Determination of Acid Producing Potential Using pXRF: A Case Study from Cypress Mine, Stockton Plateau

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Abstract

Management of acid producing materials is critical to responsible mining using best practicable approaches to protect the environment and ensure effective mine closure that achieves closure objectives. At Cypress Mine the pyritic Kaiata Mudstone changes geochemically from potentially acid forming (PAF) at the base to non-acid forming (NAF), determined by acid base accounting (ABA), as part of a marine transgression sequence, but changes back to PAF at the ground surface. A drill program together with ABA testing was initiated to determine the PAF and NAF material quantities for mine closure planning. A reliable relationship between p-XRF calcium and laboratory analysed acid neutralisation capacity (ANC) was determined. This relationship was used to create a geochemical block model for the project area, which has facilitated the development of a materials schedule.

Keywords: Acid and Metalliferous Drainage, AMD, p-XRF, material schedules

Introduction

The Cypress Mine is owned by BT Mining and is located adjacent to the Stockton Mine on the Stockton Plateau, 35 km northeast of Westport, South Island, New Zealand. Cypress Mine is key to Stockton Mine's future as a blending partner for metallurgical coal exports. Stockton is a historical mine and extends back to 1906 while Cypress Mine commenced operation in 2014 and is in a pristine, high value ecological valley. The mine plan for Cypress was in 2 stages and started with a boxcut on the valley floor followed by a push-back into the flanks of the Mt William Range.

The coal is contained within the acidic Brunner Coal Measures, which is overlain by the pyritic Kaiata Mudstone. Much of the Kaiata Mudstone has been eroded from the Stockton Plateau, leaving a wedge along the eastern margin of the plateau against the Mt William Fault of the Mt William Range where the Cypress Mine is located (Nathan 1996).

The Kaiata Mudstone has an average total sulfur of 1.6 wt% but can be up to 4 wt% and is highly reactive (comprised of reactive framboidal pyrite) (Weber *et al*. 2006). At Cypress Mine the pyritic Kaiata Mudstone changes geochemically from potentially acid forming (PAF) at the base to non-acid forming (NAF), determined by acid base accounting (ABA), as part of a marine transgression sequence, but changes back to PAF at the ground surface.

It is important for BT Mining to ensure the material classification of PAF and NAF are correct as there is currently an excess of PAF material and a deficit of NAF material in Cypress. The majority of waste rock is stored on the ex-pit Northern engineered landform (NELF) which has 2.75 Mm^3 PAF and produces ~1,000 t H_2SO_4/yr. Some of the PAF within the NELF will be placed back within the Cypress pit as backfill. This will be capped by NAF, which is limited, as part of the final cover design.

Any NAF being placed with PAF results in the loss of a valuable resource. If PAF is dumped on the NAF dump it will decrease the integrity of the NAF dump and limit future reuse and closure options for the NAF such as cover construction and rehabilitation activities.

The original 2018 geochemical block model was a good working model for the original valley floor boxcut. However, BT Mining faced issues with material classification once the push-back started as the PAF and NAF material model had significant uncertainties due to limited drill data in the push-back. This resulted in PAF and NAF materials being sent to the wrong facility.

The model was based on the net acid producing potential (NAPP) value where NAPP was greater than or less than 0 kg H_2SO_4/t. This NAPP = 0 surface was fit for purpose for the boxcut in the valley floor but proved to be inadequate for the push-back leading to: contaminated NAF stockpiles; NAF materials being disposed of as PAF; and the introduction of a low acid forming zone (due to model uncertainty with this zone containing both PAF and NAF materials). Additional in-pit sampling was also required, which incurred additional costs as well as production delays.

In 2021 a drilling program was undertaken in the push-back to develop a new geochemical block model. These samples were analysed by the pXRF and validated with laboratory testing.

Methods

A reverse circulation (RC) drilling program (50 holes) was undertaken in late 2021 in Stages 3 and 4 of the Mt William push-back targeting the NAPP = 0 surface, which is ~30 m above the interface with the Brunner Coal Measures. The RC drill produces a reasonably dry and fine, homogenised drill-chip, which was directly analysed with the pXRF.

Each of the 50 RC holes ranged in depth between 9 and 48 m and 1,019 m of drill-chip was collected. Each meter of drill-chip was riffle split to obtain a sample of ~2 - 5 kg and these samples were analysed 4 times with the pXRF. A total of 318 samples were selected to be sent to the laboratory for analysis for total S (wt%) and ANC to determine the NAPP value. NAPP was determined by:

$$\text{NAPP (kg } H_2SO_4\text{/t)} = (\text{wt\%S} * 30.6) - \text{ANC (kg } H_2SO_4\text{/t)}$$

where a NAPP value >0 is PAF and ≤0 is NAF.

pXRF-S and pXRF-Ca analyses were corrected for the blank and calibration reference samples, then the 4 analyses were averaged to give a single result for each 1 m of drill core. Samples sent to the laboratory were selected based on the geochemical model with samples being selected from the transition zones from PAF to NAF as well as some longer sections to ensure any relationships held across all samples. A relationship was established between the pXRF-Ca and laboratory NAPP values which formed the basis of the block model.

During the development of the geochemical block model any unclear transitions between PAF and NAF were assessed to see the variation in NAPP value as well as the trend of the surrounding holes and where the surface would geologically and geochemically align. If there was no clear understanding of where the NAPP = 0 surface should lie then a conservative approach was undertaken.

Results

Comparison of the results for pXRF-S and laboratory total S% showed that the pXRF is not sufficiently sensitive to detect the small changes in sulfur that occur throughout the Kaiata Mudstone. Data indicates that sulfur content only has a minor change within the project area and is not the determining factor for classification of PAF or NAF.

A good relationship between pXRF-Ca and laboratory ANC and NAPP was established with a degree of certainty – R^2 of 0.76 and 0.72 respectively (Figure 1). For the creation of the geochemical block model samples only need to be classified as PAF or NAF (i.e., NAPP >0 for PAF and NAPP ≤0 for NAF) and a pXRF-Ca value of 14,000 mg Ca/kg was determined to represent this change in the material from PAF to NAF.

Using this cutoff value of 14,000 mg Ca/kg the pXRF-Ca and laboratory NAPP value were in agreement 90% of the time and are within NAPP -5 to 5 for 95% of the time, meaning that about half of the samples incorrectly classified by the pXRF are low acid forming zone (Figure 2).

At ~14,000 mg Ca/kg pXRF-Ca there is commonly a distinct change with a sudden drop in Ca value to the 1,000's for PAF from the 10,000's for NAF (Figure 2). This occurs for both the upper and lower NAPP = 0 surfaces. Consequently, 14,000 mg Ca/kg pXRF-Ca was selected as the cutoff in the pXRF-Ca data to define PAF and NAF. This is supported by the laboratory data (Figure 2).

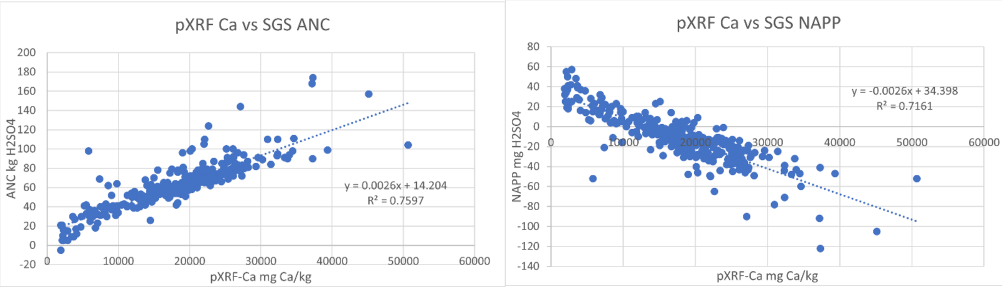

Figure 1 *Graphs showing the correlation between pXRF-Ca and laboratory ANC (R2 = 0.76) and pXRF-Ca and Laboratory NAPP (R^2 = 0.72).*

The results showed that there are 2 surfaces within the data, which is consistent across the drillholes with the lower surface occurring at ~30 m above the interface with the Brunner Coal Measures and the upper surface occurring ~5-10 m below the ground surface.

From the data collected from the drilling program a geochemical block model was developed for use in daily operations at Cypress Mine. The block model has 2 NAPP = 0 surfaces.

Discussion

The Kaiata Mudstone was deposited in the Late Eocene during a marine transgression (Flores *et al.* 1996) and the geochemical change from PAF at the base of the formation to NAF higher up due to the steady transgression through to the Nile River Limestone (i.e., increasing carbonate) (Nathan 1996), which resulted in increasing Ca. There is a minor decrease in S with younger lithologies, but it was not sufficient or consistent enough to reliably affect the NAPP prediction of the material. Rather it

DH 3878R pXRF-Ca (14000	SGS NAPP	DH 3539 pXRF-Ca (14000	SGS NAPP	DH 3909 pXRF-Ca (14000	SGS NAPP	DH 3973 pXRF-Ca (14000	SGS NAPP	DH 4011 pXRF-Ca (14000	SGS NAPP	DH 4078 pXRF-Ca (14000	SGS NAPP
3666	41	1371		1140		5458		3995		1653	
6795	32	1411		548		2218		2466		1440	
3711	39	2361	41	1095		2737	42	2208	19	1699	
3444	48	4133	37	831		3905	27	3585	29	2575	
2891	57	16284	-13	2031		18779	-14	13137		2771	
2112	55	9848	5	4100		32369	-71	8240	4	2812	
2295	50	21430	-26	15931		26110	-39	14753	-4	4830	14
4743	36	24860	-38	17170		20600	-17	11914	4	20084	-31
2413	22	24472		28574		22866	-14	15207	-3	34642	-60
19344	-23	21803		24065		24246	-14	13945	-1	20878	
26914	-46	24563		23812		29299	-30	18344	3	19403	
34467	-47	23800		31634		39358	-47	17481	-26	32728	
33748	-32	35891		20323		19428	-8	23914	-18	19695	
26381		22224		25840		18189	-4	17828	-21	25154	
14 pXRF NAF values		23325		24647		20909	-14	22455	-21	31003	
removed		21818		26352	-26	23255	-11	26183	-35	21627	
21418		22737		18866	-11	25155	-20	27415	-41	26405	-32
27113	-24	25933		17080	-11	17884	3	22922	-2	23202	-25
13034	14	17684	-7	33318	-48	25617	-21	17504	-3	9023	23
16408	-4	26255	-28	32349	-39	28239	-26	19793	4	6961	17
17529	-12	33983	-43	18795	6	25941	-21	22638	-65	19261	-30
17194	-4	6007	23	22110	-50	27116	-90	20492	-8	5802	15
17943	-16	6730	14	21429	-20	27141	-23	25113	-13	9879	
13825	1	7052	29	9055	3	9974	15	16639	14	7010	
19266	-3	6335		8054	16	11773	-5	12081	-10	5155	
22936				4842		6401	16	7909	11	5185	
7 pXRF NAF values				14182		9833		16716	-9	5565	
removed						5802		10792	5	4738	
25495						5 pXRF PAF values				5967	
18916	-22					removed				5783	
13208	0										

Figure 2 *Comparison of allocation of NAF (green) and PAF (red) for the pXRF-Ca and SGS NAPP values. For the pXRF-Ca there is often a step change from the 1,000's for PAF to 10,000's for PAF.*

is the carbonate content that controls NAPP and can be used for the prediction of AMD potential using the pXRF.

Results from the pXRF work and validated by the laboratory analyses show that it is possible to reliably predict acid producing potential from the Kaiata Mudstone, in particular from the sediment from the RC drill, when Ca is used as the indicator element with a cutoff of 14,000 mg Ca/kg. Work with the pXRF-S show that S is not a reliable indicator of acid producing potential.

For the development of the geochemical block model only a binary result of either PAF or NAF was required and this increased the correlation between the pXRF-Ca and laboratory NAPP results to 90%. However, when the NAPP values are set to between -5 and 5 kg H_2SO_4/t, indicating that the material has low acid producing potential, the correlation between the pXRF-Ca and laboratory NAPP values increases to 95%.

The geochemical model shows a wedge of NAF Kaiata, which is terminated to the east by the east dipping Mt William Fault, to the west, at surface, by the westerly dipping topographic surface and at depth by the underlying stratigraphically controlled PAF Kaiata (Figure 3). The lower NAPP = 0 surface is stratigraphically controlled and is ~30 m above the interface with the underlying acidic Brunner Coal Measures and is analogous to the original NAPP surface from the boxcut. The upper NAPP = 0 surface is topographically controlled and is likely a leaching zone on the flank of the Mt William Range. This surface was unknown prior to this work.

Prior to the development of this geochemical block model a single NAPP = 0 surface was used which was suitable for the boxcut on the valley floor. However, when the pushback into Mt William ranges was started PAF was occurring in unexpected zones which led to increased in-pit sampling, production delays or NAF being disposed of on the PAF dump to avoid production delays, planning for a low acid forming dump and PAF being deposited on the NAF dump decreasing its integrity. The development of the new block model has alleviated these issues.

The geochemical block model NAPP surfaces are used every day by the operations team and are a fundamental part of all overburden stripping plans where the

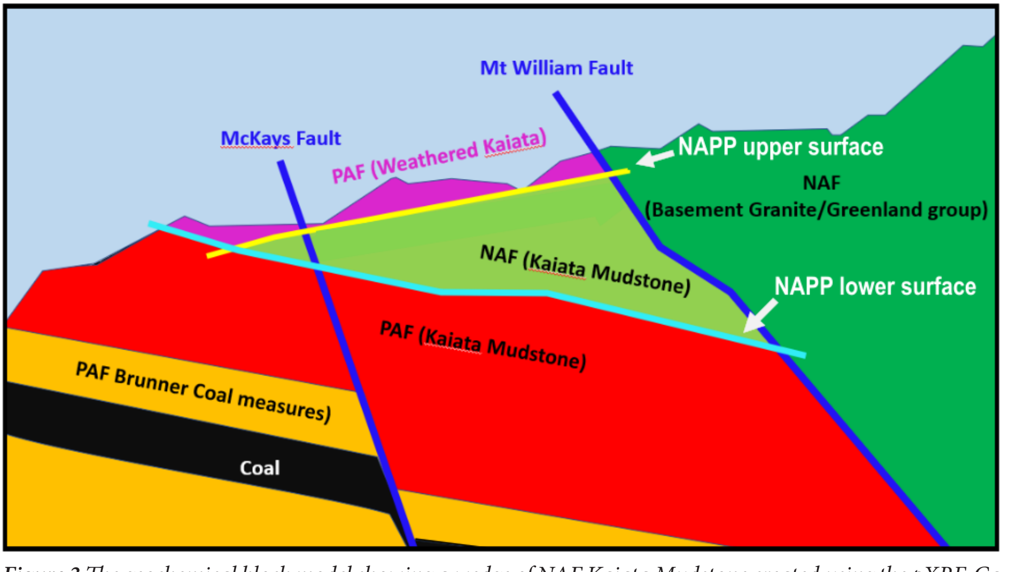

Figure 3 The geochemical block model showing a wedge of NAF Kaiata Mudstone created using the pXRF-Ca data and validated by laboratory ABA analyses. The model shows 2 NAPP = 0 surfaces with the NAPP upper surface being topographically controlled and the NAPP lower surface being stratigraphically controlled (block model created by Phillip Fick).

material type changes across the flitch. There is conservatism built into the system bought about through the method of stripping. The stripping blocks are 3 – 5 m high horizontal flitches and the NAPP surfaces are dipping. Therefore, with a vertical dig face there is a wedge of NAF in each flitch that is taken as PAF material. This means that any undulation in the NAPP surfaces has little to no effect on the integrity of the NAF dumps. The result of the introduction of the new block model is that the old NAF dump has an average NAPP value of -5.5 H_2SO_4/T whereas the new NAF dump has an average NAPP value of -19 H_2SO_4/T.

The establishment of the relationship between pXRF-Ca and NAPP means that in-pit operational decisions regarding uncertainty in PAF or NAF can be dealt with instantaneously rather than waiting in excess of 24 hours for laboratory results. This ensures no production delays, loss of NAF or incorrect material designation.

As mining progresses south the block model will be extended as the mining area is extended and cleared for stripping. This will ensure the continued correct material designation for the life of mine.

Conclusions

The use of the pXRF in determining the acid producing potential has been proven to be successful for use in the Kaiata Mudstone at Cypress Mine. The implementation of the new geochemical block model has been critical to operational activities to ensure the correct material designation of PAF and NAF. This has allowed for a decrease in in-pit sampling, costs associated with production delays and NAF being dumped on the PAF dump as well as increasing the integrity of the NAF dump, which is a scarce resource required for closure and the protection of the waterways.

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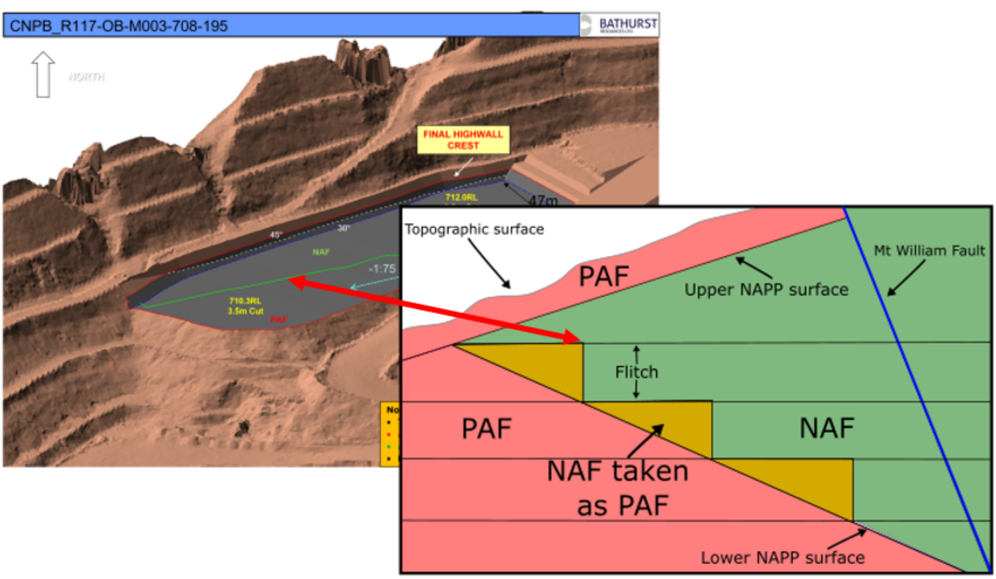

Figure 4 Schematic of the flitches in-pit which transition from PAF to NAF showing that a wedge of NAF is taken as PAF material above the lower NAPP surface. The PAF/NAF line on the Engineers digplans relates to base of the flitch to ensure no PAF ends up on the NAF dump.

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