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Green Mining Framework Under Complexity Geometallurgy – Case Study Indonesia Mining, Grasberg Orebody

By

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Abstract

Mineral extraction under the green mining concept corresponds to target improvement in the area of engineering-design, technology use, along with the need for upgrades to personal skill-competencies. Achieving harmonious production under the green mining concept, a development framework shall happen around the organization to ensure all involved key players around the process are on the same agreed path for planning and executing the tasks. Orebody containing problematic characteristics of minerals could possibly generate a risk to the environment, respectively, due to its presence of chemical compositions. Mine planning has to be adjusted according to this potentially arising issue of negative impact on the environment, following the geochemical aspects that can influence the metal recovery process at the mill, smelter, and other final refinery facility processes. Determination of mine cut-off grade values shall correspond to the cost spending at the needs for processing of mineral. It happens through properly conducted step-activities to predict how different parts of the orebody will behave during processing. Collaboration among geologists, environmental scientists, economists, and legal or regulatory experts is needed to minimize the environmental impact while pursuing the best economic and social benefits. Sulphide mineral orebody containing large volume of pyrites, could generate Acid Metalliferous Drainage (AMD), which can harm the environment for not being properly handled them from the first place. The case review of the Grasberg orebody provides a good lesson learned on the way to set up the activity process, aiming to meet the target of the green mining concept. The integration of mine planning and ore processing for properly and effectively handling the pyrites would become a reference of framework to extract minerals within the same type of sulphide orebody. The new technology implemented covers work around underground mine planning and robust engineering design for properly sequencing the underground block cave mine. Installing new additional SAG and copper cleaner circuits properly allows for segregation and carefully manages the pyrites. The harmony plan for mining operation can be achieved by applying the robust framework to ensure that decisions made in one area consider the impacts on others. This paper aims to adopt best practices from the Grasberg orebody and recommend a suitable framework for the green mining concept, considering the complexity of the orebody's geometallurgy.

Keywords—*Green Mining, Geometallurgy, Sulphide Orebody, Engineering Framework, Acid Metalliferous Drainage.*

INTRODUCTION

REFORMATION in mining science areas happens in anticipated future challenges to fulfil the concepts of green and smart mining. This replacing an outdated concept for only maximizing the economic benefits from the market by producing a good grade of metal commodities. Mineralization from past erosion process in the earth deeper creates various

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shape-dimension of orebody, location, and chemical elements of rocks, which turn into affects the way on how the mine is to design include the processing facility itself. It calls for the needs of specific skills and a certain level of expertise who can be working collaboratively as one group. As such not only provide review from the economic values standpoint but include consideration for any potential negative impacts for environmental which cause by the chemical elements of rocks in orebody. The value of cut-off grade mine is influenced by the metal price in the global market and how efficient or effective process at the mill site which measure through the percentage of metal recovery. It is commonly known that the higher recovery value means the more effective and efficient of the ore process at the mill. An orebody at various content of mineral hosting by heterogeneous rock types at include of large composition of waste or gangues requires a separate study attaining the target of an effective percentage on mill metal recovery. It means the more processing needs for ore dressing, the more its affecting and lowering the value recovery of mill. Enable achieved an effective cost for the mining operation; an effort of review shall be extended into study of impact since requirement of extra handling since present various geological formation and chemical composition inside of orebody. In today's practices, the collaboration among multidisciplinary knowledge to study the characteristics of ores has become part of the engineering design activity for mineral processing facilities only. At the new needs of enhancing mining productivities, reduction environmental impact and properly planning for later stage of mine closure, metallurgical and geoenvironmental characteristic assessment have to be extended into cover the way of planning the excavation area. This concept of interdisciplinary collaboration is currently known as the Geometallurgy study-assessment. Collaboration is performed by people who have their expertise in areas of geological, mineralogical, metallurgical, environmental, economic and legal or regulatory expert. This join review aims to reduce until eliminate any potential impact since the complexity of rock chemical characterization in the orebody throughout performing review and analysis of mine engineering design and metal processing facilities. Inline to the mandates of Indonesian government's law in maximize the benefit of mines which part of obligation to implement the good mining practice (GMP), it finds a needed to formalize the framework and become a guideline ensures collaboration program is properly implement and documented.

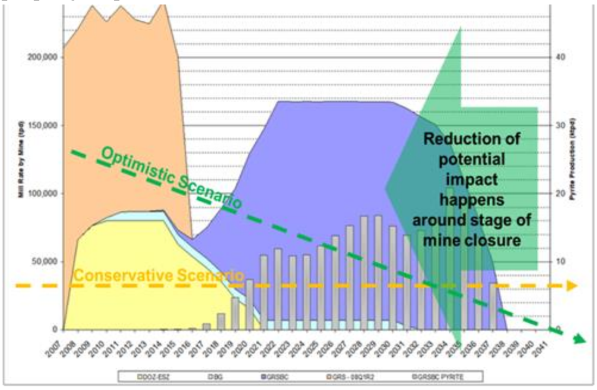

Fig. 1 Comparative plan ore tonnage from the Grasberg orebody and pyrite gangues. Plan of handling the ores and gangues involves assessment on potential reduction of negative impacts in later stage of closure and the post-mining periods. Its done by examine various mining operation scenarios aims balancing the ore extraction and optimizing all needs of effort for managing the pyrite around the period of active productions (prevent risk consequence happens in the later stage of mine closure of post-mining periods).

Case study is conducted within Grasberg orebody located in the eastern region of Indonesia on the island of Papua, with the main commodity copper. Grasberg orebody has a variety of geological characterization and effecting mining planning as well as processing facility designation. Join assessment under geometallurgy framework must be performing attaining an optimum benefit without risking the quality of the environment due to the negative impacts following presence of large volume amount of pyrite in orebody. Characterization of the Grasberg orebody fall into several categories based on the local geological rock classification. This rock classification then determines the processing methods for each type of ore under different types of hosting rocks, which consisted of Main Grasberg Skarn (MGSK), Dalam (DLM), and Heavy Sulphide Zone (HSZ).

Following the needs of obtaining the most effective handling process-system, rock characterization is re-grouped by considering of factors under the stratigraphic studies. The rock types split into separate classes of A, B, and C based on low and high recovery values, as well as D, which represents problematic ore types. More detailed classifications of ore types can be grouped as follows:

1. Type A (ore >92% recovery)
2. Type B (ore >80% recovery)
3. Type C (ore <60% recovery)
4. Type D is problematic ore classification.

The classification of problematic ore is based on the content of its contaminating minerals which are divided into:

- Clay ore: contains >5% clay from the total tonnage produced. This clay is identified as material with a size <0.06mm that has sticky properties.
- Fe Oxide ore: contains >5% iron oxide from the total tonnage produced.
- Pyrite ore: contains >5% and <20% pyrite from the total tonnage produced.
- Lead-Zinc (Pb-Zn) ore: contains >0.1% lead (Pb) and/or >0.8% Zinc (Zn) from the total tonnage produced.
- Sericite ore: contains >10% sericite from the total tonnage produced.
- Prophylitic ore: contains >20% chlorite-epidote from the total tonnage produced.

One of the major challenges is the handling of pyrite in the HSZ area, particularly at potential risks of generating acid mine drainage when it's not properly managed. The HSZ zone itself is categorized based on the consideration when pyrite content greater 20%, which, under the current processing

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facility scheme, is part of the problematic ore that needs to be avoided. The orebody containing pyrite requires a separate mining studies determining operation-production scenario and processing design at the mill-plant. The ore process containing pyrite will goes through the grinding facility (SAG regrind) and cleaner flotation circuits which been modified according to the geometallurgical concerns at ores. Additional facilities are included to better of managing the pyrites in the mill-plant while store them correctly the deposition area for further treatment process. The workload of the processing facilities can be reduced by optimizing their handling in the mining area, as such taking into consideration mixing of pyrite-ANC (Acid Neutralization Capacity) and/or pyrite-NAG (Net Acid Generation) be part of block cave operation scenario, proper drainage and mine dewatering engineering design, and properly managing the sequence of block cave during the development and pre-production phases. The design of mining operations itself will take into consideration of integration process review, starting from ore excavation and fragmentation efforts, ore blending scenario prevent the generation of acid, managing geotechnical aspects in the sequence of progressing cave, and effectively processing ore at the concentrating plant. It requires strategic planning cover the long-range plan which has to be in balanced with the tactical execution. The workflow under the term of long-range planning to involve a more of data collection during the initial stage of exploration. While in short to medium-term of tactical planning, more about doing the adjustment into the actual conditions which operation encountered in the field. These two workflows, strategic for long-range plan and tactical cover short to medium plan expect to bridge the gaps and needs for adjustments in timely manner concerning metallurgical characterization. This written paper provides a concept in building the framework for effectively handling the negative impacts since presence of rock chemical in orebody referring to research study conducted for Grasberg mine in Indonesia. This conceptual framework is expected to become reference for future planning of underground mining attaining a minimum impact on the environment due to the presence of contaminants such as pyrite in the orebody. This is particularly on its negative characterization who can generate an acid mine drainage if not properly managed from the first place. Procedure for Paper Submission

LITERATURE REVIEW

Pekka A Nurmi (2017) through research and writing titled 'green mining, a holistic concept for sustainable and acceptable mineral production' advocates for reducing environmental impacts through mining operation optimization programs. It can be achieved through energy efficiency programs, water usage efficiency, and conservative efforts in mineral excavation process. The success of optimizing mining operations is influenced by several factors, including accurate information and data about the geology of orebodies and information requirements to meet mine and processing operation aspects. Nevertheless, this research and the written paper do not specifically outline the framework and environmental impact since the challenge of chemical composition of rocks. Julie Hunt et al. (2023) through research and journal writing entitled 'A Special Issue Dedicated to Geometallurgy: Preface, stressing the essence of study function of multidisciplinary knowledge under the recognize field of Geometallurgy in assessing the ore reserves characterization that needs for planning the mine and early determination of economic studies for the mining operation. Poor in identifying the rock characteristics will affect into cost deviation following lack on planning for fragmentation/size reduction, handling of waste, and other gangues who then impacting the percentage of mill recovery. Practicing the study of Geometallurgy can provide better planning following the proper ways in addressing the technical challenges, controlling the environmental impacts, and socio-political issues in relation to the exploitation of orebodies. I however, this research and written journal do not illustrate with a framework that can serve as reference or guidelines for implementation. Hui-qi Shi (2012) through research and technical paper writing entitled Mine Green Mining persuades several environmental issues as part of the impacts of mining operations that require a balance into mine production programs. The research and written paper to highlight the negative impacts into the environment in the coal mining following the generation hazardous pollutants harmful that will affect human health, as such with the presenting of SO2, CO2, H2S, and nitrogen in the mine. Research and written paper stressing the engineering studies which can lead to recommendation of changes in planning for mine and the use of technology in reduce people's exposure into pollutants who can affect their health. This written paper provides recommendations on effort needs under engineering design attain environmentally friendly of mine operation, although it does not provide a reference framework in achieving this. Viktor Lishchuk et al. (2018), through their research and written journal entitles 'Simulation of a Mining Value Chain with a Synthetic Ore Body Model: Iron Ore Example,' provide a reference for the scenario simulation as a step addressing the uncertainty due to the incomplete of data and information at the ore body. Research emphasizes scenario simulation that was conducted to construct a plan outcome targeting an environmentally friendly mining operation. The initial study of geological aspects includes three main variables: mineralogy, rock chemical composition, and mineral content density. The production aspect covers two areas of mining operations and ore processing with simulation modelling. The economic aspect presents cost of operations and the value of economic benefits that is in comparison between current and future cash flow. Scenario simulations use reference values for the percentage of ore dilution and recovery from different mining methods. Research and paper do not specifically address the issues of handling of metallurgical complexity in the orebody. Faramaz Doulati Ardejani et al. (2023) in their research and technical paper writing entitled 'Developing a Conceptual Framework of Green Mining Strategy in Coal Mines: Integrating Socio-Economic, Health, and Environmental Factors' describes the use of a lifecycle study in identifying environmental impacts on each stage of mining activities. Each cycle of mining and mineral processing

*Corresponding Author: **Rudi Toba** .

stages, along with environmental impact is identified then compared to an effective handling component. The conceptual framework only discusses coal mining commodities who has no metallurgical complexity as happens to mineral commodities. Annika Parviainen et al. (2025) in their research and its writing entitled 'Geochemical processes related to mined, milled or natural metal deposits in a rapidly changing global environment' emphasized mineral extraction methods through chemical processes (leaching) facing the challenges of energy resource limitations under mechanical processing in the plants. The study also considers the type and shape of reserve deposits along with the metallurgical complexities on the ore body; it however, the research and study do not specifically explain the framework for mineral extraction through the chemical leaching process. N McKay et al. (2016) in their research and technical paper writing entitled 'strategic and tactical geometallurgy – a systematic process to add and sustain resource value', divide the management of geometallurgical studies into two parts: strategic execution and tactical execution. The strategic geometallurgy study is conducted based on the interpretation of geological data of the ore body, while the tactical study is based on direct observations and actual data obtained through field sampling. The combination of these two methods is seen as complementary and can provide modelling results for effective mining and processing operations. The framework conceptualized in both strategic and tactical methods is considered effective as a reference but does not specifically take into account modelling for underground mines, particularly in handling the acid mine drainage. M Bueno et al. (2023) in their research and technical writing paper entitled 'Geometallurgy Applied in Comminution to Minimize Design Risk' presenting study of ore characteristics serves as a reference in modelling the operations of processing facilities. The type of mineral ores with various geological characterizations is included into factoring the hardness of the material. The effectiveness of the study is based on the amount of energy required at the processing facility under the different geological characteristics of rock materials. The research and written paper only discuss the processing from the aspect of size reduction and do not specifically address the handling of the chemical content of the rocks. Jacob Guinot et al. (2022) in their research and paper writing entitled 'Understanding Green Innovation: A Conceptual Framework' advocate for eco-innovation by considering three main elements in forming a framework for environmental-based innovation, social aspects consideration, environmental aspects, and economic value. This environmental-based innovation not only aims to reduce negative impacts on the environment but also considers improving organizational performance in terms of reducing costs relate to the managing of environmental impacts. This research and writing do not specifically discuss the framework of mining operations innovation. Meifeng Cai et al. (2021), through their research and writing paper on the title "Key Engineering Technologies to Achieve Green, Intelligent, and Sustainable Development of Deep Metal Mines in China," persuades the identification of technology and engineering needs through the study of key issues and risks exposure in underground mining. Engineering design collaboration during the mining activities and mineral processing facilities is conducted as an effort enhancing effectiveness of production operations. This includes the uses of the latest technology, replacing conventional equipment that is seen as ineffective, poses risks to workers, and minimizes the potential for disruption or degradation of environmental quality. The research and paper writing do not specifically address the collaboration of engineering design for properly managing the chemical elements in rocks who can generate acid mine drainage. Three main activities in the operation of the Grasberg underground mine that can be optimized to reduce the impact of mill processing cost which arise due to the program for risk mitigation since the presentation of pyrites in the ore body and potential of generation of acid mine drainage. These three activities cover the study of mine development and pre-production sequence, blending scenarios, and the effectiveness of mine drainage management. A framework concept based on eco-innovation is developed by taking a case study review of the complexity metallurgy of Grasberg orebody. It further develops under principle of enhancing the performance of mining design engineering while reducing the risk cost due to the happens of unnecessary spending in the processing facilities.

UNITS GRASBERG OREBODY - CHALLENGES ON THE METALLURGICAL CHARACTERIZATION

The Grasberg ore body, more commonly referred to as the GIC (Grasberg Intrusive Complex), features a HSZ (heavy sulfide zone) that is circular, tapering, irregularly shaped, and is in direct contact through sedimentation processes with the host rock, which is predominantly limestone. The HSZ consists of a group of sulphide rocks (pyrite, pyrrhotite, chalcopyrite) but also contains a composition of magnetite-hematite (oxide-hydroxide group) and epidote-chlorite (silicate-carbonate group). The existing processing system does not allow for accommodating pyrite content above 20%. Magnetite rock is more commonly found near limestone compared to pyrite. Epidote rock is located at the top of the HSZ zone, and its formation process has not been concluded to this day, but it is estimated to be related to the mineralization process of another Kucing Liar reserve deposit that was formed after the mineralization of the Grasberg orebody. The RQD values of HSZ vary from 0 to 100%, but the majority are classified as low RQD (poor). By observing the low RQD values in the area with high pyrite content, it is very likely that this rock group will collapse and enter the drawpoint area, which could affect the magnitude of the recovery values. This raises a consideration of the need for handling through the integration of process engineering between the design of mining operations and its processing facilities in the mill-plant.

*Corresponding Author: **Rudi Toba** .

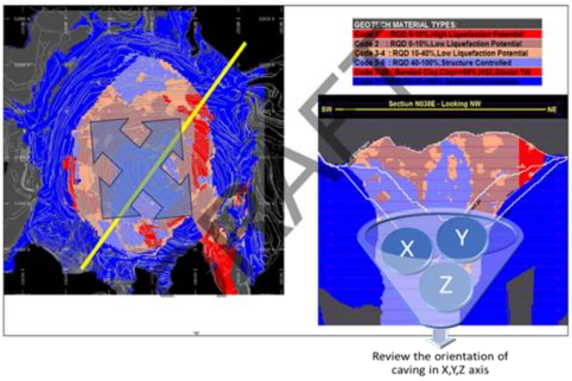


Fig.2 Collaborative efforts assessing the direction of cave developments in the X, Y, and Z axis. Where X - Z represents the direction of cave development along the horizontal axis and Y represents the height of the cave column in vertical axis.

The values of minerals from early studies of orebody provide reference as an average economic limit for the exploitation. In mining operations, this is known well as the value of COG (Cut-Off Grade) where are the baseline of grade economic. Value has considering as an initial recovery target for the mill-plant, which still requires an adjustment following the progressing of exploration activities and/or pick up sample from the drawpoint. Research-study for the underground block cave mining for Grasberg deposit from initial study indicate can produce 983 million tons of ores at average grade of 1.06% Cu, 0.85g/t Au, and 3.33 g/t Ag. The percentage recovery of copper and gold along with other various gangues predicted to be 88.4% and 69.4%. Pyrite in orebody is estimated at 93 million tons with an average percentage of 9.5% per year which expect on transported to the processing plant. Number considered be increase as mining go deeper with a larger on volume compared to the previous Grasberg open-pit mining era. Ore characterization using in assess metallurgical processing for the mill-plant are divided into three levels:

Level 1 – Study of variability and types of ores based on

- A single test of roughness at a set grinding time
- Test of the presence of copper, gold, silver, and pyrite

The level 1 sample is taken from core drilling results to a depth of 75m. The sample cylinder provides data about rock type, ore grade, alteration-mineralogy, and pyrite content. The results of the sample tests conclude the following data:

Composite	Head Grade			Recovery			Concentration Ratio
	Copper	Gold	Silver	Copper	Gold	Silver	
	(%)	(ppm)	(ppm)	(%)	(%)	(%)	
MGSK-A	0.76	1.32	1.0	97.6	93.6	98.2	5.3
MGSK-B	0.58	0.83	0.9	95.0	90.1	96.1	4.9
DLM-A	1.30	1.02	2.7	95.7	87.0	99.5	3.9
DLM-B	0.84	0.49	1.0	90.3	81.6	93.2	3.3
HSZ-A	0.86	0.60	3.1	95.4	93.5	96.4	2.1
HSZ-B	0.96	0.82	4.1	89.6	88.1	90.4	2.0

Level 2 – Standardization of simulations based on the mill or factory processing activities

- Grinding recovery
- Purity content recovery
- Processing index value, environmental parameters, penalty elements, mineralogical processes

Level 2 sample is the same sample as level 1 that has the same characteristics and in a spatial relationship. The main basis of the study of rock type is more on improvements of value recovery from side of grinding and purification.

GBC Rock Type	2003 Copper Recovery (%)	2006 Copper Recovery (%)	Difference 2006 – 2003 (%)
MGSK-A	96.1	97.6	+1.5
MGSK-B	94.2	94.9	+0.7
DLM-A	95.1	95.8	+0.7
DLM-B	94.6	91.3	-3.3
HSZ-A	89.3	95.2	+5.9
HSZ-B	73.4	89.5	+16.4

Adjustment into recovery value is made based on development data through conducted some series of rock samples testing for each type of rock. This happens simultaneously with the adjustments into mining activities and mill processing. Collection of rock samples from the underground mine drawpoints and perform study-analysis in the laboratory become part of step in tactical program. The results create an input in modifying the strategic long-range plan for mining operations. Through this process of validation geological data, results of rock type composition can build as shown in the following table:

GBC Composite	Copper Concentrate Composition				Copper Cleaner Recoveries			
	Copper	Gold	Silver	Pyrite	Copper	Gold	Silver	Pyrite
	(%)	(ppm)	(ppm)	(%)	(%)	(%)	(%)	(%)
MGSK-A	29.1	34.7	76	0	96%	73%	93%	2%
MGSK-B	22.5	16.6	41	12	94%	80%	90%	34%
DLM-A	28.8	17.8	56	12	94%	89%	93%	35%
DLM-B	22.5	10.8	33	14	94%	85%	81%	18%
HSZ-A	23.1	10.7	56	29	93%	67%	77%	5%
HSZ-B	21.8	13.3	75	16	80%	56%	60%	2%

In addition to the main commodities of copper and gold, gangues and other material who can influence the impurities provide the following notes at need of adjustment:

- Only MGSK-A and DLM-A are properly fit into exist mill circuit design as it mainly same to previous supply ores from old open pit mine.
- The MGSK-B, DLM B, HSZ-A have reached a concentrate grade of 22.5 – 23.1% on value recovery of copper.
- The recovery value of HSZ-B ore is low at 80% with a grade of 21.75%.
- DLM-A and DLM-B reached 4% and 8% at their highest concentrations.
- The gold recovery rate is lower compared to previous production from the open pit. DLM-A achieved a recovery rate of 89%.
- The gold recovery rate for types MGSK-A and MGSK-B is at 19% and 11%, the lowest.
- The gold recovery rate for types DLM-A and DLM-B is 2% to 3%.

There are two main aspects which require study in the

*Corresponding Author: **Rudi Toba** .

processing for concentrate plant who believed can significantly influence the value of percentage recovery, they are effectiveness of grinding and the separation of minerals from impurity materials. These two factors affect the amount of electricity requirement, which in turn also determines the supply of resources as part of energy provision.

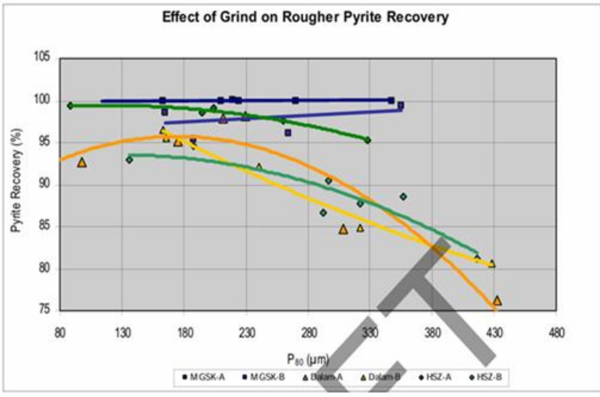
Composite	2006 Indices (kwhr/tonne)	2003 Indices (kwhr/tonne)
MGSK-A	10.6	10.7
MGSK-B	9.7	11.3
DLM-A	10.5	11.7
DLM-B	11.7	12.4
HSZ-A	12.5	12.9
HSZ-B	12.4	12.7

The management of electrical energy supply becomes important because it will influence the percentage recovery value of the plant due to the impact into production cost. Adjustments to the electricity supply needs based on the latest metallurgical characteristic data need to be made to optimize operations in the processing plant. Development data through sample analysis show the decrease in the KWHR value ratio per ton of ore as the results of rock characteristic testing become more accurate.

Composite	Head Grade (%Pyrite)	Pyrite Recovery (%)
MGSK-A	3.6	100
MGSK-B	4.8	98
DLM-A	5.6	94
DLM-B	6.4	93
HSZ-A	32.3	99
HSZ-B	30.1	92

Expanding data to better of understand the metallurgical characterization, relationship between pyrite recovery and grinding size can be illustrated in the following graph.

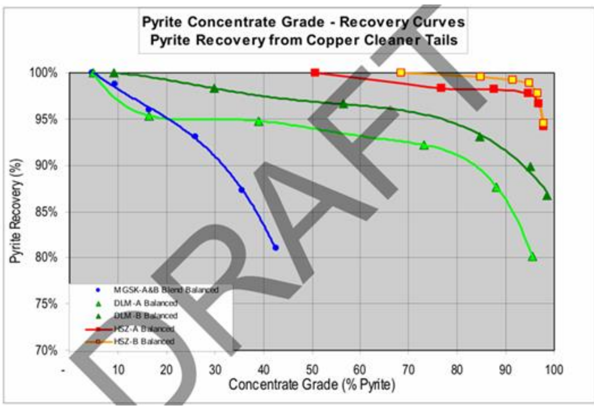
- Pyrite recovery in MGSK-A, MGSK-B, and HSZ-A types requires additional grinding.
- Pyrite recovery is easily achieved in DLM-A, DLM-B, and HSZ-B rock types.



Through this level 2 testing, a development of conclusion goes into look for specific types of rock groups that will require an additional crushing into existing processing facilities.

- Level 3 – Optimization for low-grade ore types
- ✓ Identifying modifications process in the mill-plant
- ✓ Establishing parameters for process design. As example, the adjustment into duration of flotation time.

Level 3 sample is a sample of level 1 with additional evaluation on the potential mixing of level 1 samples which under similar characteristics.



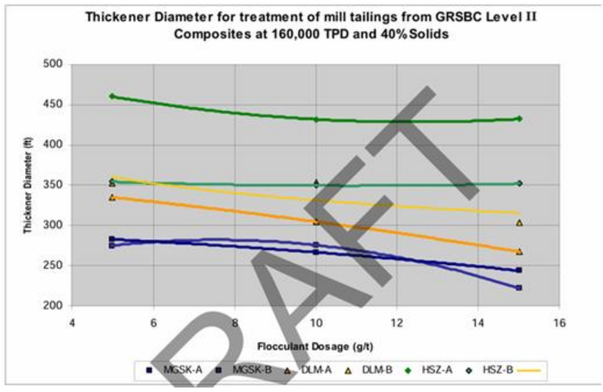
The graph indicates that the percentage of pyrite's value recovery decreased in proportion to the increase in the amount of pyrite composition in each type of rock.

Composite	Cleaner Tails (%Pyrite)	Initial pH	Final pH	$CuSO_4$ (g/t)	PAX (g/t)
MGSK-A&B	5	10.9	9.6	56	223
DLM-A	5	9.9	8.4	75	774
DLM-B	9	10.2	8.8	75	776
HSZ-A	51	9.9	8.6	75	776
HSZ-B	68	10.0	8.7	75	775

Considering the operational cost, additional flocculant materials supporting mineral separation process at the processing facility become one of the solutions. The function of flocculants can be described in detail as follows:

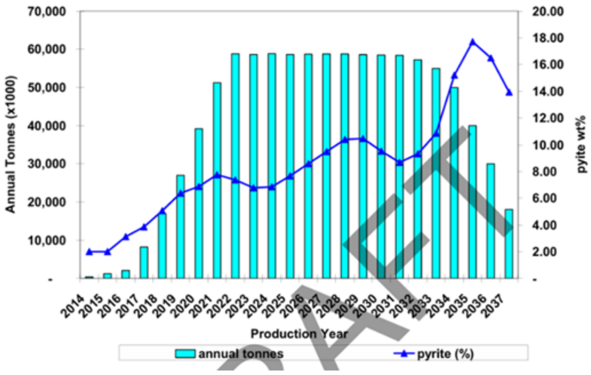
- Accelerate the process of separating fine particles that tend to settle for too long if left without additives.
- Improve the quality of mining waste cleanup through the use of flocculants where wastewater can be processed more cleanly, therefore can minimizing environmental impacts.
- Provide savings in terms of time and costs with a faster particle separation process.

The relationship between the type of rock and the diameter size of the sedimentation facility (thickener) and the composition of the flocculant material used can be illustrated in the following graph.

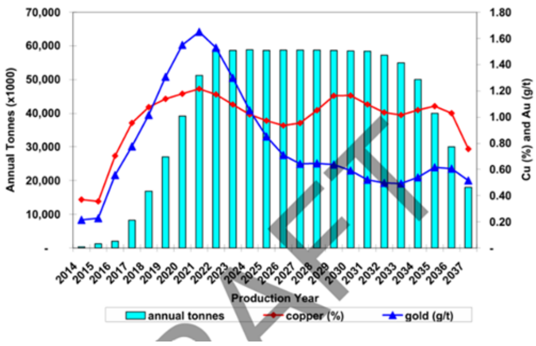


The relationship graph obtained through the conducted tests who indicates a decrease in the diameter size of the sedimentation facility with an increase in the usage of flocculant doses.

At all process of data validation along the scenario for mill-plant operation, production chart can be developed present the over year production on main commodities and pyrite.



Grasberg Block Cave Production Forecast



Presenting chart from the series of sample testing and analysis with the regards of tonnage production during the period life of mine. It indicates increases on percentage of production pyrites which happens in same time of decrease main commodities. It means there will be the period of increase the workload on processing facilities at less amount of main commodity output. This gives an indication of the potential increase in capital and operating cost in relation to learn the trend percentage along with presentation of pyrites.

Due to the increase of pyrite content and its impact into future operational cost, consideration then goes into plan for development and modify processing facilities in properly handling the pyrite. The cost for construction the facility aiming properly managing the pyrite where split into two group of pyrite processing itself and energy or electricity feeding. The total scheme cost can be tabulated as follows:

Circuit	Processing CAPEX	Energy CAPEX	Total CAPEX
Cu regrind	52.8		52.8
Cu cleaner	78.8		78.8
Total Cu Processing	131.6	80.7	212.3
Pyrite cleaner	91.0	41.9	132.9
Pyrite concentrate thickening	46.7	14.2	60.9
Pyrite concentrate storage and pumping	49.8	16.3	66.1
Pyrite Concentrate Pipeline	121.9		121.9
Pyrite Impoundment	145.2		145.2
Utilities and reagents	25.3	3.5	57.5
Total Pyrite Processing	479.9	75.9	527.0
Millsite Power Distribution	28.7		
Total	640.2	156.6	796.8

Energy cost for the increase electricity feed demand for 45MW lead into plan for addition 1 power plant unit at investment of $225 million. The detail plan allocation of cost for the processing pyrite can be tabulated as follows:

	2017		2021		2028	
Circuit	**Processing**	**Energy**	**Processing**	**Energy**	**Processing**	**Energy**
Cu regrind			52.8			
Cu cleaner			78.8			
Total Cu Processing			131.6	80.7		
Pyrite cleaner	91.0	41.9				
Pyrite concentrate thickening	46.7	14.2				
Pyrite concentrate storage and pumping	24.9	8.1	24.9	8.1		
Pyrite Concentrate Pipeline	61.0		61.0			
Pyrite Impoundment	72.6				72.6	
Utilities, reagents, power distribution	25.3					
Total Pyrite Processing	321.5	64.2	85.9	8.1	72.6	
Power distribution	28.7					
Total	351.2	67.7	217.5	88.8	72.6	
Total	418.9		305.3		72.6	

There is potential cost optimization in the processing facilities through the engineering of mining operations by better of managing the concentration of pyrite. Considering large impact on both of capital and production operation cost due to the increasing demand for electrical energy supply, re-engineering of the mine might be another option. Productivity improvements and optimization could happen by exploring any potential activity in area of mining operations which can be maximized in reduce the spending for mill processing. This, of course, needs to be assessed with the risk factors in the mining operations using the adopted method. The mining operation of the Grasberg orebody uses the block cave method, which has several risk factors that are always considered in mine design. Some of these includes:

- **Geological data**

The adequacy of geological data required to make estimates and mining plans related to rock structure, dimensions, size, and ore body grades. Mapping of production blocks based on the economic grade composition of minerals combined with other type of rock materials who can neutralize pyrite and provides a good reference for scenario of blending.

- **Geotechnical Data**

The adequacy of data regarding the engineering design requirements of geotechnical aspects includes the conditions and characteristics of the rock inside orebody and its host rock, such as major geological structures, discontinuities, rock types, in-situ pressure, and groundwater hydraulic pressure. This data will serve as a reference for studying the potential for undercutting, performance of the caving and undercutting zone, stability of openings, and mineral dilution. Diverting water flow to prevent it entering the cave zone which also aiming avoid potential occurrence of the wet muck. This also prevent formation of acid mine water due to the oxidation of pyrite material which can flows into the mine dewatering system.

- **Study of caving and/or subsidence**

Predictions from the hydraulic radius (area/perimeter) of the cave will provide an initial reference location for undercut. It

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will be based on the assessment of the geotechnical characteristics. Mapping of the production block that supports operation scenario of mixing pyrite and types of carbonate material will then provide considerations for the sequence of undercut or mine development for drawpoint production while maintaining stable openings.

- **Cave propagation**

The ability of mine to continue cave and create more fractures after the initial collapse begins is essence in block cave mine concept. Cave propagation will depend on several factors including the engineering design of the undercutting area, the rate of cave space development, pressure on the surrounding rocks in the production area and above the cave, rock structure in the ore body, geotechnical characteristics, and draw control strategies from the caving. Due to the capital-intensive nature of the mining method, which is non-selective and relatively inflexible, the inability to initiate or maintain a collapse in stable conditions for an extended period is one of the greatest risks faced in the block caving mining method.

- **The value or degree of fragmentation**

Ore production is obtained as a result of the caving process. This factor is influenced by the distance and design of the drawpoints, the selection of equipment and its performance, the amount of hanging rock that prevents ore is pull-out from the caving area, as well as the magnitude of the effort for size reduction and providing guidelines for the size and requirements of the crushing facilities and affects the overall caving productivity.

- **Performance of cave**

Describes the achievement conditions against the rate of cave propagation, average production, degree of fragmentation, ore content levels, and recovery rates.

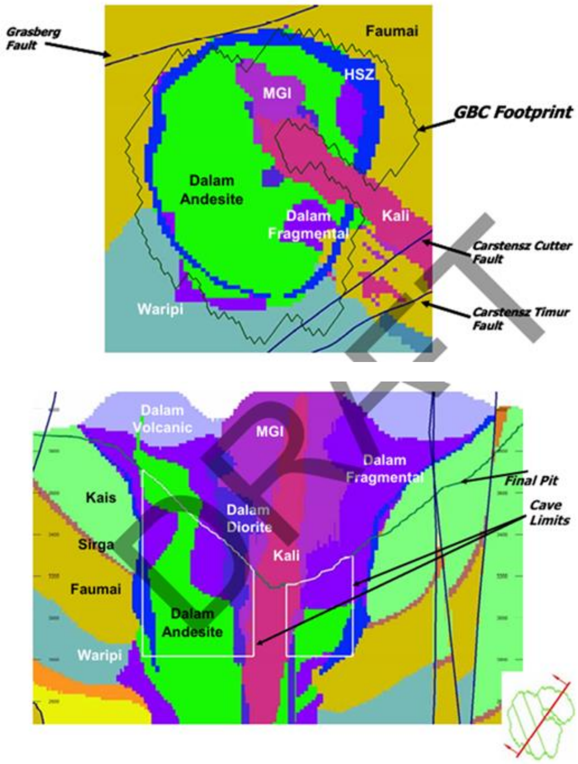
- **Stability of the opening**

Provides stability conditions of the opening according to the life of mine design and the need for ground reinforcement during the development phase. Also, for other permanent facilities that are expected to remain open for the long term in accordance with the life of mining.

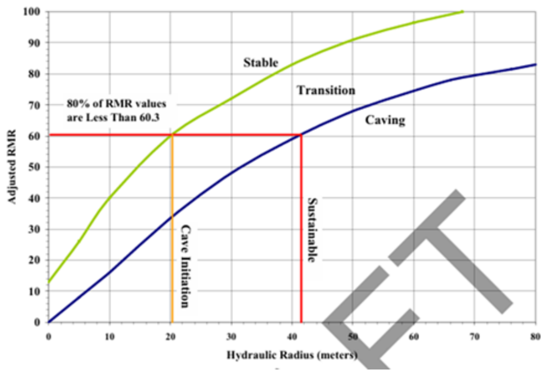
- Significant hazard management related to mining operations includes massive caving, rock explosions, air blasts, and wet mud.

Environmental risk is generally defined as the impact of the intrusion of groundwater and surface water that can affect mining operations, the management and disposal of mining waste, disturbances to flora and fauna habitats, the impact of subsidence, land rights, archaeological issues, and other community-related concerns. Acid mine drainage (AMD) represents the greatest risk when viewed from the aspect of pyrite content in the ore body.

- Financial and profit risks arise from several factors due to changes in the cost structure, changes in commodity prices, exchange rates, and unstable local politics. The cost of the process of handling pyrite along with the consequences of penalty payments and the obligations to meet licensing requirements will be a potential risk in terms of finance and will affect the significant benefits of mining. Besides that, the value of money over time, considering the investment period in the form of processing facility construction up to the production operation of the facility, poses its own risks to the financial aspect.



- Based on the criteria of the risk factor study mentioned above, the composition and characteristics of the rock in the Grasberg ore body are suitable for caving using the block caving mining operation concept. The entire production block has an adequate hydraulic radius ratio for self-collapse. 80% of the rock shows an RMR (Rock Mass Rating) value of 60, which serves as a reference for the analysis of collapse propagation.



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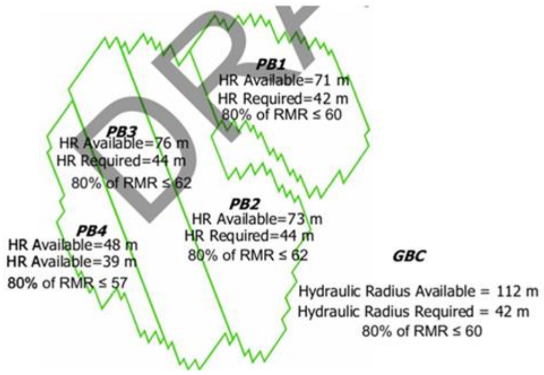


Through this research study of the Grasberg orebody, the high pyrite content zone presents around the perimeter of orebody. At assumption the angle of cave is 45 degrees from the plan final cave limit (crackline), then there is a potential for pyrite be within the boundary of cave in radius of 80m. It then serves as a reference for design the mine for limit the cave in distance of 30m from the original crackline perimeter. Furthermore, this distance then factored into designing the undercut. Nevertheless, there are other aspects be considered in presence of geological structures who will influence the cave progression. Study of geological rock structures become more important to analyst due to it influences into planning, cave progression, and sequencing the undercut.

The development of geological data and rock structures through exploration and sampling activities then find important in provides assumption for mining operations modelling, respectively to design undercutting and panel-production drawpoints. In the production level, panel space and layout is designed based on the area of caving (considering the limit of cracklines boundary), it offers the option of using the El Teniente style with a collapsible size of 300 square meters (15 x 20 m) on each drawbell. This has been reduced from the previously set dimensions of 17.5m x 20m. Reference of price commodity study is based on global market happens during the analysis at $1.20 per pound of copper, $450 per ounce of gold, and $7.50 per ounce of silver. This value then becomes a reference in determining the cut-off grade and mapping all areas who has a certain of economic values. The engineering design of the mining operation established has considered the production cost for $10.35 per ton.

The value of profit from each drawpoint is calculated for $200,000, which can generate an average profit for each metal commodities as follows: $16.01 per % of copper, $9.64 per gram per ton of gold, and $0.13 per gram per ton of silver. In order to balance the draw and keep the openings stable during life of mine, the draw of ores/pulling out muck is setup for 0.23m (9 inches) per day. Thus, based on the volume of cave, it will provide production target of 160 thousand tons per day.

Combined GRS & KL Block Cave Recovery and Concentrate Grades by Ore Type Zone

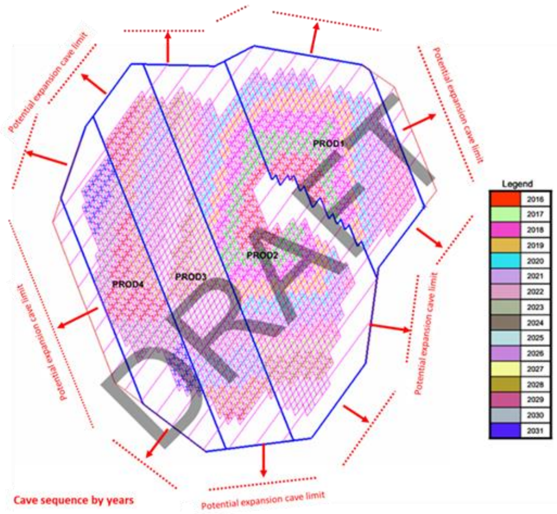
KL-Code	L2_Name	Ore_type	Tonnage	cu_rec	au_rec	ag_rec	cu_con	au_con	ag_con
	MGSK-A	1	54,145,012	93.64	66.34	70.32	33.83	34.64	75.90
	MGSK-B	2	16,087,226	85.63	63.69	56.27	22.54	16.59	41.00
	DLM-A	3	409,092,073	91.92	79.27	78.90	30.01	17.23	56.29
	DLM-B	4	97,834,864	89.28	74.69	71.26	22.51	10.80	33.00
	HSZ-A	5	33,823,149	87.95	62.03	66.76	23.75	10.11	56.00
	HSZ-B	6	45,535,692	64.49	35.18	54.48	18.91	11.10	68.49
	Type A	11	4,225,408	99.12	86.74	59.15	34.70	24.72	59.15
	Type B	12	10,846,978	91.07	90.96	59.19	28.90	14.46	38.11
	Type C	13	11,360,674	84.98	77.40	55.25	27.20	11.29	53.88
	Type D	14	342,488	65.78	34.86	43.20	10.70	11.29	53.88
ot17	NMNP	20	28,280,841	90.90	56.50	60.80	25.00	14.53	67.57
ot9	LMLP	21	217,659,668	90.90	56.50	60.80	25.00	14.53	67.57
ot10	LMHP	22	121,985,806	76.70	28.20	29.10	15.00	4.63	27.38
ot11	LPHM	23	52,680,941	93.30	60.30	61.40	25.00	15.61	60.51
ot12	HMHP	24	13,632,260	87.60	42.30	37.50	20.00	8.34	41.12
ot18	NMNP	25	15,049,589	93.50	60.80	74.10	25.00	14.95	83.25
ot13	LMLP	26	181,096,001	93.50	60.80	74.10	25.00	14.95	83.25
ot14	LMHP	27	40,474,245	89.90	39.30	41.30	15.00	5.13	35.18
ot15	HMLP	28	9,392,801	93.30	60.30	61.40	25.00	15.36	64.46
ot16	HMHP	29	9,505,194	93.70	61.10	47.10	20.00	11.04	48.73
		GRSKL-BC	1,373,050,909	89.33	62.67	65.34	25.21	14.53	58.16

C:\Documents and Settings\cbrannon\My Documents\MSOffice\Excel\GRSBC 2006 Feasibility\reserves\[grsbc_met_brf_GMD_30oct06.xls]Ore Type Codes

Scenario for pull out muck from the drawpoint at the tonnage and grades as presence on above tables then become reference for sequence opening the drawpoints.

Drawbell Opening Schedule

	Period	Drawpoints Opened Per Year				Total
		P1	P2	P3	P4	
1	Q1-2016	12	12			24
2	Q2-2016	12	12			24
3	Q3-2016	16	14			30
4	Q4-2016	18	18			36
5	Q1-2017	20	22			42
6	Q2-2017	24	24			48
7	Q3-2017	24	24			48
8	Q4-2017	24	24			48
9	2018	96	96			192
10	2019	96	96			192
11	2020	96	96			192
12	2021	96	96			192
13	2022	62	58			120
14	2023		70	50		120
15	2024		72	72		144
16	2025		40	104		144
17	2026			144		144
18	2027			144		144
19	2028			96	48	144
20	2029			44	86	130
21	2030				120	120
22	2031				78	78
23	2032					0
	TOTAL	596	774	654	332	2356



The undercutting sequence to consider risk factors based on the selected mining method of block cave mine. This set sequence of undercutting then becomes the basis in develop the mine include planning for construction of production facilities.

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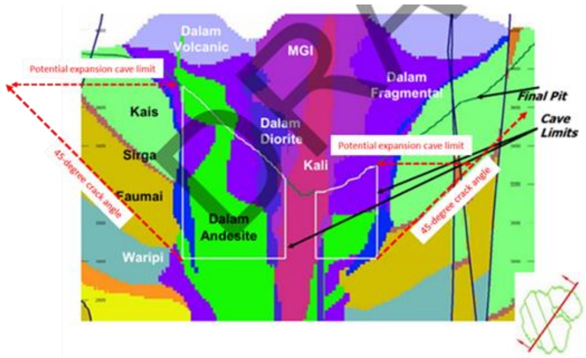
- Table 8-9. Annual Development Schedule, 160K Production Schedule.

Annual Development Ore Tons and Grade Schedule					
Year	Production (tonnes)	Cu (%)	Au (g/t)	Ag (g/t)	Production (t/d)
2014	359,978	0.37	0.21	1.21	986
2015	1,241,865	0.36	0.23	1.18	3,393
2016	897,712	0.25	0.20	1.67	2,459
2017	922,304	0.27	0.21	1.25	2,527
2018	504,359	0.40	0.35	2.26	1,382
2019	383,020	0.54	0.47	3.25	1,047
2020	719,129	0.50	0.45	4.46	1,970
2021	577,177	0.55	0.50	4.14	1,581
2022	408,125	0.53	0.48	2.33	1,118
2023	233,209	0.68	0.47	2.71	637
2024	279,176	0.61	0.33	2.97	765
2025	252,913	0.57	0.28	2.41	693
2026	327,621	0.66	0.41	3.56	898
2027	349,366	0.49	0.34	3.53	955
2028	206,219	0.71	0.48	4.05	565
2029	223,342	0.60	0.47	3.66	612
2030	103,647	0.64	0.58	3.42	284
2031	43,790	0.87	0.78	3.30	120
2032	-	-	-	-	-
2033	-	-	-	-	-
2034	-	-	-	-	-
2035	-	-	-	-	-
2036	-	-	-	-	-
2037	-	-	-	-	-
Totals	8,032,951	0.45	0.34	2.50	

As early explained, the cave boundary having its potential develop in considering of the rock condition and geological structures. Early predict will be to have a 45-degree angle as illustrated at below drawing. This could pose the risk for more deviation into the initial planning on the type of mineral that will be delivered and process in the mill-plant. It commonly call in mining operation as the happens of ore dilutions.



- Table 8-10. Final Smoothed 160K Total Production Schedule.

Annual Total Tons and Grade Schedule						
Year	Tonnes (x1000)	Production (t/d)	Cu (%)	Au (g/t)	Ag (g/t)	Py (%)
2014	360	986	0.37	0.21	1.21	2.00
2015	1,242	3,402	0.36	0.23	1.18	2.00
2016	2,057	5,621	0.70	0.56	2.01	3.12
2017	8,227	22,540	0.95	0.78	2.15	3.85
2018	16,922	46,362	1.08	1.02	2.49	5.06
2019	27,024	74,038	1.14	1.31	2.91	6.38
2020	39,188	107,072	1.18	1.55	3.27	6.87
2021	51,233	140,364	1.21	1.65	3.64	7.76
2022	58,808	161,118	1.17	1.53	3.61	7.37
2023	58,633	160,639	1.10	1.30	3.40	6.77
2024	58,839	160,763	1.02	1.05	3.13	6.84
2025	58,653	160,693	0.97	0.85	2.92	7.67
2026	58,728	160,898	0.94	0.71	2.85	8.58
2027	58,749	160,957	0.95	0.64	2.96	9.49
2028	58,766	160,563	1.05	0.65	3.21	10.40
2029	58,623	160,612	1.16	0.64	3.27	10.46
2030	58,504	160,284	1.16	0.59	3.07	9.52
2031	58,444	160,120	1.10	0.52	3.13	8.68
2032	57,254	156,431	1.04	0.50	3.51	9.32
2033	55,000	150,685	1.01	0.49	3.85	10.86
2034	50,000	136,986	1.05	0.54	4.19	15.20
2035	40,000	109,589	1.08	0.62	4.24	17.70
2036	30,000	81,967	1.03	0.61	3.63	16.49
2037	18,054		0.76	0.52	3.33	13.93
Totals	983,308		1.06	0.85	3.33	9.50

The current process on data and results of the mining operation design shows the needs of efforts who can be made to improve the caving performance by fulfilment of the geotechnical aspects. It so far does not systematically demonstrate there is an integration process in merge the design of mining itself with the plan processing at the mill-plant. This is particularly to have a good engineering collaboration attaining maximum value recovery in the processing plant by effectively designing the block cave mine. This respectively from side of handling the pyrites from the first place of mining-excavation activities and reduce the cost impact happens for the processing facility.

Learn into this case, the adjustment into flow process of block cave mine engineering design must happens ensure negative aspect of rock chemical has been accommodated into the process. The flow process modification can be described with the below chart.

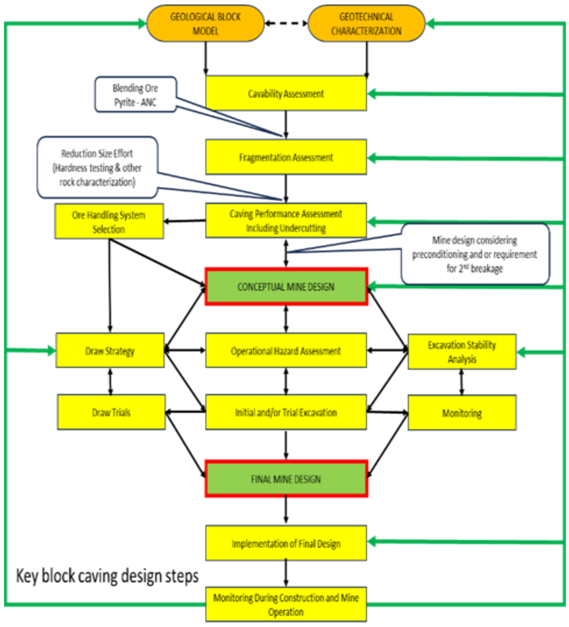
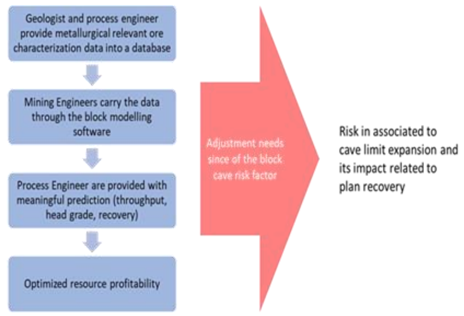


Fig.3 The process flow of the block caving mining engineering design with additional consideration for the handling of pyrite in the mine

IV. Conceptual Framework

The common practice of geometallurgy program happens in several places' presence in the following step process:



In the original geometallurgy assessment program which only to focusing on optimizing metallurgical process at the mill-

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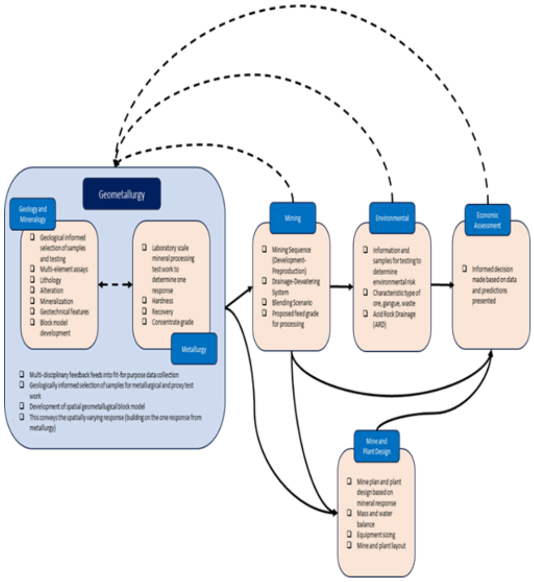
plant, will be incorporated into requirement of the meeting the risk factor for the adopted of mining method. Research study of Grasberg orebody with the selection mine method of underground block cave will apply risk factor for block cave. In addition to risk factors, preliminary assessment could be extended into look on what can be done to optimize the workload at the mill-plant facility. Following table matrix to illustrate the current process and propose change all in properly integrated.

Current process activities	**Proposed addition to the process**
Geologists and process design experts conduct studies on the metallurgical characteristics of rocks and incorporate considerations into the database.	Mine and geotechnical experts are added into studies of block cave risk factors and put their considerations into engineering-design database. This includes to studies scenario of cave developments considering rock chemical and its potential environmental impact. Hydrologists expert to consider study in area of drainage and mine dewatering needs.
Mining experts use data to model mining operations.	Mining experts consider the need of effort improve the fragmentation and ore blending scenario (pyrite-ANC) in optimize the work-load at the mill – comminution and recovery.
Expert design of the process of adding predictive references into processing planning (throughput, head grade, recovery)	Remain same
Program to optimize resources for maximum mining benefits attainment	Remain same

One of the big challenges since the decision of handling the pyrite in the mill-plant facilities is on increase future demand of energy. It happens since requirement of facilities modification in properly handling the pyrites, where are supporting program comminutions and separation under complex characterization metallurgy of ores. In order to improve energy efficiency in processing facilities, programs to better of predict rock fragmentation in mining using block caving methods has become more important. This requires collaboration and an integration study during the stage of geometallurgical assessment to determine with the appropriate modelling achieving an effective fragmentation program. Fragmentation study program to includes:

- Primary fragmentation through the study of rock hardness level, geological structures, statistics on fracture size, and the stress magnitude around the excavation location.
- Secondary fragmentation considering the factors of swelling, block hardness, active stress due to the cave and natural pressure leading into the cave or drawbell areas. This then influences the determination of the dimensions and sizes of the draw columns, drawbell volume, and draw height that measured per unit time.
- Potential high hang-up or any failure analysis based on considerations from primary and secondary fragmentation studies which having a volume greater than 40% which cannot collapse on its own (meeting the ration of cavability).



Adjustments into the engineering of mining operations to includes:

- Mining Sequence / Development & Preproduction
  The arrangement of the mining sequence referring to the study of risk factors using the adopt block caving method. This sequence to serve as a reference for planning new production tunnels development and installation of support production facilities. The determination hydraulic radius is based on geotechnical study aspects then serves as a reference for planning to complete ground support before production blasting for cave is conducted.
- Drainage and mine dewatering management system
  The considerations of assessment to includes prevent the surface water flowing into the cave, this include program back up in situations that flowing water cannot be avoided goes into the cave.
- Blending scenario
  Block mapping for economic mineral containing pyrites who consider be mixed acid neutralizing content (ANC and sulphate).
- Proposed feed grade for processing
  The baseline grade (COG-Cut off grade) to include

the calculation and/or take into account the percentage of the volume acid-neutralizing material in the cave.

- Environmental management aspects to includes:
  - Determination of risks impact from side of environmental by perform the study analysis and the needs of testing at samples to confirm the presence of rock chemical who can degrade the environmental quality.
  - Characterize the type of ores, gangue, and waste.
  - Perform a better of mapping at composition of pyrites along with the identify efforts to handling them.
- Acid mine drainage (Acid Rock Drainage-ARD)
  Handling of the runoff water containing acid that are not fully managed through the engineering design of the mine drainage system.
- Ore and processing facility engineering design
  Mine planning and plant design based on mineral characterization response. Engineering design based on plan to optimize fragmentation along with an early strategy for handling the mineral and its impurities who will negatively impact the plan recovery in the mill-plant.
- Study of volume needs and balance on water usage
  Engineering of drainage and runoff water control in the mine, which can redirection of the mine water for processing needs in the mill-plant. Collaborative studies in area of hydrology and metallurgy needs for an effective engineering design.
- Equipment sizing and dimensions
  Reconciling the block size reduction happens in the mining operation (size reduction through primary blasting activities and secondary breakages) and the comminution program for second and third size reduction in the mill-plant (tertiary crusher, SAG mill, and ball mill)
- Operation layout of mining and processing facilities
  Determination of the right direction for flow and transportation of ores in order to optimize the energy use. The adoption method is made through a comparative study between the use of conveyor belt systems or production shaft hoists.
- Economic research
  Decisions are made based on the availability of data and prediction accuracy.

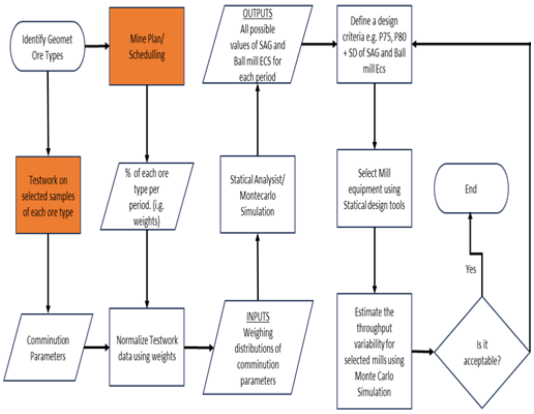


Fig.4 Engineering design of facilities use the existing geometallurgy process flowcharts is to emphasizes collaboration by link of mining operation scenarios that could potentially increase the efficiency and effectiveness of processing in the mill-plant. Planning and scheduling of mining operations provide an output on percentages of mineral on each type of ores within specific time periods of assessment in deliver tonnages. Assessment of characterization of rocks under various types of ores also conducted to better of understand the grinding parameters. More review to happens on the side of grinding aspect due to its impact into requirement of energy/electrical feeding.

Gathering data for a geometallurgy study in relation to performing the underground block cave mine can be done in parallel to the development activities. As such by collect the sample from drilling, pick sample from cave or other method of sample collection from the location. This data can further expand the parameters in programming size reduction for both area of processing facilities in the mill-plant as well as fragmentation improvement in the mine. Size reduction program and the initial handling of the rock chemical at the mine enable mill-plant to operate in effective and efficient manner. Mineral containing pyrite in the orebody will also determining the size of ores that can be properly manage at the mill plant. This is particularly concerning the abilities of processing circuit to separate the main metal commodities and the pyrites. The study of geometallurgical become an essential program in determining the particle size, density, and viscosity levels of the pyrite who can be released into the deposition area without further affect the stability of the tailing pond. Study for effectiveness process in the mill-plant to also take into consideration the way of metal slurry is transported into the facility of concentrate dryer. All these leads into the needs of join analysis to bring into recommendations by conducting series of testing, evaluation study includes the studying rheology. The main parameters of inclusion the rheology study include stiffness degree, ductility (plastic deformation limit), compressive strength (resistance to compressive load), sample damage level against load values (pressure deviation), and loading time period. All of these are important to prevent risk in associated to stability of tailing ponds and acid water permeabilities who can further risk the public land. The establish of standard framework can provide guidance for all experts who involve in the study

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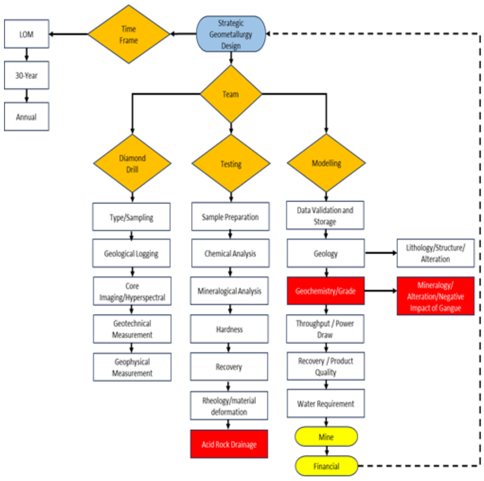
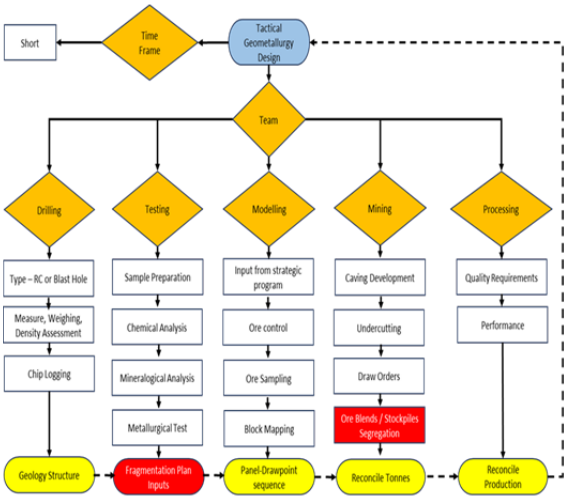
work together in determining the best strategic geometallurgy design.



The setup framework for a long-term strategic plan in area of geometallurgical assessment focus on the three main activities: detailing geological data through drilling and sampling, laboratory testing, and modeling mining operations. In perspective of environmental management and create a control on potential acid generation, modelling extended covers into the study of geochemical. While it provides benefit identifying the grade-percentage of mineral, process will also be examining the value impact due to the presence of pyrite and its impact into impurities. The engineering design of ore comminution in order to be able manage the negative effects of pyrite will determine the best process in the mill and requirement of electricity requirements. Attaining effectiveness comminution process will create the environment of more efficient the processing will be at the mill-plant. It therefore, any efforts should happen in the excavation area to reduce the workload in the mill-plant will significantly contribute into efficiency and optimization. Fragmentation planning in the mine then become an essential factor and lead into the determination of operation scenario along with all supporting facilities and infrastructure. Engineering activities synchronization through the setup of standard framework align to the long-term strategic program who define and plan all actions within the life of mine at consideration of the final cost study. That is, maximizing the value benefit while not suffering the environment by carrying out the series of geometallurgical process evaluation. In addition to the standard framework for long-term strategies, tactical steps will also find needed in responding changes who could possibly occurs during the mine development and pre-production activities. In this purpose, it is necessary to establish a short-term framework as shown in the following chart.



The short-term program standard framework provides an adjustment guidelines following any potential deviations between the initial geological exploration data and the presence actual conditions in the field. Tactical short-term through collaboration between different expertise knowledge background will provide opportunities for find the solution and do the adjustment without much further impact the long-range strategic plan. The risk factors of mining using the block caving method are much related to the management of geomechanical aspects, it requires a timely adjustment due to presence of geotechnical events which should in balance into the needs of supporting productivity targets. Pull out ores from the drawpoint shall in balance with requirement of maintaining the stability of opening where are now have an additional requirement of blending pyrite-ANC in address environmental concern. Efforts necessity for adjustment happens for five main activities which to carry out collaboratively, they are includes; sampling, conduct testing, modelling and mapping, planning of mine operations, and study performance of process in the mill-plant facilities. Managing production to include optimize the fragmentation in order to bring mill-plant more efficient in handling the pyrite. This include adding pyrite-ANC blending scenario into planning for draw order from the cave. Increase mill-plant load due to comminution of ANC materials who needs for neutralize the pyrites will also needs to evaluate, which to be carried out simultaneously in mode balance. It calls for a good coordination among the expert in different knowledge background to be able to tactically act in a timely manner to adjust into circumstances.

DISCUSSION AND SUCCESS CRITERIA FACTORS

The alignment between the engineering design of mining operations and mill or factory facilities for the Grasberg orebody production currently focuses solely on handling the ores in the processing facilities. This is seen as still having residual risks that will undoubtedly require additional of paying the consequence for future in later stage of mining. It further leading into increasing the workload for mill-plant and requires more energy/electrical supplies. Produce the good tonnage of ores while optimize the mill-plant workload is an

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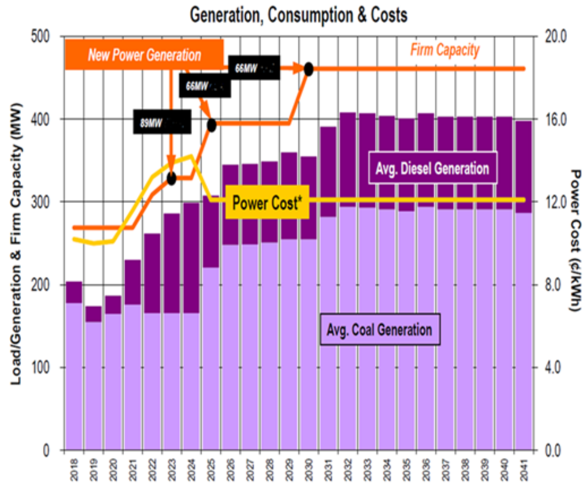
essential thing to explores, which then leading into setup a framework as a collaboration guideline achieving the context of green and smart mining. In maintaining the same productivity level of mill-plant production in the era of underground mining, characterization of Grasberg orebody requires some adjustment into exist facilities. It covers the needs of additional and modifications of comminution system and separation circuits to process the type of ores from underground mine. Additional comminution system covers SAG Mills or other ore size reduction equipment to tailoring the current operational needs, while separation circuits cover additional copper cleaner for handling the pyrites. All these additional adjustments into plant facilities certainly considering technical and economic aspects. Therefore, the addition of these facilities considers as the new capital investment and requires a comprehensive evaluation. In addition to the needs of adjustment into mill-plant facilities for size reduction program, the geochemical study of main mineral commodities along with pyrite contents recommends changes into the processing flow diagram. It requires some modifications for properly and effectively processing the ores out of mines with a much higher percentage of pyrite. The modification includes the addition of cleaning flotation facilities and processing for the pyrite concentrate itself. The pyrite (FeS2) content in era of open-pit mine generally ranges between 1% to 3% on each ton of rock delivers into the mill. The range of this grade depends on the ongoing mining production schedule and in can increase when mining is conducted in the location with the high sulfide zones. In underground mine era with exploitation at certain depths, the pyrite content will increase from 3% to 18% towards the end of the mining period. Another deposit of Kucing Liar mine which an orebody near Grasberg during production will even increase on concentration of pyrites at 10% to 26%. Increasing the pyrite content in the orebodies will subsequently affect the value of recovery, reduce copper content in the final product, and increase the presence of pyrite in the tailings. Increase of pyrite content in the tailings enhances the potential for acid mine drainage in sedimentation areas or tailings management locations. In situations where the content of pyrite in the ore is high, the content of pyrite in the tailings is not a serious issue due to the ability of the rock in the tailings to neutralize pyrite by maintaining a balance in composition between pyrite and carbonate minerals (dolomite, calcite, etc.). The type of limestone rock (ANC) mixed with mineral ore from the mine and then processed at the processing plant will directly neutralize acid. The amount of limestone needed to neutralize the acid will be equal in composition to the volume of pyrite content in the ore. In certain compositions, due to considerations of recovery value, the mixing composition becomes uneconomical. When the content of pyrite in the ore is very high, the need for limestone mixture will follow the composition of the pyrite percentage so that the production operation is economical. This is primarily due to the reduction in the grinding capacity of the ore due to the additional grinding load for the limestone. The addition of equipment in the processing plant in relation to the processing plans of ore from GBC and KL includes:

1. The Comminution or ore reduction equipment at Grasberg (new SAG) is to maintain the processing capacity of ore in anticipation of larger, harder ore and the need to handle the geochemical characteristics (rheology) of the mineral ore and its contaminants from the underground mine.
2. Modify the cleaning circuit to reduce the pyrite content in the concentrate (including modifications to the copper cleaning circuit and the addition of other necessary equipment) to anticipate high sulfide ore (high pyrite). It aiming to achieve an economical copper composition in the final product.
3. The construction of the pyrite processing circuit (flotation, thickening, and other necessary equipment) as well as the construction of additional pumping stations (pump houses) to pump the pyrite concentrate to storage locations or settling areas at designated sites, it happens along with the development of pH modification facilities in accordance with the GBC mining plan and KL.
4. Additional ball mill facilities to maintain grinding capacity, milling, and efficiency in separating minerals from their surrounding materials.
5. Optimization of pre-crusher (new SAG) to increase the processing capacity of ore from the Grasberg mine.
6. Expansion of the pyrite cleaning circuit, pyrite flotation, and expansion of the thick pyrite pumping facilities. Based on the current production plan, the expansion related to pyrite processing is needed after 2035. This plan will be regularly reviewed and evaluated to align with the production plan and existing technologies in the future.
7. Increasing the capacity of the lime processing plant, to anticipate the potential increase in lime consumption compared to current consumption, which will be used in the treatment of pyrite.
8. Increasing the concentrate handling capacity at the Dewatering Plant (DWP, Porsite).
9. Construction of pyrite concentrate storage in the designated area.



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The handling of rocks with geometallurgical complexity at processing facilities requires an additional energy supply of 66,000 kWh from the existing supply. This indicates an increase in operational cost at 2 to 3 cents per kWh or $1,320 to $1,980 per hour of operation. By effectively planning mining operations, this value can be potentially to reduced or eliminating. It can be achieved by building a mining operation scenario considering optimize the workload of mill-plant. Program to cover properly sequencing the draw order from the cave at concept of maintaining the optimum value composition of pyrite-ANC in balancing the workload in mill-plants. A constant pyrite-ANC value composition allows the processing facility effectively and efficiently planning for energy supplies.

By comparing the cost when improvement is made through optimization efforts in mining excavation area:

a. Cost of Preproduction per ton of ores
   i. Caving (drill & blast/Undercutting) $0.009
   ii. Drawbelling $0.177
b. Cost of breaking/size reduction per ton of ore $0.176
c. Total a + b $0.362

If mining operations are planned at full capacity of 160,000 tons per day and the composition of the pyrites along with its neutralizing rocks is 40%, then the cost ratio can be determined. This can build an assumption at ratio between the effort of additional electrical cost for ore processing at the mill-plant versus cost when efforts happen through the fragmentation improvements program in the underground mining area

Description of options	Cost per day of production operations	
Additional electricity costs for the factory in handling pyrite (Grinding operation costs)	$1,980 x 24 jam	$47.520
Cost of preproduction and secondary breaking (Business costs through efforts to improve fragmentation)	$0,362 x (40% x 160,000ton)	$23.104

The values in the table indicate that cost will be more less if handling is carried out in the mining area. This of course, exclude the cost calculation for capital investment since the need of new power generation which also potentially can be reduce by doing this optimization efforts in underground mine. Additionally, provision cost in associated to environmental impact (air pollution/emission control/carbon incentives) due to additional power generation when using fossil fuels become another future extra cost.

The need of collaborative efforts with the presence of standard framework attaining environmentally friendly production operations concept while targeting efficient cost is a must. An early simulation at indication of cost impact to tackling future environmental issues can be the value baseline to program necessary effort for mitigation. The simulation and comparison could be made through assessing the additional investments for pyrite processing facilities along with the needs of electricity supply versus the cost efforts to be undertaken in mining operations (as such the impact cost due to activities of blending pyrite-ANC, mine drainage-dewatering, and adjustments into development-preproduction activities). The context of the feasibility study of a project at the final outcomes of the economic benefit analysis is also influence into decision of go and no go for project execution. It happens by weighing the value of investment versus risk consequence in doing nothing, minimum and doing something. Mineral economics having its close relationship to the study risks of investment, which can subsequently affect the value of benefits by doing the mining project. The more comprehensive a study is conducted, the better of assessment process putted in place for mitigation program. When the risk consequences is properly identified, it can lead into better of handling the risk through a proper planning in both of long-range strategic plan and short-term of tactical program. The presence of a standard framework serves as a reference in completing the study from various aspects to make an accurate and effective decision.

VI. CONCLUSION

Collaboration from various disciplines of knowledge aiming achieve an optimal result requires a standard of framework. This standard framework to clearly determine the scope of responsibilities and target achievements for each party involving. Collaboration involving various disciplines of knowledge requires a clear guidance in efficiently achieving a single operational goal of mining without jeopardizing the environment. Supporting the government's campaign on good mining practices (GMP) not only looks at improving the skill levels of various scientific disciplines but also requires the establishment of standard framework and clear work guidelines to achieve the expected quality results. The application of a standard framework in managing geometallurgical aspects, especially from an environmental perspective, will provide a reference for the implementation and guidelines for conducting environmental monitoring activities in the future. Preventive efforts that can be made from the early stages of the mining operation will reduce the financial impact in the future. Prevention through the engineering design control hierarchy requires a standard framework to guide implementation with clear targets and objectives for achievement. The availability of a standard framework provides guidance for decision-making on engineering solutions for mining operations more effectively, minimizes extra handling effort or reworks for the future, and provides sufficient resources up front.

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