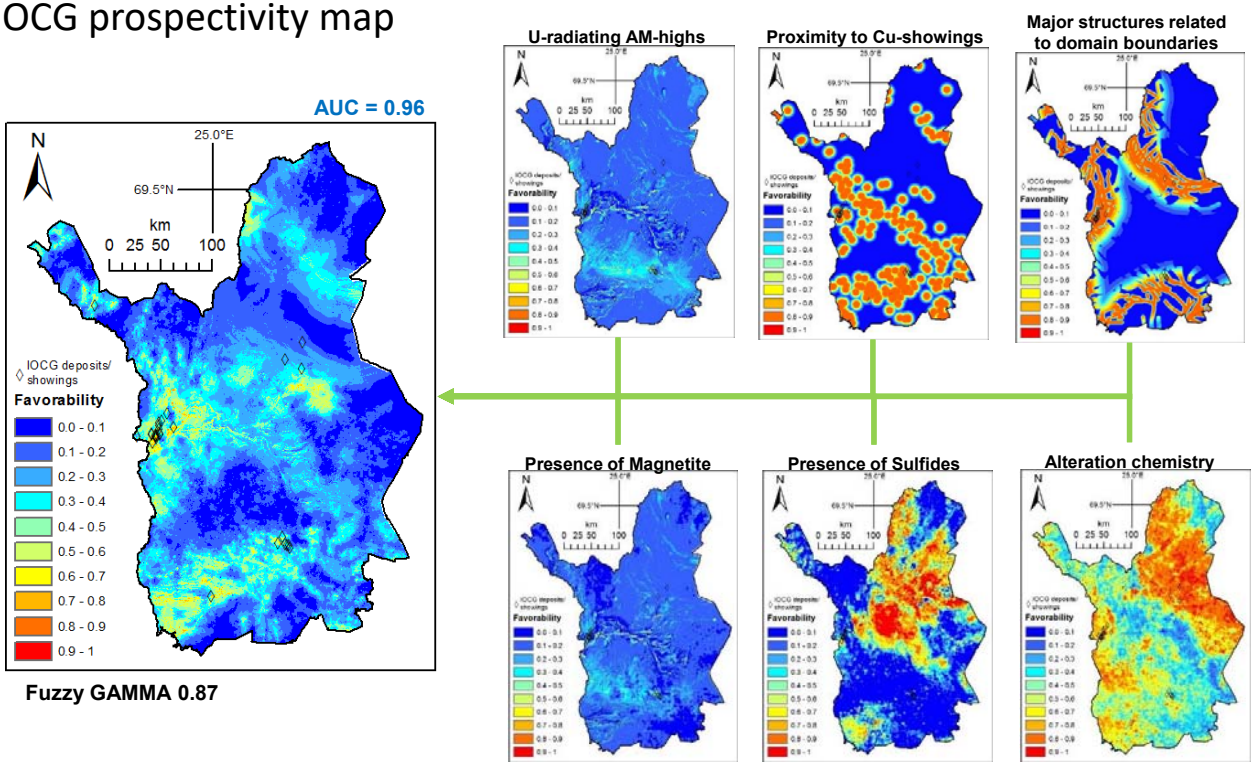
March 9th 2021

KNOWLEDGE DRIVEN (FUZZY LOGIC) REGIONAL SCALE OROGENIC GOLD PROSPECTIVITY

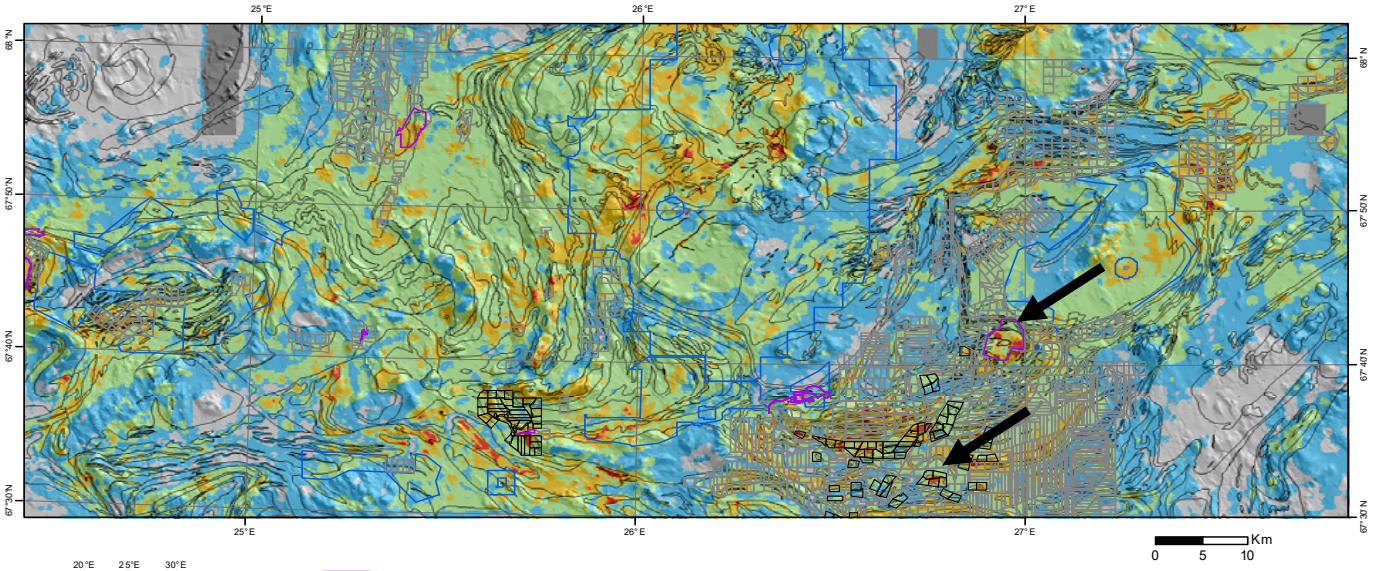


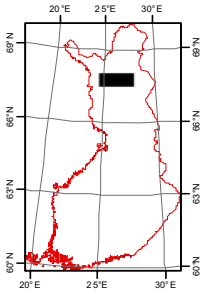
KNOWLEDGE-DRIVEN (FUZZY LOGIC) PROSPECTIVITY MODEL FOR IRON OXIDE-CU-AU (IOCG) DEPOSITS IN NORTHERN FINLAND

- IOCG prospectivity map



KNOWLEDGE DRIVEN (FUZZY LOGIC) MAGMATIC NICKEL-COPPER PROSPECTIVITY MODEL FOR CENTRAL LAPLAND

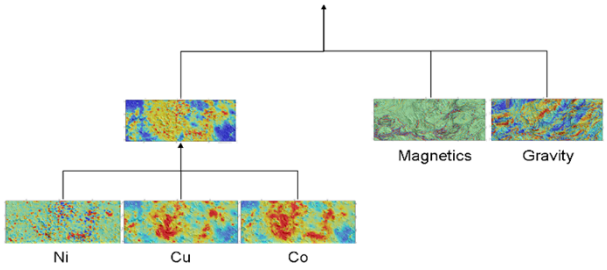




Mining concession
Claim (Ni-Cu)
Claim application
Reservation

Ni prospectivity

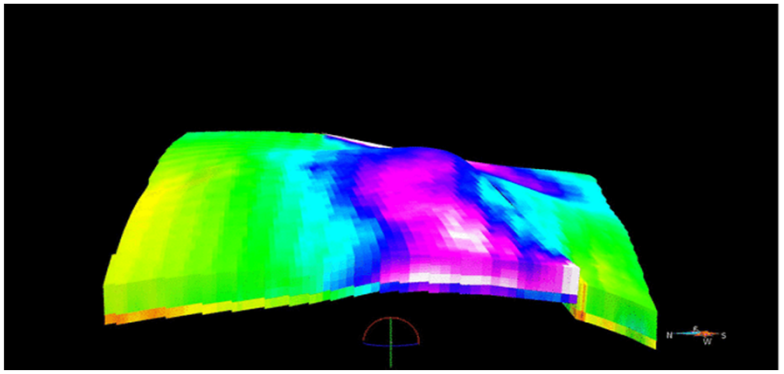
Very low
Low
Moderate
High
Very high



- Prospectivity map combining AM, gravity and till geochemistry

SUMMARY:

- ArcSDM5 available from GITHub https://github.com/gtkfi/ArcSDM
  - *Up to following versions: ArcGIS Desktop 10.5, ArcGIS Pro 2.2*
- GisSOM available from GITHub https://github.com/gtkfi/GisSOM
- MPM on-line http://gtkdata.gtk.fi/mpm/
- Hot topics:
  - *Use of mineral system parameters*
  - *New automated "artificial intelligence" type of modeling tools*
    - *Deep learning*
    - *Machine learning*
      - *SOM*
  - *3D prospectivity modeling*



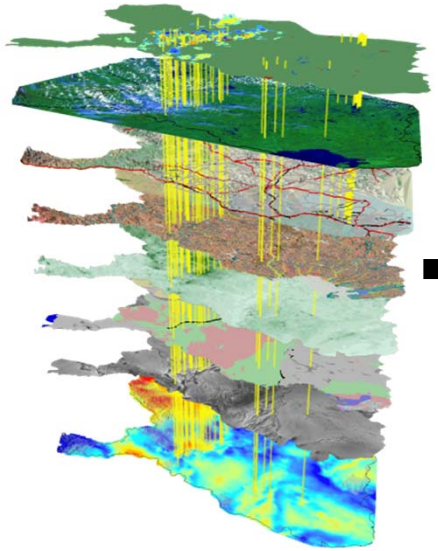
The NEXT Project

New Exploration Technologies for a More Efficient, Economic and Environmentally Friendly Ore Exploration

NEXT key figures

- Call: H2020-SC5-13c-2016-2017 - New solutions for sustainable production of raw materials
- Duration: 01.05.2018 – 30.04.2021
- Coordinator: Geological Survey of Finland
- Consortium: 16 partners from 6 EU countries

This project is funded by the European Union



Thank you for your attention!

Download ArcSDM https://github.com/gtkfi/ArcSDM

More info: http://projects.gtk.fi/mpm

This project is funded by the European Union