Control of acid mine drainage by managing oxygen ingress into waste rock dumps at bituminous coal mines in New Zealand

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Abstract

In New Zealand, bituminous coal is mined in mountainous areas with temperate climate and with high rainfall (~6 m/y). Mine drainages from the Brunner Coal Measures (BCM) in New Zealand have low pH, high Lewis acidity and elevated concentrations of trace elements such as Zn, Ni, and Mn. At historic sites and upstream of mine drainage treatment, acid flux from waste rock dumps is dependent on rainfall with minimal dilution even through two orders of magnitude change in mine drainage flow volume. Current research focuses on improved long term management of acid load from New Zealand's bituminous coal mine. We present results that examine the impact of waste rock dump construction on oxygen ingress.

Sealed probes have been installed in three waste rock dumps where short lifts have been used during construction. The results indicate the oxygen concentration in waste rock pore spaces can decrease sharply with little distance into the dump. At 2-4m into the dump, the oxygen content is often around 10% and between 4-25 m into the dump the oxygen content is often less than 1%. In contrast, probes installed a dump constructed by side cast methods (pushing out a high tip head with a dozer) have oxygen concentrations between 11 and 21%

The findings of oxygen probe studies include.

- Oxygen ingress into waste rock dumps for mines in the Brunner Coal Measures can be limited by changing dump construction processes.
- The reduction in oxygen content in waste rock dumps that have short lifts is attributed to minimising grainsize segregation.
- For waste rock dumps constructed in short lifts and prior to capping and rehabilitation, acid loads could be calculated by assessing the surface area of the dump and the top ~2m using column leach studies. This differs from previous approaches where the total tonnage of waste is used for acid load calculations.
- Information from this study will be combined with autopsy studies, rehabilitation studies, revegetation studies to identify best practise for waste rock dump construction.

Keywords: coal mine drainage, oxygen ingress, waste rock dump, acid mine drainage, acid flux.

1. Introduction

Bituminous coal is mined on the West Coast of the South Island of New Zealand from Cretaceous Paparoa Coal Measures and Eocene Brunner Coal Measures. This mining district is mountainous, has high rainfall (~6m/y) and often mine operations are constrained by lack of space for waste rock dumps (WRDs). Generally disturbance of Paparoa Coal Measures during mining activities releases near neutral mine drainage, whereas mining of Brunner Coal Measures releases acid mine drainage (AMD) (Pope et al., 2010a,b). Typically this acid mine drainage has high Lewis acidity, and elevated concentrations of Zn, Ni & Mn. Acid can be released from either the coal measures or from the overlying marine rocks of the Kiata Formation which are also net acid forming at the base (Hughes et al., 2004.). Acid mine drainage flux from poorly managed (WRDs) at mines hosted in Bruner Coal

Measures increases linearly with flow at some sites indicating little or no dilution (Mackenzie, 2010; Davies et al., 2011) by the high rainfall.

Studies on oxygen ingress into WRD's at mines hosted in Brunner Coal Measures are limited. If WRDs are built well to minimize oxygen ingress then the ingress of oxygen is diffusion controlled (Weber et al., 2013; Olds et al., in press a & b). Where WRDs are built with no thought to controlling oxygen ingress then oxygen content of air within the dump can be ambient controlled by advection processes. Controlling the ingress of oxygen is mechanism for controlling long term acidity loads from WRDs where the dominant source of acidity is sulfide minerals.

We measure oxygen ingress at WRD's constructed with low lifts ~2-6m in height to minimise grainsize segregation. Grainsize segregation and increases as the tip-head height increases and is characterized by development of coarse rubble zones at the base of or within (chimneys) dumps. Grainsize segregation permits water ingress by permeability contrast and oxygen ingress by advection (Fala et al., 2003; Wilson, 2008). In a poorly constructed WRD, advection accounts for ~90% of oxygen ingress and that diffusion accounts for 10% (Brown et al., 2014). Therefore construction of WRDs to minimise grainsize segregation is likely to reduce oxygen ingress rates by approximately one order of magnitude.

We present results of oxygen ingress studies into Brunner Coal Measures WRDs where short lifts have been utilized to control advective ingress of oxygen.

2. Materials and Methods

Three WRDs at active mines operating within the Brunner Coal Measures where management techniques are being applied to minimize oxygen ingress have been selected. Arrays of probes to measure the oxygen content of air within the dumps have been constructed and repeat measurements have been taken over several months.

The dump air measurement probes consist of several (5-7) 15mm hose pipes installed in a trench ~ 1m deep in the active surface of the WRD. The trench is aligned perpendicular to the face of the dump and the end of each hose sits in a 0.3 m^3 gravel packed reservoir excavated an additional 0.5 m into the surface of the dump. The sample sites are spaced every 2 m for the first 8-10 m into the dump then 5-10 m to a maximum of 25 m. Bentonite seals are placed around the hose pipes to prevent pathways for air connection between the gravel packed reservoirs. Each hose has a standard compressed air line fitting at the face of the dump where sampling equipment can be attached. During sampling a low volume air pump draws an air sample from the gravel reservoir and the air sample is passed through an electrochemical gas analyser which reports oxygen content between 0.1 and 21% (ambient atmospheric oxygen content). The analyses are made on site and recorded, the electrochemical gas analysers are temperature compensated and regularly calibrated.

In addition, we present data from Stockton Mine that was collected from bentonite sealed piesometers into a dump to a maximum depth of 6m. This dump was constructed by dozing material from a tip-head down a steep face by side cast methods off Mt Frederick. These piesometers were also fitted with airline fittings and measurements were made with a similar electrochemical gas analyser.

3. Results

The three sites where oxygen probes were installed include:

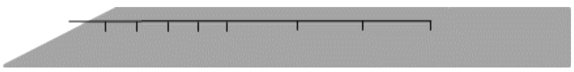
1. Cypress Northern Engineered Landform (ELF) at the Cypress Mine on Stockton Plateau
2. McCabes WRD at Stockton Mine on the Stockton Plateau
3. The Barren Valley ELF at Escarpment mine on the Denniston Plateau

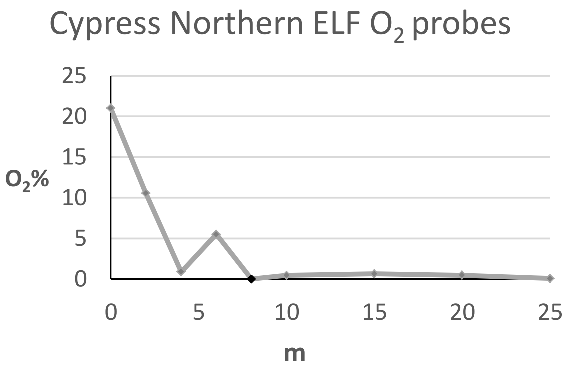
The site where the piesometers were installed is also at Stockton mine in the Mt Frederick WRD.

Cypress Northern ELF Oxygen probes.

Oxygen probes at the Cypress Northern ELFwere installed in July 2015 and the oxygen content measured in September 2015, January, February and March 2016. This dump is composed of mostly acid forming Kiata mudstone and the height of each lift is about 5m. For the first four months after installation no further dumping activity occurred over the oxygen probes. In December 2015 an additional 4m of overburden was placed over the buried probes (Figure 1).

Results indicate rapid decrease in oxygen content at many of the measurement sites from the time the trench was covered to the time of the first reading. In addition there is a sharp decrease in the oxygen content from the surface of the WRD batter slope so that 2 m into the dump, the oxygen content is between 8 and 14 % in the measurements made to date. The oxygen content 4 m into the dump is below 1% in all measurements to date. The oxygen content 6 m into the dump decreases from 5.5 to 2.3% during the between September 2015 to January 2016 and is below 1% in subsequent measurements. Beyond 6 m into the dump, all measured oxygen contents are below 1%.





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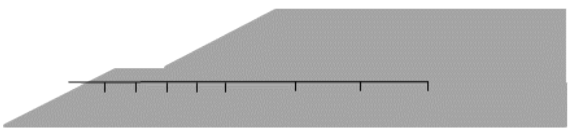

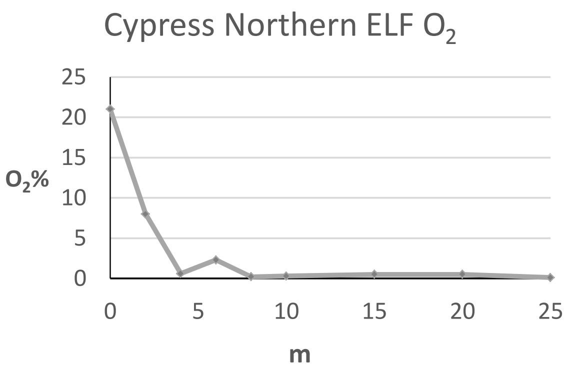

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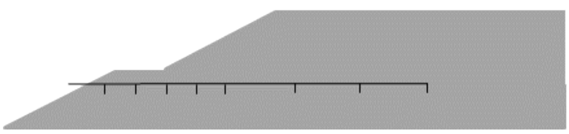

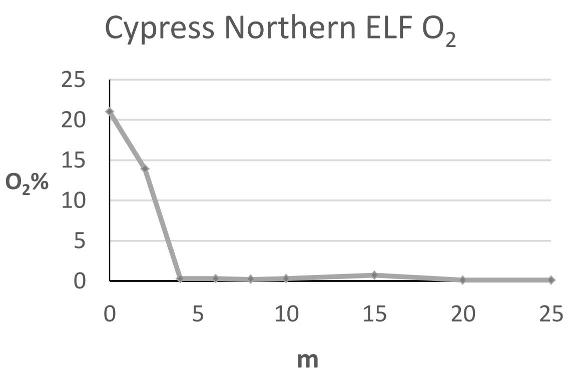

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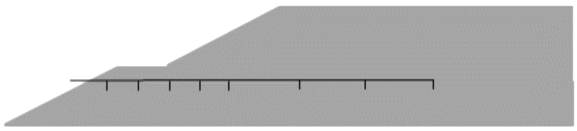

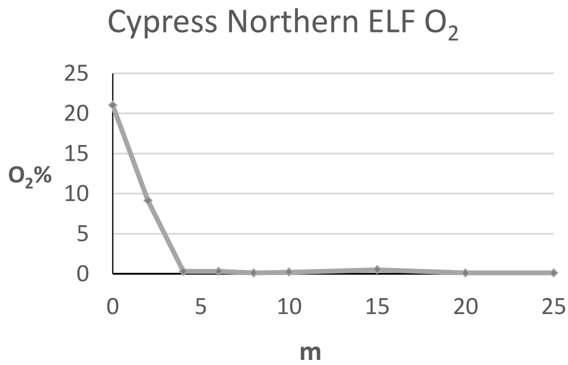

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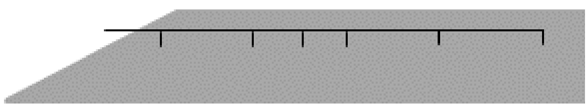
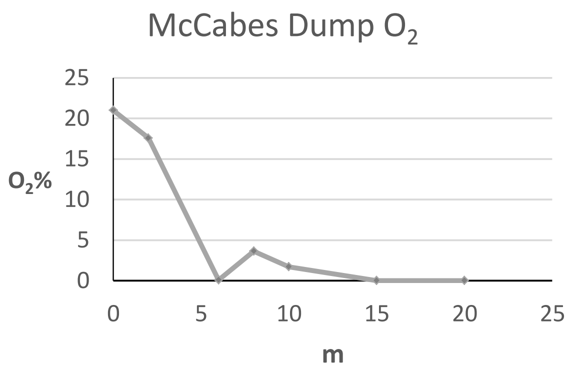
Figure 1. *Oxygen content data and Cypress Northern ELF development. Rarely the oxygen probes were flooded and an air sample could not be obtained (recorded at 0% - black symbols on graphs).*

McCabes WRD oxygen probes

The McCabes WRD oxygen probes were installed in July 2015 and this dump is a mix of Brunner Coal Measures and Kiata Formation. The dump is constructed in lifts about 6m high. The oxygen content of air within the WRD was measured in September 2015, January and February 2016. No further dumping of waste rock has occurred at McCabes WRD so the oxygen probes are only covered by 1-2 m of waste rock.

Similarly to the Cypress Northern ELF, the oxygen content of the McCabes WRD (Figure 2) decreases quickly from ambient conditions at most of the sampling locations. In addition there is a sharp decrease in oxygen content with distance into the WRD horizontally from the batter slope. In September 2015 the oxygen content 2 m into the WRD was 17%, at 8 m into the WRD the oxygen content was 3.6%, at 10 m into the WRD 1.7% and other analyses were less than 1%. Subsequent measurements of oxygen content in air in the WRD are all less than 1% except at 2 m into the dump where the oxygen content decreases to 14.9% in January 2016 and 2.8% in February 2016.





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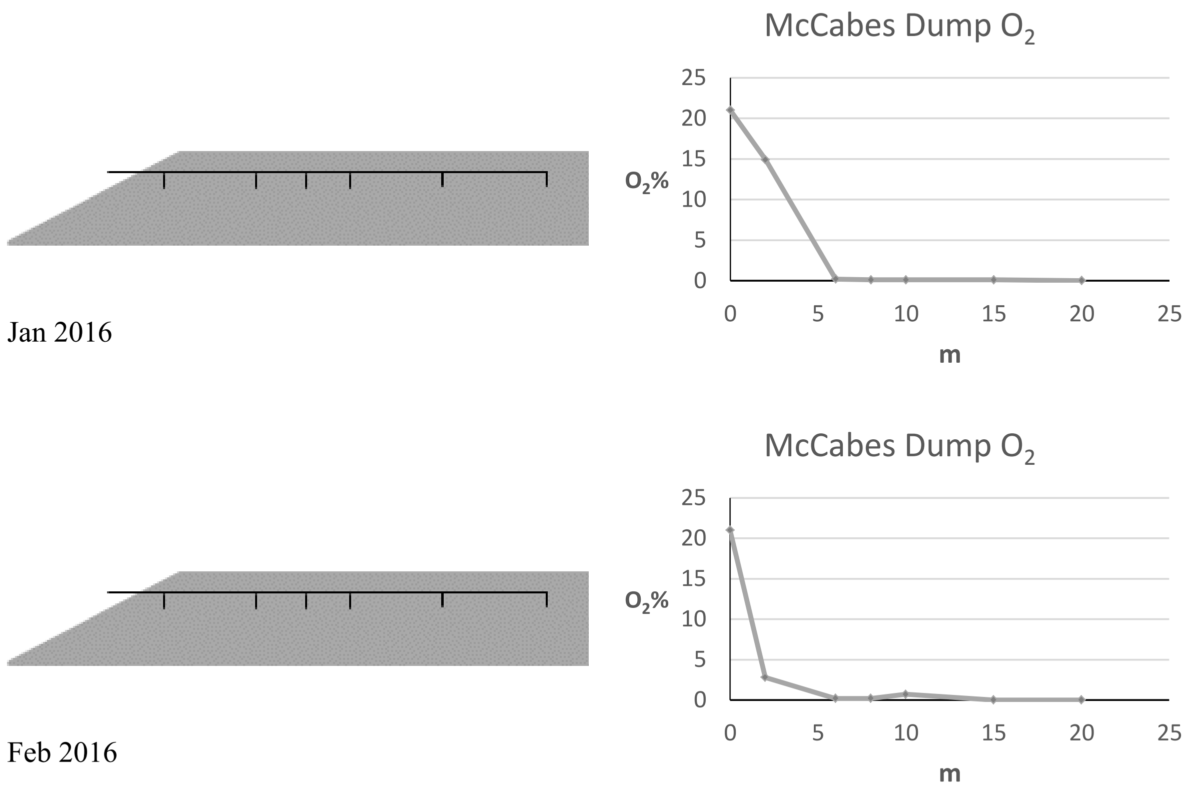
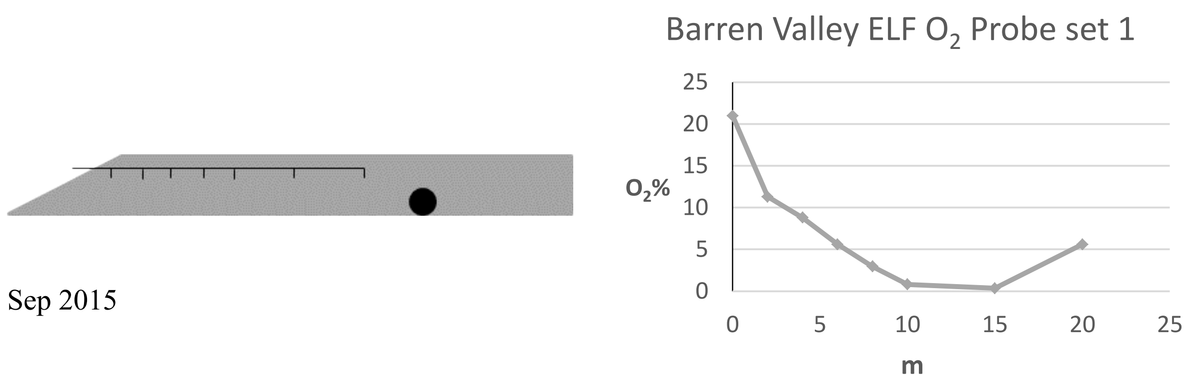


Figure 2. *Oxygen content data and ELF development McCabes Dump, Stockton mine.*

Barren Valley ELF oxygen probes

At the Barren Valley ELF oxygen probes were installed in July 2015. The dump consists of Brunner Coal Measures and this dump uses either paddock dumping of short lifts of about 2m. The WRD was re-contoured in January 2015 one week prior to measurement of oxygen contents and additional material was dumped over probes more than 10 m into the WRD. A second set of oxygen probes were installed in this WRD in January and oxygen readings commenced 2 days after the installation. The Barren Valley ELF contains an underdrain that is about 25 m into the WRD.

The oxygen content measured during September 2015 in the first probe set installed in the Barren Valley ELF (Figure 3) decreased gradually to <1% 10 m – 15 m into the dump and then increased to about 5% at 20 m into the WRD. The oxygen content measured in January 2016 showed a similar trend but with slightly higher oxygen contents. Oxygen contents measured in February and March 2016 showed a rapid decrease to about 1% at 2 m into the WRD, and then an increase to between 3 & 8% at 20 m into the WRD.



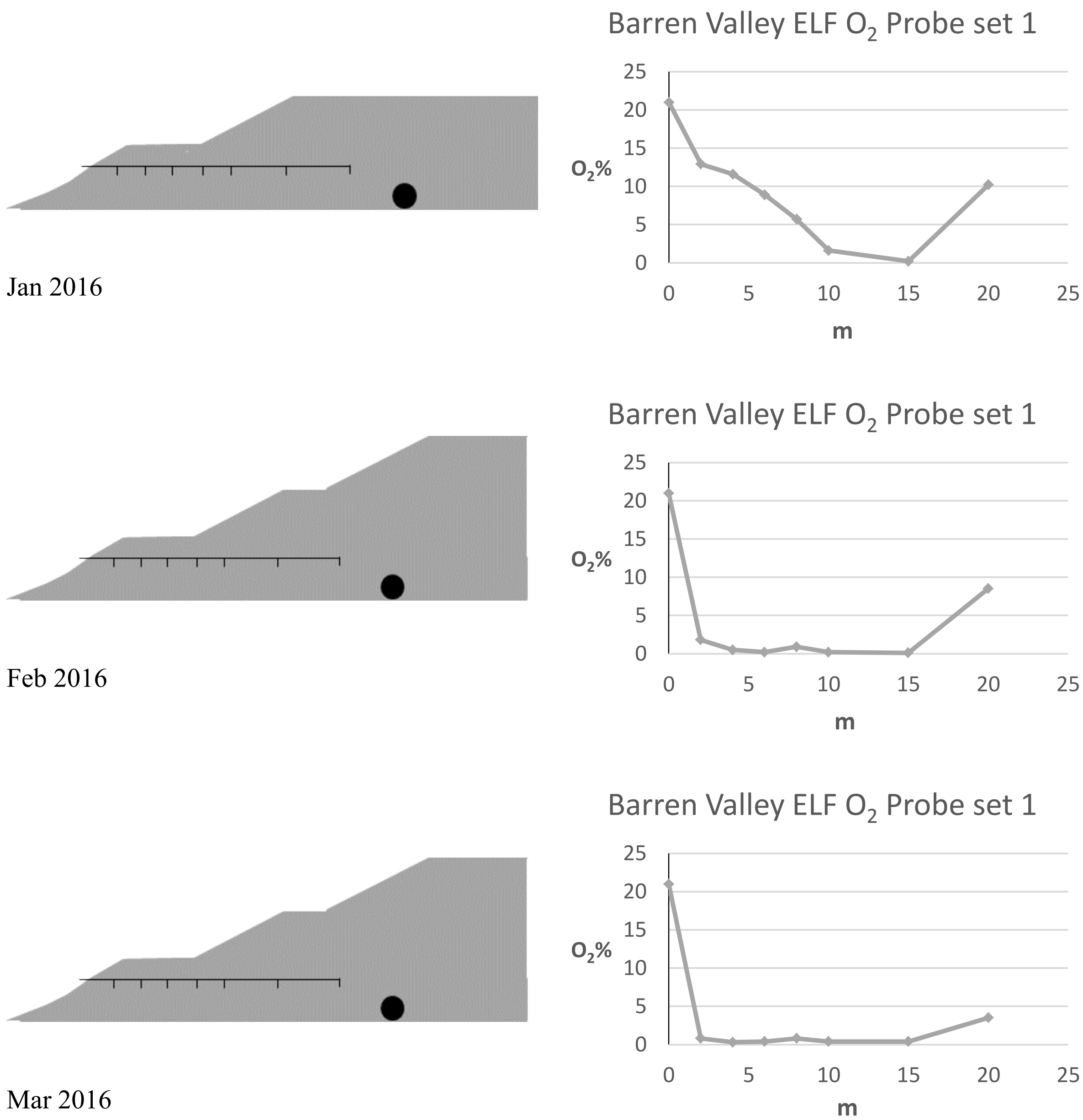


Figure 3. *Oxygen content data and dump development at the Barren Valley ELF, Escarpment Mine for probe set 1. Rarely the oxygen probes were flooded and an air sample could not be obtained (recorded at 0% - black symbols on graphs). Large black circle represents the location of the underdrain.*

The oxygen content measured during January 2016 in the second probe set in the Barren Valley ELF is relatively high >12% at all sites except 15 m into the WRD which is water saturated (Figure 4). Oxygen content measurements made during February 2016 show a rapid decrease in from the batter slope of the WRD so that probes at 2 m and 4 m have values of 2 & 7% respectively and all other oxygen contents are <1% except the probe at 20 m where the oxygen content is 7%. The oxygen content measured in March 2016 is <1% at all probes except the probe at 20 m where the oxygen content is just over 1%.

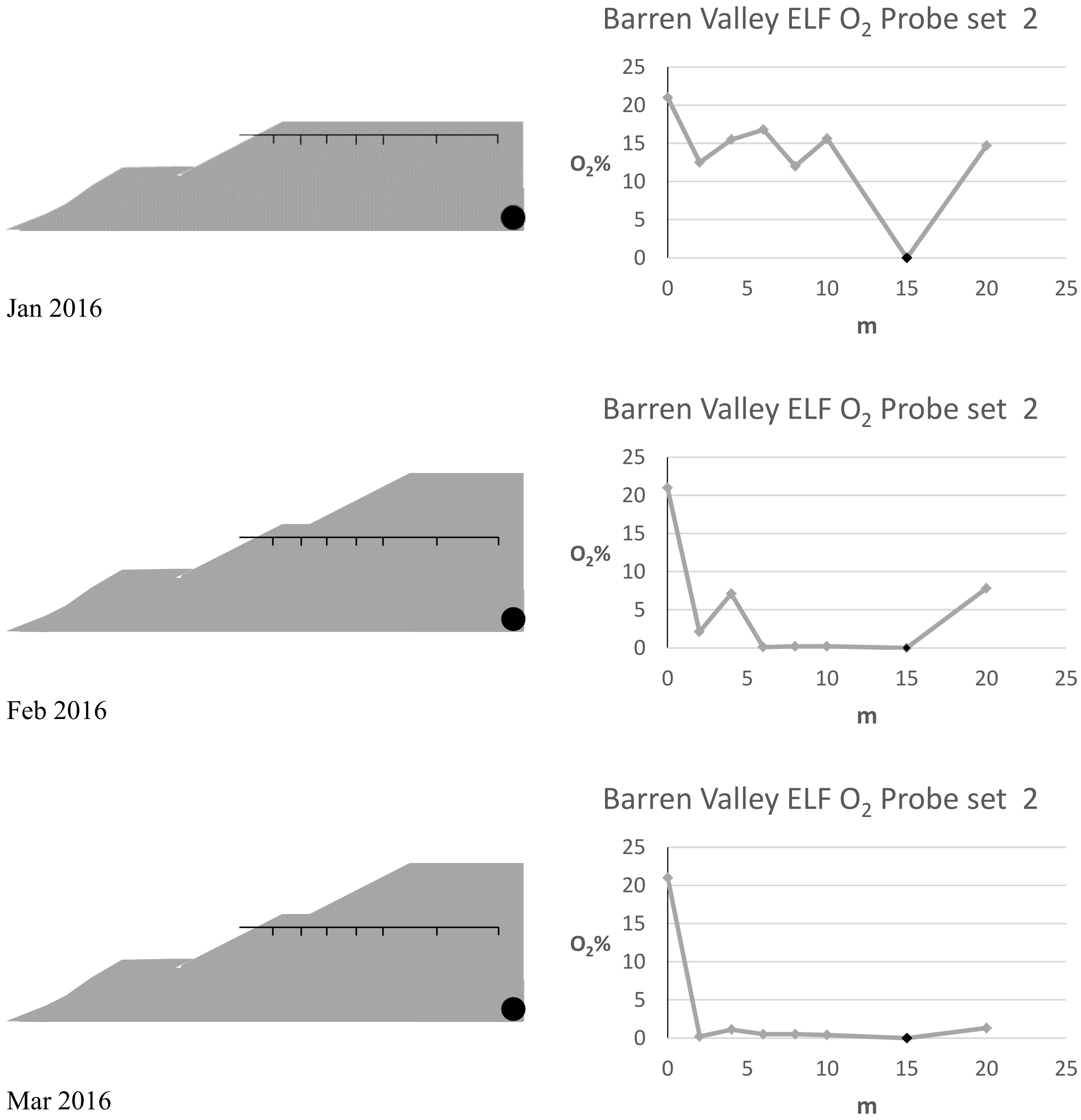


Figure 4. *Oxygen content data and dump development at the Barren Valley ELF, Escarpment Mine for probe set 2. Rarely the oxygen probes were flooded and an air sample could not be obtained (recorded at 0% - black symbols on graphs). Large black circle represents the location of the underdrain.*

Mt Frederick WRD piesometers

Data from two sets of piesometers in the Mt Frederick WRD indicate relatively high oxygen content for several years throughout the upper 6 m of the dump (Table 1 & 2).

Table 1. *Oxygen content (%) in piesometers in the Mt Frederick WRD (west). n = number of analyses*

depth (m)	2005	2006	2007	2009	2010
2	13	13	12	12	11
4	16	17	18	17	16
6	15	15	15	18	20
n	6	9	2	4	11

Table 2. *Oxygen content (%) in piesometers in the Mt Frederick WRD (east). n = number of samples*

depth (m)	2005	2006	2007	2009	2010
2	21	20	20	20	20
4	20	21	21	21	21
6	21	20	21	20	20
n	5	9	2	2	1

4. Discussion

Oxygen content data collected at Cypress and McCabes dumps indicate that there is a rapid depletion of oxygen away from the WRD batter slope and low or decreasing oxygen content at all sampling probes over the measurement period to date similarly to previous studies (Weber et al., 2013; Olds et al., in press a & b).

Oxygen content data from the Barren Valley ELF indicate slower initial oxygen depletion over the outer 10 m. In addition the data collected indicate that re-contouring of the WRD causes an increase in oxygen content, probably caused by disturbance to the WRD surface. However, once recontouring disturbance is complete and compaction had occurred, the oxygen content of the WRD rapidly decreased to less than 1%. The only exception to this is the oxygen probes located about 20 m into the WRD. At these sites it is interpreted that the underdrain provides a conduit for air this causes the elevated oxygen content. The underdrain is designed to have a swan neck with a water trap to prevent oxygen ingress however this has not been constructed yet.

These results confirm that construction of a WRD at mines in the Brunner Coal Measures using short lifts can reduce oxygen ingress compared to high tip heads or side casting. Dump construction using short tip heads to minimize grainsize segregation is therefore an important tool for management of AMD formation at mine sites where acid forming rocks are present.

5. Conclusion

Previous studies have shown the poorly managed or constructed WRDs at mines in Brunner Coal Measures release acid mine drainage in a manner that increases in a linear manner with rainfall (Mackenzie, 2010, Davies et al 2011). Typically these WRDs have been made with high tip heads or by side casting, or by dozing material out over large batter slopes. In these circumstances grainsize segregation with coarse material at the toe of the dump or within chimney zones allows relatively free oxygen ingress into at least parts of the dump and acid forming reactions proceed rapidly.

Data collected in this study indicates that the construction of WRDs in short lifts (<4 - 6 m), prevents oxygen ingress and therefore limits oxidation reactions to the margin of the dump. These data also demonstrate that oxygen ingress could be increased if the dump is disturbed after it is established (re-contouring) and that features like underdrains can provide a conduit for oxygen ingress.

Acid load prediction for these Brunner Coal Measures dumps prior to rehabilitation and capping can be calculated from the dump surface area and a zone about 2m thick covering the dump. For this part of the dump tests such as free draining oxygenated column leach trials (Pope & Weber, 2013) or humidity cell testing can be used to approximate acid loads. For the remainder of the dump acid release will be minimized by the limited availability of oxygen.

The oxygen ingress studies presented in this paper are linked to several other studies including dump autopsies, capping trials, rehabilitation, revegetation, and addition of neutralizing agents to acidic dumps. As we increase our dataset it is anticipated a new model for acid mine drainage release will be developed for WRDs associated with mines in the Brunner Coal Measures and other acid mine drainage forming rocks. The objective is to minimize rapid release of acid mine drainage, enable accurate long term prediction of acid load from mines in Brunner Coal Measures, to enable passive treatment as a long term closure plan and to develop a best practice waste rock dump construction method.

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