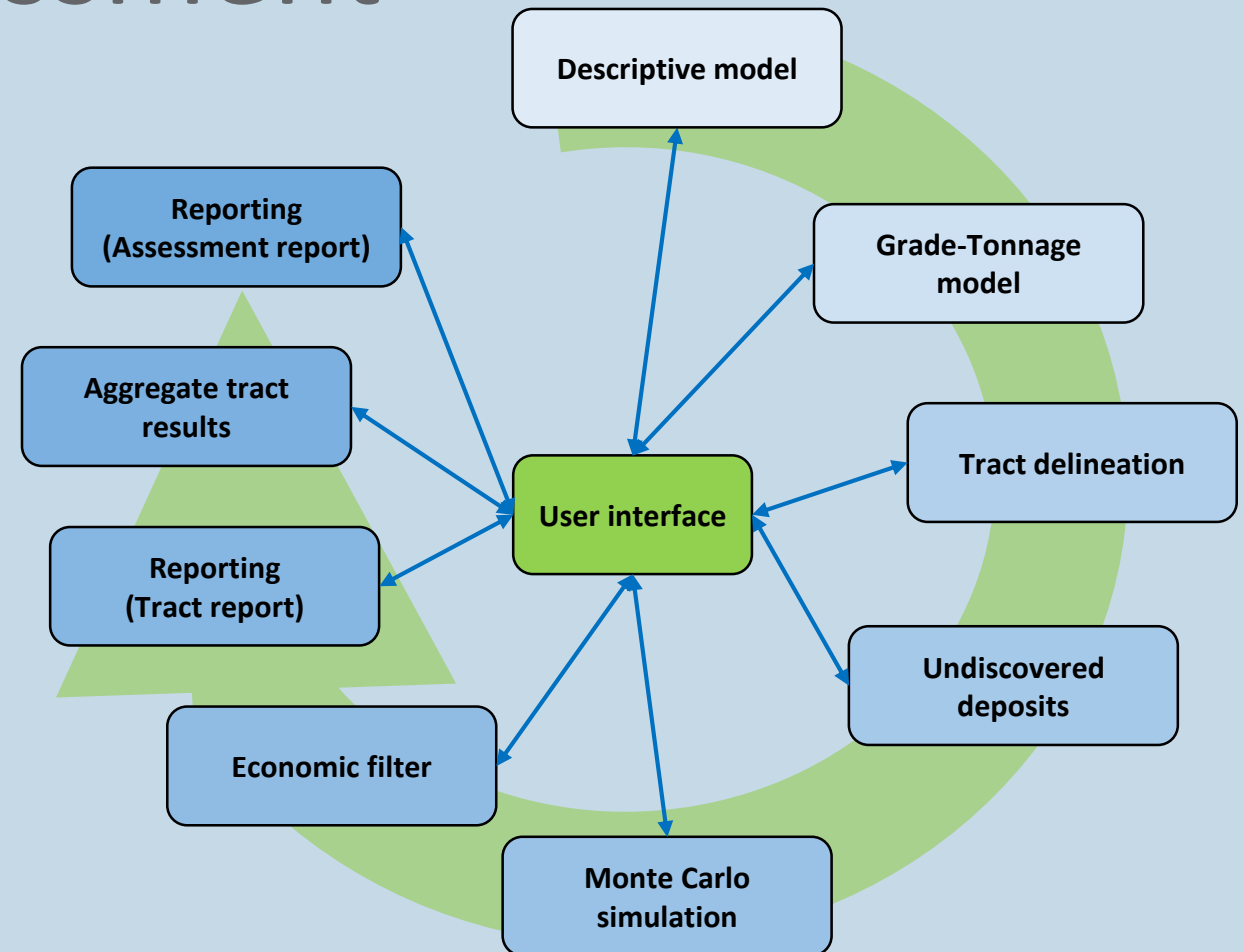


Mineral resource assessment platform (MAP)

Introduction



MINERAL RESOURCE ASSESSMENT PLATFORM (MAP)



- EIT RawMaterials KAVA upscaling project, duration 2018 – 2020
- Total budget 1.85 M€, EIT funding 1.63 M€, partner co-funding 12 %
- Coordinator Geological Survey of Finland (GTK) + 8 partners:
 - *Geological Survey of Norway (NGU), Geological Survey of Sweden (SGU), Iceland GeoSurvey (ÍSOR)*
 - *University of Oulu – Oulu Mining School (OMS), Norwegian University of Science and Technology (NTNU)*
 - *Beak Consultants GmbH (BEAK), LTU Business AB (LTUB)*
 - *U.S. Geological Survey (USGS) – supporting partner*
- **The project will produce an upgraded method and software for quantitative assessment of undiscovered mineral resources**



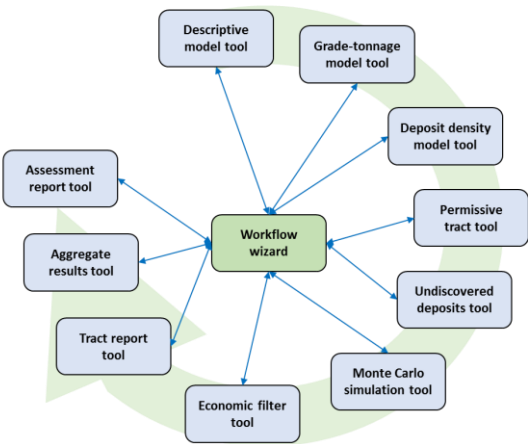
REASON FOR THE MAP PROJECT

- Three-part method is the most commonly used method for quantitative assessment of undiscovered resources
 - *Logical*
 - *Transparent*
 - *Produces probabilistic quantitative estimates of undiscovered endowment*
- There are shortcomings in the ways the three-part method is usually applied



MAJOR ENHANCEMENTS

New software to enable smooth assessment process flow



Inclusion of economic filter tool

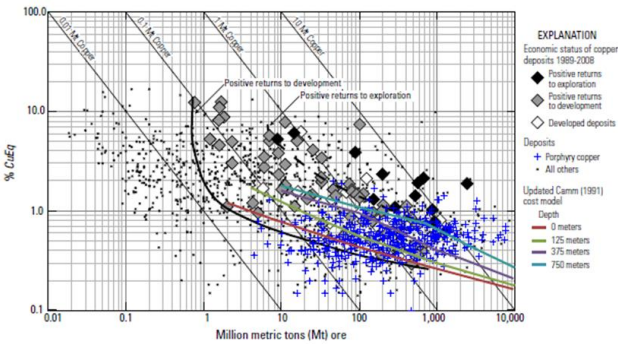
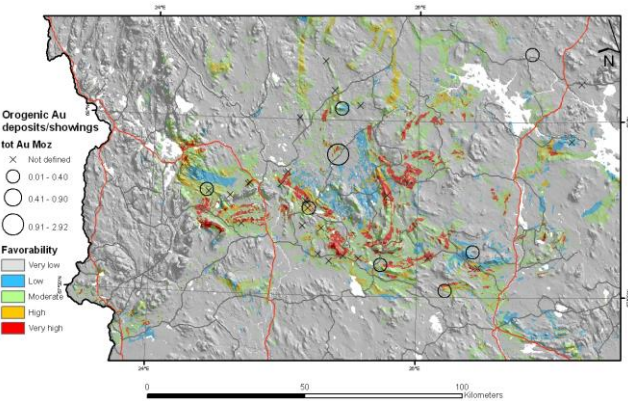


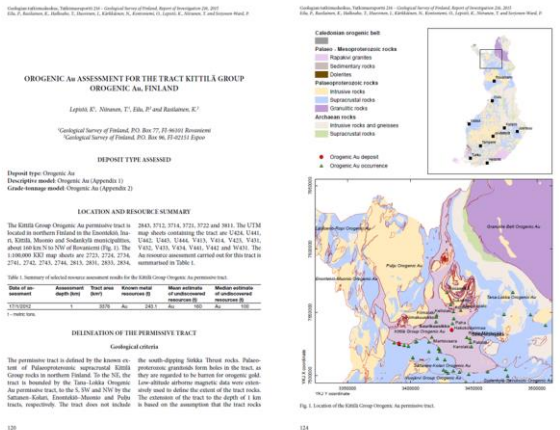
Figure 4. Comparison of the cutoff grade calculated for porphyry copper deposits using updated simplified engineering cost models for open-pit and block caving mines as a function of deposit depth and ore tonnage. Also shown are the grade-tonnage features defining the case-study economics status of recently developed copper deposits (shown as large diamond symbols) from Doggett and Leveille (2010). % CuEq, percent copper equivalence, as defined in equation 10.

Robinson & Menzie 2012. USGS SIR 2010-5090-H

Implementation of Mineral Prospectivity Modelling (MPM) tools for permissive tract delineation and classification



Inclusion of reporting tools



MAJOR OUTPUTS

- MapWizard software distribution package
 - *Freely available*
 - *Open source*
 - *Available on GitHub*
 - *Documentation includes User guide and Data guide*
- MAP Wizard for advangeo® 2D Prediction software
 - *Commercial product by BEAK*
- Assessment reports for VMS, skarn, epithermal and seafloor deposits
- Short courses and workshops during the project
 - *Stakeholder workshop*
 - *Assessment workshops*
 - *Short course at the Fennoscandian Exploration and Mining (FEM 2019, Finland) conference*
 - *Short course at the PDAC 2020 conference Toronto, Canada)*
 - *Online lecture in EIT International Summer School*
 - *New course on Resource potential estimation at NTUT, spring 2022*

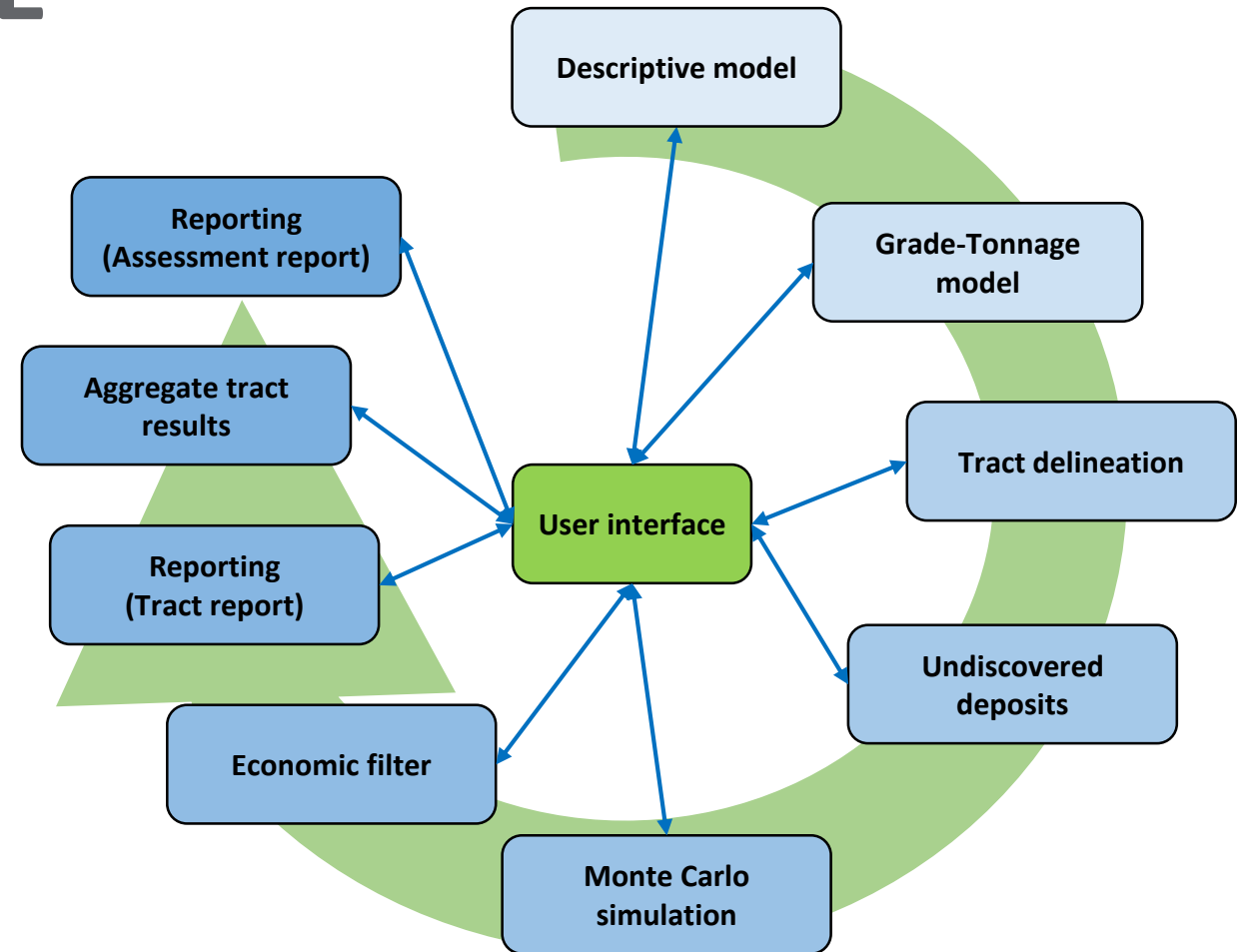
FINAL STAKEHOLDER WORKSHOP



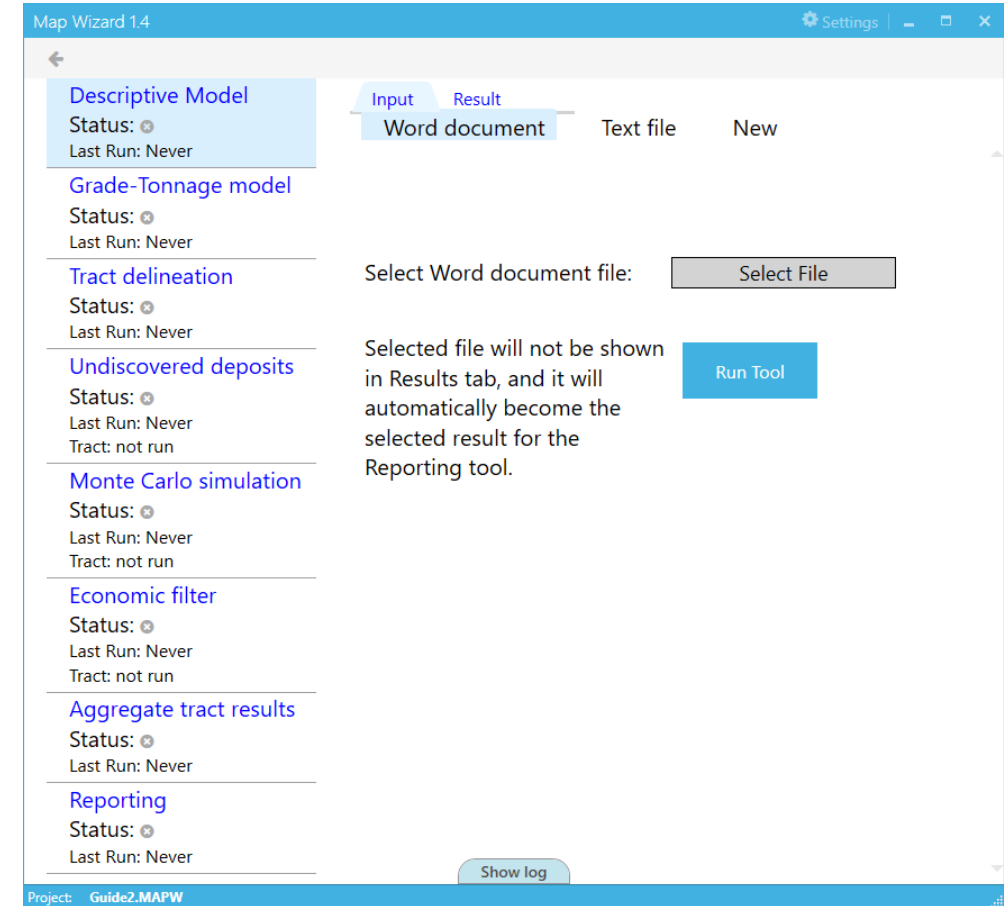
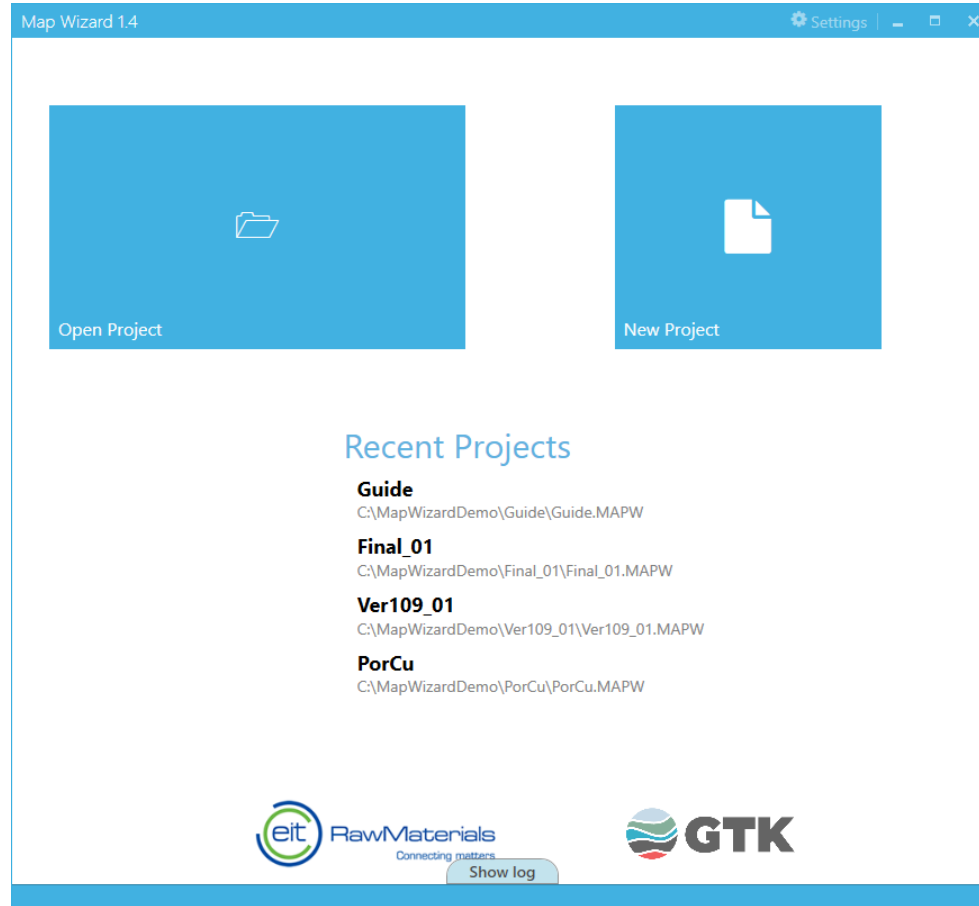
- 13:00 – 13:10 Welcome and Summary of MAP. – *Catherine Bounsaythip (EIT RawMaterials), Kalevi Rasilainen (GTK)*
- 13:10 – 13:20 Demo of Final MapWizard software. – *Kalevi Rasilainen (GTK)*
- 13:20 – 13:30 Demo of Final MapWizard in advangeo[®] 2D Prediction software. – *Peggy Hielscher (BEAK)*
- 13:30 – 13:50 Results of Volcanogenic Massive Sulfide ore assessment in Skellefteå area in Sweden and in the Caledonides in Norway. – *Martiya Sadeghi (SGU), Terje Bjerkgård (NGU)*
- 13:50 – 14:00 Results of Sn skarn assessment in Erzgebirge, Germany. – *Andreas Brosig (BEAK)*
- 14:10 – 14:20 Results of epithermal gold assessment, Iceland. – *Tobias B. Weisenberger (ÍSOR)*
- 14:20 – 14:30 Results of Seafloor Massive Sulfide assessment in the Rainbow area, Mid-Atlantic ridge. – *Steinar Løve Ellefmo (NTNU)*
- 14:30 – 14:45 Education activities in MAP. – *Shenghong Yang (OMS)*
- 14:45 – 15:00 Final remarks and discussion.

MAPWIZARD SOFTWARE

- Open source
- Freely available
- Covers the whole assessment process
- Separate tool for each task
- Several tools use existing USGS code
 - *MapMark4: USGS Monte Carlo simulator, coded in R (Shapiro 2018)*
 - *RAEF: USGS economic filter, coded in R (Shapiro and Robinson 2018)*
 - *AggExt, ATA: USGS aggregation script, coded in R (Schuenemeyer et al. 2011, Shapiro & Robinson 2019)*
 - *Fuzzy, WofE: BEAK Fuzzy logic and Weights of evidence functions, coded in python (BEAK consultants GmbH 2020)*



STARTUP PAGE AND ACTIVE PROJECT PAGE



GRADE-TONNAGE MODEL TOOL

- Reads in data from well-known deposits
- Estimates probability density functions (pdf) for tonnage and grade
 - *Tonnages are transformed with the natural logarithm*
 - *Grades are transformed using the isometric log-ratio*
- Provides summary statistics and plots of the data and estimated probability distributions
- Saves the estimated probability density functions for use in Monte Carlo simulation in the active assessment project
 - *Saves the estimated probability density functions for use in Monte Carlo simulation in other assessment projects*
- The tool is based on and uses R functions of USGS MapMark4 software

Input

Result

Select input data

Select Data

Select tools to be executed

☐ Grade ☐ Tonnage ☐ Joint Grade-Tonnage

Grade seed

1

Tonnage seed

2

Pdf type

normal

Truncated

FALSE

Random samples

1000000

Save output in separate folder?

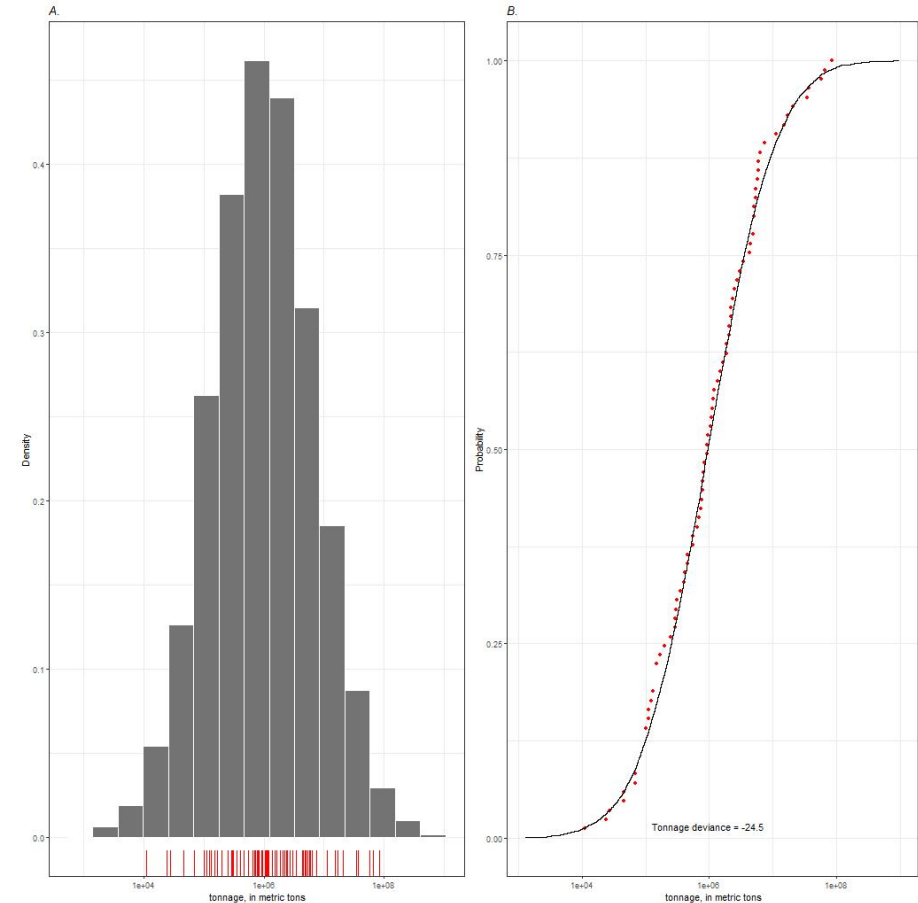
☒ Yes ☐ No

Subfolder name

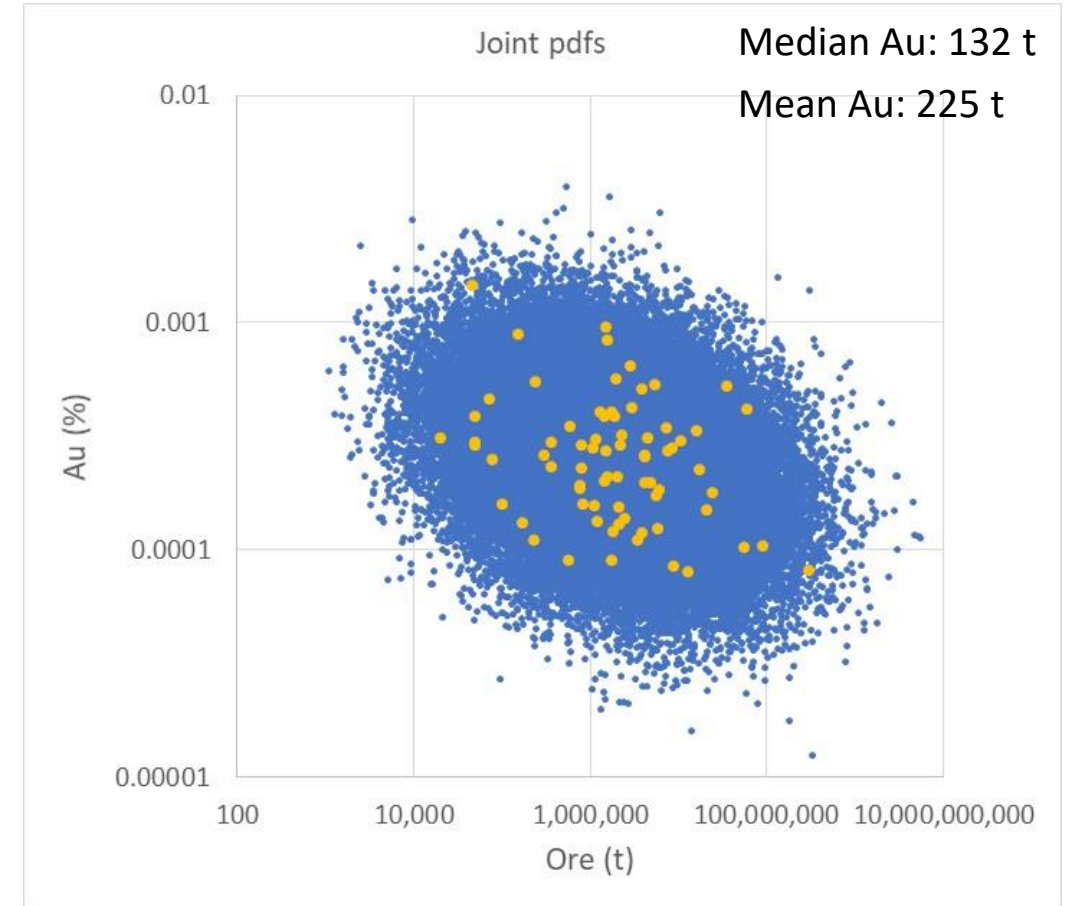
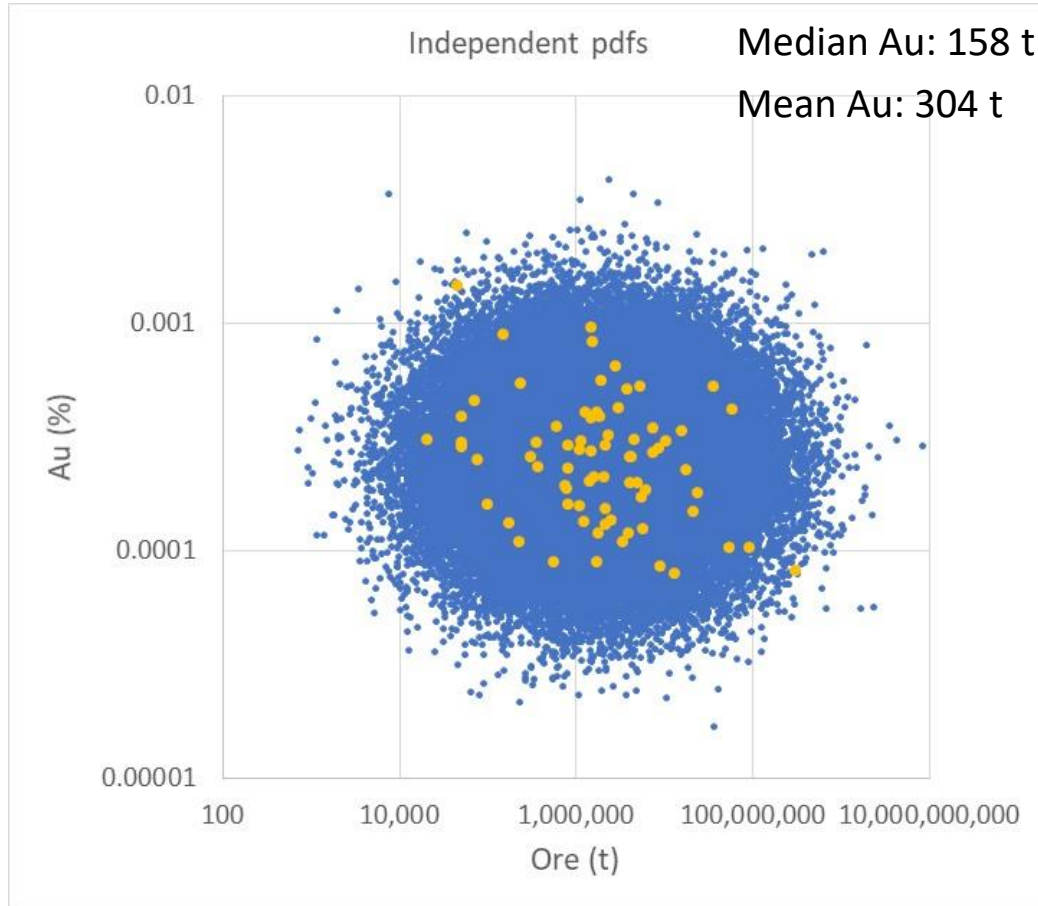
Run Tool

GRADE-TONNAGE MODEL TOOL OUTPUT

- Tonnage probability density function (pdf), grade pdf, joint grade-tonnage pdf as R objects
 - *To be used by MC simulation tool*
- Summary statistics of the probability distributions and comparison with data
- Plots of histograms and cumulative distribution functions calculated from the pdfs
- Scatterplots of the joint grade-tonnage pdf data

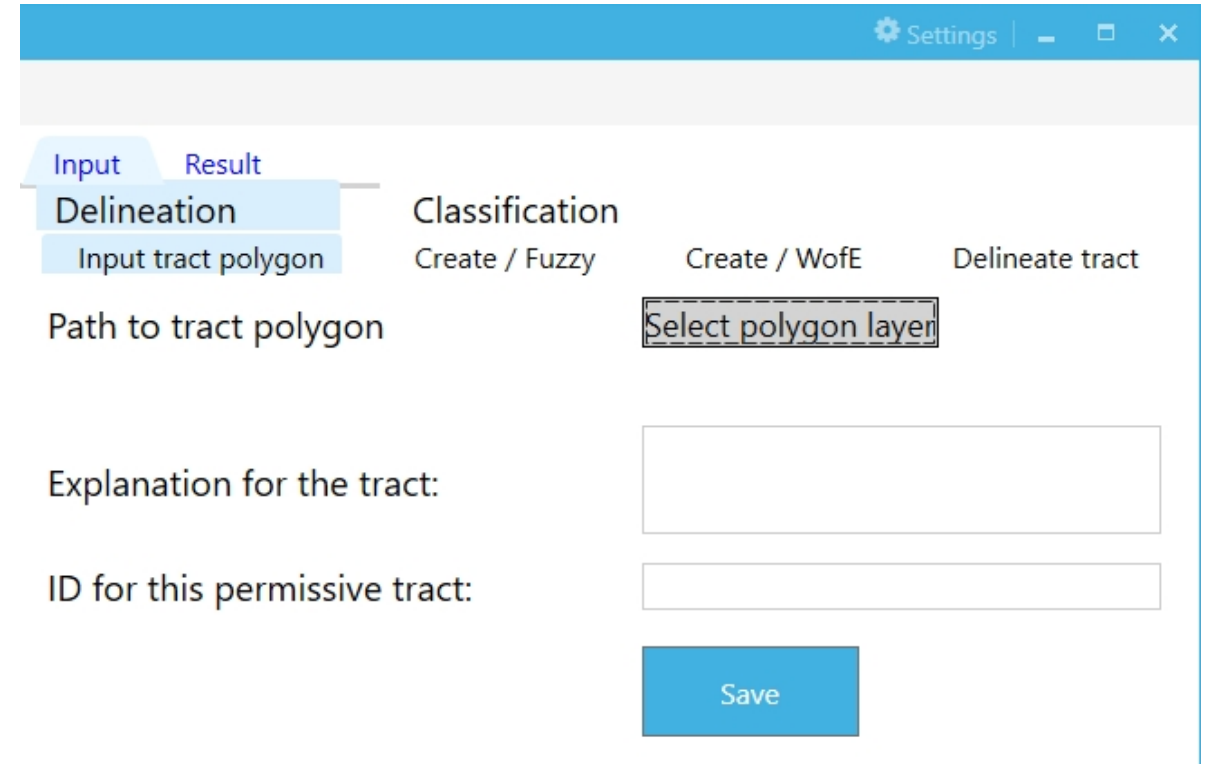


INDEPENDENT VS JOINT PDF



TRACT DELINEATION TOOL

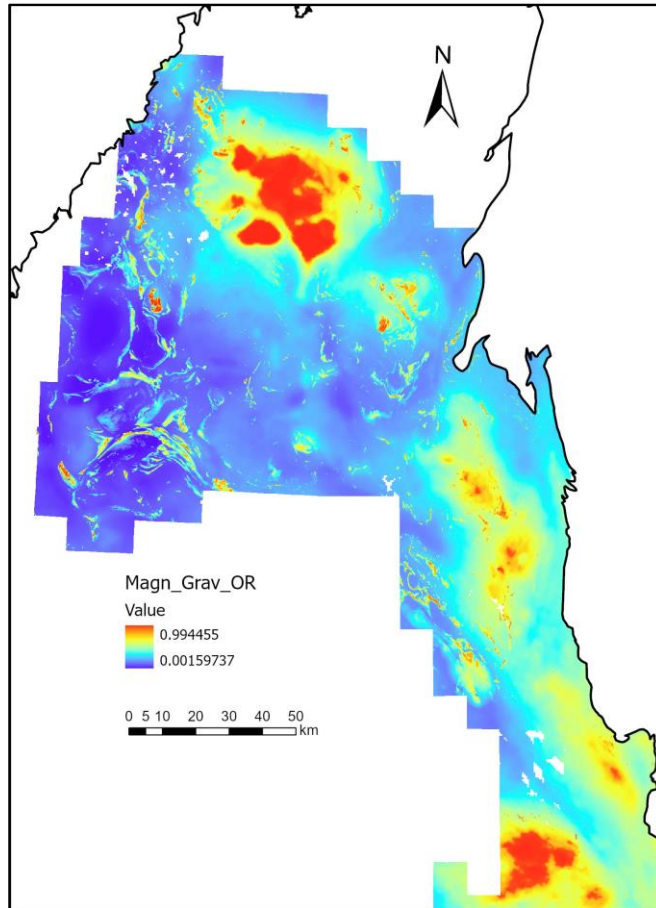
- Delineates and classifies permissive tracts using mineral prospectivity modelling techniques
- Provides the results of tract delineation and classification as raster and polygon files for use in GIS software
- Two processes:
 - *Tract delineation (based on permissiveness)*
 - *Tract classification (based on prospectivity or other characteristic)*
- Two methods:
 - *Fuzzy logic, Weights of evidence*
 - *Uses BEAK code*



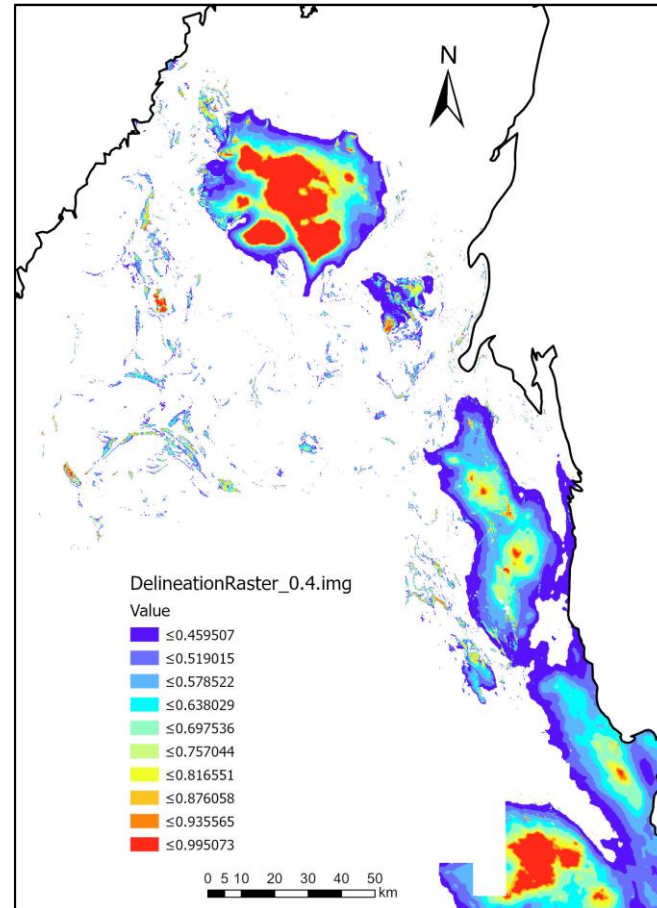
The screenshot shows the Tract Delineation Tool interface. It has a blue header bar with a 'Settings' button and window controls. Below the header, there are two tabs: 'Input' and 'Result'. Under the 'Input' tab, there is a 'Delineation' section with a sub-tab 'Input tract polygon'. To the right of this is a 'Classification' section with buttons for 'Create / Fuzzy', 'Create / WofE', and 'Delineate tract'. Below these buttons, there is a text input field labeled 'Path to tract polygon' with a placeholder text 'Select polygon layer'. Further down, there are two more text input fields labeled 'Explanation for the tract:' and 'ID for this permissive tract:'. At the bottom right, there is a blue 'Save' button.

DELINEATION AND CLASSIFICATION

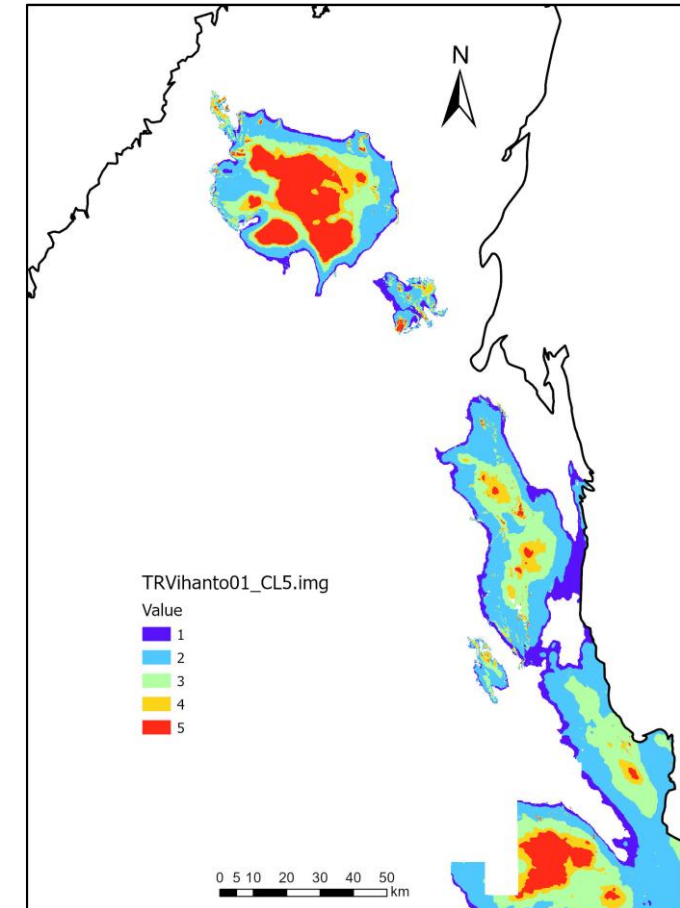
Delineation raster



Delineation raster masked at 0.4

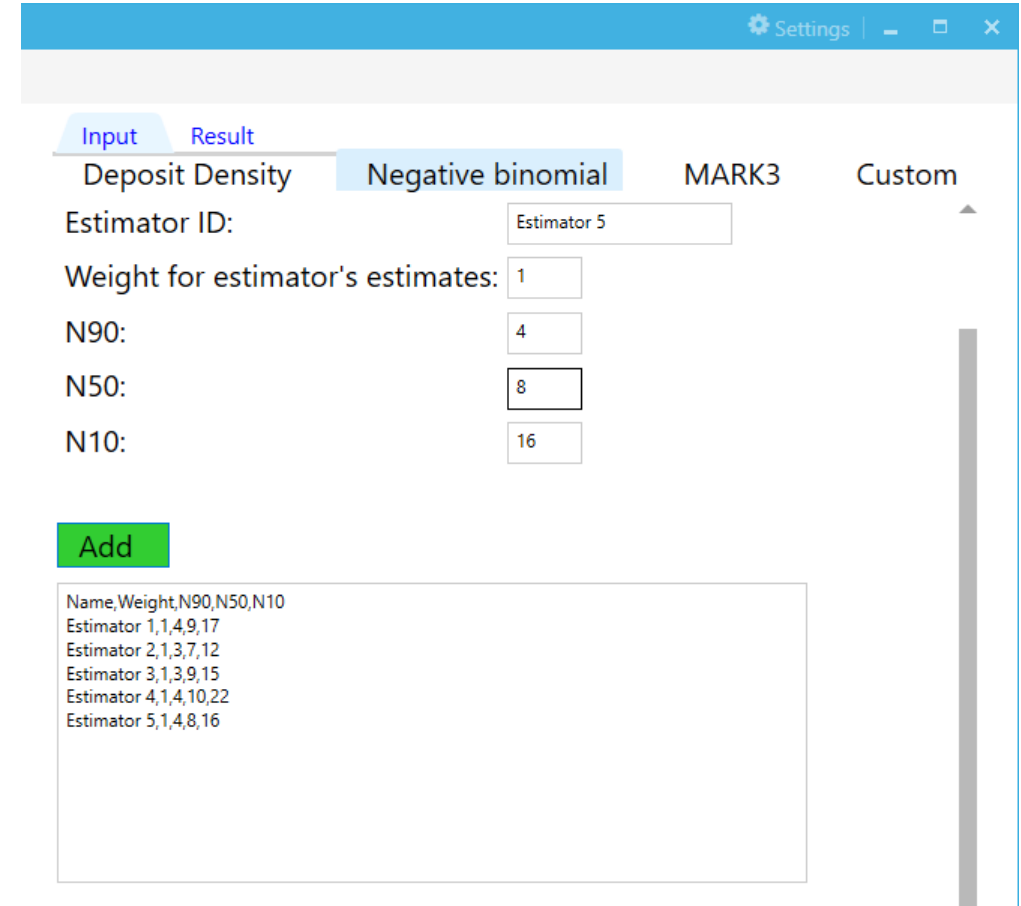


Delineation raster cleaned



UNDISCOVERED DEPOSITS TOOL

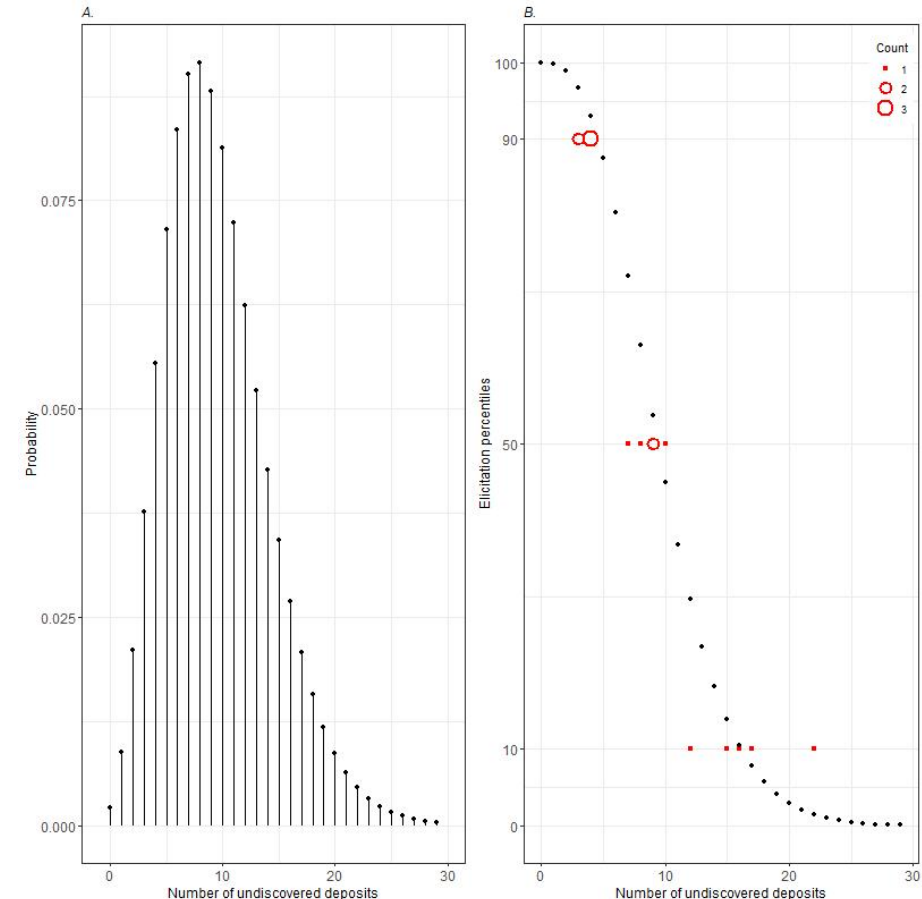
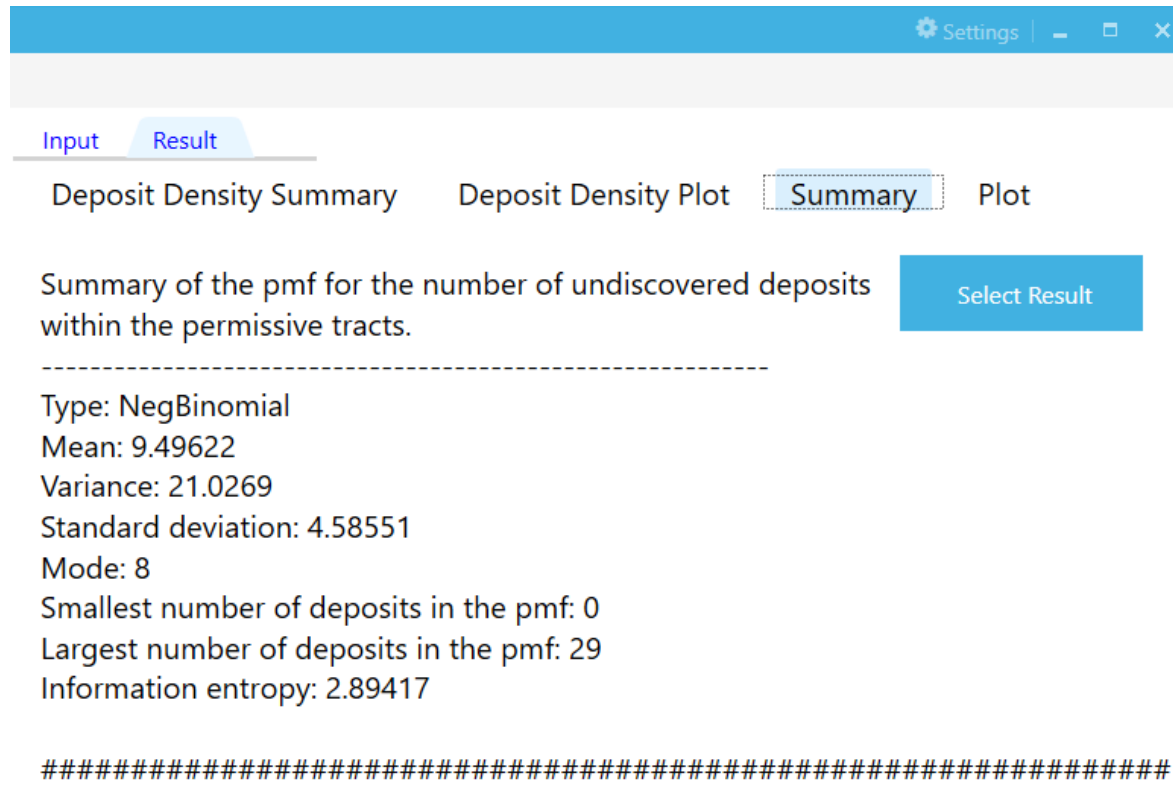
- Estimates a probability mass function (pmf) for the number of undiscovered deposits that might exist within a permissive tract
- Uses estimates provided by experts or deposit density models as input
- Provides summary statistics and plots of the input data and estimated probability distribution
- Saves the distribution probability mass function for use in Monte Carlo simulation
- The tool is based on and uses the R functions of USGS MapMark4 and Eminers software



The screenshot shows the 'Input' tab of the tool. It features a 'Deposit Density' dropdown menu set to 'Negative binomial'. Below this, there are input fields for 'Estimator ID' (set to 'Estimator 5'), 'Weight for estimator's estimates' (set to '1'), 'N90' (set to '4'), 'N50' (set to '8'), and 'N10' (set to '16'). A green 'Add' button is located below these fields. At the bottom, a list of estimators is displayed, showing their names, weights, and N90, N50, and N10 values.

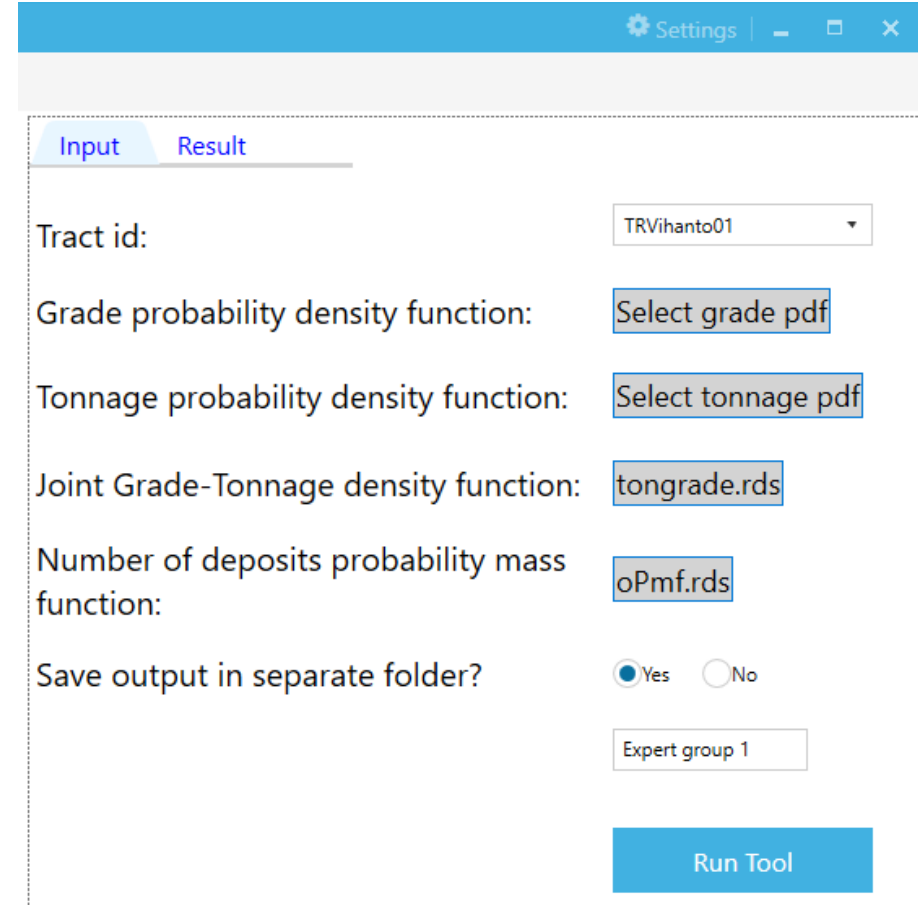
Name	Weight	N90	N50	N10
Estimator 1	1	4	9	17
Estimator 2	1	3	7	12
Estimator 3	1	3	9	15
Estimator 4	1	4	10	22
Estimator 5	1	4	8	16

UNDISCOVERED DEPOSITS TOOL OUTPUT



MONTE CARLO SIMULATION TOOL

- Produces a set of simulated undiscovered deposits
- Calculates a probabilistic estimate of the amount of undiscovered mineral resources contained by these deposits
- Provides summary statistics and plots of the estimated metal endowment
- Stores the set of simulated undiscovered deposits to be used in Economic filter tool
- The tool is based on and uses the R functions of USGS MapMark4 software



The screenshot shows the 'Input' tab of the Monte Carlo Simulation Tool. The interface includes a 'Settings' button in the top right corner. Below the tab headers, there are several input fields: 'Tract id' with a dropdown menu showing 'TRVihanto01'; 'Grade probability density function' with a button labeled 'Select grade pdf'; 'Tonnage probability density function' with a button labeled 'Select tonnage pdf'; 'Joint Grade-Tonnage density function' with a text input field containing 'tongrade.rds'; 'Number of deposits probability mass function' with a text input field containing 'oPmf.rds'; and 'Save output in separate folder?' with radio buttons for 'Yes' (selected) and 'No'. At the bottom, there is a text input field for 'Expert group 1' and a large blue 'Run Tool' button.

SIMULATED UNDISCOVERED ENDOWMENT

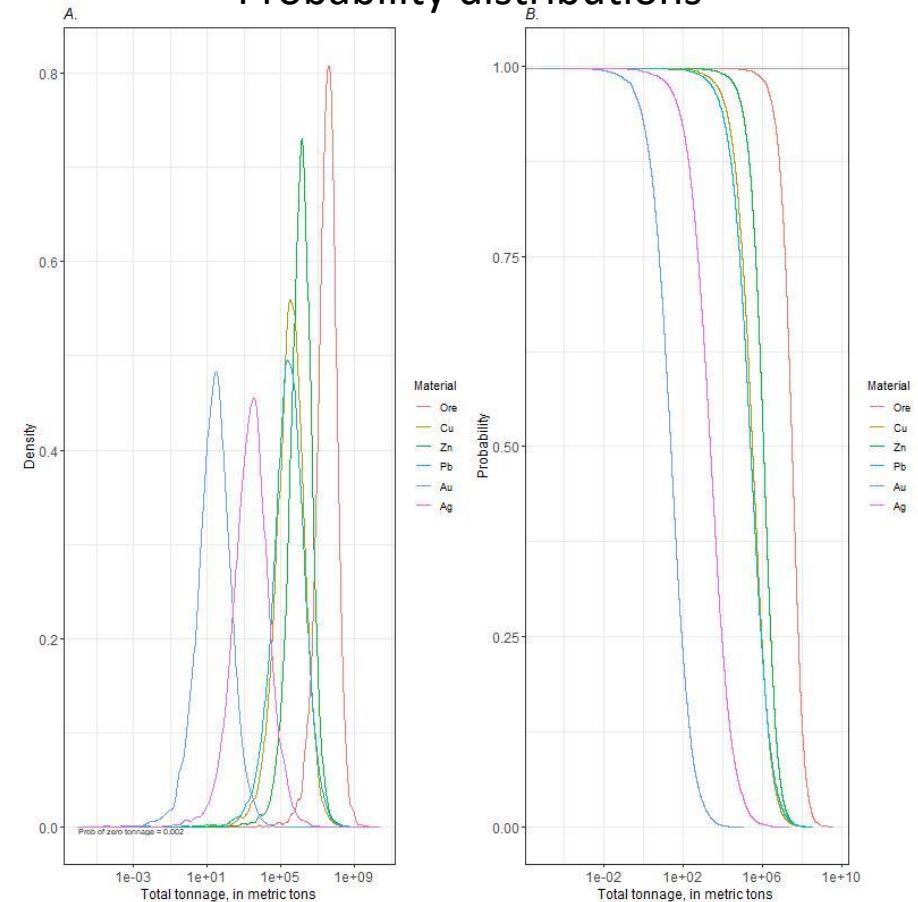
Summary statistics

Settings										
Input Result										
Summary Total Marginals Simulated deposits										
Summary of the pdf for the total ore and resource tonnages in all undiscovered deposits within the permissive tract.										
Select Result										
	Q_0.05	Q_0.1	Q_0.25	Q_0.5	Q_0.75	Q_0.9	Q_0.95	Mean	P(0)	P(>Mean)
Ore	3.12e+06	6.00e+06	1.43e+07	3.23e+07	6.69e+07	1.27e+08	1.91e+08	59100000	0.0023	0.287
Cu	1.30e+04	3.03e+04	1.01e+05	3.21e+05	9.48e+05	2.48e+06	4.66e+06	1310000	0.0023	0.188
Zn	8.83e+04	1.76e+05	4.67e+05	1.17e+06	2.72e+06	5.76e+06	9.34e+06	2660000	0.0023	0.256
Pb	7.13e+03	1.88e+04	7.30e+04	2.56e+05	8.95e+05	2.71e+06	5.53e+06	1510000	0.0023	0.166
Au	6.08e-01	1.52e+00	6.24e+00	2.44e+01	8.61e+01	2.83e+02	6.15e+02	191	0.0023	0.142
Ag	5.05e+01	1.37e+02	5.69e+02	2.43e+03	9.07e+03	3.25e+04	7.56e+04	27700	0.0023	0.114

Explanation

"Q_0.05" is the 0.05 quantile, "Q_0.1" is the 0.1 quantile, and so on.
 "Mean" is the arithmetic mean. "P(0)" is probability of zero tonnage.
 "P(>Mean)" is probability that the tonnage exceeds the arithmetic mean.

Probability distributions



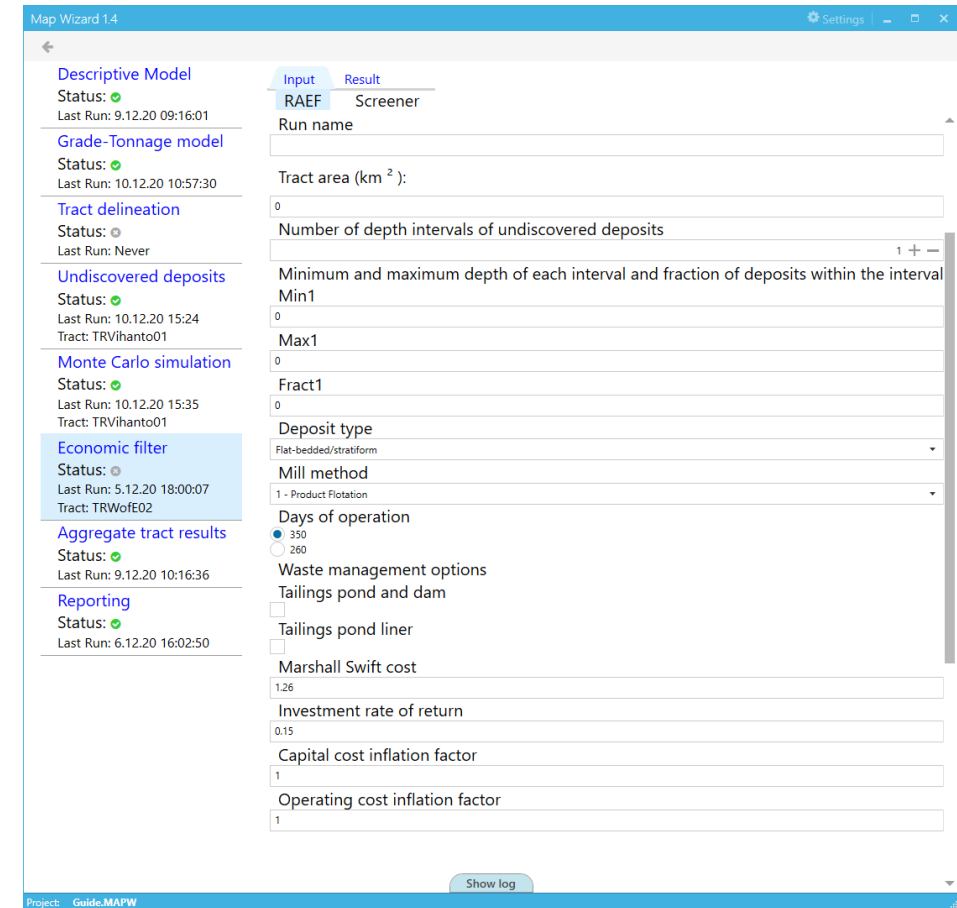
ECONOMIC FILTER TOOL

RAEF process

- Estimates the proportion of the total estimated undiscovered resource that can be considered to be economically viable for mining
- Applies simple engineering cost models to estimate the economic resource
- The tool is based on and uses the R functions of USGS RAEF code

Screeners process

- Calculates the resource contained in a selected fraction of the largest simulated deposits, or in the selected fraction of the total resource contained by the undiscovered deposits

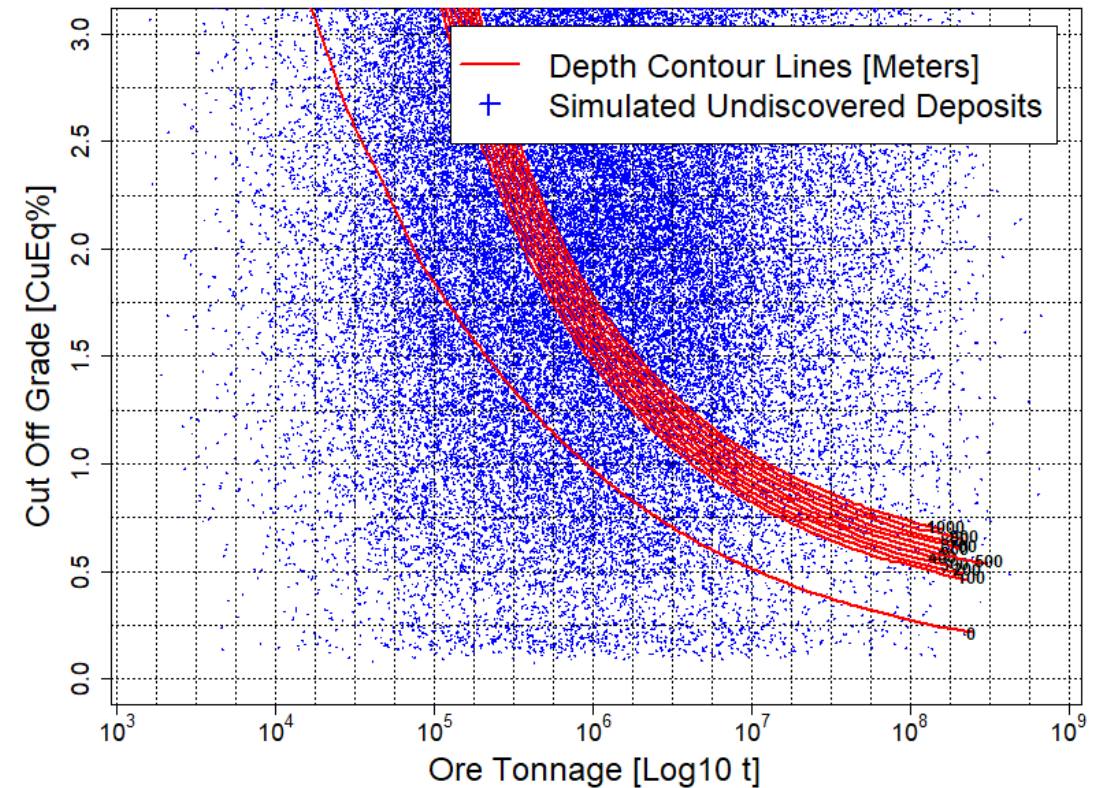


The screenshot shows the 'Map Wizard 1.4' application window. On the left, a sidebar lists several models: Descriptive Model, Grade-Tonnage model, Tract delineation, Undiscovered deposits, Monte Carlo simulation, **Economic filter** (highlighted), Aggregate tract results, and Reporting. The 'Economic filter' model is selected, showing its status as 'Never' and last run as '5.12.20 18:00:07' for tract 'TRWofE02'. The main panel is divided into 'Input' and 'Result' tabs. The 'Input' tab is active, displaying various configuration parameters for the economic filter, including 'Run name', 'Tract area (km²)', 'Number of depth intervals of undiscovered deposits', 'Minimum and maximum depth of each interval and fraction of deposits within the interval' (with fields for Min1, Max1, and Fract1), 'Deposit type' (set to 'Flat-bedded/stratiform'), 'Mill method' (set to '1 - Product Flotation'), 'Days of operation' (set to 350), 'Waste management options' (with checkboxes for 'Tailings pond and dam', 'Tailings pond liner', and 'Marshall Swift cost'), 'Investment rate of return' (set to 0.15), 'Capital cost inflation factor' (set to 1), and 'Operating cost inflation factor' (set to 1). A 'Show log' button is located at the bottom right of the main panel.

RAEF OUTPUT

	Means	Median	STD	P90	P50	P10	Prob of Zero	Prob >= Mean
Ore	28281423	10189790	49422531	882385	10189790	76756453	0.019	0.2624
Cu._Con	278513	59771	1156598	2900	59771	604204	0.019	0.19825
Zn._Con	1177701	352323	2671955	23069	352323	2985924	0.019	0.23385
Pb._Con	383618	54941	1667521	1577	54941	783008	0.019	0.1735
Au._Con	23	4	91	0	4	47	0.019	0.1809
Ag._Con	1502	320	5337	13	320	3333	0.019	0.1998
Cu._Rec	227510	38478	996887	0	38478	499093	0.1561	0.19475
Zn._Rec	966170	259403	2274686	0	259403	2509006	0.1561	0.2323
Pb._Rec	318448	36649	1416197	0	36649	651307	0.1561	0.17235
Au._Rec	16	2	66	0	2	33	0.1561	0.1794
Ag._Rec	1099	202	4035	0	202	2466	0.1561	0.1974
NPV_Tract	8.1E+08	2.11E+08	2.01E+09	0	2.11E+08	2.09E+09	0.1561	0.24185
NPV_Area	155024.3							

Cut Off Grade Vs. Ore Tonnage - VihantiMW



AGGREGATE TRACT RESULTS TOOL

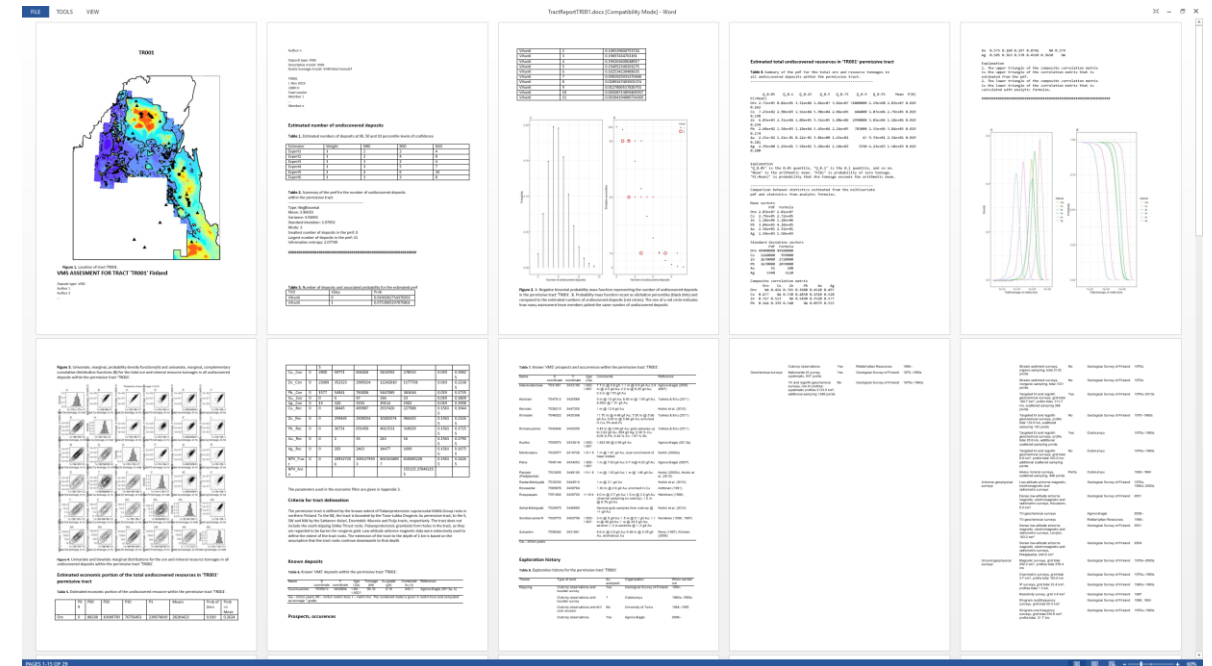
- Combines estimates of the number of undiscovered deposits for several permissive tracts
- Produces an aggregated estimate
 - *To be used as input to the Undiscovered deposits tool to estimate the probability mass function for the number of deposit in all the tracts*
- The tool is based on the R code of Schuenemeyer et al. (2011), which is also used in the USGS ATAGUI software

Tract id:

	TRWofE04	TRWofE03	TRWofE02	TRVihanto01
TRWofE04	Tract Correlation: <input type="text" value="1"/>			
TRWofE03	Tract Correlation: <input type="text"/>	Tract Correlation: <input type="text" value="1"/>		
TRWofE02	Tract Correlation: <input type="text"/>	Tract Correlation: <input type="text"/>	Tract Correlation: <input type="text" value="1"/>	
TRVihanto01	Tract Correlation: <input type="text"/>	Tract Correlation: <input type="text"/>	Tract Correlation: <input type="text"/>	Tract Correlation: <input type="text" value="1"/>

REPORTING TOOL

- Uses output from several other MapWizard tools, as well as interactive input and user-defined files containing additional information
- Produces a standard format report of the assessment results
 - *Separate report for each tract*
 - *Summary report for the whole assessment*



MAPWIZARD DOWNLOAD

- MapWizard freeware version is on GitHub:
 - <https://github.com/gtfi/MapWizard>
- The installation package includes:
 - *MapWizard software*
 - *Source code*
 - *Technical documentation*
 - *User manual*
 - *Method and data guide*
 - *Example data*

