Geology Controls Grade Variance at Grasberg Cu-Au Porphyry Deposit, Papua-Indonesia

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Abstract. The Grasberg mining district is located in the core of the highlands of West New Guinea island, in the central ranges of the Papua Province of Indonesia. The collision between Australia Plate and Pacific Plate on Late Miocene generate NW-SE compressional structures orientation that produced reactivation of NE striking dilation to control the multiple series intrusion of host to Cu-Au porphyry deposit (Sapiie & Cloos, 2004). The oldest of Dalam Intrusion characterized by andesitic rock texture, phyllic to potassic alteration, low-moderate Cu-Au grade (0.25<EqCu<1). It is intruded by Main Grasberg Intrusion (MGI) with potassic alteration dominantly, quartz monzodioritic, high Cu-Au grade (EqCu>1). The latest Kali Intrusion characterized by propylitic to potassic alteration, quartz monzodioritic, dominant barren with EqCu is below the cut-of-grade (EqCu <0.25). The forecast block model is built in quarterly basis based on technical sampling assay method combination between diamond drill core and blasthole cutting samples. The actual grade model develop in daily basis following incremental blasthole cutting samples and be used for the ore reconciliation in monthly basis. The Cu-Au grade variance can be a loss and gain comparing to the forecast block model up to +/-30%. Focused on the negative variance or grade loss within pit radial sector 300°-330° at Dalam Intrusion and Southeast Kali host to phyllic-potassic alteration, and positive variance or grade gain observed dominantly along contact intrusion host to propylitic-potassic alteration. The veinlet relationships observed early vein bearing Cu-sulfide in NE direction intensively cut by SE and NS veins that filled by barren quartz-anhydrite±gypsum and quartz-sericite-pyrite as the latest hydrothermal fluid and affected on grade variance results. The spatial data distribution also influenced on grade variance model related to the alteration and mineralization style within the Grasberg Cu-Au porphyry deposit.

1. Introduction

1.1. Regional Geology and Grasberg District Condition
The Grasberg open pit mine is located at 4285m above sea level at the core of the highlands of West New Guinea island, within central ranges of the Papua Province of Indonesia (figure 1). The Grasberg copper –gold porphyry deposit associated with trachyandesite volcanics and quartz monzodiorite intrusion rocks within Grasberg Igneous Complex (GIC) are dated at 3.5 to 3.09 ± 0.05 Ma [1][2]. The multiple intrusions were intruded into clastic sedimentary rocks of the Jura-Cretaceous Kembelangan Group and carbonate formations of the Tertiary New Guinea Limestone Group (Quarles van Ufford and Cloos, 2005). The GIC is host to a Cu-Au porphyry deposit with totally 1,022 million tonnes ore reserves at 1.01% Cu and 0.78g/t Au (as of Dec 31, 2017).
The GIC formed as upright intrusive body in the axial of Yellow Valley syncline and bounded by NW-SE left-lateral strike-slip fault zone between Meren Valley fault at the north and Idenberg fault at the south parallel to strike of uplift stratigraphy bedding. The NE Grasberg fault was emplaced into a major left stepping dilational bend connecting these fault zone [3].

![Figure 1. Aerial photograph of Grasberg Open Pit Mine January 29th, 2018.](image1)

The GIC divides into three major intrusion phases from oldest to youngest consisted of Dalam Intrusion (DD) with low-moderate Cu-Au grade that intruded by Main Grasberg Intrusion (MGI) with higher Cu-Au grade and latest by Kali Intrusion with lesser grade as known as a barren zone in southeast orientation as shown in figure 2 [4].

![Figure 2. COW “A” Geology Map (PTFI Geology Department, 1998).](image2)

In the mining activity of Grasberg mine the block model was created as guides to determine of mine design, metal grade achievement, and estimation of total metal production. During the mine activity the variances between plan grades (based on model) and actual grades were identified and affected the value of final product metal for the buyers, especially the negative variance (the actual value is lower than plan value). To mitigate that variance issue the Geology department was conducted the geology grade controls variance monitoring in weekly basis.
1.2. Background and Definition of Grade Variance Controls

The grade control is comparing the values of grade estimation in previous grade model that build from exploration stage with actual grade obtained from blasthole data. In detail the grade controls can be define as process of identifying, analyzing, and managing variance between planned and actual results as effort to take decision about furthers conditions. The conditions could be as: methods to create better estimates, improved designs, tighter and more accurate plans and schedules, improved mining techniques to minimize ore loss and dilution, and identifying methods to increase metal recoveries during the extraction processes [5][6].

2. Data and Method

2.1. Resources Data and Geology Controls

The data that used in current study for geology controls identification related to grade variance is following the assay results of blast hole, diamond drill hole and also surface mineralogical mapping. In weekly basis the predictive grade variance map is provided to identify the potential variance within the weekly mining shape from grade comparison between forecast block model and actual grade model. The forecast block model is built in quarterly basis for grade estimation using combination assay result between composited drill holes and gridded blast holes, however the actual grade model always construct and update in daily basis based on blast hole assay incremental data. The grade variance will be identified at zone of higher than +/- 10% both for Cu and Au, and also extreme variance can be up to +/- 30% or more that can be gained or even loss of metal content related with Cu and Au estimation. At the end of month, the pit reconciliation provide the comparison data between mine to mill calculation in order to identify the actual ore production economically.

The grade variance also verified by surface mineralogical mapping with observation of Cu-sulfide mineralization i.e. chalcopyrite and bornite as common minerals in Grasberg Cu-Au porphyry deposit. Based on metallurgical study, most of gold occur as inclusion in Cu-sulfide mineral that increasing Cu-sulfide will bring higher Au content. The mineralogical description include rock type, minerals (silicate, sulfide, oxide, carbonate, sulphate), vein density, alteration zone and also material type identification during the mapping for recording data.

The geological structures mapping conduct to verify the grade variance controls. The structures mapping recorded to identify the cross cutting vein relationship and its characterization related to alteration-mineralization stages and localize the higher variance resulted in both gain and loss metal content.

3. Result and Discussion

3.1. Ore Geology Characterization

Surface mineralogical mapping conducted to identify the geological feature such as intrusion rock type and mineralization to determine ore type material. Observed rock type that hosted by phyllic-potassic of Dalam Intrusion, andesitic textures, Cu sulfide mineralization by dominantly chalcopyrite, then bornite-covellite with moderate Cu-Au grade (0.25<EqCu<1) categorized as Low-Medium Ore type. The potassic Main Grasberg Intrusion, quartz monzodioritic, pervasive chalcopyrite associated with bornite in stockwork veins, high Cu-Au grade (EqCu>1) categorized as high grade ore type. The Kali intrusion with propylitic to potassic alteration, quartz monzodioritic, dominantly barren with low Cu-Au grade (EqCu<0.25) categorized as waste.

3.2. Cross cutting Vein Relationship

Mineralogical surface mapping result showing at least five sequence of veins observed with detail from the older to younger: 1). quartz – anhydrite – Cu sulfide - magnetite following NE trending, 2). quartz – anhydrite following NS trending, 3). quartz - anhydrite following SE trending, 4). quartz – anhydrite – less Cu sulfide following NW trending, and 5). clay - sericite following SE trending. This data used
to determine vein paragenesis system. In figure 03, The quartz - anhydrite (NW) cut by clay-sericite (SE) and both cutting all previous mineralization with less Cu sulfide concentration.

3.3. Exposure Barren Quartz – Anhydrite ± Gypsum in Open Pit Mine
The main Cu - Au vein mineralization in NE trending is intersected intensively by the quartz - anhydrite ± gypsum SE-NS orientation without Cu mineralization was supposed the main cause of decreasing of Cu sulfide in this concern area. The presence quartz - sericite - pyrite barren also following previous SE - NS veins, also contribute on decreasing of Cu - Au by phyllic alteration influencing zone. The occurrence of quartz – anhydrite ± gypsum as barren veins as explained above is replacing the existed Cu sulfide mineralization and degrading the Cu grade (figure 3).

![Figure 3. Cross cutting veins relationship at Northwest Wall of Grasberg Open Pit.](image)

3.4. Block Model Investigation for Negative Variance (Grade Loss Condition)
The negative variance identification show from the forecast block model with extreme variance up to +/- 30% or more in Grasberg Open Pit Mine observed consistently within pit radial sector 300°-330° PB9S3 area from 3325L until 3295L (figure 4).

Field mapping at this area conducted to identify the geology controls inside this concern area such as intrusion rock type, mineralization, and dominant vein sequence characteristics. Observed rock type that hosted by potassic altered of Dalam Intrusion, Cu sulphide mineralization by dominant chalcopyrite, then bornite-covellite as vein forming stockwork. The early vein sequence is quartz-anhydrite vein NE trending with spacing interval is 1m and as the primary vein Cu sulphide. Following the vein characterization based on Gustafson and Hunt, 1975, it is categorized as A-Type veins in Cu-Au porphyry deposit.

![Figure 4. Negative variance at Northwest Wall on July 2017.](image)
The A-Type veins is cut by the intensively veins of quartz – anhydrite ± gypsum SE trending in westward of concern area and NS trending in eastward of concern area with spacing interval is 0.3 - 0.7m without Cu sulfide associated or barren veins (figure 7). Then continued the latest vein sequence of quartz – sericite – pyrite SE trending following quartz – anhydrite ± gypsum barren vein previously with spacing interval is 3m and influenced by phyllic altered wall rock around to be 2cm to 80 cm width. It is categorized as D-Type veins [7], see figure 5 and figure 6.
3.5. Block Model Investigation for Positive Variance (Grade Gain Condition)

The positive variance identification show from the forecast block model with extreme variance up to +/- 30% or more in Grasberg Open Pit Mine observed consistently within pit radial sector 040°-100° PB9S5 Area from 3355L until 3325L (figure 10).

Field mapping also conducted in this area and observed the intrusion rock type hosted by propylitic-potassic altered Dalam Intrusion to the Kali Intrusion contact profile. Increasing Cu sulfide by pervasive chalcopyrite replaced almost the original andesitic protolith texture of Dalam Intrusion and also found as stockworking chalcopyrite veins on the propylitic alteration associated with the high pervasive magnetite content. The positive variance area located approximately 50m from the contact zone between Dalam and Kali Intrusion (figure 9).

However the increasing chalcopyrite distribution not always existed along the contact between Dalam - Kali Intrusion, but only following the NE striking structures continuity close the contact zone as the pathway of high Cu mineralization and giving a positive variance condition (figure 8).

Figure 7. SE and NS striking structure distribution controls negative variance at Northwest Wall.

Figure 8. NE striking structure distribution controls positive variance at East Wall.
Figure 9. Chalcopyrite associated magnetite veins at positive variance.

Figure 10. Positive variance at East Wall on July 2017.
4. Conclusion
Cu-Au negative variance at pit radial sector 300° - 330° caused by the two sequence of latest barren veins following NS and SE striking structures (quartz-anhydrite±gypsum barren vein, then continued filled by quartz-sericite-pyrite vein) have already replacing the pre-existed Cu sulfide of NE trending dominantly, resulted the decreasing grade on the stockwork rock mass. However the Cu-Au positive variance at pit radial sector 040-100° observed at contact zone between Dalam and Kali Intrusion with high pervasive potassic-propylitic alteration associated by high chalcopyrite – magnetite mineralization forming massive chalcopyrite in stockworking veins resulted the increasing grade. Both negative and positive Cu-Au grade variance can be identified earlier follow weekly mining shape using comparison between the Cu-Au forecast block model to the actual grade model and re-calculated at the end of month from the pit reconciliation.

More and less there is also influenced of spatial data distribution contribute of these negative and positive variance model due to the distance of intersected each diamond drill hole around the mapping area in wider spacing intervals, showing low data density for model estimation quarterly basis or forecast block model. Althought the others location with same low data density did not found negative and positive Cu-Au grade variance condition, caused by homogeny geology controls influenced as observed at the field.

Geological controls understanding can lead the proper design of infill drilling program to reduce the negative grade variance by controls the SE and NS quartz-anhydrite±gypsum and quartz-sericite-pyrite of phyllic barren veins, and also intrusion contact profile. It can help to identify the boundary domain for grade estimation modeling in order to optimize the forecast block model estimation to the actual grade model comparison.

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