SULLIVAN MINE WASTE DUMP CHARACTERIZATION, PART 1

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ABSTRACT

The control of respiration by air temperature at the No. 1 Waste Dump at the Teck Cominco Sullivan Mine near Kimberley, British Columbia, Canada has been extensively documented. Respiration flow reverses, with pore gas exiting along the dump toe whenever the atmospheric air temperature is above approximately 12ºC. A respiration flow reversal has not been observed at the nearby North Dump. To investigate the respiration differences, push-in piezometers and automated water content and soil temperature sensors have been installed at both waste rock dumps. In addition, both sites were examined with geophysical resistivity surveys, which showed the No.1 Dump to be very heterogeneous. Additional characterization of the No. 1 Dump was conducted in May 2008 to understand the heterogeneities and how they may influence dump respiration: an additional fourteen boreholes were drilled and instrumented and five additional push-in piezometers were installed in the No. 1 Dump. This paper summarizes data to compare the No.1 and North Dumps. Furthermore, the results of the No. 1 Dump characterization program will be analyzed and discussed, which reveal a dump of material segregated by pore size that in its entirety is highly permeable and facilitates respiration air flow.

KEY WORDS: waste dump, respiration, differential pressure, pore gas

INTRODUCTION

Four fatalities occurred at the toe of the closed and reclaimed No. 1 Shaft Waste Dump at the Teck Sullivan Mine on May 15-17, 2006. The fatalities took place in the Monitoring Station at the dump toe where seepage was routinely sampled. The Monitoring Station was connected to the dump toe drain via a 400 mm pipe. Measurements taken in the immediate days following the incident showed air exiting the 400 mm pipe into the Monitoring Station at approximately 0.5 m/s, with oxygen and carbon dioxide content of approximately 2% and 7%, respectively.

Following the incident a panel was formed to investigate the technical causes that led to the fatalities. Panel members represented Teck and its contractors and advisors; the British Columbia Ministry of Energy, Mines and Petroleum Resources and its advisors; and, independent members from the University of British Columbia Department of Mining Engineering and from an international consulting firm. The panel began the investigation with the working hypothesis that changes in atmospheric conditions resulted in dump pore gases generated by common geochemical reactions exiting the dump through the 400 mm seepage collection pipe.

The focus of the initial August 2006 field investigation included site meteorology, till cover material water content and temperature, and gas composition and air velocity in the 400 mm seepage collection pipe that connected the Monitoring Station at the dump toe to the dump interior. A March 2007 drilling program provided for the collection of internal dump data: temperature, gas composition and differential pressure.

Data from the first two phases of investigation showed that dump respiration is controlled by density differences between dump pore gas and the atmosphere that are the result of changes in atmospheric air temperature. Because the internal dump temperatures are within the range of annual air temperature, the direction of internal air flow changes throughout the year at the "pivot point" of approximately 12 ºC. In the winter the pore gas rises up through the dump; during the summer the opposite is true. Analysis of drill cuttings revealed that both sulfides and carbonates are present in the dump at up to 3% and 1%, respectively; these results confirmed that the gas composition measured in the Monitoring Station are caused by common sulfide oxidation and carbonate neutralization reactions. The details of the initial investigations and site layout have been previously presented (Phillip and Hockley, 2007a; Phillip and Hockley, 2007b; Phillip et al., 2008).

The No. 1 Dump and associated seepage collection system provided for the direction of pore gas flow into the Monitoring Station. The general design of a mine dump with a toe drain is not unique to the No. 1 Dump, but the risk posed by such a design was not understood until after the fatalities. To examine another similar dump that exhibits different behavior, one need not even leave the Sullivan Mine. Approximately 2 km from the No. 1 Dump is the North Dump in the Lower Mine Yard of the Sullivan Mine (see Figure 1).

The North Dump was one of the original waste dumps at the Sullivan Mine and is located on the north side of the Mark Creek drainage above the town of Kimberley. The waste rock was rich in pyrrhotite and was produced with pneumatic rock drills that produced fine waste relative to the coarser material generated with more modern mechanized equipment. Reclamation of the North Dump was begun in 1991 and involved the relocation of Mark Creek; a seepage toe drain collection system was commissioned to intercept seepage before it could enter receiving waters. The waste rock had become cemented and instead of trying to push the crest down, other waste material was consolidated at the dump and the new profile was built from the toe upwards. The dump was covered with 1 m of till material. Monitoring of the North Dump seepage collection system has not revealed any significant changes in oxygen or carbon dioxide content as occurred at the No. 1 Dump. This paper discusses the continued characterization of the No.1 Dump and the results from the North Dump investigation that support an explanation for the difference in behavior witnessed at the two dumps.

METHODS AND MATERIALS

Manual measurements of gas composition were collected with Nova Analytical or FisherThermo gas analyzers.

Geophysical resistivity surveys were performed by Klohn Crippen Berger in October 2007. The resistivity surveys measure how resistive or, in the opposite sense, how conductive *in situ* material is to electrical current. Factors that can influence conductivity are moisture content, metal content, and material density; increases in the preceding factors will increase material conductivity. Ten resistivity surveys were conducted on the No. 1 Dump and two surveys were conducted on the North Dump.

Five push-in gas piezometers (push-ins) were installed along the crest of the North Dump and first sampled November 2007 from port depths of 5 and 10 m. The push-ins allow for the collection of internal gas composition, differential pressure and temperature at two depths and are described in more detail in Phillip et al., 2008. Installation of the North Dump push-ins required the use of an air rotary drill rig to initially drill an access hole.

Fig. 1. The No. 1 Dump (top right) and North Dump (left) near Kimberley, BC. (Google Earth)

Manual collection of gas composition and differential pressure (between the dump interior and atmosphere) were obtained by connecting the FisherThermo gas analyzer or Setra 264 differential pressure sensor to the two push-in ports. Internal temperature readings were collected from Campbell Scientific 107B thermistors that were attached to the small diameter tubing within the push-ins.

Additional characterization of the No. 1 Dump was performed using both sonic and air rotary drill rigs. Static testing of drill cuttings was targeted based on results from field paste pH and electrical conductivity tests. Cuttings were collected in 20 L pails from the air rotary drilling at intervals of 76 cm. The recovery of cuttings (pail weight) was used as an indication of *in situ* material coarseness; the lower the recovery, the coarser the material. In a similar manner, the linear recovery of core from the sonic drilling from every 3 m drilling increment was used as an indication of material coarseness.

The No. 1 Dump boreholes were installed with Solinst continuous multi-channel tubing (CMT) to allow for collection of *in situ* gas composition and differential pressure data; temperature was again obtained from 107B thermistors attached to the exterior of the CMT. The boreholes were completed with alternating layers of bentonite and coarse sand or pea gravel.

Installation of additional No. 1 Dump push-ins was performed with a vibratory attachment on an excavator.

RESULTS

<u>North Dump and No. 1 Dump Comparison</u>

A field survey of the North Dump gas composition was performed on June 24, 2007 when the air temperature was 24ºC, much greater than the No. 1 Dump’s respiration pivot point of approximately 12 ºC. The seepage collection system at the toe was sampled at two locations. The gas composition at both locations was relatively consistent. This result led to the hypothesis that the North Dump internal temperature was greater than that of the No. 1 Dump and that the North Dump’s respiration pivot point was not yet reached. The crest of the North Dump was then inspected and gas composition results indicative of *in situ* pore gas were found adjacent to a ground water monitoring well that penetrated the cover.

Resistivity surveys showed a uniformly conductive North Dump, but a heterogeneous No. 1 Dump (see Figure 2a and 2b, respectively). A resistive body was evident running through the dump under the mid-slope bench. The lower slope was conductive and other resistive bodies extended back into the dump to the west.

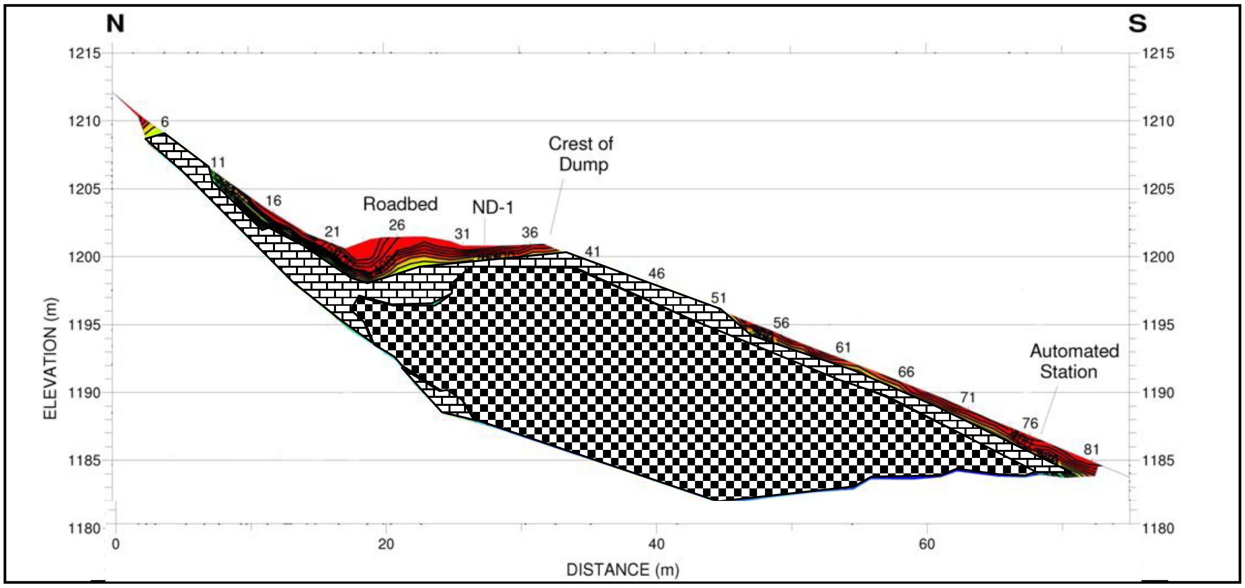

Fig. 2a. The cross-section of the North Dump showing a uniformly conductive waste rock (checkerboard area). The brick area is moderately conductive/resistive, and the remainder is resistive.

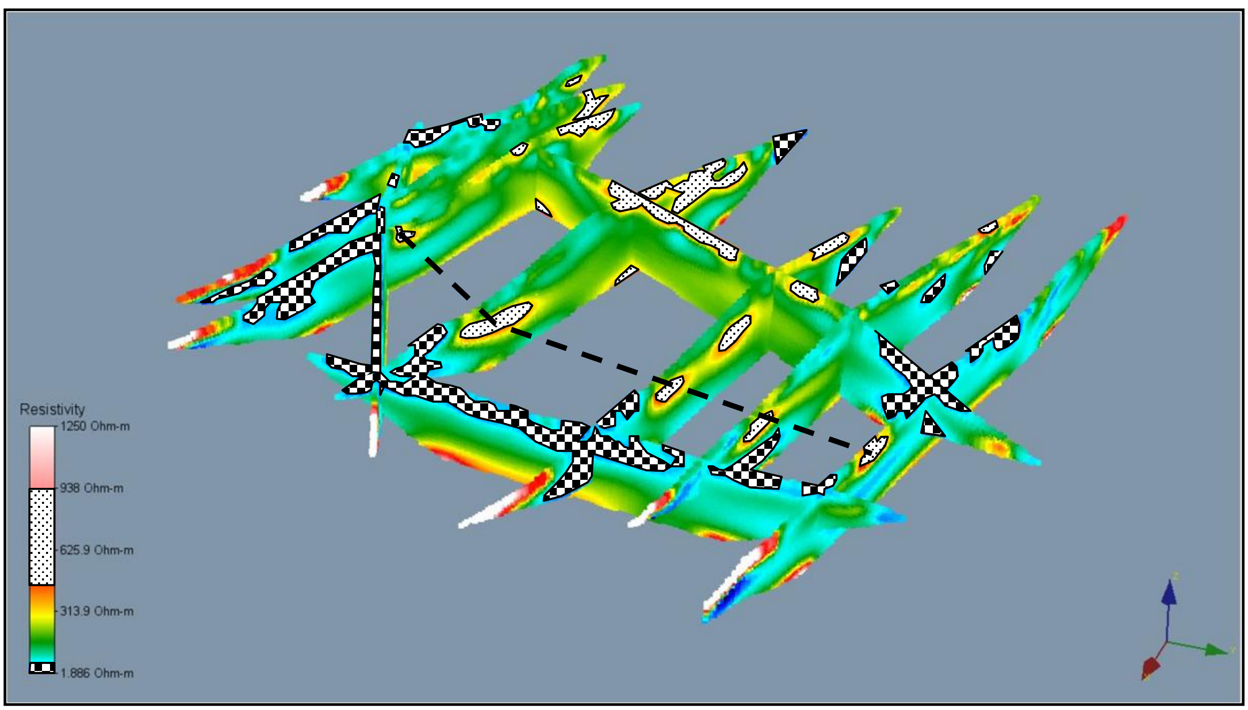

Fig. 2b. The ten interlaced resistivity survey results of the heterogeneous No. 1 Dump looking southwest. The checkered area is the most conductive. The resistive bodies within the dump are shown as polka-dotted areas; the heavy dashed line connects the resistive bodies under the mid-slope bench.

Installation of the North Dump push-ins was first attempted in the same manner used at the No. 1 Dump: with a vibratory attachment on an excavator. Rejection of the casing pipe occurred within the first meter of waste rock and the push-in installations required the use of an air rotary drill rig to initially drill an access hole through the cemented waste rock surface.

Maximum internal North Dump temperatures measured at the 10m deep port on the five push-ins ranged from 13.4ºC to 18.6ºC, which is within the range of temperatures recorded from similar locations at the No. 1 Dump. However, thermistors were placed inside the North Dump groundwater standpipes on the crest where pore gas was discovered. The maximum *in situ* temperature of approximately 33ºC was recorded in the standpipe.

The two dumps show different *in situ* gas composition results (see Figure 3). The North Dump pore gas has lower concentrations of both oxygen and carbon dioxide compared to the No. 1 Dump.

Figure 4 illustrates the differences in differential pressure at the two dumps. P-06 (No. 1 Dump mid-slope bench) has been monitored on both sides of the pivot point as evident in the change in sign of the differential pressure. NDP-04 (North Dump crest) has not been observed at the North Dump pivot point, which is 30.5ºC based on the data trendline.

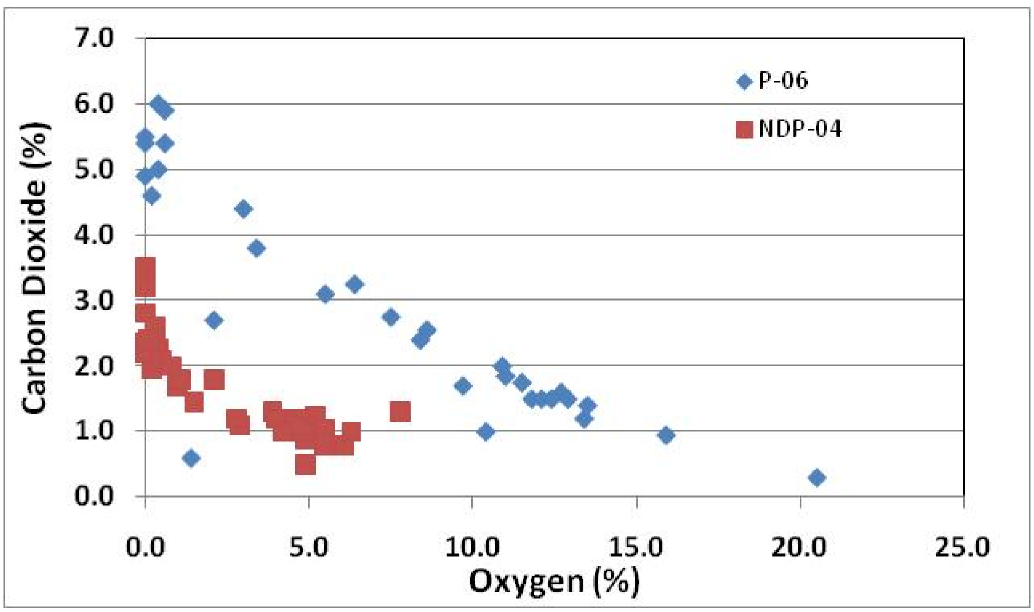

Fig. 3. Gas composition results from push-ins at the No. 1 Dump (P-06) and the North Dump (NDP-04).

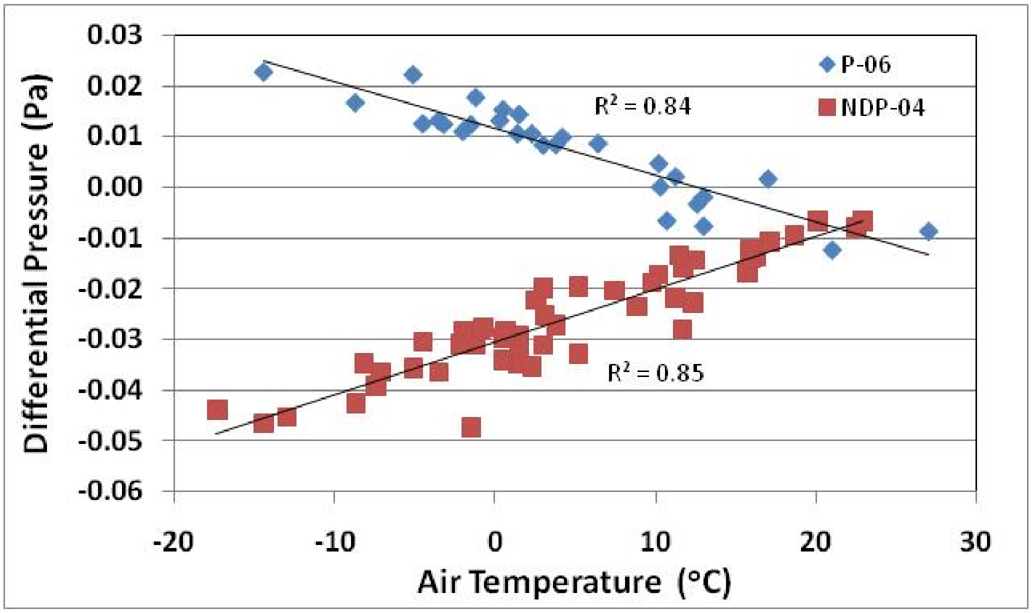

Fig. 4. Differential Pressure and Air Temperature at No. 1 and North Dump Push-ins.

<u>No. 1 Dump Characterization</u>

During the May 2008 additional characterization of the No. 1 Dump, fourteen additional boreholes were drilled and five additional push-ins were installed. Thirteen of the boreholes were completed with CMTs; one hole was a duplicate for drilling method comparison purposes. Regardless of drilling method, every borehole resulted in recovery decreasing with depth.

Static testing increased the range of both sulfide and carbonate content measured in drill cuttings with maximum values of 5.4% and 5.5%, respectively; average values were 0.95% and 0.85%, respectively. A variety of material was discovered within the dump: barren waste (cap) rock, sulfide waste rock, calcine (thermally degraded high-sulfide rock), office waste, and industrial waste (cables and timbers).

Analysis was conducted by plotting the results against the resistivity from the geophysical survey. Two main factors controlled the resistivity results: chemistry and material coarseness. Recovery along the mid-slope bench was commonly only 30%, which corresponds to the area of the original dump toe where oversize material was deposited. The lower slope area recovery in the waste rock was 30% to 50% of that encountered in the till cover material.

Initial internal temperature data from the two boreholes on top of the No. 1 Dump both showed similar core temperatures of approximately 16ºC. Internal temperature data collected from the additional boreholes revealed a more thermally complex dump (See Figure 5), with maximum values ranging from 19ºC to 27ºC in the thicker portion of the main dump body. Core temperatures increased not only at the two original top boreholes, now both residing at approximately 19ºC, but also at every borehole on the top surface except the one associated with the 27ºC area.

DISCUSSION

North Dump Composition

The lack of significant effects on gas composition measured in the North Dump seepage collection toe drain can be attributed to the dump having an elevated internal temperature compared to the No. 1 Dump. This is supported by the temperature values of nearly 33ºC in the standpipe through the North Dump, and by the differential pressure results of Figure 4. Pore gases will almost consistently vent from this dump near the crest area unlike under the flow reversal pattern seen at the No. 1 Dump.

The gas composition results in Figure 3 provide insight into an additional factor that likely results in a strengthened respiration flow from toe to crest. It has been previously discussed how the No. 1 Dump pore gas composition does not significantly influence the buoyancy of the pore gas (Phillip and Hockley, 2007b): the increase in buoyancy created from the decrease in oxygen content is offset by the decrease in buoyancy caused by carbon dioxide generation. The North Dump pore gas contains less carbon dioxide; when oxygen values are zero, the North Dump has approximately half the carbon dioxide as the No. 1 Dump. The North Dump pore gas is therefore more buoyant and would require a greater air temperature than otherwise to surpass a pivot point and cause respiration airflow to exit at the dump toe. This buoyancy effect should be incorporated in the Figure 4 results.

The North Dump pore gas composition also suggests that the waste rock contains less carbonate material than the No. 1 Dump. This possibility is supported also by the history of the North Dump, resistivity survey results showing a uniformly conductive waste rock, and the rejection of the push-ins during normal installation attempts that was caused by cemented waste rock. All three of the supporting factors are indicative of high sulfide content waste rock.

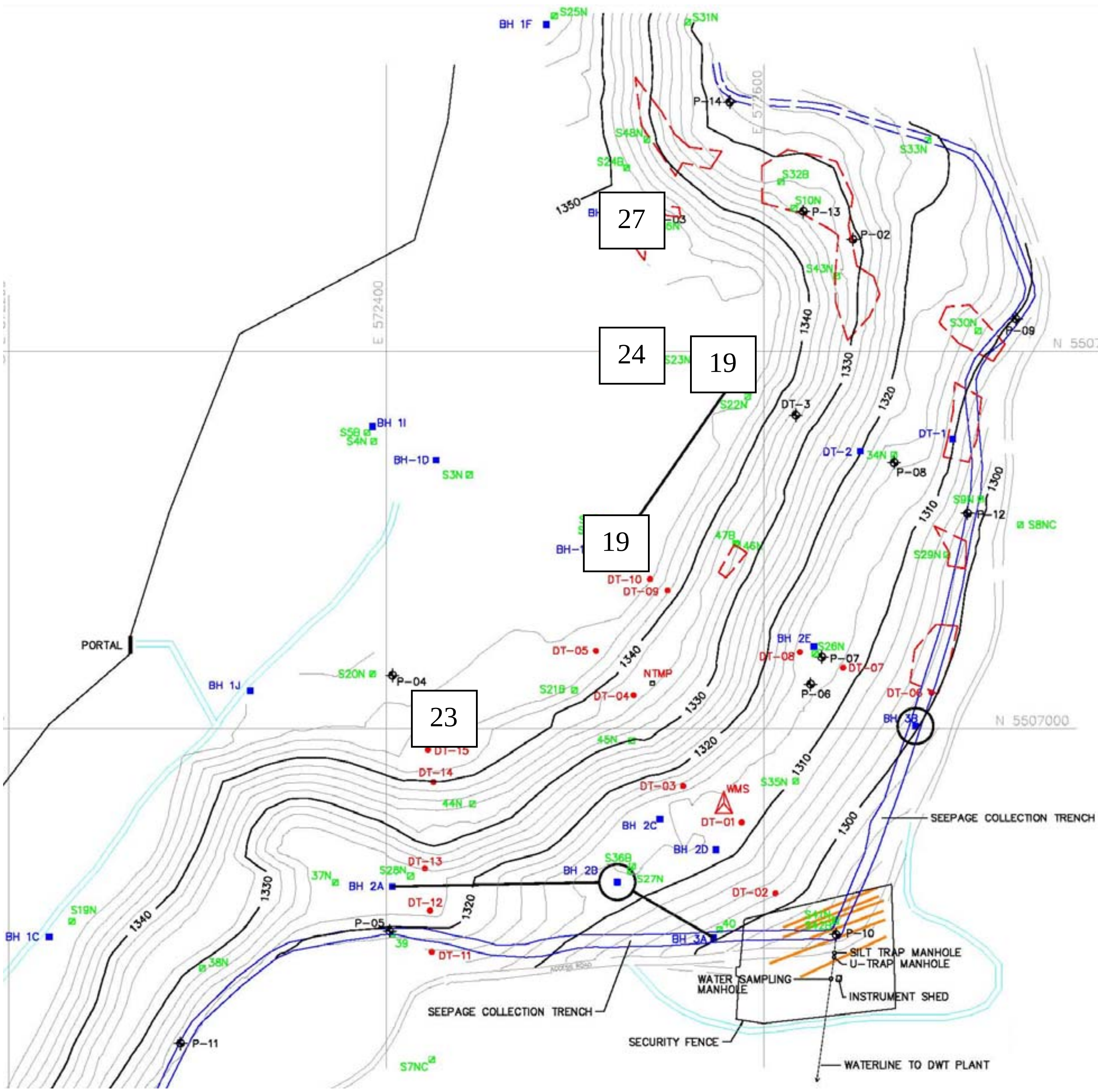

Fig. 5. Plan view of the No. 1 Dump showing the variation of internal temperature in the thickest portion of the main dump (ºC).

The cemented nature of the North Dump waste may also serve to reduce the flow of pore gas through the waste material. If this is true, it may be another factor in the lack of significant effect on gas composition along the toe seepage collection system. Given the limited number of hours in a year that the air temperature may rise above a possible pivot point of 30.5ºC, sufficient quantities of pore gas may not be capable of exiting the toe and causing hazards in this area.

No. 1 Dump Characterization

The additional No. 1 Dump characterization drilling program was conducted in May 2008 as a follow-up on the heterogeneities seen in the October 2007 resistivity surveys. The surveys and drilling program provide an image of a dump very open to pore gas flow. The 30% recovery that was common in the mid-slope bench area, when tied to the known location of oversize material helped to confirm the link between recovery and material coarseness at the No. 1 Dump. The reduction in recovery at every borehole with respect to depth is understandable given that the dump was constructed by end-dumping material over the crest of the dump, a process that results in segregation of material.

The conductive material that comprises the lower slope is likely the result of the reprofiling work performed in the fall of 2004 when the original slope was pushed down with dozers. This reprofiling would have mixed and broken the rock material, exposing fresh mineral surfaces to oxygen and moisture.

The geochemical nature of this material likely overcame the coarse content to produce a conductive material.

The chemistry results show both ample sulfides and carbonates for the consumption of oxygen and creation of carbon dioxide. Pore gas composition in the new boreholes was consistent with previous results.

The variation of *in situ* temperature seen in Figure 5 requires that the No. 1 Dump be viewed as having a number of respiration regimes that likely have individual pivot points. This is evident on the north side of the No. 1 Dump, where the maximum temperature of 27ºC and a prominent premature snowmelt area is present; the differential pressure and air temperature relationship predicts a reversal in airflow at approximately 31ºC in this part of the dump, well above the dump pivot point of 12 ºC measured at the Monitoring Station. The air flow recorded in the 400 mm pipe at the Monitoring Station was likely an integrated value of all contributing thermal regimes.

The increase in core temperatures recorded in most of the boreholes located in the main dump body signifies that the dump behavior will change with time. This has already been seen with the steady increase in the pivot point from 10.9ºC in the fall of 2006 to 12.4ºC in the fall of 2007. The till cover may be responsible for the increase of internal temperature by retaining the heat generated by sulfide oxidation.

CONCLUSIONS

The difference in North Dump respiration and the lack of gas composition effects at the toe are likely caused by a highly sulfidic waste rock that manifests itself in three ways. First, the oxidation of the waste rock has produced a greater internal temperature than the No. 1 Dump, which requires a greater air temperature to produce a pore gas flow reversal. Second, the waste rock is also likely accompanied by lower carbonate content, creating more buoyant pore gas, requiring an even greater air temperature to overcome the added buoyancy effect. Lastly, the cemented nature of the waste rock may limit the flow of pore gas in the North Dump when a respiration air flow reversal does occur, to the extent that the quantity of pore gas delivered to the toe may not be sufficient to affect overall gas composition.

The additional characterization of the No. 1 Dump reconfirmed the geochemical nature of the waste rock as being able to consume oxygen and also produce ample carbon dioxide. This results in the pore gas being neutrally buoyant from a stoichiometric standpoint when compared to atmospheric air.

The resistivity surveys and characterization program at the No. 1 Dump revealed it is heterogeneous from both a material and particle size view point. Reduced drill cuttings recovery with depth at every borehole shows that the No. 1 Dump is conducive to pore gas flow.

The distribution of internal temperature in the dump is more complex than originally conceived. A monolithic core temperature does not exist in the main body of the No. 1 Dump; instead, temperatures range from 19ºC to 27ºC, which likely results in a system of multiple respiration regimes.

While the maximum recorded internal temperature in the No. 1 Dump has remained consistently at 27ºC, the temperature at all other boreholes in the dump has increased steadily over the study period. This internal temperature increase has coincided with an increase in the respiration pivot point.

Examining the North and No. 1 Dumps provides lessons in how dumps and their associated respiration regime may change over time. The lack of, or exhaustion over time, of carbonates in sulfidic waste rock can affect the buoyancy and behavior of pore gas. Depending on the age of a dump and whether the dump is cooling or warming, the respiration regime will change over time, which may cause pore gas to expel from sections of a dump where previously no respiration had occurred.

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