

PENYEBARAN AIR SULFATE DI GRASBERG BLOCK CAVE (GBC) MINE, PAPUA, INDONESIA

DISTRIBUTION OF SULFATE WATER IN GRASBERG BLOCK CAVE (GBC) MINE, PAPUA, INDONESIA

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ABSTRACT

GBC underground mine which is operated by PT Freeport Indonesia, located at High Land of Papua which has high rate of rain fall (average 4000 mm/year) and causing water inflow through the fractured rock, and flowing inside the underground mine. The water occurrence inside the underground mine could be in seepage form, and water flow from diamond drill hole.

Water seepage inside underground mine contain many chemical compound such as sulfate (SO₄). Sulfate has ability to cause acid water and sulfate attack, which can be a problem to ground support existence. These water from seepages of existing drift during development were collected and sent to laboratory to gain detail chemical information. By correlating with geological data (formation, and its mineral), distribution of water sulfate content can be known. In the ore body of GBC, water sulfate content is higher than the other lithology existence. These data can be utilized for long term ground support plan in the future.

Key word: Grasberg Block Cave, Sulfate Water, Underground Mine

INTRODUCTION

Grasberg Block Cave is one of several underground mine, located at highland of Papua, Indonesia, with high intensity of rainfall (average 4,000 mm/year) above the underground mine, then infiltrate, and causing seepage occurrences in underground mine, which is flow directly above the surface of the ground support.

Study of water quality inside the underground mine is very important to prevent future ground support degradation that can be causing problem related to safety and mining process. One groundwater element that potentially create problem is sulfate, which can cause sulfate attack. Attack on concrete is a culmination of a series of reactions that occur in the presence of sulfate ions. Sulfate attack manifests itself in the form of loss in strength, expansion, surface spalling, mass loss, and eventually disintegration of concrete (Taylor 1997, Tikalsky and Carrasquillo 1989). **Figure 1** shows typical sulfate attack product on concrete.



Figure 1. Example case of sulfate attack on concrete

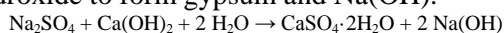
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Mechanism of Sulfate Attack

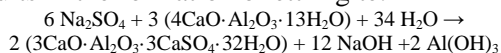
Sulfate attack is often discussed in terms of reactions between solid hydration products in hardened cement paste (such as calcium hydroxide, $\text{Ca}(\text{OH})_2$, and calcium aluminate hydrate, $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 13\text{H}_2\text{O}$) and dissolved compounds such as sodium sulfate (Na_2SO_4), magnesium sulfate (MgSO_4), and calcium sulfate (CaSO_4) (Bhatty & Taylor, 2006). Their reactions with the solid phases in hardened cement paste are as follows:

- Sodium Sulfate (Na_2SO_4)

Sodium sulfate solution reacts with calcium hydroxide to form gypsum and $\text{Na}(\text{OH})$:

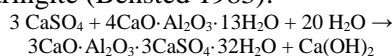


Sodium sulfate also reacts with calcium aluminate hydrate ($4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 13\text{H}_2\text{O}$) and results in the formation of ettringite:

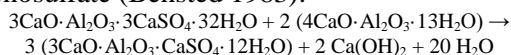


- Calcium Sulfate (CaSO_4)

In aqueous conditions, calcium sulfate reacts with calcium aluminate hydrate ($4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 13\text{H}_2\text{O}$) to form ettringite (Bensted 1983):

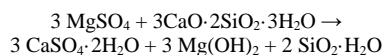
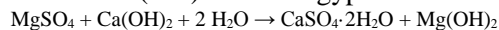


When the supply of calcium sulfate becomes insufficient to form additional ettringite, calcium aluminate hydrate ($4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 13\text{H}_2\text{O}$) reacts with ettringite already produced to form monosulfate (Bensted 1983):

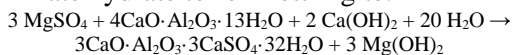


- Magnesium Sulfate (MgSO_4)

Magnesium sulfate attacks calcium silicate hydrate and $\text{Ca}(\text{OH})_2$ to form gypsum:



Magnesium sulfate also reacts with calcium aluminate hydrate to form ettringite:



High SO_4 (sulfate) content in ground water derived from various processes such as water-rock interaction, ion exchange, and different origins of sulfates, such as oxidation of sulfur minerals and dissolution of secondary and

primary evaporites mineral (Gourcy, L, et al; 2013). Evaporites mineral here is referred to anhydrite-gypsum which generally alteration product within rock or as vein in GBC Mine area.

GBC Mineralogy

In GBC Mine area, anhydrite-gypsum and sulfur mineral distribution can be traced in Grasberg Intrusive Complex (GIC), skarn, and Heavy Sulphide Zone (HSZ).

GIC and Skarn contain abundant of anhydrite-gypsum as product of alteration. Potassic alteration in GIC are characterized by anhydrite appearance within the rock or as intense stockwork veins associate with quartz-pyrite-chalcopyrite. In the skarn, anhydrite mineral appear as dominant alteration mineral especially if the skarn occurred between contact of igneous rock and Waripi Dolomite with enough temperature to form anhydrite. Not only within the rock anhydrite also as vein and fill the fracture associated with sulphide mineral pyrite-chalcopyrite. This anhydrite add by water become gypsum as result. Gypsum is easier to dissolve in water so can caused high sulfate content in water. Both potassic alteration GIC and skarn contain gypsum associated with 3-5% pyrite and 1-2% chalcopyrite content as disseminated. Even locally up to 5-10% pyrite and 3% chalcopyrite also minor sphalerite as replacement sulphide alteration or intense patchy.

Heavy Sulphide Zone in GBC area is characterized by more than 20% pyrite content and strong-pervasive replacement sulphide alteration. Locally pyrite content could up to more than 50%. The dominant sulphide content comprises of pyrite-chalcopyrite-pyrrhotite-sphalerite and easily oxidized if contact with ground water especially for pyrite.

METHODS

In GBC, water samples were collected from seepages that occurred during underground drift development. These water samples were sent to the laboratory for further analysis, to gain sulfate concentration data.

Several methods which utilized at this paper are as follows:

- Piper diagram was utilized to gain water type information and its chemical cluster.
- Statistical method such as regression was utilized to see linear correlation of its chemical parameter.
- Sulfate content contour was determined to see sulfate distribution in the underground mine.
- Geological approaching was utilized to see relation of existing mineral at each geological feature with sulfate content
- Empirical approaching was utilized to determine threshold of water sulfate content that required to be anticipated.

RESULT AND DISCUSSIONS

Hydrogeological

Water quality from GBC area can be seen on **Table 1**. Water type of seepages were determined by using Piper diagram (**Figure 2**). Based on these information, water seepages in GBC are in the same chemical cluster, no distinguished chemical compounds from each geological feature.

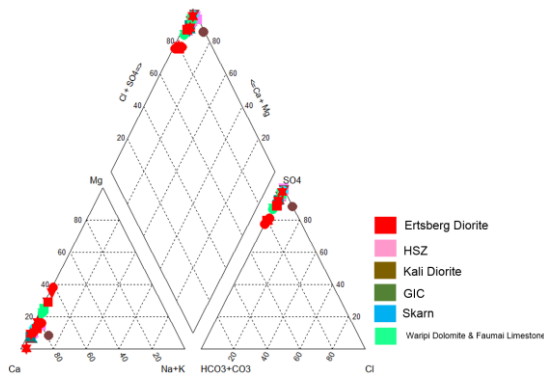


Figure 2. Piper diagram to determine chemical cluster of water compounds.

TDS content and sulfate content were compared to see their relation. **Figure 3** shows that TDS and sulfate have linear correlation with R^2 equal to 0.9614. The higher TDS value, the higher sulfate value.

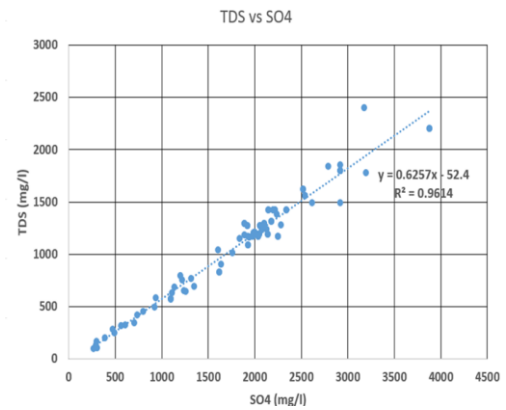


Figure 3. Correlation between TDS and SO_4 from water manifest at GBC

Drifts seepages which are closer to the surface have low TDS and low sulfate compared to drifts seepages which are farther inside the underground. The contour of water sulfate content distribution can be seen at **Figure 4**. The contour shows that water sulfate content gradually increase from portal to GBC.

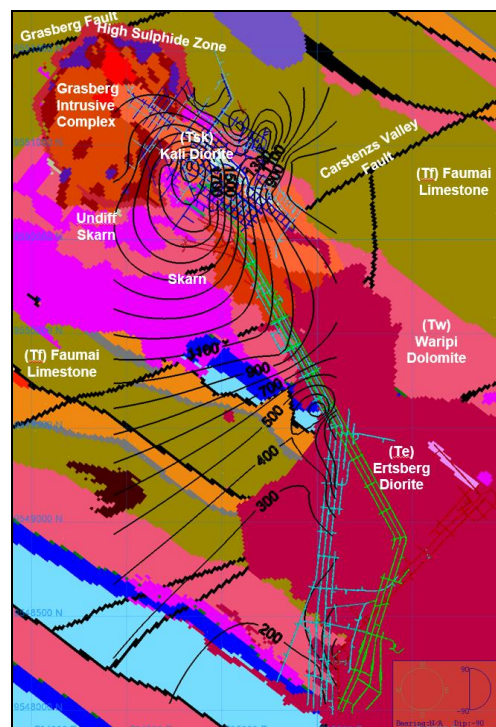


Figure 4. Water sulfate content distribution contour at existing drift of GBC (2016) and overlaid with geological information of GBC.

Geological

Hydrochemical analysis results are accordance with geological condition. **High sulfate water** are increasing toward GIC, Skarn, and Heavy Sulphide Zone, where anhydrite and pyrite abundantly occurred. High sulfate water at Kali Diorite and sediment formation (Faumai and Waripi) occurred due to current existing wet drift location were closed to GIC, which has source of sulfate content (pyrite and gypsum). The conjugate structure of major fault also interpreted as water pathways where connecting groundwater flow from GIC-skarn with high sulphide and gypsum content, so the water that come out in Kali Diorite and sediment contain high sulfate. Different circumstances maybe occurred if the water sample collected from sediment rock which are farther from intrusive rock and alteration rock.

Low sulfate water content is distributed along Ertsberg Diorite. Anhydrite-gypsum mineral are not observed in Ertsberg Diorite and minor in Kali Diorite. Pyrite mineral minor in Ertsberg Diorite, Kali Diorite, and sediment therefore sulfate content in ground water is low.

Figure 5 shows sulfate content of seepage and one case of shotcrete degradation at the Skarn-1 location. Field observation indicates the shotcrete quality has reduced by the time. The sulfate content in this area is higher than 1000 mg/l. We decided to use this value (1000 mg/l) as a threshold to identify potential sulfate attack. Using this criteria most of area in GIC, Skarn, HSZ, Kali, and sediment rocks has high potential of sulfate attack.

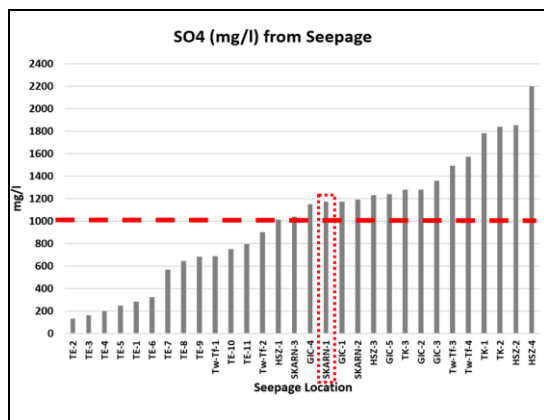


Figure 5. Water sulfate content from water seepages at GBC.

CONCLUSION

Groundwater at GBC and surrounding area have same chemical cluster with significant sulfate content in the water, although occurred at different geological feature.

Sulfate threshold content 1000 mg/l were derived from empirical approaching of cement degradation case in GBC (Skarn-1 area).

Distribution of water sulfate content indicates most area in GIC and its surrounding area has high potential of sulfate attack.

ACKNOWLEDGEMENT

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Table 1. Water quality of GBC seepages water

| Geological | Sample Code | pH | TDS (mg/l) | Na (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) | HCO3 (mg/l) | SO4 (mg/l) | Cl (mg/l) | Watertype |
|------------------------------------|-------------|------|------------|-----------|----------|-----------|-----------|-------------|------------|-----------|----------------|
| Ertsberg Diorite | TE-1 | 7.74 | 474 | 2.67 | 1.42 | 91.1 | 23.3 | 37 | 282 | 4.26 | Ca-Mg-SO4 |
| | TE-2 | 7.87 | 292 | 0.477 | 0.569 | 48.7 | 18.4 | 48 | 130 | 0.24 | Ca-Mg-SO4-HCO3 |
| | TE-3 | 8.13 | 302 | 3.21 | 0.394 | 68.1 | 6.16 | 51 | 161 | 0.54 | Ca-SO4-HCO3 |
| | TE-4 | 8.45 | 389 | 3.36 | 3.92 | 82.4 | 10 | 55 | 198 | 2.13 | Ca-SO4 |
| | TE-5 | 7.38 | 492 | 6.65 | 1.86 | 170 | 12.7 | 72 | 248 | 3.14 | Ca-SO4 |
| | TE-6 | 7.38 | 613 | 2.89 | 1.4 | 127 | 15.7 | 101 | 324 | 2.17 | Ca-SO4-HCO3 |
| | TE-7 | 7.62 | 1100 | 3.46 | 1.11 | 253 | 23 | 32 | 567 | 4.28 | Ca-SO4 |
| | TE-8 | 7.47 | 1260 | 4.06 | 1.92 | 298 | 19.4 | 14 | 644 | 3.17 | Ca-SO4 |
| | TE-9 | 7.51 | 1140 | 3.06 | 12.6 | 265 | 0.602 | 65 | 684 | 4.99 | Ca-SO4 |
| | TE-10 | 7.25 | 1220 | 4.44 | 3.03 | 194 | 63.6 | 44 | 751 | 4.77 | Ca-Mg-SO4 |
| | TE-11 | 7.69 | 1200 | 8.91 | 2.11 | 262 | 18 | 66 | 793 | 2.65 | Ca-SO4 |
| High Sulphide Zone | HSZ-1 | 7.05 | 1760 | 12.8 | 11.1 | 387 | 22.4 | 61 | 1010 | 15.7 | Ca-SO4 |
| | HSZ-2 | 6.43 | 2920 | 15.8 | 9.14 | 480 | 37.3 | - | 1850 | 3.76 | Ca-SO4 |
| | HSZ-3 | 7.26 | 2080 | 14.2 | 5.82 | 468 | 34.3 | 158 | 1230 | 7.75 | Ca-SO4 |
| | HSZ-4 | 5 | 3880 | 27.9 | 12 | 485 | 53.2 | - | 2200 | 20.7 | Ca-SO4 |
| Kali Diorite | TK-1 | 5 | 3200 | 92.8 | 12.2 | 525 | 32.9 | - | 1780 | 173 | Ca-SO4 |
| | TK-2 | 7.88 | 2790 | 10.4 | 10 | 504 | 127 | 8 | 1840 | 14.9 | Ca-Mg-SO4 |
| | TK-3 | 7.5 | 2280 | 11 | 6.82 | 513 | 23.2 | 99 | 1280 | 13.5 | Ca-SO4 |
| Skarn | SKARN-1 | 7.61 | 1930 | 15.8 | 6.55 | 466 | 33.4 | 35 | 1170 | 12.5 | Ca-SO4 |
| | SKARN-2 | 7.61 | 2150 | 11.3 | 6.55 | 483 | 27 | 150 | 1190 | 12.3 | Ca-SO4 |
| | SKARN-3 | 9.62 | 1610 | 6.04 | 2.5 | 316 | 28.5 | 9 | 1040 | 8.14 | Ca-SO4 |
| Grasberg Intrusive Complex | GIC-1 | 7.66 | 1980 | 9.79 | 5.86 | 456 | 41.8 | 135 | 1170 | 10 | Ca-SO4 |
| | GIC-2 | 7.7 | 2280 | 21.1 | 9.44 | 483 | 41.5 | 155 | 1280 | 17.3 | Ca-SO4 |
| | GIC-3 | 7.7 | 2200 | 19.7 | 7.62 | 516 | 23.9 | 129 | 1360 | 4.69 | Ca-SO4 |
| | GIC-4 | 7.55 | 1840 | 9.56 | 6.51 | 458 | 27.3 | 129 | 1150 | 2.13 | Ca-SO4 |
| | GIC-5 | 7.56 | 2130 | 10.6 | 5.37 | 457 | 23.3 | 108 | 1240 | 11.2 | Ca-SO4 |
| Waripi Dolomite - Faumai Limestone | Tw-Tf-1 | 7.78 | 1350 | 7.76 | 3.44 | 286 | 41.1 | 31 | 689 | 4.61 | Ca-Mg-SO4 |
| | Tw-Tf-2 | 8.18 | 1640 | 7.27 | 4.08 | 326 | 67 | 34 | 902 | 5.47 | Ca-Mg-SO4 |
| | Tw-Tf-3 | 6.79 | 2920 | 17.6 | 8.21 | 653 | 118 | 278 | 1490 | 5.24 | Ca-Mg-SO4 |
| | Tw-Tf-4 | 7.29 | 2620 | 16.7 | 8.56 | 617 | 109 | 287 | 1570 | 2.73 | Ca-Mg-SO4 |