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"Geoscience & Technology- based Exploration to Mining: Promoting Value-added Creation and Contribution for Sustainable Development"

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Keynote Speakers

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Zachary Casley (PT Merdeka Copper Gold Tbk)

Adi Maryono (PT J Resources Asia Pacific Tbk)

Tri Winarno (Ministry of Energy and Mineral Resources)

Simon J. Meldrum (Consulting Exploration Geologist, Peru)

Jonathan M.A. Hronsky (Western Mining Services, Australia)

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FOREWORD “COMMITTEE CHAIRMAN”

In the last 2 years we were forced to stay at home, couldn’t meet and interact in person due to the global COVID-19 pandemic. But, today we can have are able to meet, interact, and greet you in person at the 14th MGEI (Indonesian Society of Economic Geologists) Annual Convention 2022. MGEI Annual convention is a continuation of high-quality events of MGEI since 2009.

As our predecessor, this year committees have a strong commitment to provide a series of great programs. I am very proud that this year's theme is Geoscience & technology-based Exploration to mining: promoting value-added creation and contribution for sustainable development. The 14th MGEI Annual Convention 2022 will feature prominent international and national speakers/experts from government institutions, industry and academia.

We believe in the power of the implementation of adequate and advanced geoscience and technology in the field and industry which has been proven significantly make the world of exploration and mining even more exciting. The discovery of world-class deposits and handovers from exploration to mining in several locations in Indonesia is an attitude of optimism embedded in looking to the future and creating added value in sustainable development. We also provide auxiliary programs pre- and post-convention, comprising a number of workshops and fieldtrips. Workshops will consist of Advance Resource Estimation, Grade Control, and Geotechnical engineering Courses. Fieldtrip programs will offer three packages of visit to Tujuh Bukit and Ijen and , Hu’u Sumbawa Timur Mining

Finally, the convention series "Geoscience & technology-based exploration to mining: promoting value-added creation and contribution for sustainable development" will be an important moment in the journey of the mineral industry as well as for academia. Therefore, please note and save the date, present a paper and participate in the convention. For the success of this annual convention, I am very honored and grateful to all of our contributors, sponsors, organizers, and participants.

Regards,

Suyud Nugroho

ISSN 2963-9751

FOREWORD "MGEI CHAIRMAN"

Dear Beloved and Valued MGEI's Colleagues:

Exploration is a high-risk business, and the measure of its success is manifested by discoveries i.e. economic mineral deposits. (Mineral) Exploration is a multi-disciplinary field incorporating geology, geochemistry, geophysics, metallurgy, hydrogeology and mining. Making a discovery is one thing but ensuring that it can be mined economically in an effective, efficient, environmentally friendly and sustainable way is another thing that cannot be separated. Observing the discovery rate in the world, particularly in Indonesia, which is experiencing a downward trend; even when the exploration spending rose, is certainly rises a concern to us and should instigate us to whether there is anything we should do better to make the discovery rate higher. While operating a mine has evolved significantly alongside with requirements to comply with some agreed international standards.

A discovery can be a company maker and/or a game changer for a country while carrying out mining activities that refers to sustainable principles is a must so that the value creation that was originally created during/after discovery will still transpire when mining takes place and is completed.

It is the duty and mandate for our profession to ensure that exploration activities end with a discovery and the discovery that has become an operating mine is carried out responsibly. Time has taught important lessons that the application of geoscience and technology is the best way to make discoveries and an operation performs better therefore our annual convention takes the theme: Geoscience & technology-based Exploration to mining: promoting value-added creation for sustainable development. The two-day 14th MGEI Annual Convention 2022 will exhibit prominent international and national speakers/experts from the industry, government institutions, academia in their fields to convey their views, ideas and opinions offline, in Banyuwangi, East Java.

Three excellent technical workshops are scheduled to be held as pre and post convention's event while two field trips to the best geological and operation sites; Tujuh Bukit & Ijen - East Java and Huu - Sumbawa will offer the rarest opportunity. Twenty student's research posters (SRPC) from universities across the country will also be displayed and competed. We cordially and enthusiastically invite your participation in such an important annual event, as part of our continuous efforts to always contribute to the development of and for a better geology economy and mining industry in Indonesia. In fact, that we have been able to go this far is also definitely due to the extraordinary support of all of you have provided. Thank you very much indeed for always being our strong supporters. The endeavour/strive is on us and we will do it together as "something that is not fought for is not worth winning!

" Thank you!

Best regards,

STJ Budi Santoso

ISSN 2963-9751

FOREWORD "IAGI CHAIRMAN"

Dear Colleagues,

Geologists and other geoscientists have many important roles in the mining industry cycle. The role is not solely related to the technical aspects of the discovery and development of ore deposits, but in a broader sense, the role is directly or indirectly related to innovations in efficient mining ore management, extraction of valuable important minerals, environmental, post-mortem mining and mining protection, use of mining land for the sustainability of Indonesian mining. The mining industry is one of the main factors in meeting the needs for the availability of industrial materials at the national and international levels. Advances in digital technology are changing mining practices rapidly, forcing geoscientists to be ready to embrace new digital technologies through machine learning, the internet of things, and more. The combination of the role of geoscience and technological agility will certainly bring added value to innovation and discovery.

The Indonesian Economic Geological Society (MGEI) as a subsidiary of IAGI (The Indonesian Association of Geologists) which focuses on economic geology, held the flagship activity of the 14th Annual MGEI Convention 2022 and raised the main theme "Geoscience & Technology-Based Exploration for Mining: Promoting Value Creation Add and Contribute to Sustainable Development." This event will host face-to-face meetings and bring together geoscientists, mining professionals, researchers, government officials, scholars including students to discuss various topics related to exploration, mineral resources, and technology. This forum allows all participants to share and discuss their thoughts, knowledge, strategies, or even policies to address challenges in the mining industry and embrace global mining progress. This is also the reason why workshops, field trips and seminars related to these topics are important to be discussed at pre, main and post-convention events, especially for exploration and mining practices in Indonesia in the future.

Finally, I congratulate MGEI and the committee for organizing this event with strong commitment and dedication to make this event a success. The MGEI Annual Convention has been one of the key events in the Indonesian economic geology community for several years. I hope MGEI can maintain and improve the quality of this event from year to year. I hope all participants enjoyed all the sessions, including networking with colleagues, friends and business partners to get new updates on the exploration and mining industry in Indonesia.

Banyuwangi, December 2022
Regards,

Muhammad Burhannudinnur

ISSN 2963-9751

PROCEEDINGS
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December 6-7, 2022, Banyuwangi, Jawa Timur, Indonesia
Volume 14, December 2022

Table of Contents

Cover i

Foreword “Committee Chairman” vii

Foreword “MGEI Chairman” viii

Foreword “IAGI Chairman” ix

Table of Contents x

Critical Minerals of Indonesia: A Proposed Criteria and Classification 1
Tri Winarno 1

Deposit string theory: understanding and explaining magmatic activity, alteration and mineralisation within mineral districts 2
Simon J Meldrum 2

An Integrated Model for the Understanding and Predictive Targeting of Convergent Margin Gold and Copper Deposits 4
Jonathan M.A. Hronsky 4

The Ultra Ground Penetration Radar (GPR) Application in Nickel Laterite Exploration 10
Donny Prasetyo Sudiman 10

Challenges in Processing Different Ore Types in Martabe Gold Mine 20
Jan jan Hertrijana 20

Understanding and Planning for Cave Mining Challenges 22
Steve Otto 22

Nickel Heap Leach in Comparison with Other Nickel HydrometallurgyTechnologies 23
Ridho Lestari 23

Incorporating The Geological Relationship into AI/Machine Learning for Exploration Project Generation 29
Felix Mulia Hasudungan Sihombing 29

Geochemical Exploration on District Scale on Eastern Part of Indonesia as Parameter to Prospectivity for Nickel 30

ISSN 2963-9751

Ade Kadarusman 30

Embracing Digital Technology through AI and The Role of Machine Learning in Exploration and Mining 32

Steve Sullivan 32

Unsupervised Machine Learning – K-means Application for The Tujuh Bukit Alteration Domaining Using Assay, Corescan, and Equotip Data 33

Mochammad Hafid Rahadi 33

Hu'u Copper Project Onto Cu-Au Deposit – Geology and Resources Update 34

Richard Hague 34

The Magnetotelluric (MT) Method for Delineating Deep Exploration Target in Doup, Kotabunan, North Sulawesi, Indonesia 37

Eko Mario Cipta Lubis 37

Liquefaction of Indonesian Low Rank Coal: Characterization and Challenges 45

D. Hendra Amijaya 45

Key Role of ESG's Principal Implementation in an Operating Mine 49

Dicky Nugraha 49

Assessment of High Purity Quartz Deposits in Main Island of Sumatra, Bangka-Belitung and Southern Riau Archipelago for Application National Solar Cells Photovoltaic Industry 50

Andri Subandrio 50

The Applications of Slope Stability Radar for Open Cut Gold Mine 63

Ignatius Ega Putra 63

Pitram Application on Grade Control Activities for Gold Mining Industry 84

Mulya Ramadhany 84

ISSN 2963-9751

THE 14th MGEI

Annual Convention 2022

ISSN 2963-9751

Critical Minerals of Indonesia: A Proposed Criteria and Classification

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Abstract

The civilization has led to a human life system that is very dependent on high technology, especially those that are sustainable and environmentally friendly. These high-tech industries need raw materials which are produced by a mining activity. From time to time the need for these raw materials is increasing in quantity and variety. So, the mining industry have the potential to become leading partners in achieving the Sustainable Development Goals.

Due to its importance for strategic industries, several countries and regions have defined critical minerals from an economic and supply availability perspective. Critical minerals are basic substances used in industrial production today that cannot be substituted by alternative materials, and play an important role in our daily lives.

Indonesia, with its wealth of mineral resources and as a developing industrial country, also needs to immediately establish critical and strategic mineral criteria. The purpose of classifying critical minerals is to provide consideration for the governance of mining commodity-based industries, starting from upstream exploration to downstream processing and manufacture industries.

Resources and reserves are important criteria in classifying critical minerals due to their availability in Indonesia. These resources also affect the life of the mine in its production activities. Another criterion is the availability of the refining industry to meet domestic supply and demand. A combination of qualitative and quantitative methods was applied to determine the classification due to limited data for most of the commodities, particularly co-products and by-products.

A total of 50 minerals were identified as strategic industrial raw materials for steel, transportation and EV, defence and aerospace, telecommunications and H-tech, and green energy industries. The assessment, which was carried out using a combination of qualitative and quantitative results resulting 45 minerals/materials categorized as critical minerals in Indonesia. This study is an initiation stage and is expected to become a baseline for further improvements. With the addition of appropriate data and classification methods, this category of critical minerals will be evaluated periodically.

Based on this study, it is necessary to carry out an evaluation starting from the upstream sector to the downstream industries. To ensure the resilience of the resource, exploration activities must be increased and the application of geological concepts is required to discover new types of deposits.

Keywords: Critical minerals, Green energy, Co-products, By-products

ISSN 2963-9751

Deposit string theory: understanding and explaining magmatic activity, alteration and mineralisation within mineral districts

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Abstract

Numerous published articles describe in detail the pertinent features of individual deposits but very few articles address the development of or architecture of mineral districts. Similarly, most mineral deposit specific articles present deposits as static models rather than products of geological processes that initiate with the development of productive magma chambers during periods of high compression that translates to rapid uplift and erosion during a mineral districts development resulting in a cluster of alteration centres that are often aligned along linear belts – hence the 'string theory' included in the talks title. This talk focusses on process driven geological models developed from field and in-depth data analysis, based observations on multiple deposit clusters along oceanic plate / continental plate subduction margins with a focus on Indonesian examples. The talk emphasises the early formed deeper seated mafic porphyries coupled with high level detached clay dominant lithocaps grading to intermediate level Cu-Mo porphyries through to higher level Au-Cu mineralised stocks that are typically associated with phreatic breccias and epithermal gold deposits coupled with silica -potassium dominant lithocaps.

Keywords: Cu-Mo porphyries, phreatic breccias, epithermal gold

Summary

The presentation begins with a definition of a mineral district, lists the deposit types within mineral districts and relates deposit types to magma fractionation, geochemical spectrums within porphyry and epithermal environments and presents deposit cluster examples for porphyry and epithermal mineral districts including the Batu Hijau, Tujuh Bukit, Gosowong, Toka Tindung as Indonesian examples and others including Yandera (PNG) and Kele River (Solomon Islands) which highlight specific aspects of deposit clusters in different settings. The emphasis being on the string like distribution of deposits within district scale clusters.

The talk then progresses to explain the temporal development of mineral districts as a sequential series of products from a single large deep seated fractionated magma chamber formed at successively higher elevations over time which when combined with rapid uplift and rapid erosion results in an overprinting of multiple deposit styles and mineralised complexes that rarely fit the published porphyry models. The emphasis in this section is on temporal aspect of deposit formation and introduces the concept of the 60-80% interval in a district

ISSN 2963-9751

development when the most significant Cu-Au mineralisation (i.e., economic deposits) typically form.

The talk ends with examples of conceptual porphyry dominant and porphyry / epithermal district models and an impression of multiple mineral districts including Toka Tindung, Yanacocha, Tujuh Bukit, Hu’u, Batu Hijau and Yandera as ‘strings of deposits’ within individual districts coupled with the 60-80% concept

ISSN 2963-9751

An Integrated Model for the Understanding and Predictive Targeting of Convergent Margin Gold and Copper Deposits

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Abstract

The majority of the world's resources of gold and copper are hosted by convergent-margin settings, mostly because these are the primary tectonic environments where fluids are cycled from the mantle into the near-surface. Although it may seem that there is a bewildering array of different ore deposit types that form in this setting, the basic hypothesis of this paper is that, to a first order, we can explain *all* convergent-margin related Cu and Au deposits by the interplay of only two fundamental processes, operating in a range of geodynamic contexts. In this framework, ore formation is seen as the *predictable* consequence of certain particular, although relatively rare segments of the 4-dimensional evolution of host terranes, not simply the result of the random coincidence of multiple positive factors. This perspective is informed by multiple regional-scale metallogenic studies completed by the authors over several decades.

Keywords: Cu-Au metallogeny, Convergen margin settings, Loucks process, FUME process

Summary

The two underlying fundamental processes to understand the formation of Cu-Au deposits related to convergent margin settings are 1) the Loucks Process and 2) the FUME (Fertile Upper Mantle Extraction) Process.

The Loucks process is named after its discoverer, and was first documented by Robert Loucks in unpublished industry research about 20 years ago. Subsequent relevant public domain publications include Loucks (2014) and Loucks (2021). This process involves high-pressure Replenishment – Fractional Crystallisation (RFC) of initially unremarkable arc picrite magmas in deep lower crustal magma chambers to produce extremely hydrous magmas. These magmas exsolve volatiles at depth, resulting in very efficient partitioning of Cu, S, and Cl into these fluids and the consequent emplacement of pulses of hydrous magma and fluid into the upper crust to form porphyry-suite ore deposits. This is an anomalous process in arc magmatism that requires unusual regional-scale sustained compressional geodynamics.

The FUME process refers to the selective extraction of a Au and volatile-rich magma from a metasomatised upper mantle source region (typically in the form of an alkalic magma), with subsequent release of gold-rich ore-forming fluids into the upper crust (Hronsky et al,

ISSN 2963-9751

2012). This process requires low-degree partial melting, with the most effective mechanism for this being minor extension. These low-degree partial melts concentrate Au and volatiles. This process also requires anomalous geodynamics.

There are a number of lines of evidence for the FUME process, including a ubiquitous association between alkalic magmatism and gold mineralisation across a very wide range of geological settings, and evidence that (alkalic) magmas derived from the metasomatised upper mantle source are in fact enriched in Au (Choi et al. 2020; Wang et al., 2020; McInnes et al., 1999; Tassara et al., 2017, 2022) Multiple studies indicate gold mineralisation occurs in anomalous geodynamic contexts which favour strike-slip faulting and/or incipient extension, both effective mechanisms for mobilising the upper mantle source into alkalic magmatism. A link between magmatic-hydrothermal fluids and gold mineralisation is demonstrated in a wide variety of gold-rich deposits, including porphyry copper-gold, epithermal gold, iron oxide copper-gold, and sediment-hosted disseminated gold (Carlin-type; eg Holley et al., 2022). In addition, there is indirect evidence for a magmatic link with orogenic gold deposits, whereas alternative crustal metamorphic models are not viable (eg Groves et al, 2020).

Magmas associated with the FUME process typically have an alkalic chemical association, meaning that they are systematically enriched in the alkali elements, K and Na. This association simply reflects the incompatible nature of these elements – for this reason they are concentrated in low-degree partial melts, along with ore-forming components such as Au. Significantly, because the CO_2 solubility of mafic melts depends strongly on the presence of the cations Ca, K and Na, alkalic magmas have much higher CO_2 contents than background tholeiitic mafic magmas (Lowenstern, 2001). This is likely to influence ore-forming processes in many significant ways, inducing deeper level magma-fluid devolatilization, and suppressing the partitioning of chlorine and base metals into the exsolving magmatic-hydrothermal fluid (Hsu et al., 2019). This suggests that the primary difference between Orogenic gold systems and other convergent-margin deposits may relate to the initial CO_2 content of the related magma.

The Loucks process will act primarily to produce Cu mineralisation whereas the FUME process will primarily act to produce Au mineralisation. Although two separate processes, they commonly coincide because the *same geodynamic conditions* may favour both processes at the same location and time. In practice, there is a spectrum between Cu-only (Loucks process dominant) and Au-only (FUME process dominant) end members. Consistent with the predictions of this hypothesis, we see that Au-rich endmembers are typically associated with less fractionated, more alkalic magmas that show geochemical evidence in parameters such as (Ba/Zr)/(Sr/Y) ratio for a greater contribution from an enriched mantle source region. Gold-rich systems are also associated with much shorter time spans of ore-formation, consistent with a more direct extraction from the mantle source region (Chiaradia, 2020). In contrast, Cu-rich endmembers are characterised by more fractionated magmas, calc-alkaline compositions, and much longer periods of ore-formation; all observations consistent with the progressive, protracted fractionation predicted for the Loucks process.

ISSN 2963-9751

If we accept the above model, it has important implications for how we think about regional-scale metallogenic fertility. Importantly, we need to consider both *Static* and *Dynamic* aspects of fertility.

Static Fertility is the requirement for a metasomatised upper-mantle source region, which is an inherited property, not dependant on syn-mineralisation geodynamics. It is only relevant to the FUME process and Au metallogeny.

Dynamic Fertility is the requirement for a favourable, anomalous geodynamic context that allows the FUME and/or the Loucks process to operate. This is transient in both time and space, driven by heterogeneities in regional-scale geodynamics. It is relevant to both Cu and Au metallogeny.

With respect to Static Fertility, it appears that the fertile (metasomatized) upper mantle source is generally large, and widely available, relative to the scale of gold provinces. However, there is still some important variability. For example, the observed antithetic relationship between gold and diamond mineralisation in the Archean Slave Province implies that a certain level of refertilisation of original harzburgite lithospheric mantle is required. The most important variable aspect of Static Fertility is that areas of significant rifting and juvenile melt input *immediately prior* to tectonic inversion and the associated gold event(s), tend to be most fertile, producing the greatest number of, and largest size deposits (eg Norseman-Wiluna Belt, Southern Volcanic Zone of the Abitibi Belt); this probably reflects the anomalous thermal state of the lithosphere at the time of gold, favouring the FUME process.

In the case of the Loucks Process, Dynamic Fertility relates to a requirement for anomalous compressional geodynamics to be superimposed on arc magmatism. This may be caused by either a proximal collision or as a response to larger-scale geodynamic forces.

In the case of the FUME Process, Dynamic Fertility relates to geodynamic conditions that produce a coincidence of three fundamental dynamic conditions:

1. Existence of a *continuous*, focused pathway (ie a Trans Lithospheric Fault - TLF) from the upper mantle source region to the upper crust. This condition will not be met when there is extensive lower crustal melting.
2. Localised, incipient extension only, so that the selective extraction of a Au-rich melt-fraction from the upper-mantle source region occurs *without* significant dilution. This is particularly favoured by strike-slip tectonics.
3. Minimal dilution of the ascending Au-rich melt by bulk crust or slab-derived magmatism (this condition relates to condition 1 above).

Perhaps somewhat counter-intuitively, one of the most favourable settings for localised incipient extension are environments of broad-scale regional compressional tectonics. This is considered to be the explanation for the observed strong correlation between secular peaks in Orogenic Au ore-formation and final supercontinent assembly, as the peak of shortening drives wide-spread Strike Slip tectonics, as well as localized tensile reactivation of Trans-Lithospheric Faults that are subparallel to the regional shortening direction. It also explains why, despite a much longer history of Porphyry Copper metallogeny, the Neogene, which is a major regional-scale period of anomalous compression, is the most gold productive time in the Andes.

ISSN 2963-9751

To practically apply these concepts of Dynamic Fertility to Exploration Targeting, we need to introduce some new terminology. We define **"Fertile Geodynamic Scenarios"** (FGS) as particular, geodynamic situations where either the Loucks and/or FUME process can operate. These are transient, *anomalous* states, relative to the background geodynamic evolution of Convergent Margin Orogens; when they occur, mineralisation *will* form! These FGS may occur at nested scales, for example a local FGS associated with ridge subduction may occur within a much broader favourable context (eg margin characterised by shallow subduction). They may relate both to external geodynamic forcing (eg periods of accelerated convergence, or of microcontinental collision) and local anomalous lithospheric architecture (eg major bend in the upper plate margin, with localised anomalous shortening).

We define **"Fertile Geodynamic Anomalies"** (FGA) as the *spatial extent* over which a particular FGS has been operating. The interpretation of these FGAs is considered to be the ultimate output of regional-scale metallogenic analysis and exploration targeting in convergent margin orogens.

As a final comment, an important observed pattern in convergent margin metallogeny is that we see no strong spatial relationship between the locations of copper-rich districts that form at various times during margin evolution but do see such a relationship for gold-rich districts. This can be summarised in the statement that *"Gold fertility has a memory but copper fertility does not"*. This observation is consistent with the predictions of the hypothesis presented here because copper metallogeny is purely a function of transient geodynamics whereas inheritance (such as preservation of a regional zone of metasomatized Au-bearing mantle, or at the district-scale, the reactivation of long-lived trans-lithospheric faults) is a very important control on gold metallogeny. A practical implication of this is that the presence of gold deposits of a different age to those being targeted still has predictive significance.

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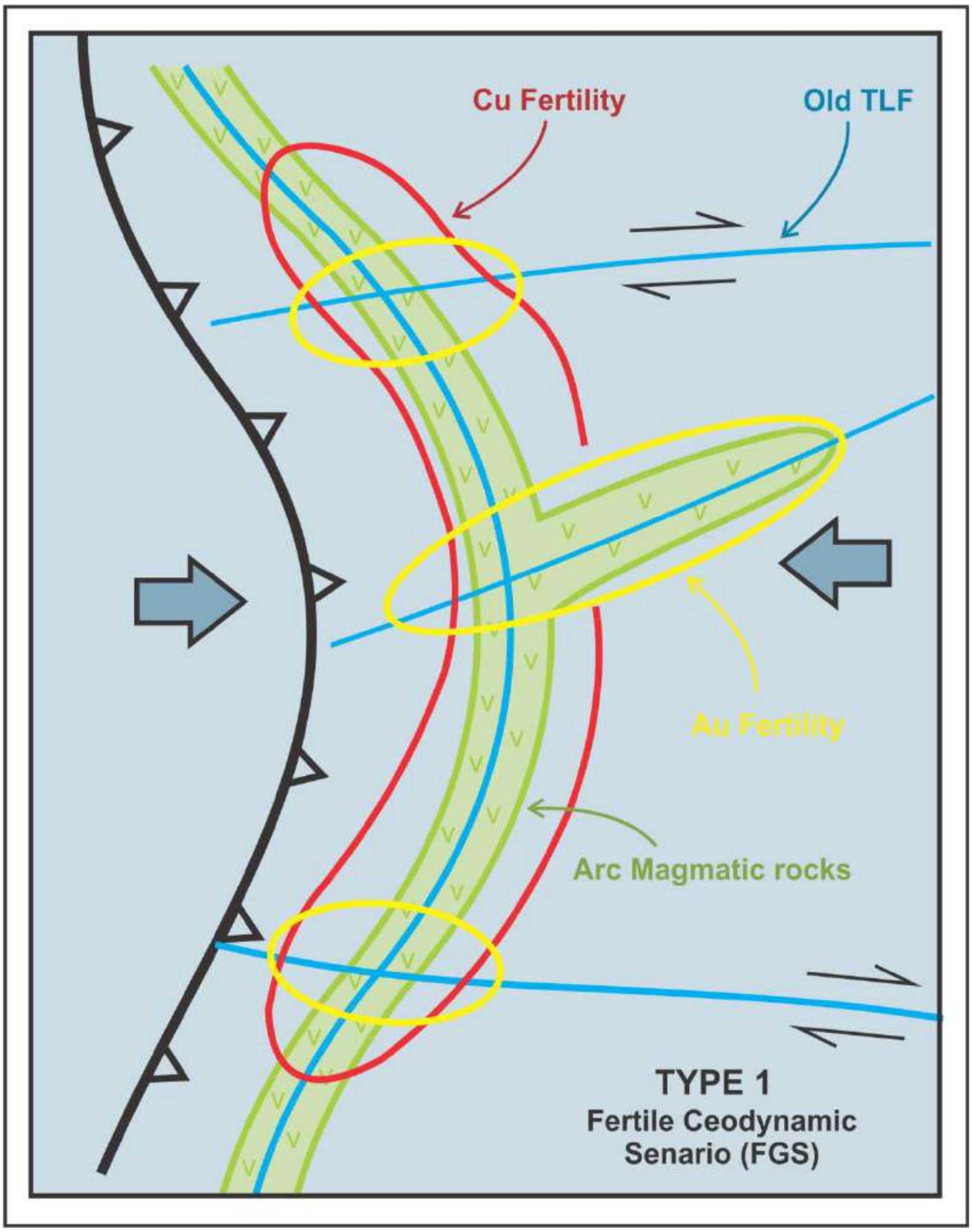

Figure 1: A schematic diagram summarising the key conceptual elements governing Cu and Au fertility in an convergent margin setting during a period of anomalous compression (referred to here as a Type 1 Fertile Geodynamic Scenario). TLF = Trans-Lithospheric Fault.

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The Ultra Ground Penetration Radar (GPR) Application in Nickel Laterite Exploration

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Abstract

The need for accurate resource delineation and careful mine planning becomes paramount as interest in nickel laterite exploration significantly grows due to increased demand and new processing technologies. A myriad of potential approaches has been implemented in the recent years but each still has their own limitations until an unconventional technology comes forward. Ground Penetrating Radar (GPR) system has developed into a specialized tool for laterite applications that address these needs in nickel exploration with various geology characteristics.

This advanced technique helps to identify the contrast between the limonite, saprolite and bedrock layers in laterite. Variation in the thickness of the laterite nickel layer allows drilling to be focused on the economic thickness of the nickel layer, making drilling more efficient, economical and systematic.

In particular, GPR applications in nickel exploration use electromagnetic waves with frequencies of 25-30 MHz, penetration depths up to 40 m, and horizontal data intervals every 20 cm. Therefore, one of the main strengths of GPR is that it is a cost-effective and fast method.

In addition, GPR is an environmentally friendly and non-destructive method that not only serves as a guide for determining pre-drilling prospects, but also improves the accuracy of reserve calculations in modeling, while allowing geologists determine the final limit when drilling.

PT Sulawesi Cahaya Mineral (SCM) has been using the GPR method since 2013 as part of its exploration activities. Initially, GPR was used for regional exploration activities. It was then also applied to modeling activities to improve the model accuracy as the data became more and more dense.

Keywords: GPR, exploration, nickel laterite, environmentally friendly, low-cost, fast method, model accuracy

Introduction

Nickel plays an important role in various industries due to its excellent properties of versatility, strength and corrosion resistance. More importantly, nickel is the main component in the batteries that power electric vehicles. The shift from fossil fuel vehicles to electric vehicles is increasing the demand for nickel in the global market. This situation makes exploration highly important in extracting nickel resources and reserves to meet global market demand.

Geological mapping as the first exploration activity in the nickel laterite prospective area is relatively straightforward, as the weathering profile of the ultramafic rock mass has been identified. The thickness of high-nickel layer determines the economic viability of potential

ISSN 2963-9751

areas for nickel exploration. To measured it, a drilling program with tight intervals shall be conducted throughout the exploration area so that variations in nickel layer thickness could be identified.

In many locations, especially those with complex weathering profiles of the tropics, conventional method of using borehole grids to calculate ore reserves may not be sufficiently accurate or cost effective. GPR, on the other hand, has demonstrated loads of successful applications with data that indicated excellent correlation with the weathering profiles as confirmed by boreholes and test pits.

In terms of reliability, it has significantly expanded the project's geological knowledge base and support better mine planning by mapping weathering texture of the rock mass, including exact location of subsurface crest structures and fault levels. This information, together with the strategically-placed boreholes, allows laterite projects to be systematically upgraded to the measured mineral resource category (Francke & Nobes, 2000).

Data and Methods

Nickel Laterite

Laterites are found almost exclusively in tropical regions characterized by high seasonal rainfall and intense solar heat. Their most distinguishable weathering features include high level of iron (Fe), magnesium oxide (MgO), and silicon dioxide (SiO2). Laterite profiles have five common layers: ferricrete, limonite, soft saprolite, rocky saprolite, bedrock (Figure 1).

Ferricrete is an iron-rich and highly resistant layer that is hard, dense, and has a low water content. Meanwhile, limonite layer is a fully-weathered layer, identifiable by the lack of bedrock texture. It is moderately elastic, soft and porous, characterized by uniform soil-like properties and moderate water content.

The third layer, which is the saprolite layer, is characterized by its moderately conductive quality with low porosity, high water content, solid and clay-like structure, and residual structure. Rocky saprolite is the transition zone between bedrock and saprolite. It is ten meters thick and is composed of ultramafic rock and saprolite. This layer consists of a conductive weather resistant skin and a resilient boulder with a low total moisture content. Soft saprolite and rocky saprolite units typically indicate the zone with the highest nickel concentration in the laterite profile (Table 1).

As the last layer, bedrock is a rock rich in olivine. Bedrock topography is usually highly irregular and understanding the frequency and amplitude of these peaks and valleys is imperative for resource estimation and mining planning (Francke & Nobes, 2000).

ISSN 2963-9751

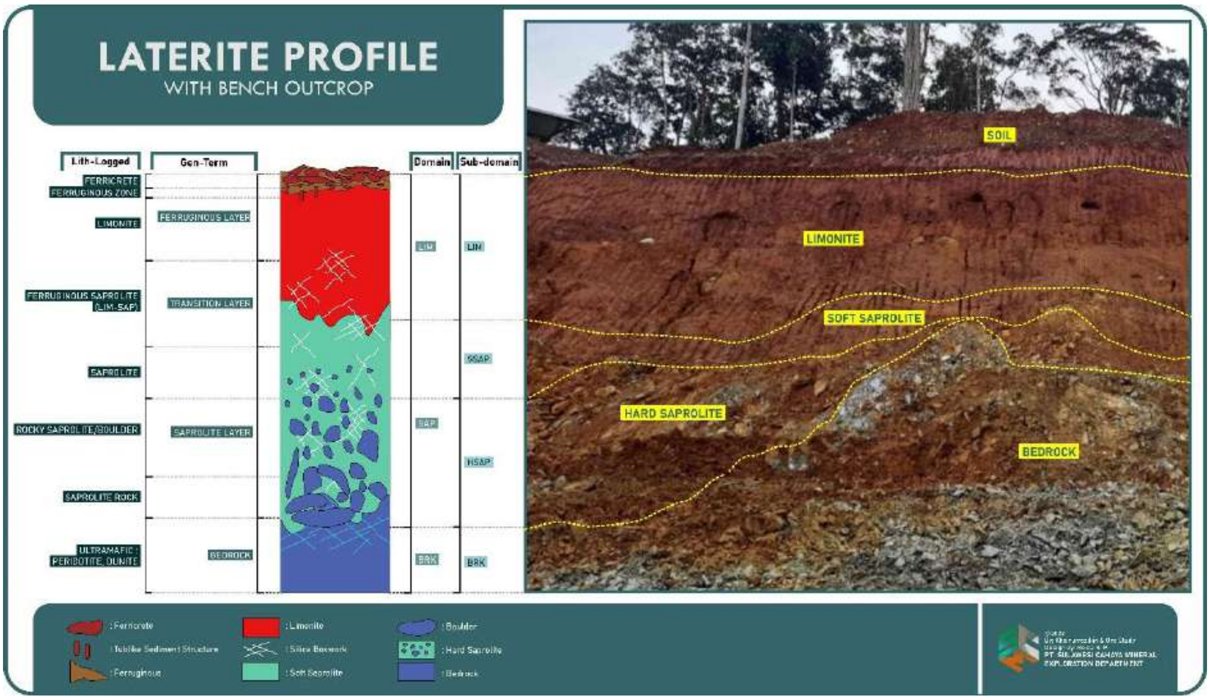


Figure 1. Laterite profile of the study area

Table 1. Characteristic and Chemical Properties of Laterite Layers in Study Area

Characteristic	Ni	Cr2O3	Fe	MgO	Water Content	Layer Hardness	Layer Texture	Dominant Mineral Composition
LIM	1-1.5%	2-3%	34-51 %	1-1.7 %	38%	Soft	Unconsolidated, Clay grain size	Hematite, Goethite, Manganese Oxide
SSP	1.3-2.1%	1.2-1.8%	15-23%	12-18%	47%	Soft	Unconsolidated, Clay grain size	Garnierite, Silica, Talc, Manganese Oxide
HSP	0.9-1.3%	0.6-0.9%	8-12%	23-34%	24%	Soft-Mediur	Unconsolidated, Clay - granule grain size	Garnierite, Silica, Talc, Serpentine
BRK	<0.4%	<0.5%	<7%	30-45%	4%	Hard	Massive	Olivine, Pyroxene, Serpentine

Ground Penetrating Radar Method

GPR works by sending a tiny pulse of energy into a material and recording the strength and the time required for the return of any reflected signal. The property measured in GPR is dielectric permittivity, a property that influence a material's ability to transmit an electrical current. Signal velocity is inversely proportional to relative dielectric permittivity (RDP). By far the greatest factor affecting RDP is moisture (Conyers, 2004), which positively correlated with RDP. Energy reflection can also be affected by magnetic permeability, but only in rare cases

ISSN 2963-9751

such as when iron or iron oxides are present in very high concentrations (van Dam & Schlager, 2000).

A series of pulses over a single area make up what is called a scan. Reflections are produced whenever the energy pulse enters into a material with different electrical conduction properties or dielectric permittivity from the material it left. The strength, or amplitude, of the reflection is determined by the contrast in the dielectric constants and conductivities of the two materials.

While some of the GPR energy pulse is reflected back to the antenna, energy also keeps traveling through the material until it either dissipates (attenuates) or the GPR control unit has closed its time window. The rate of signal attenuation varies widely and is dependent on the properties of the material through which the pulse is passing (Figure 2).

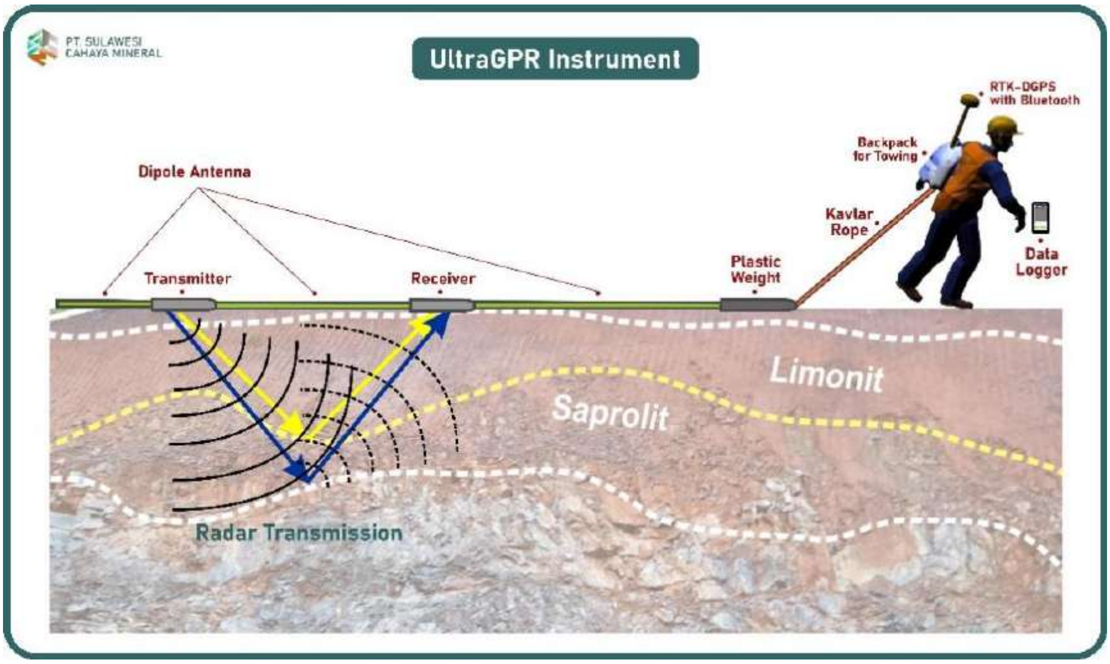


Figure 2. GPR working principle – EM waves emitted by transmitter will be recorded by the receiver after being reflected by the layers below the ground surface.

The process of sampling a GPR signal is fundamentally intricate as it requires sampling a return signal that travels at nearly the speed of light. For example, for a system with a center frequency of 40MHz, the effective bandwidth is 20MHz to 60MHz. Nyquist sampling theory requires that the returned signal be sampled at three times the center frequency (120MHz in this case).

In order to overcome these shortcomings, all commercial low-frequency GPR systems are then designed using sequential sampling techniques to significantly reduce the required sampling frequency. This method records one sample point per radar transmission. The first sample is recorded above the first trace. The transmitter is then re-fired and the second pattern below the first is recorded. Therefore, a single scan of 256 points would require the transmitter

ISSN 2963-9751

to be fired 256 times. However, this process must be repeated 32 or 64 times to achieve a reasonable signal-to-noise ratio. Recording this transmission and the 32,000 radar bursts that followed would require the antenna to be stationary during each full scan that takes 0.5 seconds. As such, surveys can be especially expensive and slow to progress when hundreds of kilometers of data need to be collected at 50 cm scan intervals.

On the contrary, real-time sampling technology in UltraGPR system enables data to be captured in a single scan, effectively capturing 64,000 stacks while the antenna is constantly in motion. UltraGPR can also stack nearly 1,000 times more than other systems, making it much more sensitive to subtle responses from distant reflectors. In most environments where comparative studies were conducted, UltraGPR can achieve much deeper penetration compared to other available systems (Groundradar, 2022).

GPR data shows the contrast among laterite layers, with each layer featuring a certain RDP value. The contrast value of the layers is represented by the reflection coefficient, which is calculated by the RDP value of each layer (Figure 3). The greater the reflection coefficient value, the clearer the contrast among layers would be. In comparison, homogeneous layer generally has no contrast in it.

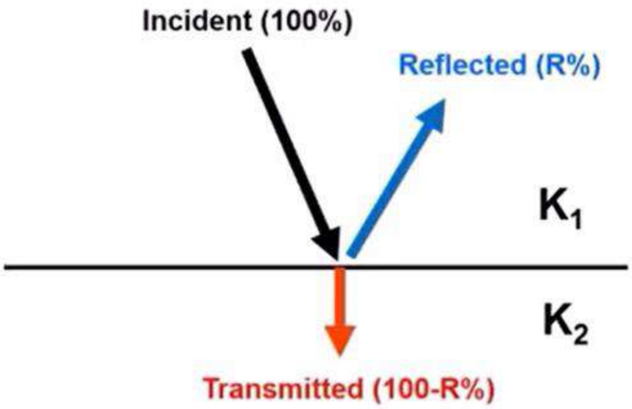


Figure 3. Reflection coefficient between two layers

$$\boldsymbol{R = \frac{\sqrt{K_1} - \sqrt{K_2}}{\sqrt{K_1} + \sqrt{K_2}}}$$

Where:
K_1 = dielectric permittivity of layer 1
K_2 = dielectric permittivity of layer 2

Limonite is a layer with fully homogeneous weathering so that no high contrast is created in it. Limonite and soft saprolite have highly similar physical properties and so do their grain size due to the fully weathering process. Soft saprolite is a transition zone between the limonite layer and the rocky saprolite layer. It has low contrast with limonite layer because its RDP value does not differ that much from limonite. The rocky saprolite layer consist of objects varying in size from large boulders to gravels contained within a matrix of soft saprolite. The

ISSN 2963-9751

boulders and gravels have a contrasting RDP value as compared to limonite and soft saprolite. Meanwhile, like limonite, the bedrock is generally a homogeneous layer. Based on the explanation above, limonite and bedrock are homogeneous layers and tend to display no contrast whereas the layer that commonly exhibits high contrast is the rocky saprolite because boulders and gravels materials have a big difference in RDP value with limonite.

Ground Penetrating Radar Application in Nickel Exploration

Thanks to its capability to map the variability in thickness of the primary facies of the laterization, GPR has three main applications that have made it a breakthrough technology in nickel exploration:

Mapping Laterite Thickness Distribution

Geological mapping and slope analysis to delineate the lithology as the first step of exploration process is only capable of doing the surface mapping without knowing the laterite thickness. GPR surveys, on the other hand, is able to map laterite thickness distribution (Fig. 4) and help focus exploration on the target areas. With this data, exploration could run more efficiently, economically and systematically.

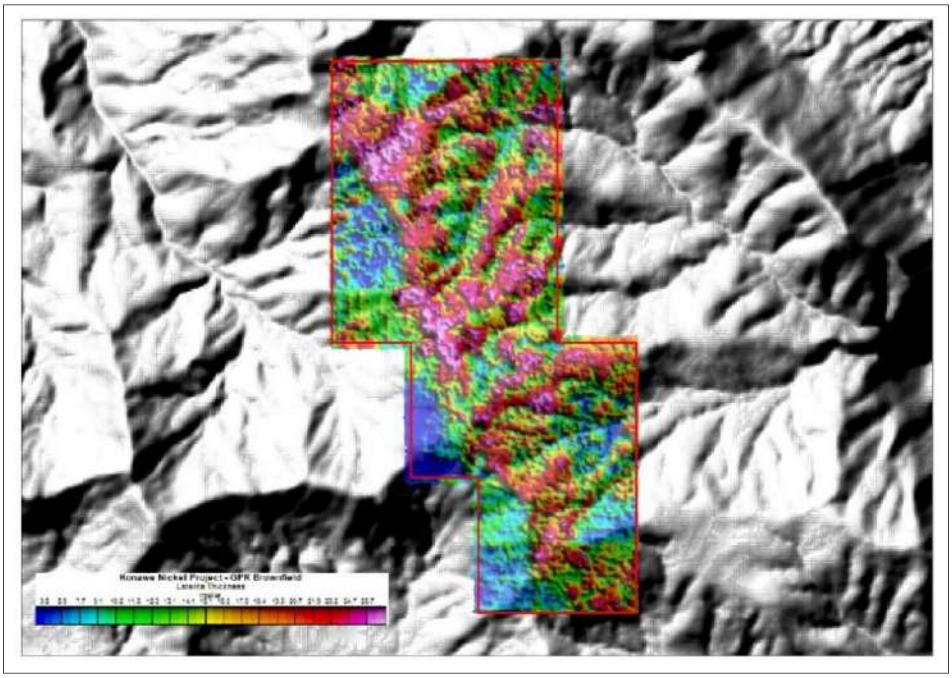


Figure 4. Distribution of laterite - the thin layer colored as blue and the thick layer colored as red.

As A Guideline for Drilling

The GPR section provides geologist with pictures of the subsurface and serves as a guideline for drilling activities. This information will come handy to geologists during drilling

ISSN 2963-9751

operations. In particular, it will help avoid the over-drills or hanging drills that hinder future modeling processes (Fig. 5).

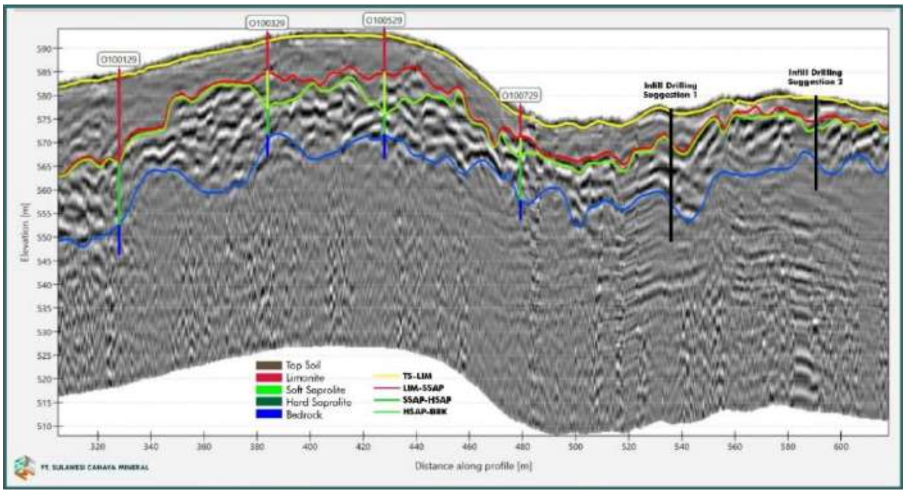


Figure 5. GPR section could provide guidelines for geologists to determine the limit of drilling in the next location (black bar).

Increase The Accuracy of Resource Modeling Calculations

The undulating form of each laterite layer can cause a dilution in block model calculations. GPR data are more accurate in the lateral direction, and thus could help delineate them accurately. The result of this data is a wireframe that can be used with modeling resources to more accurately represent the bedding edges of each laterite layer (Fig. 6).

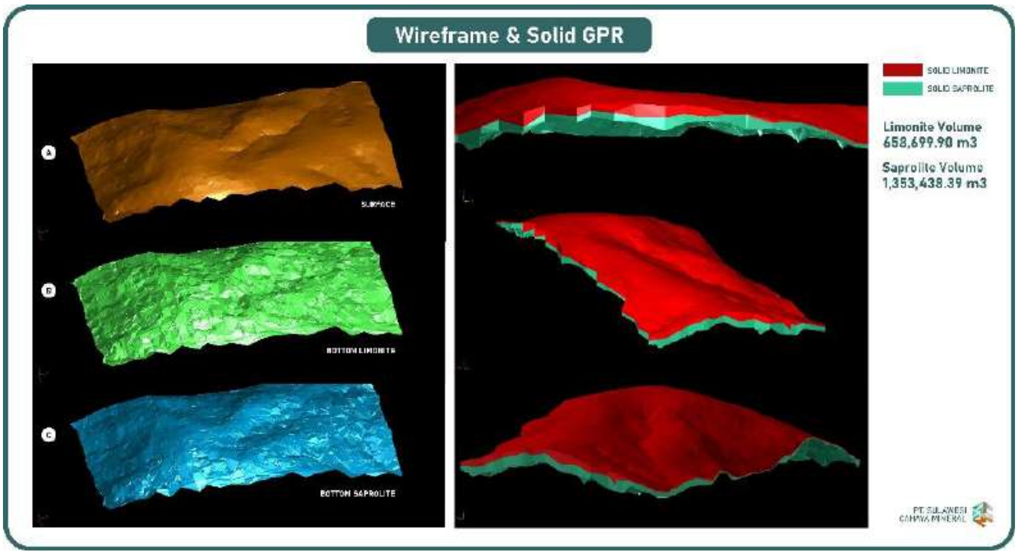


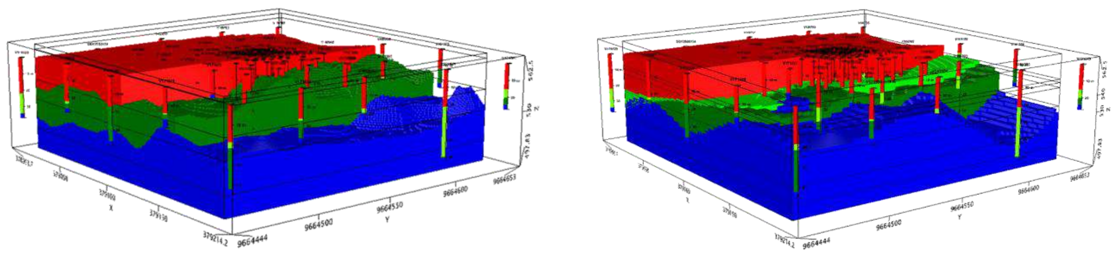
Figure 6. The GPR wireframe can be made into a solid model, which can measure a preliminary volume of the resource.

Result and Discussion

ISSN 2963-9751

A study on the GPR accuracy is conducted in a geo-statistical drilling area, in which a 3D model of GPR without drilling data is compared with a 3D model of drilling data (Figure 7). The purpose of this study is to identify the volume differences between the GPR model and the drilling model. Among the few spacing of drilling data used as comparison parameters are 200x200 m, 100x100 m, 50x50 m, 25x25 m. The smallest volume difference with the limonite layer is at a 50 m spacing, while in the saprolite layer the smallest volume difference is at a 100 m, but not much at 50 m. From this case, the optimum spacing for the data to have a good correlation is in 100 m.

3D Model of GPR Data **3D Model of Drilling Data**



Volume Difference	Area 1 (4 Ha) (200x200 m)	Area 2 (1 Ha) (100x100 m)	Area 3 (0.25 Ha) (50x50 m)	Area 4 (0.0625 Ha) (25x25 m)
Δlimonite (%)	-9.44	-5.47	1.27	2.22
Δsaprolite (%)	23.35	13.31	16.46	27.63

Figure 7. Volume comparation of 3D Model between GPR and drilling

Nevertheless, it must be noted that the aforementioned GPR data is interpreted without any drilling data. The other study to improve the GPR application in resource estimation is to do some adjustment in the GPR data, in which the GPR is correlated with drilling data, so as to improve the accuracy of the laterite layer edge. With the study conducted in 25 m grid spacing, the difference in volume becomes smaller which is 0.5 % in limonite and 5.7 % in saprolite. The GPR volume is smaller than drilling volume. The GPR layer will give a more realistic data with undulating form of each layer in laterites (Figure 8), therefore decreasing the dilution at modelling stage and enhancing the accuracy of resource calculation.

ISSN 2963-9751

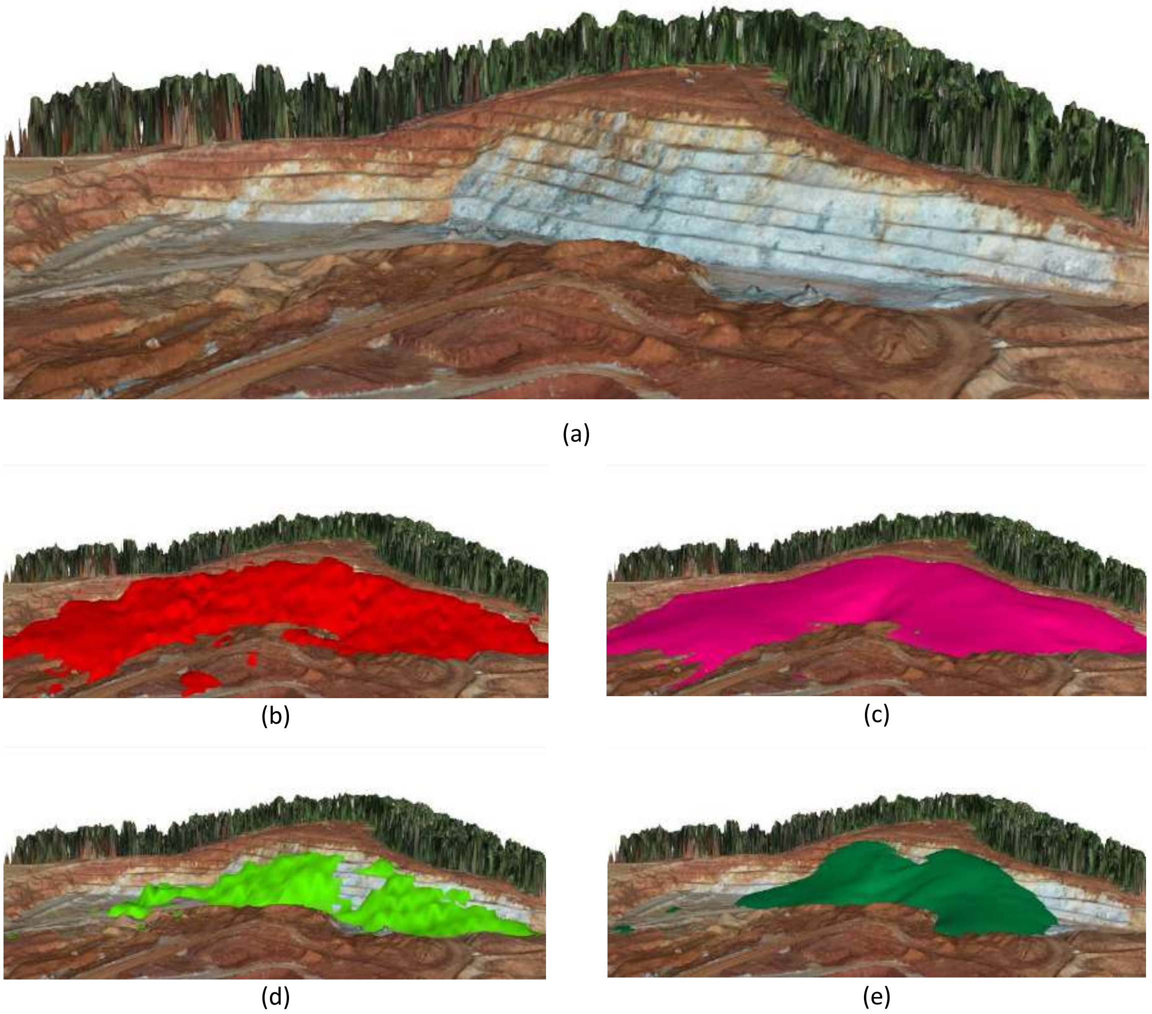


Figure 8. (a) The picture of study area (b) Limonite layer of GPR data (c) Limonite layer of drilling data (d) Saprolite layer of GPR data (e) Saprolite layer of drilling data. The GPR layer can give a more realistic lateral distribution about undulating form of each layer compared to drilling data.

Conclusions

GPR has multiple uses at all stages of nickel exploration; from regional exploration until infill drilling, to upgrade resource status from inferred to measured. In addition, GPR surveys also provide an excellent laterite distribution mapping. As such, geologists will have a system when drilling and a guideline to know the limits of drilling. On different note, with resource modeling, GPR can provide realistic wireframes for each laterite layer. All of these uses of GPR ultimately lead to cost and time savings in exploration programs.

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Challenges in Processing Different Ore Types in Martabe Gold Mine

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Abstract

The Martabe gold district is located at the North West coast of Sumatra, or 30 km to the east of Sibolga, North Sumatra - Indonesia. In 1997, Martabe Prospects discoveries by detailed geological work and sampling, that subsequently resulted in identifying a mineralized zone over 8 km x 3 km wide, which is divided into 6 main mineralisation areas: Purnama, Ramba Joring, Tor Uluala, Uluala Hulu, Barani and Horas. In general, there is two main ore type in Martabe; Oxide to Transition and Suphide Ore type, that also having slightly different on alteration and mineralisation characteristics between pits or prospect areas.

In 2012, Martabe start in to production phase with initiated by Purnama pit, and then followed by Barani in july 2016 and then Ramba Joring in the end of 2017. Till now, all of pits are still on mining progress, and then will follow by other pits that was taken into Ore Reserve. Totally 321 Koz gold and 1,399 Koz silver have produced in 2021, with remaing Ore Reserve upto June 2022 is 3.9 Mozs Au and 36 Mozs Ag.

The mine traditionally recovered gold and silver using conventional carbon-in-leach. The plant was commenced in 2012 with plant capacity increasing over the time with more than 6.2 million tonnes per annum by year 2022. The process plant is continuously upgrade to improve the plant performance by installing some additional equipments that was driven by the upcoming ore characteristics.

In general, Martabe key process of processing plant is: ore from pits delivered to primary crusher then stockpiling, continue with grinding and milling process to liberate the precious metal prior extraction process on the CIL circuit, carbon adsorption and elution process to reform back to metal in solution, and final stage is electrowinning and smelting process to produce dore bullion as final product. While tailings produced from the processing plant placed in current operated Tailings Storage Facility (TSF) in a slurry or conventional tailings with a dam embankment structure built with the mine waste rock sources directly from the pits.

Since a plant constructed for the certain ore type and characteristics, the ore throughput from pits must be controlled closely to ensure do not exceed the processing plant capacity, both of the grade of gold, silver, copper cyanide, sulphide-sulphur, and also some of physical properties such as hardness and clays content. Therefore, the ore have been grouping into four catagories of "normal" ore which is the ore can be feeding directly without any requirement to be blend, and four catagories of "difficult/problematic" ore that required to blend with a normal ore prior to feed to crusher, and also the hardness and clay content must be put into the consideration while delivering the ore, as it will slowing down the speed of crusher or mill if it exceed.

Keywords: Mineralized, Ore, Suphide, Transition, Alteration, Ore Reserve, Gold, Copper Cyanide, Silver, Suphide-Sulphur, Plant, Mill, Cyianide in Leach, Carbon, Electrowinning, Tailing, Clay, Hardndess, Tailings Storage Facility.

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Understanding and Planning for Cave Mining Challenges

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Abstract

In the search for additional resources, whether through the development of new deposits or the extension of existing orebodies, there is a trend towards the selection of underground cave mining methods for extraction. This trend brings with it new challenges as the depth and scale of the mines needed for exploitation of these resources is pushing the limits of our collective experience. This is especially the case with respect to the reliable forecasting of geotechnical character and rock mass response to mining. These geotechnical aspects, if not properly considered from the early stages of a mine development project, have the potential to severely impact mine safety, reliability, and shareholder value. This presentation will review some of the key geotechnical challenges facing tomorrow’s deep cave mines and the important role that technology-based exploration methods are playing in the proper characterization of geologic, structural, and geotechnical conditions.

Keywords: Cave mining, geotechnical characterization

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Nickel Heap Leach in Comparison with Other Nickel HydrometallurgyTechnologies

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Abstract

The new nickel commodity in electric battery industry has influenced the development and commercial application of nickel hydrometallurgy technologies, such as HPAL (High Pressure Acid Leach), AL (Atmospheric Leach) and HL (Heap Leach).

The selection of the nickel hydrometallurgy technology to extract nickel is highly dependant the types of nickel laterite. Whilst the nickel refinery technology to produce the final intermediate product is dependent on the type of nickel product in the market demand. The nickel product for the battery industry is the nickel chemical compound namely hydrated-nickel sulfate crystall produced from the nickel hydrometallurgy plants. These nickel hydrometallurgy plants produce MHP (Mixed Hydroxide Precipitates) which is the raw material to produce hydrated nickel-sulfate crystal.

In general, the one whole nickel laterite deposit is not suitable for a single extraction technology. A selective nickel laterite's mining and stockpiling the different types of ore mined are necessary in order to make value of the whole deposit. HPAL that offers the massive oxidation environment for extracting nickel is suitable for the limonitic ore types where nickel is in association with refractory mineral goethite. Whilst nickel extraction on the saprolitic ore types requires a mild-selective and moderate oxidation environment such as on HL and AL. Thus, the HPAL and HL-AL are not competitors since they require different type of ore feed.

Each nickel hydrometallurgy technology has its own risks and opportunities. HL is the weakest and selective oxidation condition when compared to that of the other two. Consequently, the process residue from HL process, known as the "spent ore", is by far the most environmentally friendly which lower the long-term environmental liabilities. The low technology on HL offers the more transferrable skills to the locals and the simpler construction that enable more accessible to the local Contractors.

Keywords: nickel, hydrometallurgy, HPAL, AL, HL

Introduction

The conventional Users for the nickel product are the stainless-steel and metal alloys industries for construction material. Starting the past 3-4 years, the nickel requirement for electrical vehicles commences, that change the commercial balance for the nickel commodity. The nickel products are different for such difference Users. The stainless-steel and metal alloys industry require nickel product in the form of Ferro-Nickel (FeNi) that comes from pyrometallurgy smelters. Whilst the raw materials for the electric vehicles battery is nickel in the form of chemical compound hydrated nickel-sulfate or $NiSO_4.xH_2O$. The raw material to produce this nickel chemical compound is generally nickel MHP (Mixed Hydroxide Precipitate). Although

ISSN 2963-9751

other nickel product can be converted into nickel sulfate compound, the converting cost is the consideration. Nickel MHP is produced from Nickel hydrometallurgy processes.

Discussions

The Main Processing Steps in Nickel Hydrometallurgy Technology

The main processes in the nickel hydrometallurgy can be divided into three major steps in sequential order:

(1) The first step being the nickel extraction from the ore into solution using sulfuric acid or other acidic chemical such as nitric acid or hydrochloric acid. The environment conditions for extraction process varied from the highly oxidating condition such in an autoclave (HPAL/High Pressure Acid Leac), moderate oxidating condition such as leaching in tanks (AL/Atmospheric leach), and mild and selective oxidating condition such as leaching the ore on top of the impermeable leaching pads or HL.

(2) The second is the hydroxide precipitation process that follows the nickel extraction process. When nickel extracted and dissolved in the solution fraction, other metallic content in ore will also extracted and dissolved. They are iron, magnesium, cobalt, chromium, aluminium, manganese, and the rest. The valuable metal product of the hydrometallurgy process is nickel and cobalt. That means, all other metallic content has to be precipitated so they can be selectively removed from the dissolved Ni and Co in the solution fraction. The principle of hydroxide metal precipitation is commonly applied by adding the alkaline reagent into solution (or slurry) containing the dissolved metallic ions.

(3) After all the unwanted metal content can be separated from the valuable metal Nickel and Cobalt, then the next process is to recover nickel and cobalt from the solution by precipitation techniques. Depending on the targeted market, the final intermediate product from a hydrometallurgy plant can be MHP (mixed hydroxide precipitate) or MSP (mixed sulfide precipitate) or crude nickel-sulfate crystal.

Regardless the extraction process being selected, the impurities removal process and the nickel-cobalt recovery process are the same.

The Typical Vertical Profile of a Nickel Laterite Deposit and Its Compatible Extraction Process

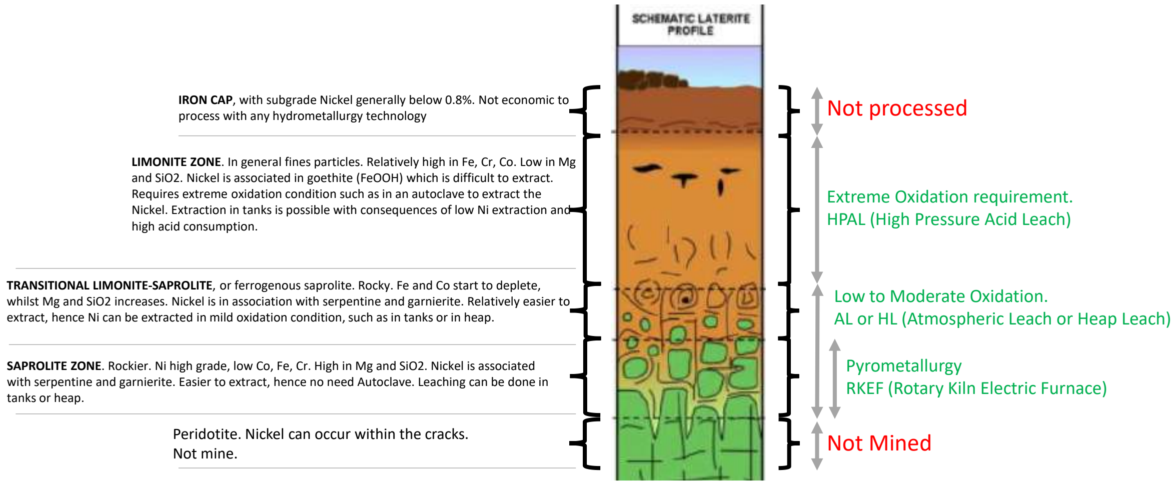
In a vertical profile of the nickel laterite deposit, the chemistry and physical characteristics is changing from the top to the bottom. The top portion is relatively low in Nickel, but high in Cobalt, Iron and Chromium. Sometime the Aluminium content is also high at the top. Going deeper within the vertical zone, the Nickel grade increases, followed by the increase of magnesium and silica, and the decrease of cobalt, iron, and chromium. The top layer is generally fine and clayey, whilst the bottom layer is generally rocky and less clay. The ore character on the top is classified as limonitic laterite and saprolitic at the bottom. Within these

ISSN 2963-9751

two layers, there are generally transitional layers between limonitic and saprolitic that called the ferrogenous saprolite.

The nickel in limonitic zone is more refractory. The nickel is in association with mineral goethite (FeOOH). Consequently, extracting the nickel from the limonitic zone will require a high oxidation conditions such as in an autoclave in HPAL technology. In the saprolitic zone, the nickel is in association with mineral serpentine and/or garnierite which are easier to extract. Hence, for the saprolitic layers, a mild and moderate oxidation condition for nickel extraction is sufficient, such as in AL and HL technologies.

At the lower zone of saprolitic layer, generally the nickel grade is increasing. This high grade saprolite is highly sought by pyrometallurgy smelters. They need high grade to compensate the price of energy for smelting. Below Figure shows the schematic of the nickel laterite mineralogy in vertical section and its compatible extraction process.



The Typical Nickel Laterite Chemistry in Earth Crust vs The Common Nickel Laterite Chemistry Traded in Indonesia

Indonesia has a long history for mining the nickel laterite ore. The mining practices are highly influenced by the existence of pyrometallurgy smelters in Indonesia. The Pyrometallurgy process targets the nickel high grade and certain ratio of silica and magnesia, ignoring other chemical components. In this conventional mining practice, the upper layer to the bottom layer of the laterite zone are mined together in order to mix the high grade with the low grade to satisfy the minimum grade (≥1.7%Ni) to feed the pyrometallurgy smelters. The remaining lower grades are wasted. The existence of HPAL, AL and HL in Indonesia, process the lower grade of 1.3%-1.5%Ni and usually have their specific criteria for Co, Al, Mg and Fe. The followings are the typical limonite and saprolite in earth crust and the low grade originated from the conventional laterite mining practices in Indonesia.

ISSN 2963-9751

Typical Nickel Laterites on Earth

Chemistry	Limonite	Saprolite
Ni (%)	0.12 – 3.0	**1.0 – 4.0**
Co (%)	**0.05 – 0.28**	0.05 – 0.08
MgO (%)	0.2 - 5	**25 – 38**
CaO (%)	0.6 – 1.0	1.0 – 2.0
Al2O3 (%)	**4.0 – 18.0**	1.0 – 3.9
CrO2 (%)	**1.5 – 4.5**	1.0 – 3.0
Fe2O3 (%)	**50 - 85**	10 – 25
MnO (%)	**0.3 – 2.5**	0.15 – 1.0
SiO2 (%)	1.3 – 6.0	**40 - 55**

Typical Nickel Laterites Trading in Indonesia

Chemistry	Low Grade	High Grade
Ni (%)	1.25 – 1.57	1.70 – 2.32
Co (%)	0.03 – 0.04	0.03 – 0.04
MgO (%)	9 – 19	14 – 19
CaO (%)	0.9 – 9	0.4 – 1.7
Al2O3 (%)	2.3 – 7.9	4 – 5
CrO2 (%)	No data	No data
Fe2O3 (%)	15 - 68	15 – 54
MnO (%)	No data	No data
SiO2 (%)	30 - 44	33 - 41

As seen on the above table, the limonite and saprolite layers on earth have distinct chemistry properties, whilst the low and high grade from Indonesian's conventional miners have no clear differences except for its nickel grade.

The current conventional mining practices in Indonesia, cannot optimally support the development of hydrometallurgy technologies which generally process the low grade nickel laterites in a distinct form of Limonite and Saprolite.

The Features of Nickel Hydrometallurgy Processes

As has been explained previously, the nickel extraction technology can be divided into three that are HPAL, AL and HL. They are typical by different oxidation conditions provided. The other extraction technologies that are currently developed are generally have the same main principle with any of the three extractions technology mentioned. Below are the features of HPAL, AL and HL.

	HPAL	AL	HL
Extraction condition	240-270°C 3,500-4,500 Kpa	95-105°C Atmospheric Pressure	Room temperature Atmospheric Pressure
Extraction equipment	Autoclave	Tanks/reactors	Leach pads
Ni-laterite ore compatibility	Limonite *Ni grade 1.2%-1.5%.* *No HG, simply because Limonite is generally LG*	Saprolite *Ni grade 1.2%-1.5%* *Ok for HG Saprolite too*	Saprolite *Ni grade 1.0%-1.5%* *Ok for HG Saprolite too*
Ni extraction (%)	92%-95%	90%-92%	75%-80%
Ni recovery to saleable product (%) *)	80%-95%	80%-90%	90%-95%
Overall recovery from Ni in ore to Ni in product (%)	75% - 90%	72% - 82%	68% - 75%
Typical H_2SO_4 consumption	250-500 kg/t	600-900 kg/t	400-600 kg/t
Ni Extraction time	60-90 minutes	18-20 hours	150 – 300 days
End product	All extraction method can have the same final products.		

*) dissolved Ni recovery to saleable product is generally lower for HPAL & AL when compared to HL. In HPAL and AL, separating the liquid fraction from the solid fraction in the leached slurry is a MUST before proceed to the next recovery process. The chances for nickel losses in the solid fraction is highly possible. The HL does not require solid-solution separation, as the product from the heap is a clear leached solution called PLS (Pregnant Leach Solution)

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	HPAL	AL	HL
Sensitivity to ore character changes	Very Sensitive	Least Sensitive	Moderate sensitive
Ore character of concerns	• NO for Saprolite • Al, Mg, Si may cause severe scaling • Some clay types will cause high slurry viscosity → problem in heat transfer & consume more energy	• Less compatible for limonite, but some tolerance • Highest acid consumption • Limonite contamination cause lower extraction and higher acid consumption	• NO for 100% Limonite → permeability issue to cause total plug-up of the heap. • Limonite okay if blending with saprolite, consequences lower extraction and high acid consumption
Environmental: Water utilization	30% water recovery in TSF 50%-60% water recovery in dry tail 0% - no recovery in DSTP	10%-20% water recovery in TSF 40%-50% recovery in dry tail 0% - no recovery in DSTP	80%-90% water recovery *(water that lost is what is in spent ore pores and MC)*
Footprints	Large for tailing dam *(tailing is generally 30-40% solids)*	Large for tailing dam *(tailing is generally 30%-40% solids)*	Large for leach pad *(roughly 2ha for 1,000tNi/y)*
Environmental : Tailing friendly	Less friendly All metal extraction, except Si. Slurry residue. Potential Cr6+	Less friendly All metal extraction, except Si. Slurry residue	Friendly Partial metal extraction Solid residue (spent ore)
Tailing placement	TSF or landfill	TSF or landfill	Waste dump, plantation, pit backfill

	HPAL	AL	HL
CAPEX INTENSITY	US$ 44,000/t.Ni (Murrin Murrin) – US$ 140,000/t.Ni (Ambatovy)	Not enough data	$ 11,100 - $16,000/t.Ni (For 30,000tNi/y)
Process challenges	• Si, Mg, Al → scaling, severe downtime • Slurry viscosity → energy consumption • Slurry % solid → energy consumption • Ni co-precipitation in Fe tailing → lower production • Ni losses in solid in CCD process → lower production • Fe2+ → high acid consumption similar to AL	Not enough data	• Poor agglomeration → low extraction • Poor stacking → low extraction • Poor irrigation management → low extraction • Direct rainfall → downstream inefficiencies, heap errotion

Why Heap Leaching?

The HL has its own positive sights in comparisons to other hydrometallurgy technology such as HPAL and AL, as follows:

- Engage a simpler and low technology
- Low capex and opex
- An easier for expansions and/or revisions on the leach pad and operations
- Construction technologies are more accessible for the local Contractors
- Low technology, provide a more transferable skills to the local people
- Process residue in the form of spent ore, offer a more sustainability
- Leaves a more secure site after operation, thus reduce the long-term environmental liabilities.

The Production from the HL Facility

The HPAL and AL provide a continuous extraction process. The HL provides the semi-continuous extraction process. The HL extraction facility consists of several cells. Each cell has a certain leaching time from 5 months to over a year, to achieve nickel extraction of 75%-80%, depending on the ore characteristics. After the complete leaching, the ore residue called the “spent ore” is reclaimed and stack on the spent ore dump for reclamation. By this definition,

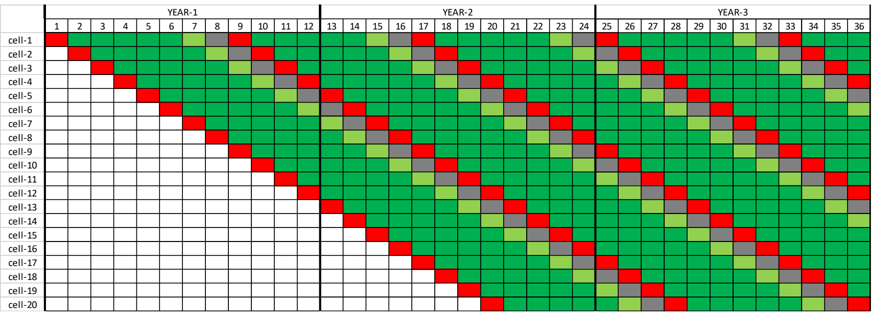
ISSN 2963-9751

the cycle of each cell is a batch process, but the combined performance of all cells produces a continuous leaching. Below table illustrate the continuous production from the leach pads.

Stacking 1 month
Leaching & production 5 month
Rinsing & draining 1 month
Destacking 1 month

Total cycle 8 months per cell

Cell-1	Cell-11
Cell-2	Cell-12
Cell-3	Cell-13
Cell-4	Cell-14
Cell-5	Cell-15
Cell-6	Cell-16
Cell-7	Cell-17
Cell-8	Cell-18
Cell-9	Cell-19
Cell-10	Cell-20



With the simulation of 8 months/cycle/cell:

- Ramp up to full capacity is achieved in month 20th forward.
- Everyday, the total production is the sum of production from each active cell under leaching.
- On the equilibrium condition, there will be 2-3 cells under stacking, 11-14 cells under leaching/production, 2-3 cells under rinsing and draining, and 2-3 cells under destacking for a total of 20 cells.

The Plantation on a Nickel HL Spent Ore

The spent ore is less hazardous due to selective leaching conditions on a HL technology. The rinsing of the spent ore before reclaim is necessary to ensure the metallic ions are flushed off from the spent ore pores. The spent ore can be used as the media for plantation for short term and long term plants as seen on below Figures.

The spent ore is distinguished by pale color when compared to the natural top-soil.

On the top and middle top pictures, the corn are planted on the spent ore media. The height of the plant reached 150-170cm after approx. 2 months.

On the top-right and bottom-right pictures, the long-term plant such as teak is planted on the spent ore media and to-date indicates normal grow, similar to that planted on the natural top-soil.

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Incorporating The Geological Relationship into AI/Machine Learning for Exploration Project Generation

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Abstract

Machine learning tools have been implemented in various geoscientific studies in recent years and have met with different levels of success. One such application is to perform mineral prospectivity mapping (MPM), which is helpful for effective planning of mineral exploration projects. Despite years of research, machine learning-assisted MPM has not been widely accepted in the industry. One possible reason for this is the stark difference between how the actual exploration geologist thinks and how the machine learning method works. For example, in mineral exploration, a geologist collects exploration data and infers relationship between sets of information that can be used to directly explore and discover a mineral deposit. The relationship can be a common geological relationship (e.g., overprinting, cross-cutting, stratigraphic), geochemical relation, the relationship between field data with secondary data, or other types of relationships. These relations are challenging to learn using the most common machine learning tools; hence, machine learning-assisted MPM cannot effectively apply the same complex relationships in exploration data. To tackle this issue, we investigated whether graph machine learning could utilise such relational information collected from various study areas across the United Kingdom. These data were converted into nodes of different types, according to the data types. Each node was then connected to the others based on their relations, forming edges. Then, all nodes and edges were compiled, creating a graph. The graph machine learning model was then trained using this graph to predict the locations of mineral occurrence and non-occurrence. The model was used to produce a prospectivity map for the United Kingdom, which we selected as the study area due to the large amount of publicly accessible data available in this region. Tin was chosen as the target metal for training because of its abundance in certain regions; a similar study could thus be performed across Indonesia, since there is a similar amount of geological data and it contains similar metal occurrences.Our study shows that graph machine learning can learn from geological relationships and predict mineral occurrence with performance levels that match the regular machine learning pipeline. This method can also reach the performance of conventional machine learning methods, although we intend to perform further iteration in order to improve performance in the future.

Keywords: Mineral Prospectivity Mapping, Graph Neural Networks, Machine Learning, Geological Relationship

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Geochemical Exploration on District Scale on Eastern Part of Indonesia as Parameter to Prospectivity for Nickel

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Abstract

Ultramafic rocks exposing on the surface occurred in Eastern Indonesia. They are mostly exposed inland of south-eastern part of Kalimantan, Sulawesi, Halmahera, Banda Arc and Papua. Because of these large, exposed rocks in the surface, Indonesia is often cited as the country which has the largest in the world of exposed ultramafic rock in the surface, and as consequence Indonesia is the country that has largest Nickel laterite deposit in the world. In the order word, Nickel resources in Indonesia is similar with "Saudi Arabia position in the World Oil Resources".

The nickel laterite deposits are formed as weathering profiles developed upon ultramafic rocks through chemical leaching and supergene enrichment within the ophiolites and/or orogenic ultramafic massifs. In addition to nickel; chromite, lateritic iron ores, cobalt and PGM are additional product of weathering-product of ultramafic rocks exposed in Earth's surface.

Indonesian Regions that have large resources is consist of Halmahera, North Konawe, Morowali, Lake Deposit (East Luwu), Kolaka and Konawe, respectively. The distribution of limonite resources is widespread in the North Konawe, Halmahera and Morowali areas. While the saprolite resources mainly in Lake area, Halmahera and Morowali.

We separate of Nickel laterite deposit divided into 11 regional areas based on chemical differences, As follows, 1. Lake Deposit, 2. Kolaka-Konawe,3. Morowali, 4. North Konawe, 5. Kabaena-Buton-Wowoni, 6. Sulawesi East Arm, 7. Halmahera-Gebe-Obi, 8. Kalimantan, 9. Maluku-Seram, 10. West Papua, 11. Papua. Differences chemistry of laterite on 11 area regions were contributed different on geology of each location. The main significant differences are Fe content, Fe/Ni ratio and S/M ratio for saprolite ores, and Co, Fe, SiO_2, MgO and Al_2O_3 for limonite ores. Among them showed that three area have less develop of Nickel laterite, e.g., South Kalimantan, Sulawesi East Arm and Papua. Those area did not have a good laterite development because of steep elevation and have undergone vertical movement (or uplifting) due to tectonic. Its mean that erosion has higher rate compare with laterization. Several areas have unique characterization such as North Konawe and Kabaena-Buton Region. Laterite deposit at Kabaena and Buton has a very high S/M ratio due to high SiO_2 contents, whereas in the North Konawe region it has the ore characteristics of High Ni, High Fe and Low MgO. It should be noted that range of S/M ratio is very critical for future ore processing scenario specially for RKEF.

S/M ratio average on Sulawesi Island is relatively higher than Halmahera, Kalimantan and West Papua Island. The high ratio of S/M show that the laterization rate is the parent rock is consisting dominant of olivine or with additional orthopyroxene containing high MgO. Furthermore, olivine as mineral contained high MgO and low SiO2. The S/M ratio difference also indicated by the serpentinisation

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process and ultramafic rock characteristics as the parent rock in geological setting, and also presence of silica as both silica boxwork or silica vein and silica massive.

Presence of gabbro and cumulate in the ultramafic rock will increase Al_2O_3 content in the laterite, especially in the limonite. High Al_2O_3 may relate to bedrock composition, if the bedrock contains more cumulate rocks such as gabbro or pyroxenite, it will increase Al_2O_3 grade compare with the bedrock only peridotite and dunite.

Most RKEF smelters and hydrometallurgical processing companies (eg HPAL) are find large of ores meet with their Nickel ore specification for their plants, and most of them are not fully supply by their own deposits because of limited ores resource that meet their own plant specification. Therefore, they have to find alternative limonite or saprolite ores source from different area and blending with their own ores to meet with their Nickel ore specification. Understanding chemistry specification in each region must be addressed to find ore supply solution.

Keywords: Ultramafic rock, Geology differences, Nickel laterite, Region distribution, chemistry characterization.

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Embracing Digital Technology through AI and The Role of Machine Learning in Exploration and Mining

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Abstract

Artificial intelligence and machine learning techniques have been adapted to generate rapid geological models from data collected during exploration and mining activities. This paper explores techniques used to build data driven deposit models directly from this geological data using a machine learning workflow. Resultant models provide an insight to domain geometry, including structural elements such as complex folds, multiple phases of intrusion and late-stage fault displacements. Case studies illustrate how machine learning has been applied to a variety of mineral deposits and compare results with previous studies.

Keywords: Machine learning, Geological models, Workflow, Complex, Fault

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Unsupervised Machine Learning – K-means Application for The Tujuh Bukit Alteration Domaining Using Assay, Corescan, and Equotip Data

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Abstract

The Tujuh Bukit deposit is a complex porphyry Cu-Au deposit, where faulting and overprinting processes have destroyed the initial texture of the rocks. Conventional logging methods are often unable to precisely separate alteration facies due to the intense overprinting alteration. Understanding this complex alteration requires a quantitative approach in terms of separating the initial porphyry alteration and the overprinting alteration. Since human observation is limited to a qualitative approach, technology assistance is being used to overcome these limitations, including Corescan hyperspectral logging, multi-element assay, and equotip datasets are collected and machine learning algorithm is applied to support interpretation and model domaining.

Geotechnical and metallurgical behaviour at Tujuh Bukit varies across diverse hydrothermal alteration facies. In general, rock strength is commonly increased from argillic to advanced argillic/silica alteration while floatation recovery of copper sulphides is commonly decreased from argillic to advanced argillic/silica alteration. Understanding the control of geotechnical/metallurgical behaviour at Tujuh Bukit is critical to optimize mining and mineral processing design.

Previously, the alteration model that is being used in geotechnical & metallurgical domaining is based on conventional alteration logging. These conventional alteration facies are based on qualitative logging of silica, advanced argillic, argillic, intermediate argillic, and propylitic alteration facies. These alteration facies may not accurately represent the actual mineralogy assemblages that affect the geotechnical and metallurgical behaviour of Tujuh Bukit. Building the alteration facies based on mineralogy composition is crucial for better geotechnical and metallurgical domaining.

K-means clustering, an unsupervised machine learning method, can provide new domains based on features similarities of each data population from quantitative Corescan mineralogy, equotip, and assay data. These domains are data-driven and effectively represent mineralogy assemblages that can be used to reveal the actual geotechnical and metallurgical characteristics at Tujuh Bukit deposit.

Keywords: Machine learning, K-means, alteration, geotechnical, metallurgy

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Hu'u Copper Project Onto Cu-Au Deposit – Geology and Resources Update

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Abstract

The Onto Deposit is located within the Hu'u Project CoW in Dompu Regency, Nusa Tenggara Barat Province, Indonesia. The Hu'u Project is owned by PT Sumbawa Timur Mining (STM), a privately-owned Indonesian company which holds a 7th Generation Contract of Work (CoW) entered into with the Government of Indonesia on 19 February 1998. The shares in STM are owned by Eastern Star Resources Pty Ltd (ESR), a 100% Vale SA-owned subsidiary, and PT Antam Tbk. ESR owns 80% of STM and PT Antam Tbk. owns the remaining 20%.

The Onto deposit is a large hybrid porphyry/high sulphidation copper-gold deposit. The deposit is hosted in quartz-alunite-pyrophyllite advanced argillic altered intrusive stocks and a polymictic breccia below a less- altered andesite. Copper occurs predominantly as disseminated covellite and pyrite-covellite veinlets in a tabular block measuring at least 1.5 km x 1 km with a vertical extent of ≥ 1 km. A thick advanced argillic alteration zone hosts the mineralization with continuous advanced argillic alteration zones up to about 1,300 m thick. Deep exploration has outlined a series of porphyry stocks that intrude a thick, unsorted polymictic breccia that formed within a large diatreme vent with the intrusive carapaces at approximately -50 m RL (400 m to 500 m below the surface).

The resource database consists of the data outlined in Table 1 and contains a comprehensive down hole geological logging dataset. A comprehensive quality control and quality assurance program is implemented in parallel with the sampling process to provide quality assurance and to measure assay accuracy and precision, and to detect sample contamination.

Summary

Drill hole spacing is variable due to the early stage of evaluation of the deposit and the nature of the terrain. However, the nominal drill hole spacing is a combination of 400 x 400 m infilled to a 200 x 200 m density in some areas. Assay samples are collected on a constant two metre length basis.

Table 2. Resource estimate data summary

Item	Value
No. Drill-holes	92
Meterage (m)	94,440
No. Assay data	41,900
No. bulk density data	14,450

The Onto deposit was discovered in June 2013 when VHD034 intersected significant

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copper-gold mineralization from 548 m through to 835 m (end of the hole). Further drilling was undertaken in the area surrounding VHD034. This subsequent drilling led to a significant intersection in VHD037 and constituted the discovery of the Onto deposit.

The Onto deposit is open at depth in several areas and the margins have not currently been fully
defined. To date, 28 holes have been drilled with ≥ 700 m intervals of continuous mineralization grading between 0.7-1.3% Cu and 0.3-0.9 g/t Au with kilometre long intervals in nine holes.

In classifying the Onto deposit mineral resources, several aspects that affected resource confidence were assessed. This included an assessment of sampling uncertainties, data quality, geological and grade continuity, geological understanding and the quality of the geological modelling, data density and configuration and quality of grade estimates. Mineral resource classification was determined independent of the grade estimation process and accounted for these items. The mineral resource estimate was classified using the confidence categories set out in S-K1300.

To support the assessment of reasonable prospects of economic extraction, an initial assessment study was undertaken. This study assessed the following:

1. Infrastructure, mining, and process plant requirements;
2. Mining methods;
3. Process recoveries and throughputs;
4. Environmental, permitting, and social considerations relating to the envisaged mining operation;
5. Processing methods and proposed waste disposal; and
6. Technical and economic considerations.

Details of the Onto deposit mineral resource estimate can be found in the Vale's 2021 Form 20-F filing10. The Onto deposit mineral resources as at 31 December 2021 is presented in Table 2. This December 2021 resource estimate represents a >20% increase in the size of the Onto deposit, equivalent to 0.4 Bt, since the December 2019 resource estimate.

Table 3. Onto deposit mineral resources (as at 31 December 2021)

Summary of Copper Mineral Resources at the Fiscal Year Ended 31 December 2021				
Resource category	Mineral resources			Cut-off grade
	2021			
Category	Billion tonnes	Cu	Au	
Measured	-			
Indicated	1.1	0.96	0.58	>$0/t NR
Measured + Indicated	1.1	0.96	0.58	
Inferred	1.0	0.7	0.4	>$0/t NR

The high grade and significant volume of the Onto deposit supports STM's objective of being a leading copper producer in Indonesia. The project is in the feasibility study stage of exploration, as outlined under the Hu'u Project CoW, with the objective of proving a

ISSN 2963-9751

technically and economically viable block caving mining operation. STM is currently undertaking resource drilling within and surrounding the Onto deposit. Technical challenges associated with developing the Hu'u Project will need to be overcome and is the focus of ongoing and future drilling, data acquisition and engineering studies.

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The Magnetotelluric (MT) Method for Delineating Deep Exploration Target in Doup, Kotabunan, North Sulawesi, Indonesia

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Abstract

The Doup project located in the southern part of the north arm of Sulawesi near the well-known Messel sediment hosted Au mine. The previous systematic near surface exploration studies has indicated and developed an important conceptual exploration model of an intermediate sulphidation epithermal (quartz ± carbonate ± basemetal) vein system in Doup. It was not until the discovery of porphyry mineral markers such as secondary K-feldspar, secondary biotite, secondary magnetite, and shreddy chlorite with some porphyry's vein such as M-vein, D-vein, A-vein, and B-vein from the re-logging of the previous Panang's and Benteng's drill cores by J Resources in 2016, an overprinting of older porphyry system by the intermediate sulphidation epithermal vein is suspected. The new evidence has brought some light for upside potential in the area at deeper level. However, the magnetic map does not indicate any significant porphyry signature for some reasons.

A geophysical MT survey conducted in order to delineate deeper potential exploration target under the conductive cover of Panang. At least 925 number of MT stations were deployed using 16 northeast oriented profiles of scalar (reconnaissance) electrodes array in TM mode. The array was used closed electrical dipole spacing at 25 and 50 meters within a 1,700 meters long profile. Data acquisition was done using 4 frequency bands with lowest frequency at 0.09375 Hz (of low band range) up to 8192 Hz (of the high band range) to map more than 1,000 meters deep anomaly below the ground. At the end, we compare the recovered MT model with the previous induced polarization dipole - dipole (ipdd) and magnetic susceptibility model.

The resulted MT resistivity model indicates a resistive sub-vertical structure under the conductive silica-clay-pyrite (SCP – *phyllic alteration*) altered Panang Porphyry at the upper part of Panang. The underlain resistive structure was undetected by the depth of investigation of the previous ipdd datasets. However, the previous ipdd indeed showing higher open chargeability anomaly centered at this area which is coincides with the top of the underneath potassic altered Panang Tonalite from drilling. The MT model also shows a resistive respond of the Benteng skarn. While the Benteng structure zone is characterized by a sub-vertical high resistivity respond right between Benteng and Panang. At the end, an updated 3D constrained magnetic susceptibility model using new drillhole magnetic susceptibility data is presented together with the MT model.

Keywords: MT, Magnetic, Ipdd, Mineral exploration geophysics, Porphyry, Doup geophysics

Introduction

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The Doup prospect is located in the Kotabunan village, Bolaang Mongondow Timur, North Sulawesi, Indonesia. The mineralization in the area known as an intermediate sulphidation epithermal Au vein system. However, some porphyry alteration markers and veins observed from the re-logging of the previous drilling cores by J Resources in 2016. A detail surface re-mapping, several geochemical, and geophysical studies followed the founding to better understand the subsurface geology and establish a new conceptual model for exploration targeting.

MT (MT) method is a passive geophysical method that utilized the naturally existing electromagnetic signal. The MT signal has very long frequency band between 10,000 Hz to 0.0001 Hz (10,000 s). Hence, MT method is able to observed shallow to deep long period signal that generate from deeper source. The depth of investigation of the method could extend from hundreds to thousands of meters in a very long period of data acquisition. In addition, a simple data acquisition process and logistic supply, this makes MT method attractive for deeper geophysical mapping compared to other active geophysical method. In order to provide deeper geophysical model for exploration targeting, the MT survey been conducted in Doup in 2017.

The geology and alteration

The geology of Doup comprises of a series of Intrusion Diorite from youngest to oldest as Panang Quartz Diorite, Panang Tonalite, cross cutted by Benteng Diatreme Breccia, and Panang Late Quartz Diorite intruded the older Benteng Andesite and a series of dipping calcareous sedimentation group comprises of Benteng Clastic Limestone, Tungou shale, and Tungau Clastic Limestone (Fig.1). The regional or tectonic event after the last intrusion marked by a paleo soil. The deposition event continued by the deposition of Polawat Carbonaceous Siltstone that inter-fingering with Dacite. The later Ongkobu Epiclastics deposited at the top of Polawat Carbonaceous Siltstone. The upper part of the stratigraphic consists of Ongkobu Epiclastics, Collovium, and soil.

The characteristic of porphyry system alteration includes: (i) secondary K-Feldspar + secondary Biotite ± Shreddy Chlorite ± secondary Magnetite /Potassic (PO), (ii) Sericite + Shreddy Chlorite + secondary Chlorite + secondary Magnetite + secondary Biotite + Muscovite – Illite /Sericite-Clay-Chlorite (SCC), (iii) Silica + Clay + Pyrite /Phyllic (SCP), (iv) Chlorite ± Epidote ± Calcite /Propylitic (PP). Along with the alteration, some porphyry veins are observed as: (i) "A" vein: granular dark quartz vein, irregular quartz vein, discontinue quartz vein, (ii) "B" vein: quartz ± pyrite ± chalcopyrite vein with teeth texture and ± suture, (iii) "M" vein: magnetite vein, and (iv) "D" vein: quartz + pyrite ± chalcopyrite vein (Johari M., 2016).

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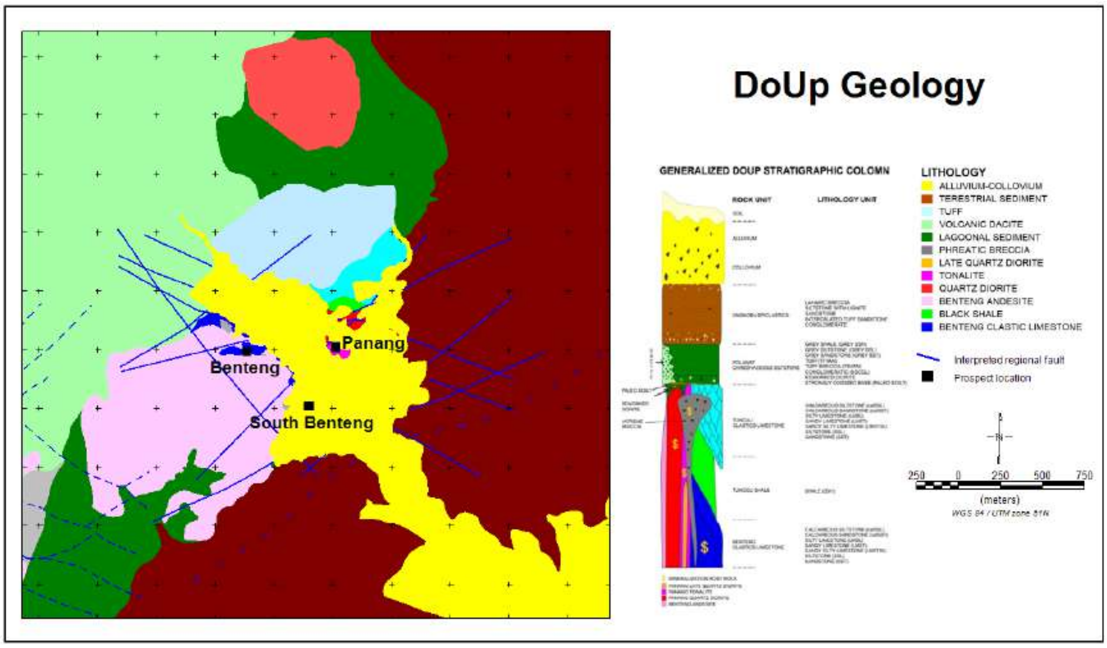
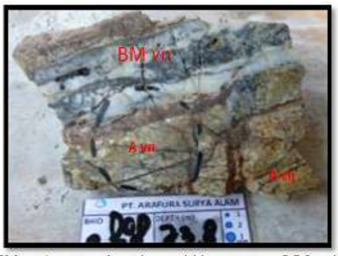


Figure 1. Geological map of Doup.

Mineralization

The mineralization system in Doup consists of skarn and porphyry overprinted by intermediate sulphidation epithermal (quartz ± carbonate ± basemetal) vein. The mineralization host rocks including Benteng Clastic Limestone, Panang Quartz Diorite, Panang Tonalite, and Benteng Diatreme Breccia.



BM vein cut A veins within strong SCC alt Tonalite hostrock, **3.52 g/t Au, 0.114% Cu, 0.131% Pb, 0.289% Zn, 0.0524% AS.**

@38.10-39.00m : Sheared zone filled by qt-py+black sulphide within scp alt Phyric Andesite, returned 78 g/t Au

DOD290 @ 57.80m : qt ± ca-py-sp ± ga veinlet on calcareous SST
16.25 g/t Au; 0.006 % Cu; 1200 ppm Zn; 238 ppm Pb; and 128 ppm As

Figure 2. Some photograph of Doup core and assay results (Santosa A., I., 2019)

ISSN 2963-9751

Data and Methods

The electromagnetic phenomena are governed by Maxwell's equations. The equations have been widely explained in several geophysical theory books (Simpson & Bahr, 2005).

The first Maxwell equation is called Ampere's Law,

$$\nabla \, X \, \vec{H} = \vec{J} + \frac{\partial \vec{B}}{\partial t} \quad (1)$$

Where H is magnetic field, J is electrical current density, and D is the electrical flux density, which is related to the electrical field.

The second Maxwell equation is called Faraday's Law,

$$\nabla \, X \, \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (2)$$

Where E is electric field and B is the magnetic flux density, which is related to the magnetic field.

The third Maxwell equation is Gauss's Law,

$$\nabla . \vec{D} = \rho \quad (3)$$

Where ρ is electrical charge density. This equation explains that charge creates electrical field diverging from it.

The fourth Maxwell equation is nameless,

$$\nabla . \vec{B} = 0 \quad (4)$$

Which tells us that magnetic field don't diverge from anything, they only curl around.

In the application of MT method, for most of the problem, we assumed isotropy, homogeneity, linearity, and temperature-time-pressure independence of the electrical parameters of local regions of the Earth (Ward and Hohmann, 2008). In a symmetry homogeneous isotropic medium, there are only one component of electrical field (Ex) and one component of perpendicular magnetic field (Hy) that vary with depth. The relationship of horizontal component of both observed field is described as,

We observed,

$$E_x^t(z,t) = E^t e^{-k_1 z} e^{-i\omega t} \quad (5)$$

$$H_y^t(z,t) = (1/i\omega\mu) E^t(-k_1) e^{-ik_1 z} e^{-i\omega t} \quad (6)$$

Where the MT impedance (Zxy) calculated using the ratio between Ex and Hy as,

ISSN 2963-9751

$$Z_{xy} = \frac{E_x}{H_y} = \sqrt{i\omega\mu_0\rho} \quad (7)$$

The impedance equation shows that the homogeneous medium impedance is a complex number and the function of frequency and the resistivity of the medium. As a complex number, impedance has amplitude and phase following the equations,

$$\rho_a = \rho = \frac{1}{\omega\mu_0}|Z_{xy}|^2 \quad \text{and} \quad \phi = \tan^{-1}\left(\frac{\Im Z_I}{\Re Z_i}\right) = 45^0 \quad (8\ \&\ 9)$$

where $\rho_a = \rho$ is the apparent resistivity or the resistivity of the homogeneous medium and ϕ is phase at the homogeneous layer. In the free space ϕ will be 0. The depth where the amplitude of the EM wave reduced to 1/e from its surface amplitude defined as the skin depth. The calculated resistivity described the average value up to the radius of its skin depth or it can be say as the depth of investigation and it defined by the average resistivity value of the medium and frequency of the signal. The MT skin depth calculated using the equation,

$$\delta = (\pi f \mu \sigma)^{-1/2} \equiv 0.503\ \sqrt{\rho / f}\,(Km) \quad (10)$$

Since the MT is a frequency domain method, the previous formula shows us how to calculate apparent resistivity, phase angle, and predicts the depth of investigation for each recording frequency. The plot of apparent resistivity and phase angle versus frequency will give the general sense of parameter changing with depth.

In order to model the actual subsurface resistivity distribution, a forward or inversion modelling follows. Some theoretical explanation of the methods found in several papers (see Vozzoff, K., 1991; Grandis, 1997 & 1999; Hohmann, G., W., 1987).

Data acquisition

The MT data acquisition in Doup conducted using Zonge GDP-32ii. The variation of MT signal observed using six electrical dipoles and one orthogonal magnetic coil in scalar (reconnaissance) configuration. The dipole spacing is 25 meters to 50 meters within 1,700 meters long for each survey line. The survey line spacing is 100 meters to 200 meters. There are 16 northeast oriented survey lines with total 925 MT stations within. All the station recorded MT signal with the lowest frequency at 0.09375 Hz (of low band range) up to 8192 Hz (of the high band range). By using the estimated average medium resistivity of 25 Ohm.m (rough average of the overburden conductivity), the lowest skin depth is about 8.2 Km (around 5.8 Km effective depth). While survey target is a kilometer depth of interest.

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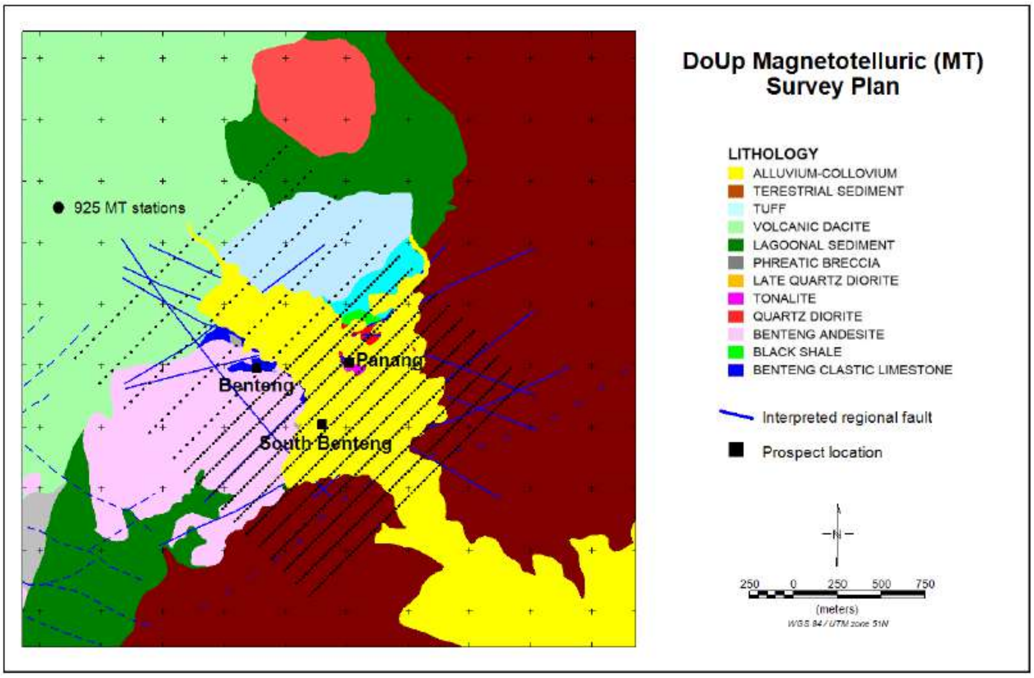

Figure 3. MT survey plan over geology.

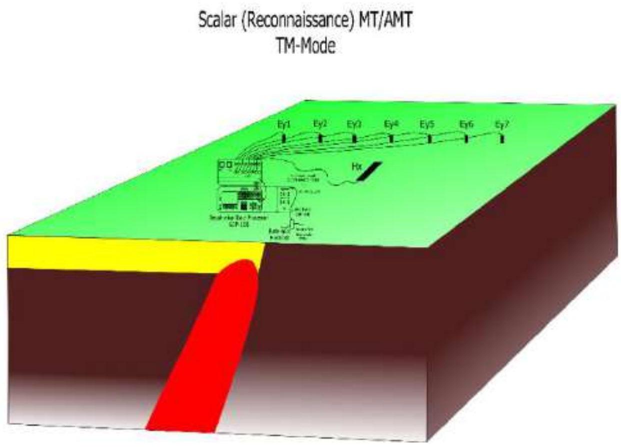

Figure 4. The illustration of used MT survey configuration (not to scale).

Result and Discussion

The recovered MT model at line 08 indicates high resistive body under the conductive silica-clay-pyrite (SCP) altered Panang porphyry. The underlain resistive anomaly was undetected by the depth of investigation of the previous ipdd model. However, ipdd chargeability anomaly appear at the top of the body that is probably due to the increasing of sulphide content in this

ISSN 2963-9751

area. The deep hole drilling intercept at the lower part of the resistive body shows the correlation of the anomaly with potassic altered Panang Tonalite. This study also presents the correlation of the magnetic model with the MT and drillhole data.

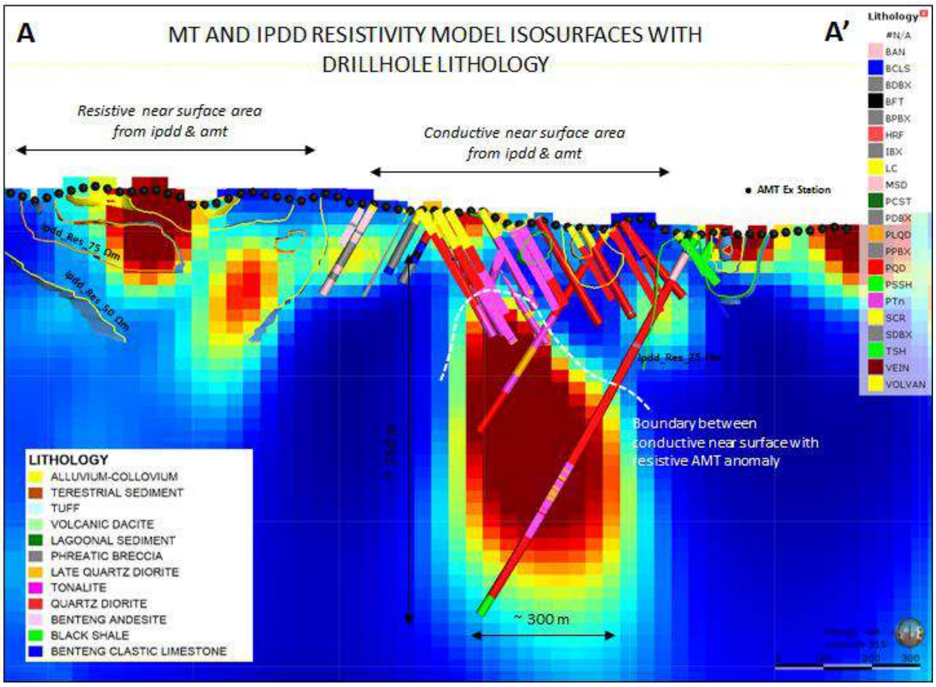

Figure 4. Line 08 MT resistivity model profile with borehole lithology and ipdd resistivity isosurfaces.

Conclusions

The effectiveness of the MT method for deep exploration under a resistive target is well known. The study in Doup has shown the effectiveness of the MT method in mapping deeper exploration target under a conductive cover in mineral exploration. Model comparison with ipdd resistivity indicates higher resolution of the recovered MT model at shallow depth. The deeper depth of exploration and simple logistic support also make the method more attractive compared to others active electromagnetic methods such as time domain electromagnetic (TDEM) or control source audio frequency magnetotelluric (CSAMT). Furthermore, together with magnetic, MT is a powerful geophysical method for deeper geophysical study in Doup.

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Liquefaction of Indonesian Low Rank Coal: Characterization and Challenges

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Abstract

Coal-to-liquids (CTL) technology or coal liquefaction is a method to achieve "greener" coal utilization. It is one of the 10 priority programs in the Indonesian coal development and utilization road map. Results of the studies on the liquefaction of Indonesian low rank coal by author and other related references is presented. Lignite and subbituminous coal from Warukin Formation in Barito Basin and Muara Enim Formation in South Sumatera Basin were studied. Low temperature (120°C) and normal pressure conversion process in autoclave can give up to 51% conversion yield. High temperature (up to 450°C) and high pressure with longer conversion time produces up to 87% liquid. Direct solvent extraction in very low temperature (55°C) only give up to 31% product. Even though Indonesia has abundant resources of low rank coal, other studies indicate that commercial projects are not yet feasible. Special treatment from the government on coal liquefaction project in Indonesia is needed.

Keywords: coal liquefaction, low rank coal, Indonesia

Introduction

Coal-to-liquids (CTL) technology or in general known as coal liquefaction have been developed since early 20th century. It converts coal into valuable liquid fuels. Methods include indirect conversion (coal to syngas, which can be converted to liquid hydrocarbons) or direct conversion (by various direct coal liquefaction methods). This technology is considered as one of the methods that can by applied to achieve "greener" coal utilization.

Indonesian Law No. 4/2009 on Mineral and Coal Mining, as amended by Law No. 3/2020 clearly express the importance of coal development or utilization technology especially in downstream sector. One of the methods mentioned is coal liquefaction. It is one of the 10 priority programs in the coal development and utilization road map [1]. Governmental Regulation, Presidential Decree and Instruction as well as Ministerial Regulation have been released to speed up the coal liquefaction program of Indonesian coal [2,3].

Studies have been conducted for Indonesian coal liquefaction including the industrial feasibility aspect [see 4]. This paper presents results of the studies on the liquefaction of Indonesian low rank coal by author and other related references.

Data and Methods

ISSN 2963-9751

Lignite and subbituminous coals from Warukin Formation in Barito Basin and Muara Enim Formation in South Sumatera Basin were used. Both group of coals were treated differently. Warukin Formation coal was liquified in an autoclave on normal pressure and temperature (120°C). Alumina was used as catalyst, while hydrogen donor was NaOH and water was used as solvent. Heating was conducted in three times variables of 30 minutes, 60 minutes and 90 minutes (see details in [5]).

Higher temperature (375°C, 400ºC, 425ºC, 450ºC) in higher pressure (100 bar) was used in other test, with anthracene as solvent and iron ore as catalyst for 2 hours heating (see details in [6]). Muara Enim Formation coal was tested by simple liquefaction which is solvent extraction using n-methyl-pyrrolidone and carbon disulfide solvent by 1:1 ratio in very low temperature of 55°C in 90 minutes.

Result and Discussion

Low pressure and temperature liquefaction on lignite samples of Warukin Fm. (fixed carbon maks. 29% adb) give a yield of 25.37% - 51.27%. Sub bituminous samples (fixed carbon max. 39% adb) produce 1,99%-15.45% liquid product. The result indicates that lower coal rank has higher yield conversion. 60 minutes heating gives the highest yield [5].

Other treatment on subbituminous coal (fixed carbon maks. 35.34% adb) from Warukin Fm. indicates different result. Highest conversion achieved is 87.28 % at temperature of 450ºC [6]. The amount of conversion product is increasing with the increasing processing temperature. Theoretically high conversion rate will be achieved in 425 - 450ºC, because in this range free radicals will be significantly produced by thermal cracking which contributes to high conversion rate [7].

Solvent extraction procedure which was conducted on low rank coals of Muara Enim Fm. (average fixed carbon 29% adb) gives conversion product of 29.76%-31.66%. Low temperature and low-pressure liquefaction give less conversion result. Liquid product in this case is only produced by physical conversion. Chemical dissolution is unsignificant in low temperature.

Low-rank coal such as lignite produces more conversion product during liquefaction process than high-rank coals [8]. High-rank coals have less hydroxyl content rather than low-rank coals. Hydroxyl content leads to higher percentage of H/C compounds this makes low rank coal is easier to be converted into liquid coal since it only needs few hydrogen donors. However, liquefaction condition will have effect on the result produced. In general, longer time of conversion process enables coals to have more contact with solvent and hydrogen donor. Hence, conversion result becomes higher.

The abundance of Indonesian low rank coal significantly gives advances on the possibility of coal liquefaction project in Indonesia. Liquefaction project facilities in pilot scale have been established for example by Research Agency of Mineral and Coal under The Ministry of Energy and Mineral Resources (Tekmira). Cooperation in industrial scale have been initiated by the government (see [2],[4]). Unfortunately, no commercial projects are

ISSN 2963-9751

continued [3]. The feasibility of the projects especially in economical point of view is still questionable (see [2],[4], [9], [10], [11]). Special incentives and policies are needed to the realization of coal liquefaction project in Indonesia.

Conclusions

Coal liquefaction projects is a proven technology to produce liquid fuels. With the abundance of low rank coal resources Indonesia, coal liquefaction becomes one of the potential value-added strategies. High conversion product (up to 87%) can be achieved in laboratorium scale. Studies in pilot scale have been done, however commercial projects are not yet feasible. Coal liquefaction project in Indonesia needs special treatment from the government for examples in incentives and policies.

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Key Role of ESG's Principal Implementation in an Operating Mine

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Abstract

In this session I examine how metals mining companies understand and act upon Environmental, Social & Governance (ESG) as risk management and the consequences for projects. I begin by exploring the literature on ESG in the mining industry, motives for ESG engagement in the industry, and risk management. I then draw on my presentation to map how ESG initiatives are seen as an important method of managing strategic challenges to firms — categorized here as reputational, operational, or regulatory 'risks'—and note how competition for capital and recent changes in the legal environment have furthered this process.

A focus on ESG as risk management can illuminate the poor development outcomes of ESG initiatives, despite recent rises in spending. 'ESG as risk management' introduces immanent limitations including treating ESG as a branding, targeting those that pose the greatest threat rather than those with the greatest need, excessively simplifying complex processes and focusing on maintaining the status quo. In risk management thinking, ESG activities may be a high organizational priority, integrated into central decision-making processes and subject to a great deal of investment, but still see little progress towards inclusive development for those living closest to mining operations.

The laterite nickel ore processing and mining operational area of Harita Nickel on Obi Island, North Maluku enhance ESG as one of their business strategies. With three pillars that focus on climate change, human rights, and corporate governance, under one of Harita Nickel business unit, PT Trimegah Bangun Persada has succeeded in identifying ESG risks to support their strategy by developing product of FeNi, MHP, $NiSO_4$ & $CoSO_4$ and doing business diversification of derivative products from metallic materials in Obi Industrial Area.

Keywords: ESG, Environmental Social & Governance, Mining, Risk, PT Trimegah Bangun Persada

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Assessment of High Purity Quartz Deposits in Main Island of Sumatra, Bangka-Belitung and Southern Riau Archipelago for Application National Solar Cells Photovoltaic Industry

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Abstract

In the future the total capacity of manufacturing photovoltaic industries will amount to 2.6"106 m^2 solar cells, which, assuming an average thickness of 300 microns, require 1,860 tons of high purity Si. To produce one kilogram Si suitable for manufacturing solar cells, 30 pounds are required, i.e. approx. 15 kg, (precisely 13.6 kg) of pure quartz. The application of High Purity Quartz (HPQ) in any array of end-use industries has expanded at an impressive rate over the past two to three decades. As research and development activities within the high purity quartz market are underway in full swing, new potential applications of the same have periodically emerged over the past decade due to which, the global demand for HPQ is ascending. This research is designed to provide information on quartz resources in some western part of Indonesian region that can be used further by the industry as a raw material for production of modern commercial products with high demand and added value. The HPQ market is presently characterized by a stable growth and annually increases by 3 to 5%. After being mined by open pit or dredging mining methods, quartz sand rocks need to be purified to get high purity quartz sand. The purification methods include classification, scrubbing, chemical acid leaching, flotation (fluorine flotation and non-fluorine flotation), gravity separation, magnetic separation, and microbial leaching. To produce one kilogram of silicon (Si) suitable for manufacturing solar cells (PV), it takes about 15 kg pure quartz. Cumulative intstalated photovoltaic capacity worlwide is 138.9 GW. The Indonesian government plans to install solar power by year 2025 of 6.5 GW while in 2050 it is targeted to be up to 45 GW, but the installed capacity in 2019 only reaches 0.2 GW. This study focuses on the evaluation of the HPQ potential in western part of Indonesian region, especially main island of Sumatra, islands of Bangka and Belitung as well as Riau Archipelago. In Sumatra the HPQ potential is in Pasaman of West Sumatra which associated with a shear zone-hosted hydrothermal quartz veins in granitic environment. The weathering product of Sibolga Granitoid Complex is mainly quartz sand which mainly associated with intermontane basin and beach placer. This quartz sand deposit is partly comprise High Purity Quartz (HPQ). The HPQ deposit is scarcely found in pegmatite vein. Quartz sand in the intermontane basin and beach placer of Sibolga consisting of 96-98% of SiO_2. The mineral characteristics of quartz in the Pasaman Granitoid Complex area based on petrological analyses the facies of granite range from Quart Monzonite to Alakali Granite. Based on the results of the XRF analysis, SiO_2 levels ranged from 63.13-93.37%. In quartz veins it has levels ranging from 65.41-99.97%. Four granitods intrusions in Bangka Island have been studied in the area, two along the south coastal Menumbing and Tempilang, and two further norths ara Pelangas and Kelapa. The contact of this intrusions with surrounding country rock is mostly concealed by younger Quaternary quartz sand deposit of granite weathering product. Some microscopic analyses of sand beach show high purity quartz as well rounded grains. Weathering of greisenization on Singkep Granitoid Complex produce thick layer and extensive of quartz sand that distributed in intermontane basin and beach area. PT. Timah have a lot of area for tin mining that cut off grade of Sn approximately 1-2%. The tailing after

tin mining in land is very huge in volume, because 95-98% is dominated by quartz sand. A large part of Selayar granitoid consists of porphyritic monzogranite with medium-coarse grained hypidiomorphic-granular matrix. Mega-phenocryst up to 4 cm in size, include microperthite, plagioclase and quartz. The rocks are characterized by the development of granophyric and micrographic textures, and the formation of mica. The latter is dissemninated in the groundmass usually between quartz and feldspar (Cahyono, 2014). Both of metamorphic and granitoid rocks of Selayar Island are partly weathered produce huge volume of quartz sand that distributed surronding beach area. Sand beach geochemical analyses show the grade of silica range on 97-99% SiO_2. The lithology of islands of Lingga, Sebangka and Tamiang are dominated by arenitic quartz sandstone of Cretaceous age (Sutisna, et all., 1996). The weathering product of these folded sandstone is huge volume of silica sand which deposited on the valleys of sincline and anticline as well as on the beach. Geochemical analysis of beach sand from some location in Sebangka island shows high of silica content, grading between 97 to 99% SiO_2.The investigation of quartz samples from Sumatra, Bangka-Belitung and Riau Archipelago in by XRF analysis characterized low to medium impurities of Fe_2O_3 and trace elements. The analyses Sebangka, for example, show that the SiO_2 content is very high (97-99% wt%) with very low concentration of trace elements. The translucent quartz of Pasaman shows optimistic results as HPQ ore resource after analysis.

Keywords: Photovoltaic, Quartz, HPQ, Sibolga granitoid complex,

Introduction

In the future, the total capacity of manufacturing photovoltaic industries will amount to 2.6"106 m^2 solar cells, which, assuming an average thickness of 300 microns, require 1,860 tons of high purity Si. To produce one kilogram Si suitable for manufacturing solar cells, 30 pounds are required, i.e. approx. 15 kg, (precisely 13.6 kg) of pure quartz. The application of High Purity Quartz (HPQ) in any array of end-use industries has expanded at an impressive rate over the past two to three decades. Cumulative intstalated photovoltaic capacity worlwide is 138.9 GW (Fig.1)

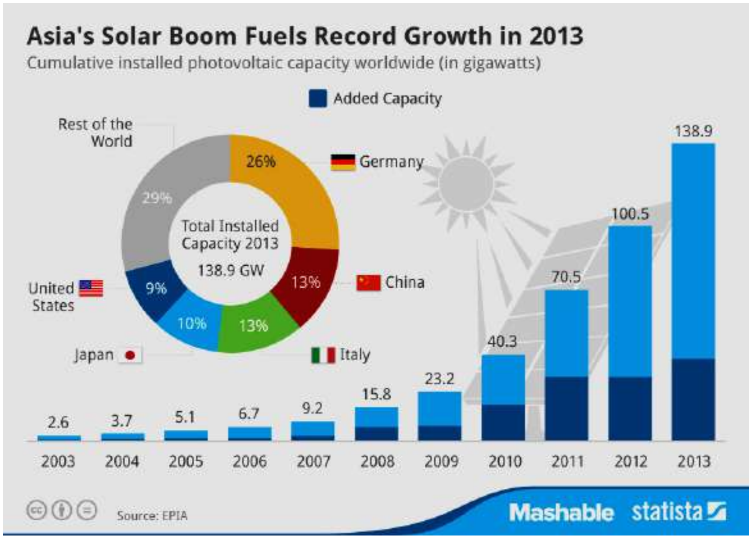

Figure 1. Worldwide instalated photovoltaic (EPIA, 2013)

The Indonesian government plans to install solar photovoltaic (PV) by year 2025 of 6.5 GW while in 2050 it is targeted to be up to 45 GW, but the installed capacity in 2019 only reaches 0.2 GW, the smallest capacity in SE-Asian (Fig. 2). Indonesia's hypothetical quartz

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sand reserves are estimated at 2.3 billion tons while the potential measured by the Director General of Energy and Mineral Resources is 441 million tons (Director General of IKFT-Ministry of Industry of the Republic of Indonesia, 2002).

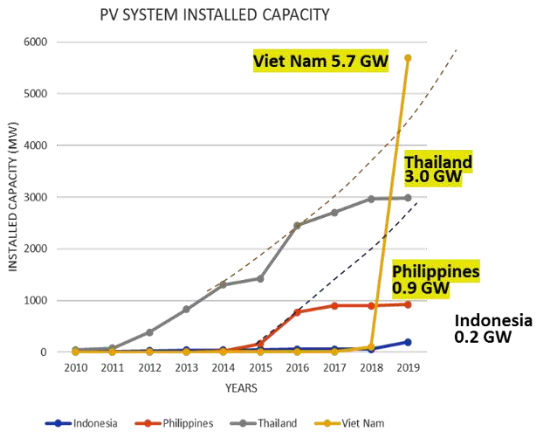

Figure 2. Installed PV in SE-Asian

This research is designed to provide information on quartz resources in some Indonesian region that can be used further by the industry as a raw material for production of modern commercial products with high demand and added value. The products of ultra-pure quartz are widely utilized in modern high-tech applications, such as optical fibers, semiconductors for the electronic industry, production of silicon cells for use in solar cell photovoltaic systems, as well as in industrial catalytic chemistry for the synthesis of catalysts, zeolites and adsorbent materials in general. To produce one kilogram of silicon (Si) suitable for manufacturing solar cells (PV), it takes about 15 kg pure quartz.

Raw crystalline material (crystalline silica) is the scientific name for a group of minerals consisting of silicon dioxide, (SiO_2) in which silicon and oxygen atoms are arranged in a repeated three-dimensional pattern. Although the chemical formula is quite simple, SiO_2 occurs in many different shapes and crystal structures. The most common forms of crystalline silicon dioxide are quartz, cristobalite, and tridymite. This group of minerals is composed solely of silicon and oxygen, the two elements found in greater abundance in the earth's crust. Crystalline silica is ubiquitous, found in rock deposits of all geological eras and in all global locations. Fig.1. shows the temperature and pressure conditions at which SiO_2 polymorphs are stable in a so-called phase diagram of SiO_2. A complete phase diagram would also show the conditions where SiO_2 forms a gas, above 2477°C at normal pressures, but since I don't have data on pressure dependence for that area, this temperature range is omitted (Wenk and Bulakh, 2003)

Quartz is characterized as high purity (HPQ) only when it contains less than 50 µg/g of impurities, including especially structurally bound trace elements (B, Li, Al, Ge, Ti, Fe, Mn, Ca, K, Na and P) in the quartz lattice, but also micro mineral inclusions and entrapped liquid. Ultra-pure quartz is rare in nature and larger deposits thereof even more rare. The few ultra-pure deposits found around the world include some kinds of quartz-rich granitic pegmatite and hydrothermal quartz veins (Müller et al.,2007)

ISSN 2963-9751

The production chain with quartz as raw material reaches the silicon metal Si with price 255 €/tons, silicon tetrachloride $SiCl_4$ sold for 630 € / tons and finally ultra-pure quartz for the electronics industry sold for 80,000 €/ tons. Modern technological applications span a huge range of scientific fields, from manufacturing crystal silicon for photovoltaic solar energy exploitation systems to the production of semiconductors for the electronics industry. To produce one kilogram Si suitable for manufacturing solar cells, 30 pounds are required i.e. approx. 15 kg, (precisely 13.6 kg) of pure quartz. The global demand for ultra-pure quartz is 30,000 tons annually. The annual production of quartz in Greece in recent years is about 15,000 tons. The annual quartz requirement for the thirteen Greek ceramics and glass industries is about 80,000 tons. (Vatalis and Benetis, 2014).

In the solar industry all signs point to further growth in the coming years. Production of c(crystalline)-Si in the 2007-2011 period saw Compound Annual Growth Rate (CAGR), of 45% while Si-production for 2010-2014 is forecast to slow to CAGR in the 20-30% range reaching 300.000-400.000 tpa(2010: 170.000 tpa). In 2010 solar cell production was up 118% compared with 2009, when more solar cells were produced than the combined total in all prior years (House et al., 2012). Specifications: The starting material is silicon crystals or amorphous silicon. The operation of a photovoltaic (P/V) cells requires three basic characteristic properties: 1. light absorption ability, generating either electron-hole pairs or excitons, 2. separation of the types of opposite charge carriers and 3. separate transfer of such charge carriers to an external circuit ((Vatalis and Benetis, 2014).

In the coming years, the total capacity of manufacturing photovoltaic industries will amount to 2.6"106 m^2 solar cells, which, assuming an average thickness of 300 microns, require 1,860 tons of high purity Si. To produce one kilogram Si suitable for manufacturing solar cells, 30 pounds are required, i.e. approx. 15 kg, (precisely 13.6 kg) of pure quartz. Therefore, the annual requirements of industries producing photovoltaic systems in Greece for high purity quartz will amount to 55,800 tons. Trade Prices: The Solar Grade Silicon (SOG-Si) produced following the most common process today is derived from SIEMENS and its subsidiaries. This method provides the greatest possible purity Si but consumes large amounts of energy resulting in high prices, up to € 40 /kg.

In the current scenario, owing to mounting environmental concerns and growing emphasis on utilizing greener sources of energy, the demand for solar components and energy has witnessed exponential growth, which, in turn, has directly impacted the growth of the global High Purity Quartz (HPQ) market. Rise in usage of new-generation wafers in semiconductors is driving the demand for HPQ. Demand for high purity quartz is expected to increase in the near future due to the growth of semiconductor and solar industries Demand for high purity quartz is also anticipated to rise in emerging regions, especially Asia pacific. The global electronics industry is expanding rapidly, owing to the increase in demand for electronics in developing economies such as India, China, and South Korea.

The application of High Purity Quartz (HPQ) in any array of end-use industries has expanded at an impressive rate over the past two to three decades. HPQ is extensively used in a wide range of applications, including solar cell or photovoltaic, semiconductor, optics, and lighting. As research and development activities within the high purity quartz market are

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underway in full swing, new potential applications of the same have periodically emerged over the past decade due to which, the global demand for HPQ is ascending. The HPQ market is presently characterized by a stable growth and annually increases by 3 to 5%.

Muller et al. (2012) determined that for quartz to be classifed as HPQ, the total impurity content should be less than 50 µg g−1. The high content of some impurities such as Al, Ti, Ge and Fe affects drastically the quality of quartz (Minami et al., 2011). For example, Al content can generate devitrifcation, resulting in cristobalite white spots, whereas Ti and Fe can contaminate the silicon melt (Santos, et e., 2015) derived from HPQ during industrial applications. Another type of impurity in quartz is fluid inclusions. Despite the fact that fluid inclusions are less difficult to remove in quartz compared to metallic impurities (Ti, Fe, Ge),

HPQ is witnessing rise in demand for use in various applications, including the production of semiconductors and solar photovoltaic cells. The growing emphasis on utilizing renewable energy due to mounting environmental concerns is another factor that is expected to generate considerable demand for high purity quartz during the forecast period. Market players are projected to improve the quality and consistency of their products by upgrading existing processing technologies. Due to the growing market competition, companies in the high purity quartz market should increase research in new technologies such as multi-channel laser sorting to gain an advantage over other manufacturers.”

After being mined by open pit or dredging mining methods, quartz sand rocks need to be purified to get high purity quartz sand. The purification methods include classification, scrubbing, chemical acid leaching, flotation (fluorine flotation and non-fluorine flotation), gravity separation, magnetic separation, and microbial leaching. In practice, we usually combine these methods accordingly to improve the grade and output of quartz sand, fully utilizing quartz sand resources. There are six quartz sand purification processes (also called quartz sand beneficiation methods) used by quartz sand processing companies and laboratories : 1 Comminution, classification, and magnetic separation, 2. Communition, classification, and magnetic separation, and flotation, 3. Roasting water quenching, acid leaching, and flotation, 4. Scrubbing, grading, grinding, magnetic separation, flotation, acid leaching, 6. Ultra—fine comminution, classification, flotation, microwave-assisted acid leaching.

This study focuses on the evaluation of the HPQ potential in western part of Indonesian region, especially main island of Sumatra, islands of Bangka and Belitung as well as Riau Archipelago (Fig. 3).

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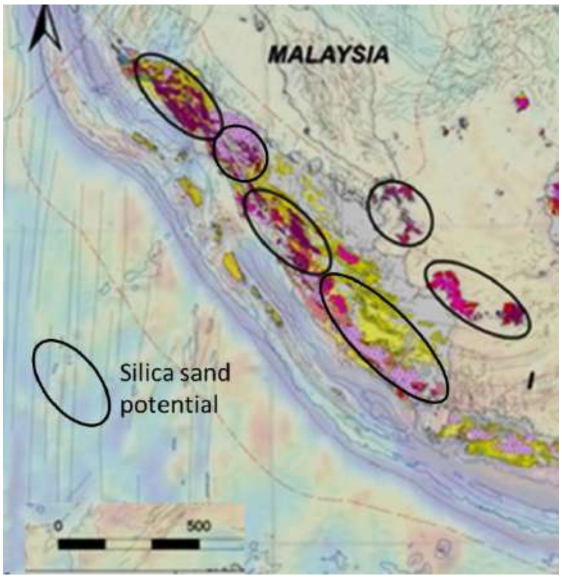

Figure 3. Map of deposit silica mineral potential in main island of Sumatra, Bangka-Belitung and Riau archipelago. Map is cut from regional geology of Indonesia (GSI, 2011)

In Sumatra the HPQ potential is in Pasaman of West Sumatra which associated with a shear zone-hosted hydrothermal quartz veins in granitic environment. The shear zone quartz-rich rock is monomineralic and consists of both milky and translucent varieties. The XRF analytical techniques was used to assess the chemical purity of both quartz varieties. These compositional analyses show that all quartz samples have SiO_2 content of 65.41-99.97% wt% . The impurities is very low concentrations of all the other elements.

Translucent quartz when compared to the milky quartz variety shows low concentration of most of the elements including the following principal impurities: Al (mean 107 µg g−1), Ca (mean 27.85 µg g−1) and Fe (mean 26.05 µg g−1). Bubble generation in the samples after fame fusion over a silica plate was assessed to test the suitability of the quartz in industrial uses. The results also indicate that the majority of impurities are likely hosted by fuid inclusions and thus the quartz can be upgraded to HPQ after purifcation by suitable methods.

Sibolga Granitoid Complex – North Sumatra

The Late Paleozoic – Mesozoic geological evolution of the South East Asian metallogenic province including Bangka and Belitung islands are marked generally by S-type granitoid emplacement coevally with a regional tin mineralization. However, Sibolga Granitoid Complex of North Sumatra shows contrastingly characteristic A-type granitoid. The $FeO^{*}_{(total)}/MgO$ ratio versus SiO_2 (Lehmann, 1990) show also an effective discriminant and most granitoids of Sibolga Complex falling in A-type field as well as have higher ratios than the I- or S-type granitoids. Four facies have been identified based on texture and mineralogy, biotite granites, biotite syenites, hornblende syenites, and acid meta-volcanics. The biotite granites occupy most of the granitoid complex, whereas biotite syenites and meta-rhyolites exposed as an east-west trending belt in the central part of the pluton. Their chief minerals are

ISSN 2963-9751

quartz, K-feldspar (mostly microcline), plagioclase albite, biotite, with minor hornblende and accessory minerals (Fig.4).

The Sibolga granitoid has invaded the rocks of Kluet Formation, radiometric dating of the granitoid by K/Ar methods on biotite yields ages of 257±24 Ma and 217.4±4.4 Ma by Rb/Sr on biotite (Barber, et al., 2005). The pluton is composed of equigranular biotite granite and porphyritic biotite syenite (Late Carboniferous) and was intruded by hornblende syenite of Hatapang (Triassic) and mafic dykes such as lamprophyre (Subandrio and Suparka, 1994; Subandrio et al., 2009; Subandrio et al., 2011).

Figure 4. Granitoid rock of Sibolga is primary resources for pegmatite quartz vein and silica sand on intermontane basin and down stream area as well as western beach.

The granitiod rocks, show SiO_2 contents of ~69-76%, and are enriched in alkalis, high Rb, Zr and Ga with high Ga/Al ratios, but depleted in Ba, Sr and transition metals (Subandrio et al, .

The rock chemistry indicated by slightly, metaluminous to peraluminous composition. Other geochemical signatures suggest that the granitoid belong to transisitional environment between late orogenic and anorogenic as well as within plate environment. The A-type granitoid of the Sibolga, proposed for petrogenetic models of an interaction of mantle-derived magmas and overlying crustal rocks. After comprehensive petrology and geochemical analyses that coupled with Late Paleozoic-Mesozoic history of Sumatra, suggested that the A-type granitoid of the Sibolga associated with anorogenic or rift related environment.

The weathering product of granite is mainly quartz sand which mainly associated with intermontane basin and beach placer. This quartz sand deposit is partly comprise High Purity Quartz (HPQ). The HPQ deposit is scarcely found in pegmatite vein. Quartz sand in the intermontane basin and beach placer of Sibolga consisting of 96-98% of SiO_2.

Pasaman Granitoid Complex – West Sumatra

The mineral characteristics of quartz in the research area based on geological mapping data on granite range from 30-40%. The results of the quartz XRD analysis had levels of 23.2% and 28.4%. Based on the results of the XRF analysis, SiO_2 levels ranged from 63.13-93.37%. In quartz veins it has levels ranging from 65.41-99.97%. Quartz in veins has an average of 95.323% in granite having an average content of 77%. Quartz in veins has a content of 18.323%

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higher than quartz in granite. The volume of quartz in granite was identified at 34,129,385.98 tons and in veins at 1,267,113.40 tons. The valuation value of quartz in granite at the research site is low-grade but still economical considering its relatively large deposits. The price of per ton is estimated at 10-12 USD. The valuation value of quartz in medium veins, is still economical considering its relatively large deposits. The price of per ton estimated at 15-20 USD.

Bangka Island

Bangka is one of the Indonesian tin islands within the tin bearing granitoid belt which can be followed further northwest through Peninsular Malaysia, Thailand and Burma. Along this belt tin mineralization exhibits close to relationship with granitoid intrusions and regional tectonic setting. Bangka consist isolated outcrops of granitoid plutons which are separated by extensive area of alluvial deposits and strongly folded meta-sediments (Soeria-Atmadja et al., 1986); There are about 14 granitoid masses of which Klabat and Buluh are the largest intrusion (Fig. 5). Dating by Priem et al. (1975) gives the age range of granitoids of Bangka, Belitung and Pulau Tujuh Islands as Late Triassic: Rb/Sr age (127 Ma) is closely similar to K/Ar age.

Figure 5. The famous tin rich granitoid rocks of Bangka island with enormous silica sand deposit from natural processes and tailing after tin mining.

The southern part of West Bangka is underlain mostly by folded and contorted Paleozoic and Triassic metasediments and lowgrade metamormorphic rocks, with major fold axes striking almost east-west. Statistical studies of fold axes reveal three different directions northeast-southwest and almost east-west successively representing Paleozoic, Late Triassic and Poast Triassic deformations. The rocks include meta-quartzite, quartz arenite, claystone, siltstone, phyllite and low grade schist. In some parts they are intrude by Late Triassic granitoid and covered by extensive alluvial deposits (Soeria-Atmadja et all., 1986).

Four granitods intrusions have been studied in the area, two along the south coast ata Menumbing and Tempilang, and two further norths ara Pelangas and Kelapa. The contact of this intrusions with surrounding country rock is mostly concealed by younger Quaternary deposit. The nature of contact is commonly discordant indicating emplacement at a late tectonic stage of Late Triassic deformation. So far no indications of mappable thermal auerols have

ISSN 2963-9751

been observed around the granitoid intrusions. However, petrographic studies of few samples point to hornfels thermal metamorphism (Soeria-Atmadja, et all., 1986).

Riau Archipelago

Riau Archipelagos is located in the south-eastern part of Semenanjung Malaya. The biggest island in this archipelago is Batam and Bintan which very close to Singapore and Malayan Peninsula. In the southern area (Lingga, Sebangka and Tamiang islands) is tend to be smaller in size but seem to be elongated with strict direction on NW-SE. The morphology is characterizing by undulated smooth hills with the highest peak approximately 200m above sea level. The irregular coast's line of almost islands in Riau archipelago characterized by white sandy beach that partly comprise of quartz silica. The lithology of primary rock consists of granites and meta-sedimentary until low-medium grade metamorphic rocks. Some granite plutones in Singkep are also mineralized by Sn-W-Fe that charaterized by very intensive greisenization which give enormous silica quartz deposit. The weathered of greisen granites produce bauxite, kaolin and quarts sands

Singkep Island

Singkep is the island located on the most southern part of Riau archipelago. The lithology of this island is characterized by metamorphic complex of Persing and Bukit Duabelas of Carboniferous-Permian age (Sutisna, et al., 1994). This metamorphic comples is cross cut by Triassic and Jurassic Muncung and Tanjungbuku granite intrusions that give also tin mineralization with very intensive and extensive greisen alteration areas . The SiO_2 contents the Singkep granites is 71.16 to 73.02wt% (Usman, 2015). Plot on SiO_2 vs. Na_2O+K_2O diagram shows Singkep granite is classified into granite to alkali granite. K_2O content ranges from 3.49 to 5.34 wt% and can be classified as calc-alkaline type.

Weathering of greisen alteration zone produce thick layer and extensive of quartz sand that distributed in intermontane basin and beach area. PT. Timah have a lot of area for tin mining that cut off grade of Sn approximately 1-2%. The tailing after tin mining in land is very huge in volume, because 95-98% is dominated by quartz sand.

Lingga-, Sebangka- and Tamiang Islands

In general, the topography of southtern part of Riau archipelago is gently and dominated by slighly undulated topography. Islands Lingga of Lingga, Sebangka and Tamiang are controlled by folding structure with longitudinal axis trending in NW-SE direction. The lithology of these islands are dominated by arenitic quartz sandstone of Cretaceous age (Sutisna, et all., 1996). The weathering product of these folded sandstone is huge volume of silica sand which deposited on the valleys of sincline and anticline as well as on the beach (Fig. 6).

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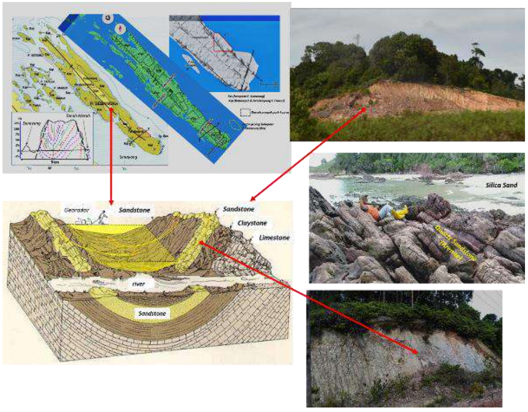

Figure 6. Deposit of high grade silica sand associated with folded Cretaceous sandstone formation in Sebangka island of Riau Archipelago.

Geochemical analysis of beach sand from some location in Sebangka island shows high of silica content, grading between 97 to 99% Si*O2*. This southern part of Riau archipelago is characterized by some remnants of granite plutone, folded metamorphic and meta-sedimetary rocks of Jurassic and Cretaceous age. Lingga, Sebangka and Tamiang are the group of elongated islands that trending NW-SE and almost comprise Cretaceous of thick and strongly folded arenitic quartz sandstone. Weathering in these three islands give huge of high purity quartz sand which distributed in sincline valley and along the beach. The grade of quartz sand taken from Sebangka beach is up to 99.50% SiO_2.

Selayar Island

Selayar island is an small island that located in the north-eastern part of Singkep island. This small island comprise metaporphic complex of Persing (Carboniceous-Permian age) that cross cut by granitoid rock of Muncung of Triassic age (Sutisna et a., 1994).

A large part of Selayar granitoid consists of porphyritic monzogranite with medium-coarse grained hypidiomorphic-granular matrix. Mega-phenocryst up to 4 cm in size, include microperthite, plagioclase and quartz. The rocks are characterized by the development of granophyric and micrographic textures, and the formation of mica. The latter is dissemninated in the groundmass usually between quartz and feldspar. Other structural features in the Selayar Island are jointing and faulting; the former is developed in both the granitoid and country rock. The joint pattern obtained from systematic measurements seem seem to correspond to two principal stress directions representing Late Triassic deformations (Cahyono, 2014).

Both of metamorphic and granitoid rocks are partly weathered produce huge volume of quartz sand that distributed surronding beach area. Sand beach geochemical analyses show the grade of silica range on 97-99% SiO_2.

Conclusion

The quarzitic material is very common in nature, it is produced in many countries and also consumed locally and globally, combined with different prices for most products. According to (GWP, 2010) the suitability of silica sand and high purity quartz for different uses is

ISSN 2963-9751

determined by the quality of the quartz in terms of (1) chemistry - typically the grade is determined by the iron content of the sand in the ground. High grade sand is low in iron (Fe_2O_3), (2) Grading or grain size distribution of a natural sand may be suitable for a limited range of uses. Washing and sizing greatly increases the possible product range, by separating the coarser and finer fractions from the main product (Vitalis and Benetis, 2014). The requirements for very high grade, low in iron silica sand in the glass, chemical and ceramic industry can be used if the iron content of the silica sand is naturally low or can be lowered sufficiently and economically through processing.

The investigation of quartz samples from Sumatra, Bangka-Belitung and Riau Archipelago in by XRF analysis characterized low to medium impurities of Fe2O3 and trace elements. The analyses Sebangka, for example, show that the SiO_2 content is very high (97-99% wt%) with very low concentration of trace elements. The translucent quartz of Pasaman shows optimistic results as ore resource after analysis. Principal impurities in it are Al (mean 107 µg g−1), Ca (mean 27.85 µg g−1) Fe (mean 26.05 µg g−1) and Ti (mean 23.75 µg g−1).

The western arhipelago of Indonesia have enormous reserves of silica. These reserves are scattered in magmatic, metamorphic and sedimentary rocks as well as their weathering products. Silica deposits with high purity quartz (HPQ) occur as veins such as those found in Pasaman - West Sumatra. High grade SiO_2 (up to 99%) is found on the sand beaches as well as on the intermontane basins that associated with valleys of granite hills and syncline folds on the islands of Sebangka and Lingga.

According to the "zero carbon emission" consensus in year 2060, the use of fossil energy will decrease drastically. The combination of very large deposits of coal and silica and the small portion of installed solar cells photovoltaic, requires Indonesia to utilize fossil energy resources, especially coal reserves to develop the solar cell industry based on national silica deposit (Fig.7).

Figure 7. Simplified of work flow of fabrication proces from silica sand to single quartz crystal until solar photovoltaic panel.

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The Applications of Slope Stability Radar for Open Cut Gold Mine

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Abstract

An open cut mining method is one of surface mining method to extract economical ore found near the earth surface with the primary goal to extract as much ore as possible in a safe and economical manner. To ensure that this goal is achieved, a comprehensive and robust slope monitoring campaign become an integral part of mining operation.

In order to define the best slope monitoring tools to be applied during mine operation, the mine should adequately consider various objective-related monitoring strategies. The commonly used monitoring strategies are based on the monitoring tools (point and area monitoring) as well as monitoring approach (tactical – short range and short time -- and strategic – broad-area and long term).

One of the most sophisticated real-time area monitoring tools is Slope Stability Radar (SSR). SSR in open cut mines are mostly used as a critical-targeted highwall monitoring system to ensure the safety of personnel including machineries from slope failure hazard. Furthermore, SSR could also be utilized to help the mine ramp up their productivity by optimizing their overall slope angle, drill blast technique (by evaluating the blast effect to the slope), monitoring in-pit or out-pit waste dump slope, and monitoring tailing storage facility.

All in all, an optimally utilized SSR will leverage mine companies to achieve their goals to maximize the ore extraction without any harm to the people, machinery, and environment.

Keywords: Open pit, Gold mine, Slope monitoring, Slope stability radar (SSR)

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Mine Geology: Present and Future Challenges in Underground Mine Operation

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Abstract

PT. Freeport Indonesia (PTFI) mining operations have been in place since 1967 with production commencing in 1973. It had been primarily an open-pit operation but has had a significant underground mining component from a series of caving operations that began in the 1980s. As the major Grasberg open pit mine reached the end of its mining life in 2019, PTFI transformed into total underground operation with production from its several deposits. The underground operation, mines in complex geological condition and in various mining stages, includes a spectrum of challenges with varying levels of associated risk. The paper describes various risk and challenges faced in underground mine operation and how the Geology department of PT. Freeport Indonesia aligns its business process to manage the challenges and to add value to the underground mine operation.

Keywords: Mine geology, Underground mine.

Introduction

PT. Freeport Indonesia Mining District

PT. Freeport Indonesia (PTFI) minerals district is in the Jayawijaya mountain range on the Western half of the island of New Guinea in the Indonesian province of Papua. The discovery of a large outcropping of chalcopyrite-rich magnetite skarn at ~3,600m elevation level by Jean-Jacques Dozy (1936), followed by later exploration efforts by Forbes Wilson of the Freeport Sulphur Company in 1960-1970, has led to one of the largest mining complexes in the history of Indonesia.

PTFI mining district is an exploration success story. The continued and extensive brownfield exploration program has led to discovery of giant deposits that is mostly controlled by the two main igneous intrusion, Ertsberg Intrusion and Grasberg Intrusion.

The East Ertsberg Skarn System (EESS) is a large skarn and porphyry deposit. Since the initial discovery of the orebody named *Gunung Bijih Timur* (GBT), PTFI continued to mine the EESS orebody utilizing open pit and underground mining methods. PTFI has finished its third lift of the EESS deposit through the Deep Ore Zone (DOZ) mine in 2020 and continues in the Deep Mill Level Zone (DMLZ) mine operation in 2590-3000 level.

Grasberg Igneous complex, host to giant porphyry Cu-Au deposit whose hypogene mineralization is remarkably high grade [1], ended its open pit mine life in 2019 but continues ramping up underground production through the Grasberg Block Cave (GBC) mine.

ISSN 2963-9751

Big Gossan deposit, a near-vertical deposit of pyroxene-garnet-chalcopyrite skarn and hosted in the Tertiary Waripi Formation [2], is mined through the transverse blasthole open-stope mining method.

Kucing Liar deposit, a sediment-hosted of magnetite-chalcopyrite-garnet-pyroxene skarn [3], has become one of the latest resources of PTFI. The mine is currently ramping up its development stage and will be mined with the block cave mining method.

The PTFI mining district is illustrated in Fig. 1. After Grasberg ends its open pit operation in 2019, PTFI became a total underground operation. PTFI is currently mining its large deposit simultaneously in DMLZ, GBC and Big Gossan mine.

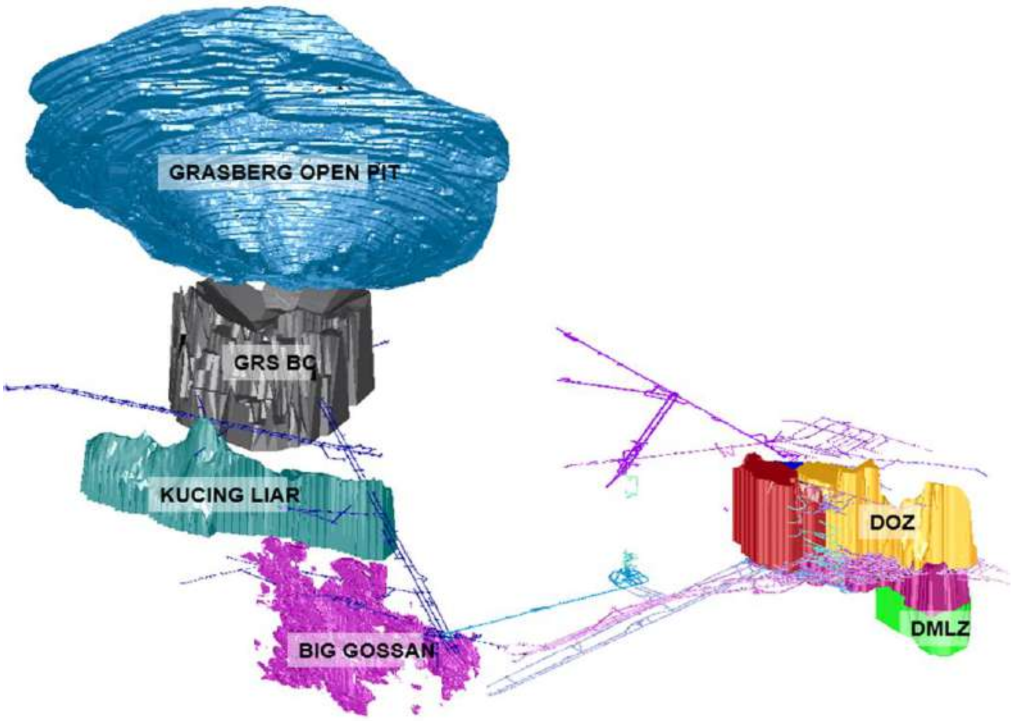

Figure 1. PTFI mining district illustration (east west cross section)

Underground Mine Operation

Comprehensive discussion on various underground mining method and system are beyond the scope of this paper. There are detailed accounts of modern underground mining methods and criteria [4]. The mining principles and methods must meet the geomechanical and operational challenges posed in the recovery of ore deposits. A common industrial requirement is to establish the mining method most appropriate for an orebody, or segment of an orebody, and to adapt it to the specific conditions applying in the prospective mining domain. In addition to orebody characteristics that influence method selection, the various mining methods have, themselves, operational characteristics which directly affect their scope for application. These

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operational characteristics include mining scale, production rate, selectivity, personal ingress requirements and extraction flexibility.

Block Cave Mining Method

The block caving mining methods are the most preferred mass mining option especially in deep and massive orebodies, where the objectives are low cost and high production rates. This mining method exploits caving technique, with the aim to have the orebody break under the natural stresses and allow recovery at high rates and comparatively low cost, allowing economical mining of large deposits by underground mining. This means transforming the insitu ore into a mechanically mobile state by drilling and blasting. The mobilization of the ore into a caving takes advantages of the natural pattern of fractures in the rock, the stress redistribution around the cave boundary, the rock strength of the ore domain and the capacity of the gravitational field to displace unstable blocks from the cave boundary.

At a particular elevation in the orebody, an extraction layout is developed beneath a block or panel of ore which has plan and vertical dimensions suitable for caving. An undercut horizon is developed above the extraction level. Failure and progressive collapse of the undercut are initiated, in which the process is called undercutting. The ore body is expected to swell and fail. The removal of the fragmented ore on the extraction panel level through drawpoints will incudes caving of the material (figure 2). Vertical flow of the orebody within the cave boundary is therefore directly related to the extraction of fragmented ore and to the swell of ore in the disintegration and caving process.

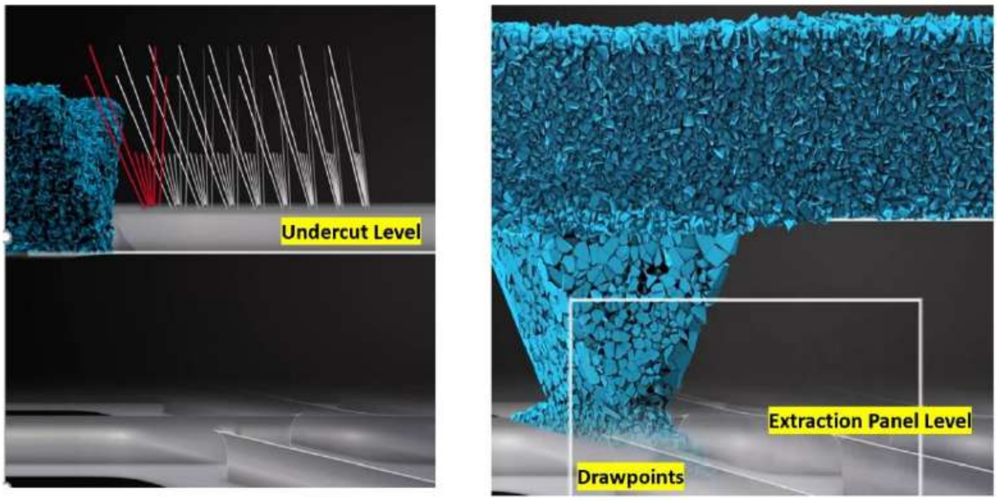

Figure 2. Block cave mining operation stage

The success of block caving operations lies on the geological and geomechanical knowledge of the orebody. Factors to be considered in evaluating the caving potential of an orebody include the pre-mining state of stress, the rock mass characterizations (joint-fracture frequency, weak vein distribution and other structural geological domain), and the geology structural orientation for determining the cave propagation orientation.

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The block caving method has been historically implemented by PTFI since the first underground mine operation in the GBT mine, the top level of EESS deposit. PTFI has two major underground block caving mines in operation in GBC and DMLZ, while also continuing to develop KL mine infrastructure.

Stope Mining Method

Stope mining method is one of the selective mining methods in the underground mining world. Ore is produced from a stope block in which extensive development has been undertaken prior to stoping activity. Stope pre-production development consists of an extraction/ production level, drilling level and slot raise (figure 3). An expansion slot is developed by enlarging the slot raise, using parallel hole blasting, to the width of the stope. Ore is fragmented in the stope using ring-drilled or long parallel blast holes, exploiting the expansion provided by the stope slot. Broken ore is mined through the production level. Stope mining method is expensive in terms of mining costs with low production rate, compared to mass mining block caving method.

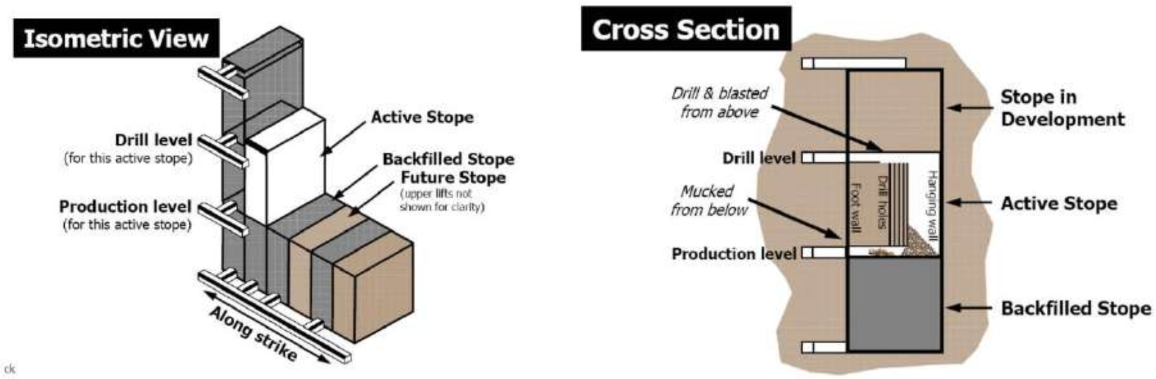

Figure 3. Stope mine conceptual design

PTFI applies transverse blasthole open-stope mining method for Big Gossan deposit. The narrow and near-vertical skarn mineralization style following Ekmai and Waripi formation bedding, but higher grade compared to porphyry style deposit, fits and is ideal for stope mining method in Big Gossan. The primary stope sequence is produced ahead the secondary stope sequence. Finished and empty stope is then filled by paste material to manage the stress distribution due to open void, prior continuing to the next secondary sequence.

Underground Mine Production Risk and Challenges

PTFI mining district is currently mining the lower portion of its large deposits as explained in the previous chapter. The complex insitu of geological, geotechnical and hydrology setting itself has already raise a series of challenges for operating underground mass mining operation. The route by which a mining project develops, from the earliest scoping study to the final

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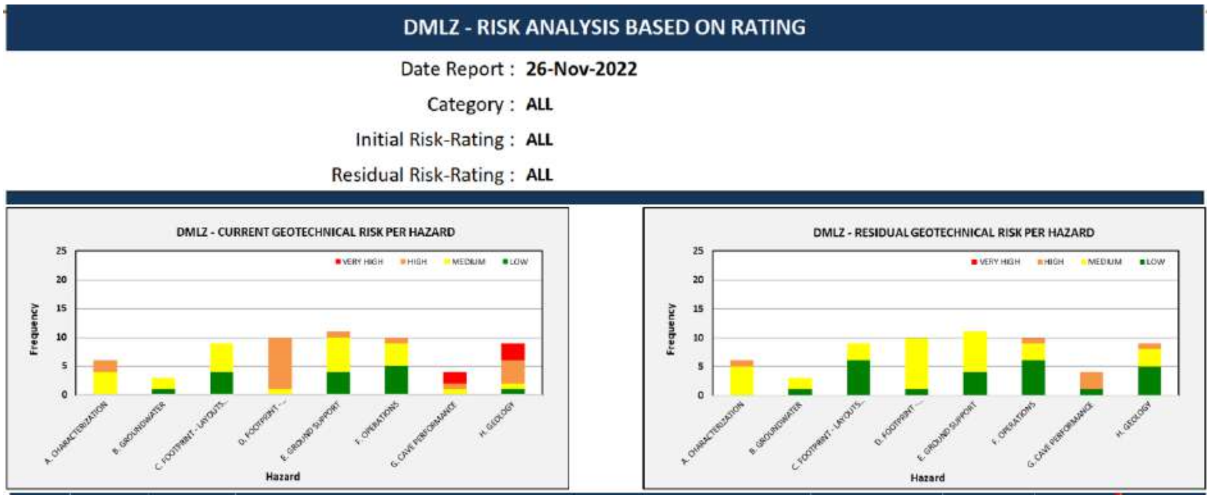
construction stage through to operation, reflects an ever-increasing level of complexity with more and more detail added.

It is also very common that how the company operates its underground mine can be shifted from what was originally planned during the feasibility studies. Realities change as the project shifts from pre-production stage, development stage and production stage. The knowledge of geology, geotechnic and hydrology aspects evolves when more data is obtained. The dynamic change will eventually alter the mine operational strategy and mine plan.

PTFI Geoengineering division develops a risk-based approach to scope definition and to manage the geology, geotechnical and hydrology (geoscience) risks at underground mine operations, as explained in [5]. The approach focuses on identifying, managing, and communicating those risks from planning through operational stages. Risk management is centered around an online platform that enables users to reference and determine initial, current, and residual risk ratings (figure 4).



MINE CODE	LOCATION	ID	HAZARD DESCRIPTION	UNMITIGATED / INITIAL RISK	% RISK ACHIEVEMENT	CURRENT RISK	RESIDUAL RISK
DMLZ		H.1	High grade and metal variance between Mine and Mill leading to lower than expected grade and metal tonnages	VERY HIGH	10%	VERY HIGH	MEDIUM
DMLZ		H.10	Not meeting the SOX requirements	HIGH	100%	LOW	LOW
DMLZ		H.2	High grade and metal variance between Mill and Port leading to lower than expected grade and metal tonnages	VERY HIGH	0%	VERY HIGH	MEDIUM
DMLZ		H.3	Geologists are not suitably trained to carry out their duites and support the mining operations	HIGH	25%	HIGH	LOW
DMLZ		H.4	Penalty minerals affecting metal recovery resulting in lower than forcasted grades and metal	HIGH	20%	HIGH	MEDIUM
DMLZ		H.5	Unplanned hot muck DPs causing production delays due to elevated heat in panels	MEDIUM	50%	MEDIUM	LOW
DMLZ		H.6	Unplanned combustibles leading to unsafe working conditions and production delays	HIGH	50%	HIGH	LOW
DMLZ		H.7	Unplanned gases found in headings leading to unsafe working conditons and production delays	VERY HIGH	0%	VERY HIGH	HIGH
DMLZ		H.8	Drilling providing poor data for logging and analysis and leading to unrepreseative models leading to lower than expected m	HIGH	0%	HIGH	LOW

Figure 4. Risk register online platform

The risk register system is assessed accordingly by the geoscience practitioners in PTFI in a timely manner. This will also enable management to focus their efforts on scope definition, manpower and budget allocation to manage the risk and challenges. The risk register can be accessed by various underground mine departments through the online platform and any action plan can be updated accordingly. Reporting and auditing are done in timely manner to mitigate the residual or remaining risks.

ISSN 2963-9751

These are several geosciences risk and challenges in underground mine operations that have been successfully captured by PTFI Geoengineering division.

Rock Mass Characterization Challenges

Geological data (rocktype, alteration, structures, and other mineralogical features) defines the character of rock mass domain. Rock mass characterization is fundamental to all underground mine planning. It will drive ground support system in the development stages and the caveability, hydraulic radius, drawpoint spacing and the fragmentation extraction management in block caving mine production stage.

Ground support systems and applications are crucial from the development stage to the life-of-mine in underground mine operations. The ground support aims to compensate for the imbalances that occur around the excavations due to the distribution of the in-situ ground stress. As the cave initiates and propagates through the undercutting and extraction process, the rock in the tunnel will experience load static stress and the ground deformed following the change of stress regime due to mining activity. Ground support system and application are becoming increasingly complex when PTFI mines the lower portion of the ore deposits. High-stress environments, due to vertical elevation and competent rock mass rating, cause challenges to design an optimum ground support to safely continue mine production.

Caveability and Fragmentation Challenges

Caveability assessments are typically undertaken to assess whether the mining geometry is sufficient to induce natural caving. It is becoming important as PTFI establishes large-scale cave mines in hard, competent rock masses (such as in DMLZ mine and several rock domains in GBC mine) and the cave are being established at considerable depths (greater than 1,000 m) with high cave column heights. Cave mining was not perceived to be suitable for those conditions. This will create unfavorable conditions in achieving the expected hydraulic radius for cave propagation as well as for fragmentation forecasting during the extraction process.

The under estimation of caveability will result in larger hydraulic radius requirements, delay the caving propagation stage and coarser fragmentation than planned. At the local scale, cave propagation is the focus which is the ability to propagate the cave locally through planned draw to achieve an ideal cave shape. The rate of propagation relative to the height of draw typically varies across the footprint as a function of the local cave back stress and rock mass strength and is termed the caving rate.

Fragmentation in cave mining comprises primary and secondary fragmentation. The primary fragmentation involves the separation of particles from the original intact rock the cave back primarily controlled by induced stress during propagation. This is of interest because primary fragmentation controls the early flow zone width and draw interaction. The primary fragmentation is sensitive to the Cave Propagation Factor (CPF) [6]. CPF is equivalent to the conventional assessment of overstressed rock unravelling potential (i.e., stress induced gravity assisted failure processes) and is equal to the ratio of cave back stress to rock mass strength. This ratio varies across the cave back depending on local rock mass strength, rock unit stiffness

ISSN 2963-9751

contrasts, and cave back geometry. Secondary fragmentation is when the rock fragment enters the discharges point, which is the drawpoints in the extraction level. Secondary fragmentation derives from the reduction in size of caved rocks as they descend through the draw column [7]. It is generally smaller than primary due to comminution in the cave column. It becomes the main interest because secondary fragmentation is the dominant control on hang-up frequency, secondary breakage requirements, and drawpoint availability. Hang-up is defined as caved ore obstructing the natural flow of material at drawpoints, resulting in temporal production stoppage. Hang-up frequency is considered as a key parameter to assess how this phenomenon influences the available production tonnage of short-term scheduling Hang-ups and oversize rocks resulting from cave fragmentation are generally dealt with secondary breaking, a process which involves additional drilling and blasting of oversized fragmentation in drawpoints. This implies additional work and less drawpoint availability for production.

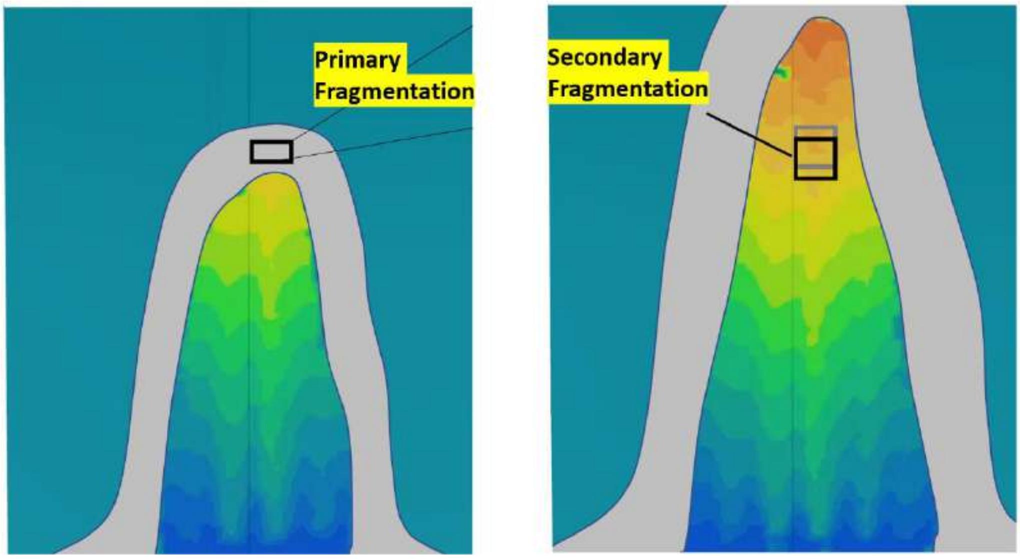


Figure 5. Illustration of primary and secondary fragmentation in cave perspective

The Geoengineering Division drives the caving and fragmentation forecasting and monitoring to all PTFI block cave mines. Lessons are learned from the massive, less jointed and veined nature of several rock mass domains. The analysis and forecasting tools are updated to adjust the production plan. The Geology department closely monitors fragmentation to reconcile the forecasted with the actual fragmentation in the drawpoints.

Rockburst and Seismicity Challenges

Rockburst and seismicity are the latent risk for underground mass mining condition in competent rock mass and in the deeper elevation, which creates high vertical in-situ stress. Rockburst is defined as damage to an excavation that occurs in a sudden or violent manner and is associated with seismic events [8]. The damage mechanisms are, respectively, volume expansion (bulking) of the rock due to fracturing, violent ejection of block due to seismic

ISSN 2963-9751

energy transfer, and seismically induced rockfalls (figure 6). Peter Kaiser in the Canadian rockburst support handbook explained that the seismic event may be either remote from the rockburst location, in which case various damage processes may be triggered by the incoming seismic energy, or the seismic event may lie directly at the damage location, in which case the damage and the seismic are intimately related.

Figure 6. Illustration of rockburst event

One of the causes of a rockburst event is when the stress in the boundary of an excavation exceeds the rockmass strength. The stress generally increases and shifts during the mining stage, and the rock mass strength may degrade over time due to weathering and groundwater involvements. The failure process in the tunnel is sudden and violent if the stored strain energy in the rockmass is not dissipated in a gradual manner.

Wetmuck Spill Challenges

Wetmuck is a term used at PTFI to describe ore that has a sufficient water and fines content to present an inrush hazard. This type of ore and resultant wet muck inrush, locally termed as "spill", was first experienced in the underground operations in 1989 and is generally understood to be a consequence of comminution within the draw columns and the high rainfall experienced at the mine. Three conditions for the wetmuck material forming are [9]:

- The material must be fine grain (grain size < 5cm) with more than 20% grain size > 5cm.
- The material has to be loose grain (less than 90% optimum density).
- The material must be saturated or near saturated (80%).

ISSN 2963-9751

All drawpoints in the PTFI block caving mines are classified based on fine percentage and water saturation (figure 7). The drawpoint wetmuck class dictates how the mining procedures for each drawpoints and/ or panel production.

Level of Wetness (Water Content)	*Material Size > 5 cm (M)*		
	M > 70% (dominated by coarse material)	*30% < M < 70% (mixture of coarse and fine/medium material)*	*M < 30% (dominated by fine material)*
Dry (<8.5%)	**A1**	**B1**	**C1**
Moist - No flowing water (8.5 to 11%)	**A2**	**B2***	**C2**
Wet – Saturated with/without flowing water >0.5 gpm (>11%)	**A3**	**B3**	**C3**

Figure 7. Drawpoint wetmuck classification

The learning curve and understanding of wetmuck handling management at PTFI are built on long-term experience from the previous mines. The future challenge is how to develop forecasting tools in terms of wetmuck spill risk and susceptibility to safely mine the wetmuck ore and to optimize future mine plan. The fines prediction is one of the domains, related to fragmentation tools explained above and is continuously improved by Geology department.

Grade Optimization Challenge

The Big Gossan stope mining operation requires comprehensive orebody knowledge. The orebody boundaries must be well-delineated to optimize the stope shape and to reduce potential dilution. The rockmass and hydrological characteristics must be well-defined prior excavation. Big Gossan grade control practices [10], from grade control drilling program to stope reconciliation, are crucial to determine the success of extracting from the Big Gossan orebody. It is imperative for the Geology department to present the highest confidence level of geological (grade distribution, ore boundary, structures, and potential groundwater) data ahead of pre-production stage.

The PTFI block cave mine continuously elevates its understanding of the flow material in the block cave mine. The main goal is to forecast the mined grade and to mitigate risk from dilution material. Estimation of ore recovery and waste dilution requires good knowledge of parameters such as geology and grades distribution of the orebody, cave propagation, tonnage mined location, and composition of the actual caved rocktype in the drawpoints. It is a very elaborate process from end-to-end, from model, mine to mill. However, the demand is high for delivering the grade and tonnage from ore as forecasted at PTFI block cave mines.

ISSN 2963-9751

Geology Department Improvement in Managing the Underground Mine Challenge

The Geology department, part of Geoengineering division, is fundamentally responsible in collecting, analyzing, modeling and properly using all the geosciences information to optimize mine operation in a safe efficient manner. The business process of geology departments includes covering many clients in PTFI business environments, including Mine Operation Department, Mine Engineering Department, Metallurgy Department, Environmental Department and from internal Geoengineering Division, such as Geotechnical Department, Hydrology Department and Civil Engineering Department (figure 8).

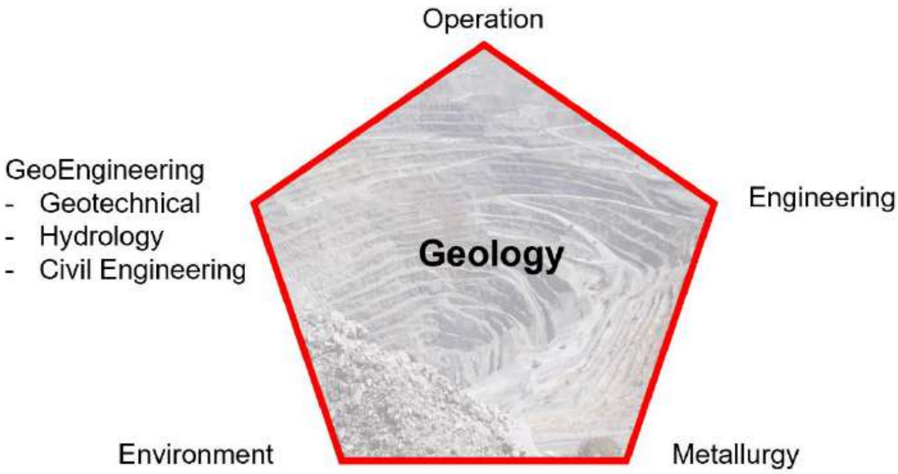


Figure 8. Various clients of PTFI Geology department

The Geology department must also evolve its roles and vision to accommodate the current business needs in the underground mining industry. The traditional role of providing up-to-date geologic information evolves in many aspects, following the demands in overcoming the risk and challenges. The conventional geology modeling and interpretation should align with the underground mining business process.

PTFI is a large mining organization with 50+ years of mining operation experience. The history of geological data collection has been organized since the exploration stage. A robust geological database with varying methodologies has been created and is an invaluable asset for PTFI. An extensive amount of analysis, research, and publication from decades of interaction with various academics and consultants is also part of PTFI archives.

As the mines evolve into more complex and challenging underground mass mining environments, PTFI Geology department wants to capitalize that data into valuable knowledge that can capture the technical and operational needs of the underground mines. It is essential to avoid heuristics and bias when it comes to technical and operational decision-making. Transforming the data into knowledge is the challenge for the future.

ISSN 2963-9751

Digital Transformation in Geology Department

Geological data must be processed and well-defined before being translated into knowledge that will be useful for an underground mine operation. The knowledge must be useable for estimation, correlation and all decision making that will add values to the mines.

In the Industry 4.0 era, the Geology department is also accommodating the process to converge the digital technology in its business process, or what is now commonly referred to as digital transformation. The technology improvement allows the Geology department to explore and apply digital transformation in its daily business process. Digital data collection as the first fundamental step has been developed by the Geology department. The management mindset is that the digital transformation in data collection will bring efficiency and eventually will produce higher confidence of data. The following is the implementation of digital data collection in Geology Department.

Photogrammetry Digital Data Collection

The underground production mining cycle works at a very fast pace and exposes personnel to hazardous environments, such as hanging rocks and heavy equipment operations. At the same time, the demand for capturing detailed and high confidence data in underground heading tunnel remains high for the Geology department.

Photogrammetry is a digital technique that obtains a 3D image from an underground heading where detailed geological mapping can be undertaken in a safer manner. Photogrammetry digital data collection allows geologists to capture the high-resolution images of the tunnel (figure 9) and conduct structural geology detail analysis of the rock mass domain. Geologists will capture a series of images from the newly developed heading tunnel, using high resolution camera and additional lights. The image is then processed and turned into a 3-D tunnel image, using computer software. Geological structures digitation is done through the 3-D image. This allows geologists to carefully measure and register every possible structure captured in the image. The high-resolution data will contain many specific measurements such as fracture frequency, structure separation and length as well as the conventional structure orientation plot in Stereonet (figure 10). The data is stored in one integrated database and can be reviewed together for further analysis and references. This is done in a relatively short period of exposure time in the heading, without disturbing the tunneling operation cycle time.

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Figure 9. Photogrammetry data collection in underground tunnel

Photogrammetry data is utilized for quantification of fracture frequency, vein density and major trend of structures. It is considered as high confidence data for caveability and fragmentation analysis, which will be explained in the next chapter.

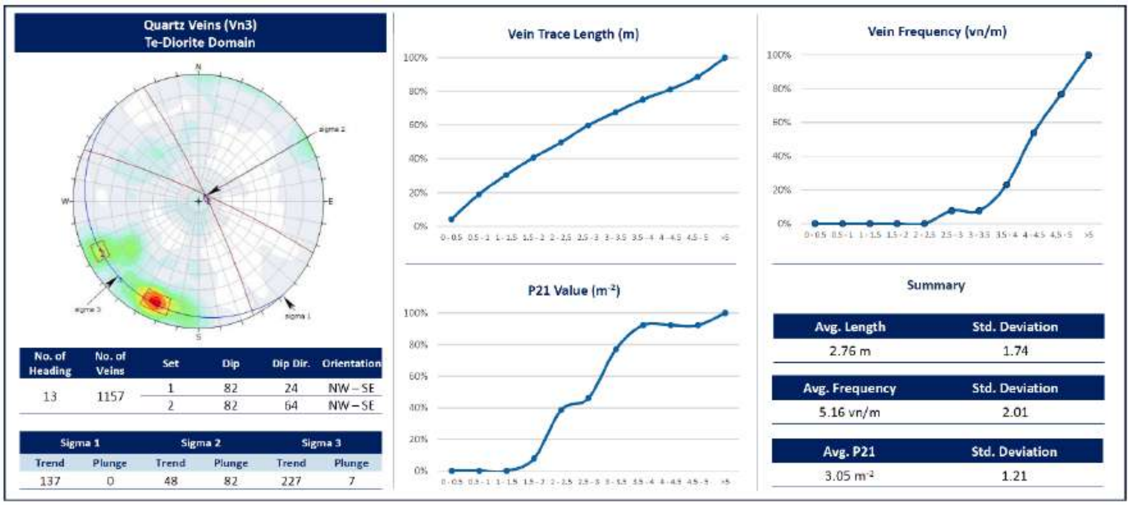

Figure 10. Photogrammetry data analysis

Fragmentation Digital Data Collection

One of the main tasks for geologists in the underground block caving mine is to periodically record the rocktype and fragmentation. The objective is to quantify and monitor rock and fragmentation propagation along the cave as it came out in the drawpoints. This is the first step of rocktype, grade and fragmentation calibration. The Geology department will highlight when there is sudden change in the drawpoints muckpile, such as increasing of dilution material, fines, or other fragmentation features that will possibly disrupt the drawpoint availability and mining process. The result is reported periodically to the underground mine department and

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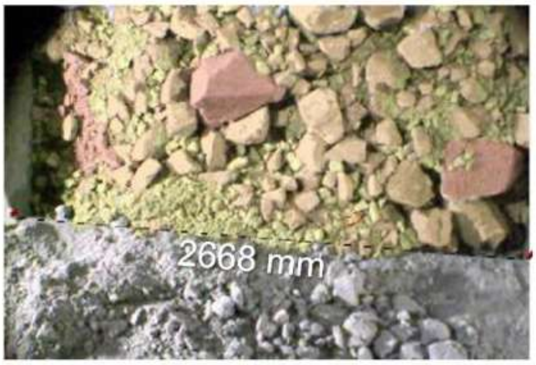
has proven to be beneficial for further calibration and the reconciliation process. The Geology department, as part of the underground wetmuck committee, is also responsible for determining the drawpoint wetmuck class by measuring the well-calibrated fragmentation percentage in the drawpoints.

Digital data collection of the drawpoint muckpile is established since the fragmentation calculation software became feasible to use in Geology department. Geologists will capture the image on the extraction panel and conduct fragmentation distribution measurement by using the software. The software itself has been calibrated and sufficient to accurately measure the fines fragmentation distribution. By optimizing the digital data recording, the data will be preserved for further calibration as well as to capture the evolution of fragmentation on the specific drawpoints (Fig. 11).

Color	Lower (mm)	Upper (mm)	Individual	Cumulative	Rosin-Rammler
	2000		0.0 %	100.0 %	100.0 %
	1000	2000	0.0 %	100.0 %	88.5 %
	500	1000	0.0 %	100.0 %	82.4 %
	50	500	51.2 %	100.0 %	75.1 %
		50	48.8 %	48.8 %	48.8 %



Color	Lower (mm)	Upper (mm)	Individual	Cumulative	Rosin-Rammler
	4096		0.0 %	100.0 %	100.0 %
	256	4096	11.8 %	100.0 %	100.0 %
	64	256	54.9 %	88.2 %	83.1 %
	4	64	22.6 %	33.3 %	23.2 %
	2	4	0.4 %	10.7 %	0.6 %
	1	2	0.1 %	10.3 %	0.2 %
	0.5	1	0.1 %	10.2 %	0.1 %
	0.25	0.5	0.0 %	10.1 %	0.0 %
	0.125	0.25	0.0 %	10.1 %	0.0 %
	0.0625	0.125	0.0 %	10.1 %	0.0 %
	0.031	0.0625	0.0 %	10.1 %	0.0 %
	0.0156	0.031	0.0 %	10.1 %	0.0 %
	0.0078	0.0156	0.0 %	10.1 %	0.0 %
	0.0039	0.0078	0.0 %	10.1 %	0.0 %
		0.0039	10.1 %	10.1 %	0.0 %

Figure 11. Digital fragmentation drawpoint data acquisition

Televiewer Digital Data Collection

In the process of designing rock mass characterization for future mines, often the only data available is drilling data. The Geology department has a well-managed core logging system and database. The highest standard and procedures of core management have been applied for decades, providing, and retaining knowledge for further geological and geotechnical analysis.

ISSN 2963-9751

The latest improvement, in terms of digital data collection from drillholes, is televiewer data collection. Televiewer logging tools are designed to take images of borehole cores with the objectives to capture detailed and oriented structural information and to do continuous high resolution in-situ geology structure measurement. Televiewer data collection, both acoustic and optical televiewers, deliver higher resolution images directly from the drilled hole. It provides fracture measurement and evaluation detailed and oriented structural information (Fig. 12).

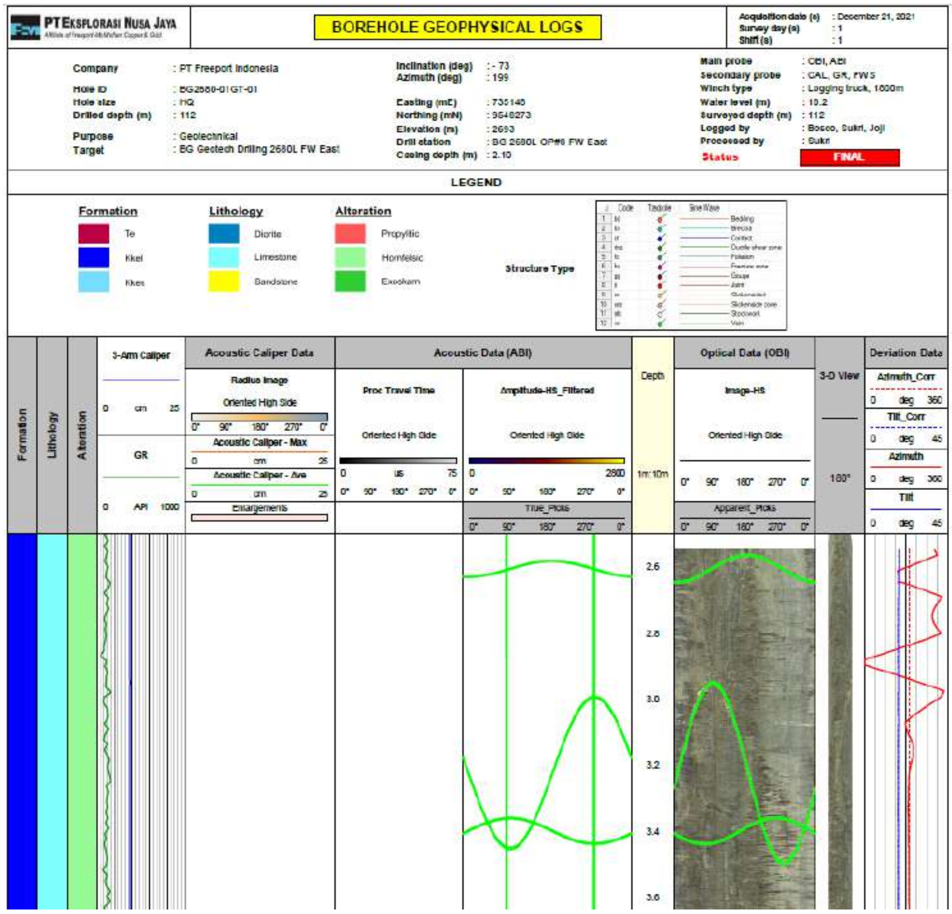


Figure 12. Televiewer data report

Core orientation practice for structural measurement in the drillholes has been applied by the Geology department since the early 2000s. It serves well for early structures observation. However, the demand for improving rock mass characterization has become higher. There are several limitations on conventional core orientation (such as true number of fracture frequency) that can be overcome by using televiewer. The digital data collection nature from televiewer also means preserving the data for further analysis and calibration.

Geology Analysis and Modeling Improvement

During the underground mining production stage, the Geology department is expected to provide higher resolution and more complex geological model deliverables. Numerous risk and

ISSN 2963-9751

challenges, as explained earlier, also must be incorporated into an action plan that provides solutions to the mines.

The previous pure geosciences mindset of geologist must be evolved into more practical mine geology field. How the data published in reporting must answer the mine and engineer's problem. There is no such thing as a pure geology problem anymore in the mine. Instead, the application in the geology field must be developed, such as engineering geology, grade control geology and geometallurgy field. These are several examples of how the Geology department can improve its geological analysis and modeling to answer challenges in underground mines.

Geological Fault Characterization

The regional structural geology understanding of the PTFI mining district is well developed. This is through ongoing efforts of the Geology department and the long-term involvement of academics from various universities and consultants. In a seismically-active mine, such as DMLZ mine, the understanding of the mine-scale stucture geology such as faults [10] and vein characterization are the key fundamental elements for the rockburst and seismic risk mitigation.

The geology structure domain characterization is continuously improved by the Geology department. The higher resolutions and the geotechnical fault strength are also developed to understand how the structure behaves on a smaller and detail scale. The Geology department develops detail characterizations for each fault domain, while also rating the fault based on its geotechnical strength (Fig. 13). The continuous analysis and engagement with geophysicists are also developed to understand the structure behaviour to seismicity, especially in seismic-active deep undergound mines such as DMLZ.

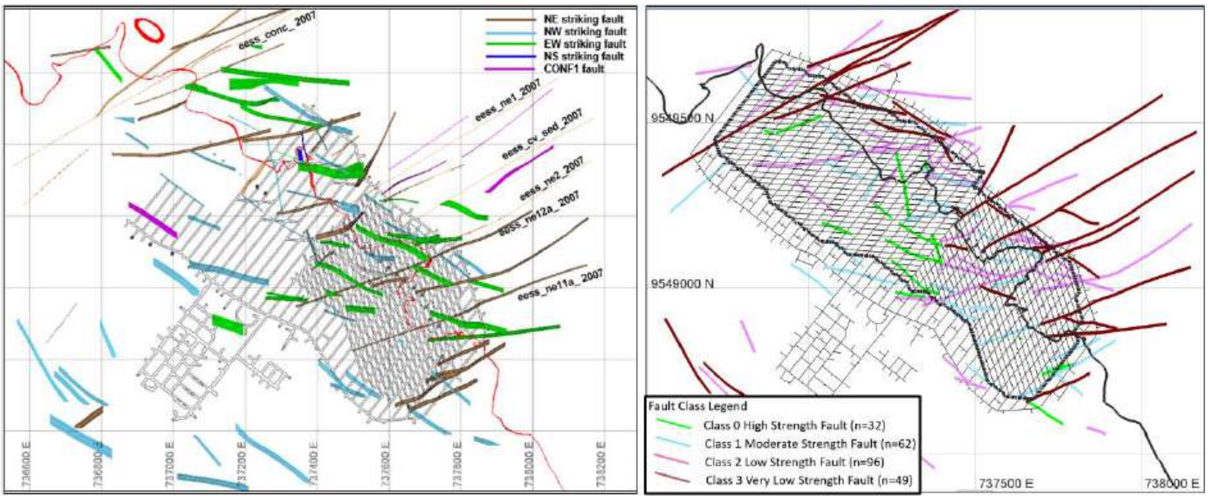


Figure 13. Transforming conventional fault model (left) to fault strength rating (right), modified from [11] and [12]

Discrete Fracture Network Modeling

ISSN 2963-9751

The discrete fracture network (DFN) modeling is a modelling methodology that seeks to describe the rock mass fracture system in statistical ways by building a series of discrete geology structure (such as faults, vein and joints) based upon actual geological conditions of the structure properties [13]. The modeling approach is increasingly being used to address both fundamental and practical geomechanical challenges in underground block caving mine.

The basic DFN model requires at least three fundamental structures properties (size, orientation, and intensity) to be incorporated. Defining those three major aspects is very critical to produce the realistic approach with the actual structural condition. The previous digital data collection, elaborated in the previous chapter, increases the resolution for defining this structural definition, especially for fracture intensity definition. The DFN modeling system develops a unified fracture intensity measurements system (Fig. 14) to provide an easy framework to move between differing scales and dimension. The P32 value is then used to develop DFN Model through the software (Fig. 15).

Dimension of Sample	Dimension of Measurement				
	0 (#)	1 (m)	2 (m^2)	3 (m^3)	
1D (Boreholes, scanlines, etc.)	**P10** No of fractures per unit length of borehole	P11 Length of fractures per unit length			***Linear Measures***
2D (Mapping, photogrammetry, etc.)	P20 No of fractures per unit area	**P21** Length of fractures per unit area	P22 Area of fractures per area		***Areal Measures***
3D	P30 No of fractures per unit volume		**P32** Area of fractures per unit volume	P33 Volume of fractures per unit volume	***Volumetric Measures***
	Density		***Intensity***	*Porosity*	

Figure 14. Fracture intensity definition, adapted from [14]

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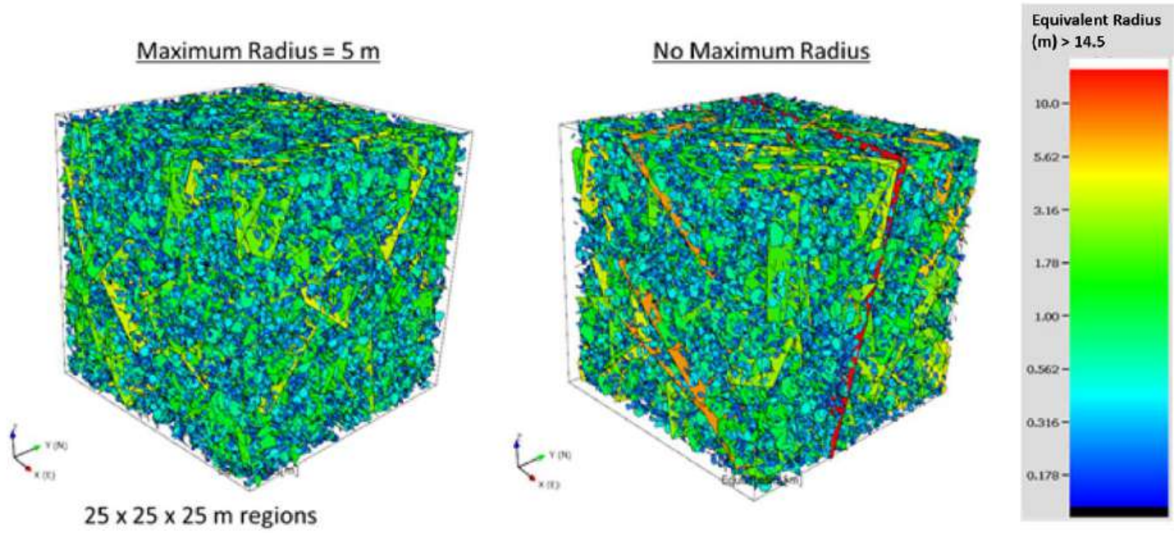

Figure 15. Examples of DMLZ DFN representative model

The major objective of DFN is to provide the most realistic fragmentation model that will then develop into forecasting tools for mine planning [15]. The fragmentation forecasting provides critical information for drawpoints availability and secondary breaking strategy, which eventually translates to the drawpoints production cycle time.

Big Gossan Short Range Model

The Big Gossan short range model (SRM) is developed as an effort from the Geology department to serve the demand in selective underground stope mine operations. The model accommodates higher resolution and updates in shorter period of times, compared to the resource parent block model, while still following the same methods in grade estimation and domaining. The SRM is built in a 5x5x5m dimension, compared to 25x25x25m on the resource model. This provides a more accurate definition on the ore-waste boundary and gives flexibility for underground mine engineering in determining stope shape in meter scale (Fig. 16). SRM also accommodates the recent update of the grade control drilling program faster since it can be updated on a quarterly basis (compare to the annual resource block model). Underground mine engineering can update the mine faster in a higher resolution model, without compromising the good mining practices guidelines.

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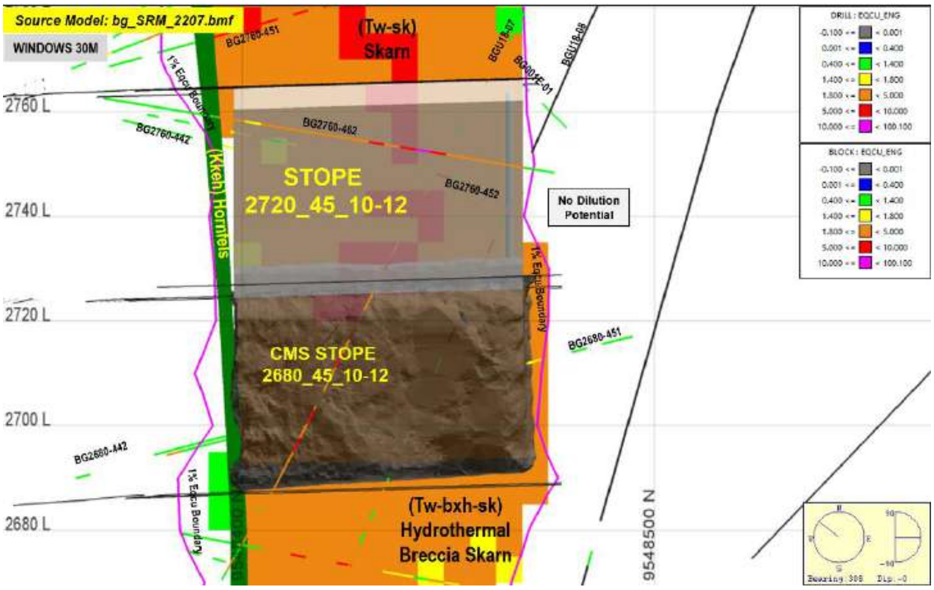

Figure 16. Illustration of stope note design with the SRM

Ore Control Sampling Protocol Analysis and Recommendation

Sampling of drawpoints in block cave mines is a critical task for tracking the grade of material produced by the operation. The drawpoint sample grades are used to report a daily head grade, monitor grade performance relative to the model, make decisions about closing drawpoints at the end of their productive life, and for understanding material flow within the cave. The sampling process, however, presents many challenges and constraints related to obtaining a representative sample, gaining safe access to the drawpoints, and limiting interruption to production activities.

A series of bulk sampling was undertaken by the Geology department to study grade distributions and thereby devise an optimum routine sampling protocols in block caving mines (illustration in Fig. 17). The recommendations form the basis for allocation of resources to conduct sampling and laboratory analysis, and for design of the sample preparation and assay workflows [16].

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Figure 17. Illustration of ore control sampling practice in drawpoints

Conclusions

The PTFI mining district embarked on a new full underground mine operations era, with several large volume caving operations underway and ramping up rapidly. The risk and challenges emerge given the nature of underground mining operation in complex geological conditions in deeper elevations.

The fundamental aspect of the risk and challenges associated with underground mine operations is deeply related to the knowledge of the geology and orebody of each domain, which is within the geosciences scope of work.

Evolving the mindset from pure geoscience to applied geology is needed to engage with the underground mine stakeholders. Digital data transformation and elevating its model and analysis are the current key improvements for the PTFI Geology department in responding to underground mine operation challenges.

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Pitram Application on Grade Control Activities for Gold Mining Industry

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Abstract

Mining activity is a complex activity and has “related" between departments so that the mining activity/process can operate well and optimal. These activities mainly will be related with Engineering, Operations, Mine geologist and survey departments.

Conditions that are often experienced and occur in the field are “information sources” that are not connected to each other, or the various versions possessed by this activity. And if examined more specifically, the data used have similarities, namely truck tonnage, grade/quality material, material movement (source – destination), Stockpile volume and Quality (WAG). And another thing is that with multiple versions of the data, mining operations will extract more time and human resources, the outcome of which is a **non-optimal business process**.

MICROMINE Pitram Productivity plus (Include HPGPS Solution) has capability to "integrated" and answer these issues by combining Fleet Management features, Material Movement monitoring, High precision solutions and a centralized platform for the Mining Operations Department to be mutually "connected" and answer reporting needs, analyze and identify areas to be improved. Several case studies show that this “integrated solution” can provide significant outcome savings/improvements including material tracking $540k p.a, reduction of misidentified loads $1.7m p.a or correct floor elevation $680k p.a. With a general investment ranging from $1.2m to $1.5m (depending on the number of units being monitored), the payback period for this technology ranges from 3.8 to 4 months and immediately Mining Operation will see improvement occur in their operation.

Keywords: Micromine pitram, Integrated solution, Outcome savings, Mining operation

Introduction

Mining operations are a very complex process and have ties to various departments within an organization. This itself has challenges and special handling for operational activities to run properly and effectively.

MICROMINE is a technology company that has been involved in various projects for +30 years throughout mining operations. Micromine is also currently providing solutions for operational exploration to mining operations, both open pit and underground operations, of which currently there are around 50+ active mines or approximately +3000 active projects that are being supported and partnerships to provide outcomes in terms of optimization and effective mining operations.

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Currently with mining operational conditions that are becoming very complex and deposit conditions that are increasingly narrow or deep, it is very important for a company to have an operational system that can provide the ability to control, monitor & analytic for the purposes and capability for the needs of the improvement that is needed for the process. mining itself.

Industry Needs and Trend

In the current engineering or operational process, in various operations, mining is still very dominant, which is carried out as an "operational pattern" which is carried out locally. Where this process itself provides an in-efficient process for the mining operation itself. These various processes themselves are often divided into various processes such as:

- Engineering/modelling process
- Use of Fleet Management System
- Surveying (total station or Drone application)
- Reporting to each department

What often happens with this pattern is that a lot of the details needed to make improvements cannot be done or identified correctly and quickly so that many "lost opportunity" conditions occur. Conditions that are often identified and captured by mining activities include:

- Accurately track most complex material flow across tonnage, type, grade source and destination material
- Manage dilution
- Utilize Mine design, survey, and production data for real time monitoring
- Correct floor elevation
- Mine to design or reduce floor dilution/ ore loss
- Reduce misidentified loads, etc
- Reduce idle time
- Improved fragmentation
- Reduce labour cost – working inside pit area (safety factor)

Figure 1. Operation Grade Control trend

The processes that are generally applied to mining operations are every process starting from truck movement, digging block monitoring, actual loading point progress/stockpile. Volume survey to process reconciliation is carried out partially/independently from each department in an organization/department.

These concerns and trends by MICROMINE provide solutions and capabilities that are "integrated" from various platforms owned by the Pitram system and combined with High

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Precision Technology (HP), from one of MICROMINE's partners which is very reliable and implemented, with digging outcomes. block can be tracked and monitored more precisely.

Micromine Technology

MICROMINE, which has been involved in implementing and implementing operational systems in various mining operations globally, has one solution, namely the Micromine Pitram system. Pitram system is a comprehensive mine control and fleet management solution (FMS) for capturing, managing, analyzing, and optimizing holistic mine site activities. The productivity platform brings core operational asset data (equipment, material, locations, and people) together to deliver data-driven insights in real or near-real-time, improving operational outputs and outcomes (reference Micromine website).

The solution needed for this mining process itself will consist of various platform features owned by the Pitram system to be able to provide "real time" monitoring from the Block digging control side - Fleet Management system - Stockpile Management - to Centralize Analytic tools.

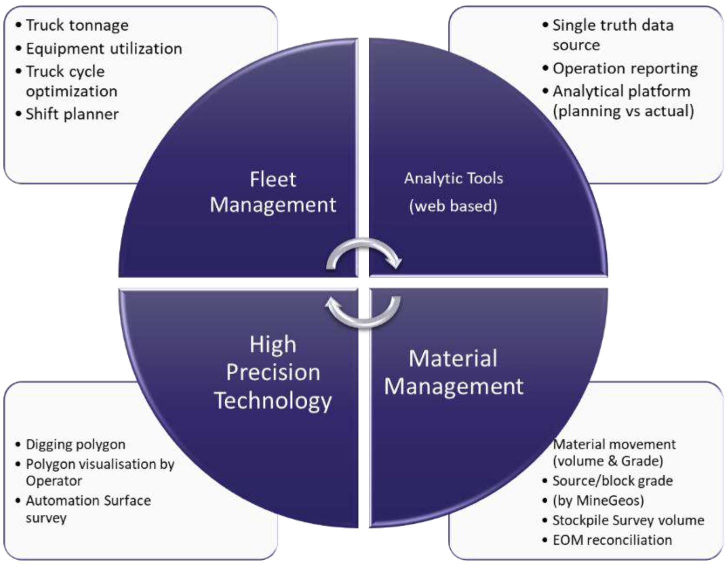

Figure 2. Pitram Grade Control Platform

Fleet Management, is a "centre Mine Operation" because the material flow/material movement will be obtained through the FMS system where material moves from a source location to a destination location. Of course, through this FMS system, there has been a naming convention that has been standardized so that the volume of material can be known precisely.

High Precision Technology, is a platform that will provide the level of accuracy of the material digging by loading equipment can be obtained in real time and precisely. High Precision

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Technology. MICROMINE has worked with technology partners to provide this technology. Some things that will be provided by this technology are:

- High precision GPS+GLONASS solution
- ±5cm positioning accuracy
- Works with any RTCM3.x RTK base stations
- Supports RTK via UHF or optional NTRIP
- Wireless network independent, works with 802.11a/b/g/n, mesh, 3G etc.
- DXF based design data workflow
- Pre-flight tools including localisation
- GNSS coverage planning tools
- Remote connection of machine in the field
- Wireless data transfer of projects and logs to/from machines

In this process, the heavy equipment operator (excavator) will be given a 3D visualization of the material digging activities carried out in which mining block and will be accurately integrated with Fleet Management that the material being digging comes from which block. Another thing that upgrades the use of this technology is the ability to carry out automatic surveys of mining fronts by Technology High precision.

Material Management, Pitram system will provide the ability to track and 'linked" grade of each material/digging block that has been captured by the FMS system into the Pitram system. On this Material Management platform, the Mine Geologist will be given the ability to “entry” grade value from each Mining Block/block digging so that material flow will be captured “integrated” by the Pitram system.

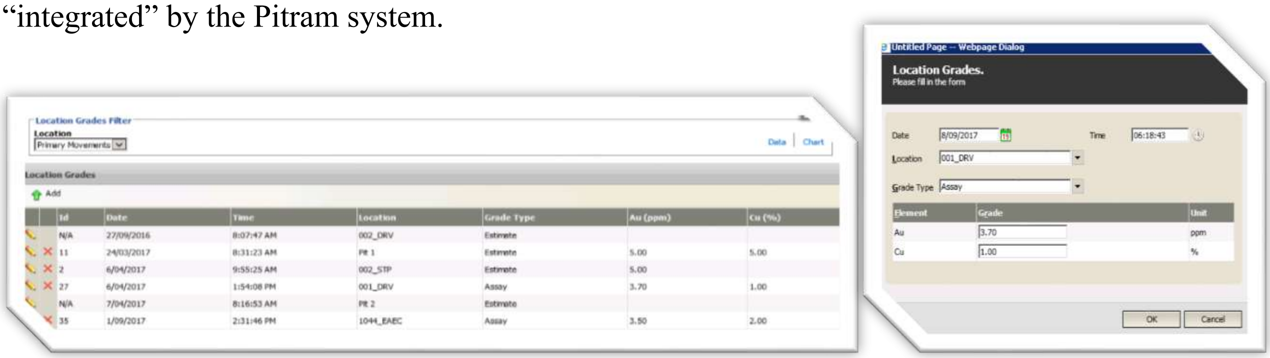

Figure 3. Grade element Entry by MineGeologist

Another thing that will be processed, of course, is the capability to capture volume from each destination location (ROM or temporary location or final stockpile) so that the volume of material moved can be recognized as final figures from the material tracking process.

Analytic Tools, this process is "compiling" all data that has been captured by the features of the Pitram system to provide real time information so that processes that occur in the field can be immediately known by all departments/stakeholders in mining operations.

Pitram system can provide various views and reporting templates for monitoring material needs daily, Week to Date (WTD) or Month to Date (MTD) and the information to be provided

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includes information on Truck movement (tonnage), material movement, grade element, stock status and reconciliation outcome (claimed vs reconciliation different %).

Case studies in many mining companies showed several rooms can be improved by utilizing Pitram system. In general, this type of solution provides a payback period is 3 to 4 months with saving coming from (Jarosz and Finalyson, 2003):

- Reduction of misidentified loads (~$1.7m p.a.)
- Correct floor elevations (~$680k p.a.)
- Material Tracking (~$540k p.a.)
- Reduced overhaul costs (~$400k p.a.)

Discussion and Conclusion

In general, mandatory mining operations require a system that can integrate all departments within the mining organization it owns. This will provide an opportunity to immediately find out the "un-expected condition" so that it can be handled quickly and accurately so that room for improvement can occur.

The solution implemented by MICROMINE for the Grade control area is a combination of applications from Fleet Management system, High Precision Technology, Material Management and Web based Analytic tools as a platform to be applied in mining operations so that outcomes and areas to improve can be applied by a mining operation.

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