

Resource estimation

ENSG- Marie-Cécile FEBVEY, Zélie
JANNEL

Using a case study developed by P.
Marchal

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Geological context

Stratiform Zn-Cu-Ag-Au volcanogenic massive sulfide (VMS)

Located in central Mexico, southern Zacatecas.

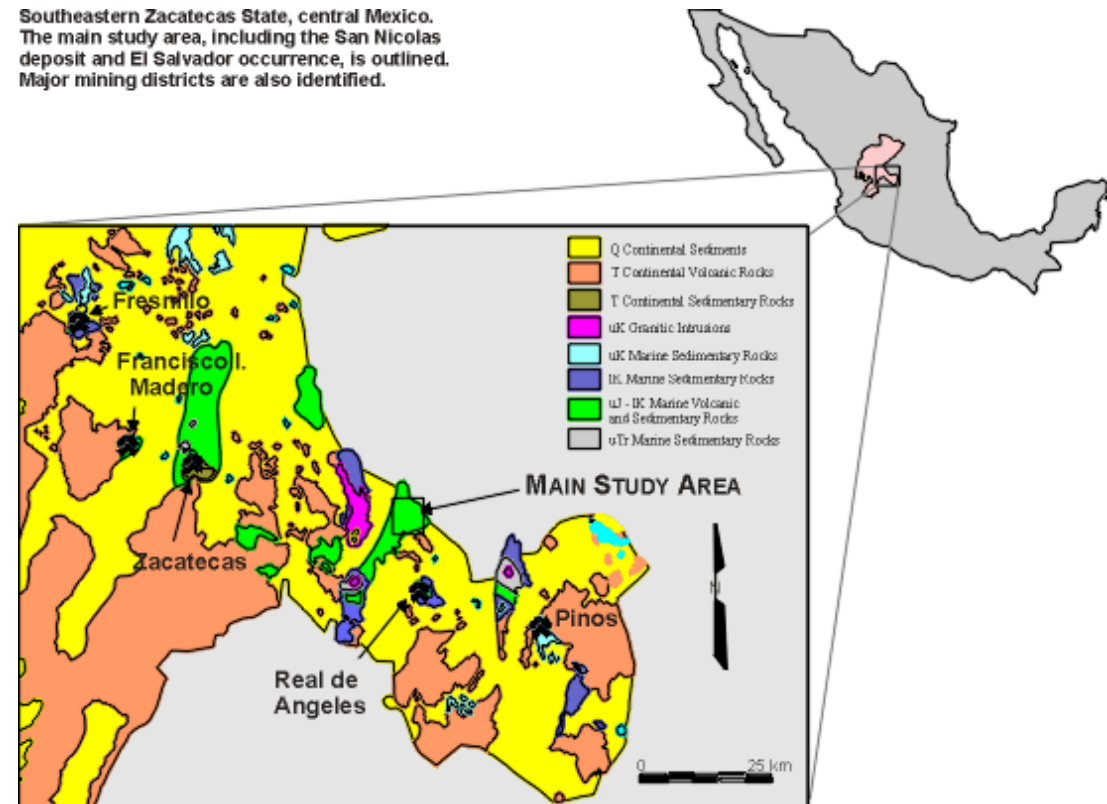
Late Jurassic-Early Cretaceous

Mineralization age (U/Pb) ~ 148 Ma

Resource estimation: 100 Mt at

- 1.36% Cu,
- 1.64% Zn,
- 0.15% Pb,
- 0.41 g/t Au,
- 24.0 g/t Ag

Southeastern Zacatecas State, central Mexico. The main study area, including the San Nicolas deposit and El Salvador occurrence, is outlined. Major mining districts are also identified.

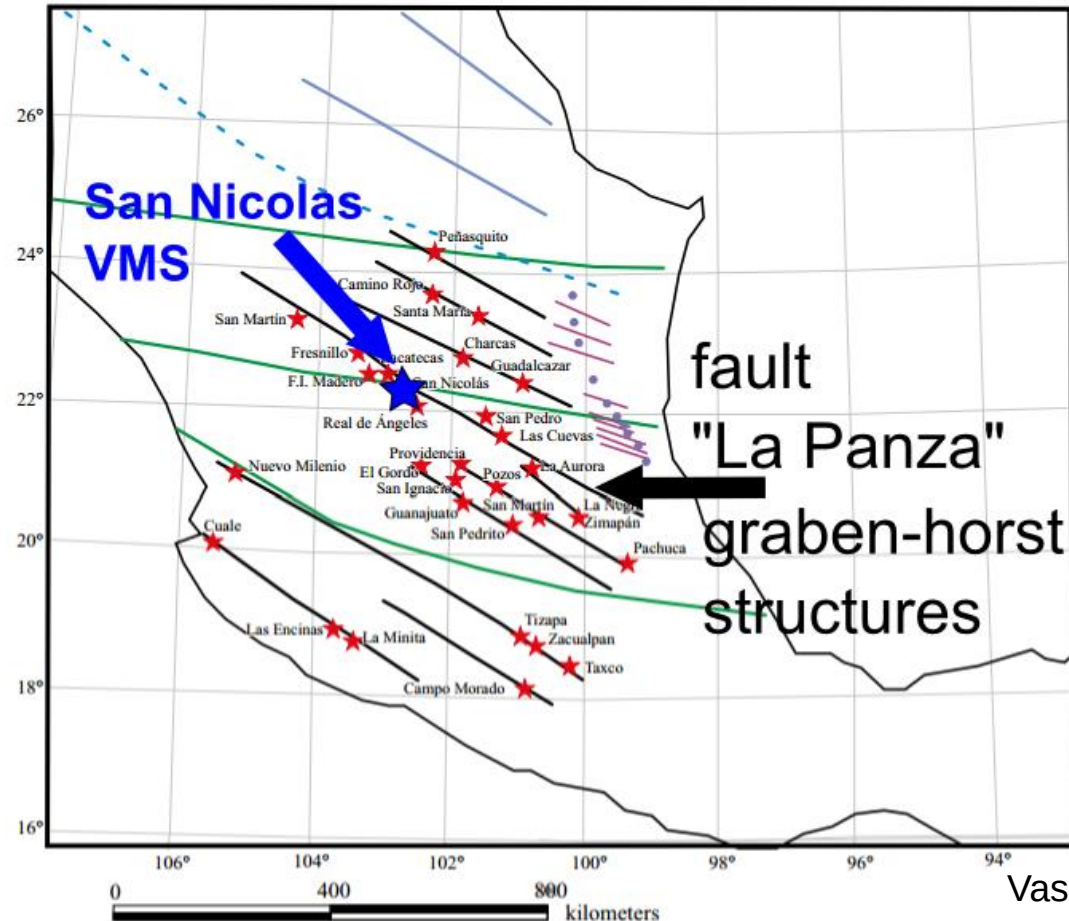
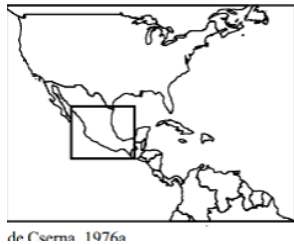


Geological context

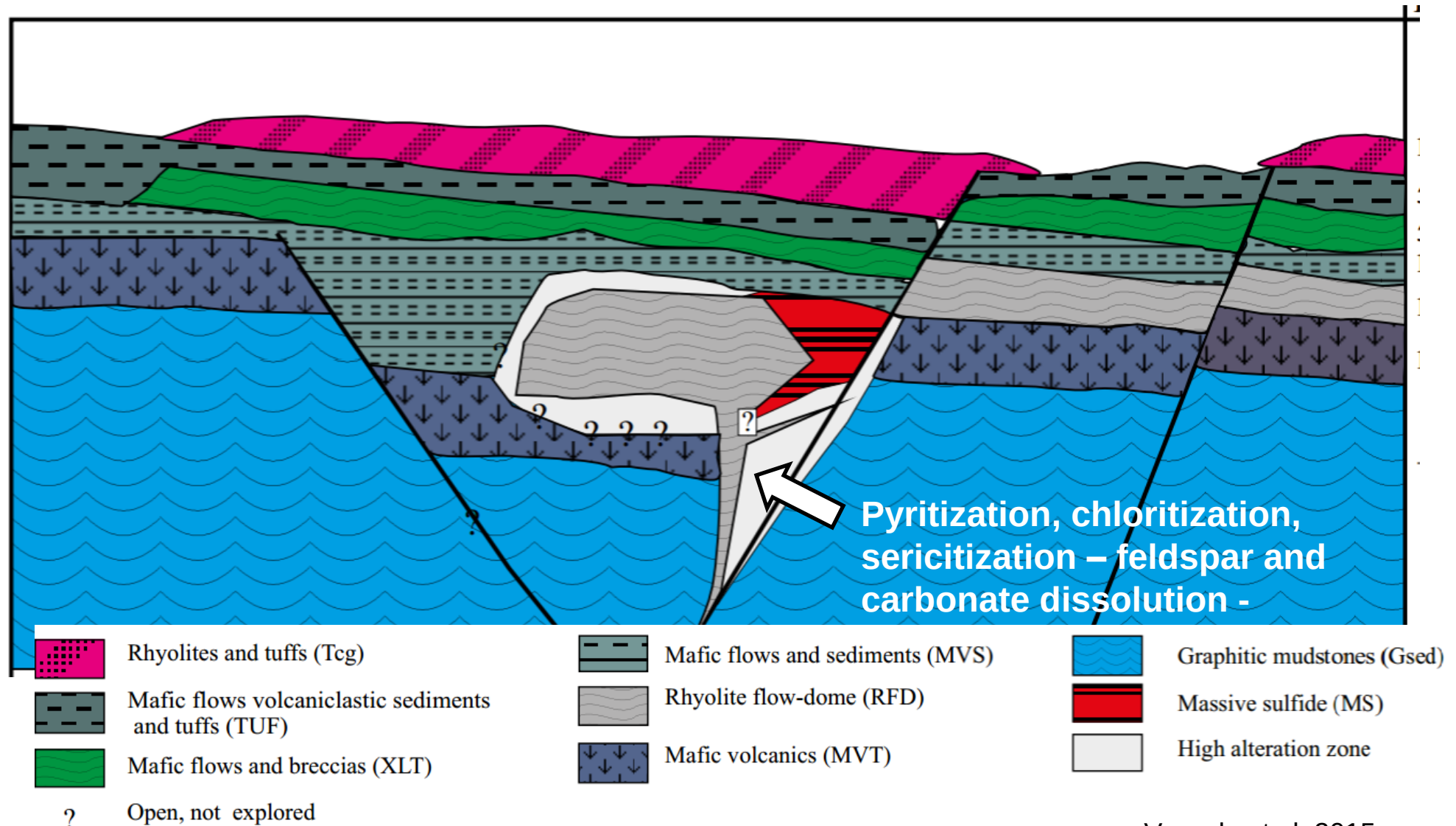
Geological setting

Related to a graben-horst – extension – opening of the Gulf of Mexico

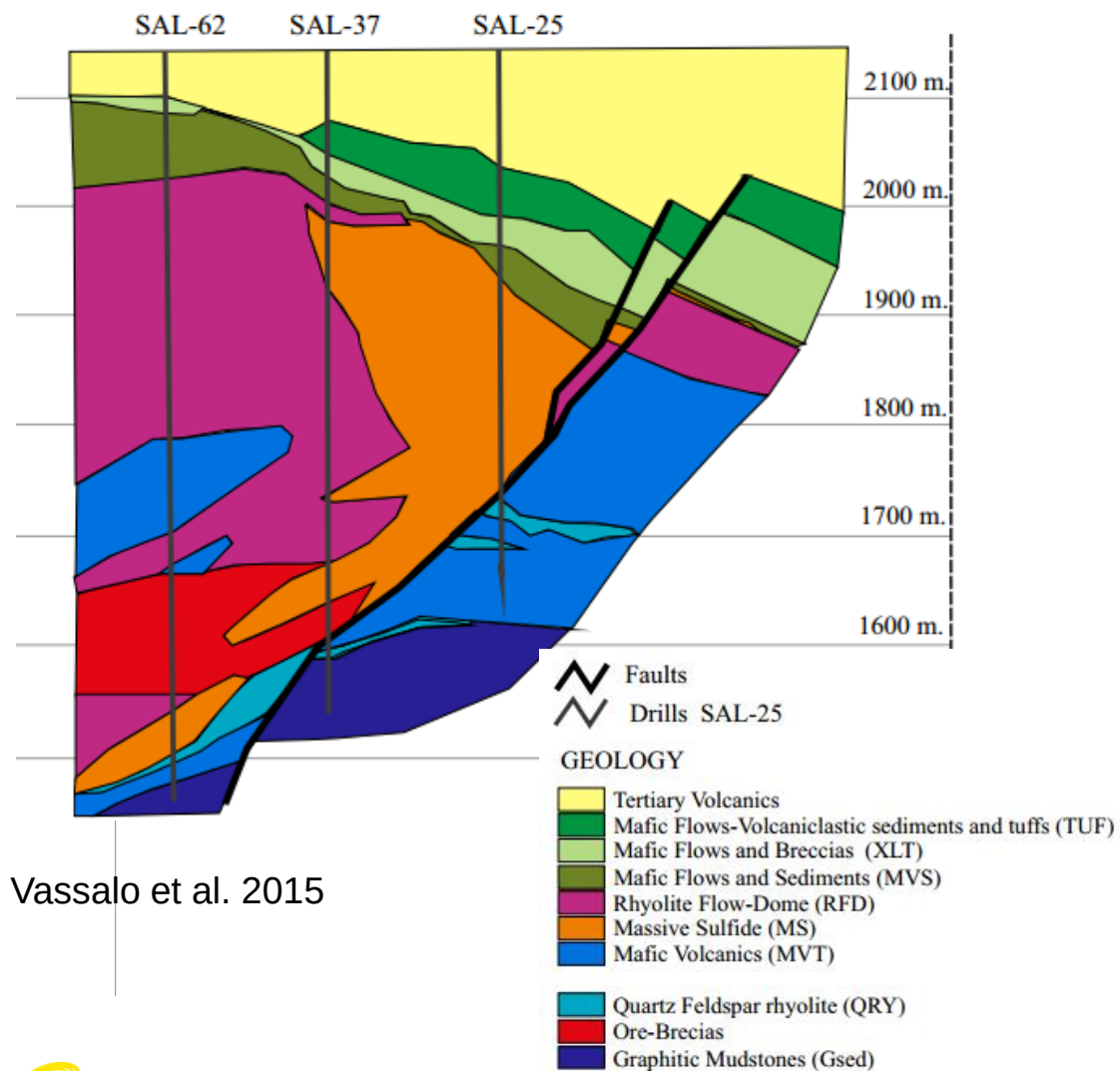
The « *LaPanza* » fault
control the mineralization



Proposed model for the volcanic structure



Case study



Vassalo et al. 2015

Johnson et al.

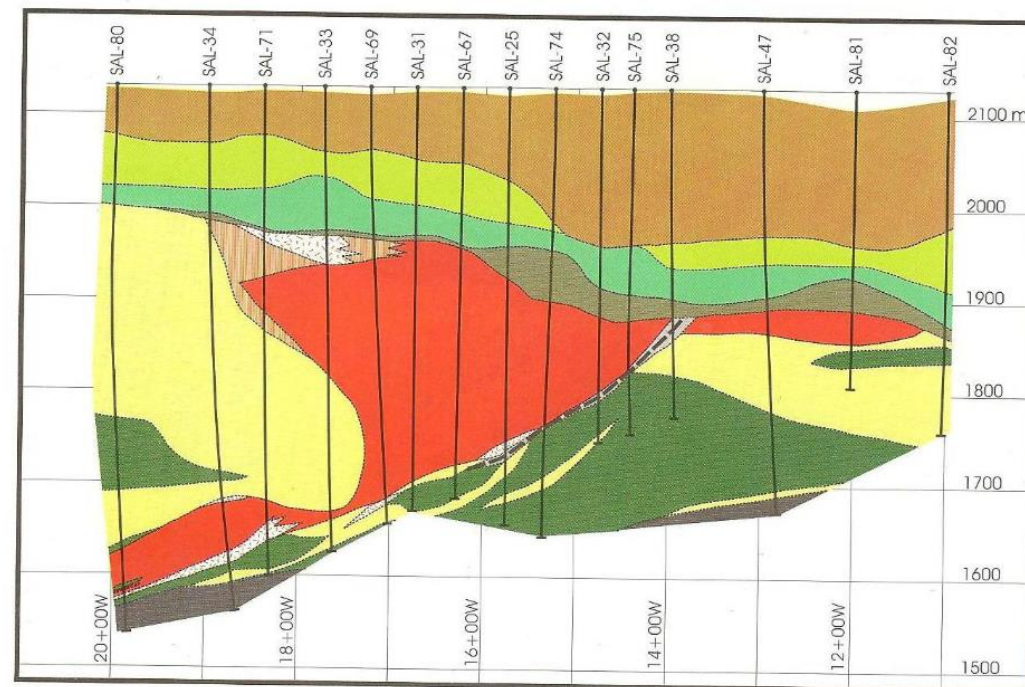


Figure 5. Geological cross-section, line 4+00S. See Figure 4 for grid location.

**Tertiary conglomerates and
volcanoclastic breccias (Tcg) (32,3Ma)**

Mafic Flows and Tuff (TUF)

Mafic flows & breccias (XLT) (117,94Ma)

**Mafic flow & sediments
(MVS)**

**Rhyolite
Flow-Dome
(146.5 Ma)
(RFD)**

**Massive
Sulfides
(MS or ore)**

**Mafic volcanics (MVT)
(≈149Ma)**

**Late Triassic Graphitic mudstone
(Gsed)**

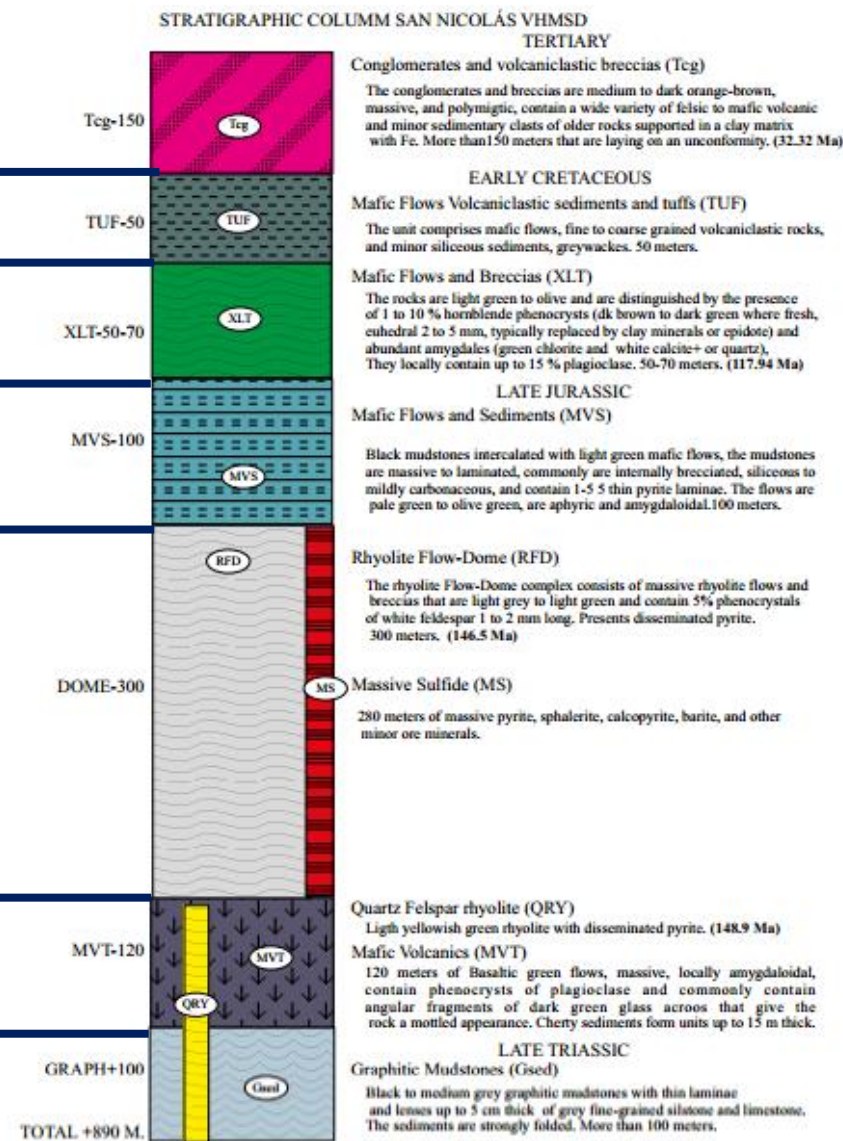


Figure 4. Stratigraphic column VMS San Nicolás. Modified after Johnson et al. (2000).

TD – 5 groups of 4 students and 2 groupS of 3

- Concerning Cu mineral body, compare different estimations of grades (OK, inverse distance, nearest neighbor)
- As you did with Cu grade, estimate Ag, Au, Pb and Zn grades in the grid. Justify your choices of interpolation, variograms if needed, ...
- Compare ore tonnage for other metals. Economic grades are 0.5 g/t for Au, and 30 g/t for Ag. Is it worth changing the processing unit to extract Au and Ag in areas mined for Cu ($>1.4\% \text{Cu}$) and Zn ($> 2\% \text{Zn}$)?
- And what if you change Ag/Au cut-off values?
- What about Pb?
- Where would you drill ($< 2500\text{m}$) to have a better idea of mineable reserves of Cu/Zn? Of Au/Ag?

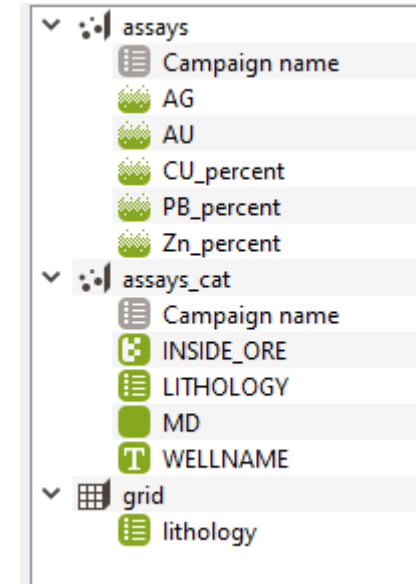
RQ: density around 4500kg/m^3

Context

Work with the San Nicolas VMS dataset

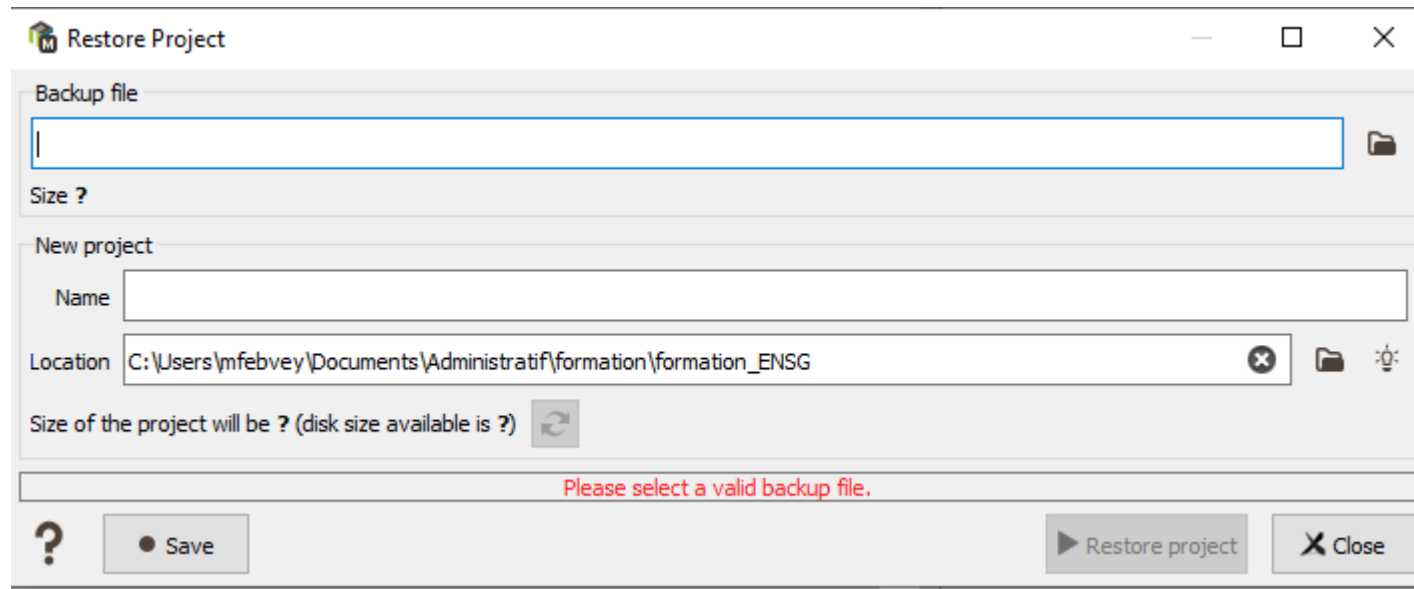
In Isatis.Neo: we will do the resource estimation

You have a backup available with the dataset (assays and grid)



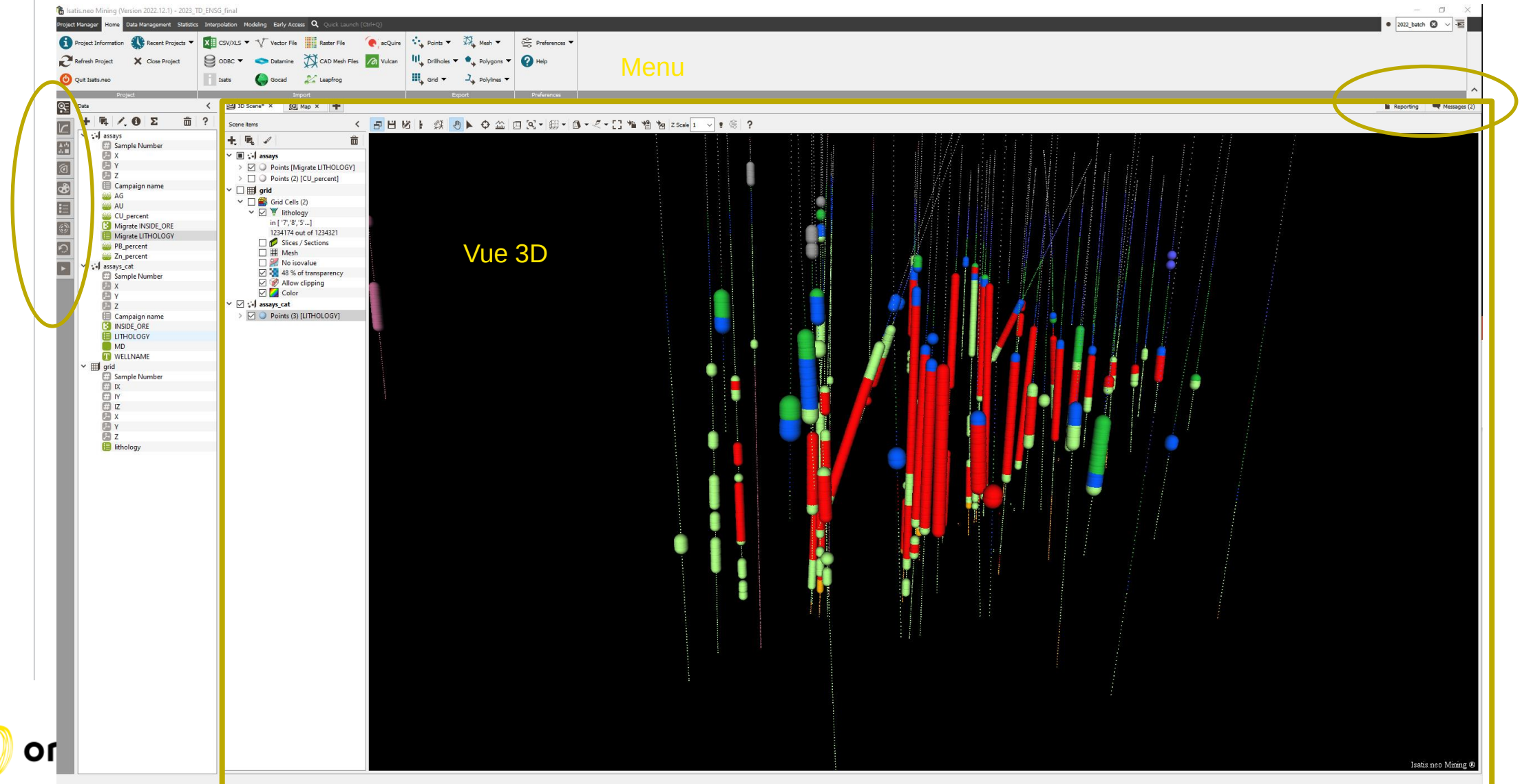
Project restoration

In Project manager → To restore the backup



Select  to choose the backup file

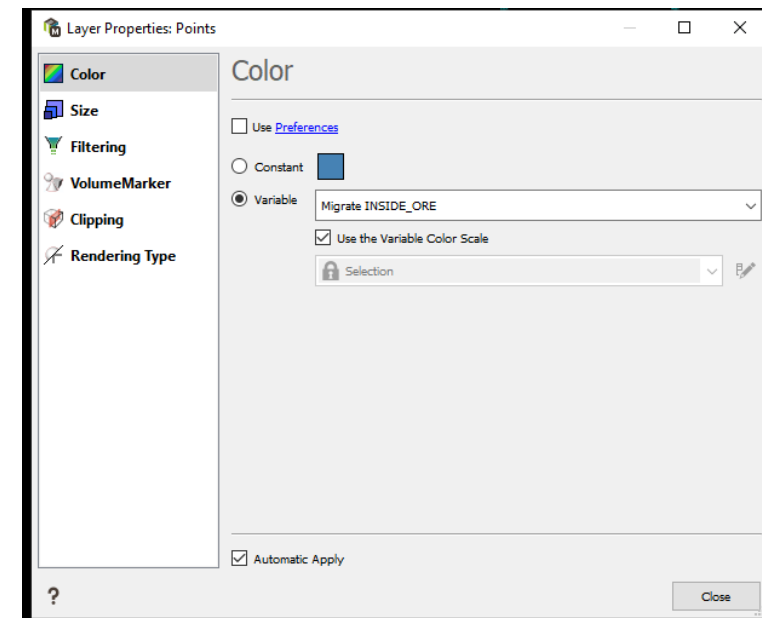
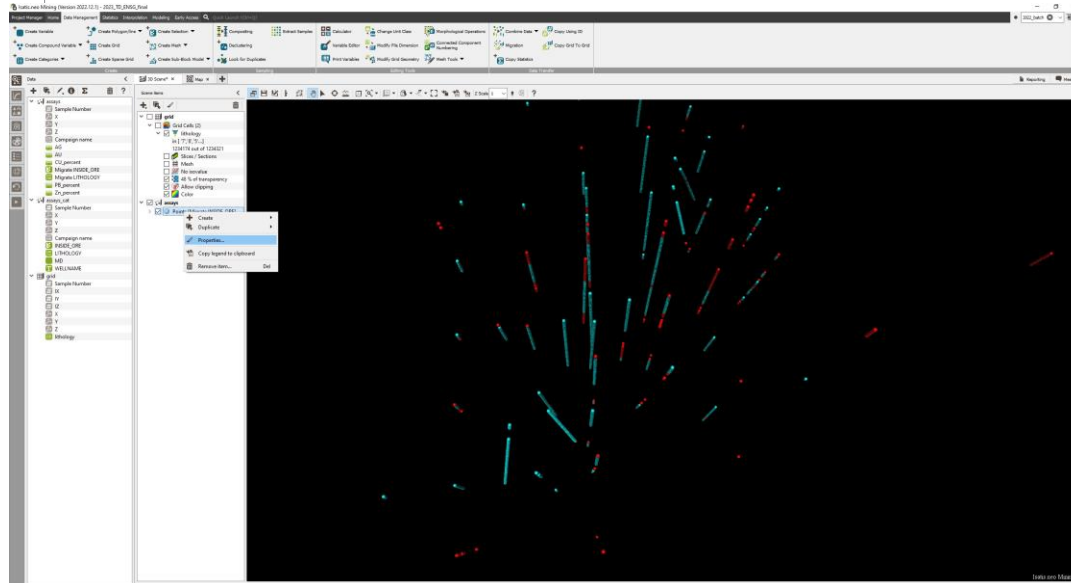
Isatis.Neo



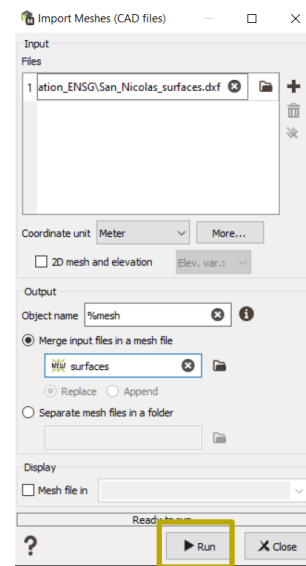
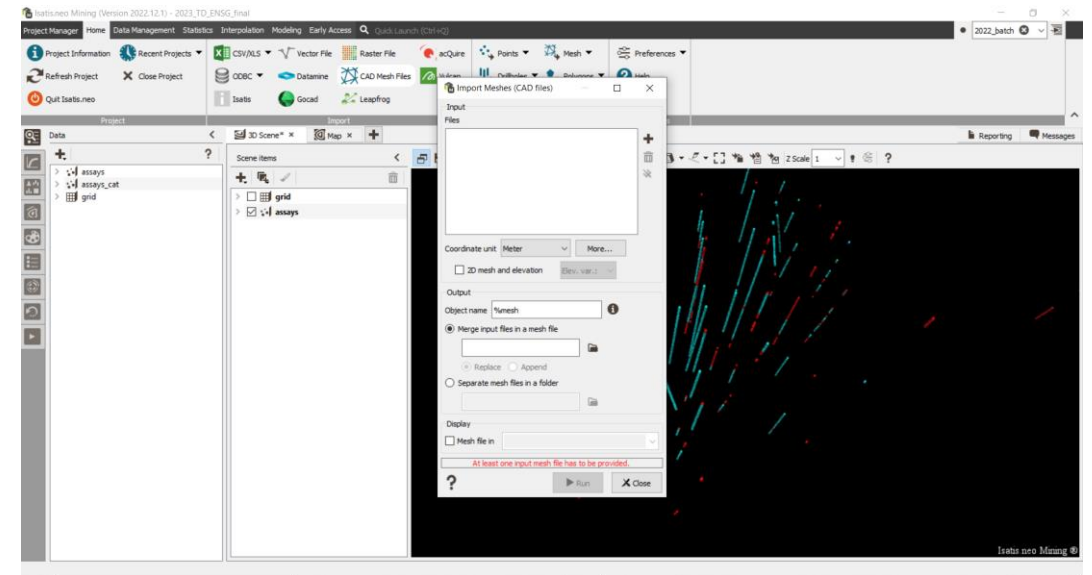
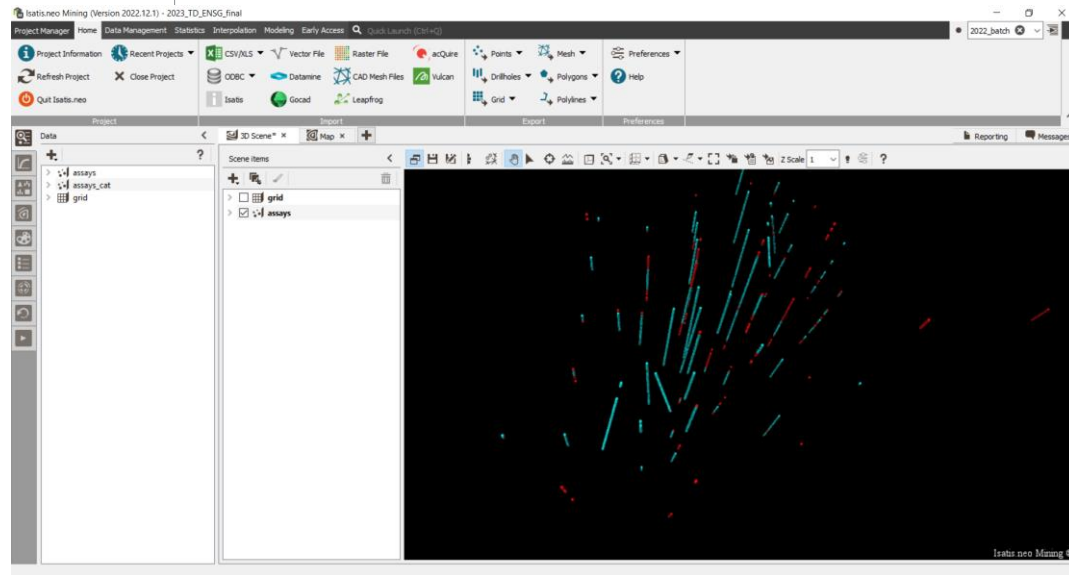
Display of the data

Drag and drop the data from the data tree to the 3D Scene or 2D Scene

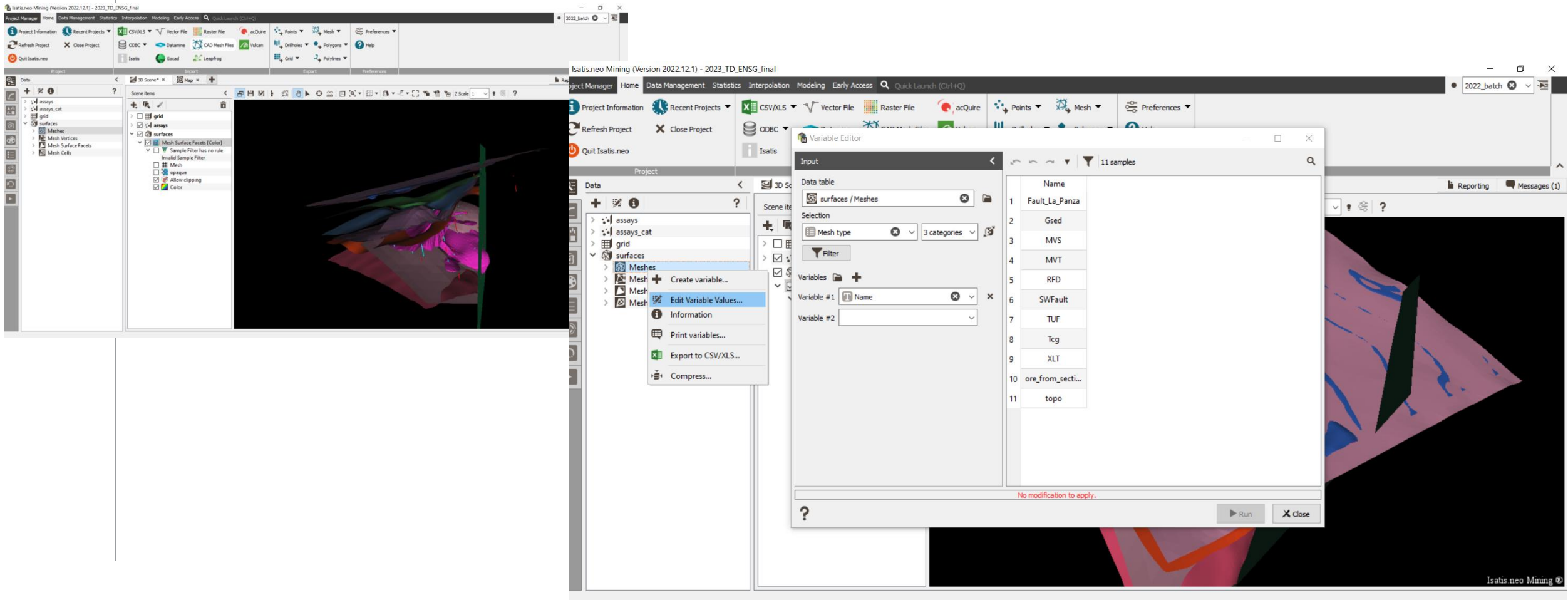
In the scene items, right click on a layer



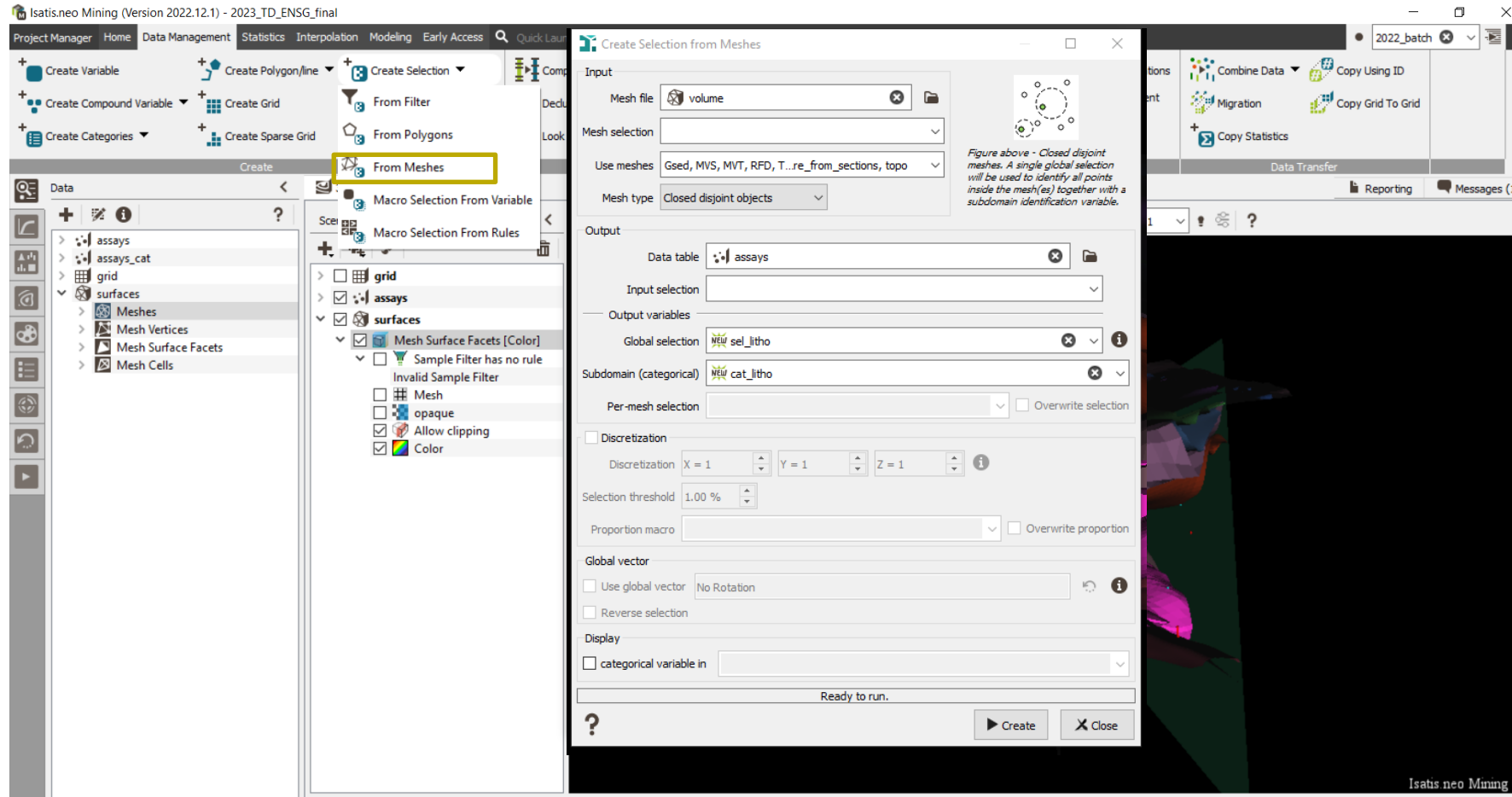
DXF file import



File visualisation

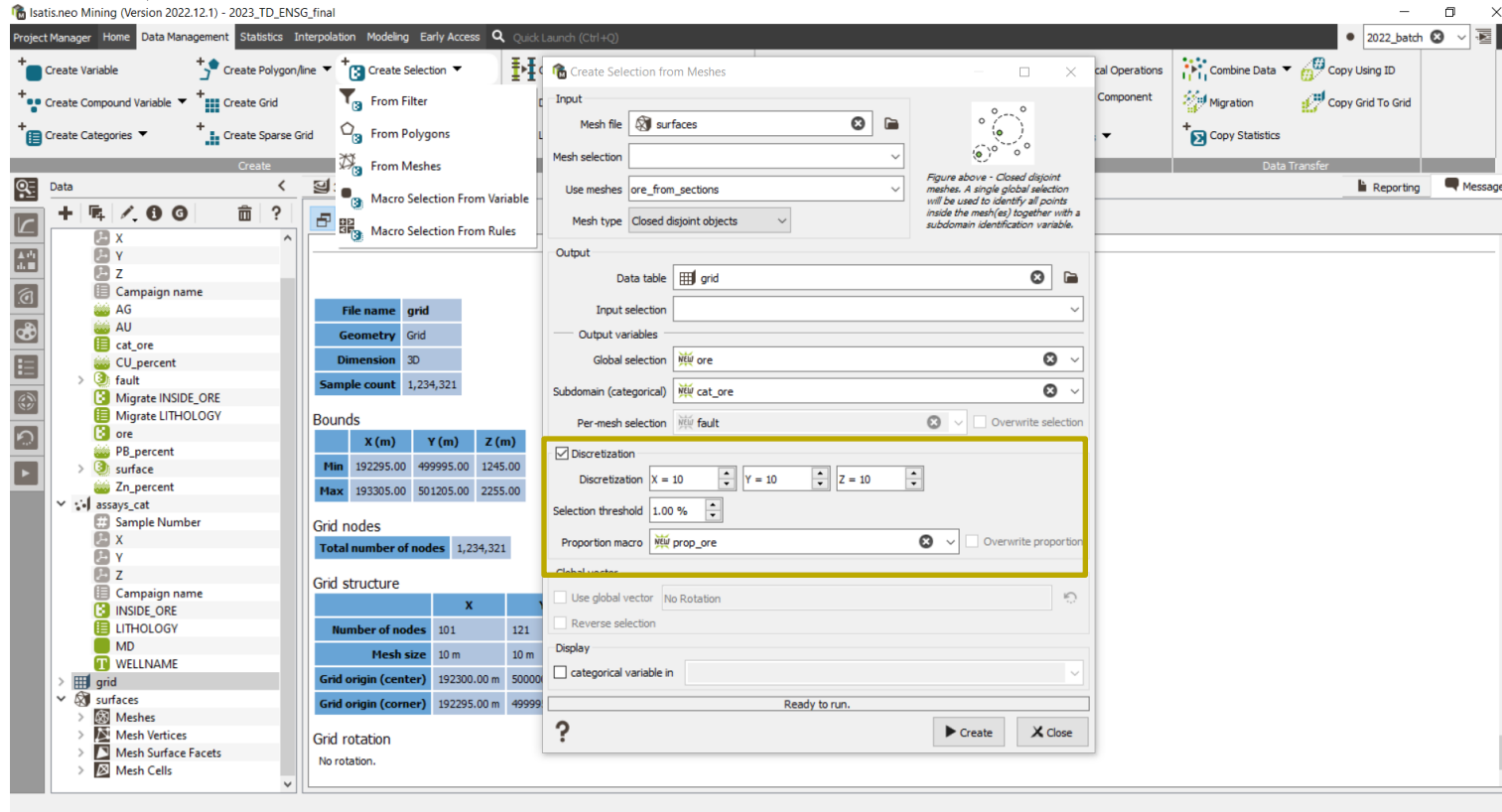


Create selections



+ Create only a selection for the ore on the assay, same on the grid

Creation of the selections on the grid



Only create a selection for the ore on the grid

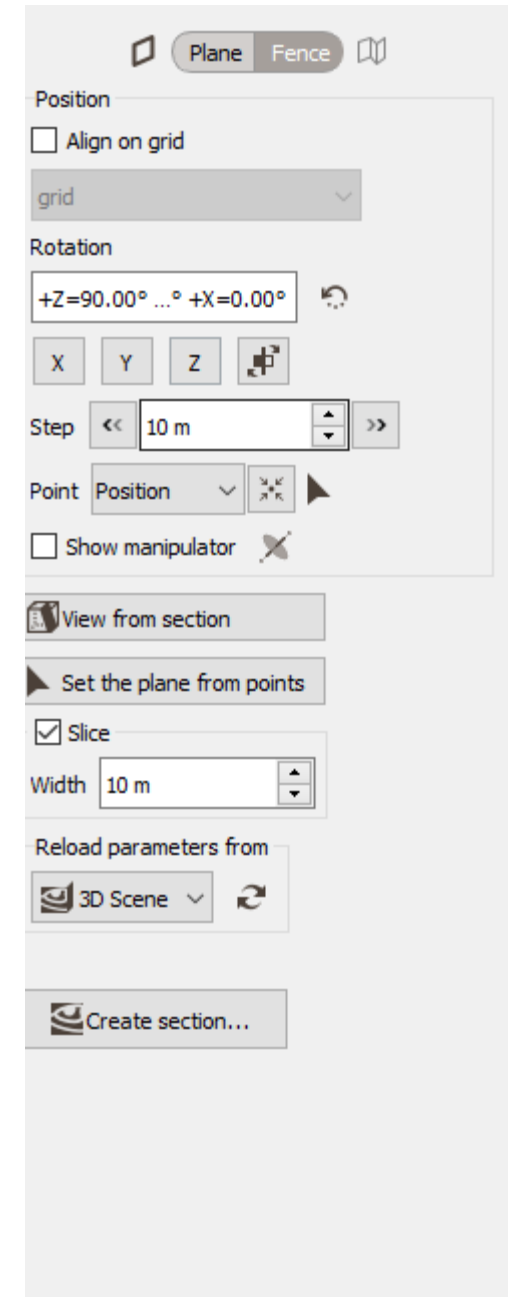
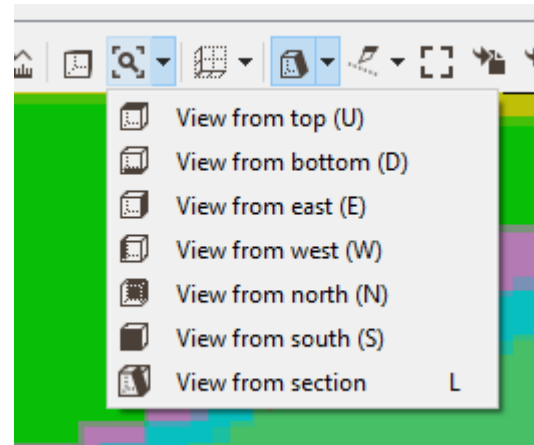
Be cautious when intersecting proportions!

Data validation

Do cross sections all over the deposit 

Two options: plan and fences

You can go from one view to another by pressing the keyboards letters (E, U, W, N)

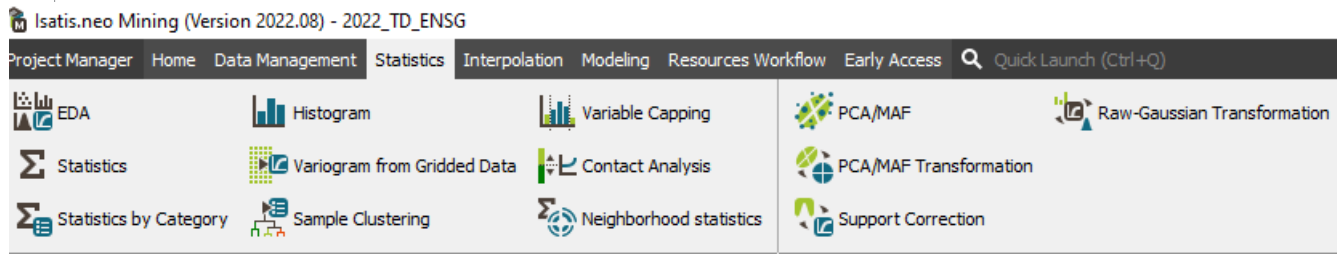


Data validation

Compile statistics on the different variables

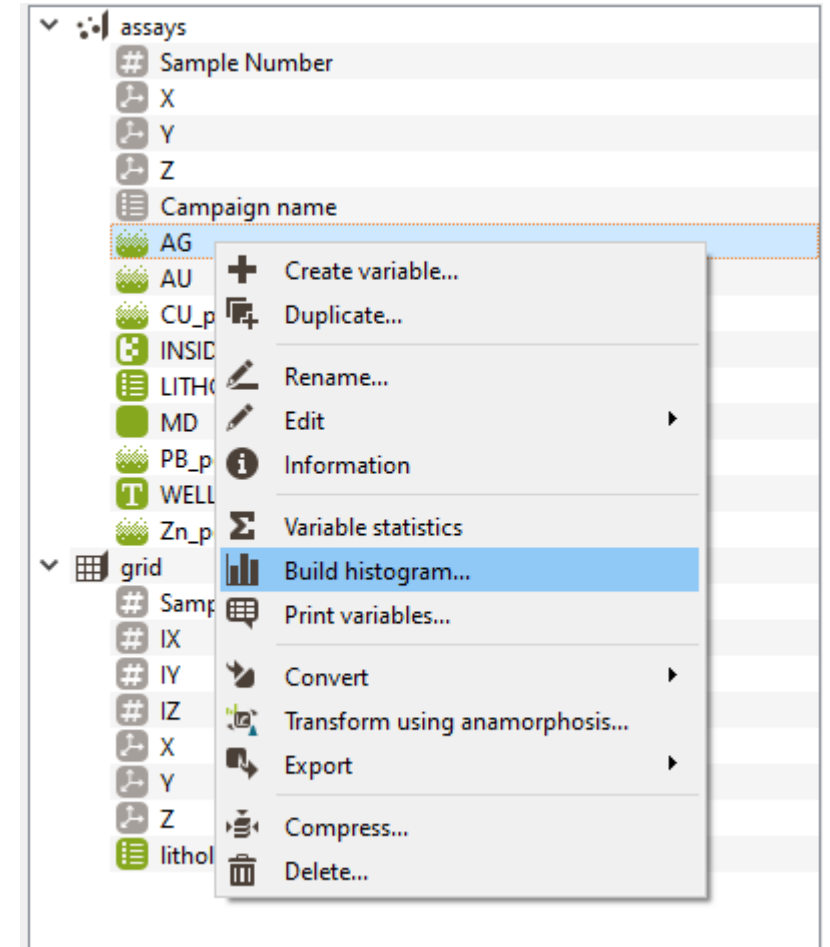
Right click → Build histogram...

→ Variable statistics



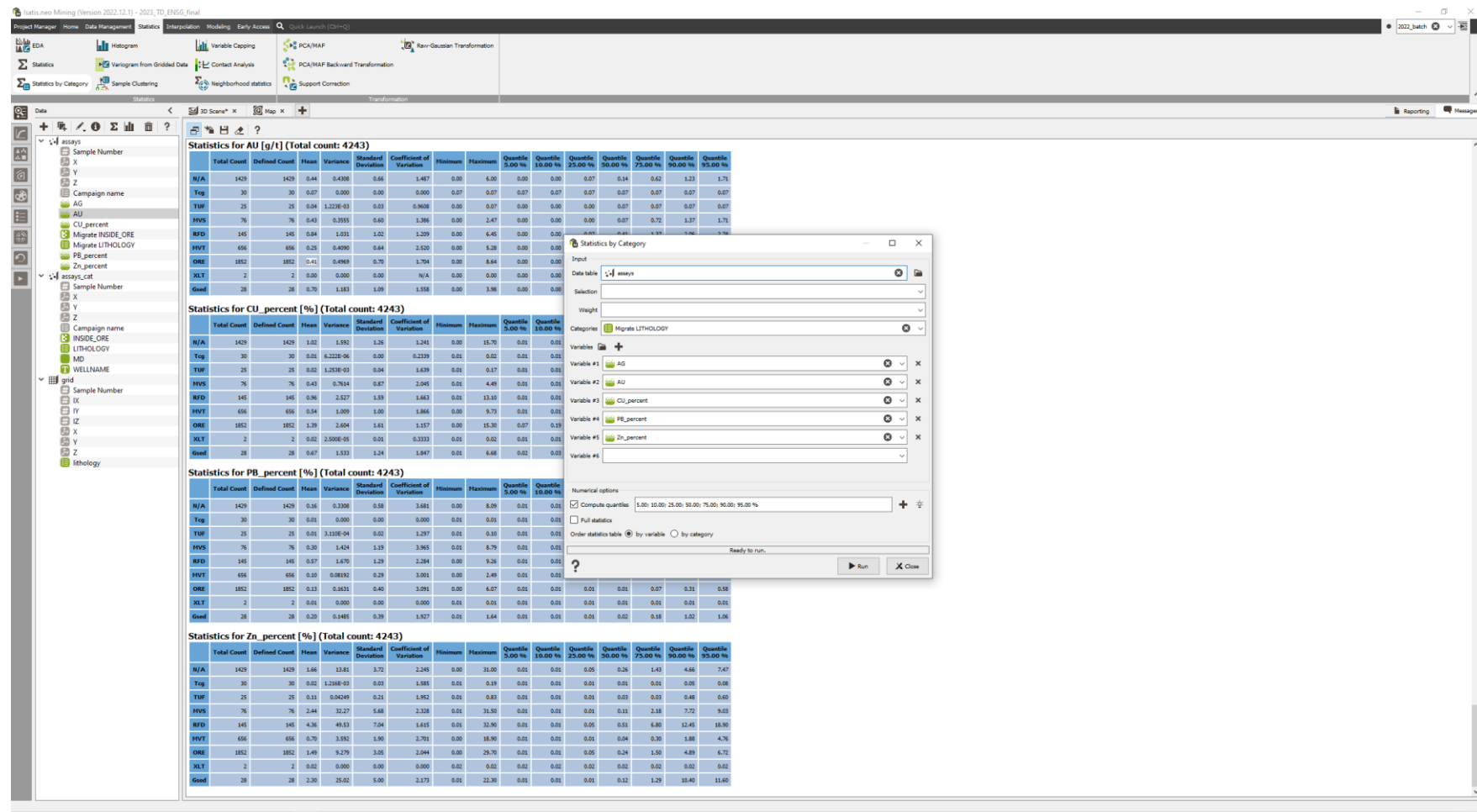
What do you notice in the statistics?

You can do statistics by category



Data validation

Statistics by category → Statistics



Statistics using these selections

Statistics by Category

Input

Data table: assays

Selection:

Weight:

Categories: cat_litho

Variables

Variable #1: AG

Variable #2: AU

Variable #3: CU_percent

Variable #4: PB_percent

Variable #5: Zn_percent

Variable #6:

Numerical options

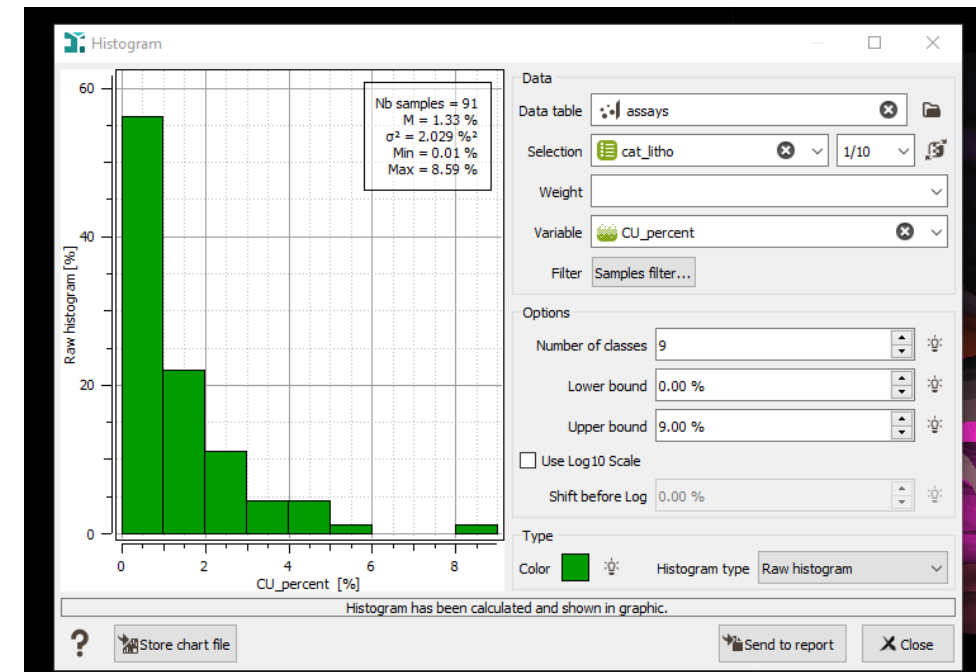
☒ Compute quantiles: 5.00; 10.00; 25.00; 50.00; 75.00; 90.00; 95.00 %

☐ Full statistics

Order statistics table: ☒ by variable ☐ by category

Ready to run.

Store chart file Run Close



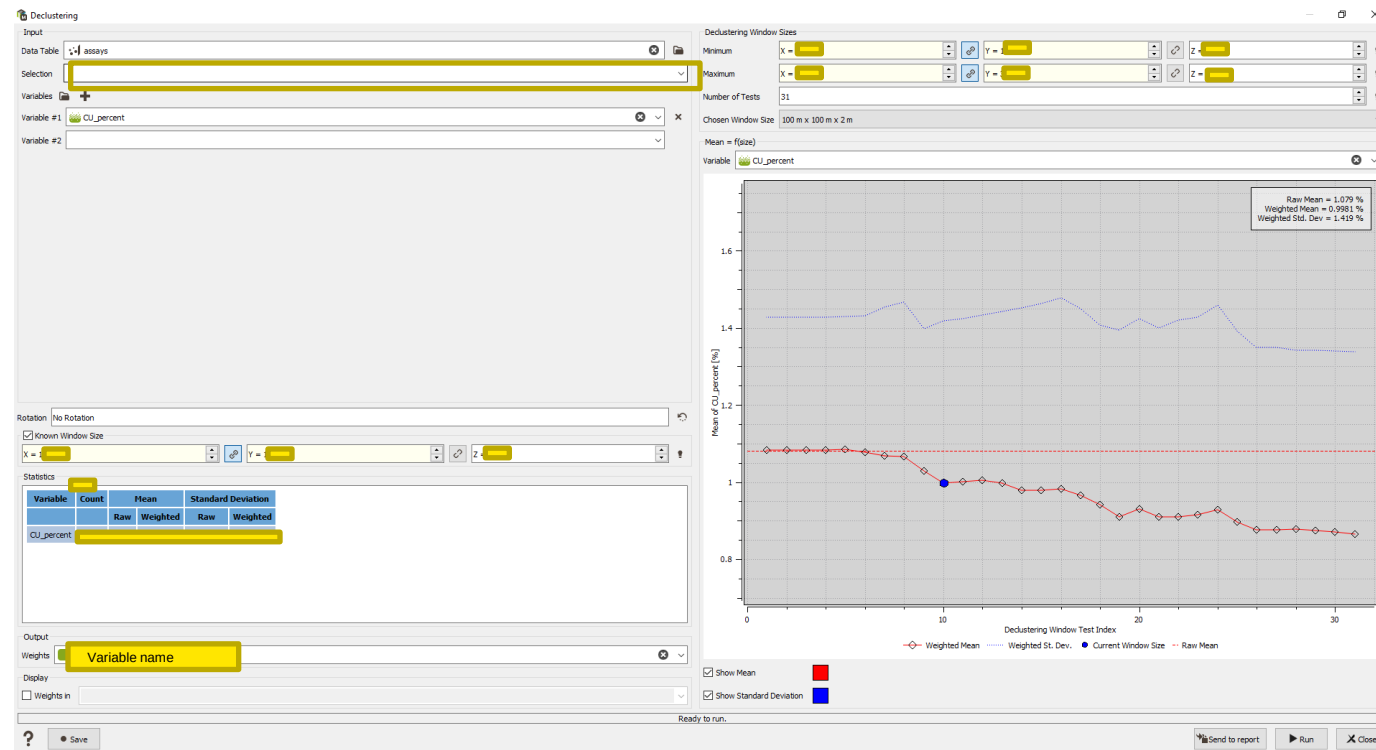
Then we will only use a selection « ore »

Declustering

Are the data clustered?

- Measure the drillhole spacing (if any) in the 2D map
- Play with the declustering tool to see if the mean and standard deviation evolves

You can use a selection



Exploratory data analysis

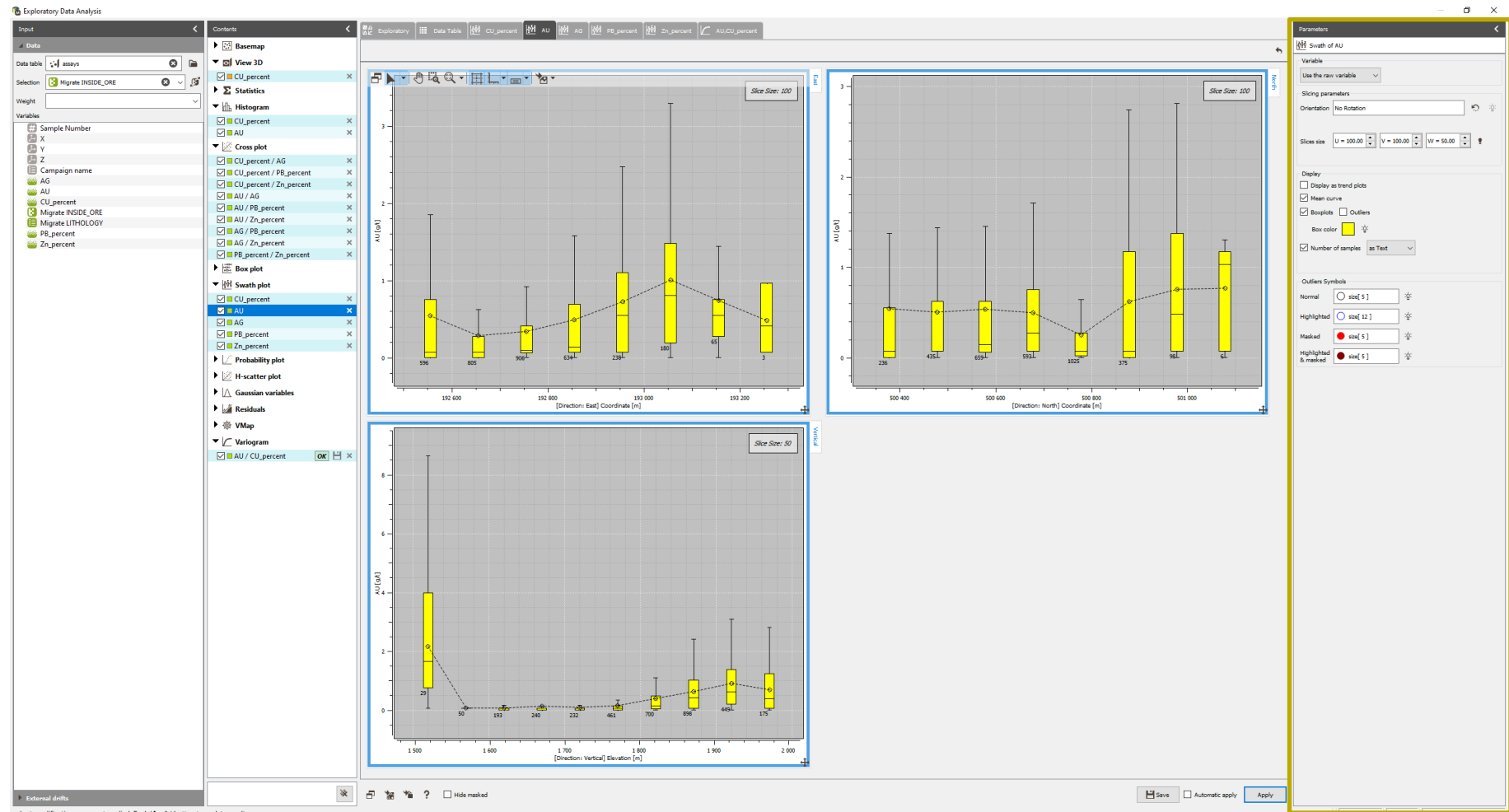
EDA is working with drag and drop functionalities, apply is to compile the graphs

You can use another selection

The screenshot displays the 'Exploratory Data Analysis' software interface. The 'Input' panel on the left shows the 'Data table' set to 'assays' and the 'Selection' set to 'Migrate INSIDE_ORE'. The 'Variables' list includes 'Sample Number', 'X', 'Y', 'Z', 'Campaign name', 'AG', 'AU', 'CU_percent', 'Migrate INSIDE_ORE', 'Migrate LITHOLOGY', 'PB_percent', and 'Zn_percent'. The 'Contents' panel in the center lists various visualization options: 'Basemap', 'View 3D', 'Statistics', 'Histogram', 'Cross plot', 'Box plot', 'Swath plot', 'Probability plot', 'H-scatter plot', 'Gaussian variables', 'Residuals', 'VMap', and 'Variogram'. A yellow arrow points from the 'AU' variable in the 'Variables' list to the 'Histogram' section in the 'Contents' panel. The 'Apply' button at the bottom right is highlighted with a yellow box. The 'Parameters' panel on the right is empty, with a message: 'Select a category or an item in the Contents list to modify its parameters.' The bottom status bar indicates 'Last modifications were not applied. Push 'Apply' button to update results.'

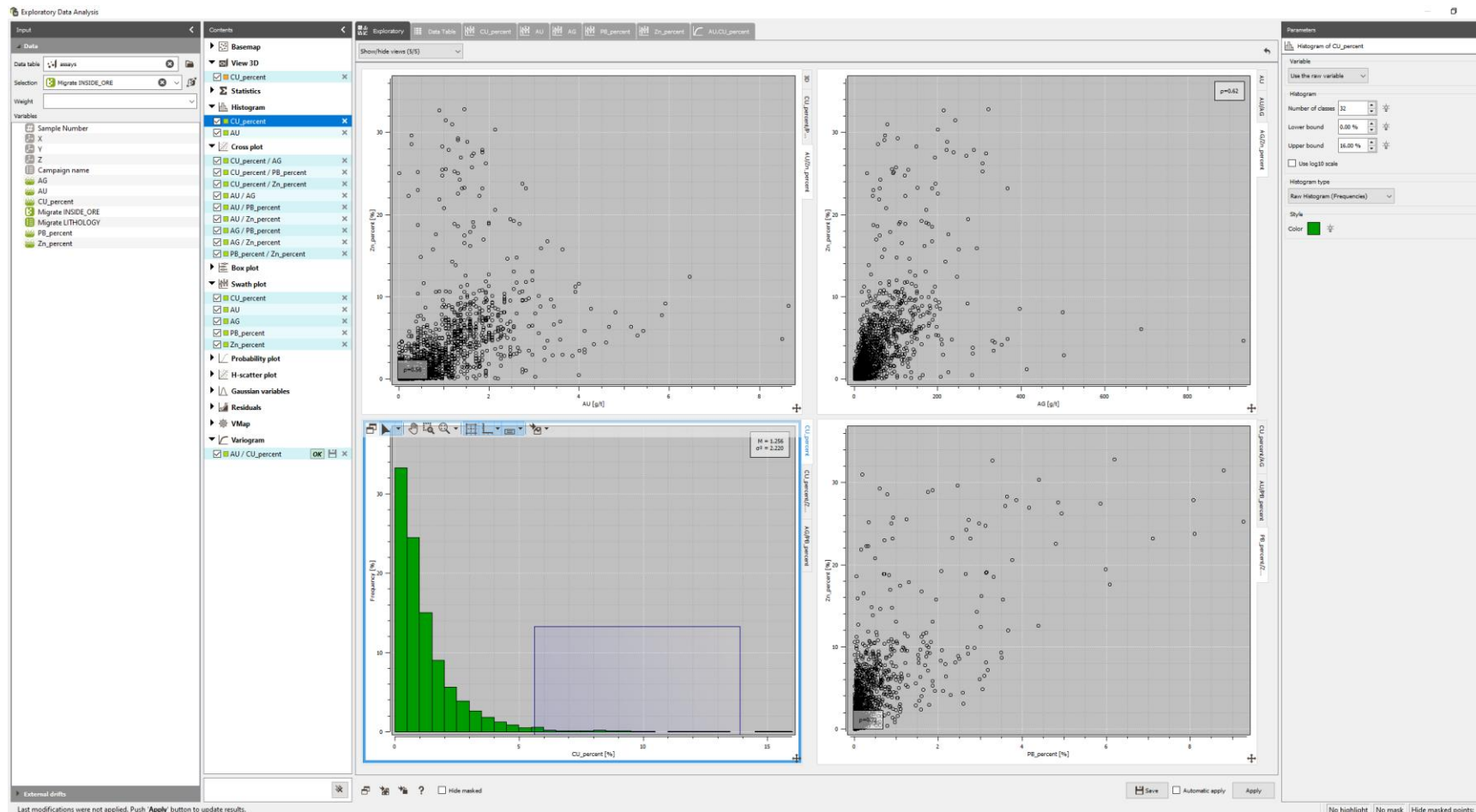
Exploratory data analysis

For each window, a parameters part can be displayed and graphs can be customized

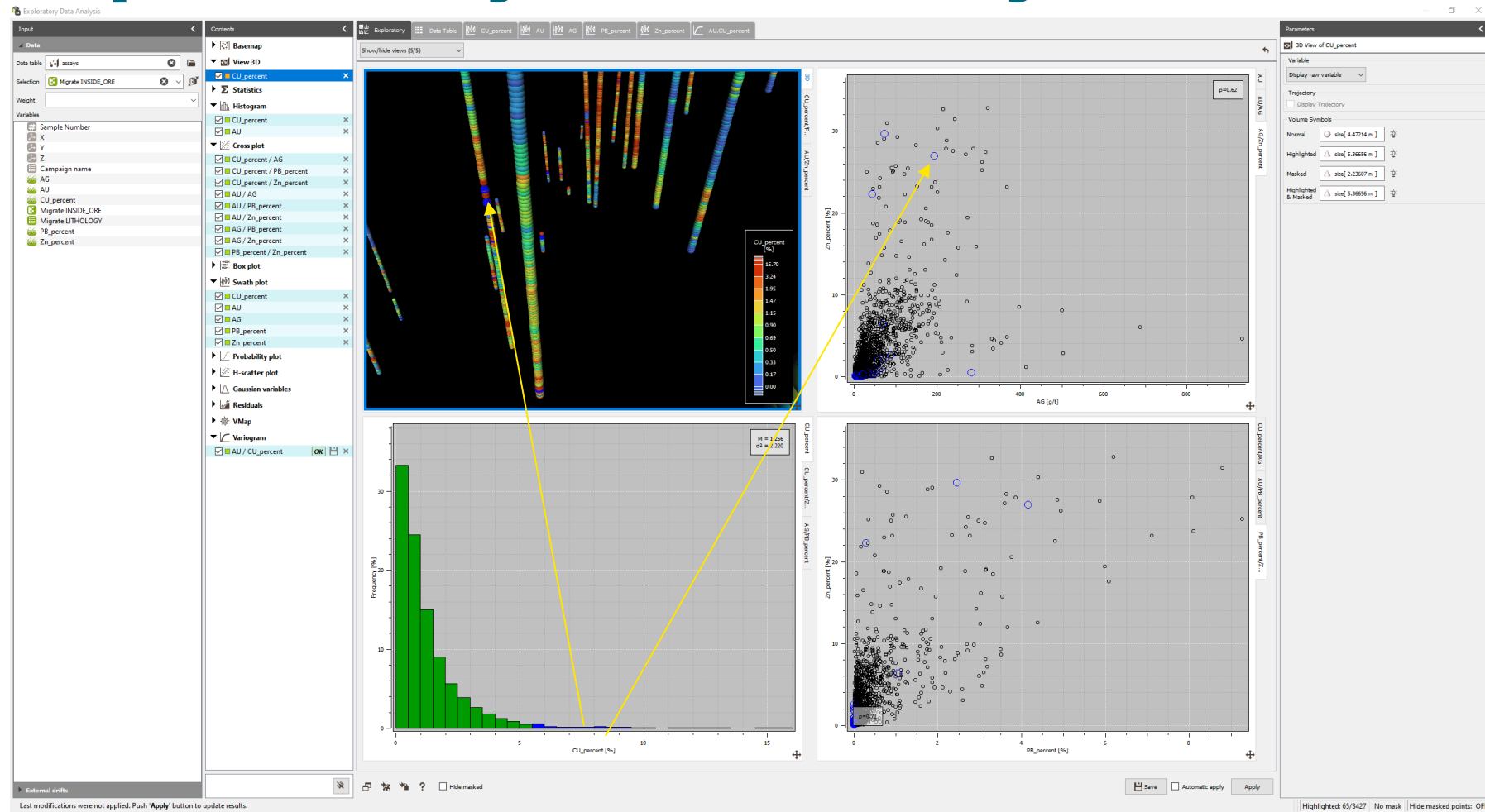


Exploratory data analysis

Data can be selected, and then highlighted in other graphs or masked (Right click → mask highlighted points)



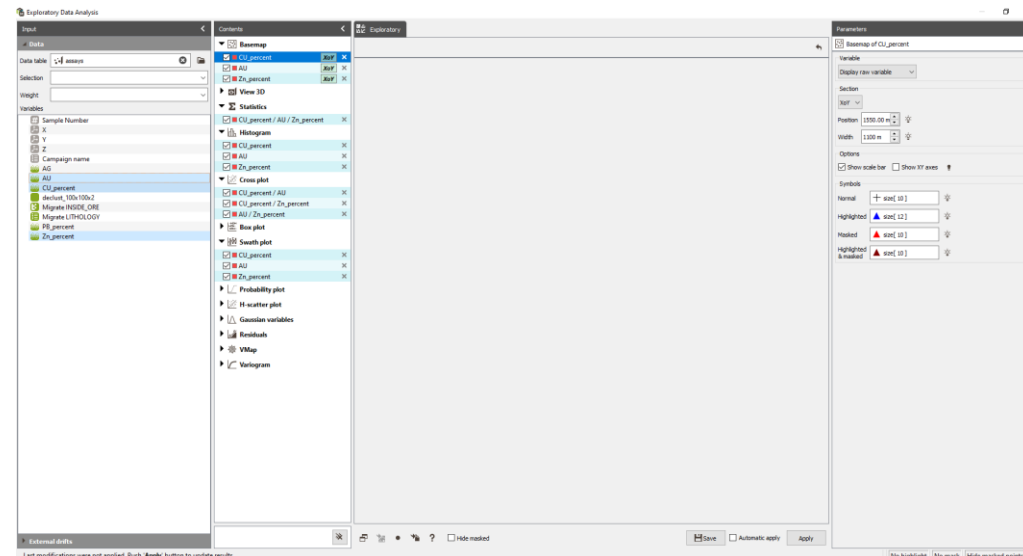
Exploratory data analysis



Exploratory data analysis

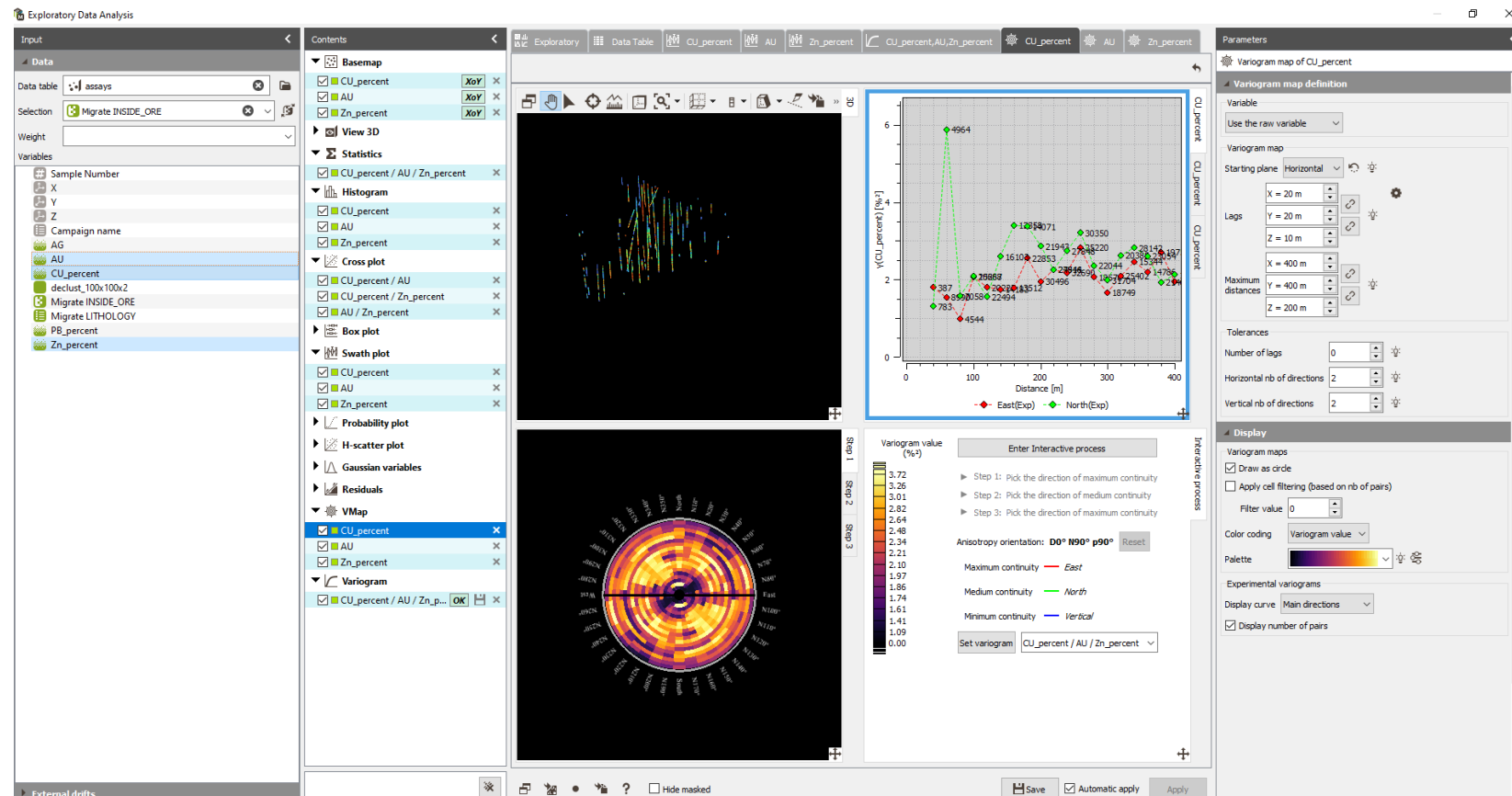
First, realise a kriging of the Cu and then, choose only 3 variables to do the co-kriging (Cu + 2 other between Ag, Au, Pb and Zn)

Check the statistics and the stationarity for the choosen variables (Menu statistics → Exploratory data analysis ou EDA)



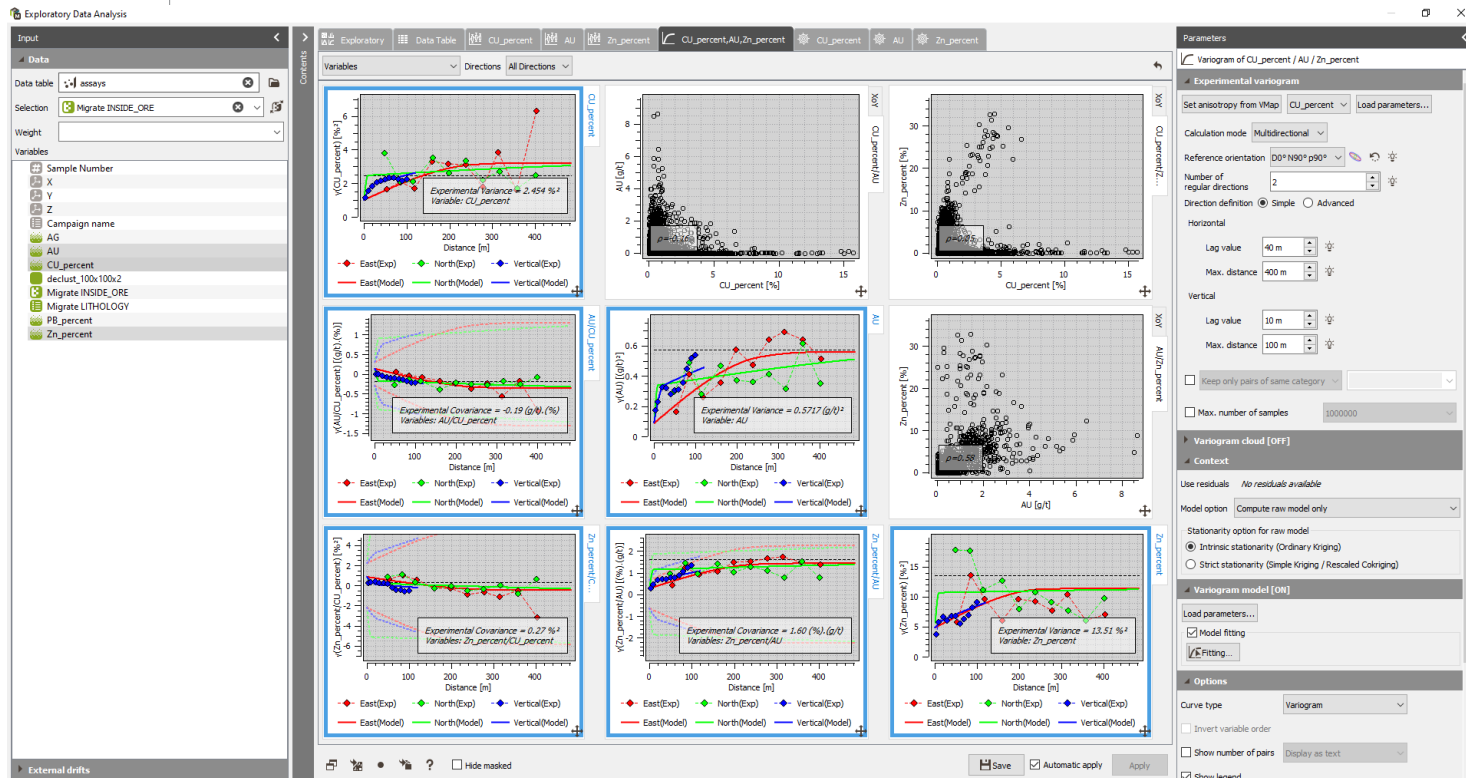
Exploratory data analysis

When the domain has been chosen, look at the experimental variogram and co variogram, you can look at the variogram map to see if you observe an anisotropy. *Do you see an anisotropy?*



Exploratory data analysis

Then go to the variogram to model it : you first have to review the experimental variogram parameters. Two modes for the direction definition: simple or advanced



Advanced direction definition

Regular directions in plane

Reference orientation: D0° N90° p90°

Number of regular directions: 2

Height angular tolerance: 30.00°

Special direction(s)

☒ Use the vertical direction

Free direction(s)

East Add direction

Direction parameters

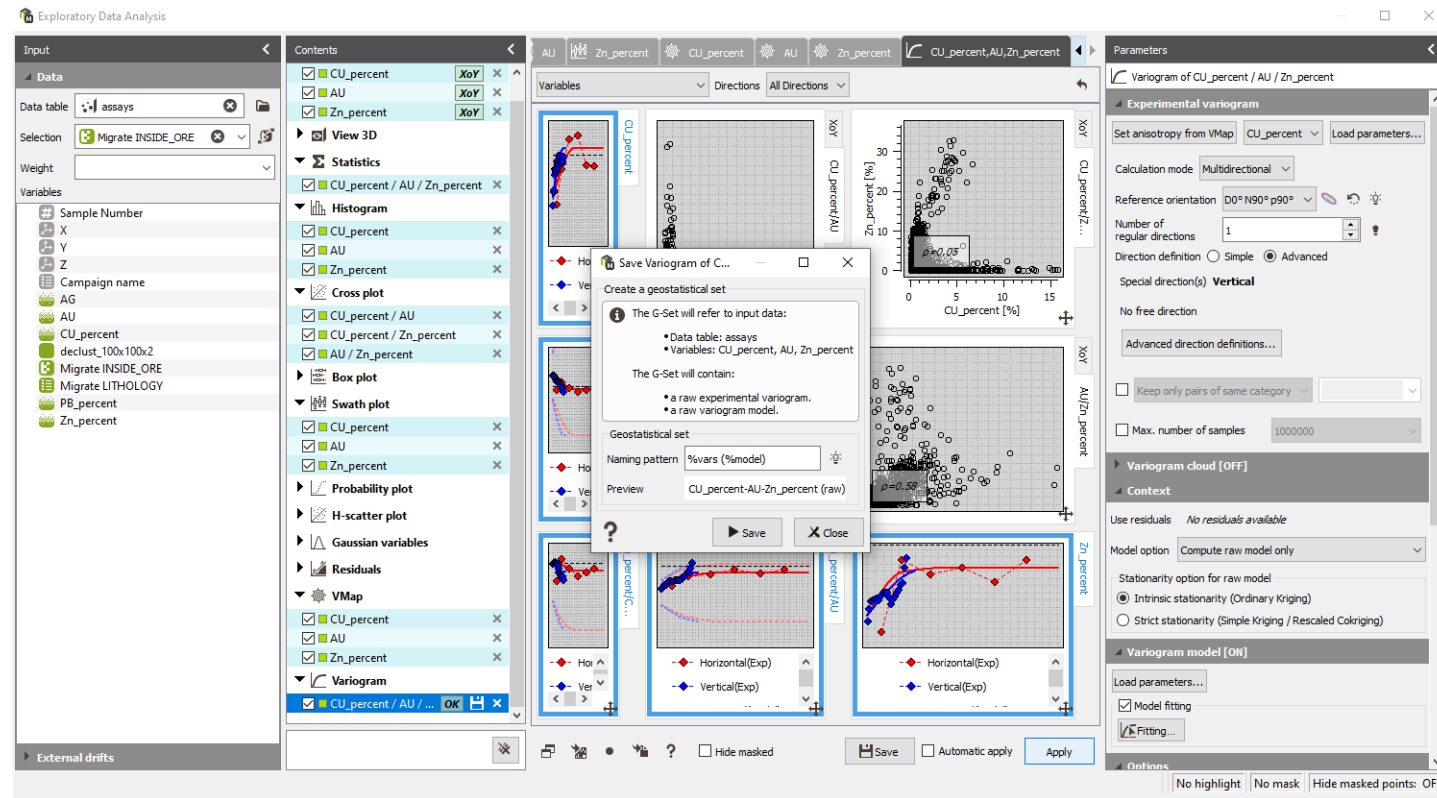
	Regular 1/2	Regular 2/2	Special 1/1
Name	East	North	Vertical
Color	■	■	■
Lag value	40 m	40 m	10 m
Maximum distance	400 m	400 m	100 m
Lag tolerance	50.00 %	50.00 %	50.00 %
Nb lags to be refined	0	0	0
Lag subdivision	8 m	8 m	2 m
Angular tolerance	45.00°	45.00°	45.00°
Plane slicing width	200 m	200 m	
Plane slicing height	10 m	10 m	
Slicing radius			10 m

Report

OK

Exploratory data analysis

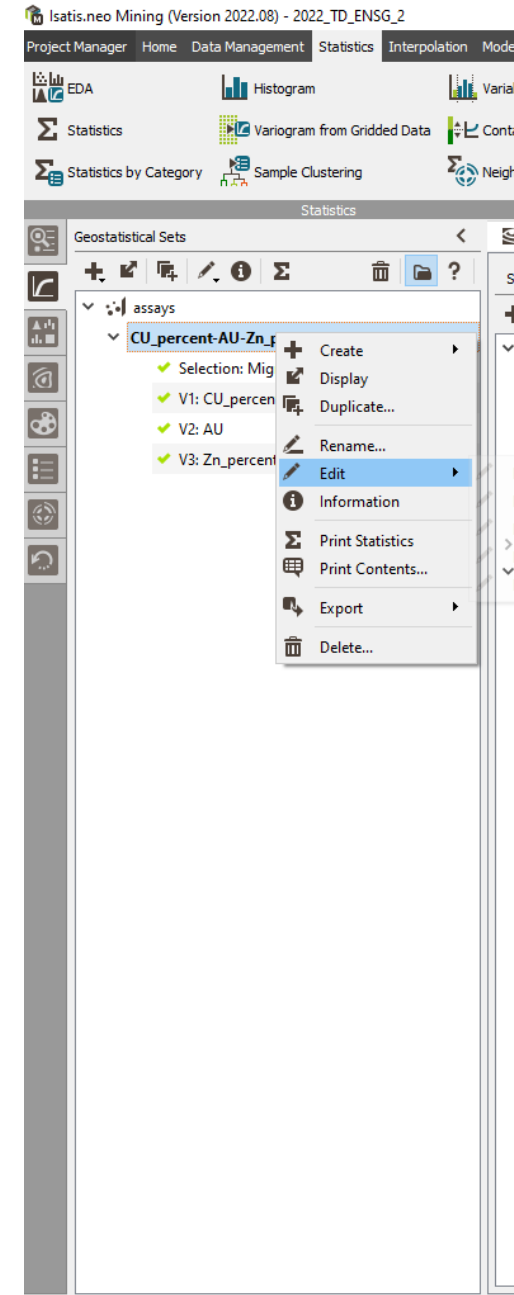
When the variogram fitting seems OK, remember to save the geostatistical set



Geostatistical set

The geostatistical set is saved and
can be reviewed any time (right click)

It will be used for the co kriging



Another way

Create a sub block model

Create Sub-block Model from Mesh(es)

Input

Grid File

Selection

Boundaries

Envelope

Top Surface

Bottom Surface

Triggers

Mesh dataset Use meshes

Subdivision

Mode Regular Z

U = 4 2.5 m

V = 4 2.5 m

W = 4 2.5 m

Output

Sub-block File

Categorical

Macro Selection

Display

☐ Sub-block File in

Select an output file

? Run Close

Kriging

In interpolation → kriging

Choose your geoset and your grid. Make sure the selections are coherent. We will do a block kriging

The screenshot shows the 'Kriging - Main Parameters' dialog box. Two yellow circles highlight specific fields: the 'Geostatistical set' field, which contains 'CU_percent-AU-Zn_percent (raw)', and the 'Data table' field under the 'Output' section, which contains 'grid'. A yellow arrow points from the text 'Choose your geoset and your grid' to the 'Geostatistical set' field. The dialog box includes sections for 'Stationarity option' (set to 'Ordinary Kriging'), 'Calculation Mode' (set to 'Block Kriging'), and 'Special Options' (all unchecked). The status bar at the bottom indicates 'Ready for next step: Special Options.' and includes buttons for '?', 'Save', '< Back', 'Next >', 'Run', and 'Close'.

Kriging

Use several discretisation points = block kriging

Can be justified by the Cvv

Kriging - Special Options

Block discretization

The target block size is constant: [10 m, 10 m, 10 m]

☒ Discretization Steps Number

NU = 3 NV = 3 NW = 1

☐ Discretization Steps Size

DU = 3.33333 m DV = 3.33333 m DW = 10 m

Print Cvv

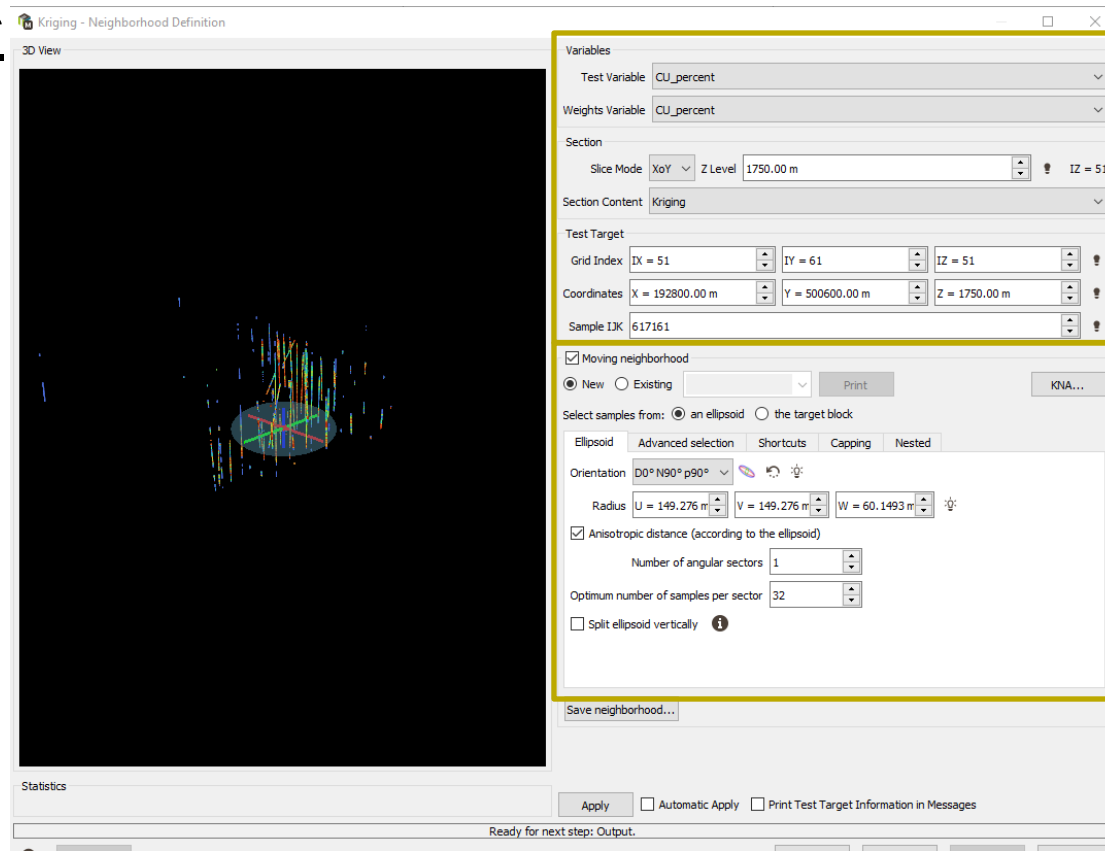
Ready for next step: Neighborhood Definition.

? < Back Next > Run Close

Kriging

Check the discretization (equal or more points than 3 over X, Y and Z, can be verified via the CVV)

Neighborhood definition: check all the sheets. *Quick justification of your choices*



Test target parameters: for the the 3D view display

Neighborhood parameters

Kriging

Neighborhood parameters

Kriging Neighborhood Analysis - Criteria and Varying Parameters

Criteria

☒ Kriging efficiency ☒ Slope of regression $Z|Z^*$ ☒ Sum of positive weights

☒ Weight of the mean ☒ Correlation $Z|Z^*$ ☒ Number of estimated targets ☐ Running time

Analysis options

☐ Exhaustive method

Reset to default

Varying neighborhood parameters

☒ Ellipsoid rotation

D0° N90° p90° D0° N330° p90° D0° N300° p90°

☐ Ellipsoid size U

500 m 250 m 750 m

☐ Ellipsoid size V

500 m 250 m 750 m

☐ Ellipsoid size W

40 m 20 m 60 m

☒ Ellipsoid size factor

1.00 0.50 1.50

☐ Use anisotropic distances

yes

☒ Number of angular sectors

1 2 4

☒ Maximum number of samples per sector

30 15 60

☒ Split ellipsoid vertically

no

☐ Optimum number of samples per Borehole

2 4

☐ Maximum number of samples per Borehole

2 4

☒ Minimum number of samples

5 1 10

Next Step: Results for maximum 12 tests

? Store chart file < Back Next > Finish X Close

Kriging

Save at least the standard variables for the kriging. You can look at some additional variables for validation purpose (advanced variables)

Kriging - Output

Output variables
Generate output variables for following input variables

All

Context: Pattern: %method-%context-%var-%label

Main variables Advanced variables

	Name	Label	Preview
☒	Kriging	Krig	grid / OK-CU_percent-Krig
☒	Standard deviation	StdDev	grid / OK-CU_percent-StdDev
☐	Variance	Var	grid / OK-CU_percent-Var
☐	Kriging weights	KrigW	assays / OK-CU_percent-KrigW

Variable of interest: CU_percent

Display

☐ Display kriging results

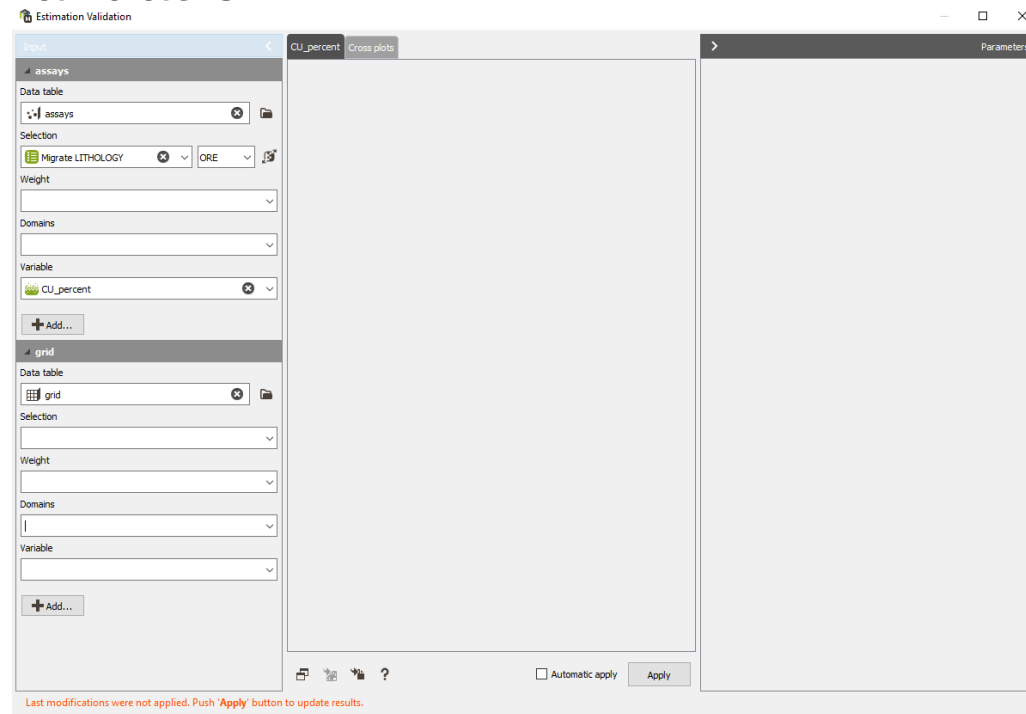
Ready to run.

? Save < Back Next > Run Close

Kriging validation

In Interpolation → estimation validation

Look at the statistics and the swath plots to see if the estimation seems OK. You can also do cross sections in the 3D view. It's also possible to run a quick inverse distance and nearest Neighbors estimation as a validation.



Grade tonnage curve

In interpolation → Grade tonnage curve and table

Grade Tonnage Curves and Tables

Curves Definition

C1 Grade Variables

Data Table: grid

Selection: lithology (9 categories)

Curve Name: C1

Line Style: [Green line]

Input Variables

Grade Variable: OK-CU_percent-Krig

☐ Use Auxiliary Variable

Categorical Domain Variable: [Empty]

Table By: [Empty]

Boundaries

Surface Selection: All

Solid Selection: All

Polygon Selection: All

Reporting Zone

☐ Solid Selection

☐ Polygon Selection

☐ Categories

☐ Cut to Fill

Parameters

Table Type: Global

Table Columns: All

Tonnage: Kilogram Volume: Cubic meter

Draw Curves... Build Table

Report

C1 Table (Grade Variables)

Cutoff [%]	Tonnage [kg]	Metal OK-CU_percent-Krig [kg]	Grade OK-CU_percent-Krig [%]	Benefit [kg]	Volume [m³]	Mean Density [kg/m³]
0.00	6.93592E+11	4.61147E+09	0.66	4.61147E+09	2.56886E+08	2700
0.20	4.89623E+11	4.5021E+09	0.92	3.52285E+09	1.81342E+08	2700
0.40	3.88679E+11	4.20738E+09	1.08	2.65267E+09	1.43955E+08	2700
0.60	3.01633E+11	3.77209E+09	1.25	1.96229E+09	1.11716E+08	2700
0.80	2.28644E+11	3.2661E+09	1.43	1.43695E+09	8.4683E+07	2700
1.00	1.69792E+11	2.73448E+09	1.61	1.03656E+09	6.2886E+07	2700
1.20	1.24737E+11	2.24193E+09	1.80	7.45078E+08	4.6199E+07	2700
1.40	8.88732E+10	1.77734E+09	2.00	5.33112E+08	3.2916E+07	2700
1.60	6.48729E+10	1.41783E+09	2.19	3.79861E+08	2.4027E+07	2700
1.80	4.58136E+10	1.09501E+09	2.39	2.70363E+08	1.6968E+07	2700
2.00	3.29292E+10	8.51007E+08	2.58	1.92423E+08	1.2196E+07	2700
2.20	2.39112E+10	6.62089E+08	2.77	1.36042E+08	8.856E+06	2700
2.40	1.65078E+10	4.92101E+08	2.98	9.59142E+07	6.114E+06	2700
2.60	1.13643E+10	3.64206E+08	3.20	6.87338E+07	4.209E+06	2700
2.80	8.0973E+09	2.76183E+08	3.41	4.94584E+07	2.999E+06	2700
3.00	5.6322E+09	2.04862E+08	3.64	3.58962E+07	2.086E+06	2700
3.20	4.0473E+09	1.55897E+08	3.85	2.63831E+07	1.499E+06	2700
3.40	2.619E+09	1.08973E+08	4.16	1.99267E+07	970000	2700
3.60	2.1195E+09	9.1566E+07	4.32	1.5264E+07	785000	2700

Ready to run.

Save Store chart file Send to report Run Close



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Giving nuclear energy its full value