

The use of Indirect Distributions of Selective Mining Units for Assessment of Recoverable Mineral Resources Designed for Mine Planning at Gold Fields Tarkwa Mine, Ghana

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Introduction

- At the exploration stage kriged estimates with a proper search routine will be conditionally unbiased, but will unavoidably be smooth because of the level of data available.
- The smooth estimates will generally overstate the tonnage above economic cut-off and underestimate the corresponding grade.
- At the feasibility or early production stages the problem is to estimate the tonnage and grade that will be recovered on the basis of information that will become available at the later production stage.

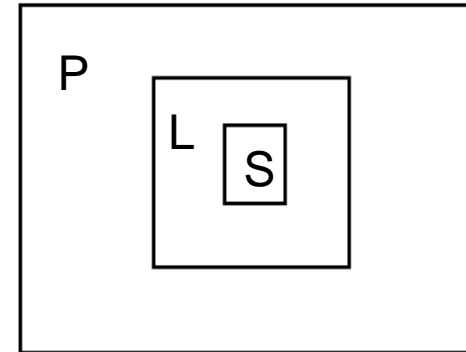
Introduction

- Various post-processing techniques have been proposed to correct for the smoothing effect where data is widely spaced and sparse:
 - Spectral-processor(Journel et al 2000)
 - Sequential Gaussian Conditional simulations (Deutsch and Journel, 1992)
 - Indirect post-processing (Assibey-Bonsu and Krige 1999, Marcotte and David 1985)
 - Uniform Conditioning and assumed lognormal distribution of SMU's within large planning blocks.

Introduction

- Regardless of the theoretical soundness, from a practical point of view, actual follow-up comparisons are absolutely essential.
- It should be realised that whatever post-processed technique is used, the result will depend on the efficiency of the technique and parameters used in the execution of the process.
- In this paper the case study compares long-term indirect recoverable estimates based on typical widely spaced data to the corresponding production grade control and mine production
- The paper also proposes certain critical regression slope and kriging efficiency control limits to avoid in-efficient medium- to long-term recoverable estimates.

Indirect Approach



Let us define:

L = Large planning block

S = Selective mining unit (SMU) of interest

P = Entire population or global area being estimated

$B^{(s/L)}$ = Variance of actual SMU grades within large planning blocks

BV_s = Variance of actual SMU grades within P

BV_L = Variance of large planning block grades within P

$\sigma^2_{se1}, \sigma^2_{se2}$ = Error variances of conditionally unbiased estimates at exploration and final production stages for SMU's respectively.

$\sigma^2_{LE1}, \sigma^2_{LE2}$ = Error variances of conditionally unbiased estimates at exploration and final production stages for the large planning blocks respectively (σ^2_{LE2} is assumed to be zero).

Indirect Approach

From Krige's relationship; Variances of actual SMU grades:

$$BV_s = B^{(s/L)} + BV_L$$

$$\text{That is, } B^{(s/L)} = BV_s - BV_L$$

Dispersion variances of conditionally unbiased estimates within P for L (" $D^{(L/P)}$ ")

$$D^{(L/P)} = BV_L - \sigma_{LE1}^2 \quad (\text{at exploration stage}) \dots\dots\dots (1)$$

$$= BV_L - 0$$

(at final production stage)

Similarly, dispersion variances of conditionally unbiased estimates within L for S (" $D^{(s/L)}$ ")

$$D^{(s/L)} = B^{(s/L)} - \sigma_{se1}^2 \quad (\text{at exploration stage})$$

$$= B^{(s/L)} - \sigma_{se2}^2 \quad (\text{at final production stage})$$

Dispersion variance within P for S (" $D^{(s/P)}$ ") ie, the required variance for long-term estimates:

$$D^{(s/P)} = BV_s - \sigma_{se1}^2 \quad (\text{at exploration stage})$$

$$= BV_s - \sigma_{se2}^2 \quad (\text{at final production stage})$$

$$= B^{(s/L)} + BV_L - \sigma_{se2}^2 \quad \dots\dots\dots (2)$$

To arrive at this required variance for long-term estimates (i.e. equation 2), the variance of L estimates at exploration (i.e. equation 1), must be adjusted or increased by:

$$B^{(s/L)} + BV_L - \sigma_{se2}^2 - (BV_L - \sigma_{LE1}^2) = B^{(s/L)} - \sigma_{se2}^2 + \sigma_{LE1}^2$$

$$= BV_s - BV_L - \sigma_{se2}^2 + \sigma_{LE1}^2$$

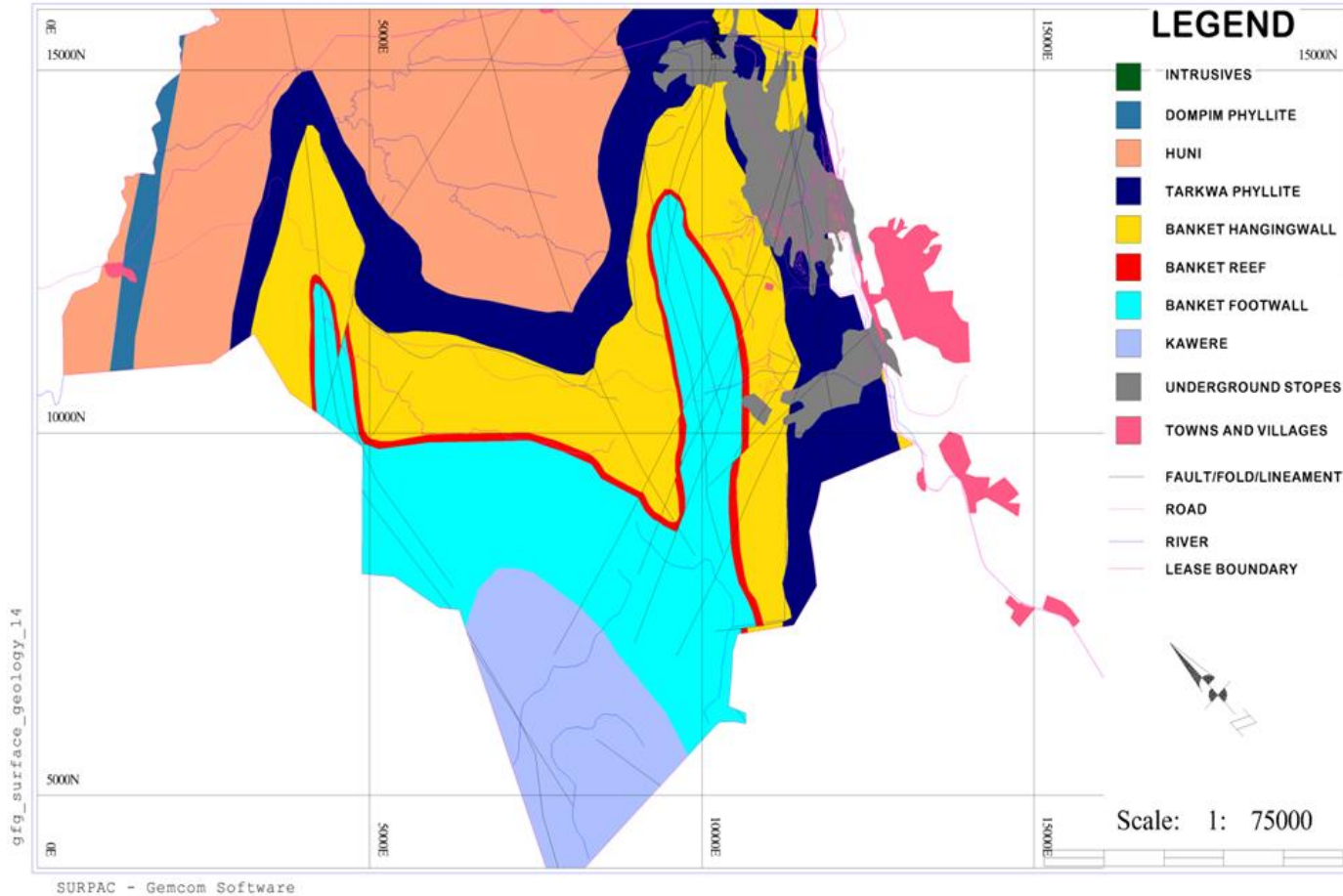
Indirect Approach

- In all cases, the large panels *must be conditionally unbiased* and are adjusted accordingly (as per above) to reflect the average grade improvements and tonnage reductions expected on the basis of the additional information that will become available at the later production stage.
- Though all analyses (including variograms and panel kriging) are done in the untransformed space, the required variance adjustments assumes lognormal distribution of SMU's within the large planning blocks

Case Study – Tarkwa Gold Mine, Ghana

- The Gold Fields' Tarkwa operation exploits narrow auriferous conglomerates, similar to those mined in the Witwatersrand Basin of South Africa and currently mines from four open pits – Pepe-Mantraim, Teberebie, Akontansi and Kottraverchy.

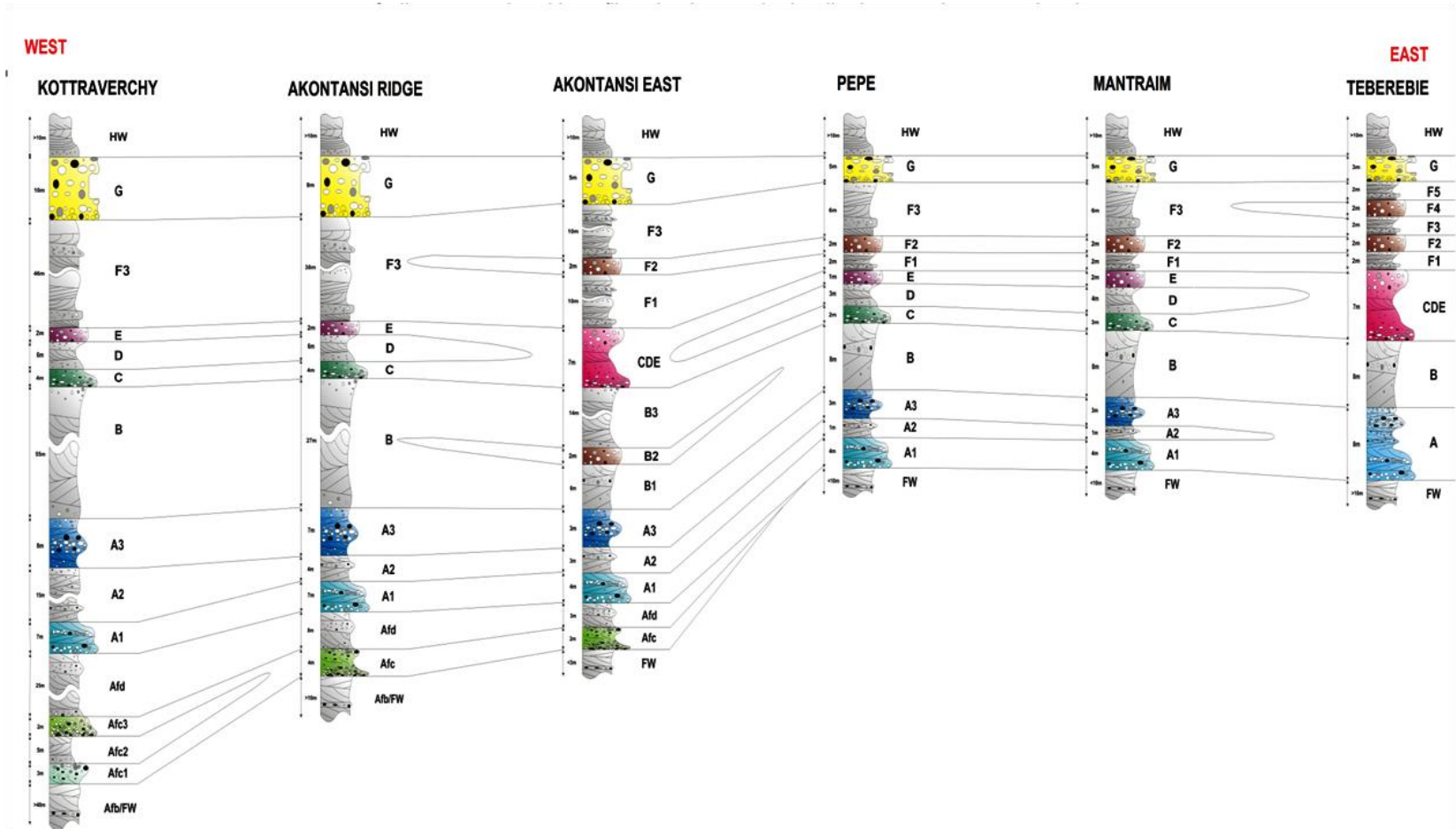
Geology



Geology

- The Banket Series, which hosts the Tarkwa ore body, varies in thickness from 32m in the east at Pepe, up to 270 m in the west at Kottraverchy.
- Sedimentological studies of detailed stratigraphy within individual footwall reef units have led to the recognition of both lateral and vertical facies variations.
- The sedimentological data, gold accumulation, gold grade and channel width data is further used to delineate geological domains or geozones.
- These domains are particularly important for the Simple Kriging panel estimates, which are used for conditioning of the recoverable resource estimates.

Geology



SMU

- Selective Mining Units
 - All Selective Mining Unit (SMU) sizes are as defined according to possible equipment, mining method, mining selectivity, together with the geology of the orebody. At Tarkwa, the SMU size is 10m x 5m x 3m with an assumed RC grade control drilling grid of 25m x 25m. During the early production period, certain areas were drilled on 12.5mx12.5m grid.

Estimation

- Both Ordinary Kriging (OK) and Simple Kriging (SK) techniques are applied in developing the panel (50mx50mx3m) resource estimation grade models. SK used for post-processing.
- The simple kriging process uses a local or “global” (Domain) mean in the kriging process depending on availability of data.
- Global mean based on historical data – need to be robust and efficient.
- Tarkwa’s case, the geological homogeneous domains provide practical stationary domains for this purpose

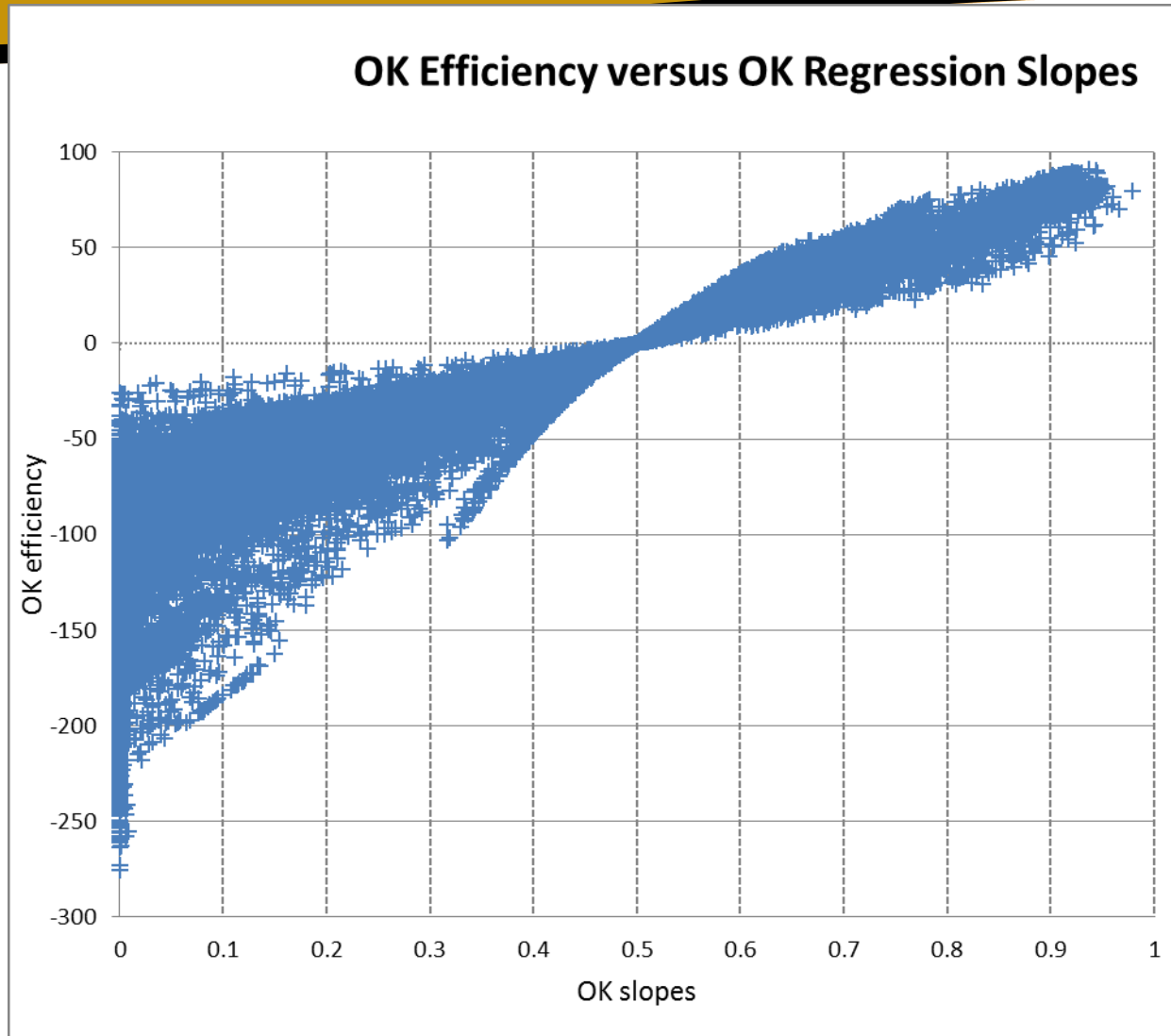
Analysis of Kriging Efficiency and Slope of Regression

- Kriging efficiency can be negative if $KV > BV$
 - It should be noted that unlike ordinary kriging, the minimum kriging efficiency under simple kriging is zero.
- Regression Slope = $(BV - KV + |LM|)/(BV - KV + 2|LM|) \dots(3)$
 - In order to avoid negative efficiency of block estimates, the following critical control limit test has been proposed for regression slopes (Assibey-Bonsu, 2014):
 - Where only a global estimate of all blocks is practical, all blocks will be valued at the global or sub-domain mean ie,
 - $KV = BV$ and Kriging Efficiency = 0 Substituting $KV = BV$ in equation (3)
 - *Regression Slope* = $|LM|/2|LM| = 0.5$

Analysis of Kriging Efficiency and Slope of Regression

- Thus, a regression slope less than 0.5 will always lead to a negative block kriging efficiency estimate. This highlights the danger of accepting block estimates which have slope of regression less than 0.5.
- The critical regression slope limit of 0.5 should only be used to identify blocks which will result with negative kriging efficiencies. Ideal slopes of regression should be greater than 0.95 as proposed by Krige (Krige, 1996).

Typical OK Efficiencies and Slope of Regression – Tarkwa Gold Mine



Typical OK Efficiencies and Slope of Regression – Tarkwa Gold Mine

- These significant conditional biases as observed with the OK estimates, particularly in areas with limited data have adverse consequences on ore and waste selection for mine planning, as well as financial planning.
- As a result, relatively efficient local mean SK panel estimates, as reflected by higher kriging efficiencies are used for resource panel conditioning, which form the bases of the recoverable resources estimates at the mine.

Post-Processing – Indirect Approach

- The parent kriged blocks/panel (50mx50mx3m) are subjected to post-processing as per the indirect recoverable resource methodology
- The methodology incorporates the information effect and change of support correction for the relevant Selective Mining Units (“SMUs”)
- A final production grade-control grid of 25m x 25m has been assumed.
- The base model provides recoverable grade tonnage estimates based on 5mx10mx3m selective mining units derived taking into account the production equipment on the mine.

Comparison of Resource and Grade Control Models

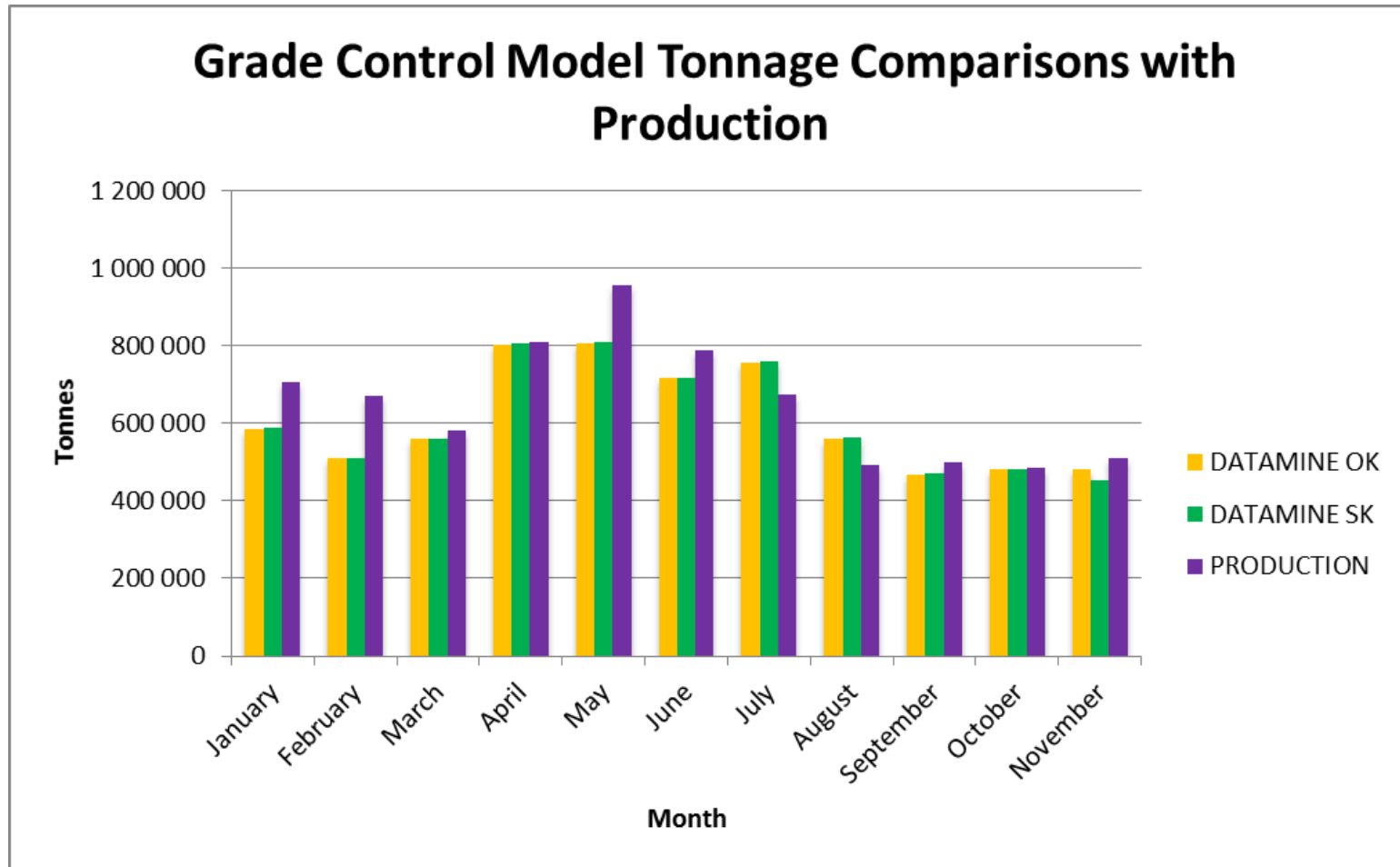
- The table shows good in-situ reconciliation of the resource model, which is based on the SK indirect post-processing technique, when compared to the grade control models.

Reef	Tonnes (%)	Grade (%)
A	-0.70%	-1.02%
C	-0.15%	3.30%
E	3.88%	1.27%
F2	2.10%	-5.00%
G	0.80%	-2.22%
Total	-0.07%	-0.95%

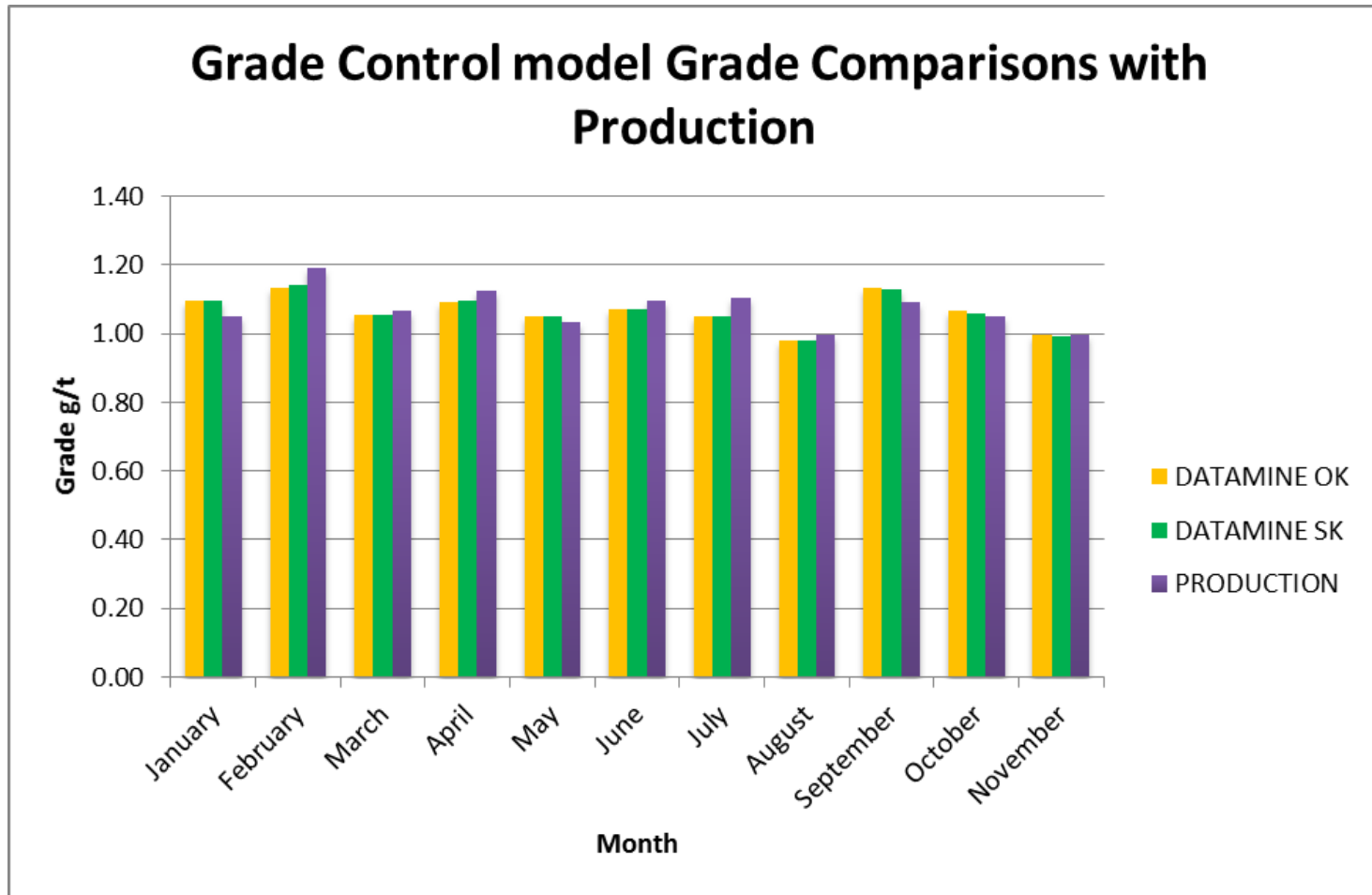
Reconciliation of Grade Control with Production

- There is a good reconciliation between grade control and production.
- As the Resource models and the grade control models reconcile well, it shows that a good reconciliation exists between the proportional post-processed recoverable resources estimates and production at the mine.

Grade Control vs production - Tonnes



Grade Control vs production - Grade



Conclusions

- The study shows that appropriate application of indirect post-processing technique provides efficient recoverable resource estimates for mine planning and financial forecast.
- The study further shows that it is critical that the conditioning panel estimates used for the post-processing are conditionally unbiased, if the corresponding recoverable resources estimates are to provide the lowest level of uncertainty for mine planning and financial forecast.
- The study shows that Kriging Efficiency and Slope of Regression provide useful tools to measure the extent of conditional biases

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