Optimisation grade control procedures at the open pit mines:

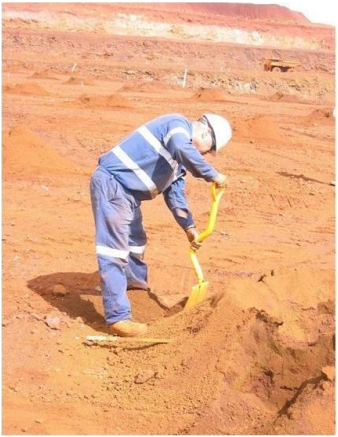
GEOSTATISTICAL APPROACH

Dr. M.Abzalov

Dr. M.Abzalov

Rio Tinto

Grade control



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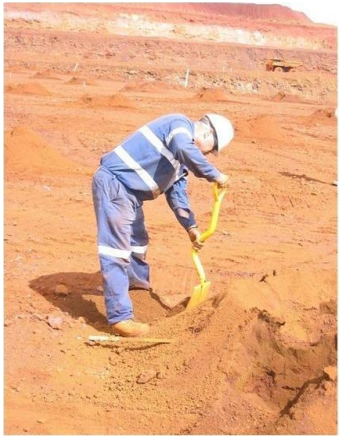
Grade control



A large Copper open pit mine in Chile has lost US$134 million over a **10-year** period because of suboptimal grade control procedures based on the blast holes sampling.

It was estimated by the difference between actually used blast hole sampling protocol and its optimized version.

(P. Carrasco: WCSB1, Denmark 2003)

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Grade control at open pit mines

Cost of the lost/gained metals

Grade control variable :

Sampling grid :

Sample quality :

Grade control costs

RioTinto

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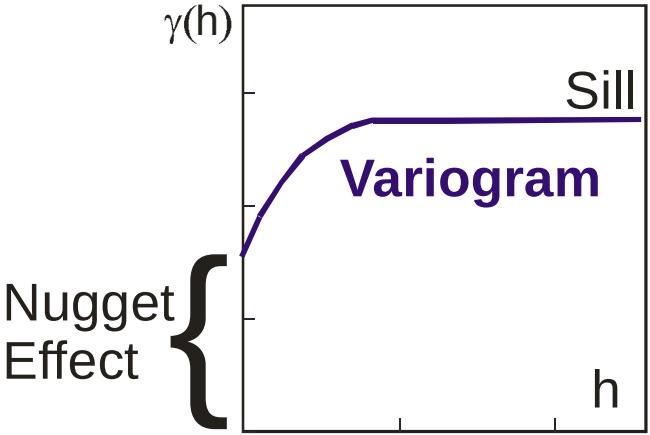
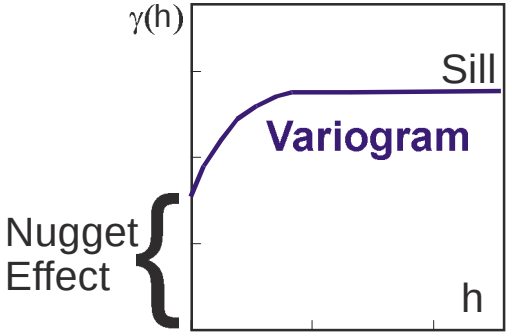
Nugget Effect and Estimation Error



Nugget Effect and Estimation Error



Nugget effect is caused by:

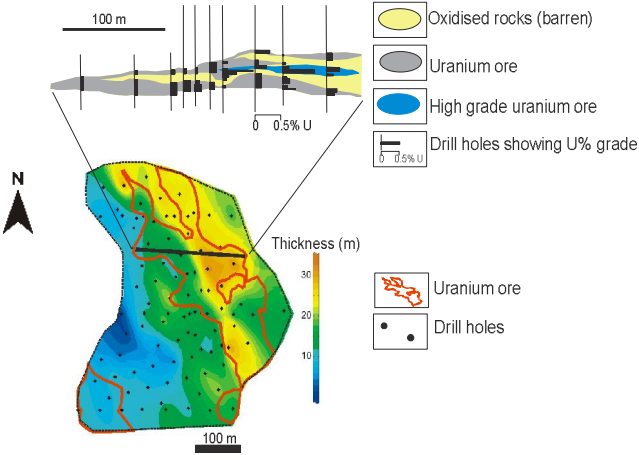
(a) poor samples repeatability (i.e. large precision error)
and
(b) geological factors (i.e. geological variability at the short distances

Nugget effect is a geostatistical term defining
"**an apparent discontinuity in the experimental variogram near the origin caused by measurement errors or by nested structures that have ranges smaller than the sampling interval, or both**"

Olea, R.A., ed., 1991, Geostatistical glossary and multilingual dictionary: Oxford University Press, New York, Oxford, 177 p.

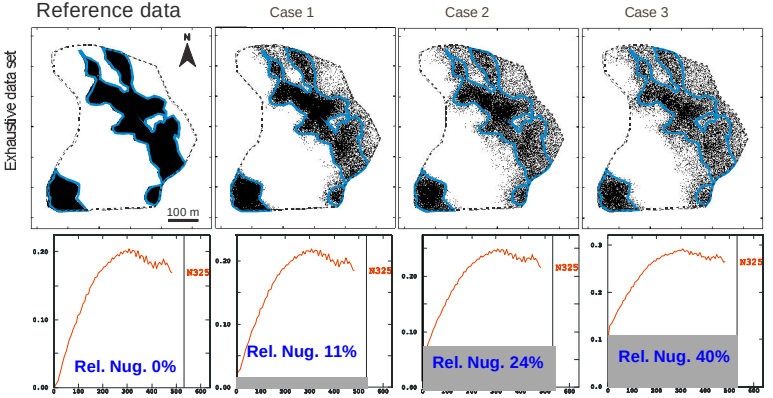
Nugget Effect and Estimation Error

CASE 1: Uranium ISL operation



Nugget Effect and Estimation Error

CASE 1: Uranium ISL operation



Nugget Effect and Estimation Error

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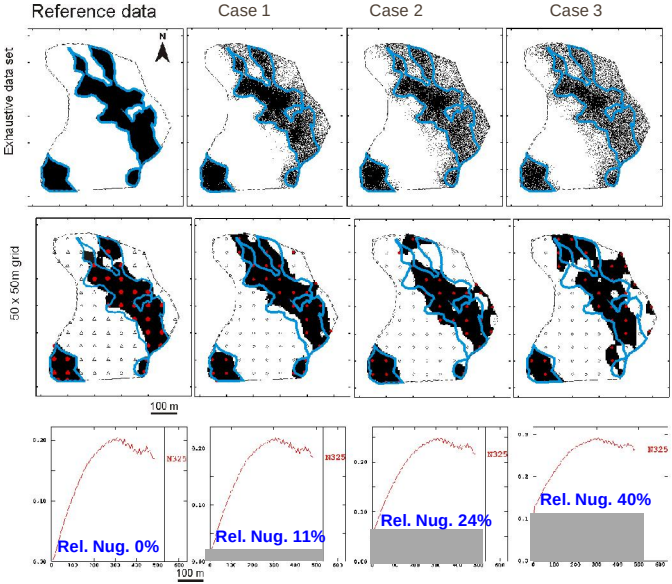
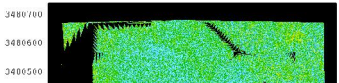
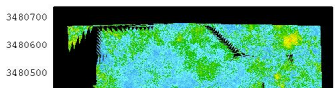


Nugget Effect and Estimation Error

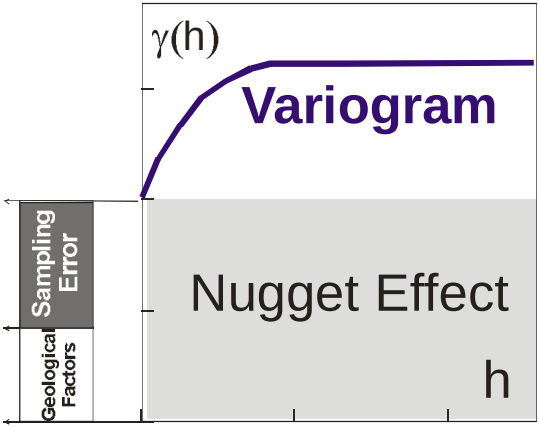
CASE 2: Uranium project





Avr. relative error: 0.75 0.58

Nugget Effect and Estimation Error



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Grade control at open pit mines

Cost of the lost/gained metals

Grade control variable :

Sampling grid :

Sample quality :

Grade control costs

Sample quality

$$CV = \sqrt{\frac{2}{N}\sum_{i=1}^{N}\left(\frac{(a_i - b_i)^2}{(a_i + b_i)^2}\right)}$$

N pairs of Sample and Duplicate

The average coefficient of variation (CV%) is suggested to be used as the universal measure of relative precision error

- **Pitard, F.** 2004: Pers. Communication
- **Stanley, C.R. and Lawie, D.** 2007: Average relative error in geochemical determinations: clarification, calculation and a plea for consistency: *Exploration and Mining Geology*, 16(3-4): 265-274
- **Abzalov, M.Z. 2008**: Quality Control of Assay Data: A Review of Procedures for Measuring and Monitoring Precision and Accuracy, *Exploration and Mining Geology*, 17(3-4): 1-14

CV% can be calculated using AMZ_QAQC.xls file **which is explained in** (Abzalov, M.Z. 2008, 2011) **and available on your request**

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Sampling grid

Pair-wise Variogram

$$\gamma_{PWR}(\mathbf{h}) = \frac{1}{2N}\sum_{i=1}^{N}\frac{[Z(x_i) - Z(x_i+\mathbf{h})]^2}{\left[\frac{Z(x_i)+Z(x_i+\mathbf{h})}{2}\right]^2} = \frac{2}{N}\sum_{i=1}^{N}\frac{[Z(x_i) - Z(x_i+\mathbf{h})]^2}{[Z(x_i)+Z(x_i+\mathbf{h})]^2}$$

$$\gamma_{PWR}(\mathbf{0}) = \frac{2}{N}\sum_{i=1}^{N}\frac{[Z(x_i) - Z(x_i+\mathbf{0})]^2}{[Z(x_i)+Z(x_i+\mathbf{0})]^2}$$

(Nugget Effect of γ_{PWR})

Sampling grid *vs*. Sample quality

$$CV = \sqrt{\frac{2}{N}\sum_{i=1}^{N}\left(\frac{(a_i - b_i)^2}{(a_i + b_i)^2}\right)}$$

$$CV^2 = \sigma^2_{RSV} = \frac{2}{N}\sum_{i=1}^{N}\left(\frac{(a_i - b_i)^2}{(a_i + b_i)^2}\right)$$ (Relative Sampling Variance)

$$\gamma_{PWR}(\mathbf{0}) = \frac{2}{N}\sum_{i=1}^{N}\frac{[Z(x_i) - Z(x_i + \mathbf{0})]^2}{[Z(x_i) + Z(x_i + \mathbf{0})]^2}$$ (Nugget Effect)

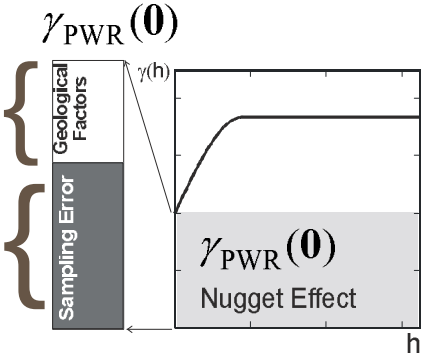
Abzalov, M.Z. 2011: Geostatistical approach for estimation sampling precision. *in (eds.) Proceedings of the 5th World International Sampling Conference 2011, p.243-250, Santiago, Chile, 26-28 October, 2011*

Sampling grid *vs*. Sample quality

Contribution of the Sampling Errors and Geology to the Nugget Effect

$$\sigma^2_{\text{Geol}} = \gamma_{\text{PWR}}(0) - \text{CV}^2_{\text{Field Duplicates}}$$

$$\text{CV}^2_{\text{Field Duplicates}}$$



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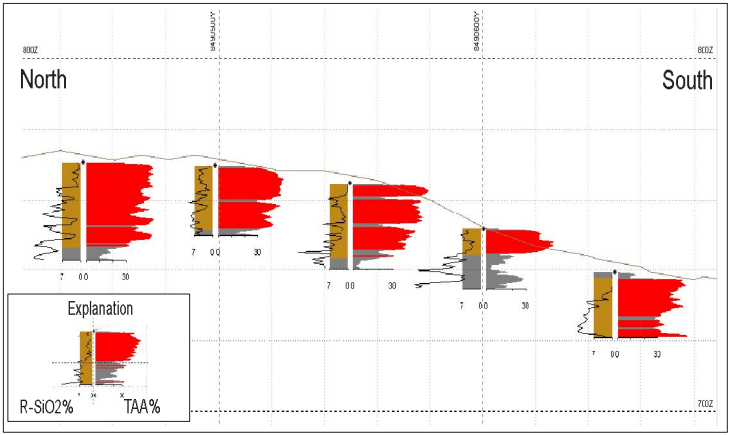
Sampling grid *vs*. Sample quality

Case 2: Bauxite project

Contribution of the Sampling Errors and Geology to the Nugget Effect



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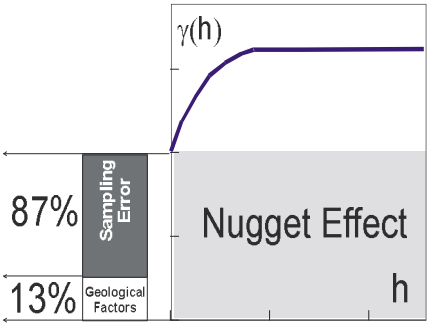

Geological Factor constitutes 13% of nugget effect of LOI

Abzalov, M.Z. 2011: Geostatistical approach for estimation sampling precision. *in (eds.) Proceedings of the 5th World International Sampling Conference 2011, p.243-250, Santiago, Chile, 26-28 October, 2011*

Sampling grid *vs*. Sample quality

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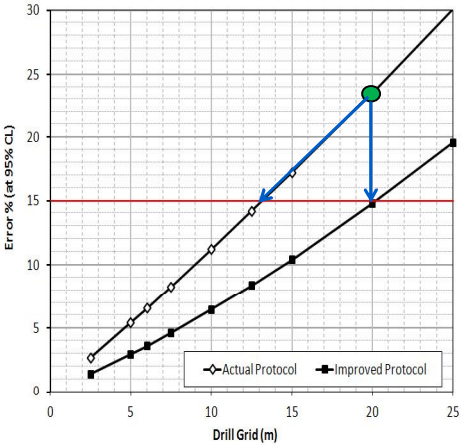


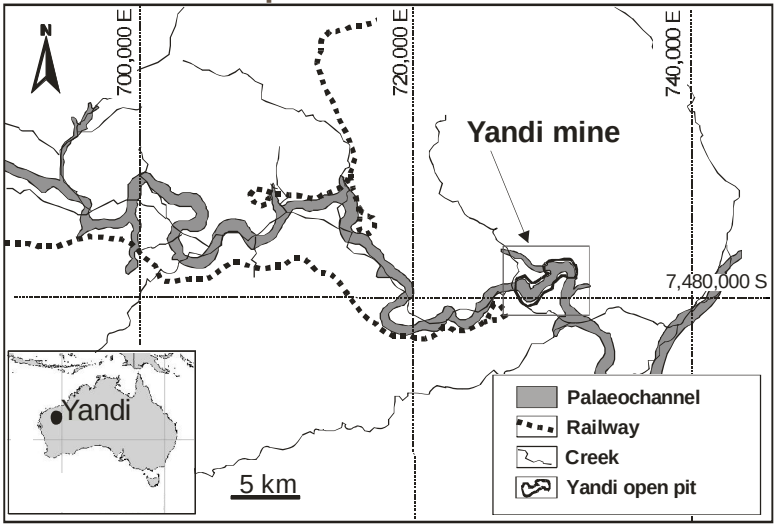
Error decreased from 24% to 15%

(1) by reducing drill spacing from 20x20m to 12.5 x 12.5m;

(2) by optimising sampling procedures and decreasing sampling error

Sampling grid *vs*. Sample quality

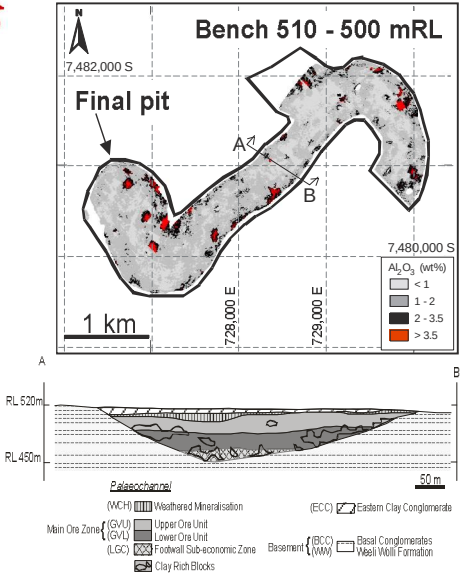
Case 3: Yandi Open Pit

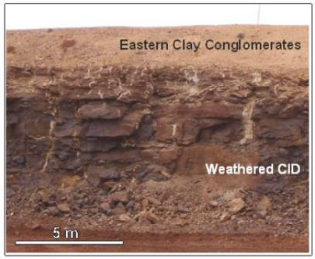


Abzalov et al., 2010: Optimisation of the grade control procedures at the Yandi iron-ore mine, Western Australia: geostatistical approach, Applied Earth Science Journal, v.119, No.3, p.132-142

Sampling grid *vs*. Sample quality

Case 3: Yandi Open Pit





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Sampling grid *vs*. Sample quality

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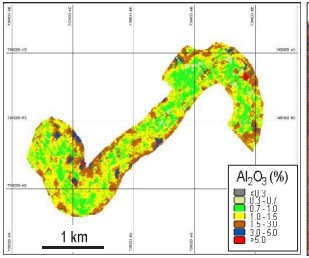

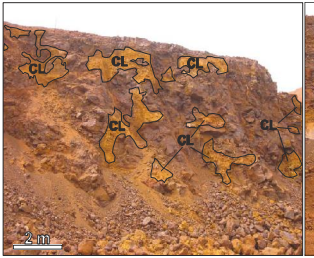

Geological Factor constitutes 52% of nugget effect of Al_2O_3

Abzalov, M.Z. 2011: Geostatistical approach for estimation sampling precision. *in (eds.) Proceedings of the 5th World International Sampling Conference 2011, p.243-250, Santiago, Chile, 26-28 October, 2011*

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Grade control at open pit mines

Cost of the lost/gained metals

Grade control variable :

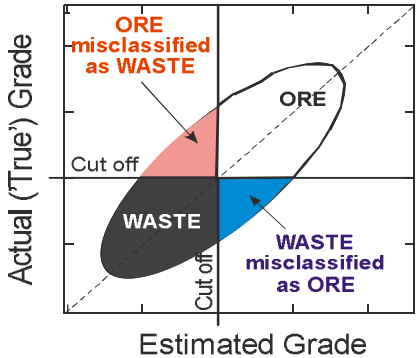
Sampling grid :

Sample quality :

Grade control costs

Economics: OPEX *vs.* Cost of Lost/Gained metal

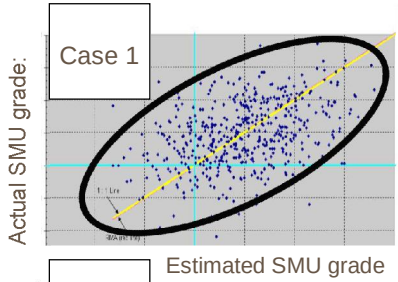
Cut off by VALUABLE component
(e.g. Au, Ni, Fe)



Economics: OPEX *vs.* Cost of Lost/Gained metal

Correlation: 0.43

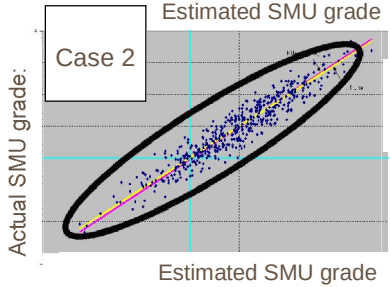
Ore to waste: **11%**
Waste to Ore: **11%**



Mean 1 = 7.9
Mean 2 = 7.9
CV% = 21%

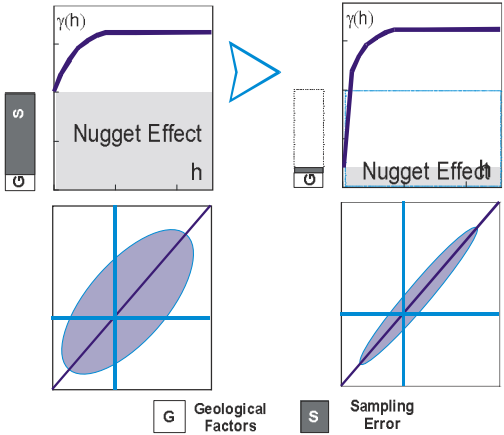
Correlation: 0.95

Ore to waste: **3%**
Waste to Ore: **3%**



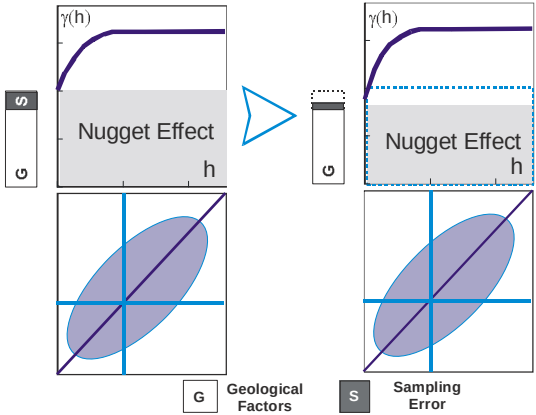
Mean 1 = 7.9
Mean 2 = 7.9
CV% = 6.7%

Economics: OPEX *vs.* Cost of Lost/Gained metal



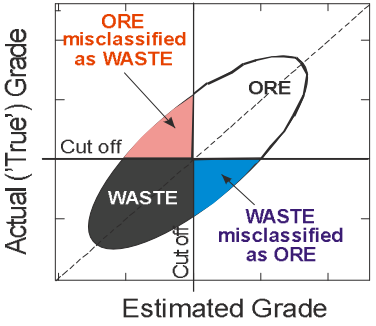
(Case 1) Nugget effect is caused by poor samples repeatability (i.e. large precision error)

Economics: OPEX *vs.* Cost of Lost/Gained metal

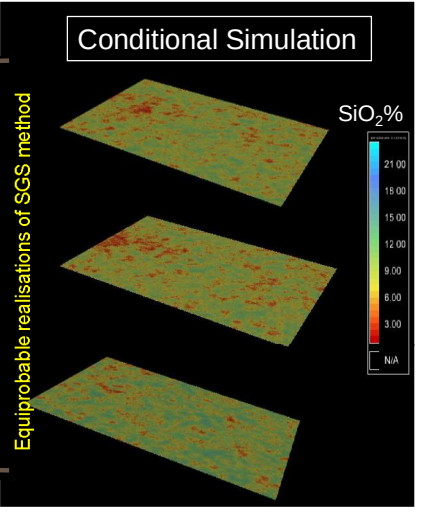


(Case 2) Nugget effect is caused by geological factors (i.e. geological variability at the short distances)

Economics: OPEX *vs.* Cost of Lost/Gained metal



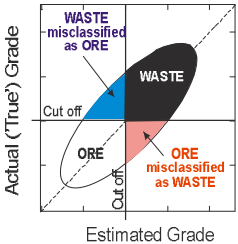
In the current study Z was generated using Conditional Simulation technique

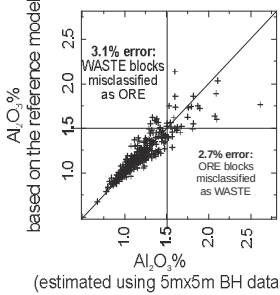


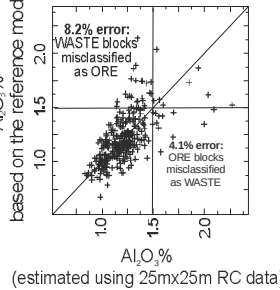
References can be found in: Abzalov, M.Z. and Bower, J. 2009: Optimisation of the drill grid at the Weipa bauxite deposit using conditional simulation. in (eds.AusIMM) 7th International Mining Geology Conference, p.247 – 251, Perth, Western Australia, 17-19 August, 2009

Economics: OPEX *vs.* Cost of Lost/Gained metal

Case 3: Yandi Open Pit







2.7% of SMU size ORE blocks are misclassified as WASTE

4.1% of SMU size ORE blocks are misclassified as WASTE

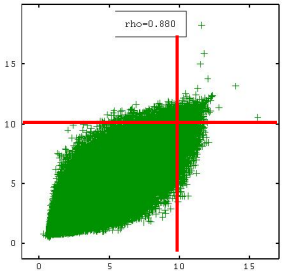
Abzalov et al., 2010: Optimisation of the grade control procedures at the Yandi iron-ore mine, Western Australia: geostatistical approach, Applied Earth Science Journal, v.119, No.3, p.132-142

Economics: OPEX *vs.* Cost of Lost/Gained metal

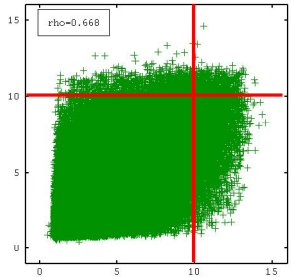
CASE 4: Bauxite operation

Y axis: 2nd Estimate - SiO_2

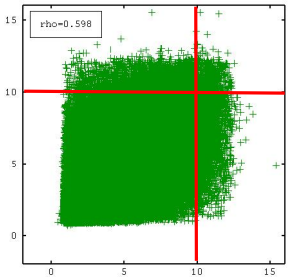
Grid 20 x 20m



Grid 50 x 50m



Grid 100 x 100m



X axis: 1st Estimate - SiO_2 of the SMU blocks

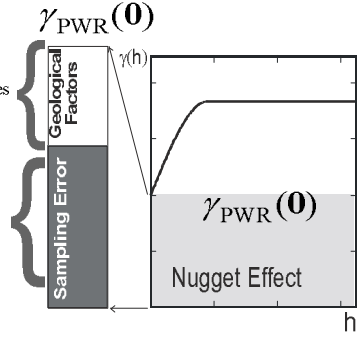
1.3% misclassified blocks Contain 80,775t bauxite Which cost **$2.8M**	2.3% misclassified blocks Contain 139,725t bauxite Which cost **$4.9M**	2.7% misclassified blocks Contain 161,145t Bauxite Which cost **$5.6M**
5318 drill holes which cost **$3.03M**	664 drill holes which cost **$0.38M**	222 drill holes which cost **$0.13M**

Summary and Conclusions

- Efficiency of Grade control depends on sampling grid and samples quality. Right balance between them can be find by estimating contributions of 'Geological factors (discontinuity)' and 'Sampling errors' to 'Nugget Effect' of the Pair-Wise Relative Variogram [$\gamma_{PWR}(\mathbf{0})$]
- The proposed approach is as follows:

$$\sigma^2_{Geol} = \gamma_{PWR}(\mathbf{0}) - CV^2_{Field\ Duplicates}$$

$$CV^2_{Field\ Duplicates}$$



- Optimisation of the grade control procedures requires estimation costs of the lost/recovered metals which are deduced from the Z *vs.* Z* diagrams.

Next Step…

MINING PROJECT DASHBOARD

STANDARDISED SET of 'GAUGES'

Rio Tinto

Thank you

Questions ?

Comments ?

Suggestions ?

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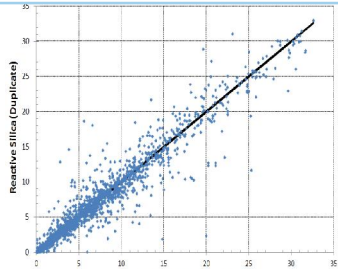
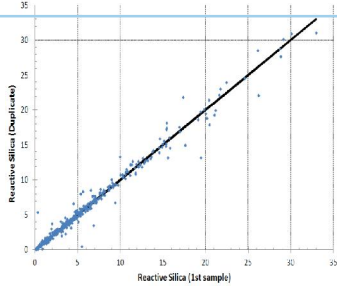
CASE 2: Bauxite project – South America



CV = 20.7%

Field (coarse) duplicates:

No of sample duplicates = 1868



CV = 13.5%

Pulp duplicates:

No of sample duplicates = 472

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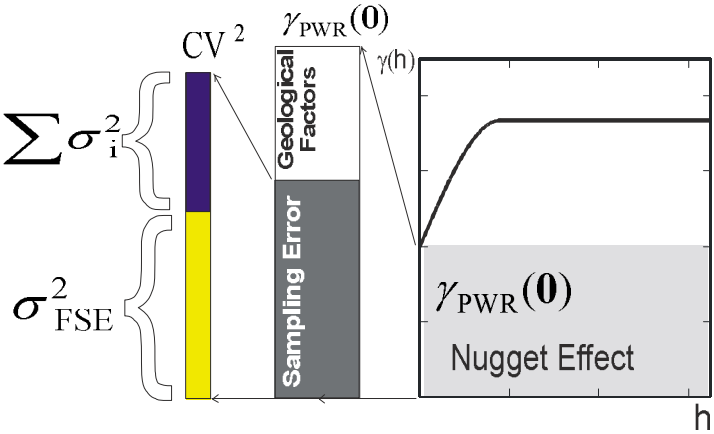
$$CV\% = 100\% \times \sqrt{2}\,\frac{|a-b|}{(a+b)} = 100\% \times \frac{\sigma}{m}$$

$$CV = \frac{\sigma}{m} \qquad \sigma^2 = \frac{\sum_i (x_i - \frac{\sum x_i}{N})^2}{n-1} \qquad m = \frac{\sum_i x_i}{n}$$

$$\sigma^2 = \frac{(a - \frac{a+b}{2})^2 + (b - \frac{a+b}{2})^2}{2-1} = \frac{(\frac{2a-a-b}{2})^2 + (\frac{2b-a-b}{2})^2}{1} = \frac{(a-b)^2 + (b-a)^2}{4} = \frac{(a-b)^2}{2}$$

$$\text{Standard Deviation} = \sqrt{\sigma^2} = \frac{|a-b|}{\sqrt{2}} \qquad \text{Mean} = \frac{(a+b)}{2}$$

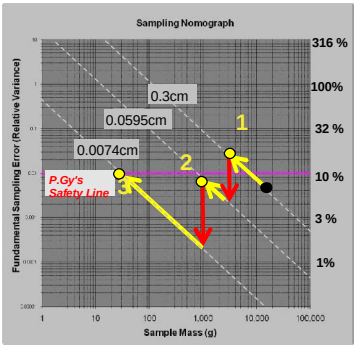
$$CV = \frac{\sigma}{m} = \frac{\frac{|a-b|}{\sqrt{2}}}{\frac{(a+b)}{2}} = \sqrt{2}\,\frac{|a-b|}{(a+b)}$$


$\sum \sigma_i^2$
σ^2_{FSE}
CV^2
$\gamma_{PWR}(0)$
Geological Factors
Sampling Error
γ(h)
$\gamma_{PWR}(0)$
Nugget Effect
h

RioTinto

$$\sigma^2_{\text{Total}} = \underbrace{\sigma^2_{\text{Sampling Protocol}}} + \underbrace{\sigma^2_{\text{Practical Implement.}} + \sigma^2_{\text{Instrument}}}$$

FSE ($\sigma^2_{FSE} = \dfrac{K\, d_N^{\alpha}}{M_S}$)



Another errors ($\sum \sigma_i^2$)

It includes: Extraction Error

Preparation Error

Delimitation Error

etc.

$$\sum \sigma_i^2 = \sigma^2_{\text{Field Duplicates}} - \sigma^2_{\text{FSE}}$$