RISET
Geologi dan Pertambangan

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

Penyebaran Air Sulfat di Grasberg Block Cave (GBC) Mine, Papua, Indonesia

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ABSTRACT Grasberg Block Cave (GBC) underground mine, which is operated by PT Freeport Indonesia, located at High Land of Papua which has intensity of rainfall (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 drilling hole. Water seepage inside underground mine contain many chemical compounds such as sulfate (SO_4^{2-}). Sulfate has ability to cause acid water and sulfate attack, which can be a problem for ground support existing. Water from seepages of existing drift during development were collected and sent to laboratory to obtain detail chemical information. By correlating with geological data (formation and its content), distribution of water sulfate can be known. In the ore body of GBC, sulfate water content is higher than other lithologies. These data can be used for long term ground support planning in the future.

Keywords: Grasberg Block Cave, sulfate water, underground mine, groundwater.

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ABSTRAK *Tambang bawah tanah Grasberg Block Cave (GBC) yang dioperasikan oleh PT Freeport Indonesia, berlokasi di dataran tinggi Papua mempunyai curah hujan yang tinggi (rata-rata 4000 mm/tahun) dan menyebabkan adanya aliran air melewati rekahan batuan dan mengalir menuju ke dalam tambang bawah tanah. Keberadaan air di dalam tambang bawah tanah dapat berupa rembesan dan aliran air yang mengalir dari dalam lubang pengeboran. Rembesan air di dalam tambang bawah tanah mengandung banyak senyawa kimia seperti senyawa yang memiliki sulfat (SO_4^{2-}). Sulfat mempunyai kemampuan untuk menyebabkan air asam dan sulfate attack, yang notabene bisa menjadi masalah terhadap ground support yang ada. Air yang terdapat di terowongan tambang bawah tanah, diambil dan dikirim menuju laboratorium untuk mendapatkan informasi kimia secara rinci. Dengan melakukan korelasi terhadap data geologi (formasi dan kandungan mineralnya), distribusi dari air sulfat bisa diketahui. Di dalam tubuh bijih utama GBC, air mengandung sulfat lebih tinggi dibandingkan dengan di area litologi lainnya. Data-data ini bisa digunakan untuk perencanaan pemasangan penyangga batuan di masa yang akan datang.*

Kata kunci: *Grasberg Block Cave, air sulfat, tambang bawah tanah, air tanah.*

INTRODUCTION

Grasberg Block Cave (GBC) is one of several underground mine operated by PT Freeport Indonesia with high intensity of rainfall (average 4000 mm/year) above the underground mine and then infiltrate, and causing seepage occurrences

in underground mine, which is flow directly above the surface of the ground support Soebari & de Jong (2007).

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 creates a 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).

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, $Ca(OH)_2$, and calcium aluminate hydrate, $4CaO \cdot Al_2O_3 \cdot 13H_2O$) and dissolved compounds such as sodium sulfate (Na_2SO_4), magnesium sulfate ($MgSO_4$), and calcium sulfate ($CaSO_4$) (Bhatty & Taylor, 2006; Butler, 1995). 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 $Na(OH)$:
$$Na_2SO_4 + Ca(OH)_2 + 2\ H_2O \rightarrow CaSO_4 \cdot 2H_2O + 2\ Na(OH) \quad \text{...(1)}$$
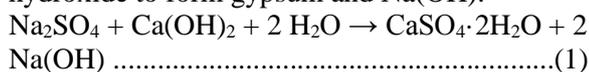
Sodium sulfate also reacts with calcium aluminate hydrate ($4CaO \cdot Al_2O_3 \cdot 13H_2O$) and results in the formation of ettringite:
$$6\ Na_2SO_4 + 3\ (4CaO \cdot Al_2O_3 \cdot 13H_2O) + 34\ H_2O \rightarrow 2\ (3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O) + 12\ NaOH + 2\ Al(OH)_3 \quad \text{...(2)}$$
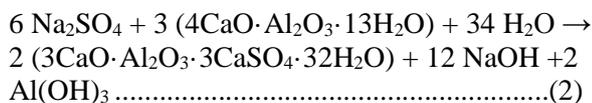
- Calcium Sulfate ($CaSO_4$)
In aqueous conditions, calcium sulfate reacts with calcium aluminate hydrate ($4CaO \cdot Al_2O_3 \cdot 13H_2O$) to form ettringite (Bensted 1983):
$$3\ CaSO_4 + 4CaO \cdot Al_2O_3 \cdot 13H_2O + 20\ H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O + Ca(OH)_2 \quad \text{.........(3)}$$
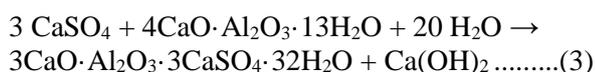
When the supply of calcium sulfate becomes insufficient to form additional ettringite, calcium

aluminate hydrate ($4CaO \cdot Al_2O_3 \cdot 13H_2O$) reacts with ettringite already produced to form monosulfate (Bensted 1983):
$$3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O + 2\ (4CaO \cdot Al_2O_3 \cdot 13H_2O) \rightarrow 3(3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 12H_2O) + 2\ Ca(OH)_2 + 20\ H_2O \quad \text{..(4)}$$
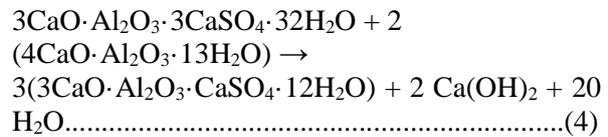
- Magnesium Sulfate ($MgSO_4$)
Magnesium sulfate attacks calcium silicate hydrate and $Ca(OH)_2$ to form gypsum:
$$MgSO_4 + Ca(OH)_2 + 2\ H_2O \rightarrow CaSO_4 \cdot 2H_2O + Mg(OH)_2$$

$$3\ MgSO_4 + 3CaO \cdot 2SiO_2 \cdot 3H_2O \rightarrow 3\ CaSO_4 \cdot 2H_2O + 3\ Mg(OH)_2 + 2\ SiO_2 \cdot H_2O \quad \text{....(5)}$$
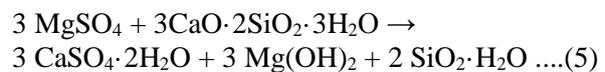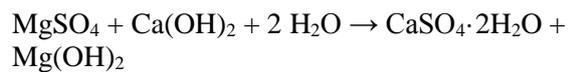
Magnesium sulfate also reacts with calcium aluminate hydrate to form ettringite:
$$3\ MgSO_4 + 4CaO \cdot Al_2O_3 \cdot 13H_2O + 2\ Ca(OH)_2 + 20\ H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O + 3\ Mg(OH)_2 \quad \text{......(6)}$$
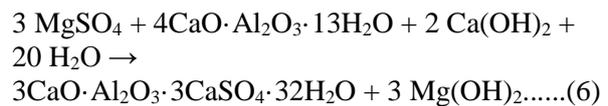
High SO_4^{2-} (sulfate) content in ground water derived from various processes such as water-rock interaction, ion exchange, and different origins of sulfates, such as oxidation of sulfur minerals and dissolution of secondary and primary evaporites mineral (Gourcy *et al.,* 2013). Evaporites mineral here is refered to anhydrite-gypsum which generally alteration product within rock or as vein in GBC Mine area.

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 (Biniawski, 1989). Potassic alterations 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 suphide mineral

pyrite-chalcopyrite. This anhydrite added 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-pyrhotite-sphalerite and easily oxidized if contact with ground water especially for pyrite.

Location

PT Freeport Indonesia contract of work area located at Jayawijaya Highlands, Mimika District, Papua Province, Indonesia with following geographic 04º 06' - 04º 12' South Latitude and 137º 06' – 137º 12' East Longitude (Figure 1).

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 obtain 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 between existing mineral at each geological feature with sulfate content

- Empirical approaching was utilized to determine threshold of water sulfate content that required to anticipated.
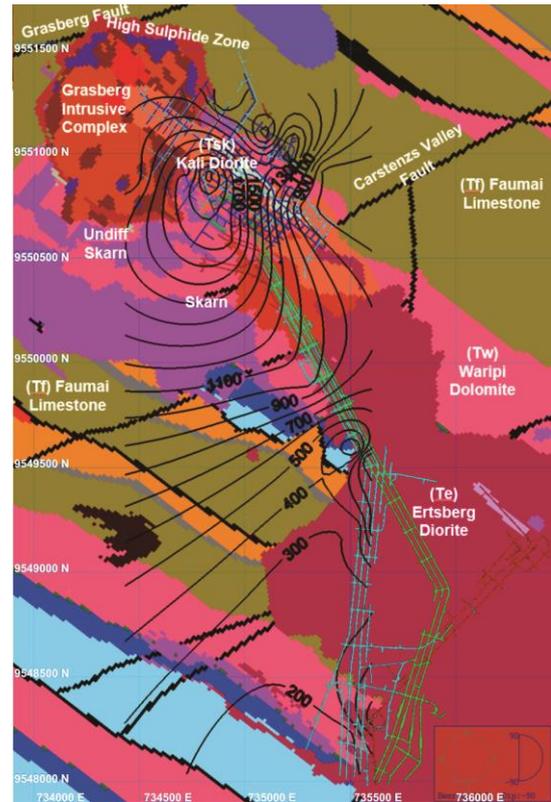
Figure 1. Water sulfate content distribution contour at existing drift of GBC (2016) and overlayed with geological information of

RESULT AND DISCUSSIONS

Hydrogeological

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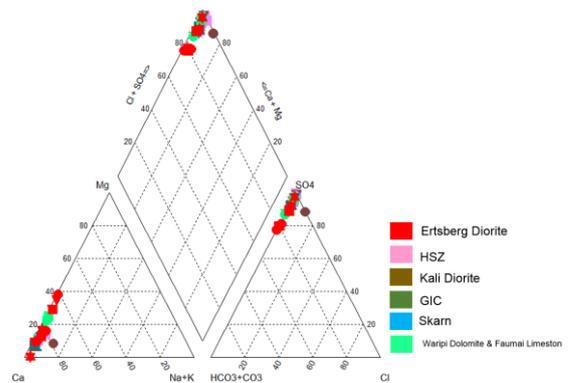
Figure 2. Piper diagram to determine chemical cluster of water compounds.

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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)	HCO_3 (mg/L)	SO_4 (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-SO_4
	TE-2	7.87	292	0.477	0.569	48.7	18.4	48	130	0.24	Ca-Mg-SO_4-HCO_3
	TE-3	8.13	302	3.21	0.394	68.1	6.16	51	161	0.54	Ca-SO_4-HCO_3
	TE-4	8.45	389	3.36	3.92	82.4	10	55	198	2.13	Ca-SO_4
	TE-5	7.38	492	6.65	1.86	170	12.7	72	248	3.14	Ca-SO_4
	TE-6	7.38	613	2.89	1.4	127	15.7	101	324	2.17	Ca-SO_4-HCO_3
	TE-7	7.62	1100	3.46	1.11	253	23	32	567	4.28	Ca-SO_4
	TE-8	7.47	1260	4.06	1.92	298	19.4	14	644	3.17	Ca-SO_4
	TE-9	7.51	1140	3.06	12.6	265	0.602	65	684	4.99	Ca-SO_4
	TE-10	7.25	1220	4.44	3.03	194	63.6	44	751	4.77	Ca-Mg-SO_4
	TE-11	7.69	1200	8.91	2.11	262	18	66	793	2.65	Ca-SO_4
High Sulphide Zone	HSZ-1	7.05	1760	12.8	11.1	387	22.4	61	1010	15.7	Ca-SO_4
	HSZ-2	6.43	2920	15.8	9.14	480	37.3	-	1850	3.76	Ca-SO_4
	HSZ-3	7.26	2080	14.2	5.82	468	34.3	158	1230	7.75	Ca-SO_4
	HSZ-4	5	3880	27.9	12	485	53.2	-	2200	20.7	Ca-SO_4
li Diorite	TK-1	5	3200	92.8	12.2	525	32.9	-	1780	173	Ca-SO_4
	TK-2	7.88	2790	10.4	10	504	127	8	1840	14.9	Ca-Mg-SO_4
	TK-3	7.5	2280	11	6.82	513	23.2	99	1280	13.5	Ca-SO_4
Skarn	SKARN-1	7.61	1930	15.8	6.55	466	33.4	35	1170	12.5	Ca-SO_4
	SKARN-2	7.61	2150	11.3	6.55	483	27	150	1190	12.3	Ca-SO_4
	SKARN-3	9.62	1610	6.04	2.5	316	28.5	9	1040	8.14	Ca-SO_4
Grasberg Intrusive Complex	GIC-1	7.66	1980	9.79	5.86	456	41.8	135	1170	10	Ca-SO_4
	GIC-2	7.7	2280	21.1	9.44	483	41.5	155	1280	17.3	Ca-SO_4
	GIC-3	7.7	2200	19.7	7.62	516	23.9	129	1360	4.69	Ca-SO_4
	GIC-4	7.55	1840	9.56	6.51	458	27.3	129	1150	2.13	Ca-SO_4
	GIC-5	7.56	2130	10.6	5.37	457	23.3	108	1240	11.2	Ca-SO_4
Waripi Dolomite – Faumal Limestone	Tw-Tf-1	7.78	1350	7.76	3.44	286	41.1	31	689	4.61	Ca-Mg-SO_4
	Tw-Tf-2	8.18	1640	7.27	4.08	326	67	34	902	5.47	Ca-Mg-SO_4
	Tw-Tf-3	6.79	2920	17.6	8.21	653	118	278	1490	5.24	Ca-Mg-SO_4
	Tw-Tf-4	7.29	2620	16.7	8.56	617	109	287	1570	2.73	Ca-Mg-SO_4
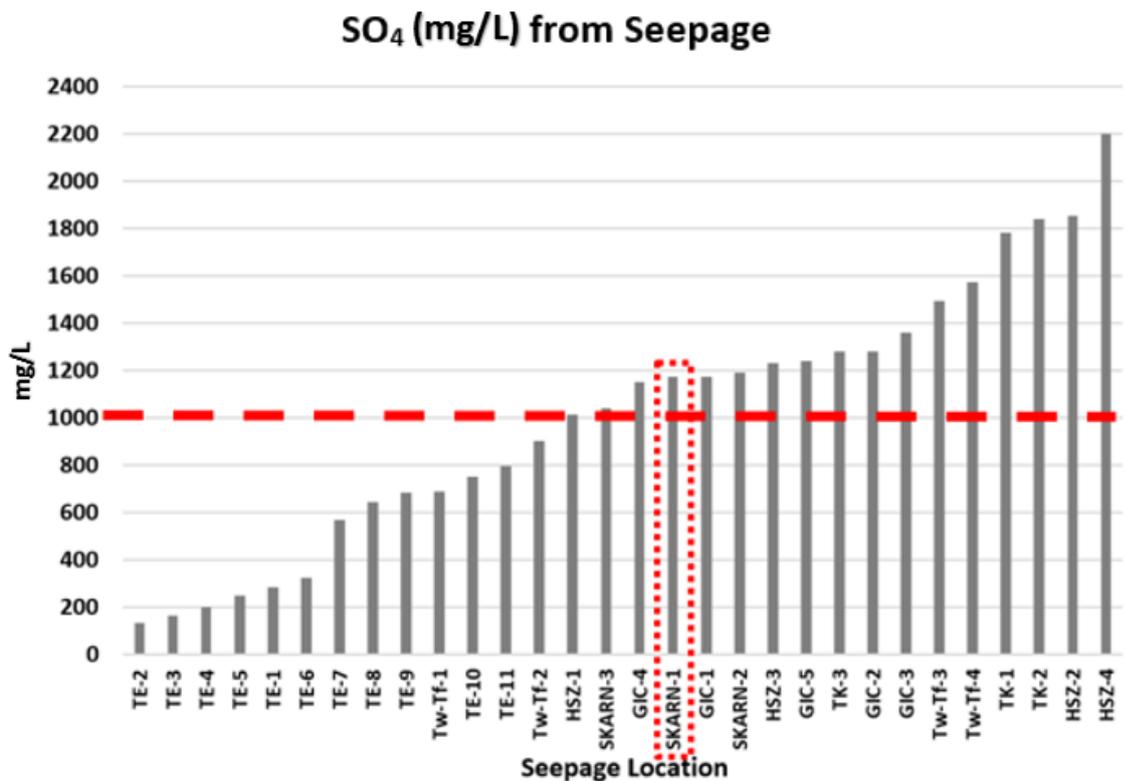
Figure 4. Water sulfate content from water seepages at GBC.

TDS content and sulfate content were compared to see their relation. Figure 3 shows that TDS and sulfate has linear correlation with R^2 equal to 0.9614. The higher TDS value, the higher sulfate value.
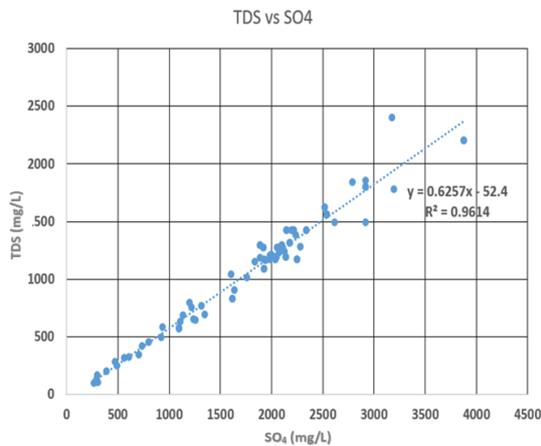
Figure 3. Correlation between TDS and SO_4 from water manifest at GBC.

pH of all water samples are in neutral range although has high sulfate content. The existence of carbonate formation surrounding GBC mine causing almost all water seepage in GBC are in neutral pH range.

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 in Figure 2. The contour shows that water sulfate content gradually increases from portal to GBC.

Geological

Hydrochemical Analysis results are accordance with the geological condition. High sulfate water is 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 a 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 sulfide and gypsum content, so the water that comes out in Kali Diorite and sediment contain high sulfate. Different circumstances may be occurred if the water sample collected from sediment rock, which is farther from intrusive rock, and alteration rock.

Low sulfate water content is distributed along Ertsberg Diorite. Anhydrite-gypsum mineral is 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 4 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) by as a threshold to identify potential sulfate attack. Using this criteria, most of area in GIC, Skarn, HSZ, Kali, and sediment rocks has a high potential of sulfate attack.

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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