Geochemical studies of waste rock at proposed Escarpment open cast mine, Denniston Plateau West Coast.

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Abstract

Geochemical data has been collected to enable prediction of mine drainage chemistry at the proposed Escarpment open cast mine on Denniston Plateau. The data collected includes analysis of regional datasets of acid base accounting data and mine drainage chemistry, site specific acid base accounting data, column leach testing and lysimeter testing. These data can be combined to indicate that mine drainage chemistry will be strongly acidic with elevated concentrations of Fe, Al, Ni, Zn and other trace elements. Additional acid base accounting data and kinetic testing data are currently being collected to optimise waste rock management strategies.

Keywords: Acid Mine Drainage (AMD), trace element, acid base accounting, kinetic testing, lysimeter.

Introduction

Buller Coal Ltd plans to develop the Escarpment open cast mine on the Denniston Plateau, West Coast, South Island, New Zealand. Buller Coal Ltd has completed extensive environmental management planning to minimise the environmental impact at the mine and prevent any significant disturbance to the surrounding environment. This environmental management planning is governed by a consenting process that includes preparation of assessment of environmental effects (AEE) documents, resource consent applications with the West Coast Regional Council and application for access with land owners (Department of Conservation). Much of the documentation supporting these studies and application processes is publically available (Buckingham, 2008; Patrick et al., 2008; Rait et al., 2008) and can be obtained on-line at the West Coast Regional Council website.

Mining on the Denniston Plateau has a long and rich history (Barry et al., 1994) and currently continues at the Cascade Mine which produces ~50000t of coal per year. The planned Escarpment open cast mine overlaps the abandoned underground Escarpment mine and is planned to produce 1-2Mt of coal per year. The abandoned mine and remaining resource is hosted in the Brunner coal measures. The underground mine was operated between the early 1960s and the early 1980s and produced moderate ash, low S coking coal. Currently portals of the underground Escarpment mine discharge acid mine drainage into the surrounding environment without treatment or management (Pope et al., 2006; Pope et al., 2010a) because water management planning and remediation were not conducted at the time the Escarpment underground mine ceased to operate. This is not uncommon at abandoned mines that are hosted in the Brunner Coal Measures. However, modern and future operations are planned to have zero net environmental effect and sometimes positive environmental effects.

The consenting process requires that all water discharged from the proposed Escarpment open cast mine meet appropriate targets for quality. In order to demonstrate that these targets can be met Buller Coal Ltd prepared a detailed water management plan (Golder, 2011). Predictions of mine drainage chemistry (Rait et al., 2008; Pope and Rait, 2010; Rait and Pope,

2011) have been fed into a detailed water management plan so that appropriate management and treatment of the drainages can be designed as required.

We present results of the prediction of mine drainage chemistry at the proposed Escarpment open cast mine by several methods (Cavanagh et al., 2010) comprising;

1. assessment based on regional geology and regional geochemistry
2. analogy to similar mines operating in similar environments
3. acid base accounting analysis
4. laboratory based kinetic testing
5. field based kinetic testing.

These methods provide information on different aspects of the prediction of mine drainage chemistry and are best interpreted in combination for maximum certainty. They provide enough information to characterise the likely mine drainage chemistry, identify treatment requirements and make plans for waste rock and water management on the mine site. The data collected to date will be combined with more information from resource definition drilling, mapping and modelling during mining operations, and monitoring of seeps and discharges upstream of treatment operations.

Methods

Assessment of mine drainage chemistry by analysis of regional datasets and analogy with other mines that operate in similar conditions to those at the proposed Escarpment mine is completed mostly by literature review (Cavanagh et al., 2010). Several studies that include regional compilations of coal mine drainage chemistry for the West Coast of the South Island have been published (James, 2003; Hewlett et al., 2005; Pope et al., 2010a). In addition, there are several mine site specific studies of operations in the Brunner coal measures that have drainages that could be comparable with those expected at the proposed Escarpment mine (Alicorn Leon and Anstiss, 2002; Davies, 2009; MacKenzie, 2010; McCauley et al., 2010).

Acid Base Accounting Sampling and Testing

Acid base accounting analyses are often referred to as static tests and include several commonly applied procedures (Smart et al. 2002). Units for all values, except pH, are kg H_2SO_4/tonne.

- Maximum Potential Acidity (MPA). This test typically uses a total sulphur analyses to determine the maximum possible acid released assuming all S is bound in pyrite. This assumption usually valid, however, it is possible that sulphate minerals or organically bound S could provide false positive data. Pyrite specific S analyses can be used for calculation of MPA if necessary (Sullivan et al., 1999; 2000).

- Acid Neutralising Capacity (ANC). This analysis determines the acid consumption of a crushed rock sample by reaction with a fixed quantity of acid.

- Net Acid Production Potential (NAPP). This analysis is the difference between MPA and ANC

$$\text{NAPP} = \text{MPA} - \text{ANC}$$

- Net Acid Generation (NAG). This analysis oxidises all reactive sulphide forming acid and allows the acid to react with any ANC in the rock. Acidity titrations and pH measurements of the reaction liquor are used to quantify the acid producing potential.

False positive analyses can occur in NAG data if samples contain abundant organic material because organic acids can be released (Smart et al. 2002).

- Paste pH measures the water soluble acidity within a sample and includes adsorbed protons, soluble acidic salts and adsorbed metals that hydrolyse (Lin et al., 2000). The paste pH does not measure the potential of a sample to produce acid with continued weathering because that process requires oxidation to release acid but paste pH can be correlated with other data to indicate acid producing samples (Weber et al., 2006).

Kinetic Testing

Kinetic testing was conducted in the laboratory using leach columns and in the field using field based columns (or lysimeters). The objective of the leaching columns is to rapidly react the rocks from the proposed Escarpment mine site to determine the total amount of leachable acid, alkalinity and trace elements. This is likely to differ from the theoretical maximum values obtained through acid base accounting. The objective of the lysimeters is to determine the influence of field conditions on rates of AMD forming reactions and compare the chemistries of AMD from different rocks under field conditions.

Both column and lysimeter kinetic tests are conducted on drill core made up into five different rock blends.

- Rock type 1 contains sandstone (likely PAF). Included are medium and granular sandstones with some carbonaceous bands that contain pyrite.
- Rock type 2 contains mudstone (likely PAF). Includes highly carbonaceous mudstone, mudstone with coaly bands and pyrite.
- Rock type 3 contains sandstone (likely NAF). Includes sandstones and fine carbonaceous sandstone.
- Rock type 4 is a rock mixture. The proportions are based on relative abundance of rock types at the proposed Escarpment Mine site based on drill hole data and comprises 40% sandstone, 38% carbonaceous mudstone, 5% mudstone, 15% conglomerate and 2% high ash coal.
- Control sample was an unreactive, acid washed greywacke gravel chip.

Column Tests

The rock samples were placed into apparatus and tested using the standardised free draining column leach method (Smart et al., 2002). Two columns of each rock blend and one column of control were set up in plastic Buchner funnels and contain about 1.8kg of rock material. To simulate high rainfall, each column is watered weekly with deionised water at 1:10 mass ratio (water:rock) and every fourth week each column is flushed 2:5 mass ratio. Samples of leachate are collected after the flush has drained through the column. Columns are exposed to a diurnal drying cycle with heat lamps to stimulate capillary water movement and evaporative processes and are set up in racks so that 9 columns sit 30cm below 3, 275W heat lamps. After sampling, measurements of physical properties and chemical analyses on the leachate are completed. Analytes include pH, ec, acidity, alkalinity, major cations and anions and trace elements.

Lysimeter Tests (field columns)

Lysimeters are field trials that are embedded into waste rock dumps to collect leachate. At the proposed Escarpment mine site there are currently no waste rock dumps so the lysimeters are more like field based columns, but we refer to them as lysimeters to prevent confusion between lab and field trials. Each lysimeter was constructed with about 25kg of rock in a 50L plastic bucket with an open top to receive rainfall and drain at the base into a 210L drum. All leachate is retained in the drum between sampling rounds and the volume is measured at sample collection and the drum is drained prior to collection of the next sample. A coarse quartz gravel layer was placed in the bottom of each 50L drum and was covered by the rock sample. Geotextile cloth was used to prevent any material being lost through the outlet. Head space of 25cm above is left above the top of the sample to allow for slow drainage through the system (Figure 1).

Figure 1: Lysimeter (field column) setup

Two lysimeters of each rock blend and one control were set up (nine lysimeters in total). After sampling, measurements of physical properties and chemical analyses on the leachate are completed. Similar to the column tests, analytes include pH, EC, acidity, alkalinity, major cations and anions and trace elements.

Results

Acid base accounting

Acid base accounting analyses have been completed for 95 samples at the proposed Escarpment opencast mine site (Table 1). Non acid forming (NAF) rocks are typically defined to have NAG pH > than 4.5 and a negative NAPP value and 17 samples have these characteristics. Potentially acid forming (PAF) rocks are typically defined to have NAG pH < 4.5 and positive NAPP values and 58 samples are potentially acid forming. The remainder of the rocks can not be classified as PAF or NAF with standard acid base accounting tests.

Column and lysimeter tests

Leachate data is available for the first six months of column and lysimeter tests. Leachate chemistry has varied with time as different components within the rocks react and release acid, alkalinity, major cations and anions and trace elements (Table 2).

Acid base accounting tests were conducted on the samples prepared for columns (Table 3). Rock types 1 and 2 are PAF as required. Rock type 3 was planned to be NAF and has ANC but has excess MPA and therefore in not NAF. Rock type 4 is PAF with roughly average MAP for the rocks encountered at the proposed Escarpment mine site.

Table 1: Acid Base Accounting data for rocks from the proposed Escarpment Mine. Total S % air dried basis, other units as per text above.

Lith Code	NAG pH	NAG	Total S	Paste pH	ANC	MPA	NAPP	Lith Code	NAG pH	NAG	Total S	Paste pH	ANC	MPA	NAPP	Lith Code	NAG pH	NAG	Total S	Paste pH	ANC	MPA	NAPP
CO	2.7	56	0.47	7.4	2	14.4	12.4	MCMST	2.9	12	0.56	4.9	-0.4	17.1	17.1	HCM	4	17	0.07	5.9	0	2	2.1
ZST	6.6	3	0.01	6.0	0.0	0.3	0.3	MCMST	3.4	25	0.25	6.4	4	8	3.7	HCM	2.9	45	0.13	5.7	0.8	4.0	3.2
VCSS	6.8	4	0.01	7.0	0.0	0.3	0.3	MCMST	2.4	35	0.4	5.1	-1	12.2	12.2	HCM	5.5	3	0.03	5.5	0.0	0.9	0.9
VCMST	2.3	126	0.58	5.1	0	17.7	17.7	MCMSS	3.2	23	0.13	4.0	0.7	4.0	3.3	HCM	2.7	21	0.86	6.7	4.3	26.3	22.0
SCZST	7.7	0	0.03	6.3	4.5	0.9	-3.6	MCMSS	5.2	5	0.03	5.2	0.1	0.9	0.8	HCM	6.0	1	0.05	6.2	5.0	1.5	-3.4
SCVFSS	6.5	4	0.02	5.7	1.7	0.6	-1.1	MCMSS	5.2	3	0.03	5.8	4.7	0.9	-3.8	HCM	2.1	49	1.84	6.2	3.5	56.3	52.8
SCVFSS	6.3	6	0.03	5.9	0.5	0.9	0.4	MCFSS	5.3	4	0.03	6.6	5.2	0.9	-4.3	HCM	2.9	33	0.32	6.1	5	10	4.8
SCMSS	2.3	47	1.98	7.1	-1.1	60.6	60.6	LVCSS	2.6	12	0.48	6.8	3.7	14.7	11.0	HCm	3.0	14	0.74	6.8	0.9	22.6	21.7
SCGSS	5.1	5	0.13	6.9	-1.4	4.0	4.0	LSCVFSS	6.6	2	0.05	5.8	1.0	1.5	0.5	HCM	5.9	1	0.07	6.2	4.6	2.1	-2.5
SCGSS	6.9	1	0.01	6.9	0.0	0.3	0.3	LSCSS	5.8	2	0.01	6.3	3.6	0.3	-3.3	HCM	2.8	27	1.45	5.5	3.2	44.4	41.2
PBCG	5.2	5	0.01	6.1	0.0	0.3	0.3	LMST	2.6	27	0.99	4.8	-1.1	30.3	30.3	HCM	4.1	14	0.06	5.8	0.4	1.8	1.4
MST	2.6	34	0.59	5.4	2.5	18.1	15.5	LMST	6.5	2	0.03	5.4	-1.3	0.9	0.9	HCM	2.9	37	0.26	7.7	3	8.0	5.0
MST	5.2	4	0.10	6.2	4.9	3.1	-1.9	LMSS	7.0	0	0.01	6.9	0.8	0.3	-0.5	GSS	7.1	0	0.01	7.2	0.0	0.3	0.3
MST	4.5	9	0.08	6.2	3.9	2.4	-1.5	LMCVFSS	6.5	2	0.02	6.4	-0.2	0.6	0.6	GSS	7.5	0	0.10	6.2	0.1	3.1	3.0
MSS	3.7	10	0.38	5.9	1	12	10.6	LMCSS	2.8	49	0.12	5.4	6.3	3.7	-2.6	GSS	7.2	0	0.04	7.3	0.2	1.2	1.0
MSS	2.7	27	1.49	6.2	-1	46	45.6	LMCMSS	4.7	4	0.16	6.8	4.4	4.9	0.5	GSS	6.0	0	0.18	6.1	0.2	5.5	5.3
MSS	3.6	15	0.30	6.1	1	9	8.2	LMCFSS	2.6	31	1.33	6.7	2.9	40.7	37.8	GSS	2.2	35	1.36	6.4	-0.4	41.6	41.6
MSS	3.3	11	0.44	5.3	1	13	12.5	LHCZST	6.7	1	0.01	5.8	1.0	0.3	-0.7	GSS	5.0	6	0.02	8.0	-3.0	0.6	0.6
MSS	3.4	4	0.33	7.4	3.3	10.1	6.8	LHCM	4.3	9	0.01	6.0	0	0	0.3	GSS	5.3	5	<0.01	7.8	0.8	0.0	-0.8
MSS	6.3	1	0.14	7.3	2	4	2.3	LHCM	2.3	52	2.37	3.9	2.1	72.5	70.4	CSS	7.5	0	0.02	5.5	0.0	0.6	0.6
MCZSMST	2.6	30	1.19	4.3	-1.4	36.4	36.4	LFSS	7.4	0	0.03	6.9	4.8	0.9	-3.9	CQ	3	30	0.1	5.9	2	3	1.0
MCZSMST	2.4	30	1.20	5.0	0.5	36.7	36.2	LCSS	3.0	7	0.39	7.0	-0.1	11.9	11.9	CQ	3.5	16	0.06	5.9	0.2	1.8	1.6
MCVFSS	2.3	32	1.31	4.2	-2.6	40.1	40.1	HCZST	6.8	1	0.01	6.1	0.6	0.3	-0.3	CQ	2.7	62	0.16	5.2	0.9	4.9	4.0
MCSS	3.1	17	0.71	4.4	1	22	21.0	HCVFSS	4.4	11	0.04	5.9	5.3	1.2	-4.1	CQ	2.0	129	7.12	2.3	0.0	217.9	217.9
MCMST	2.3	42	1.45	5.8	0.7	44.4	43.6	HCM	3.5	20	0.09	4.2	1.6	2.8	1.2	CQ	3.2	23	0.25	6.3	3	8	4.7
MCMST	3.6	13	0.13	3.9	0.9	4.0	3.1	HCM	2.6	21	1.07	4.5	-1	33	32.7	CO	5.4	4	0.34	8.2	12	10.4	-1.6
MCMST	6.1	1	0.02	6.2	1.5	0.6	-0.9	HCM	3.2	37	0.06	6.8	1.4	1.8	0.4	CO	2.2	187	0.47	7.8	2	14.4	12.4
MCMST	4.8	7	0.04	7.2	2.3	1.2	-1.0	HCM	3.6	20	0.06	6.0	0.6	1.8	1.2	CO	2.1	74	2.95	3.1	-2.4	90.3	90.3
MCMST	7.1	0	0.03	7.1	5.4	0.9	-4.5	HCM	3.9	14	0.06	5.5	0.9	1.8	0.9	CO	3.1	26	2.05	4.2	0	62.7	62.7
MCMST	3	21	0.65	4.8	1	20	19.0	HCM	2.8	15	0.60	4.5	0.0	18.4	18.4	CO	2.6	65	0.9	6.1	0	27.5	27.5
MCMST	2.4	50	1.76	4.0	0	54	54.0	HCM	2.5	41	0.92	3.8	0.3	28.2	27.8	CO	3.1	27	0.04	7.3	0	1.2	1.2
HCM	3.0	15	0.44	3.7	-0.9	13.5	13.5																

Codes: CO – Coal, CQ – High ash coal, ZST – siltstone, SS – Sandstone, CG – conglomerate, MST – Mudstone, HCM – Highly carbonaceous mudstone. PB – pebble, G – granular, VC – very course, C – Course, M – Medium, F – Fine, VF, Very fine, SC – Slightly carbonaceous, MC – moderately carbonaceous, L - laminated.

Table 2: Maximum, minimum and average values for lysimeter tests on rocks from the proposed Escarpment mine site. Bicarbonate g/m^3 as $CaCO_3$, EC conductivity S/m, other analytes g/m^3.

	Rock Type 1			**Rock Type 2**			**Rock Type 3**			**Rock Type 4**		
	Average	**Max**	**Min**	**Average**	**Max**	**Min**	**Average**	**Max**	**Min**	**Average**	**Max**	**Min**
pH		3	2.6		3.8	2.7		5.5	4.4		4.3	2.8
Bicarbonate	0	0	0	0	0	0	1.94	4.9	1.2		1.2	1.2
EC	112	175.3	51.1	93.2	154.7	26	4.29	6.2	2.6	46.2	143.1	23.4
Sulphate	336	670	91	327	610	66	16.1	34	7.5	171	370	62
Aluminium	3.37	11.8	0.37	5.84	12.7	0.93	0.022	0.037	0.01	3.85	7.3	1.25
Arsenic	0.019	0.068	0.0011	0.007	0.0117	0.0028		0	0		0	0
Barium	0.008	0.029	0.0017	0.005	0.023	0.00152	0.025	0.034	0.0136	0.019	0.025	0.0138
Boron	0.007	0.007	0.007	0.009	0.009	0.009	0.006	0.009	0.005	0.006	0.007	0.005
Calcium	5.13	34	0.2	18.1	31	4.5	2.08	3	1.25	14.4	23	3.6
Chromium	0.069	0.37	0.0025	0.009	0.022	0.0005		0	0	0.00194	0.0042	0.0006
Cobalt	0.042	0.29	0.0014	0.136	0.26	0.026	0.012	0.0192	0.0025	0.152	0.3	0.023
Copper	0.395	0.97	0.106	0.358	0.92	0.037	0.002	0.0048	0.0008	0.215	0.49	0.072
Iron	63.7	134	12.9	44.9	115	0.46	0	0	0	0.984	2.3	0.04
Lead	0.111	0.22	0.039	0.019	0.061	0.0046	0.0006	0.00193	0.00013	0.017	0.047	0.0036
Magnesium	0.535	3.6	0.05	4.68	8.2	0.73	0.88	1.45	0.4	5.98	13.6	0.8
Manganese	0.299	0.77	0.043	0.656	1.14	0.183	0.251	0.48	0.078	0.658	1.33	0.097
Nickel	0.7	3.4	0.061	0.402	0.73	0.142	0.041	0.066	0.0184	0.312	0.57	0.054
Potassium	1.15	6.1	0.26	1.45	5.3	0.2	1.34	2.1	0.72	3.64	6.9	1.12
Sodium	1.149	1.6	0.86	1.24	1.61	1	1.28	1.53	0.95	1.49	2.8	1.02
Uranium	0.005	0.029	0.00029	0.006	0.0143	0.00104	0.00006	0.00011	0.00002	0.003	0.0067	0.00085
Zinc	2.97	5.7	1.06	2.58	4.4	0.54	0.082	0.111	0.04	2.53	4	0.59

Table 3: Acid base accounting data for column leach and lysimeter samples

	NAG pH	NAG	Total S	Paste pH	ANC	MPA	NAPP
Rock type 1	3.9	4	0.33	6	0	10	10
Rock type 2	2.5	30	1.16	5.2	1	35	34
Rock type 3	6.8	0	0.25	5.7	2	8	6
Rock type 4	3.6	11	0.48	5.5	1	15	14

Discussion

Prediction of mine drainage chemistry by analogy indicates that the proposed Escarpment mine will produce acid mine drainage (AMD). In general, disturbance (natural or anthropogenic) to Brunner coal measures will produce acid rock drainage (ARD) and if that disturbance is mine related then AMD occurs. This interpretation can be drawn either by examining mine drainages from current and historic mines hosted in the Brunner coal measures (Hewlett, 2003; Black et al., 2005; Pope et al., 2010a) or by examining regional compilations of rock geochemistry (Pope et al., 2010b). There are several detailed site specific studies that provide constraints on the likely chemistry of mine drainage at the proposed Escarpment mine (Alicorn Leon and Anstiss, 2002; de Joux, 2003; de Joux and Moore, 2005; Trumm et al., 2008; Davies, 2009; MacKenzie, 2010; McCauley et al., 2010). These studies indicate large variations in the chemistry that can occur in rock drainage from Brunner coal measures (Table 4). Studies of the Mangatini catchment present results of mine drainage chemistry at seeps, impacted and unimpacted tributaries as well as upstream and downstream of mine drainage treatment (Davies et al., 2008; Davies, 2009).

Table 4: Variation in published data for Brunner Coal Measures AMD and predicted acidity values for Brunner Coal Measures opencast mines (BCM oc) from Cavanagh et al (2010).

Site Name	Source	pH	ec	Ca	Mg	Na	K	B	Fe	Mn	Al	As	Co	Cr	Cu	Ni	Pb	Sb	Tl	Zn
Whirlwind Seep	Pope et al (2010a)	3.46	107	3.52	2.77	3.07	1.78	< 0.00	0.72	0.54	5.73	< 0.00	0.03	< 0.00	0.01	0.04	0	< 0.00	0	0.15
Collis Seep	McCauley et al (2010)	2.1	5660	264	235	3.4	0.8	-	1430	29	627	0.15	1.9	0.83	0.58	3.9	<	<	-	18
Mangatini Headwater	Davies (2009)	2.6	1048	41.5	7.5	3.2	2.1	<	12.7	-	39	<	0.11	-	0.06	0.24	-	-	-	1.15
Mangatini Stream	Davies (2009)	2.8	946	40.1	13.6	3.7	3.7	0.01	36.4	-	58	0.02	0.16	-	0.06	0.32	-	-	-	1.57
Max BCM oc	Cavanagh et al (2010)	2							50		200									
Min BCM oc	Cavanagh et al (2010)	3							10		20									

The range in chemistry of coal measures mine drainages and seeps (Table 4) reflects variation in mine drainage chemical evolution. Pyrite oxidation initially produces sulphuric acid, dissolved Fe(II) and dissolved trace elements. However, these are diluted and products react with air and surrounding rocks which modifies pH, dissolves additional components such Al, Ca, Mg, K and also precipitates new minerals (Espana et al., 2005). In the Mangatini catchment mine drainage chemistry is relatively uniform despite significant (>1km) distances between sites (Table 4). Mine drainage chemical evolution from Brunner coal measures requires more study, but values in Table 4 and other compilations of data can be applied to prediction of mine drainage chemistry at new mine sites such as the proposed Escarpment mine. Application of these data require assessment of which samples are most appropriate based on sample descriptions and the characteristics of the new site.

Acid Base Accounting

Acid base accounting data assesses acid producing potential by two different methodologies: theoretical maximums of acid production and acid neutralisation through net acid producing potential (NAPP) analysis; and simulated rapid weathering through net acid generation (NAG) analysis. Agreement between NAPP and NAG pH analysis occurs in most samples and they can be classified (Figures 2-4) as either Non-Acid Forming (NAF) or Potentially Acid Forming (PAF). NAF samples either do not produce acid, or have an excess of acid neutralising capacity compared to acid production potential. In general the dataset collected from the proposed Escarpment mine site has slightly more NAF rocks than other datasets published for the Brunner coal measures (Pope et al., 2010b).

About 20% of samples (20 out of 95) cannot be classified as either PAF or NAF. Two of these samples are acid producing by NAG pH analysis (Low NAG pH) but non acid producing by NAPP analysis (ANC>MPA). The other 18 samples that are difficult to classify have low acid producing potential (NAPP) but circum-neutral NAG pH. There are various interferences and uncertainties in acid base accounting analysis and these can usually be resolved with additional testing. Preliminary interpretation of the unclassified samples that cannot easily be classified as PAF or NAF indicates that organic material is oxidising during NAG analysis and reduces pH in samples that are otherwise NAF. In addition, it is likely that some samples contain sulphur species such as organic bound sulphur or gypsum that are not acid forming. This has the effect of falsely classifying samples as NAPP positive. Further analyses can be completed to confirm these interpretations and it is likely that many of these samples will be NAF. Currently a conservative approach is taken for interpretation of these samples and it is initially assumed that they are acid producing.

The data collected indicate that there is little relationship between static test results and, rock type (Figure 2), proximity to coal (Figure 3) or location area (Figure 4).

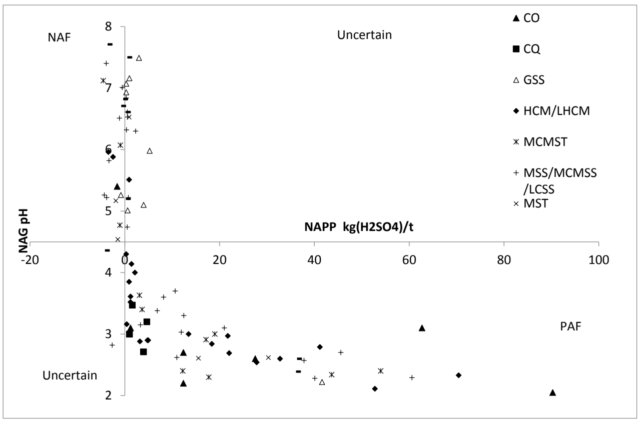


Figure 2: Acid Base Accounting data for different rock types

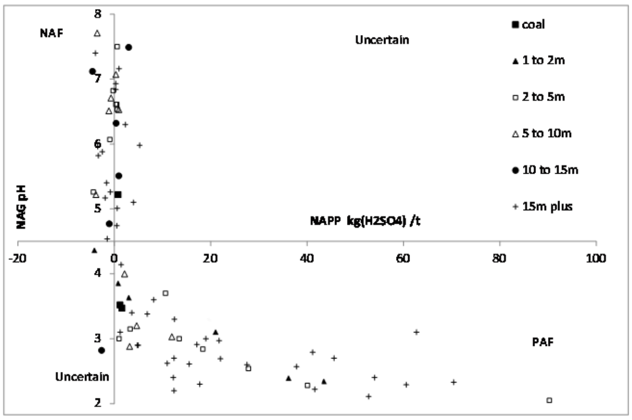


Figure 3: Acid Base Accounting data for rocks at different distances from coal seams

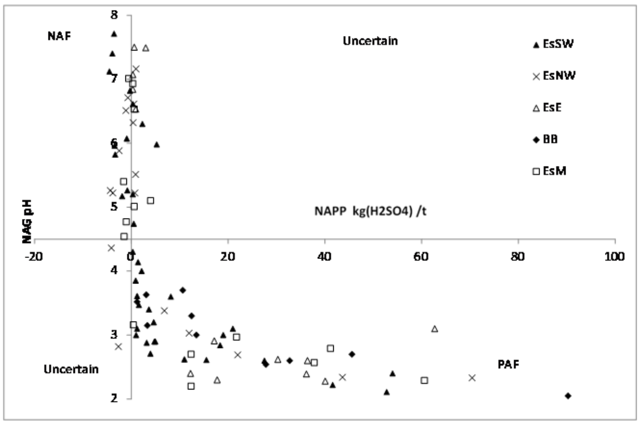


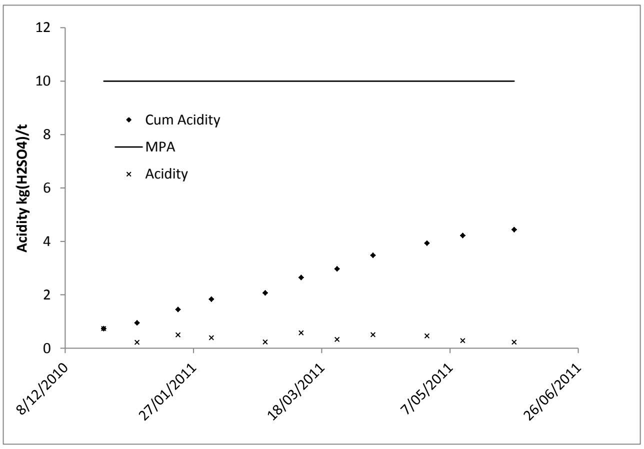
Figure 4: Acid Base Accounting data for rocks in different parts of the proposed Escarpment mine site

Kinetic Testing

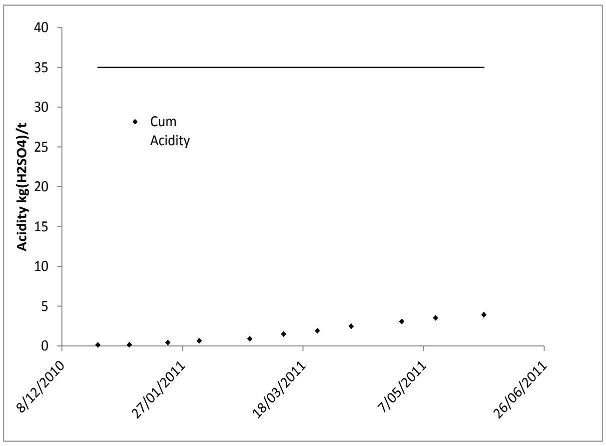
Kinetic testing indicates the chemistry of mine drainage produced by different rock types and relative rates at which different rock types will weather. Column tests are designed to identify the maximum leachable acid from different rock types, and this is likely to be less than theoretical maximum values obtained through acid base accounting. These values cannot be obtained from the six months worth of data collected to date. About 10-15% of the available acid has leached from rock types 1 and 2. Less of the available acid has leached from rock types 3 and 4 because acid neutralising capacity in these rocks is causing a lag period before maximum acid production. Leachate from rock type 3 has a pH between 5-6 and contains alkalinity.

Lysimeter testing indicates the likely range of mine drainage chemistries that can be expected at the proposed Escarpment mine (Table 3). Precise interpretation of this data requires appropriate integration in waste and water management plans. These results should be interpreted carefully because the leachate from lysimeters has not had opportunity to react with rocks to the same extent as mine drainage in the field. However, these data provide a good indication range of total acidity and trace element concentrations that are likely. Lysimeter data from rock types 1 and 2 can be considered likely analogies for unmanaged PAF rocks at the proposed Escarpment mine site. It is likely that mine drainage within sumps and drains prior to treatment will have a lower Fe:Al ratio than lysimeter data because of reactions between rock and the mine drainage. Lysimeter data from rock types 3 and 4 relate to the average rock type and rocks that contain acid neutralising capacity respectively.

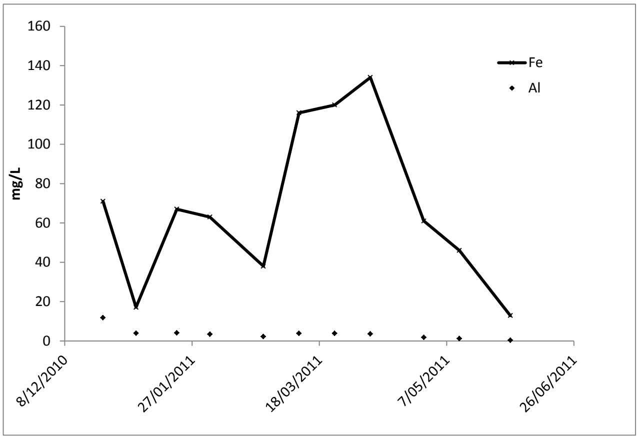
Lysimeter data also indicate the relative reaction rates under field conditions for different rock types, and how the mine drainage chemistry will change with time (Figure 5). Final interpretation of this data can not be completed yet because reactions are still in progress, however, differences between the rocks can be identified. For example, rock type 1 releases acid very rapidly compared to rock types 2, 3 and 4, but the acid release is diminishing after six months. Concentrations of Fe, Al, Ni and Zn are also decreasing in leachate from rock type 1 after 6 months. Acid and alkalinity are released at about the same rate in rock type 3. Rock type 4 has a lag period prior to onset of acid production. Identification of the speed at which reactions take place and the presence or absence of lag periods prior to acid generation in particular rock types are useful for site management.



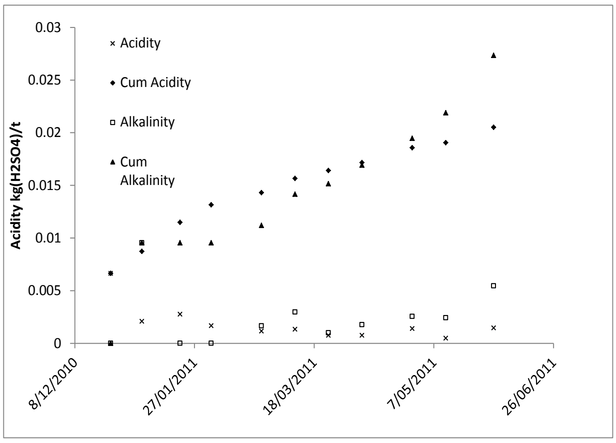
Rock type 1. Acidity per kg of rock



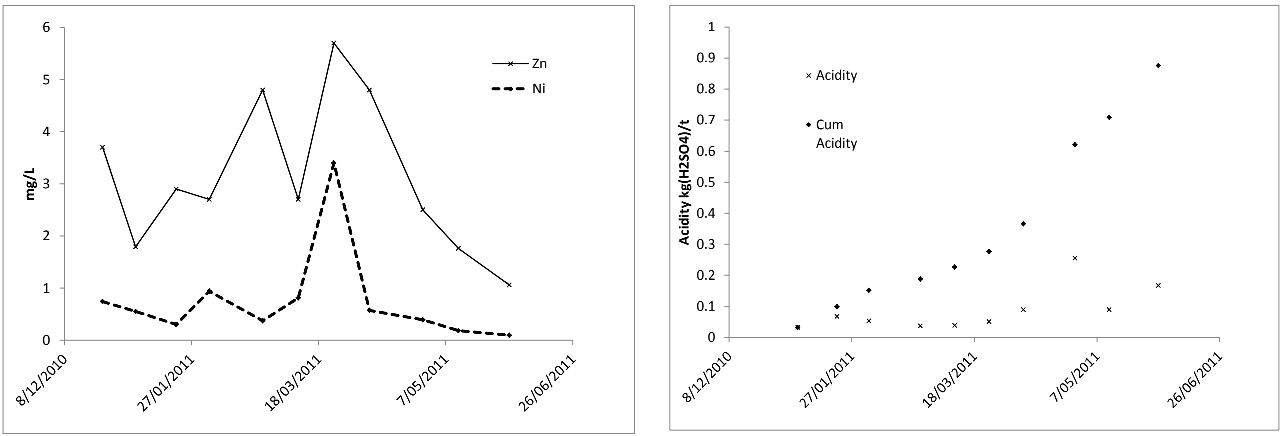
Rock type 2. Acidity per kg of rock



Rock type 1. Fe and Al concentrations in leachate



Rock Type 3. Acidity and alkalinity per kg of rock



Rock type 1. Zn and Ni concentrations in leachate

Rock Type 4. Acidity per kg of rock

Figure 5: Selected chemical trends in lysimeter data after 6 months

Further work

From the acid base accounting data set, additional analysis to identify sulphur speciation is required to validate the interpretation that most of the rocks that are classified as uncertain are actually NAF. This analysis requires pyrite specific S analysis such as chromium reducible S. In addition, work needs to be completed to identify NAF rocks prior to stripping of waste rock. These studies will enable optimisation of the analysis methods that are used in the field for identification of rocks that might be used for capping or other purposes at the proposed Escarpment mine site. Currently there are studies to characterise the upper part of the stratigraphy at the proposed Escarpment mine site because some of this material appears to be consistently NAF.

Column leach and lysimeter trials require extended leaching to identify the maximum leachable acidity and also to determine likely mine drainage evolution trends. These data will be integrated into waste rock management plans and long term mine drainage planning on the proposed mine plan.

Summary

Regional datasets, site specific acid base accounting data and kinetic test data are used to predict mine drainage chemistry at the proposed Escarpment open cast mine. All data indicate that mine drainage at the proposed Escarpment mine will be strongly acidic with elevated trace element concentrations.

Acid base accounting data indicate that a substantial proportion (17 out of 95 samples) of the rocks at the mine site are NAF and many more (20 out of 95 samples) are uncertain. The remaining rocks (58 out of 95 samples) are PAF. It is likely a substantial proportion of the rocks classified as uncertain are NAF because they are likely to contain non acid forming S species such as organic S. Additional work is being completed to identify NAF rocks in a predictive manner.

Lysimeter data provide detailed mine drainage chemistry prediction that has been integrated into water management planning. In addition, these lysimeter data indicate the relative reaction rates of different rocks at the proposed Escarpment mine site. Some rocks react very rapidly, others have a lag period prior to production of maximum acid production. These interpretations can be integrated into waste rock management plans.

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