SULLIVAN MINE WASTE DUMP CHARACTERIZATION, PART 2

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ABSTRACT

Premature snowmelt areas on the No. 1 Waste Dump at the Teck Cominco Sullivan Mine near Kimberley, British Columbia, Canada have been documented annually since their discovery in March 2007. Surface vents discharging pore gas through the dump cover were discovered February 2008; further surveys on three mine site dumps revealed more extensive venting areas during the 2008-2009 winter. In nearly all cases, oxygen levels returned to normal at a height of 15 cm above the dump surface.

In October 2008 the No. 1 Dump seepage collection system was modified as a remediation measure, eliminating the 400-mm drainage pipe as a conduit between the dump and atmosphere. While it was expected that this action would reduce the respiration flow rate through the dump and internal oxygen levels would be seen to decrease, oxygen levels did not decrease, suggesting that the 400-mm drainage pipe was more a preferential flow path than a primary respiration conduit. To examine the diffuse nature of dump respiration a total of 48 gas traps – inverted plastic storage containers - have been placed across three mine site dumps and in control areas. Gas traps are installed on unaltered cover, on biased locations with small holes through the cover, and over known surface vents. This paper provides the internal pore gas composition results that demonstrate the inability of the U-trap to limit respiration, and discusses gas trap and vent monitoring results.

KEY WORDS: Pore Gas, Respiration, Convection, Diffusion

INTRODUCTION

Part 1 of this paper provides a brief description of the No. 1 Dump Monitoring Station and the responses to the fatalities incident. Dump respiration and specifically air flow through the 400 mm pipe is controlled by air temperature as detailed in Phillip and Hockley, 2007a. The point at which air flow changes direction is the pivot point and is approximately 12 ºC. When the air temperature is below this value air enters at the dump toe and lower slope; when above, pore gas exits at the toe and lower slope. Air velocity in the 400 mm pipe was monitored from August 2006 to October 2008, at which time the Monitoring Station was removed and a U-trap, or "gooseneck" was placed in the seepage line to prevent the seepage line from being a conduit for gas outflow.

Air velocity was not monitored from December 2007 to May 2008 due to sensor failure resulting from freezing of the seepage line and flooding of the Monitoring Station. During the time that the sensor was submerged, the 400 mm pipe was sealed and was not a conduit from the atmosphere to the dump interior. Some monitoring locations within the dump showed a drop in oxygen composition at the time of the flooding and it was expected that the U-trap installation could impact *in situ* gas composition because air flow at the toe would now need to pass through the cover.

Premature snowmelt areas (PSAs) were discovered in the spring of 2007 and monitored throughout the two successive winters. The PSAs are believed to be areas where warm internal pore gas exits the cover. In February 2008, a discrete pore gas vent was discovered near the north crest of the No. 1 Dump with an oxygen composition of 6% at the dump surface. PSA and vent background information can be found in Phillip et al., 2009. Figure 1 shows PSA and vent areas on the No. 1 Dump.

Fig. 1. No. 1 Dump PSA (grey) and known vent areas (black).

Following the initial discovery of the discrete vent in February 2008, surveys were conducted along the surface of the No. 1 Dump during the summer and winter along the toe and crest, respectively. An additional group of vents was discovered near the north crest and a small vent was discovered on the top surface where a small subsidence area developed. A vent was discovered near the northeast toe of the dump in the summer of 2008. The three vent areas near the crest and on the top surface were again found to be active during the 2008-2009 winter. In addition, a new vent near the eastern crest was discovered.

For comparison purposes and to understand the extent of surface vents on Sullivan Mine waste dumps, surveys were conducted on the South Dump in the Lower Mine Yard in November 2008. Oxygen levels as low as 1% were measured where cracks were found in the cover, or adjacent to items that penetrated the cover, such as well casings, fence posts and survey stakes. As well, an oxygen content of 3% was measured inside a well casing. In all cases oxygen values returned to 20.9% at a height of 15 cm from the surface.

With the effect of pore gas measureable on surface gas composition, the extent of such effects was important to understand from both a scientific and safety perspective. In an attempt to gain an initial understanding of the distribution of pore gas venting through the cover, a total of 48 "gas traps" were installed across the North, South, and No. 1 Dumps, and in undisturbed natural settings adjacent to the dumps in four categories:

1. Control – those in the natural areas adjacent to the dumps;
2. Normal – those installed on the dump surface without cover modification;
3. Biased – those installed adjacent to a Normal gas trap and on the dump over areas where the cover was purposefully penetrated in an attempt to create a preferential flow path; and
4. Uber-Biased – those installed over known pore gas vents.

The initial 18 gas traps were installed January 2009 on or adjacent to the North, South and No. 1 Dumps. An additional ten gas traps were added to the No. 1 Dump in February 2009. To broaden the coverage on the No. 1 Dump and focus more closely on lower slope and toe areas where pore gas outflow would be expected with warmer weather, 20 additional gas traps were deployed on the No. 1 Dump in April 2009.

In April 2009 the No. 1 Dump toe in the area where the Monitoring Station was previously located became a focus of study. The concern with this area was the possible response to the installation of the U-trap; specifically, would the movement of pore gas to the toe during warm weather result in pore gas exiting the cover in a concentrated and potentially dangerous manner now that the easy conduit of the 400 mm pipe was no longer present? To evaluate this scenario, a series of transects were established in what became known as the chevron – the "v"-shaped convergence point of the toe drain where the Monitoring Station previously resided. The surface gas composition was manually monitored along these transects. In addition, the automated gas analysis system that was used for the Monitoring Station was modified to collect hourly samples from the chevron surface at two locations.

This paper presents results from the gas trap program, the chevron monitoring program, and *in situ* pore gas composition in response to the U-trap installation.

METHODS AND MATERIALS

Manual gas composition readings were collected with a FisherThermo analyzer. Automated hourly gas analysis of samples from the chevron were collected and analyzed using a Nova Analytical sequencer and gas analyzer.

Internal gas composition measurements were obtained from push-in gas piezometers (push-ins) and Solinst CMTs in completed boreholes.

The gas traps are built around an inverted plastic storage container as shown in Figure 2. At monitoring locations the ground was cleared of vegetation as much as possible and made uniform where the gas trap would contact the ground surface. Bentonite was used to seal the container on the surface; the bentonite was wetted and covered. A PVC bulkhead provides access through the container for sampling; slotted PVC pipe continues down to the surface inside the gas trap and the pipe extends upward from the trap. To avoid creating an inadvertent preferential pathway, a gas trap could not be staked to the ground and was instead secured with rope and cinder blocks. A second hole through the plastic container was created to allow for purging with fresh air. The second hole was sealed by inserting a small length of PVC pipe (capped) and surrounding the pipe cap with plumbers' putty; recently installed gas traps featured a second bulkhead for purging. Purging was performed with a dual-action manual powered hand pump.

Fig. 2. A gas trap being purged with fresh air.

When monitoring a gas trap, initial conditions were measured by placing the gas analyzer sample tubing down into the gas trap via the PVC sample tube. When the gas trap monitoring began, a trap showing any pore gas effect was flushed with fresh air following the recording of initial readings. This flushing was done to verify the affected readings during the next monitoring event. Monitoring was conducted weekly. However, to confirm the consistent nature of results, daily measurements for a two week period were made under cold and warm conditions, in March and June 2009, respectively. The few gas traps that showed oxygen composition less than 10% were found to respond quickly to flushing and recovery tests were performed by monitoring the change in oxygen and carbon dioxide composition in two minute intervals for at least 20 minutes.

The chevron monitoring contained both automated and manual components. Hourly gas composition readings were obtained from the P-10 piezometer and from two locations on the ground surface. The surface locations were approximately 30 cm from a vent.

Transects were established across the chevron area (see Figure 3) and surface gas composition measurements were made at three meter intervals. Surface features, such as cracks or holes, near a transect measurement point were also monitored.

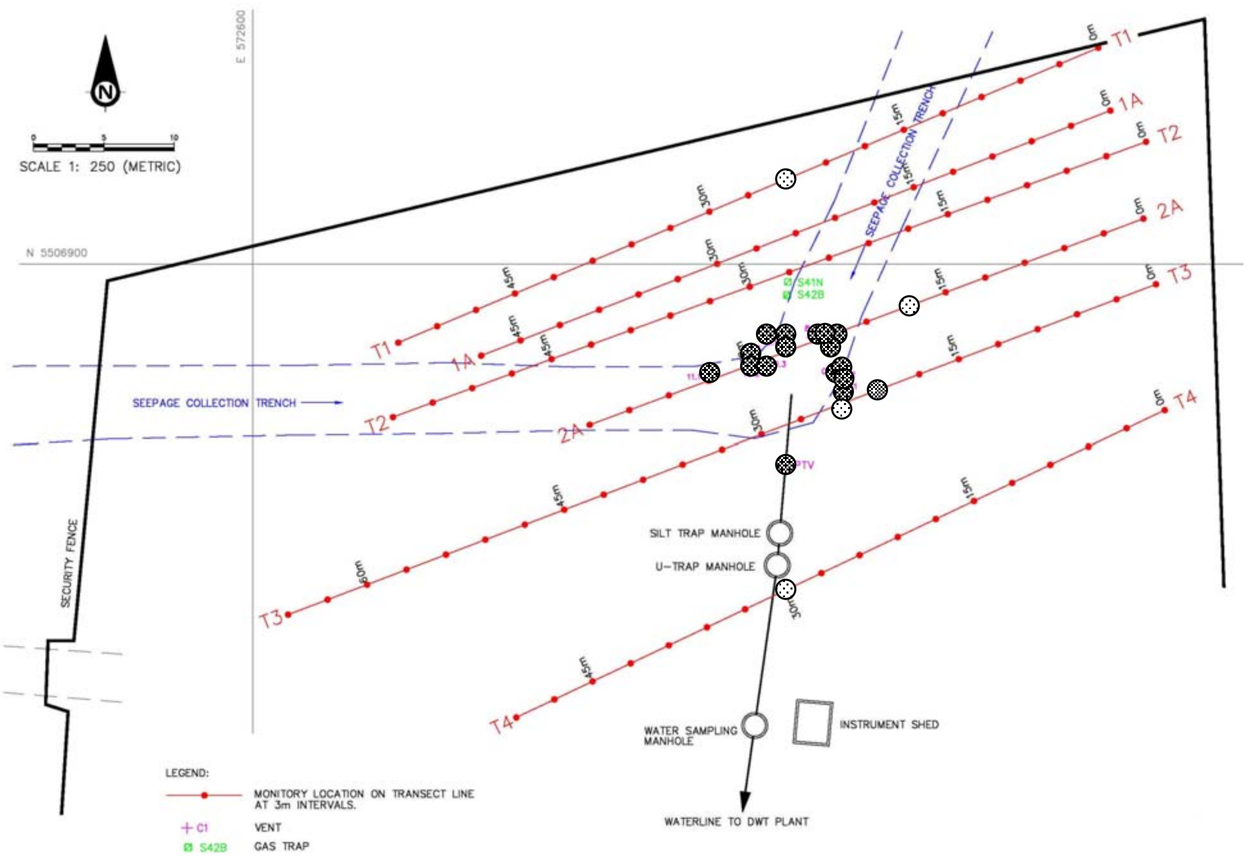
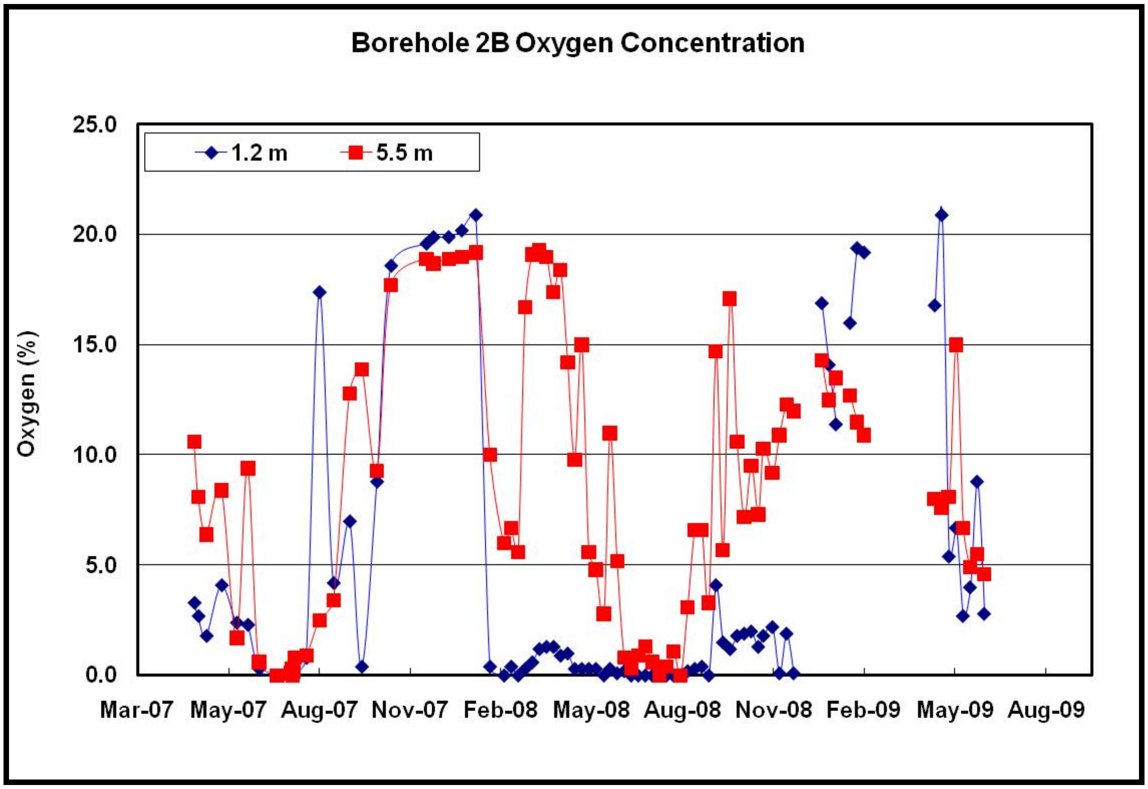


Fig. 3. Chevron surface transect monitoring locations. Locations with measured pore gas effects are shown as shaded circles; the darker the circle, the more prevalent the effects. The vent locations are clustered at the confluence of the toe drain (dashed line).

RESULTS

Monitoring of temperatures and gas compositions within the No. 1 Shaft Dump continued during the gas trap studies. Results such as those shown in Figure 4 show that the removal of the Monitoring Station and the installation of the U-trap did not significantly influenced *in situ* pore gas composition. At borehole BH-2B on the mid-slope bench near the chevron, the oxygen values at the bottom of the borehole do appear slightly lower during the winter following the October 2008 U-trap installation. Locations further afield from the former Monitoring Station reveal little if any effect. Gas composition under the mid-slope bench (P-07) follows the same trend for the previous two years.

Gas trap results show a clear trend with control traps and uber-bias traps showing the least and greatest effects, respectively. Table 1 compiles the average, the average minimum and the ultimate minimum percent oxygen values recorded at the gas traps located along the crest or top surface of the three mine site dumps. A steady decrease in oxygen content exists when moving from the Control to the Uber-Bias gas traps. Comparing the four paired normal and biased gas traps, average oxygen content in three of the four biased traps was less than in the normal.



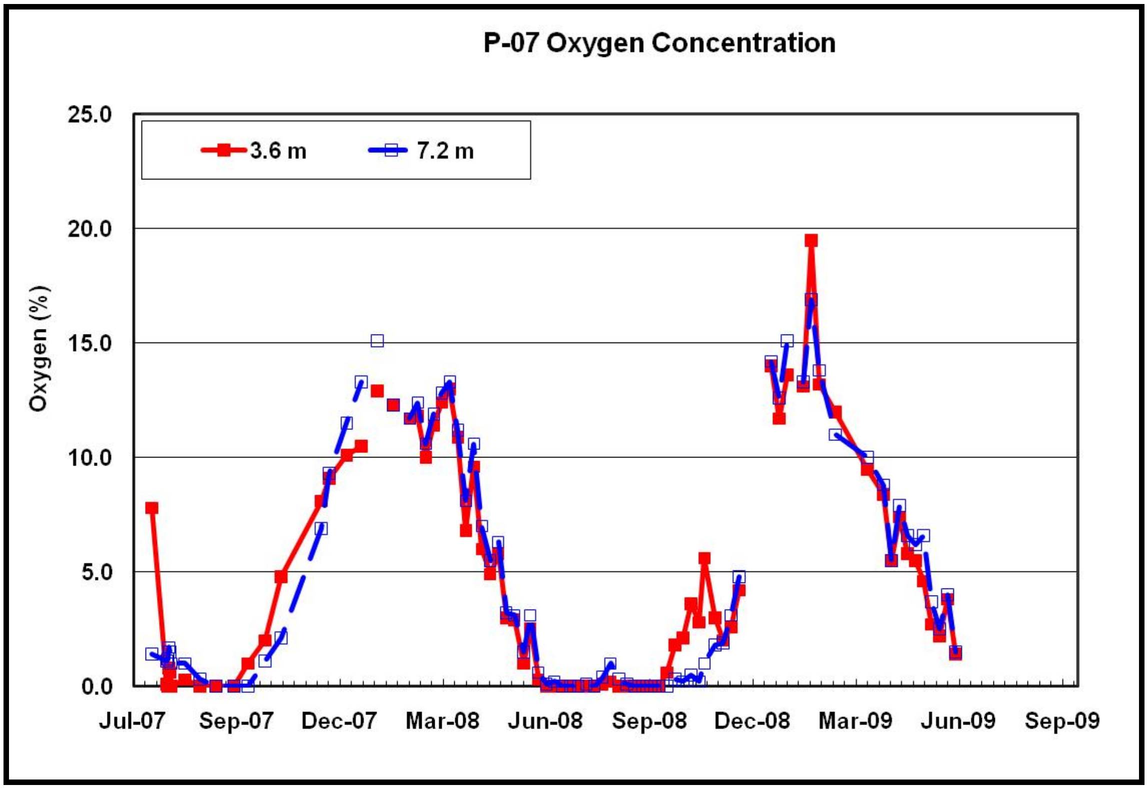


Fig. 4. Pore gas oxygen composition at BH-2B and P-07.

Table 1. Crest gas trap results during cold weather monitoring (air temperature < 10 ºC).

Gas Trap Type, Quantity	Oxygen Composition (%)		
	Average	Ave. Minimum	Minimum
Control, 2	20.8	20.4	20.2
Normal, 13	20.5	19.6	16.3
Bias, 4	19.9	18.1	13.2
Uber-Bias, 2	7.6	6.7	4.2

The oxygen content in the five gas traps located along the toe and lower slope of the No. 1 Dump showed essentially no impact during the same period of time. The average oxygen content was 20.9%, while the minimum value of 20.8% was recorded only twice.

Resampling of normal and bias gas traps that were flushed with fresh air showed that it took several hours to return to similarly affected gas composition readings. Recovery to affected conditions at uber-biased gas traps were observed in minutes and commonly dropped from 20.9% to under 10% oxygen within six minutes at the most productive gas trap. Details of the uber-bias recovery data is still under analysis to determine if it can be used to provide accurate flux data. Simple bag tests have been conducted and used to both inflate and deflate plastic bags at the uber-bias gas traps. Bag tests were conducted on July 22 when the air temperature was 28ºC. A gas trap near the crest of the No. 1 Dump deflated approximately 10 L in 5.5 minutes; at the toe a bag was inflated approximately 2 L in 4 minutes.

The gas traps along the toe and lower slope that would show pore gas effects during warm weather have not demonstrated the response described below in the chevron area. One noted exception to this is an uber-bias gas trap located at the northeast toe of the No. 1 Dump in a known PSA and vent area. From January to early June, the oxygen content was nearly always 20.9%; on June 17 it dropped to 9.9% and low oxygen values are now the norm.

The monitoring of the chevron area at the No. 1 Dump toe that began in June provides warm weather respiration data, when the air temperature is greater than the pivot point and pore gas is expected to be exiting at the toe and lower slope. Automated readings from the P-10 deep port located at the toe drain convergence show that oxygen and carbon dioxide composition are commonly 0% and 11%, respectively. Continuous days of cool weather are needed to slowly effect change in gas composition at P-10 (see Figure 5). Diurnal changes in the gas composition are not observed, even when minimum air temperature fall below the pivot point.

Manual surface monitoring of pore gas was measured along transects in the chevron area and found in cracks and holes associated with differential settlement resulting from the installation of the U-trap. Due to the recent nature of the installation, the chevron area is largely void of any plant growth. The intense rain storms during the 2009 summer resulted in soil transport and surface features showed continuous change. Surface features with measureable pore gas composition would be sealed with fines and new openings would emerge. Figure 6 shows a typical vent hole.

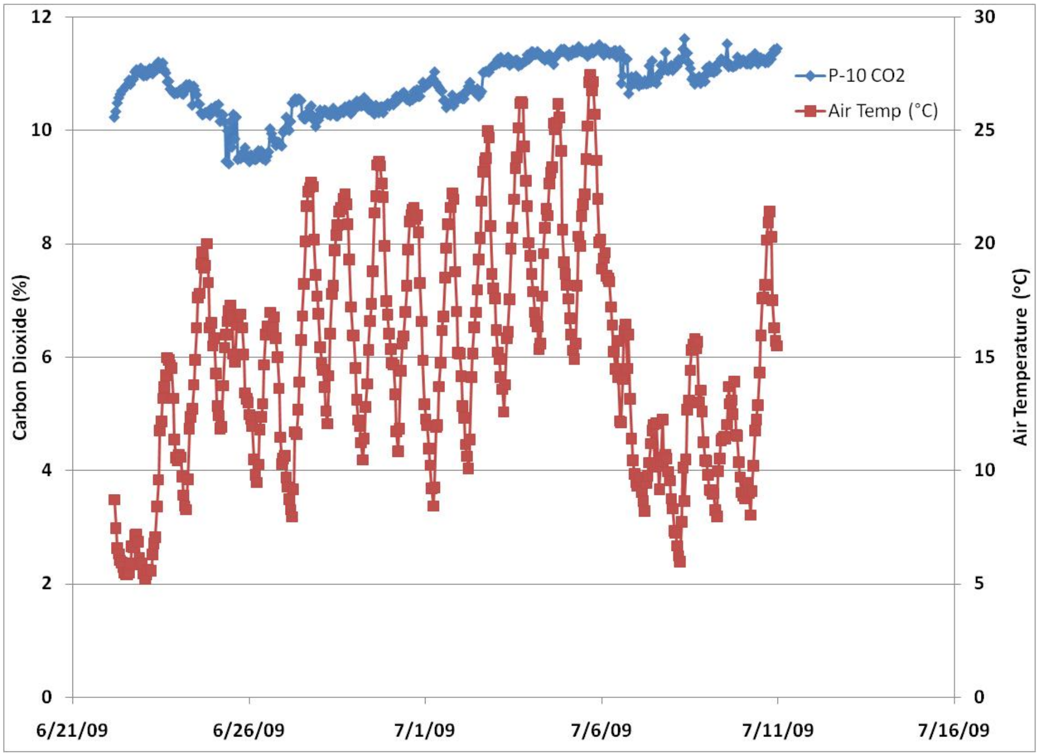


Fig. 5. Carbon dioxide composition in push-in P-10 and atmospheric air temperature.

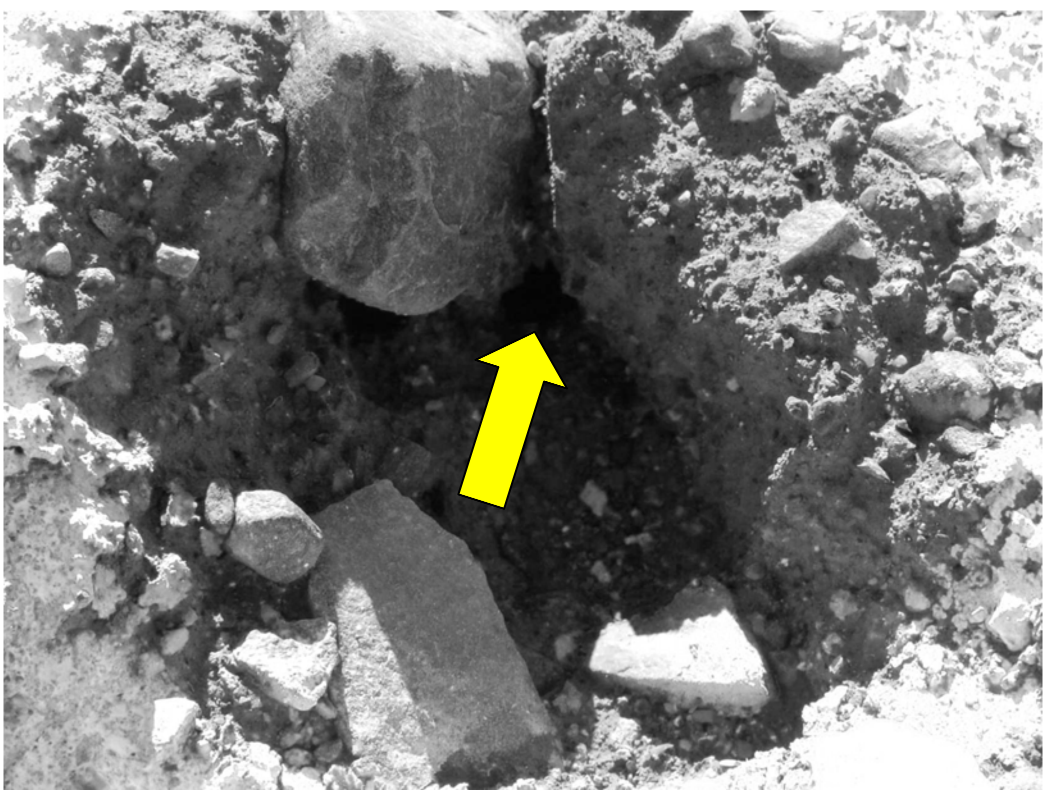


Fig. 6. A typical vent hole (1 cm wide at the surface) in the chevron area at the No. 1 Dump toe.

Measurement of largely undiluted pore gas requires inserting the gas analyzer sampling tube into the vent hole or crack. Oxygen content measured in chevron vents was as low as 2.7% with carbon dioxide as great as 11%. When the sample tubing was raised and held above the vent level with the ground surface, in nearly all cases the oxygen composition was greater than 19.5%. One hole, T2A-8.1, stands out with surface level oxygen values as low as 14.2%. All oxygen measurements taken 15 cm above a surface feature in the chevron area were 20.9%. Pore gas effects on gas composition were not found on the ground surface at the next transect down gradient of a vent.

Automated gas composition readings from the two surface sampling points recorded one instance of pore gas effects, when oxygen content decreased from 20.9% to as low as 4.7% over a three hour period. The incident occurred during a storm event at the sample point approximately 30 cm from the noted active vent of T2A-8.1.

DISCUSSION

Monitoring of the gas traps and vents across the three mine site dumps, and especially at the No. 1 Dump, has provided another tool confirming the flow regime evident from internal gas composition, differential pressure results, and air velocity data from the Monitoring Station's 400 mm pipe. Winter gas trap results show clear differences among the different types of traps. The control traps show a minimal reduction in oxygen content, which is most likely caused by surfical organic matter and not pore gas. The normal gas traps do show pore gas effects and the biased gas traps show them more strongly. The biased gas trap results show that cover penetrations allow pore gas to more readily move between the waste rock and atmosphere. Given the relatively slow response time following flushing of the normal and biased gas traps, it is believed that diffusion is the primary mechanism responsible for pore gas transport.

The uber-biased traps were installed over known vent areas. It was common for these vents to show limited pore gas effects at a height of 15 cm above the surface of the vent. Given the response time in minutes following gas trap flushing and the results from bag tests, it is believed that flow of pore gas into the uber-bias gas traps is controlled by convection. Analysis of the data continues in an attempt to determine whether it can be used to accurately provide convective flow rates.

The pore gas vents that were originally discovered in February 2008 raised questions about their distribution across the dump surface, both from a scientific and safety perspective. Gas trap results and surface surveys have also shown that the vents are not common on the dump surface and are limited to three areas: three locations that coincide with premature snowmelt areas, the small area of subsidence on the top surface, and the chevron area at the toe that is related to differential settlement. Vent monitoring data show the effect of pore gas is limited to the immediate vicinity of the vents. To obtain gas composition results that could be considered pore gas, the measurement must be taken *inside* the vent. Mixing with air rapidly dilutes the pore gas at the surface with the majority of oxygen readings above 19.5%.

The installation of the U-trap at the No. 1 Dump has affected one location significantly: the toe drain confluence monitored by P-10. Now that airflow is not possible through the seepage collection system, the confluence point is the ultimate low point in the dump. Since convective flow must now move entirely through the cover, the confluence low point has become a stagnant zone that requires continuous inflow at the toe to affect gas composition.

The differential settlement and associated vents in the chevron area provided an opportunity to examine the possibility that a high volume of pore gas flow could emerge at the toe in response to the installation of the U-Trap. While pore gas could be detected within the vents, the pore gas appeared to rapidly mix with the atmosphere and only at one primary location was oxygen still below 19.5% at the surface.

The U-trap installation has had minimal effect on the No. 1 Dump internal gas composition as a whole. The bottom-most port at borehole BH-2B shows limited effect based on reduced oxygen content in 2009 compared to 2008. When the Monitoring Station was present, this bottom port was noted as being a likely preferential pathway between the toe drain and the dump interior based on gas composition and differential pressure data. Given the connection between the Monitoring Station and BH-2B, it is not surprising that the gas composition values have decreased, but it is remarkable that they are not lower.

Based on the limited effect on gas composition at other locations in the No. 1 Dump, it appears that significant airflow is achieved through the cover. This is also supported by the gas trap and vent monitoring results, which show widespread, although highly variable, evidence of gas flux. It appears that numerous tiny pathways have replaced the large air entry and exit pathway that was previously provided by the 400 mm drainage pipe.

CONCLUSIONS

Combined with surface surveys, the gas traps have been a useful tool to examine the distribution of pore gas flux through the cover. Nearly all of the pore gas effects on gas composition in the gas traps are considered to be the result of diffusion. However, there are three locations whose pore gas flux is believed to be caused by convection as evidenced by low oxygen values, quick recovery after flushing with air, and bag tests. The timing of pore gas effects in gas traps relative to air temperature has provided another confirmation of the No. 1 Dump respiration conceptual model. The measureable effect of pore gas at the dump crest and toe throughout the year highlight the importance of evaluating both buoyant and dense pore gas exiting a dump.

The vent locations where pore gas effects can be measured at the surface without a gas trap are limited to three areas on the No. 1 Dump: premature snowmelt areas, a small subsidence area, and the chevron area that is caused by differential settlement. Such vents could easily be targeted and addressed as a component of cover maintenance, by compacting the existing cover and/or placing additional cover material. Nearly all gas trap effects are the result of diffusion of pore gas through the cover.

The chevron area has shown the nature of pore gas exiting at the lowest elevation of the dump. This dense gas quickly dissipates and has shown that a large and concentrated outflow of pore gas from the No. 1 Dump is not likely.

The U-trap installation has had minimal effect on *in situ* gas composition, showing that sufficient air flow is able to transfer through the till cover. When combined with the uniformly coarse nature of the waste rock with depth, as described in Paper 1, the spatially distributed nature of the respiration flux is evident.

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