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USE OF MINE PLANNING SOFTWARE FOR THE EVALUATION OF RESOURCES AND RESERVES OF A SEDIMENTARY NICKEL DEPOSIT

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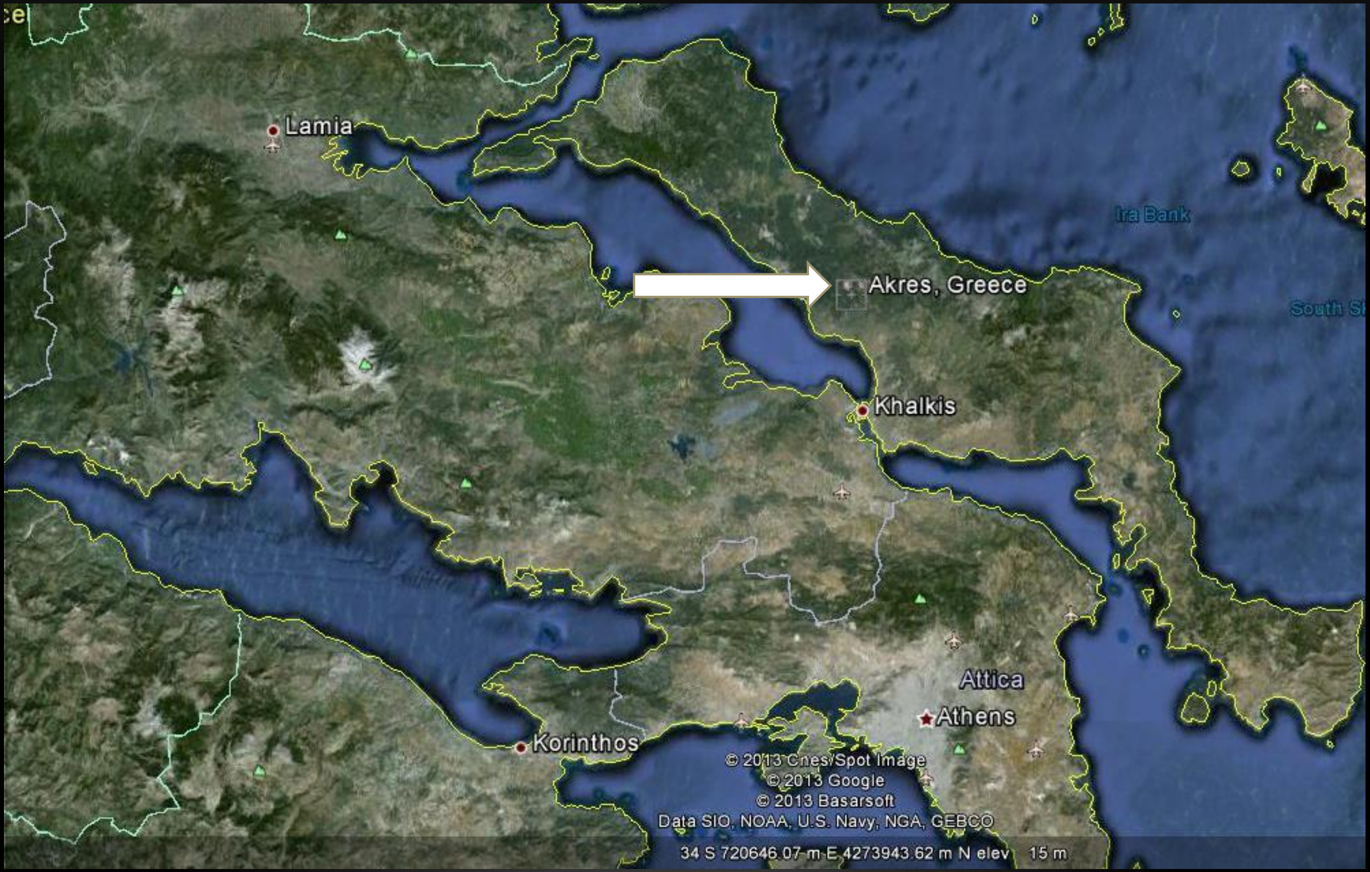
LARCO

GEOLOGICAL SETTING

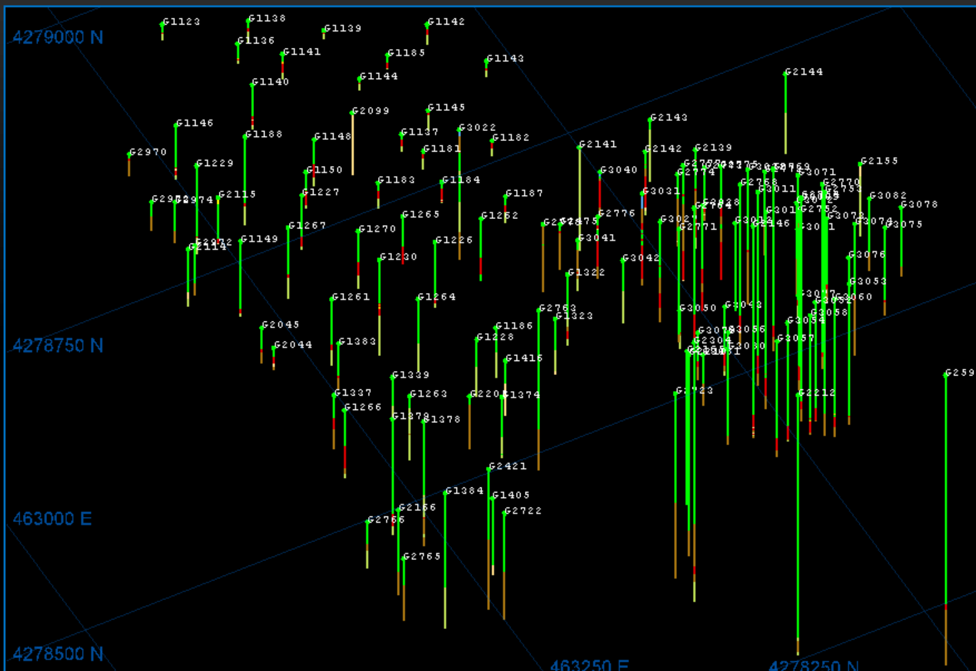
- The nickeliferous mineralization in Greece is related to the geotectonic zones of Almopia, Pelagonian and Sub-Pelagonian.
- In Central Euboea, iron and nickel ores of Cretaceous age occur.
- They are of sedimentary type and consist of stratified lenses and layers, overlain by Upper Cretaceous limestones and underlain by ophiolites (and in exceptional cases by Jurassic limestones).
- Mineralization is either pissolitic or compact with silcretes developed within the ore.
- The development of lenticular intercalations or siliceous layers is also common, while silcretes can also found in the bedrock.
- A large number of significant deposits exist in the Psachnon area, the Akres, Katsikiza, Isomata and the Katavolo-Fterada in the Kimi's area.
- The deposit used in the study presented in this paper is from the Akres area.

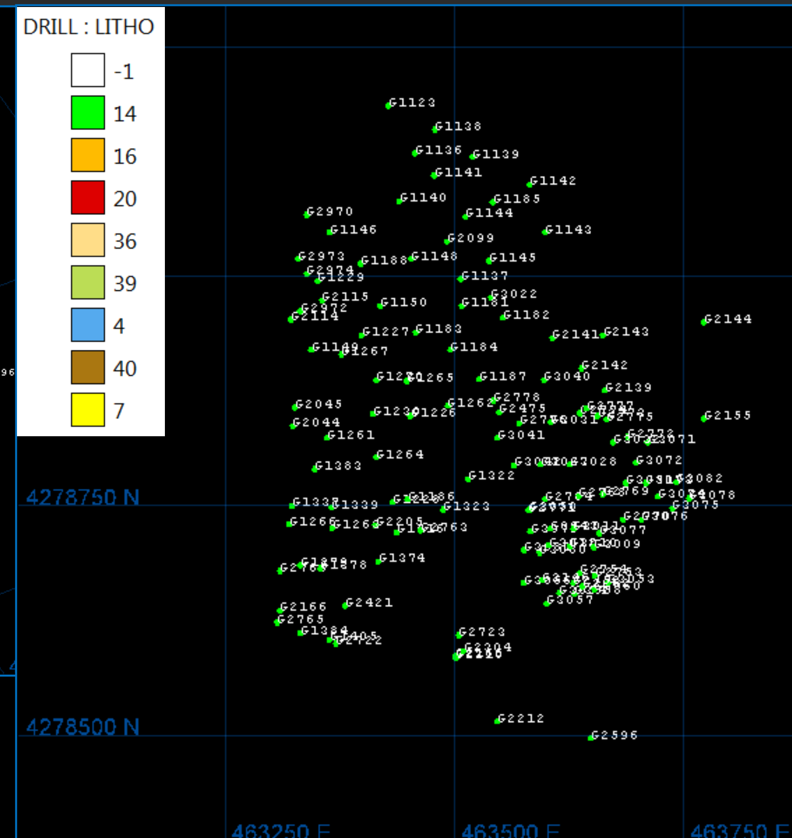
LOCATION OF AKRES DEPOSIT



AVAILABLE DATA

- Drilling information from 126 surface drillholes from the NE Akres deposit was provided for the purposes of this study.
- This data was imported to a drillhole database in Vulcan.
- The database contains collar, lithology and assay information.
- The database was validated using a number of checks for overlapping intervals, numerical field ranges (coordinates and grade fields), and numeric order (lithology and assay interval fields).





COLLAR

	HOLE	X	Y	Z
1	G1188	463398.000	4279014.000	404.300

QUAL

	FROM	TO	THICK	LITHO	DIAMET	RECOVE	SAMPTY	CASING	NI%	FE%	SIO%	S%
1	0.000	64.000	64.000	14	60	100	3.000					
2	64.000	65.000	1.000	20	60	100	3.000		0.830	34.000	25.800	0.670
3	65.000	66.000	1.000	20	60	100	3.000		0.810	34.300	24.400	0.670
4	66.000	67.000	1.000	20	60	100	3.000		0.800	37.300	26.100	0.670
5	67.000	86.000	19.000	39	60	100	3.000					
*	0.000	0.000	0.000		0	0	0.000		0.000	0.000	0.000	0.000

PROCEDURE

- The modelling and resource/reserve estimation study was performed using Maptek's Vulcan 3D software.
- LARCO SA begun the implementation of Vulcan in 2007.
- All steps of the study presented were supervised by qualified personnel as required by reporting codes.

PROCEDURE

- The implementation of industry standard software based mine planning techniques aimed at meeting the requirements set by international reporting codes.
- These techniques regarded:

  - database generation and validation,
  - statistical analysis and compositing of samples,
  - geological modelling of the orebody,
  - structural analysis (variography),
  - grade estimation on a block model basis,
  - pit optimisation and design, and
  - reporting of resources and reserves.

OREBODY BOUNDARIES MODELLING

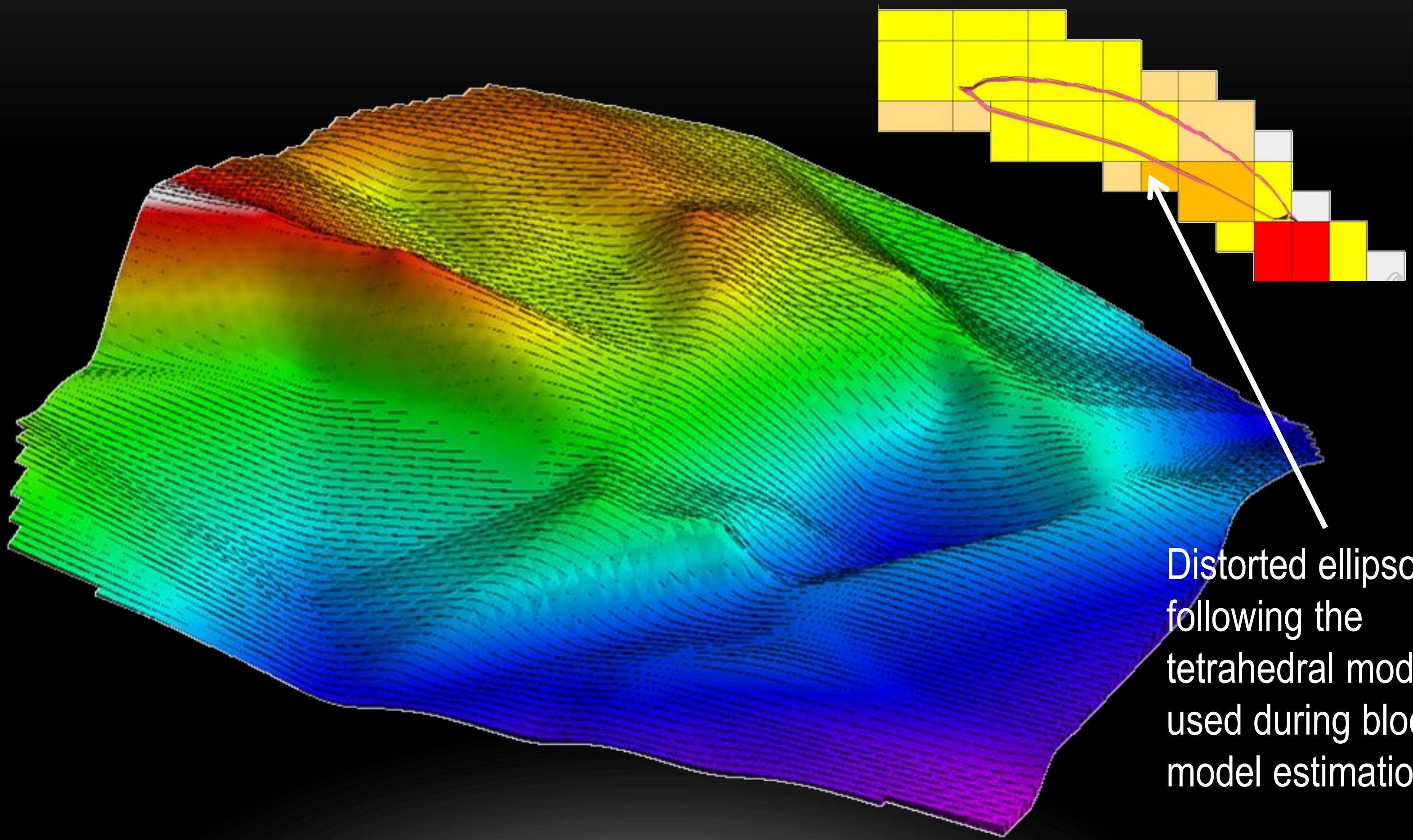
- The structural roof and floor of the main orebody area and of an internal low grade envelope were modelled using grid model interpolation based on drillhole lithological intervals.
- The highest points of a particular lithology code (20) which corresponds to the main orebody area were derived from the database and were used to generate a grid model of the roof.
- The same procedure was used to model the floor from the lowest points of the same lithology code.
- The triangulation algorithm with trending was used to interpolate grid points between drillholes in all cases.

OREBODY MODEL

UNFOLDING OREBODY DEFORMITIES

- A tetrahedral model was generated in this study using the structural roof and floor models of the main orebody area.
- Using this model the search ellipse is distorted to follow nominated structural surfaces leading to improved estimation accuracy and improved classification of resources.
- For this model to be generated, the structural surfaces (roof and floor) of the deposit needed to be modelled as surface triangulations.
- The tetrahedral model captured the orientation and shape of all deformities as represented by the structural models and was used to bring samples to an unfolded location relative to blocks during grade estimation.

TETRAHEDRAL MODEL



Distorted ellipsoid following the tetrahedral model used during block model estimation

STATISTICS AND SAMPLE COMPOSITING

- General statistics and histograms of nickel grade were calculated to gain a better understanding of its distribution characteristics.
- Original assay intervals were then composited to standard length composites (1m) to derive a set of equal support values to use for variography and grade estimation.
- The choice of composite length was based on the selectivity of the mining method used in this deposit and also on the effect of the compositing to the statistical characteristics of the composited values.

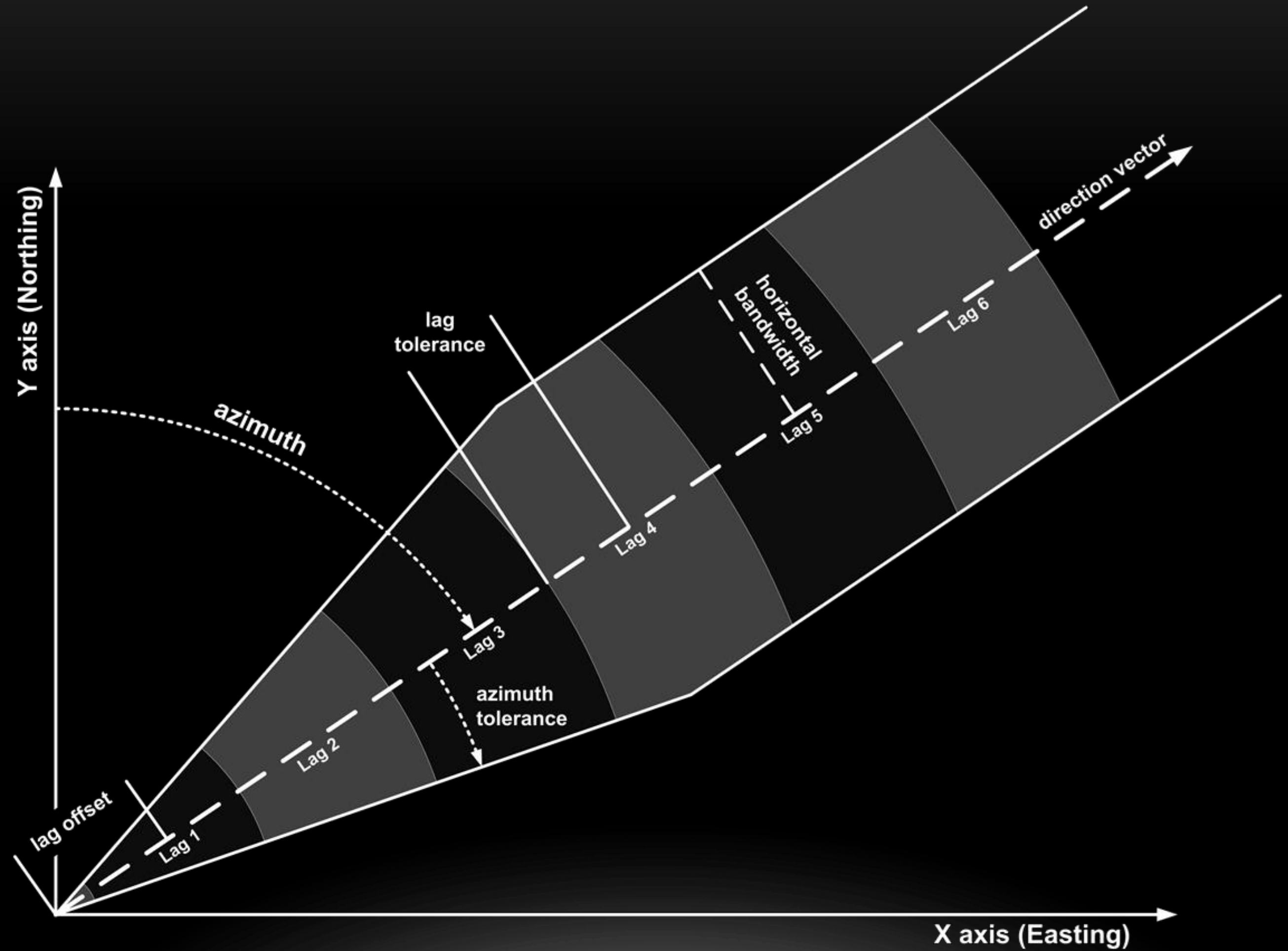
DOWNHOLE VARIOGRAPHY

- Downhole variography was performed in order to set the nugget effect presented by the composites used in this study.
- The standard semivariogram was used in this study as the mode for experimental variography.
- The downhole variogram was calculated using nickel composited values, a lag of 1m to match the composite length, 30 lags, and a lag tolerance of 0.3m.
- The range and sill displayed was also used for the final variogram model as the drillholes are all vertical, hence correspond to a particular direction in space.
- The fitted value for the nugget effect was 0.002. This value was used in the final variogram model fitted in different directions.

DIRECTIONAL VARIOGRAPHY

- Directional experimental variograms of the Ni composited values were calculated in various directions and were used to fit a model.
- A lag size of 10 was used in all directions and a total number of 15 lags were calculated, i.e. a semivariogram value was calculated every 10m and up to 150m.
- A lag tolerance of 2m was used to allow for irregularities of the drilling pattern.
- Azimuth and plunge tolerances were set to 20^{o} and a horizontal and vertical bandwidth of 20m was applied.

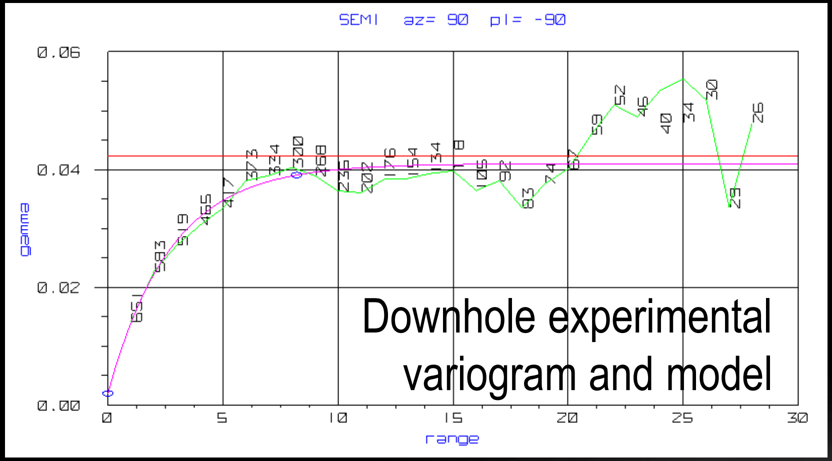
DIRECTIONAL VARIOGRAPHY (CONTINUED)

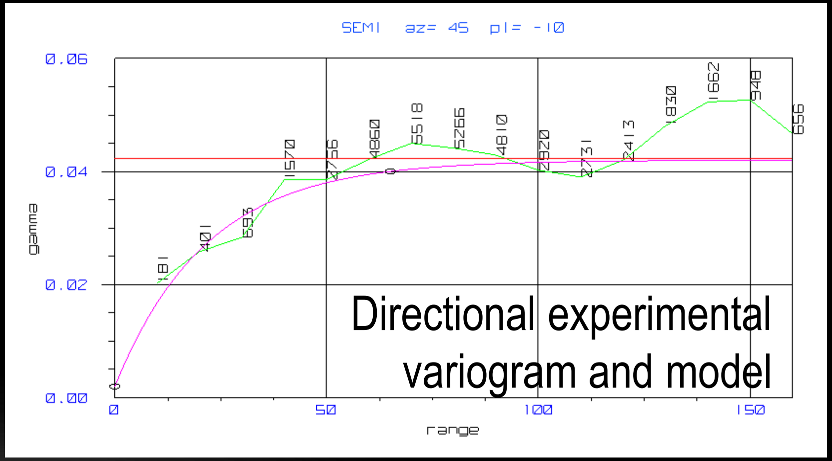


VARIOGRAM MODEL

- A variogram model consisting of a single exponential structure was fitted to the experimental variogram.
- The exponential model was chosen as it seemed to match better the curvy shape of the experimental variogram at distances between 0 and 50 meters.

Experimental Variogram Type	Standard Semivariogram
Fitted Model Type	Exponential
Nugget Effect	0.002
Sill Differential	0.04
Bearing	45
Plunge	-15
Dip	0
Major range	65
Semimajor range	42.85
Minor range	8.2





GRADE ESTIMATION

- A block model with 10x10x12m main blocks and a minimum sub-block size of 1x1x1m was generated covering the entire area of the deposit.
- The main and sub-block sizes were set to reflect pit geometry and mine method selectivity.
- The model was not rotated around any axis in order to be used for pit optimisation.
- Ordinary Kriging (OK) was used as the method for interpolating Ni values to the blocks coded as part of the main orebody using the variogram model.

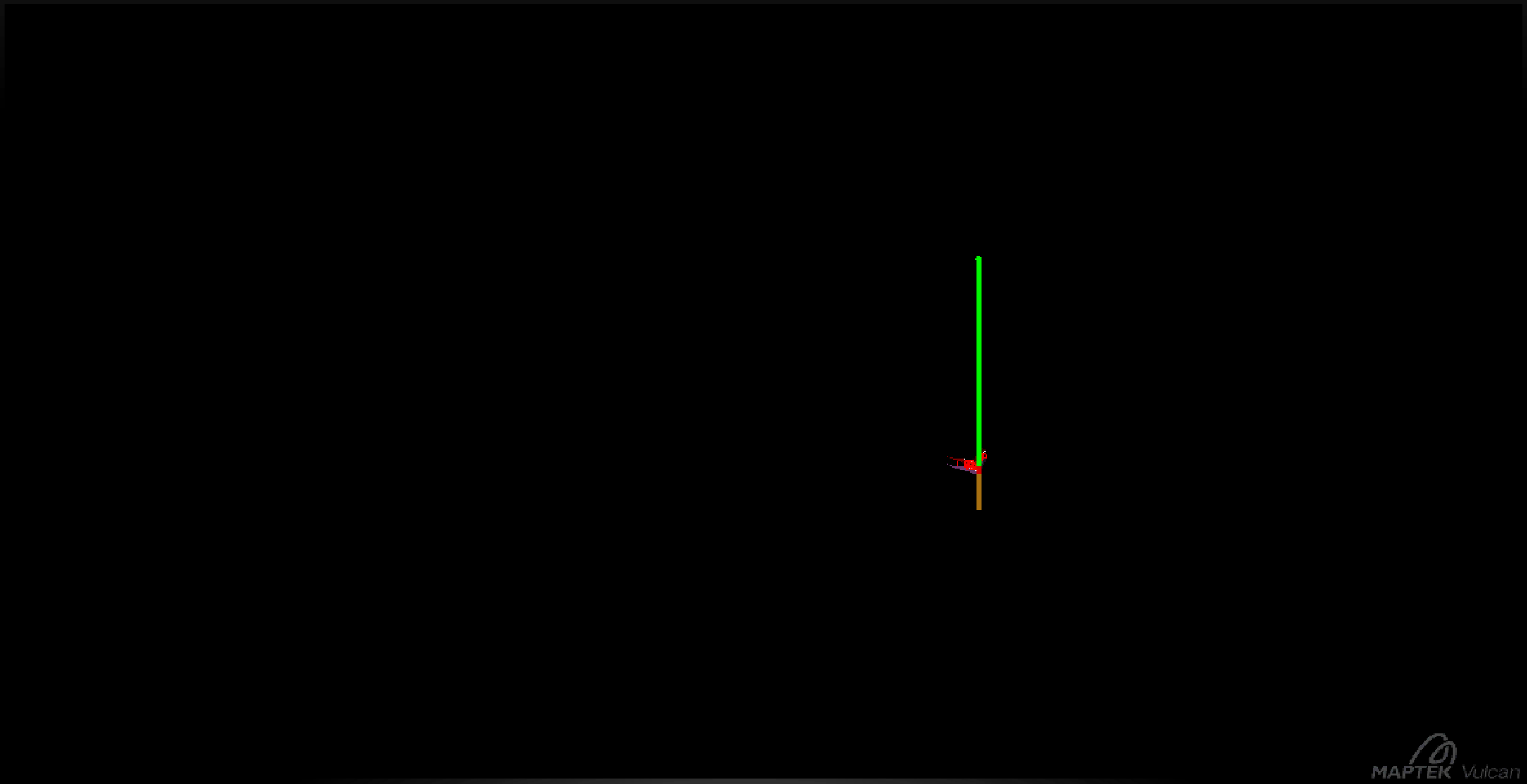
GRADE ESTIMATION (CONTINUED)

- Three separate estimation runs were performed, each with different sample selection strategies and varying search ellipsoid dimensions, corresponding to three different resource classifications.
- In each run the blocks estimated received a flag in the class variable of the block model according to the classification: 1 for measured, 2 for indicated, and 3 for inferred.

	Measured	Indicated	Inferred
Bearing	45	45	45
Plunge	-10	-10	-10
Dip	-25	-25	-25
Major	32.5	65	65
Semi	21.4	42.8	42.8
Minor	8.2	8.2	8.2
Minimum Samples	8	4	4
Maximum Samples	16	16	16
Octant Based Search	Yes	Yes	No
Maximum Samples per Octant	2	2	-
Minimum Octants	4	-	-
Minimum Samples per Octant	2	-	-
Blocks Estimated	9958	27528	1

- Blocks estimated in one run were excluded from the next to avoid overwriting of estimates.

GRADE ESTIMATION – BLOCK MODELLING



CALCULATION OF TECHNICAL AND FINANCIAL PARAMETERS FOR PIT OPTIMISATION

- Technical and financial parameters related to the mine geometry and location, mining method, haulage and ore processing were calculated for each block individually using a script written in Perl and utilising Vulcan's Lava extensions to this popular scripting language.
- The calculated values for the various parameters were used to estimate a total block value that was used for pit optimisation using the following equation:

block_value = revenue – mining_cost – haulage_cost – crushing_cost – metallurgy_cost – sea_transport_cost – other_block_cost

- The values for the each of the parameters were also stored in separate block model variables for validation purposes.
- Through this process, all the applicable resources to reserves conversion parameters according to reporting standards were applied to the resource block model before using it for pit optimisation.

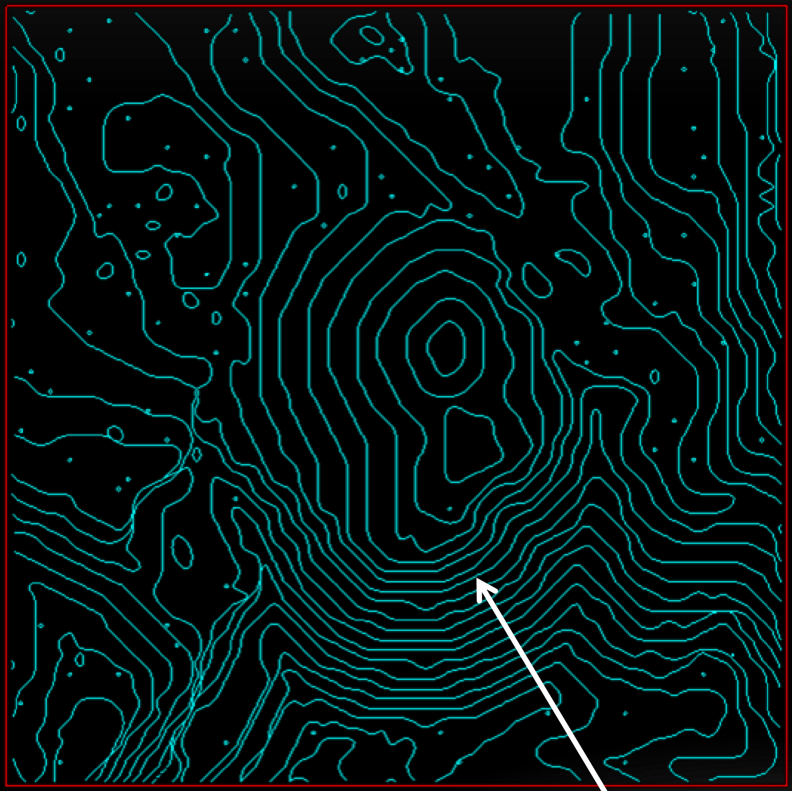
PIT OPTIMISATION

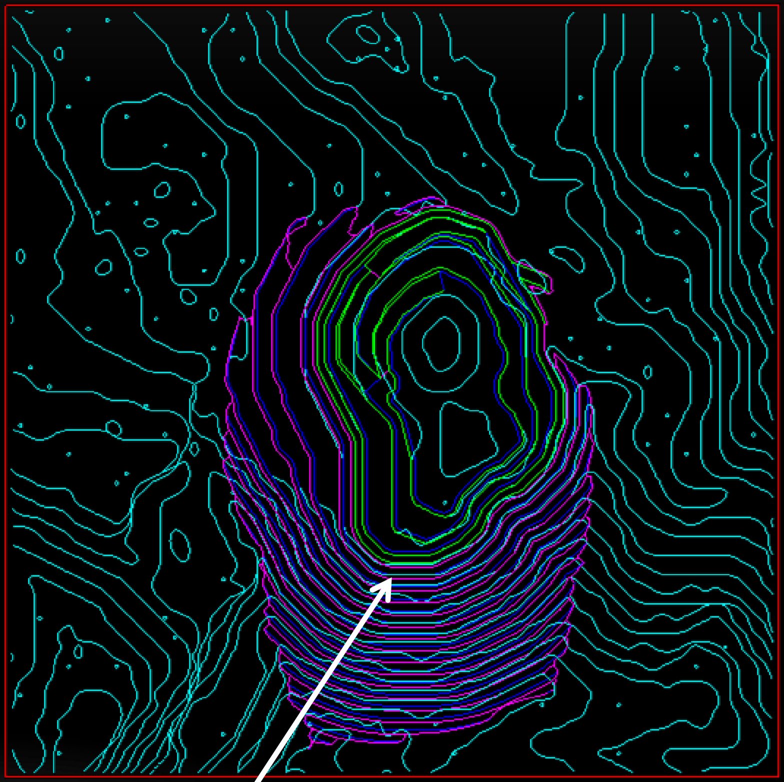
- The block value calculated in the previous step was passed to Vulcan’s Pit Optimiser module – an implementation of the Lerchs-Grossman algorithm.
- Two different angles were used to control the slope of the final pit limits, matching the bench angle and height, and berm width configuration and also allowing for the presence of haul road on one side of the pit.
- A 45^{o} pit slope was used in the East side and a 25^{o} slope in the west side (the side of the haul road).
- The pit slope was also controlled by a lithology block model variable.
- The result of pit optimisation was stored as a code in a block model variable.

PIT DESIGN

- Pit design was performed using the optimum pit limits as a guide.
- The top part of the pit from the lowest open bench was designed with projections upwards and outwards of the corresponding optimum pit limit to generate the toe and crest polygons without a haul road.
- The bottom part of the pit from the highest closed bench, was designed using a more complex function in Vulcan that inserts the haul road and then projects the toe and crest polygons for each bench.
- Two switchbacks were introduced to maintain the haul road only on the west side of the pit as this was the side with the lower pit slope set in pit optimisation.
- The benches were 12m high with 8m berms and a 70^{o} batter angle.
- The haul road was 12m wide with a 10% grade applied to the shortest side.

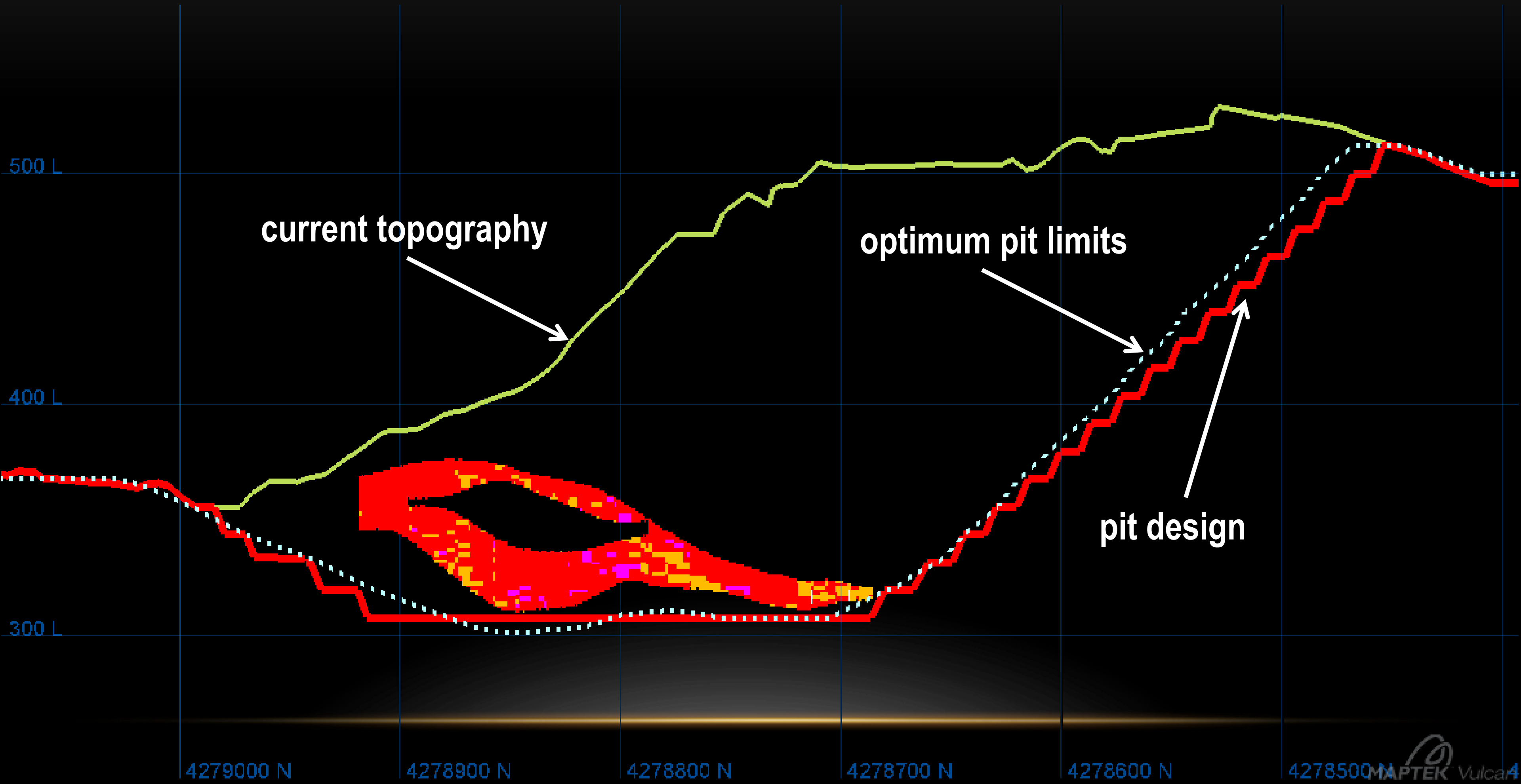
PIT DESIGN AND MODELLING - 1



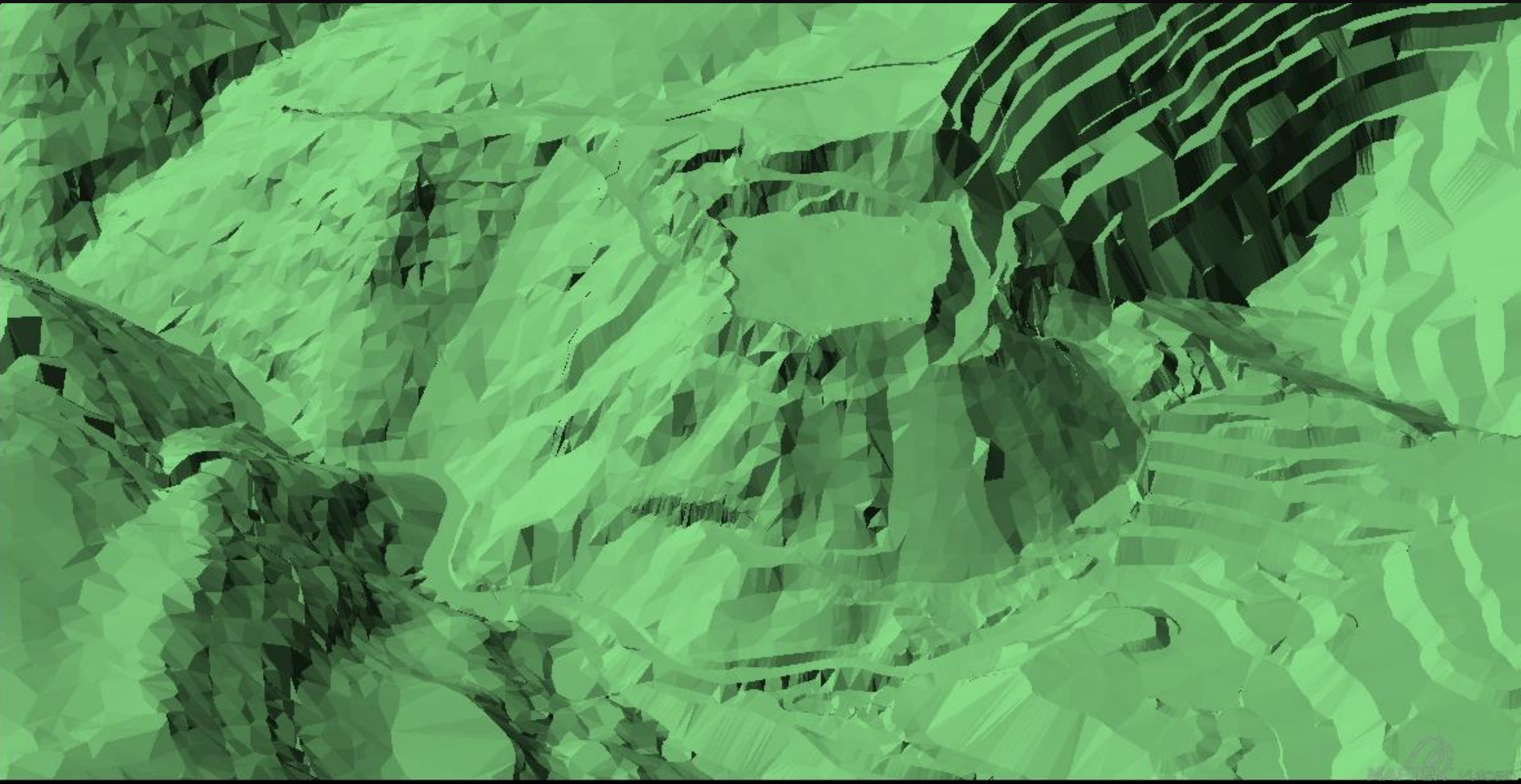


from optimum pit limits to actual pit design

PIT DESIGN AND MODELLING - 2



PIT DESIGN AND MODELLING - 3



COMPARISON OF ACTUAL VS. ESTIMATED RESERVES

- Comparison of the estimated reserves with the production figures for the period up to the end of 2012 was based on a solid triangulation model representing the volume of the actual excavation at the end of this period.
- There was some over-estimation of tonnage combined with an under-estimation of grade which translates to very similar nickel content in both cases (6,005t actual versus 6,344t estimated).

	Total Estimated Resources		Estimated Reserves (2011- 2012)			Actual Reserves (2011-2012)
	Measured	Indicated	Measured	Indicated	Total	Total
Ore Tonnage	587,812	1,108,906	96,851	479,925	576,777	508,926
Ore Ni Grade %	1.07	1.08	1.15	1.09	1.10	1.18

CONCLUSIONS

- This paper discussed most aspects of the application of mine planning software to the evaluation of mineral resources and mineral reserves of the sedimentary nickel deposits in Euboea.
- The implementation of commercial mine planning software produced results that increased confidence as to the available resources, aided the configuration of the mining methods applied, and helped in planning future mining operations by developing different mining scenarios with speed and clarity.
- The adoption of a geostatistical approach to grade/reserves estimation increased confidence in the produced results and reduced the risks associated with the estimates.
- The use of a pit optimisation tool helped convert resources to reserves with more confidence and in a more standardised fashion that is widely accepted by the mining industry.
- The procedures described in this paper have been adopted with minor adjustments to other nickel deposits exploited by LARCO SA in other areas of Greece.