Drill hole grid spacing analysis in nickel laterite exploration: A geostatistical comparison of two Ni-laterite deposits with varying drill hole spacing

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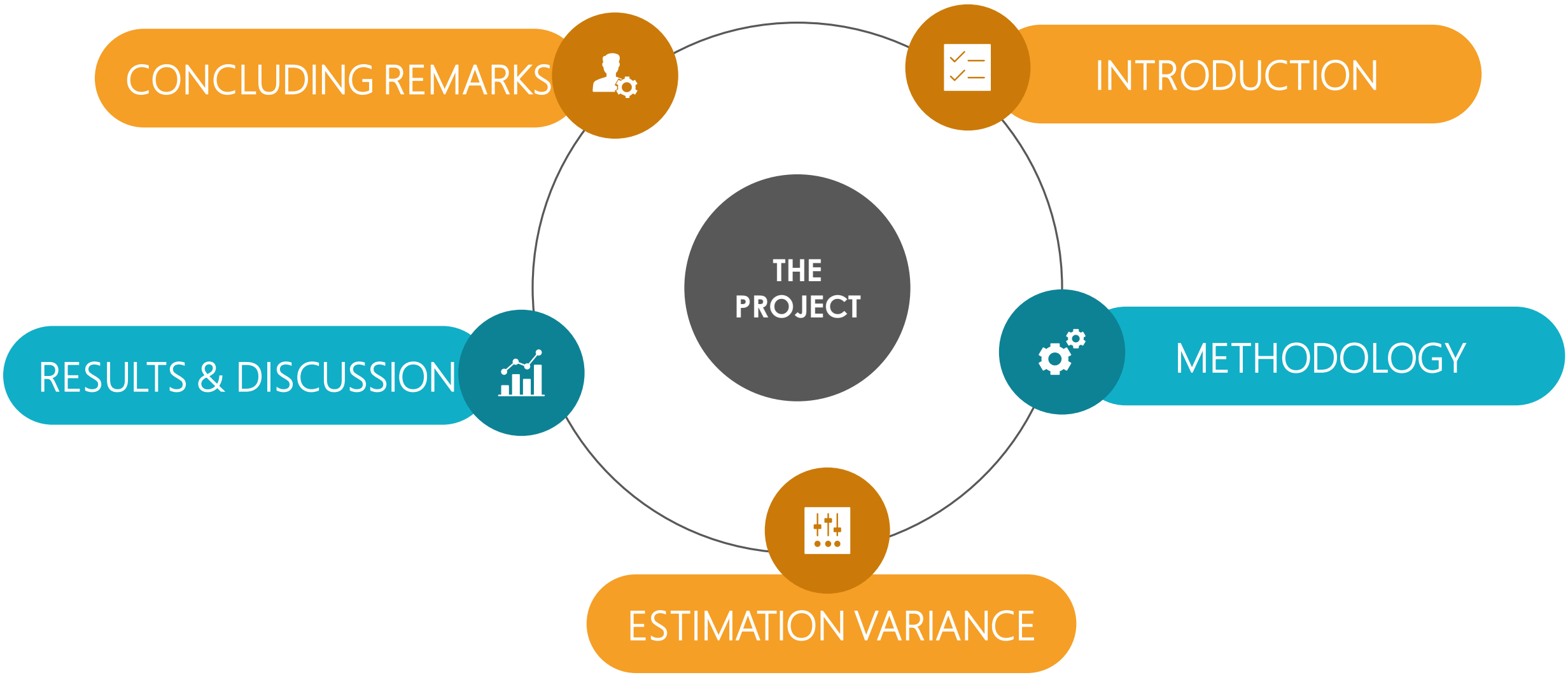
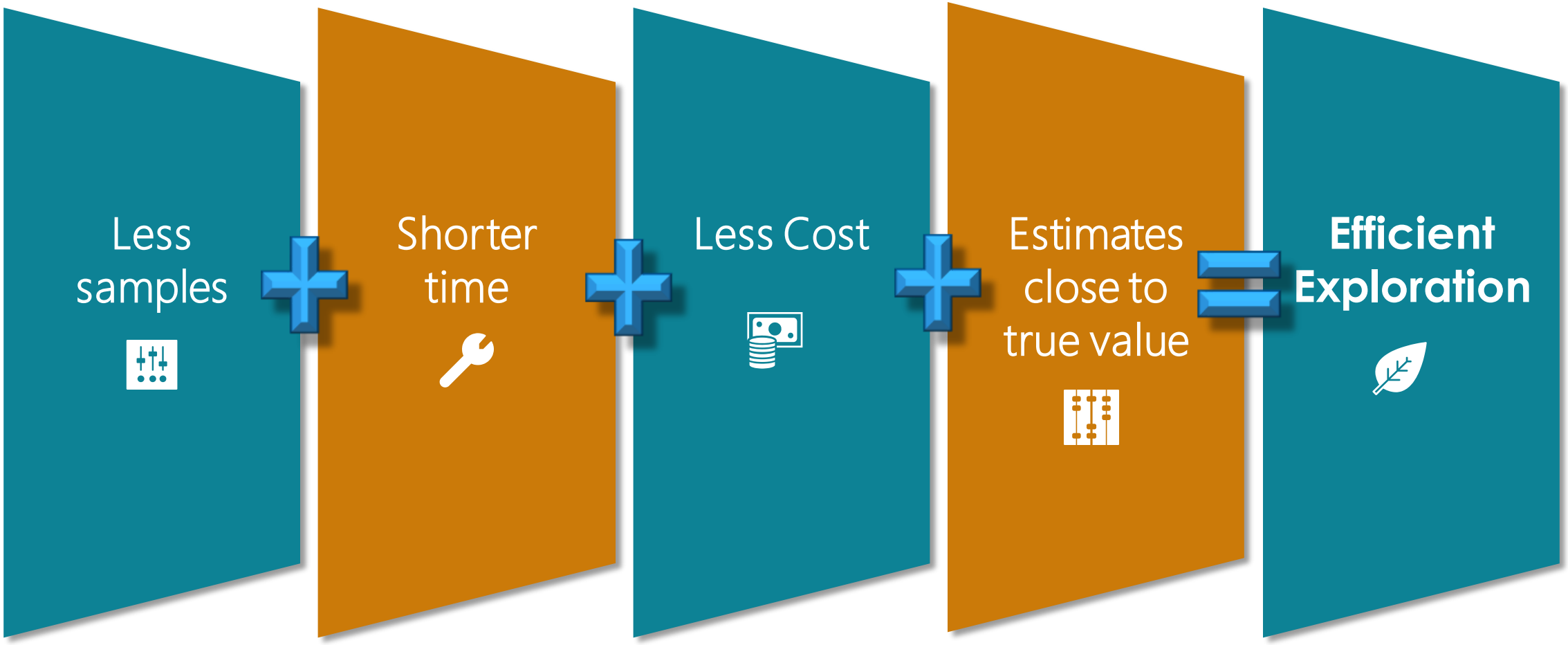
The Outline


CONCLUDING REMARKS
INTRODUCTION
THE PROJECT
RESULTS & DISCUSSION
METHODOLOGY
ESTIMATION VARIANCE

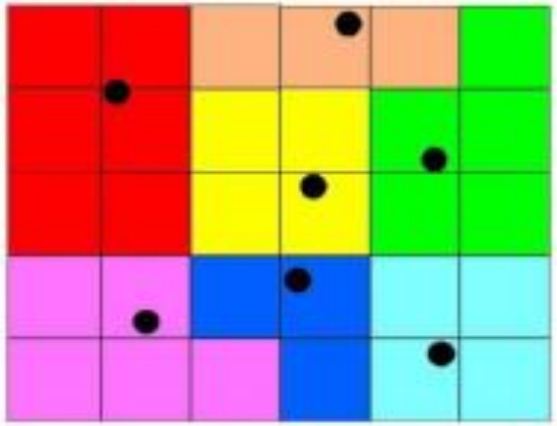
Importance of the Work



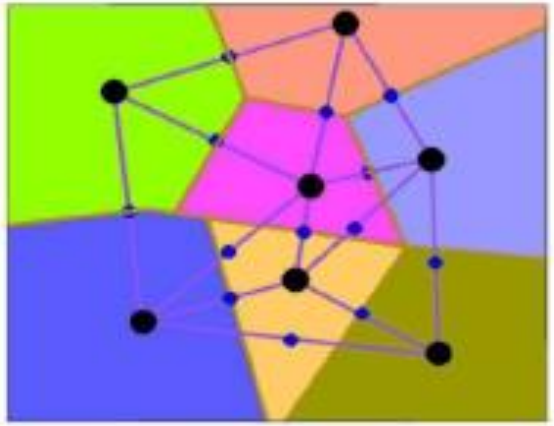
More Samples/Drill Hole = (?) Improvement in Resource Category

INTRODUCTION

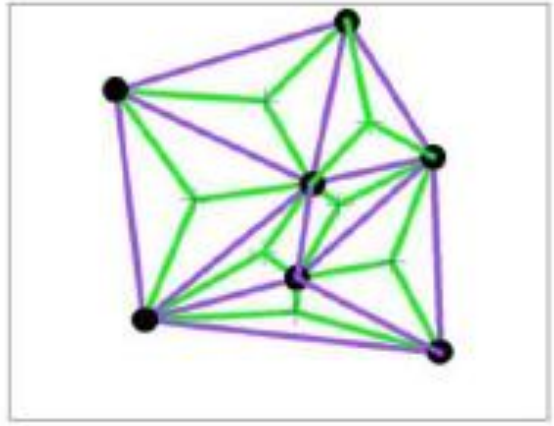
Resource Estimation Techniques



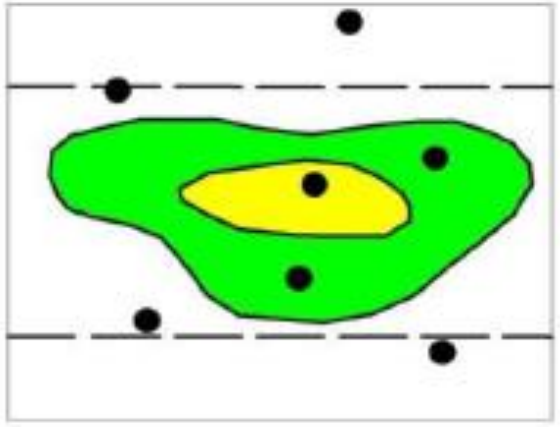
NEAREST NEIGHBOR



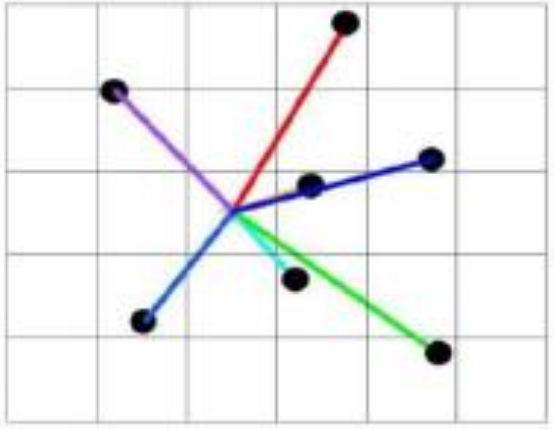
POLYGONAL



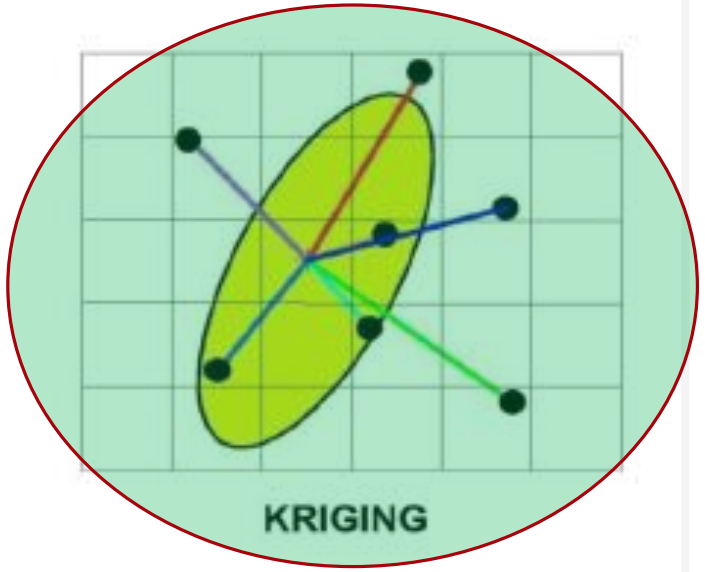
TRIANGULATION



SECTIONAL



INVERSE DISTANCE



KRIGING

Resource Categories

Reporting of Mineral Resources

20. A 'Mineral Resource' is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade (or quality), and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade (or quality), continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling. Mineral Resources are sub-divided, in order of increasing geological confidence, into Inferred, Indicated and Measured categories.

Inferred Mineral Resource

21. An 'Inferred Mineral Resource' is that part of a Mineral Resource for which quantity and grade (or quality) are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade (or quality) continuity. It is based on exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes.

Indicated Mineral Resource

22. An 'Indicated Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit.

Measured Mineral Resource

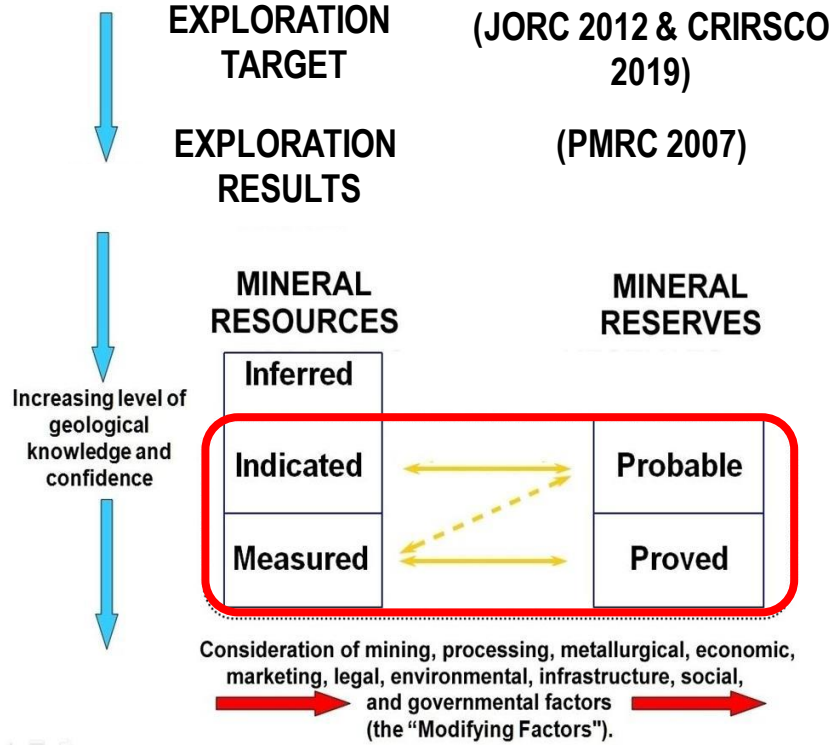
23. A 'Measured Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit.

After JORC (2012)

Resource Categories

An **Exploration Target** is a statement or estimate of the exploration potential of a mineral deposit in a defined geological setting where the statement or estimate, quoted as a range of tonnes and a range of grade (or quality) relates to mineralization for which there has been insufficient exploration to estimate a Mineral Resource **(JORC 2012 & CRIRSCO 2019)**

Exploration Results include data and information generated by exploration programs that may be of use to investors, but which do not form part of a declaration of Mineral Resources or Mineral Reserves **(PMRC 2007).**

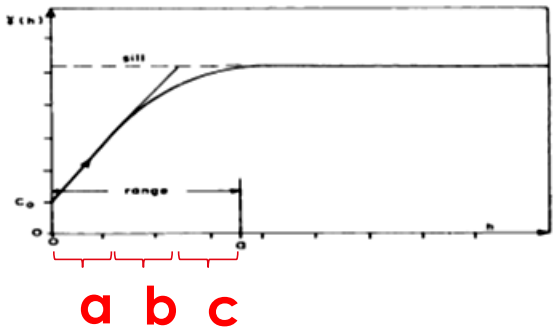


After Draft PMRC (2020)

Resource Category Determination

A.

1. 1/3 of range = Measured (a)
2. 2/3 of range = Indicated (b)
3. Equal of range – Inferred (c)



B. Polygonal

1. 25m X 25m = Measured
2. 50m X 50m = Indicated
3. 100m X 100m = Inferred

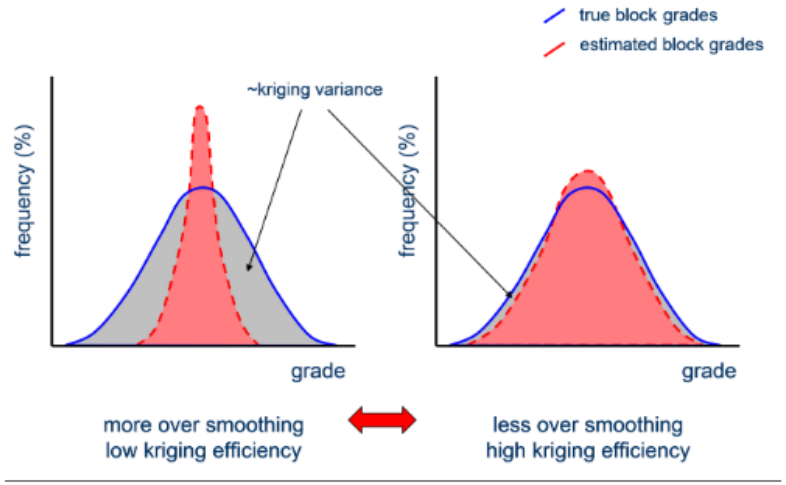
C.

Grade Category	Volume Of Search Ellipse	Minimum Samples Required
Measured	0 – 80%	10
Indicated	80 – 120%	10
Inferred	> 120%	1

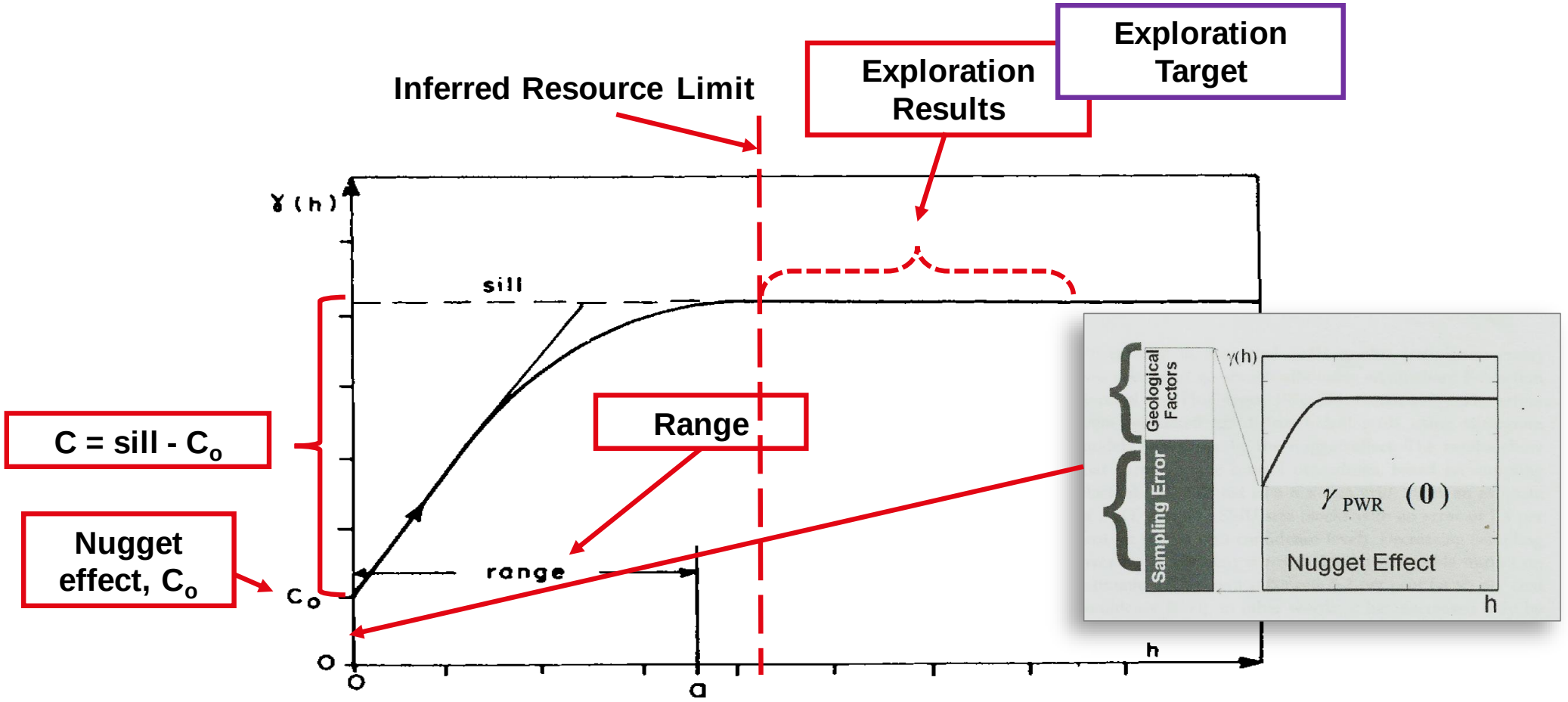
E. Harry Parker (JORC 2012 Checklist)

Grade Category	90% Confidence Interval (of a Quarter)	Relative Accuracy
Measured	90%	within ±15%
Indicated	90%	within ±30%
Inferred	90%	within ±30% and ±100%

D. Kriging Efficiency



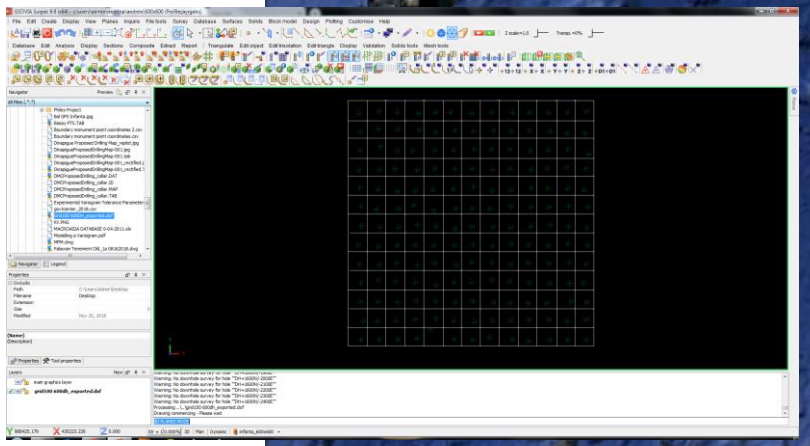
Standard Variogram & the Resource Categories

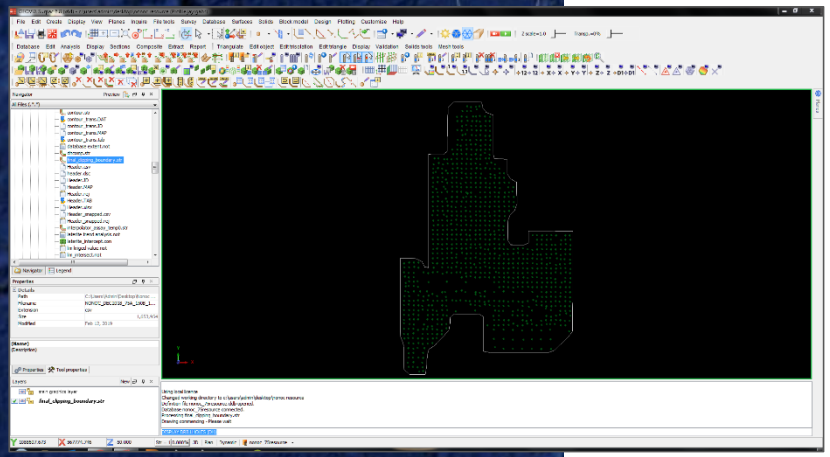


a - The **range** represents the distance limit beyond which the data are no longer correlated. The sill represents the variance of the variable.

C_0 - The nugget could represent the measurement error.

The Study Area:
Southern Palawan & Surigao Del Norte





Philippine Sea
Babuyan Channel
Philippines
Manila
Lamon Bay
Tayabas Bay
Sibuyan Sea
Tablas Strait
Mindoro Strait
Semirara Islands
Visayan Sea
Leyte Gulf
Panay Gulf
Tañon Strait
Palawan
Bohol Sea
Sulu Sea
Moro Gulf
Talikud
Davao Gulf
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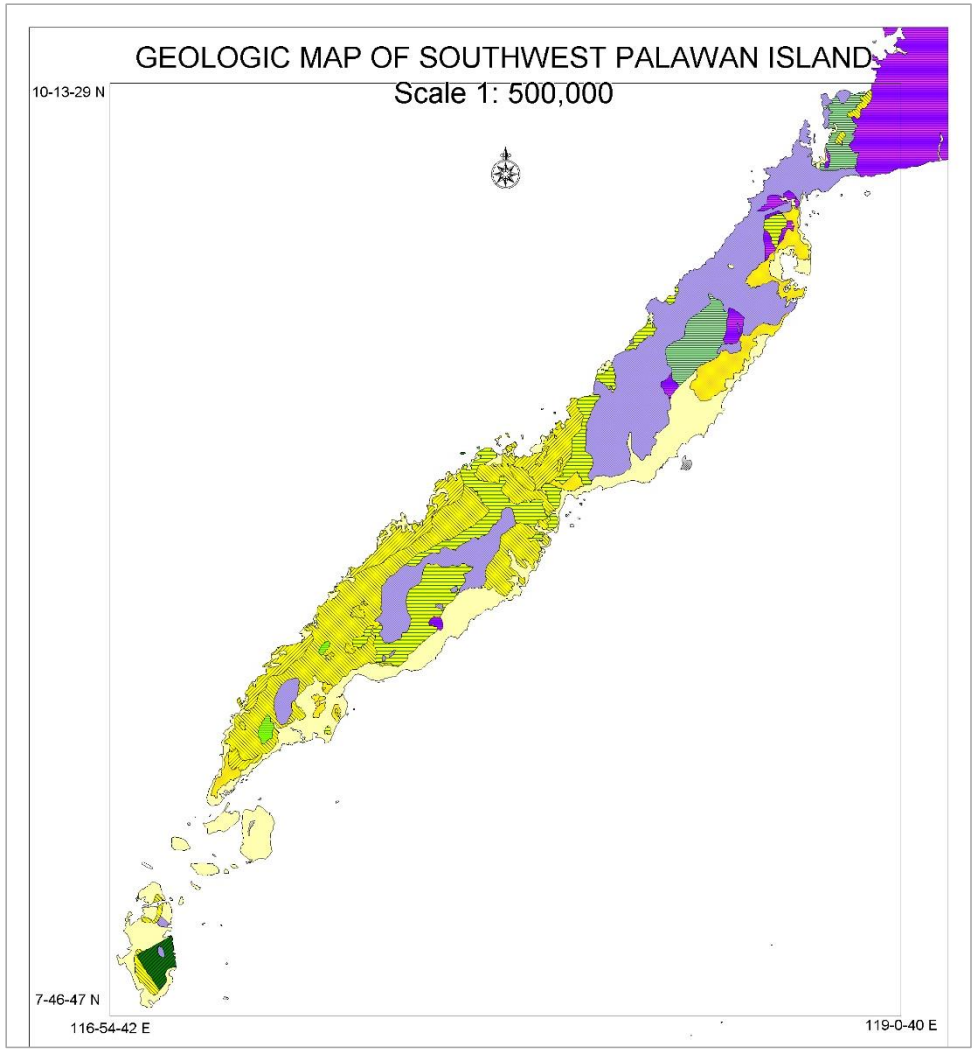
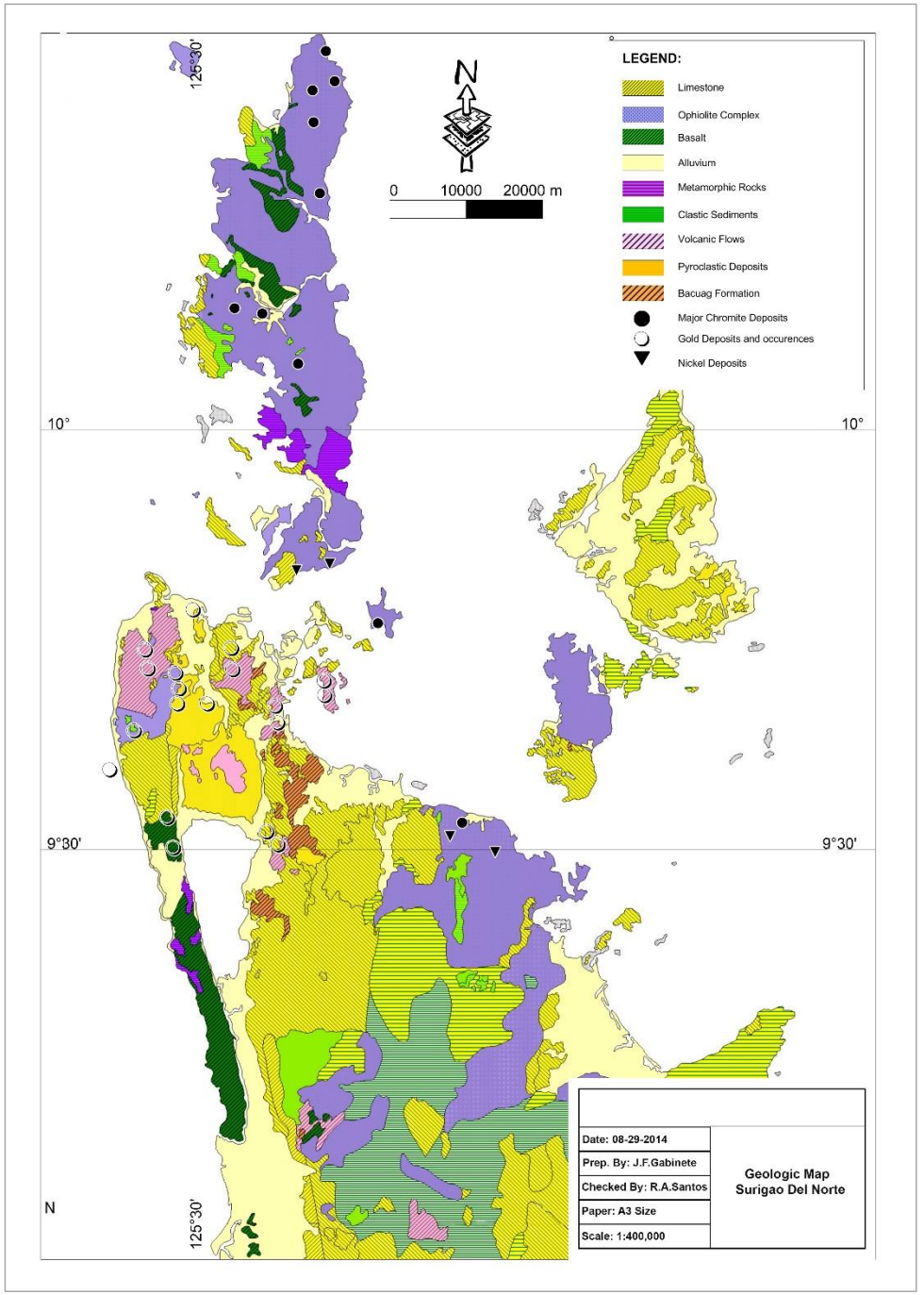
Google Earth

Southern Palawan

Surigao Del Norte

Regional Geology: the Dinagat and Palawan Ophiolite Complexes





Resource Parameters

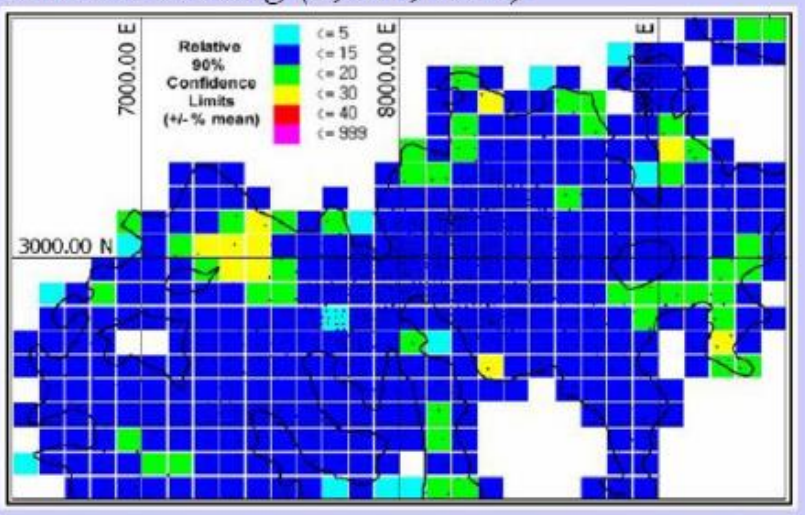
Geological interpretation	• *Confidence in (or conversely, the uncertainty of) the geological interpretation of the mineral deposit.* • *Nature of the data used and of any assumptions made.* • *The effect, if any, of alternative interpretations on Mineral Resource estimation.* • *The use of geology in guiding and controlling Mineral Resource estimation.* • *The factors affecting continuity both of grade and geology.*
Estimation and modelling techniques	• *The nature and appropriateness of the estimation technique(s) applied and key assumptions, including treatment of extreme grade values, domaining, interpolation parameters and maximum distance of extrapolation from data points. If a computer assisted estimation method was chosen include a description of computer software and parameters used.* • *The availability of check estimates, previous estimates and/or mine production records and whether the Mineral Resource estimate takes appropriate account of such data.* • *The assumptions made regarding recovery of by-products.* • *Estimation of deleterious elements or other non-grade variables of economic significance (eg sulphur for acid mine drainage characterisation).* • *In the case of block model interpolation, the block size in relation to the average sample spacing and the search employed.* • *Any assumptions behind modelling of selective mining units.*
Estimation and modelling techniques (continued)	• *Any assumptions about correlation between variables.* • *Description of how the geological interpretation was used to control the resource estimates.* • *Discussion of basis for using or not using grade cutting or capping.* • *The process of validation, the checking process used, the comparison of model data to drill hole data, and use of reconciliation data if available.*

INTRODUCTION

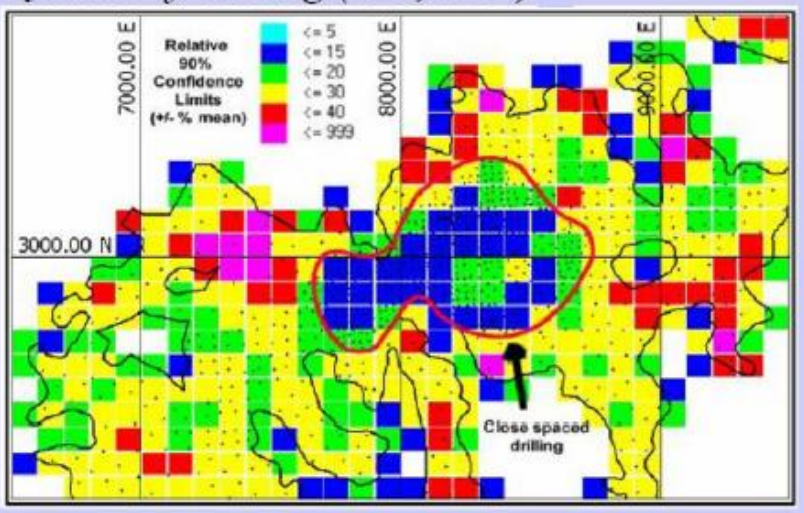
Resource Parameters

Criteria	Explanation
Discussion of relative accuracy/ confidence	• *Where appropriate a statement of the relative accuracy and confidence level in the Mineral Resource estimate using an approach or procedure deemed appropriate by the Competent Person. For example, the application of statistical or geostatistical procedures to quantify the relative accuracy of the resource within stated confidence limits, or, if such an approach is not deemed appropriate, a qualitative discussion of the factors that could affect the relative accuracy and confidence of the estimate.* • *The statement should specify whether it relates to global or local estimates, and, if local, state the relevant tonnages, which should be relevant to technical and economic evaluation. Documentation should include assumptions made and the procedures used.* • *These statements of relative accuracy and confidence of the estimate should be compared with production data, where available.*

Annual scaling (2,500,000 t)



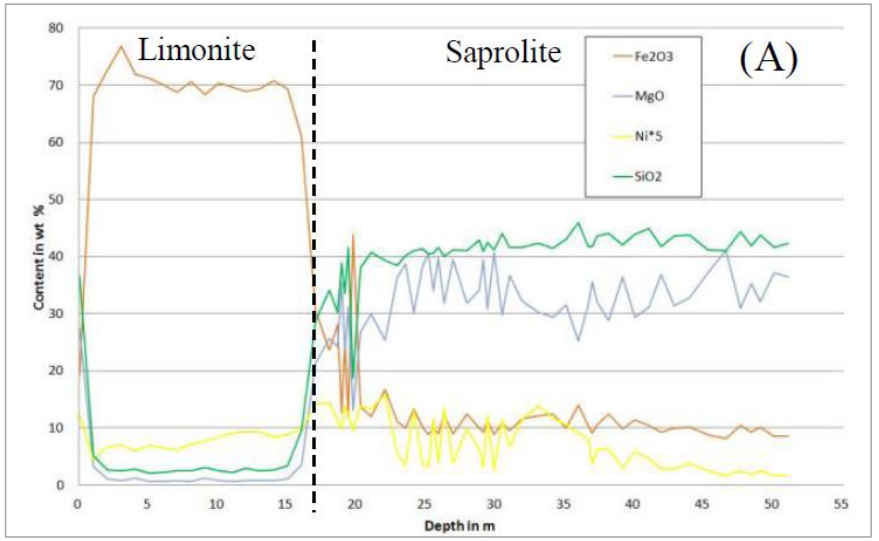
Quarterly scaling (625,000 t)

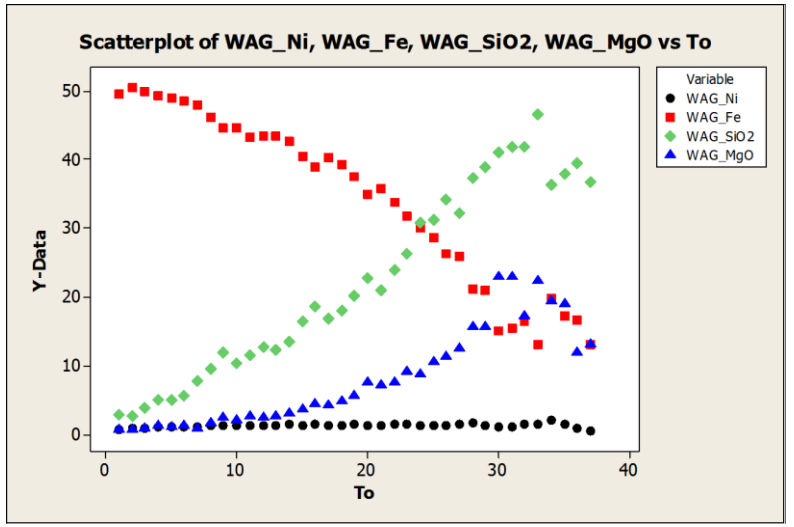


The parameters used to define measured, indicated, and inferred resources as suggested by Harry Parker in Rossi and Deutsch (2014) are as follows: (i) a **measured resource** would be a quarter known within ±15%, 90% of the time; (ii) **indicated resource**, within ±30%, 90% of the time; and (iii) **inferred**, within ±30% and ±100%, 90% of the time. Values that exhibit more than ±100% will not qualify as resource, and may be flagged (but not reported publicly) as blue sky or potential mineralization.

Resource Parameters

- **Volume of the Deposit**
  - Topographic Survey and Drillhole Distribution (re-shots and control points)
- **Grade**
  - Duplicates, Blanks, and Internal Standards
  - Limonite-Saprolite Boundary (Geochemistry)
- **Density**
  - Sand Displacement Method, Water Displacement Method, Calipher Method





Resource Parameters: Topographic Survey

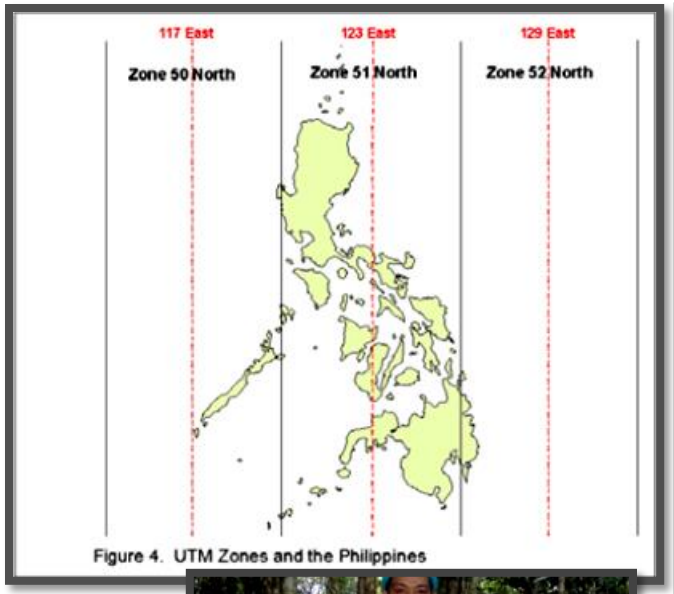


Figure 4. UTM Zones and the Philippines

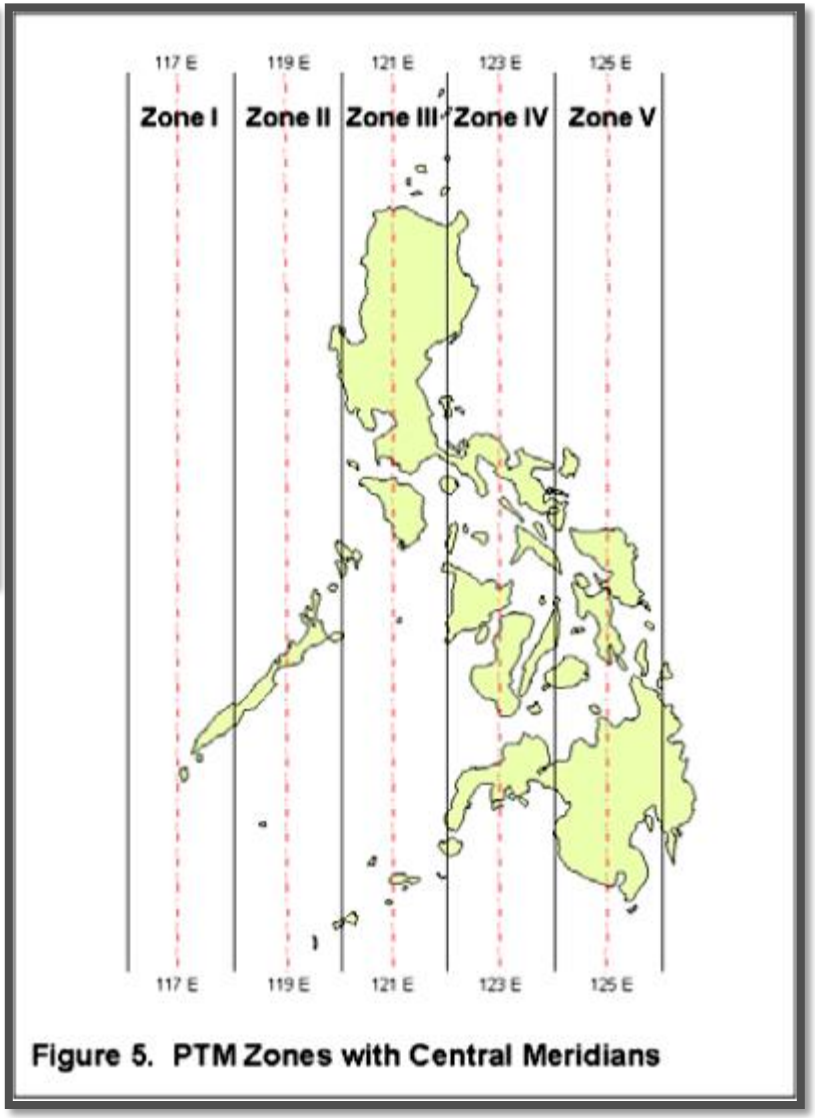
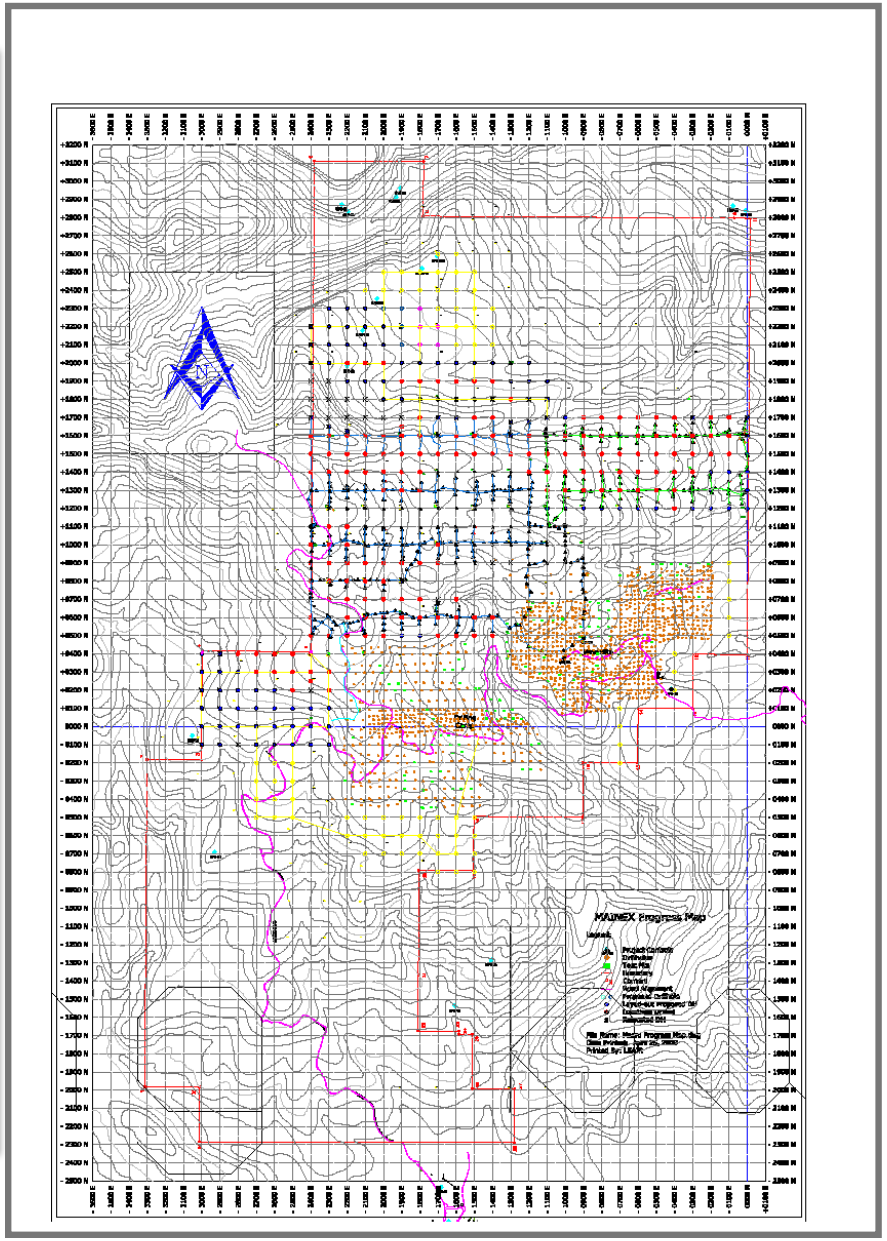
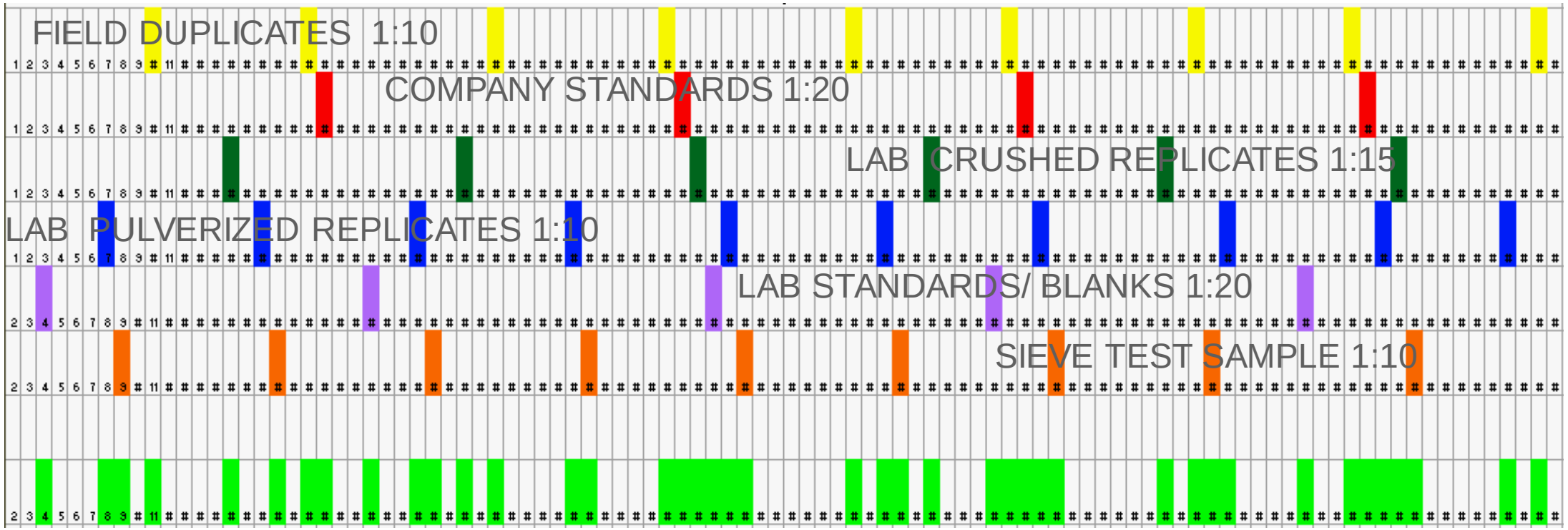


Figure 5. PTM Zones with Central Meridians



Check Samples: Field & Laboratory

1 100

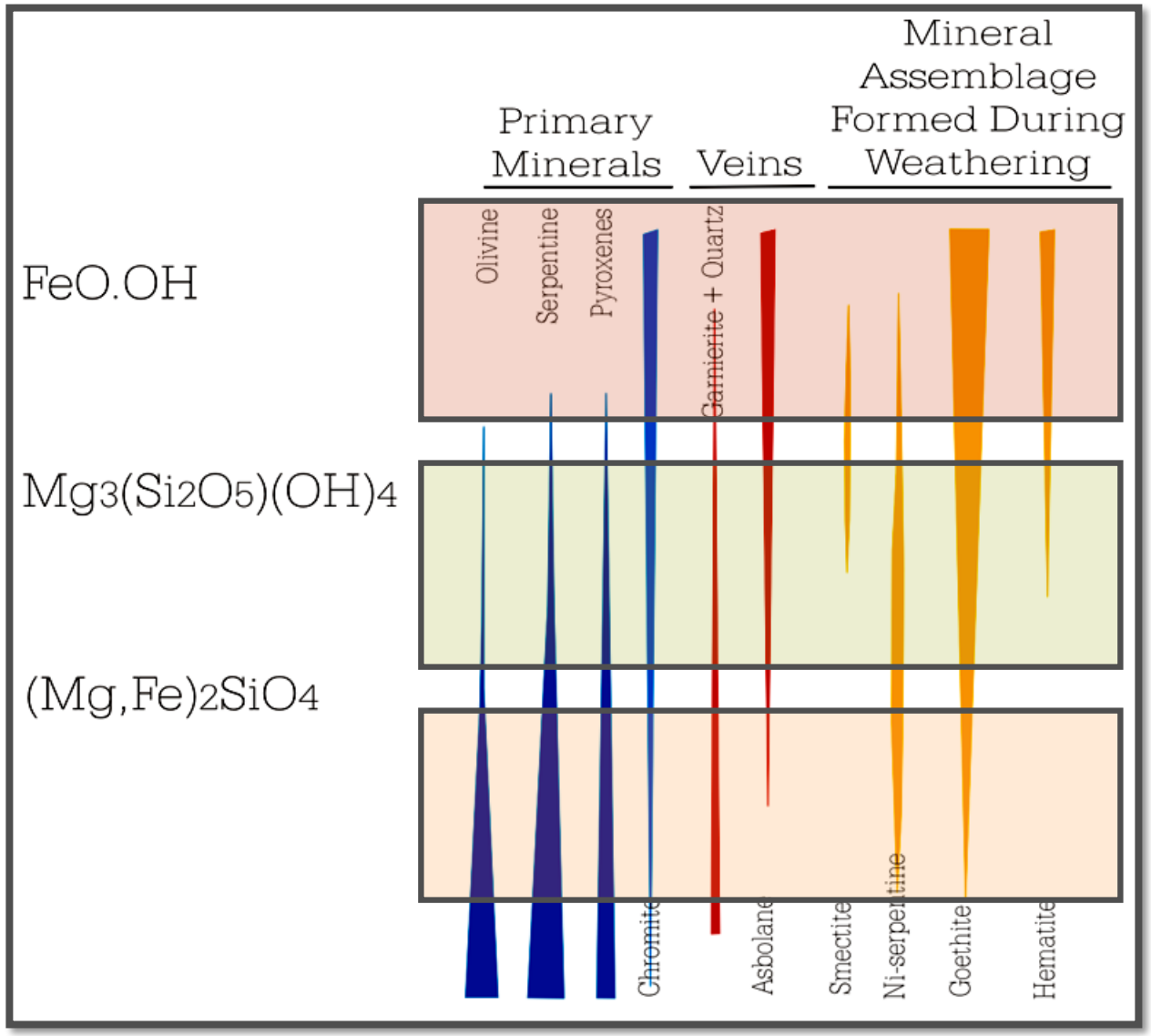


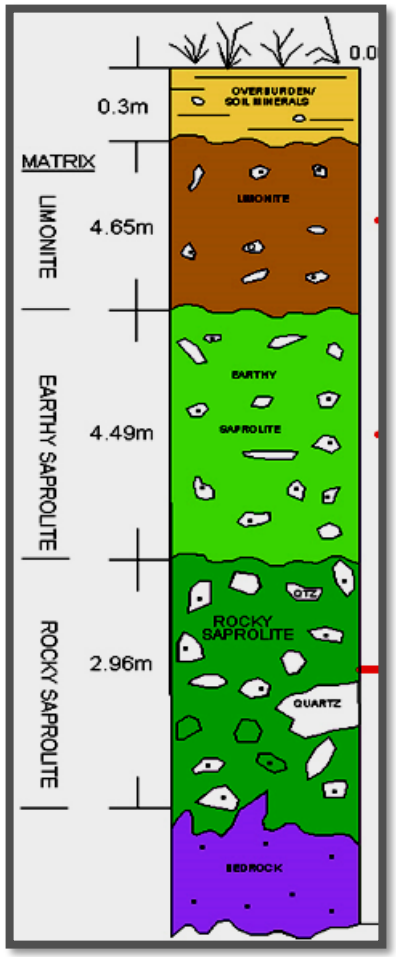
QA/QC SAMPLE RATIO - 1:2

Density Values

OBSERVED MINERAL SPECIES increasing depth from surface to bedrock	THEORETICAL DENSITY	VOLUME%	RELATIVE ABUNDANCE		
			LIMONITE	EARTHY SAPROLITE	ROCKY SAPROLITE
Goethite	4.27 - 4.29	5 - 30%	**HIGH**	MOD	LOW
Limonite	2.7 - 4.3	5 - 15%	**HIGH**	LOW	MOD
Fe Mg Si MIX/ Talc	2.7 - 2.8	15 - 35%	**HIGH**	MOD	LOW
Cr Minerals/ Spinels	4.50 - 5.09	5 - 7%	MOD	LOW	**HIGH**
Magnetite	5.1 - 5.2	<3%	**HIGH**	MOD	LOW
Asbolane	5.03	<5%	MOD	**HIGH**	LOW
Smectite	2.74 - 2.86	4 - 11%	**LOW**	**HIGH**	MOD
Pyroxene	3.20 - 3.88	2 - 12%	LOW	**HIGH**	MOD
Silica	2.65	2 - 11%	MOD	**HIGH**	LOW
Olivine	3.27 - 3.37	2 - 9%	LOW	**HIGH**	MOD
Serpentine	2.4 - 2.44	5 - 50%	LOW	MOD	**HIGH**
Ni Serpentine/ Garnierite	2.27 - 2.87	1 - 5%	ABSENT	MOD	**HIGH**

Density Values

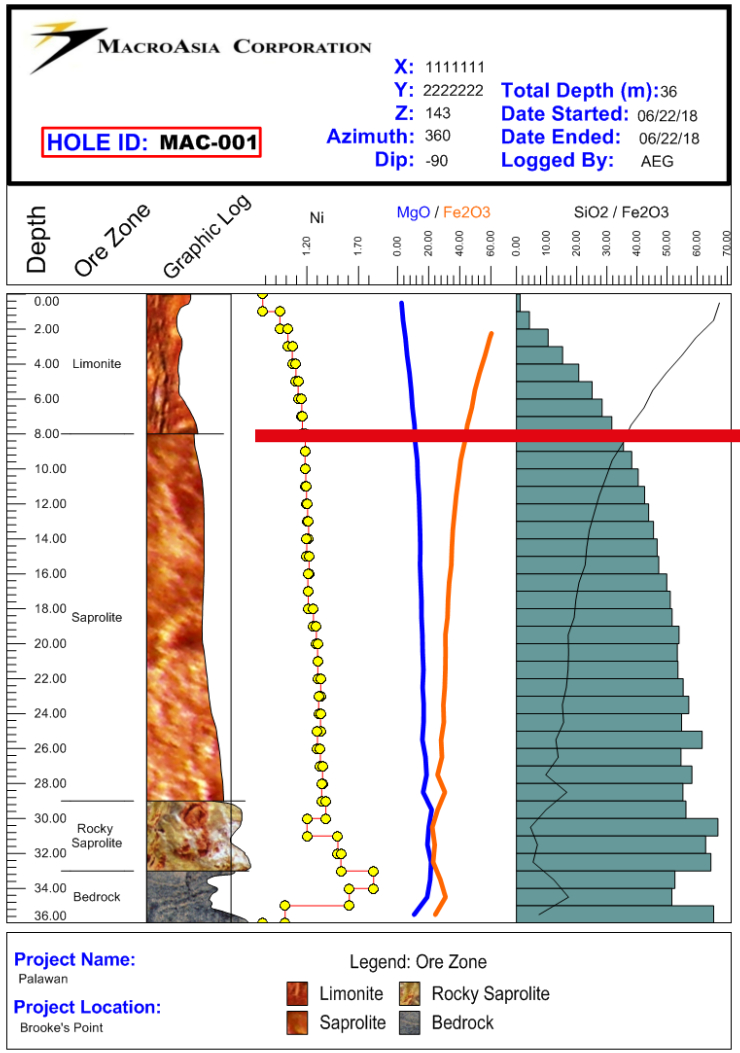




Field Procedure: Density

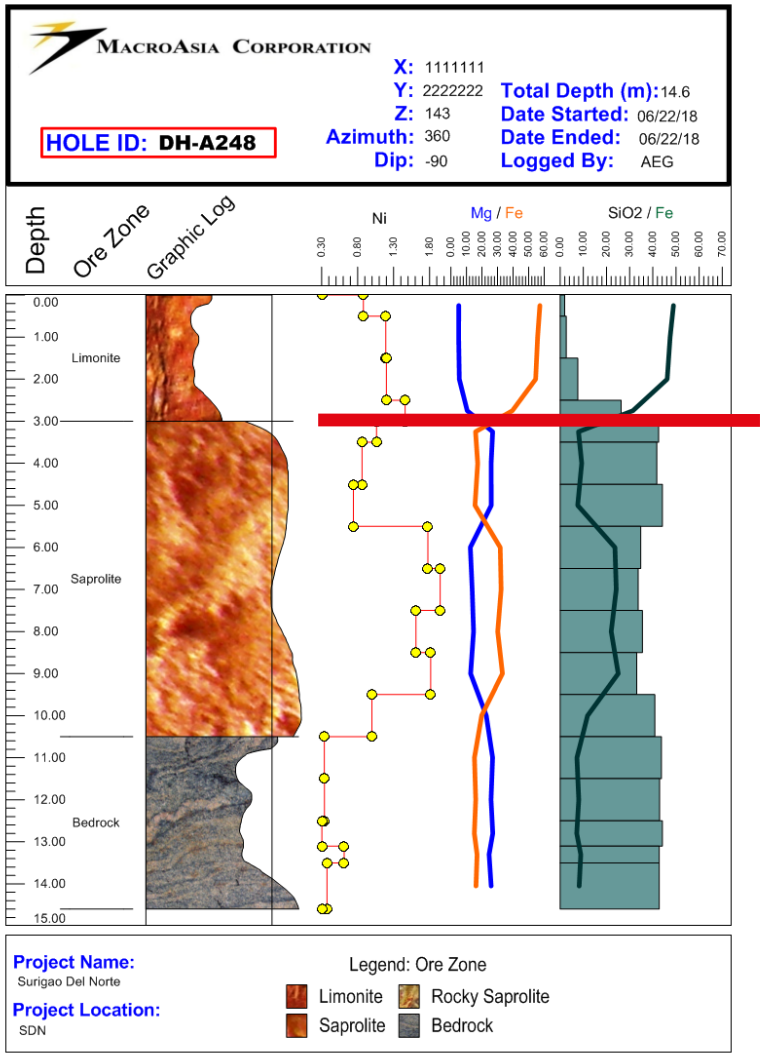
Results & Discussion

Southern Palawan (Graphic Log)



SiO2 & Fe2O3 Contact

Surigao Del Norte (Graphic Log)



SiO2 & Fe Contact

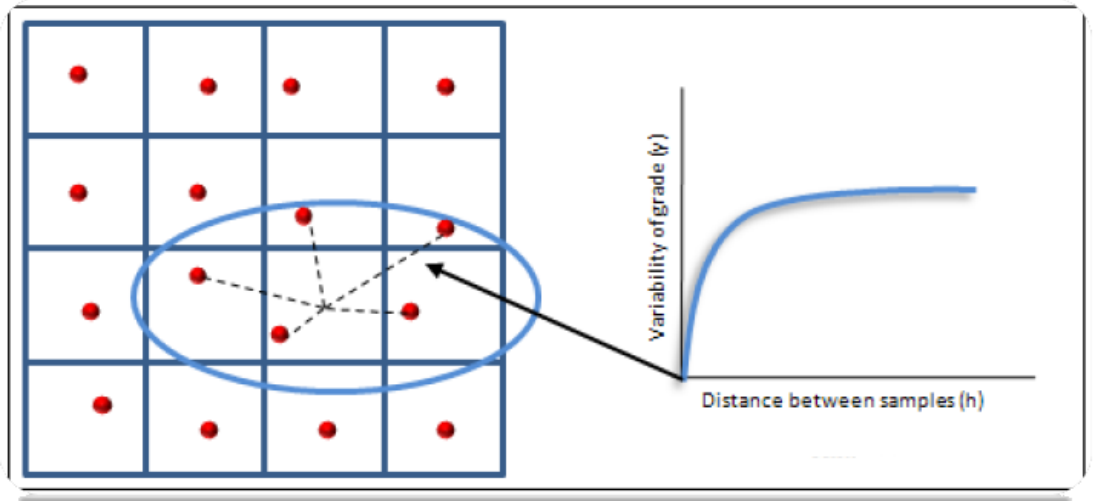
Methodology & Estimation
Variance

Kriging (**BLUE**) – **B**est **L**inear **U**nbiased **E**stimator

Ordinary Kriging

- Is an inverse distance weighting technique where weights are selected via the variogram according to the sample distance and direction (anisotropy)

The variance of the error of estimation will be called in short the **Estimation Variance**.



Results & Discussion

From Parker's quantitative rule:

$$Sample\ size\ (n) = \frac{Tonnage\ for\ production\ period}{Tonnage\ of\ reblocked\ panel} = Number\ of\ Panels$$

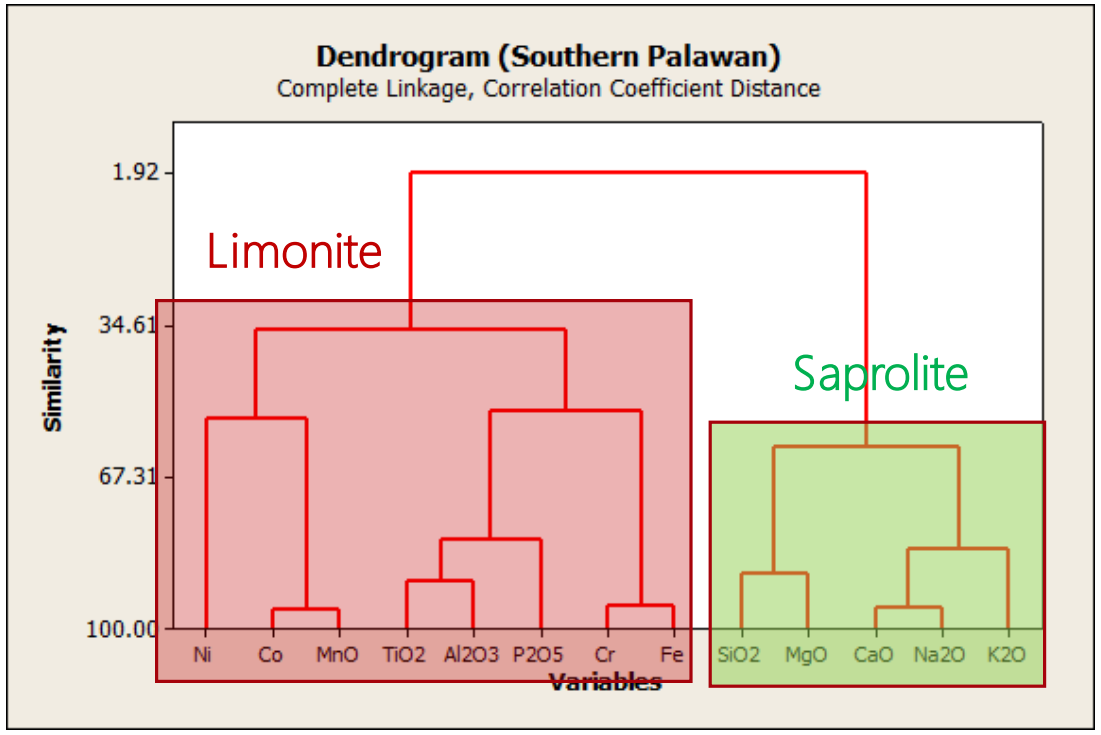
$$Relative\ standard\ deviation\ (\sigma_R) = \frac{Panel\ standard\ deviation}{Panel\ mean} * 100\%$$

$$Relative\ 90\%\ confidence\ limit = \pm\frac{(z_{90\%})(\sigma_R)}{\sqrt{n}} = \pm\frac{(1.645)(\sigma_R)}{\sqrt{n}}$$

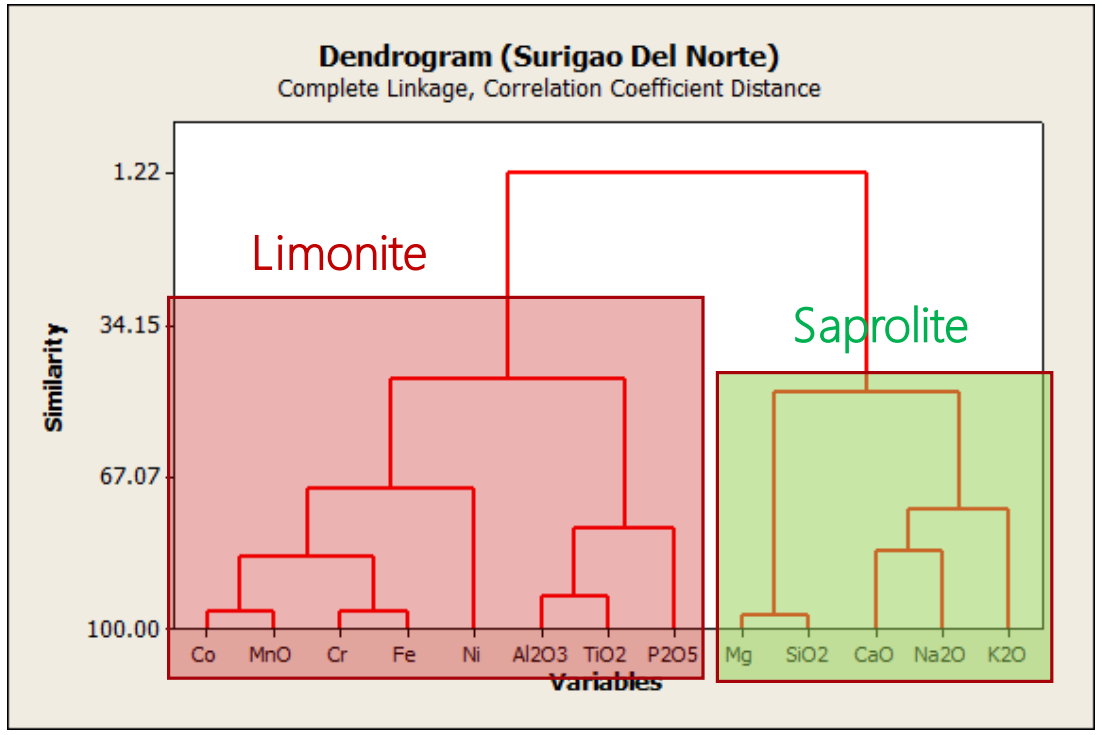
The probability used to define measured, indicated, and inferred resources depends on the mining company's practice. Many will simplistically translate the kind of precision required of other engineering studies and cost estimates during pre-feasibility or feasibility studies into resource classification. Typically, a measured resource would be a quarter known within ±15%, 90% of the time; an indicated resource, within ±30%, 90% of the time; and inferred, within ±30% and ±100%, 90% of the time. Material known within more than ±100% will not qualify as resource, and may be flagged (but not publicly reported) as blue sky or potential mineralization.

Results & Discussion

Southern Palawan (Dendrogram)

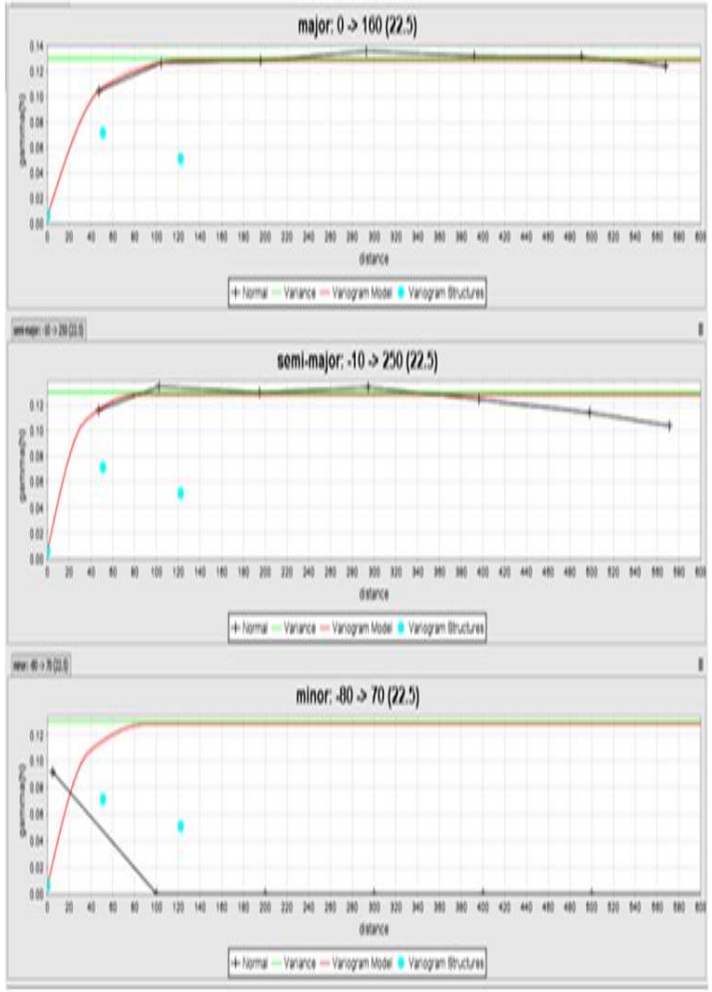


Surigao Del Norte (Dendrogram)

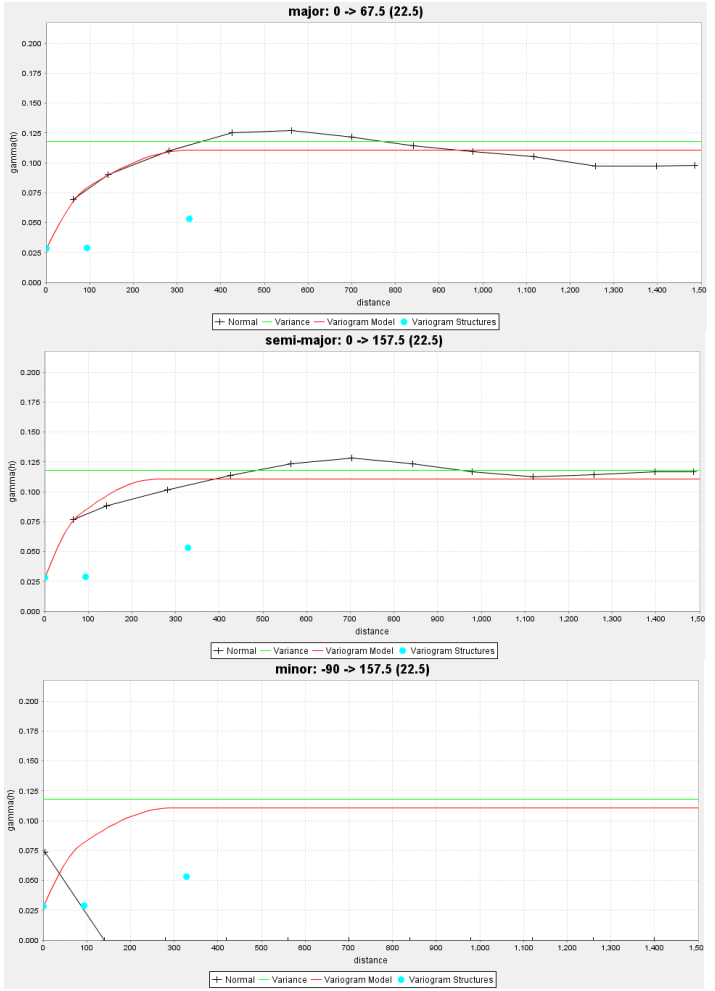


Results & Discussion

Southern Palawan (Limonite Variogram)

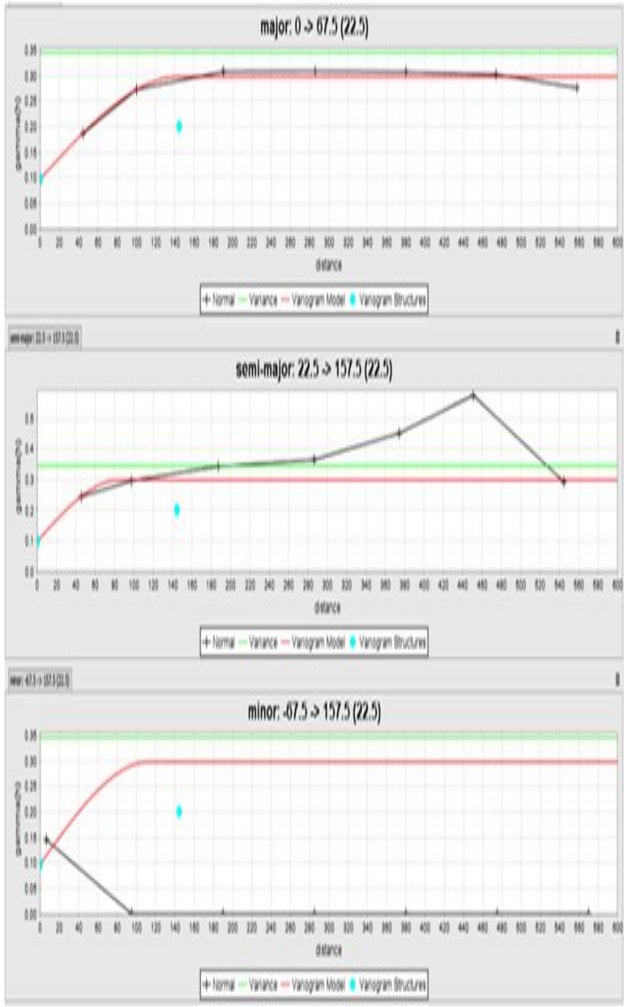


Surigao Del Norte (Limonite Variogram)

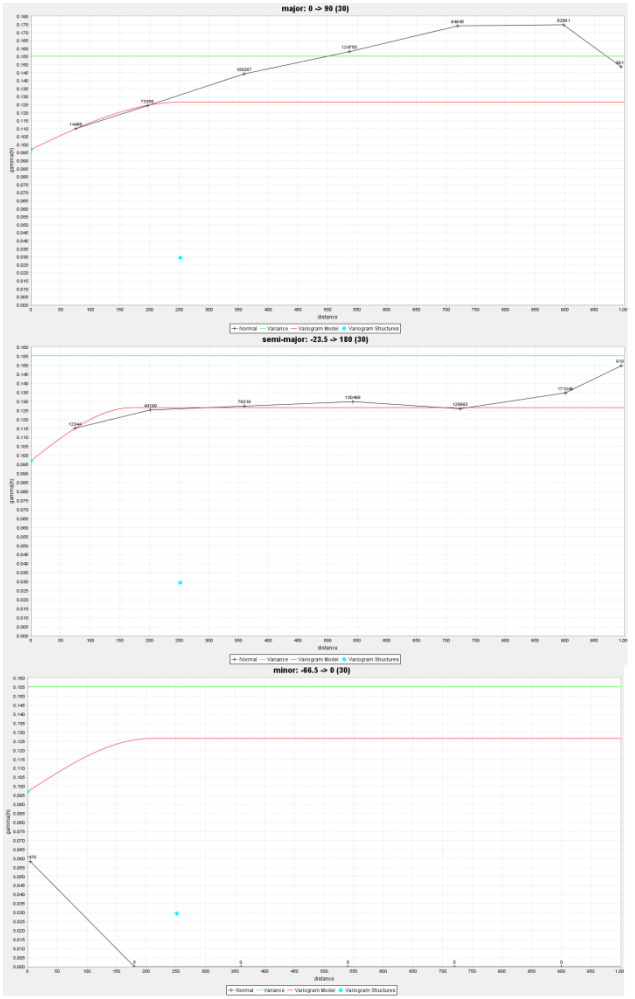


Results & Discussion

Southern Palawan (Saprolite Variogram)

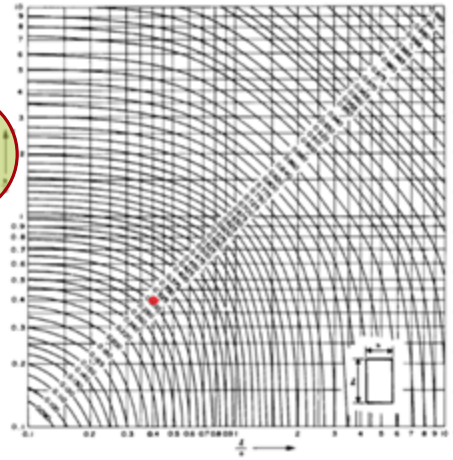


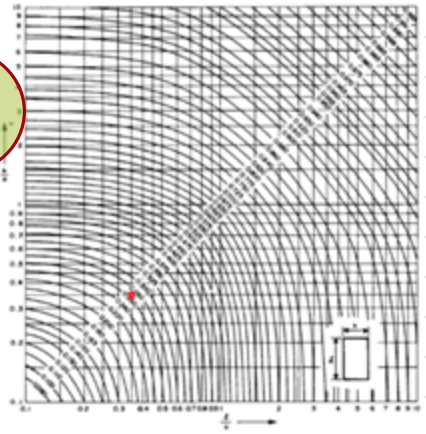
Surigao Del Norte (Saprolite Variogram)



Results & Discussion

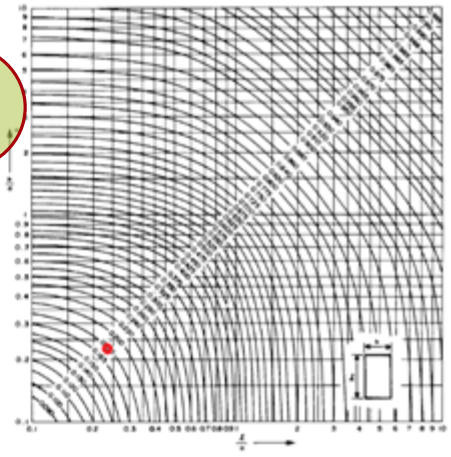
SOUTHERN PALAWAN DATA					
LIMONITE			**SAPROLITE**		**TOTAL**
Tonnage	3,825,991.15		Tonnage	6,320,523.28	**10,146,514.43**
Annual Production (Assumption)	2,500,000.00		Annual Production (Assumption)	2,500,000.00	
% Production	0.38		% Production	0.62	
I	50		I	50	
h	50		h	50	
Sill	0.1300		Sill	0.3000	
C0	0.0059		C0	0.0974	
C	0.1241		C	0.2026	
a	122.40		a	144.47	
F(I/a,h/a)	0.300		F(I/a,h/a)	0.270	
Est Var	0.043		Est Var	0.152	
Panel STD	0.208		Panel STD	0.390	
Standard Error of Mean	0.016		Standard Error of Mean	0.030	
Mean	1.0732		Mean	0.9689	
Panel Tonnage	24,552.00		Panel Tonnage	39,235.00	
Density	1.3200		Density	1.1800	
Mean Depth	7.44		Mean Depth	13.3000	
N	169		N	169	
Panel N	9.50		Panel N	9.92	
Rel STD	19.8		Rel STD	40.3	
Rel 90% CI (Quarterly)	10.3		Rel 90% CI (Quarterly)	21.0	

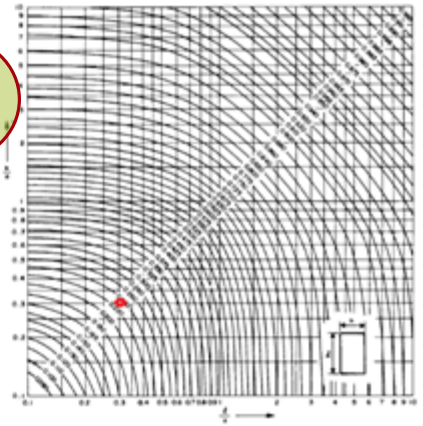




Results & Discussion

SURIGAO DEL NORTE DATA					
LIMONITE			**SAPROLITE**		**TOTAL**
Tonnage	31,167,669.61		Tonnage	24,991,436.25	**56,159,105.86**
Annual Production (Assumption)	2,500,000.00		Annual Production (Assumption)	2,500,000.00	
% Production	0.55		% Production	0.45	
l	75		l	75	
h	75		h	75	
Sill	0.1100		Sill	0.1260	
C0	0.0285		C0	0.0970	
C	0.0815		C	0.0290	
a	328.65		a	251.63	
F(l/a,h/a)	0.180		F(l/a,h/a)	0.223	
Est Var	0.043		Est Var	0.103	
Panel STD	0.208		Panel STD	0.322	
Standard Error of Mean	0.007		Standard Error of Mean	0.010	
Mean	0.8698		Mean	0.9557	
Panel Tonnage	29,517.13		Panel Tonnage	17,257.32	
Density	0.9190		Density	0.9120	
Mean Depth	5.71		Mean Depth	3.3640	
N	947		N	947	
Panel N	11.75		Panel N	16.12	
Rel STD	23.9		Rel STD	33.7	
Rel 90% CI (Quarterly)	11.5		Rel 90% CI (Quarterly)	13.8	





Results & Discussion

Particulars	Southern Palawan	Surigao Del Norte
Spacing (m)	50 x 50	75 x 75
Lim (Rel 90% CI)	10.30	11.50
Sap (Rel 90% CI)	21.00	13.80
Lim (Range/Sill/Nugget)	122.4 / 0.13 / 0.0059	328.65 / 0.11 / 0.029
Sap (Range/Sill/Nugget)	144.47 / 0.30 / 0.0974	251.63 / 0.126 / 0.097
Polygonal	10,780,003.00	56,459,471.98
Kriging	10,146,514.43	56,159,105.86

Results & Discussion

Estimation Variance

39.7	41.4	14.5	48.3	45.0	52.0	44.1	35.6	53.3	47.1	19.9	17.9	20.3
44.1	29.0	23.3	23.3	30.3	44.1	36.2	49.4	31.2	13.2	13.9	15.7	19.9
35.6	29.8	30.7	23.3	22.8	33.8	43.1	33.2	18.9	11.1	12.6	13.7	18.8
23.0	32.7	14.5	42.2	28.5	34.9	25.0	20.7	20.5	19.7	14.5	17.0	26.7
15.2	18.9	18.9	15.4	17.3	22.8	27.4	17.9	12.4	12.2	13.2	12.3	14.4
20.1	17.6	17.9	17.3	27.4	20.1	28.2	11.8	21.3	9.5	18.3	24.1	11.0
20.9	25.7	19.5	21.6	18.3	30.3	24.4	9.9	13.3	28.5	12.1	22.0	17.8
15.0	26.0	13.8	23.3	26.3	18.6	24.7	16.5	11.9	11.1	19.3	16.3	14.1
20.7	30.7	16.6	17.6	19.5	40.5	16.9	16.6	17.0	12.6	19.9	23.6	19.1
21.6	23.3	32.7	17.3	18.4	22.5	14.6	10.1	15.4	18.9	26.0	23.0	19.5
12.4	16.9	19.5	25.7	12.4	17.5	20.9	27.8	9.5	27.4	10.1	11.0	27.4
25.7	31.2	12.1	25.7	11.9	15.8	18.4	42.2	29.4	18.4	18.9	14.0	19.9
21.6	18.9	19.1	10.5	18.1	21.8	22.5	19.3	28.5	34.4	29.4	14.2	16.8

LEGEND:

- <15%
- >15% to <30%
- >30% to <50%
- >50%

Results & Discussion

Kriging Variance

31.0	28.7	11.8	23.5	39.4	43.8	39.5	57.1	41.6	31.7	25.9	18.8	15.8
31.6	21.9	19.5	28.9	29.6	42.2	50.6	44.7	27.7	14.4	12.8	18.2	19.5
28.9	35.1	23.9	27.6	23.2	35.9	30.9	27.7	13.8	8.9	9.8	13.5	14.0
22.0	28.9	16.9	27.4	22.0	26.0	16.7	16.1	14.4	13.9	12.7	13.7	19.1
12.5	18.9	13.3	13.9	14.4	17.5	20.1	16.7	8.9	7.7	9.5	13.4	16.4
12.7	16.8	14.6	18.4	18.5	15.2	17.0	9.3	9.8	7.7	11.0	20.2	15.1
15.1	14.8	14.6	17.8	12.8	14.4	15.9	8.4	10.3	11.6	10.5	15.1	20.8
9.1	14.9	11.7	17.1	17.2	12.1	11.1	9.8	8.8	9.7	14.0	9.4	14.8
13.4	17.3	10.9	13.9	14.5	29.6	12.1	10.7	9.0	13.4	15.8	16.1	14.1
14.1	16.3	16.8	14.4	13.5	15.4	10.6	7.7	8.4	12.5	35.1	17.2	12.5
9.5	10.3	13.4	13.1	8.4	10.3	11.9	14.4	9.2	13.9	10.1	9.1	12.2
14.4	16.3	9.9	12.4	8.0	9.6	13.2	20.5	17.0	13.1	11.8	8.1	13.4
13.7	14.3	11.5	8.7	12.9	19.5	19.3	15.4	18.7	20.4	16.6	11.1	14.9

LEGEND:

- <15%
- >15% to <30%
- >30% to <50%
- >50%

Comparative Grades per Cut-off

	Indicated Resource Computation By Cut-Off											
	Limonite			Saprolite			Rocky Saprolite			Total		
	DMT	NI	% by Tonnage	DMT	NI	% by Tonnage	DMT	NI	% by Tonnage	DMT	NI	% by Tonnage
	T	Grade		T	Grade		T	Grade			Grade	
0.00	3,825,991.150	1.039	100.00%	6,320,523.280	0.974	100.00%	0.000	0.000	0.00%	10,146,514.430	0.999	100.00%
0.25	3,821,548.520	1.040	99.88%	6,265,764.610	0.981	99.13%	0.000	0.000	0.00%	10,087,313.130	1.004	99.42%
0.50	3,819,902.640	1.041	99.84%	5,415,160.080	1.075	85.68%	0.000	0.000	0.00%	9,235,062.720	1.061	91.02%
0.75	3,573,120.390	1.066	93.39%	4,310,358.990	1.187	68.20%	0.000	0.000	0.00%	7,883,479.380	1.132	77.70%
1.00	2,191,959.010	1.171	57.29%	2,816,012.350	1.361	44.55%	0.000	0.000	0.00%	5,007,971.360	1.278	49.36%
1.25	571,947.760	1.372	14.95%	1,496,450.630	1.582	23.68%	0.000	0.000	0.00%	2,068,398.390	1.524	20.39%
1.50	90,028.130	1.595	2.35%	809,141.720	1.770	12.80%	0.000	0.000	0.00%	899,169.850	1.752	8.86%
1.75	2,437.880	1.790	0.06%	379,653.520	1.951	6.01%	0.000	0.000	0.00%	382,091.400	1.950	3.77%
2.00	2,437.880	0.000	0.00%	161,522.110	2.073	6.01%	0.000	0.000	0.00%	163,959.990	2.042	3.77%
2.25	0.000	0.000	0.06%	2,181.090	2.280	2.56%	0.000	0.000	0.00%	2,181.090	2.280	1.59%

Limonite

Attribute	Cutoff	Cumulative Volume	Cumulative Tonnes	Grade Above Cutoff
ni	0	33914765.63	31167669.61	0.85
ni	0.25	33516328.13	30801505.55	0.86
ni	0.5	32529609.38	29894711.02	0.87
ni	0.75	23531718.75	21625649.53	0.96
ni	1	8462812.5	7777324.69	1.13
ni	1.25	1133671.88	1041844.45	1.36
ni	1.5	101250	93048.75	1.56

Saprolite

Attribute	Cutoff	Cumulative Volume	Cumulative Tonnes	Grade Above Cutoff
ni	0	27402890.63	24991436.25	0.99
ni	0.25	26899453.13	24532301.25	1.01
ni	0.5	26413359.38	24088983.75	1.02
ni	0.75	22942031.25	20923132.5	1.08
ni	1	13313906.25	12142282.5	1.21
ni	1.25	5172187.5	4717035	1.39
ni	1.5	733828.13	669251.25	1.58
ni	1.75	41718.75	38047.5	1.79

Concluding Remarks

Estimation Variance

Regular Grid Spacing	Density		# of Holes	Ore Thickness	Total Tonnage (DMT)	Cost (PhP)	Remarks
	L	S		Mean			
50m X 50m	1.32	1.18	169	20.57	10.14M	8,689,980.00	
25m X 25m	1.32	1.18	528	20.57		27,149,760.00	Total DH 676 (minus 148 of <15% Rel CI Panels)
25m X 25m	1.32	1.18	676	20.57		34,759,920.00	Total DH 676
						7,610,160.00	Savings for drilling excluding panels <15% Rel CI
25m X 25m	1.32	1.18	528	13.30		17,558,640.00	Channel/Face Sampling for Saprolite Zones only with >15% Rel CI
						17,201,280.00	Savings for channel/face sampling excluding panels <15% Rel CI

Kriging Variance

Regular Grid Spacing	Density		# of Holes	Ore Thickness	Total Tonnage (DMT)	Cost (PhP)	Remarks
	L	S		Mean			
50m X 50m	1.32	1.18	169	20.57	10.14M	8,689,980.00	
25m X 25m	1.32	1.18	312	20.57		16,043,040.00	Total DH 676 (minus 364 of <15% Rel CI Panels)
25m X 25m	1.32	1.18	676	20.57		34,759,920.00	Total DH 676
						18,716,880.00	Savings for drilling excluding panels <15% Rel CI
25m X 25m	1.32	1.18	312	13.30		10,375,560.00	Channel/Face Sampling for Saprolite Zones only with >15% Rel CI
						24,384,360.00	Savings for channel/face sampling excluding panels <15% Rel CI

Note:
Density result from Mainex data
Density value for Saprolite (S) is the average of ESap (1.21) and RSap (1.14)
Estimated drilling cost @ 2,500PhP/m

Concluding Remarks

- Blocks falling within the MEASURED category based on calculation of RELATIVE ACCURACY using **Estimation Variance** for both LIMONITE and SAPROLITE may no longer require further infill drilling.

- Resource Estimation yields the following results:

  - A comparative study with **Palawan laterite** shows that at 50m X 50m grid interval drilling there are blocks which fall under the *MEASURED category* while **Surigao del Norte laterite** shows similar signature at 75 x75m grid interval for both LIMONITE and SAPROLITE.
  - Geochemistry of Surigao del Norte laterite yields possible boundary of LIM-SAP at Fe around 25% while a comparison from a laterite in PALAWAN ISLAND exhibits Fe at around 30% for the LIM-SAP boundary.
  - Surigao del Norte laterites shows higher degree of homogeinity than Palawan laterites though of slightly lower grade at equivalent cut-off grades.

References

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2. Murphy, M., Parker, H., Ross, A., and Audet, M., 2005. Ore-Thickness and Nickel Grade Resource Confidence at the Koniambo Nickel Laterite (A Conditional Simulation Voyage Of Discovery)

3. Rossi, M. and Deutsch, C., 2014. Mineral Resource Estimation

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Thank You