Temporal Variability and Gas Transport Rates in Waste Rock

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Abstract

The production of acid mine drainage through the oxidation of sulfide minerals requires a constant supply of oxygen gas to proceed. Poor water quality on mine sites is therefore influenced by gas transport rates through mine waste, for which few studies currently exist. A field-based investigation was carried out into gas transport mechanisms and rates through a waste-rock pile with a low permeability till cover.

The results of the field monitoring of a waste rock pile at Detour Gold Corporation mine (Detour) in northern Ontario, Canada are presented. The relationship between external and internal gas pressure is indicated to be linear, indicating that advective flow is laminar through the cover and waste rock pile. Sub-atmospheric O_2 pore gas concentrations and super-atmospheric CO_2 concentrations were recorded within the pile, indicating that sulphide oxidation and carbonate neutralisation are occurring. Temperature monitoring in the pile indicates increased dampening of variations in ambient temperature inside the pile and some insulation from the frozen cover in the winter.

Introduction

Consumption of O_2 gas through acid producing reactions reduces the O_2 concentration in the pore gas of waste rock piles to sub-atmospheric levels, and advective (pressure driven) and diffusive (concentration driven) mechanisms contribute to the transport of O_2 from the atmosphere into the pile (Pantelis and Ritchie 1992; Amos et al. 2009; Chi et al 2012). It follows that a possible strategy to reduce the production of AMD and poor quality seepage from mine wastes could be to reduce O_2 gas ingress through low permeability covers.

A field based investigation into gas transport mechanisms and rates has been carried out for an historical waste-rock pile at Detour. Production at this mine was during 1983-1999 (recommenced in 2013) and a low permeability cover was installed on the test pile at the end of operations. The waste rock pile at Detour provides a unique opportunity to consider waste that has been oxidising for approximately 30 years.

Methods

The study site for the gas transport investigation was a waste rock pile from historic operations at Detour Gold Corporation mine, Ontario, Canada. Two boreholes (BH2011-3-1 and BH2011-3-2) were drilled on an approximately north-south axis on the crest of the waste rock pile during 2011. Soil moisture and temperature measurement probes (ECH2O probes and thermistors) were installed at several depths during the completion of the boreholes. In addition, ¼” LDPE tubing was installed to several depths for monitoring of pore-gas concentrations (Figure 1).

The magnitude of the pressure gradients, pore-gas concentration of O_2 and CO_2 as well as the wind speed and direction, barometric pressure and temperature were measured. The pile was instrumented to record exterior gas pressures and pore-gas concentrations at the surficial location of BH2011-3-1, and 12 locations around the pile. The ¼” tubing that was installed within the boreholes dur-

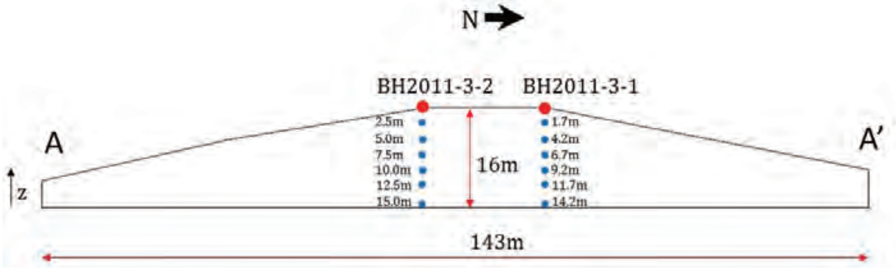

Figure 1 Cross-section schematic of the waste rock pile and the monitoring locations for internal pressure and pore-gas concentrations.

ing 2011 was used to record measurements within the pile.

A measurement of barometric pressure was taken on the crest of the pile, and the other pressure measurements were taken relative to this location (hereby referred to as differential pressure) (Figure 1). A wind sensor was mounted to the apparatus, and measurements of temperature within the pile were recorded using the ECH_2O probes and thermistors that were installed in 2011.

Measurements of wind vector and exterior and interior pressure were taken at 4 second intervals. The data capture program recorded average measurements at 1 minute intervals, to average out erratic data. These data were averaged to 10 minute and daily intervals to reduce the size of the data set. A measurement was recorded for gas O_2 and CO_2 once per day, and measurements for temperature were recorded every 6 hours. Data collection was from May 2014 - November 2015, however the quality of the data set is better during the summer months than the winter.

Results and Discussion - External and Internal Pressure

Mean wind speed over the monitoring period was 3.56 m s^{-1}, with a median of 3.32 m s^{-1} and a standard deviation of 1.97 m s^{-1}. The maximum observed wind speed was 15.55 m s^{-1}.

The relationship between wind speed and differential pressure measured on the pile surface is typically parabolic as predicted by Bernoulli's fluid flow principal (Bird 1960). Figure 4 presents a plot of the wind speed versus differential pressure at the southern toe; some outlying data is indicated, however the differential pressure was between 0 and 18 Pa at a wind speed of 5 m s^{-1} and was between 15 and 25 Pa at 10 m s^{-1}.

The mean barometric pressure over the monitoring period was 979.3 hPa. The barometric pressure data was noted to vary by up to 2000 Pa (20 hPa) over the course of a day, however differential pressures both around the exterior of the pile and within the pile was typically within ±10Pa at any time. Changes in barometric pressure are reflected within the pressure regime within the pile, even at depths beyond 15m.

Average external differential air pressures increase towards the toe of the pile. Average differential pressures was typically 0.5 Pa near the crest of the pile and 4-5.9 Pa at the toe. The exception was the western side of the pile, which had an average differential pressure of 2.4 Pa towards the middle of the batter and 1.7 Pa at the toe.

Positive and negative values were observed at internal monitoring points. Negative internal differential pressure indicated flow into the pile at that time, and positive internal differential pressure indicated outward flow. Positive internal differential pressure was indicative of decreasing barometric pressure. The differential pressure within the pile is positive for a greater amount of time during the winter (37.5% on average) than the summer (78% on average).

A linear relationship is typically observed for the external and internal pressures for summertime readings (Figure 5). The Pearson's correlation coefficient is typically higher for the comparison between an internal monitoring location and the exterior toe of the embankment versus towards the crest, and is also typically higher for the daily aver-

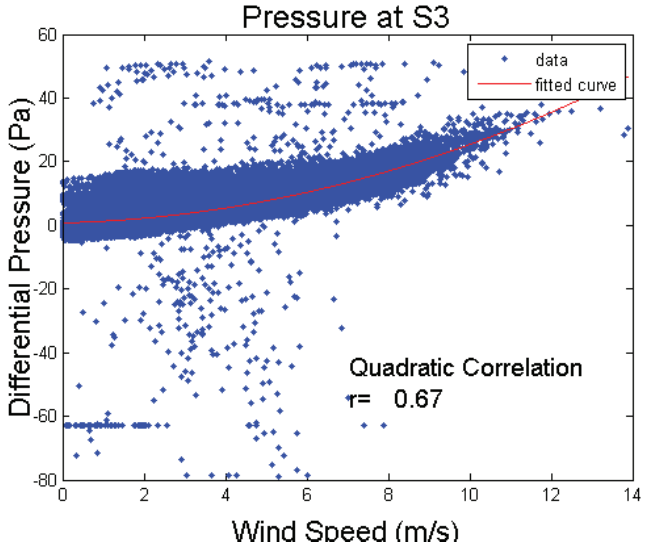

Figure 2 *Correlation between wind speed and differential pressure at the southern toe.*

aged data than the 10 minute averaged data. The linear relationships between external and internal pressure indicate that gas transport through the cover and waste-rock is laminar, and therefore Darcy's law is applicable. This observation is in agreement with the observations of Chi et al. (2013).

Pore Gas Oxygen Content

Pore-gas O_2 content was typically sub-atmospheric at all monitoring locations, indicating that sulphide oxidation is occurring and the rate of ingress of atmospheric O_2 is insufficient to return the pile to a fully oxygenated state. The pore gas concentration within the waste-rock fluctuated to a larger degree during the summer than the winter. Fluctuations in the O_2 content of up to 8% v/v were observed over the course of 24 hours during the summer (Figure 4). Trends in the time series of the different monitoring locations were similar in the summer, and a decreasing trend with depth was evident (Figure 4). The O_2 content at the base of the pile was relatively constant in the winter and summer, below 5% v/v, however this location was likely within the natural underlying peat and not the waste rock material.

A linear O_2 profile with depth has been described as an advective dominated system (Lefebvre et al. 2001). This profile was observed during the summer (Figure 5d), indicating that the permeability of the cover was insufficient to provide a barrier to advective transport. Particle size distribution test results provided in Cash (2014) indicate that the percentage of fines (passing the 75µm sieve) was less than 20% for most samples of the cover material, which is considered to be low for a mine waste cover. A typically diffusive profile was observed during the winter (Figure 5a and b) and the month of July is considered to be part of the transition months (Figure 5c).

Pore Gas Carbon Dioxide Content

Pore-gas CO_2 content was above atmospheric levels (effectively above zero in the context of this investigation) at all monitoring locations, indicating that carbonate neutralisation of acidic solution is occurring within the pile. The trends in pore-gas CO_2 content were similar to the O_2 in that they were variable during the summer (Figure 6a) and relatively constant during the winter (Figure 6b). However, an increasing trend with depth was indicated which is the contrasting observation for the O_2 content.

Temperature

Heat is transported within waste-rock piles through conductive and convective mechanisms, and advective flux of air/gas is in the di-

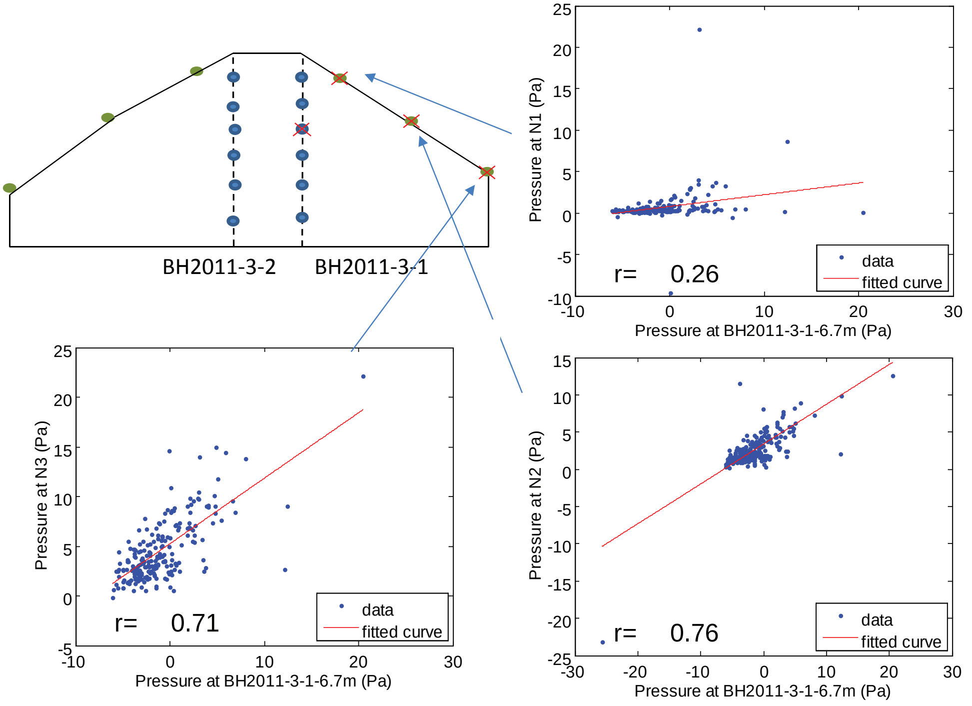

Figure 3 *Correlation between the internal pressure at BH2011-3-1-4.2m and a) external location N1 (crest), b) external location N2 and c) external location N3 (toe). Daily averaged data sets. The data sets are predominately summer-time data but does include winter-time data as well.*

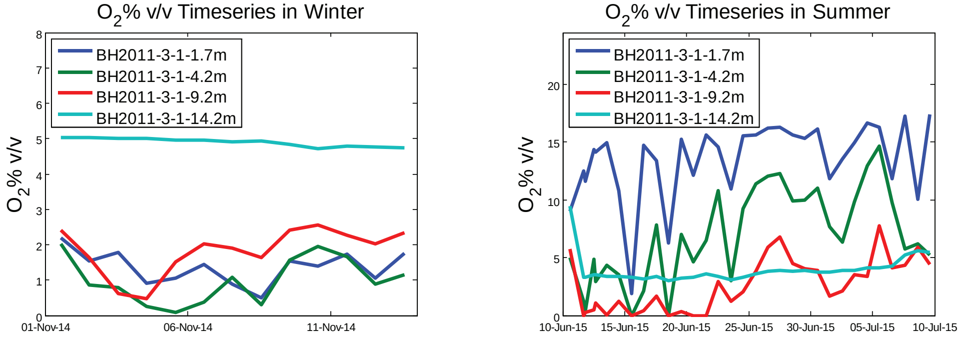

Figure 4 *Time series for pore-gas oxygen content during a) a period in the winter and b) the summer.*

rection of increasing temperatures. Soil covers are a poor conductor of heat in comparison to the waste-rock (Pham 2013), and will therefore reduce heat influx into the waste-rock pile during those times when the exterior temperature is higher than the internal temperature. Conversely, and undesirably, soil covers retain heat within the pile when the internal temperature is greater than the external temperature. The winter conditions at Detour and northern Canada in general are such that the cover will likely freeze and the permeability will subsequently reduce, thereby reducing the advective influx of air. Nonetheless, the timing of the maximum and minimum temperatures within the pile does not necessarily correspond with

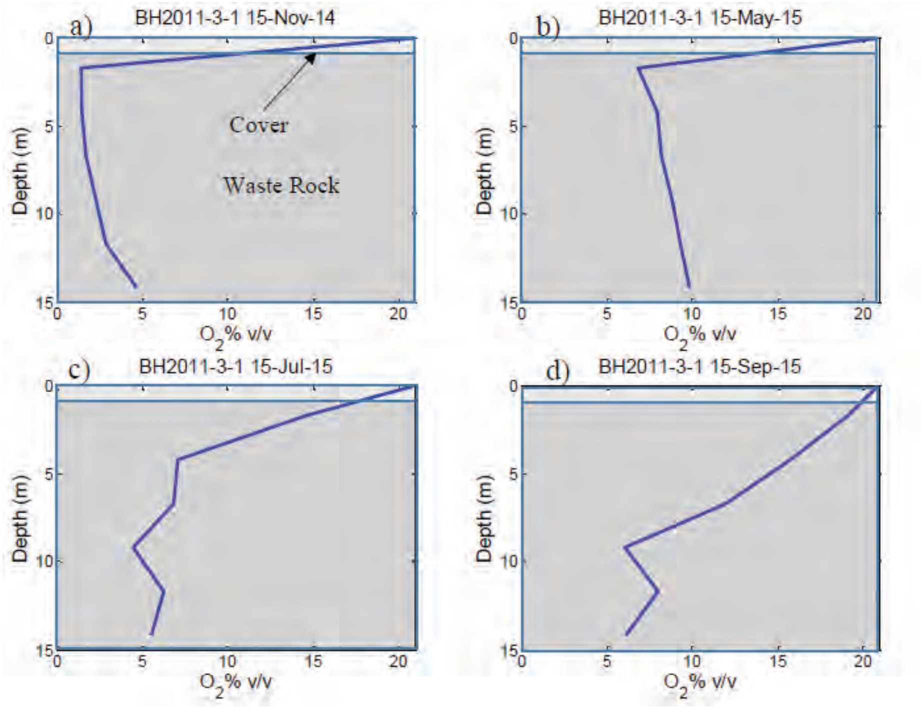

Figure 5 *Pore-gas oxygen content with depth for a) typical diffusive profile during the winter on a) 15t November, 2014, b) 15th May, 2015, c) transition period including both the advective and diffusive profile on 15st July, 2015 and d) typical advective profile during the summer on 15st September, 2015*

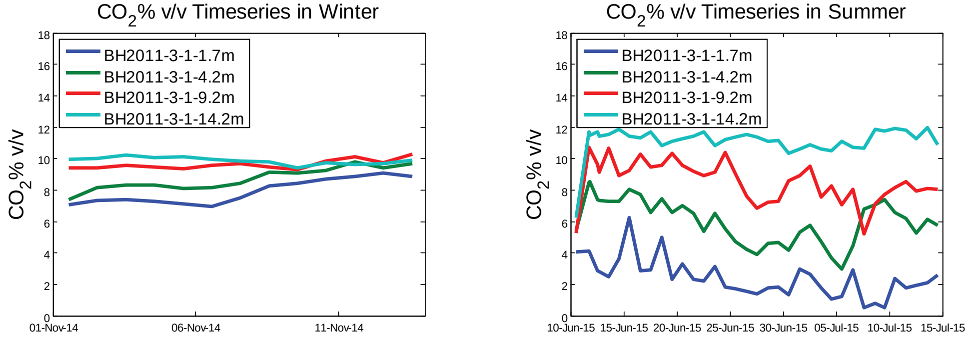

Figure 6 *Time series for pore-gas carbon dioxide content during a) a period in the winter and b) the summer.*

the summer and winter seasons due to time factors in heat transport and the insulating nature of the cover. The peak temperature at 9.18 m depth is around mid-January, which is in the middle of winter.

The temperature was monitored within the cover and the waste-rock at the test pile. The temperature profile of the locations within the cover indicates the magnitude of the seasonal fluctuations is reduced compared to the ambient temperature (Figure 7). This effect is greater during the winter as indicated by the lower rate of change of temperature. The frozen cover in the winter has a relatively

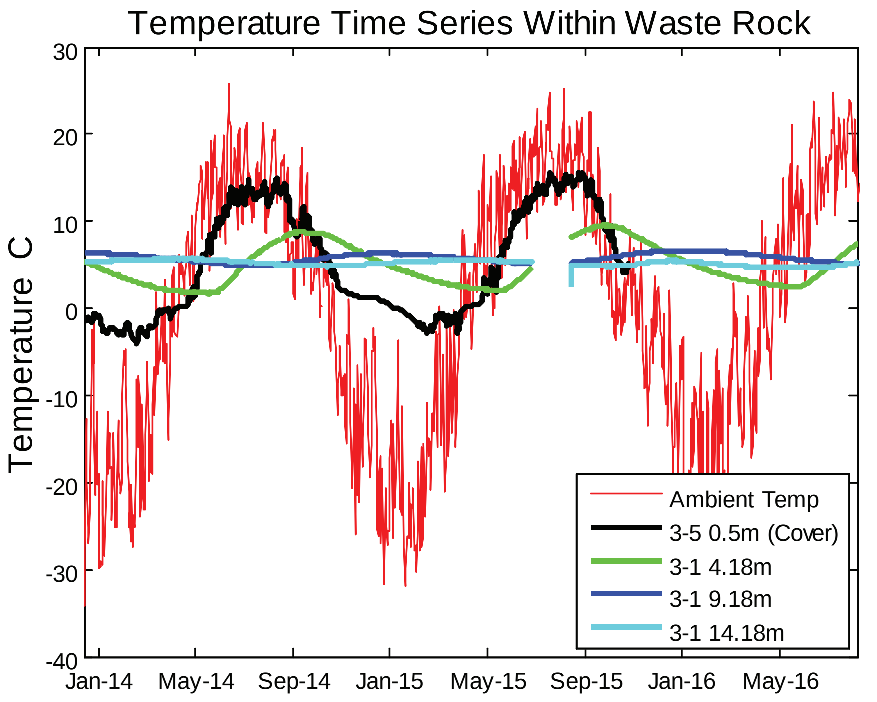

Figure 7 Time series for the ambient temperature and temperature within the cover and waste-rock at WRS#3.

higher insulating capacity and lower permeability. Within the waste rock, the amplitude of the temperature fluctuations reduces further into the pile (Figure 9).

The temperature regime in the pile affects gas pressures according to the ideal gas law. It follows that a complete understanding of the pressures and flow of gas through a waste rock pile cannot be achieved without concurrent temperature monitoring.

Conclusions

Field monitoring for gas transport through the covered waste rock pile indicates that laminar advective flow of gas is the dominant mechanism under summertime conditions, however diffusive flows prevail in the winter. Sulfide oxidation and carbonate neutralisation are occurring in the pile as indicated by sub-atmospheric O_2 contents and super-atmospheric CO_2 concentrations. Monitoring of pile internal temperatures indicates that dampening of fluctuations in ambient temperature occurs with depth, and the cover is likely reducing heat influx in the summer and insulating heat production in the winter.

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