On The Spatial Variation of Geochemical Rock Characteristics in Coal Mining: Case Bukit Asam Coal Mine in South Sumatra, Indonesia

Rudy Sayoga Gautama[1], Ginting Jalu Kusuma[1], Eko Pujiantoro[2],
Pajar Hariadi Wisnugroho[2]

[1]Department of Mining Engineering, Faculty of Mining & Petroleum Engineering, Institut Teknologi Bandung, Jl Ganesha 10, Bandung 40132, Indonesia
[2]PT Bukit Asam, Jl Parigi, Tanjung Enim 31716, Indonesia

Abstract

Bukit Asam Coal Mine, consisting three mining blocks, namely Muara Tiga Besar (MTB), Air Laya (TAL), and Banko Barat (BB) is one of the important coal mine in Indonesia. Having high rainfall, mine water management in Bukit Asam Mine is quite challenging and most of the pits have acid mine drainage problem. Mining pits in all mining blocks are excavating the same coal seams which also means the same interburden or lithology. The mine water in the three mining blocks is showing different quality. In general, mine water in the pit sump in BB has pH of 2.92-3.06, whilst in TAL pH 4.10-4.12 as well as in MTB pH 4.41-6.57. To understand the spatial characteristics of overburden and interburden, rock characterization programs have been conducted which included sampling campaign followed by laboratory tests, both static and kinetic test. Rock samples representing different lithology and mining blocks were collected from cores of 31 drill holes.

The results indicate that there were a variety of geochemical characteristic in each mining blocks, both vertically and laterally. Vertical variety relates to the difference in lithology whereas the lateral characteristic variation also exists on some specific interburden samples from the same lithology. Analysis on the quality of leachate water from laboratory column leach tests were comparable with the quality of mine water taken from the pit sump.

Keywords: AMD in coal mine, rock geochemical characterization, spatial variability

Introduction

Indonesia is the world 5th coal producer and one of the world's largest coal exporters with 27.7% of export on a tonnage basis (IEA, 2017). The main coal basins are South Sumatra Basin in the island of Sumatra and Kutai & Barito Basins in Kalimantan.

Bukit Asam Mine is located in South Sumatra coal basin. It is operated by a state-owned company named PT Bukit Asam (or PTBA). Coal mining activity in this area began in 1919 during Dutch colonial period. Bukit Asam Mine covers an area of approximately 100 km2 and is one of the important coal producers in Indonesia. As high as 18.7 million tons of coal have been excavated in 2016 from several open pits operating in three mining blocks, namely Muara Tiga Besar (MTB, in the west), Air Laya (TAL, in the middle), and Banko Barat (BB, in the east). Mine pits in all mining blocks are excavating the same coal seams, namely A1, A2, B1, B2 and C seams and the coal quality is heavily influenced by intrusion activity as indicated by the existence of three intrusive bodies in this area. Having high rainfall, mine water management in Bukit Asam Mine is quite challenging and most of the pits have acid mine drainage problem.

Monitoring of water quality from mine pit sumps indicated the acid drainage in most of the pits. Less acid with pH of from 4.49 to 6.57 has been measured in MTB and there is a trend that to the east (Banko pit 1) the mine drainage becomes more acid except Banko Barat Pit 3 (see figure 1).

We conducted study to analyse the geochemical characteristics of coal seam interburden from different mine blocks since the pit sump water quality depends on the rock geochemical characteristics in the respective pits. Rock samples had been collected from 31 core drills representing different lithology from the three mining blocks.

Geological Setting and Mining Activities

Regional geology

The South Sumatra coal basin is one of the most important coal mining regions in Indonesia (Thomas, 2005). This basin is tectonically active and the coal in some parts has been affected by igneous activity (Belkin, 2009) as shown in Figure 2. South Sumatra Basin is a back-arc basin, which was formed during east–west extension which took place during pre-Tertiary and early Tertiary (de Coster, 1974).

The stratigraphy of South Sumatra Basin is summarized in Gafoer (1986). There are 5 formations in PTBA mine areas, i.e. Aluvial Deposit (Qa) consists of sand, silt and clay; Volcanic Deposit Dempo (Qhvd) consist of andesitic volcanic breccia, lava and tuff; Andesite (Qpva) consist of igneous rock of andesitic rock in the joint of dykes; Air Benakat Formation (Tma) consist of alteration of claystone, siltstone and shale., mostly calcareous and carbonaceous.; and Muara Enim Formation (Tmpm) consists of tuffaceous claystone, siltstone and sandstone with coal intercalation. The coal bearing Muara Enim Formation consists of tuffaceous claystone, siltstone and sandstone with coal intercalation as shown in figure 3.

Shell Mijnbouw (1976) divided the Muara Enim Formation into two parts (members), known as the lower MPa (Middle Palembang 'a') and the upper MPb (Middle Palembang 'b'). Both members have been subdivided again into M1 – M4 Both MPa and MPb contain about eight coal seams. It is estimated that the maximum net coal thickness is about 140 m. Some economically valuable coal seams are those from the upper part of MPa (Mangus, Suban and Petai). In Tanjung Enim, the Mangus, Suban and Petai coal seams each split into two seams, namely Upper (A1) and Lower (A2) Mangus seams, Upper (B1) and Lower (B2) Suban seams and Upper (C1) and Lower (C2) Petai seams. The coal-bearing strata were subjected to at least one period of folding and faulting, and later to invasion by plug-like masses of andesite (Amijaya, 2006).

Those three coal seams, Manggus (A1 & A2), Suban (B) and Petai (C), are found and mined in all mining blocks (MTB, TAL and BB). Single B seam is found in MTB and in TAL and BB Suban seam splits into B1 and B2 seams.

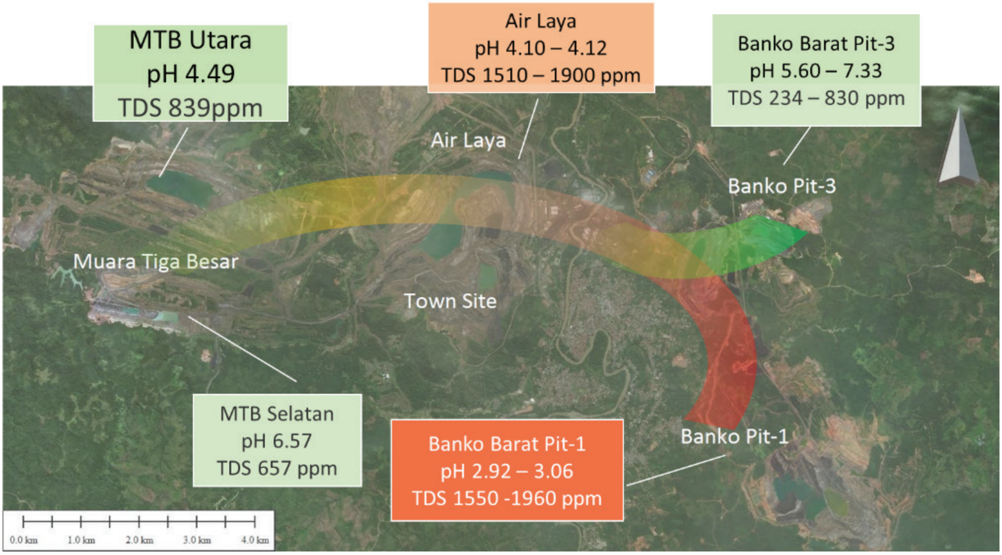


***Figure 1** Mine Sump Water Quality*

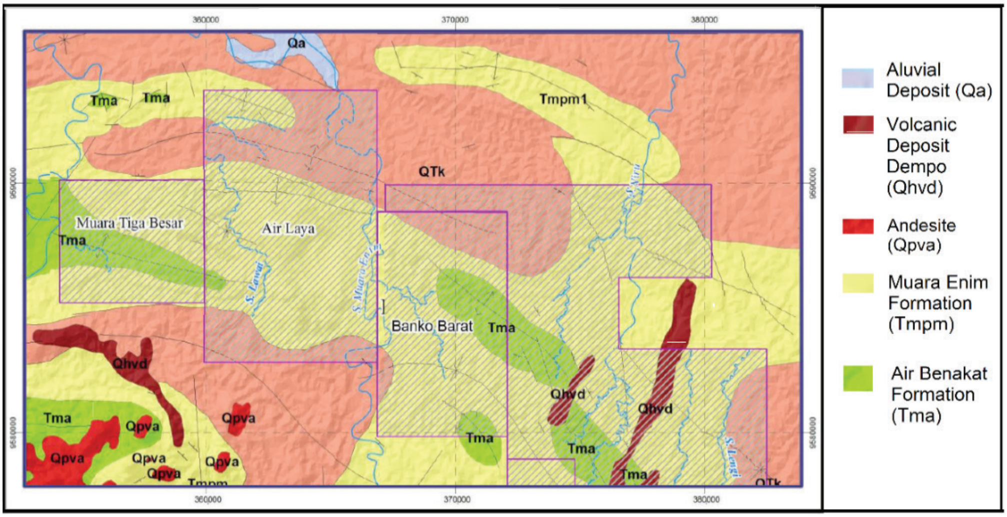


***Figure 2** Geological Map of PTBA (Modified from Gafoer,1986).*

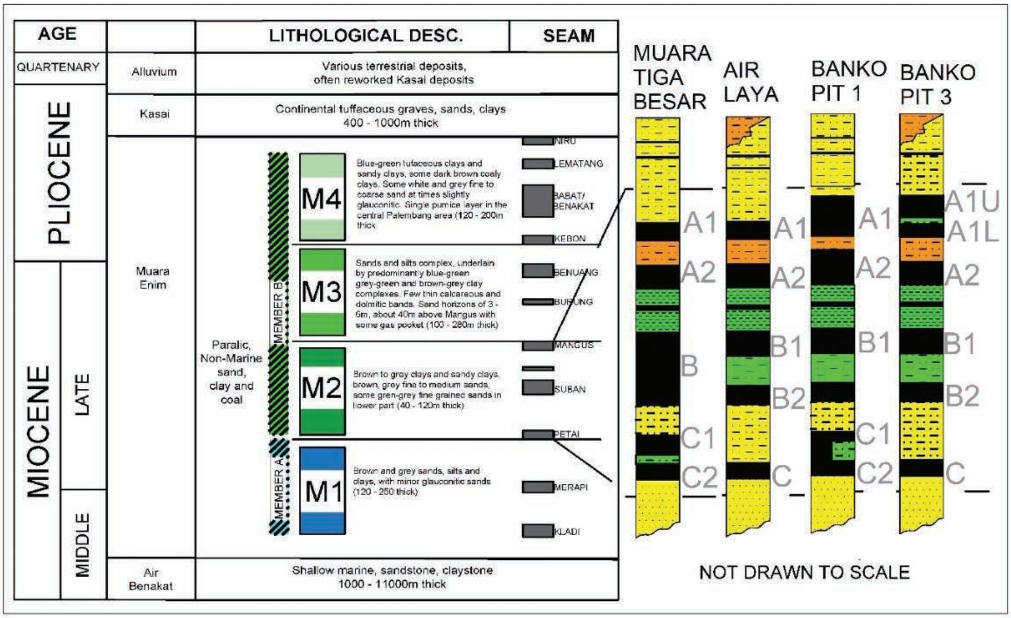


***Figure 3** Regional Statigraphy of Muara Enim Formation (Modified from Gafoer,1986)*

Coal seams in PTBA intercalated with sedimentary rock layer (interburden) named based on their location relative to coal seam (e.g. Interburden A1-A2 for layer between coal seam A1 and coal seam A2). Thickness of stratigraphic layers and coal seams are varying for each mine areas and resumed in Table 1.

Mining activities

Surface mining system is implemented to mine the coal using a conventional truck and shovel method. A bucket wheel excavator is also operating in one of the pit in Muara Tiga Besar. From the mining front the ROM coal is hauled with dump trucks to the ROM stockpile then conveyed to the train loading

Table 1. *Thickness of stratigraphic layers (in meter)*

Stratigraphic Layer	Lithology	Mining Blocks		
		MTB	TAL	BB
Coal A1		6.80 – 10.00	6.50 – 10.00	6.50 – 9.00
Interburden A1-A2	Tuffaceous Sandstone	1.74 - 2.70	6.85 - 17.30	12.3 - 19.50
Coal A2		9.80 – 14.75	5.00 – 12.90	7.50 – 11.50
Interburden A2-B1/B	Claystone, sandstone layer	10.90 - 35.12	29.30 - 42.20	12.10 - 38.10
Coal B1	Claystone, siltstone layer		8.00 – 12.00	9.10 – 14.10
Interburden B1-B2	Sandstone with siltstone,	Coal B	3.06	24.90 - 57.10
Coal B2	claystone	15.30 – 20.00	3.00 – 5.00	4.35 – 5.55
Interburden B2-C		42.00 - 44.70	34.76 - 45.78	33.10 - 82.74
Coal C		0.80 – 2.75	6.00 – 10.00	11.00 – 11.30

Table 2. *Static Test Resulst*

Stratigraphic Layer / Mine Area (%)	TS	ANC	NAPP	pH Paste	NAG pH	NAG pH 4,5	NAG pH 7	
	(%)	(kg H2SO4/ ton)	(s.u.)	(s.u.)	(kg H2SO4/ ton)			
IB A1-A2	MTB	0.23 ± 0.41	4.32 ± 5.96	2.64 ± 8.70	5.46 ± 1.74	4.35 ± 1.19	4.54 ± 8.52	12.07 ± 12.86
	TAL	0.07 ± 0.10	10.81 ± 9.10	-8.8 ± 10.26	8.84 ± 1.25	6.36 ± 1.36	1.99 ± 5.61	5.35 ± 11.27
	BB	0.24 ± 0.30	11.90 ± 8.64	-4.41 ± 13.69	7.61 ± 1.42	5.01 ± 1.76	7.41 ± 15.66	16.03 ± 24.68
IB A2-B1/B	MTB	0.95 ± 0.48	11.13 ± 5.97	17.88 ± 18.49	6.31 ± 1.09	2.96 ± 0.52	21.37 ± 14.41	38.85 ± 20.96
	TAL	0.42 ± 0.23	15.14 ± 11.60	-2.34 ± 16.11	5.51 ± 1.29	2.83 ± 0.71	41.84 ± 30.12	65.73 ± 43.69
	BB	0.80 ± 0.62	14.99 ± 11.16	9.59 ± 24.68	6.06 ± 1.80	3.23 ± 0.98	23.26 ± 27.51	-42.70 ± 37.93
IB B1-B2	MTB	-	-	-	-	-	--	-
	TAL	0.74	11.84	10.83	3.81	2.45	41.58	83.97
	BB	0.92 ± 0.81	13.45 ± 8.66	14.66 ± 25.78	5.38 ± 1.00	3.14 ± 0.85	25.10 ± 24.47	44.52 ± 34.61
IB B2-C	MTB	0.89 ± 0.77	12.19 ± 6.23	14.92 ± 25.74	5.29 ± 0.74	2.97 ± 0.30	19.87 ± 22.72	33.98 ± 30.42
	TAL	0.35 ± 0.19	13.38 ± 7.12	-2.52 ± 10.14	5.18 ± 0.85	2.76 ± 0.36	27.67 ± 20.74	48.25 ± 28.14
	BB	0.96 ± 0.67	14.34 ± 23.80	15.56 ± 36.03	5.29 ± 1.48	3.10 ± 0.75	22.25 ± 24.24	38.05 ± 30.53

Note: All data reported in mean ± standard deviation. TS=total Sulphur, MPA= Maximum Potential Acidity, ANC=Acid Neutralizing Capacity, NAPP=Net Acid Producing Potential, NAG=Net Acid Generating; IB=Interburden, MTB=Muara Tiga Besar, TAL=Air Laya; BB=Banko Barat

station (TLS) for further transportation to the ports using railway.

Geochemical Characterization

Rock geochemical characterization has been conducted on samples collected from cores of 31 drill holes representing three mining blocks. Rock geochemical characterization based on AMIRA (2002) is conducted by performing static test consisting of paste pH (1:2), Net-Acid Generation Test, Total Sulphur and Acid Neutralizing Capacity Test. Statistic of static test is shown in Table 2.

Laboratory-scale kinetic test using Free Draining Column Leach Test method for selected samples was also performed to verify the static test results. Result of static test (NAPP and NAG pH value) and pH range of kinetic test is shown on Table 3. The kinetic test result shows that IB A1-A2 layer yields circumneutral- alkalic pH leachate ranging from 6.72 to 9.20, whilst IB B1-B2 produces acidic leachate ranging from 2.75 to 4.15. IB A2-B1 and IB B2-C yields various pH leachates.

Discussion

Vertical variation of geochemical characteristic on each mine area

Stratigraphically, MTB mine is consisting of IB A1-A2, IB A2-B and IB B-C layer. Whereas, TAL mine and BB mine are consisting of IB A1-A2, IB A2-B1, IB B1-B2 and IB B2-C layer. In MTB mine, IB A1-A2 layer is classified as NAF (Non-Acid Forming) since it has NAPP value of 2.64 ± 8.70 kg H_2SO_4/ton,

Table 3. Static Test (NAPP and NAG pH) and Kinetic test result for Selected Samples

Stratigraphic Layer / Mine Area NAPP (kg H2SO4/ton		Static Test		
		NAG pH (s.u.)	Kinetic test leachate pH (s.u.	
	MTB	1.89	5.45	6.72 – 8.02
IB A1-A2	TAL	-96.32	7.72	8.05 – 7.87
	BB	-9.71	3.29	9.20 – 8.10
	MTB	16.26	2.64	3.95 – 6.20
IB A2-B1/B	TAL	35.85 - 38.25	2.56 -3.16	4.34 – 3.83
	BB	9.12 - 36.57	3.21 - 3.62	2.10 – 8.40
	MTB	-	-	-
IB B1-B2	TAL	43.06	6.55	2.75 – 4.15
	BB	23.86	2.93	2.80 – 4.10
	MTB	0.43	6.66	7.02 – 8.20
IB B2-C	TAL	17.44 - 22.05	2.88 - 3.54	2.89 – 7.10
	BB	13.16 - 19.97	2.24 - 2.42	2.10 – 6.80

NAG pH value of 4.35 ± 1.19 and kinetic test leachate pH values ranges 6.72 to 8.02. The IB A2-B layer is classified mainly as PAF (Potentially Acid Forming) with NAPP value of 17.88 ± 18.49 kg H_2SO_4/ton, NAG pH value of 2.96 ± 0.52 and kinetic test leachates pH values ranges 3.95 – 6.20. The lower IB B-C with NAPP value of 14.92 ± 25.74 kg H_2SO_4/ton, NAG pH value of 2.97 ± 0.30 is classified mainly as (low) PAF since it has kinetic test leachates pH values ranges 7.02 – 8.20.

The IB A1-A2 layer in TAL mine is classified as NAF with NAPP value of -8.8 ± 10.26 kg H_2SO_4/ton, NAG pH value of 6.36 ± 1.36 and kinetic test leachate pH values from 8.05 – 7.87. Layer IB A2-B is classified mainly as PAF with NAPP value of -2.34 ± 16.11 kg H_2SO_4/ton, NAG pH value of 2.83 ± 0.71 and kinetic test leachates pH values ranges 4.34 – 3.83. Layer IB B1-B2 is classified mainly as PAF with NAPP value of 10.83 kg H_2SO_4/ton, NAG pH value of 2.45 and kinetic test leach-

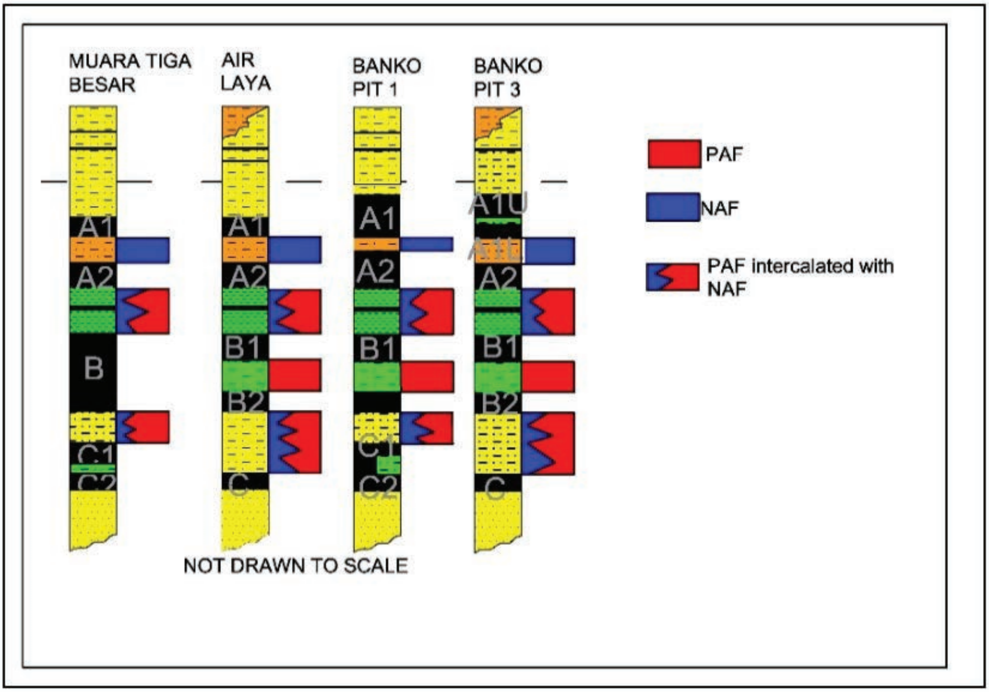
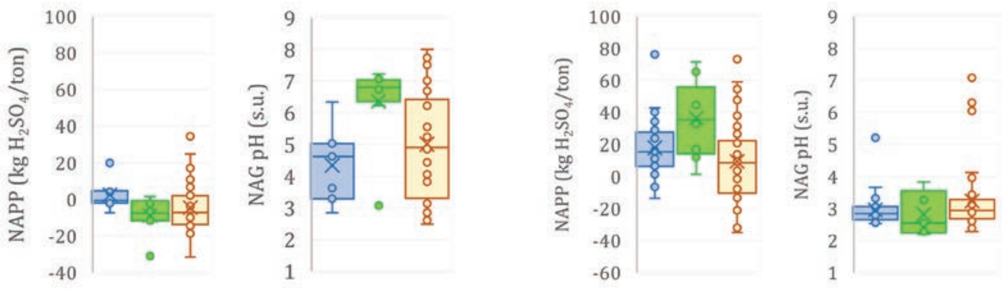
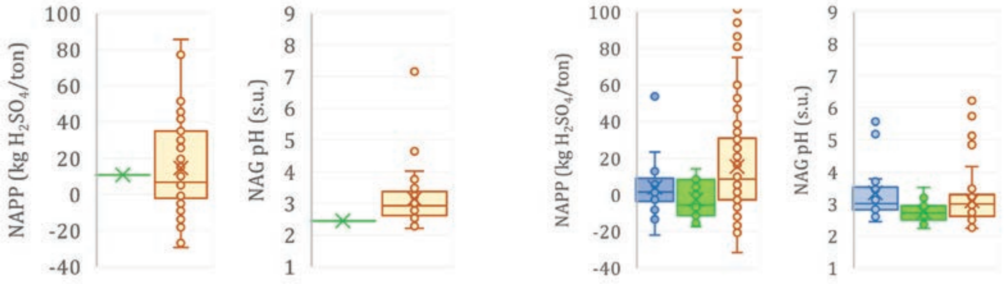


Figure 4 Geochemical Classification based on Stratigraphic Layers



IB A1-A2 Layer

IB A2-B1/B Layer



IB B1-B2 Layer
(No layer for MTB)

IB B2-C Layer

🟦 MTB Samples 🟩 TAL Samples 🟨 BB Samples

***Figure 5** Boxplots of Static Test Result for each stratigraphic layer*

ates pH values ranges 2.75 – 4.15. Layer B2-C is classified mainly as PAF with NAPP value of -2.52 ± 10.14 kg H_2SO_4/ton, NAG pH value of 2.76 ± 0.36 and kinetic test leachates pH values ranges 2.89 – 7.10.

Similar with TAL mine, in BB mine IB A1-A2 layer classified as NAF with NAPP value of -4.41 ± 13.69 kg H_2SO_4/ton, NAG pH value of 5.01 ± 1.76 and kinetic test leachate pH values ranges 9.20 – 8.10. The following layer of IB A2-B is classified mainly as PAF with NAPP value of 9.59 ± 24.68 kg H_2SO_4/ton, NAG pH value of 3.23 ± 0.98 and kinetic test leachates pH values ranges 2.10 – 8.40. Layer IB B1-B2 is classified mainly as PAF with NAPP value of 14.66 ± 25.78 kg H_2SO_4/ton, NAG pH value of 2.45 and kinetic test leachates pH values of 3.14 ± 0.85. Layer B2-C is classified mainly as PAF with NAPP value of 15.56 ± 36.03 kg H_2SO_4/ton, NAG pH value of 3.10 ± 0.75 and kinetic test leachates pH values ranges 2.10 – 6.80.

It can be concluded that vertical stratigraphical variation is evident as follows: IB A1-A2 classified as NAF, IB A2-B1 classified as PAF intercalated with NAF, IB B1-B2 classified as PAF, B2-C classified as PAF intercalated with NAF, as shown in figure 4.

Lateral variation of geochemical characterization

Lateral variation of geochemical characteristics is proven by comparing the same stratigraphic layer of three mine blocks as shown in Figure 5. It is found that there are variations of geochemical characteristics of some stratigraphic layers along MTB to TAL and BB as indicated from the results of static and kinetic tests particularly NAPP and NAG values. In all mine blocks IB A1-A2 is classified as NAF whereas IB A2-B1/B and IB B2-C are classified as PAF. Difference in geochemical characteristics exist among the PAF layer. The NAG pH value of IB A2-B1/B layer and IB B-C layer at TAL mine and BB pit 1 tend to be lower than at MTB and BB-3 mine. This lateral variation of geochemical characterization is possibly explained by geological setting of mine areas. It seems that quarternary andesitic intrusions in the south and underneath of TAL affected the coal and IB layers in TAL mine. In BB, there is significant difference between pit 1 in the south and pit 3 in the north. The PAF characteristic in BB pit 1 is similar to TAL mine while BB pit 3 is dominated by NAF material. Refer to the case in TAL, it seems that there exist the subsurface influence of andesitic intrusion activity as indicated in the southeast of BB in the geological map.

Conclusions

Vertical or stratigraphical variation of geochemical characterization is evident by comparing static and kinetic test results for each mine areas. It is concluded that IB A1-A2 is classified as NAF, IB A2-B1 is classified as PAF intercalated with NAF, IB B1-B2 is classified as PAF, and B2-C is classified as PAF intercalated with NAF,

Lateral variation of geochemical is evident due to quarternary andesitic intrusion. IB A1-A2 classified as NAF in all mine areas. IB A2-B yields more acid in TAL mine, compare to BB and MTB based on NAPP and NAG pH values. IB B1-B2 is classified as PAF in TAL and BB and IB B2-C is classified as PAF and yields more acid in BB mines compare to BB and MTB. Lateral variation shows elevated acidity from MTB to BB, except BB Pit 3 Timur due to its distant location to the intrusion bodies.

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