PHYSICAL AND CHEMICAL INVESTIGATION OF WASTE ROCK FROM PAST OPERATIONS AT THE DETOUR LAKE GOLD MINE

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Abstract
In August 2011 researchers from the University of Waterloo, the University of Alberta and Detour Gold Corp. began a research program at the Detour Lake Gold Mine (DLM). This research program involves extensive field and laboratory studies and data analysis (*e.g.,* internal structure, grain size, porewater, pore gas) focused on four waste-rock stockpiles deposited at the DLM site during operations between 1983 and 1999, and which had 13 years of post-closure with covers. The goal of the study is to understand the processes that control the movement and composition of porewater in the historic waste-rock stockpiles. Although some of the waste rock at DLM is potentially acid generating (PAG) and has the potential to release dissolved constituents to the environment, most (83%) of the waste-rock is non-acid generating (NAG). The current investigation showed that the distribution of PAG and NAG waste-rock in the historic stockpiles and the degree of oxidation are variable, and zones of oxidized waste rock are found throughout these piles. The degree of oxidation appears to be related to the waste-rock type and amount of sulfide minerals rather than the location in the stockpile. Elevated concentrations of dissolved sulfate and depleted concentrations of pore-gas O_2 indicate that sulfide oxidation is occurring, but the concentrations of dissolved metals in the matrix porewater are generally low. A predominance of neutral pH porewater and paste-pH results for the waste-rock matrix suggest that ARD has not set in, however, acidic paste pH values in about 20% of the samples indicates that once the pH neutralization capacity of the waste rock is depleted, acidic conditions can develop. A thin soil cover placed on the stockpiles in the 1990s restricts the rate/extent of sulfide oxidation. Analysis of these decades-old waste-rock stockpiles will provide DLM with insight into how to design the new waste-rock stockpiles in a manner that will minimize the risk of seepages that may evolve during operations as well as for the post closure period decades into the future. This knowledge will also improve Detour's ability to manage new waste-rock stockpiles that are being designed and permitted for the new West Detour developments. The research project is continuing with additional financial support from DLM and NSERC and technical support from the staff and graduate students from the Universities of Waterloo and Alberta, and Carleton University.

Detour Gold Mine Site Description

Detour Gold Corporation (Detour Gold) is operating an open pit mine at their Detour Lake property in northern Ontario, approximately 180 km northeast of Cochrane, Ontario. The topography around the mine is typical of the James Bay glacial lowlands underlain by glacially deposited clay, silt, sand and gravel in depths ranging from a few meters to tens of meters. Some of the sandy sediments at the site are carbonate-rich (several percent $CaCO_3$).

The ore deposit is situated in the area of the former Detour Lake mine, which was operated by Placer Dome Inc. from 1983 to 1999. The deposit contains an open pit mineral reserve of 16.4 million ounces of gold, which will be recovered over a mine life of 23 years. The orebody is near surface and is being mined as an open pit with a waste to ore ratio of 3.7. Mining of the orebody is expected to produce on the order of 500 million cubic meters (1.5 billion tonnes) of waste rock over the life of mine. Mineralization is accompanied by sulfide minerals including pyrite, pyrrhotite and chalcopyrite, and lesser amounts of pentlandite and arsenopyrite (AMEC, 2010). Approximately 83% of the waste rock has a low potential to generate acid, as the neutralization potential (NP) to acid potential (AP) ratios (NP/AP = NPR) are > 1.5. Approximately 17% of the waste rock is predicted to have the potential to generate acid (potentially acid generating, PAG), as the NPR is < 1.5 (BBA, 2014). To facilitate management of ARD if it occurs, PAG rock is being stored separately from NAG rock.

Previous operations at the Detour Lake site generated waste-rock stockpiles (WRS1, 2, 3 and 4) dating from 1983 to 1999. Around the year 2000, these stockpiles were resloped and covered with 0.3-1.5 m of overburden, to meet closure requirements of the previous mine owner (Placer Dome, 2001). Monitoring indicates that these stockpiles had not released dissolved metals or acidic drainage to the environment during the 17 years of operation, nor in the 13 year post closure period.

Objectives

DLM is considering installing a low permeability soil cover on new PAG waste rock areas to minimize the potential for ARD. Four of the historic waste rock stockpiles are being examined for this project to evaluate how chemical conditions have evolved in the historic WRS over the past 15-30 years and to determine which physical and structural characteristics contributed to this behaviour.

Methods

Historic WRS 1 and WRS 2 are located within the footprint of the open pit and were relocated. They were examined for internal structure, physical, chemical and biogeochemical characteristics during relocation. WRS 3 and 4 fall outside the open pit footprint. They are being evaluated for mineralogical, chemical and gas transport characteristics in the long-term using instruments (e.g. thermistors, moisture sensors, tensiometers, suction lysimeters, pore-gas sampling points) installed into boreholes. The research program has included test-pit and vertical profile excavation and borehole drilling and instrumentation programs in 2011-2012, followed by data collection and analysis since 2012. A large number of samples collected during these programs have been processed to determine the physical and hydrological characteristics of WRS 1 and 2 (Cash, 2014; Cash et al., 2014). The composition of the pore water and pore gas within WRS 3 and 4 and chemical/mineralogical characterization of the waste rock solids has been extensively examined in all four stockpiles (McNeill, 2016). NSERC funding was obtained in 2012 to support this project and a second grant was received in 2015 for a further five year program to continue these studies.

Observations

Observations from more than 20 test pits (< 5 m depth) and full-thickness profile excavations in WRS 1 and 2 indicated that these stockpiles are structured with multiple benches 10-15 m high, separated by compacted traffic surfaces (Figure 1). The soil cover is typically 0.3 to 1 m thick, and consists of silty-sand glacial overburden with rounded boulders up to about 0.3 m diameter.

Structural features identified during the excavation study indicate that the stockpiles were likely constructed as a combined push dump and paddock dump. Areas with angle of repose slopes and a trend of grain size coarsening downward, representative of push-dump construction, were visible in the interior of the stockpiles. Areas with an absence of bedding structure are probably the result of smaller tip faces or paddock dumping.

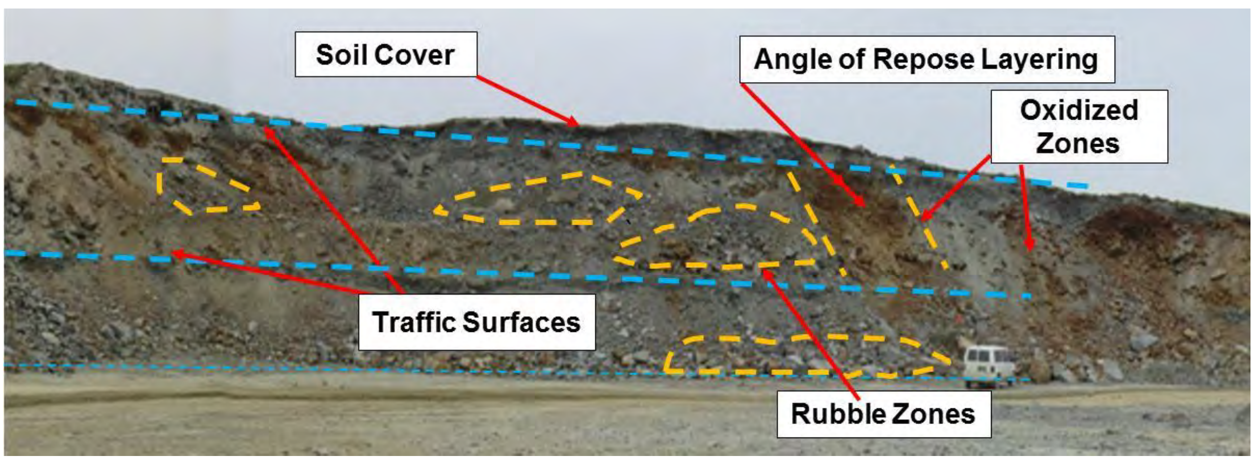

Figure 1. Excavation face (approximately 20 m vertical) on WRS1, showing internal structural features and zones of oxidation

Waste rock composition and weathering are variable in the stockpiles. Areas of weathered (oxidized) waste rock were found at throughout WRS 1 and 2, and a distinct oxidation profile was not evident. The presence of oxidation appears to be related to the waste rock type (PAG material) and amount of sulfide minerals rather than the location in the stockpile. A predominance of neutral paste pH results for fine material from WRS 1 and 2 (Figure 2) suggest that ARD has not set in. Acidic paste pH values in about 20% of the samples indicates that after a 30 year lag time, the pH neutralization capacity of the waste rock has depleted in some areas, allowing localized acidic conditions to develop.

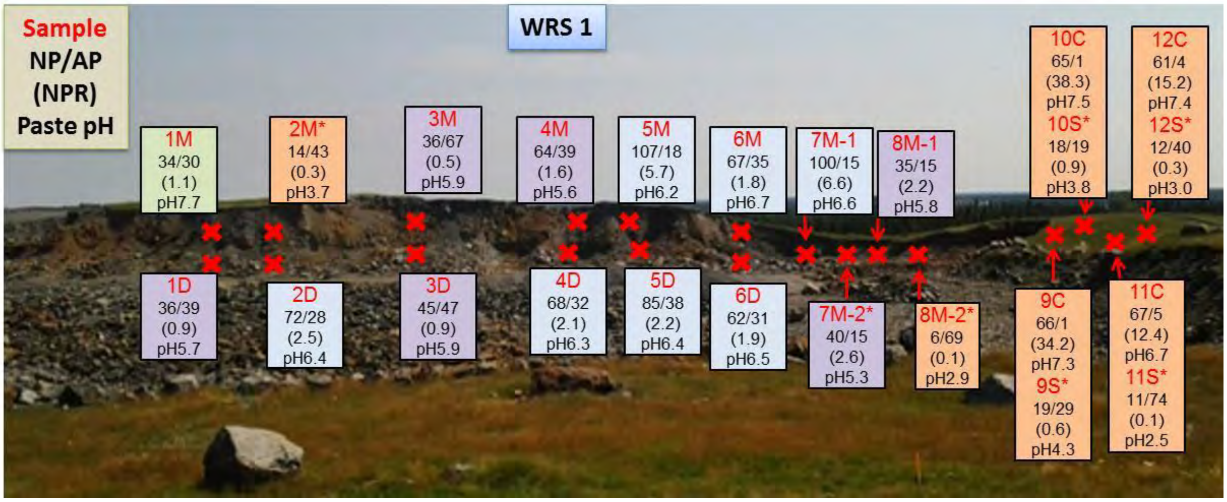

Figure 2. NPR and paste pH values for waste-rock matrix samples. The box shading groups the samples by pH.

Solid phase and aqueous chemical characterization of the waste-rock stockpiles

Analyses indicate that the whole rock composition and major mineralogy of WRS 1-4 are uniform. Total carbon and sulfur analyses indicate that WRS 1, 2 and 4 have similar, but variable C and S content (Table 1), and WRS 3 has a higher C content and a significantly lower S content. Acid-base accounting (ABA) conducted with these results indicates that approximately 60% of the waste rock samples collected from WRS 1, 2 and 4 are potentially acid generating (PAG) and have a neutralization potential (NP) to acid potential (AP) ratio (NP/AP = NPR) of < 1.5. WRS 3 is lower in sulfur compared to WRS 1, 2, and 4 and has fewer PAG samples. In these respects, most of the new waste rock at Detour is more like the rock in WRS 3.

Table 1. Carbon and sulfur analysis on samples from historic WRS 1, 2, 3 and 4 (range and average value).

	WRS 1	***WRS 2***	***WRS 3***	***WRS 4***
Carbon (wt %)	1.7-0.02 (0.5)	2.8-0.03 (0.63)	2.5-0.4 (1)	0.9-0.2 (0.6)
Sulfur (wt %)	4.3-0.01 (1.4)	3.9-0.03 (1.2)	0.5-0.05 (0.13)	1.96-0.03 (0.8)

In-situ monitoring of WRS 3 and 4 has provided several insights into the hydrological and chemical conditions of these stockpiles. Air permeability measurements of the cover (10^{-11} m^2) are 1-2 orders of magnitude lower than in the waste rock (~10^{-10} to 10^{-9} m^2). Diffusive gas transport dominates at air permeability values below 10^{-10} m^2 (Pantelis and Ritchie, 1992; Amos et al., 2015), thus the cover is restrictive to advective gas transport even during dry summer months, a key factor in reducing the rate of sulfide oxidation. Pore gas O_2 is sub-atmospheric at WRS 3, due to oxidation of sulfide minerals and the presence of the low permeability cover that restricts the replenishment of oxygen (Figure 3). Increased CO_2 levels in WRS 3 are associated with acid production and neutralization by carbonate minerals.

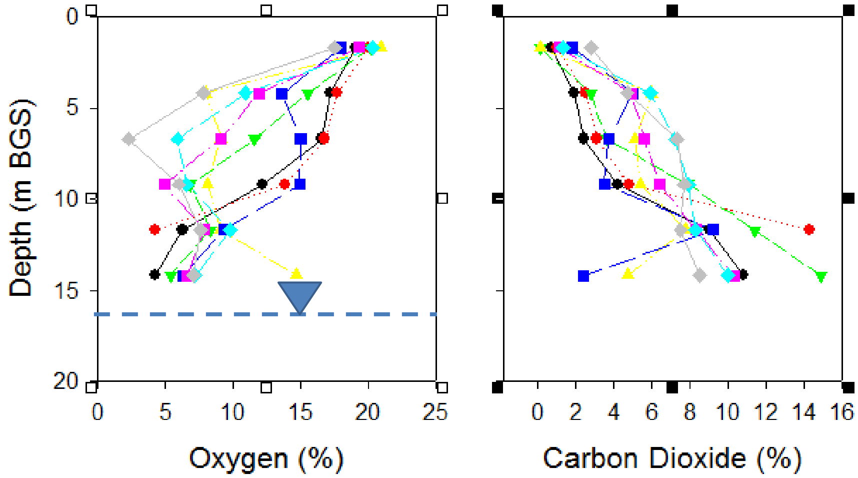

Figure 3. Pore gas O_2 and CO_2 concentrations versus depth in WRS 3 on different dates in 2012.

The pore water composition in the unsaturated zone of WRS 3 and WRS 4 also indicates that sulfide oxidation is ongoing in both stockpiles. Pore-water chemical conditions at WRS 3 and 4 (Table 2) are similar. Pore-water pH is near neutral (6-8) throughout both stockpiles. Elevated sulfate concentrations and depletion in total alkalinity indicate that sulfide oxidation is ongoing and acidity released is being neutralized internally. Metal and anion concentrations are generally higher at WRS 4 (higher PAG content) than at WRS 3. Dissolved metal concentrations are low at both piles indicating that metals released by sulfide oxidation are probably being attenuated within the stockpile. Natural attenuation of the metals and sulfate may also be occurring at the base of the waste rock piles, where infiltrating water passes through organic-carbon rich peat. Despite ongoing sulfide oxidation within the stockpiles, monitoring conducted by DLM indicates that the stockpiles are not currently releasing dissolved metals or acidic drainage to the environment.

Table 2. Selected water chemistry parameters for porewater in the unsaturated zone of WRS 3 and 4 (range and average values). Porewater chemistry for WRS 1 and 2 is not available.

	pH	Eh (mV)	Alkalinity (mg/L as $CaCO_3$)	SO_4 (mg/L)	Al (µg/L)	Fe (µg/L)	Mn (µg/L)	Ni (µg/L)	Cu (µg/L)	Zn (µg/L)
WRS 3	7.6-8.6	197-498	160-1550	670-42	1-102	3-121	7-1054	4-10	2-150	82-1163
		374	700	280	27	29	216	6	17	225
WRS 4	6.97-8.6	197-498	19-675	34-2401	1-34	2-3164	0-1785	0-146	0-80	2-329
		366	196	1136	10	129	127	20	9	58

Project outcomes

- The high NP values of the waste rock result in a long lag period (more than 30 years) before acidic conditions set in

- Careful management of the new waste rock is required to prevent future generation of low-quality drainage
    - The new NAG waste rock piles appear to be similar to WRS 3
    - The new PAG waste rock piles appear to be similar to WRS 1, 2 and 4
- New waste-rock stockpile construction techniques (larger equipment, more size segregation) are likely to lead to more extensive advective gas transport. Advective gas transport may be addressed through:
    - Disruption of gas transport on pile slopes
    - Use of low permeability covers to limit advective gas transport
    - Improved cover design to limit diffusive gas transport and downward migration of sulfide oxidation products

Summary

The findings from our investigations improve our understanding of the contributions of physical structure, cover integrity, construction method, mineralogy and geochemical characteristics toward ARD generation in the old waste-rock stockpiles, which had 17 years of operating history and 13 years of closure history with covers. It is anticipated the ARD-generating and -limiting mechanisms in the new stockpiles will be similar. This knowledge can be used by DLM to guide the design and management of the new waste-rock stockpiles to lessen the risks of ARD generation in both the short and long term. The research project is continuing with additional financial support from DLM and NSERC and technical support from the staff and graduate students from the Universities of Waterloo and Alberta, and Carleton University.

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