

PROVEN TECHNOLOGY – A BLISS OR CURSE FOR MINE RECLAMATION IN THE NORTH?

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Abstract

Proven technologies are often emphasized in mine reclamation activities in the North without due considerations given to complications derived from local conditions. This often leads to high project costs without achieving the desired results. With three examples, this paper aims to show that proven technologies that work well under southern conditions may not always be effective in cold climates. The examples examined include: 1) in-situ lime treatment at the Galkeno 300 adit in the Keno Hill mining district, Yukon Territory; 2) column leaching experiments to compare the relative rates of acid generation and alkalinity depletion at different temperatures; and, 3) metal attenuation in boreal wetlands. From a chemical stability viewpoint, walk-away solutions can only be developed if the important mechanisms and processes controlling metal leaching and aqueous metal transport in the northern environment are identified and utilized. A holistic approach is required to devise practical solutions for mining reclamation in the North.

Introduction

While mining and exploration have long been the mainstay of economic development in the Canadian northern territories, particularly in the past, such activities have also led to some costly environmental legacies. Through the Contaminated Sites Program, the Northern Affairs Program of the Department of Indian and Northern Affairs Canada spent approximately 37 million dollars Canadian in 2002-2003 maintaining, assessing, remediating and monitoring 43 priority sites, many of which are mining related (Indian

and Northern Affairs Canada (2003). Proven technologies are often relied upon to reclaim northern mine sites without duly considering complications given rise by the local conditions. This invariably leads to a high project cost without achieving the desired results. With examples, this short paper aims to show that proven technologies that work well under southern conditions may not always be effective in cold climates. A holistic approach is essential in devising cost-effective solutions for mining reclamation in the North.

Lime Treatment of Contaminated Drainage from the Galkeno 300 Adit

In-situ lime treatment of zinc-contaminated drainage emanated from the closed Galkeno mine in the Keno Hill mining district, Yukon Territory, furnishes a good example of how a long-tested technology does not work according to expectation under site conditions. The Keno Hill mining district is historically the second largest silver producer in Canada. More than 65 vein silver ore deposits and prospects have been identified in a belt about 8 km wide and 22 km long. Although mining has ceased since 1989, there remains active exploration in the area and public concerns regarding metal-rich discharges from some of the abandoned mine workings. In particular, drainages from the Galkeno 300 and 900 adits are characterized by high dissolved zinc concentrations (approximately 100 and 10 mg/L Zn, respectively). To protect the health of the downstream environment, the Abandoned Mines Project of the Yukon Territory Government (AMP-YTG) currently oversees the treatment of the adit discharges before they reach the South McQuesten River drainage system. Lime treatment has been used as the primary process for zinc removal. According to officials of AMP-YTG, the current lime treatment systems on site work but not efficiently or consistently (F. Patch, personal communication, June 2004). To help resolving the mystery, raw and treated water from the Galkeno 300 site as well as the treatment sludge have been analyzed. The results are briefly discussed below.

Table 1 shows the selected chemistry of water and sludge samples collected from the treatment pond system at the Galkeno 300 site. During the in-situ lime treatment, nearly all the dissolved iron and zinc as well as the majority of dissolved manganese (61%) but

relatively very little dissolved magnesium (19%) and sulfate (3.6%) were removed from solution. The pH of the adit water was raised by nearly 1.5 units through the lime treatment, which also gave rise to an added alkalinity of 80 mg/l as CaCO₃. Chemically, the treatment sludge was dominated by zinc, iron, sulfate and manganese with minor amounts of carbon (presumably as carbonate) and calcium. Assuming that the balance of the sample is largely made up of hydroxide, the hydroxide component in sludge solids can be as high as 32% by weight.

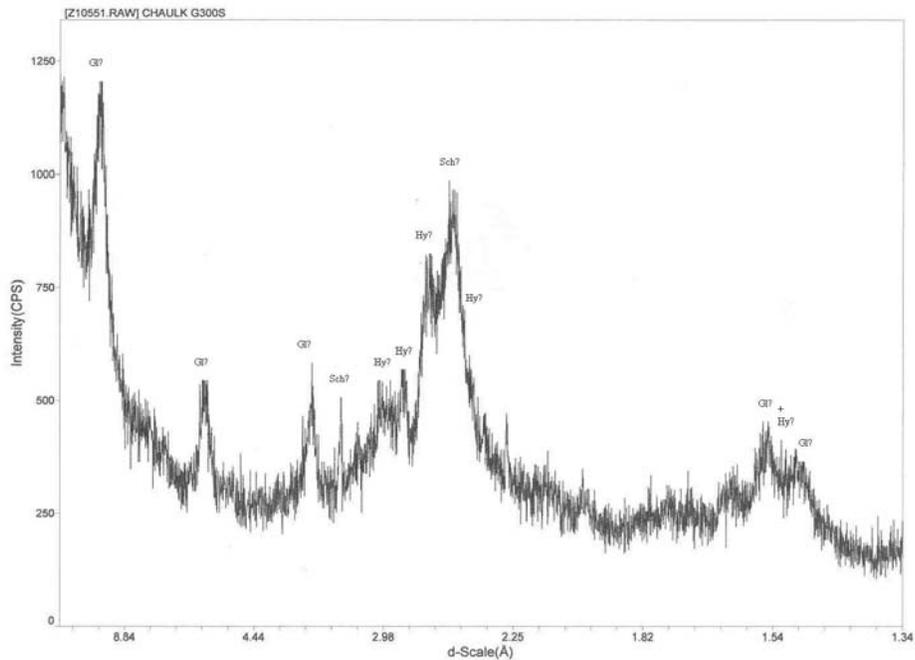
Table 1. Selected chemistry of raw and treated water as well as sludge collected from the treatment pond system at the Galkeno 300 Adit.

	Raw water A	Raw water B	Treated water	Sludge*
pH	6.17	6.26	7.60	8.07
Acidity	353 mg/l	342 mg/l	-	-
Alkalinity	-	-	80 mg/l	116 kg/t CaCO ₃ *
Ca	187 mg/l	187 mg/l	317 mg/l	1.48%
Fe	3.93 mg/l	3.81 mg/l	0.017 mg/l	17.0%
Mg	39.6 mg/l	40.1 mg/l	32.3 mg/l	0.236%
Mn	156 mg/l	157 mg/l	61.3 mg/l	4.19%
Zn	106 mg/l	102 mg/l	0.049 mg/l	30.2%
Sulfate	980 mg/l	966 mg/l	938 mg/l	8.39%
Total carbon	-	-	-	1.19%
Total solids	-	-	-	2.01%
Free lime	-	-	-	<0.1%

*With the exception of pH, the reported values pertain to the sludge solids, in which alkalinity corresponds to neutralization potential.

Figure 1 shows an X-ray diffraction pattern of the sludge solids. The high background and broad diffraction peaks indicate that the sludge solids are mainly made up of amorphous and poorly crystalline phases. Simple, crystalline metal hydroxides like those of iron and zinc are prominently absent. Instead, the diffuse reflection peaks can be

accounted for by complex metal hydroxyl sulfate or mixed metal oxide hydrate phases akin to glaucocerinite ($Zn_5(Fe, Al)_3(OH)_{16}(SO_4)_{1.5} \cdot 9H_2O$), hydrohetaerolite ($Zn_2Mn_4O_8 \cdot H_2O$) and schwertmannite ($Fe_8O_8(OH)_6SO_4$). This means that zinc hydroxide is not the dominant precipitate as expected from classical chemical reactions involved in the liming process. It appears that the formation of and coprecipitation with complex hydroxyl sulfates and oxide hydrates dominate the attenuation of zinc transport in the treatment pond at the Galkeno 300 adit. MacGregor and Li (2001) also reported that natural attenuation in organic and mineral soils simultaneously removed zinc and manganese from the adit drainage by factors of about 75 and 510, respectively, over a distance of approximately 1.7 km down-gradient of the Galkeno 300 adit. Under the situation, the introduction of an organic ligand or any means to enhance the precipitation of manganese oxides may be more effective than adding excess lime or optimizing solution pH for reducing the dissolved zinc concentrations in the adit discharges.



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Figure 1. X-ray diffraction pattern of treatment sludge from the Galkeno 300 adit (GI?= glaucocerinite-like mineral; Hy?= hydrohetaerolite-like phase; Sch?=schwertmannite?)

Safe Neutralizing Potential Ratio (NPR) for Preventing Net Acid Generation

The determination of a safe NPR for preventing net acid generation in mine wastes furnishes another example of conventional wisdom in the south not necessarily applicable in the North. NPR, the ratio of neutralization potential to the acid generation potential, is the preferred parameter for predicting the likelihood of net acid generation in the acid-base-accounting (ABA) scheme of static acid rock drainage assessment (MEND, 2000a). A conservative ratio of 4/1 is the recommended value for use in minesites in British Columbia (Price, 1997). In a guideline document prepared for the Department of Indian and Northern Affairs Canada, Steffen, Robertson and Kirsten (1992) concluded that there should be no difference in the methodology or interpretation of ABA for northern climates. However, the variation in the relative rates of sulfide oxidation and alkalinity depletion with temperature casts doubts on whether the same safe NPR derived from observations made in southern climates can be applied to the North. This is further discussed below with reference to some observations made in a column study designed to clarify the impact of temperature on acid generation and metal leaching.

To compare the weathering behaviour of mine wastes at different temperatures, humidity-cell-type column leaching experiments have been conducted with fresh waste rocks from a northern gold mine at two different temperatures. Figure 2 shows the cumulative sulfate production (indicative of sulfide oxidation) and alkalinity depletion with time. It is evident that with decreasing temperature the depletion of alkalinity occurs at a faster rate relative to sulfide oxidation. At room temperature (25°C), the cumulative alkalinity production is about twice as much as cumulative sulfate production. At 4°C, however, the two parameters differ by a factor of about four. With faster alkalinity depletion than sulfide oxidation, the exposed mine waste will be characterized by a decreasing NPR with time. Thus, contrary to what have been shown to be practical under warmer climates, mixing of rocks with different neutralization capacities to achieve a “safe” NPR of 4/1 does not necessarily prevent net acid generation in the long run in the North. At a minimum, the “safe” NPR should be set at a higher value than that applicable in southern

conditions. On the other hand, allowance must also be made for potential alkalinity generation through cryogenic precipitation of secondary carbonates, which is not uncommon in permafrost terrains (Vogt, 1991). For this to occur in a waste rock pile, however, a source of high-alkalinity water is required.

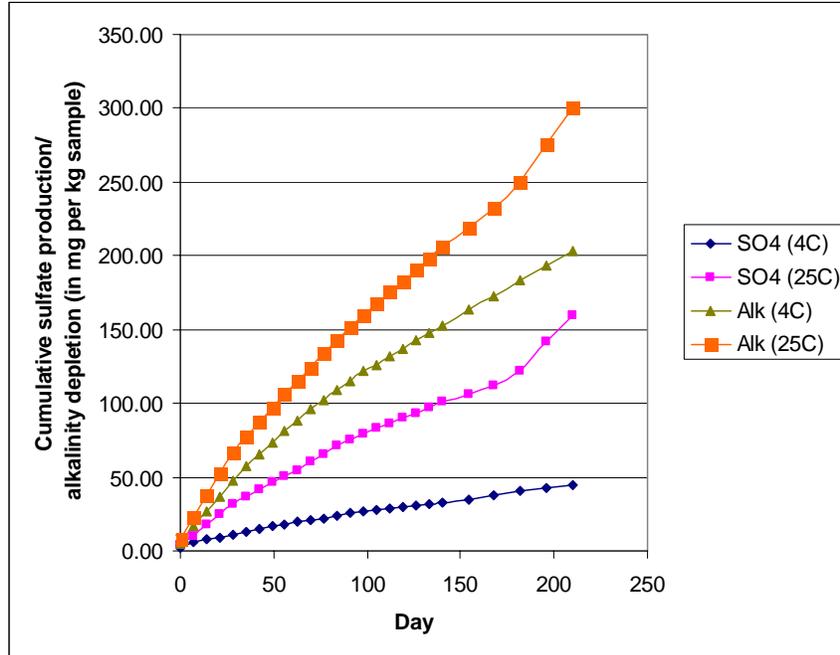


Figure 2. Cumulative sulfate production (indicative of sulfide oxidation) and alkalinity depletion at two temperatures (4°C and 25°C) in humidity-cell testing of fresh waste rock from a northern gold mine.

Wetland Treatment in Northern Latitudes

The functionality of wetland treatment in northern climates provides a good example of the need to consider local settings in devising effective remediation schemes. Although numerous examples of metal removal occurring in natural and constructed aerobic and anaerobic wetlands have been documented in southern Canada, Australia, Britain and the United States (MEND, 2000b), the effectiveness of passive wetland treatment in northern latitudes remains controversial. Price and Errington (1998), for example, cited the

unreliability of passive treatment systems to consistently meet compliance limits due to prevailing high metal concentrations, low temperatures in the winter and high metal loadings during the spring freshet. In boreal wetlands, different metal attenuation mechanisms and products have been identified depending on the environmental conditions at an individual site. A couple of examples are illustrated in Figures 3 and 4.



Figure 3. X-ray maps of (a) Zn, (b) S and (c) Si and a secondary electron micrograph (d) of a wetland sediment from central Yukon, illustrating the precipitation of zinc sulfide on diatoms.

Figure 3 shows the evidence of zinc-sulfide precipitation in a wetland downstream of a naturally acidic lake in central Yukon (Kwong and Lawrence, 1998). Figure 4 shows the formation of hydrozincite ($Zn_5(CO_3)_2(OH)_6$) in a resurgent stream down-gradient of the Onek adit in the Keno Hill mining district. In wetland areas near Macmillan Pass in east-central Yukon and along Engineer Creek beside the Dempster Highway in northern Yukon, Kwong and Whitley (1993) reported intensive trapping of iron oxyhydroxide with sphagnum moss, which in turn scavenged dissolved metals from the flowing water. It appears that the local pH, sulfate concentration and temperature in the drainage systems largely control the process and form of metal attenuation at the individual sites.

However, a common feature in all of these examples is the close association of the attenuation product with organic matter (diatoms, organic litter and sphagnum moss, respectively), which provides both convenient nucleation sites and the suitable chemical environment for mineral precipitation. This appears to be particularly important in northern environments where the ambient temperature is low. Nevertheless, without a detailed knowledge of the relative importance of sulfate reduction, sorption and desorption reactions occurring in a boreal wetland, it is generally fruitless to rely on natural attenuation to arrest aqueous metal transport.

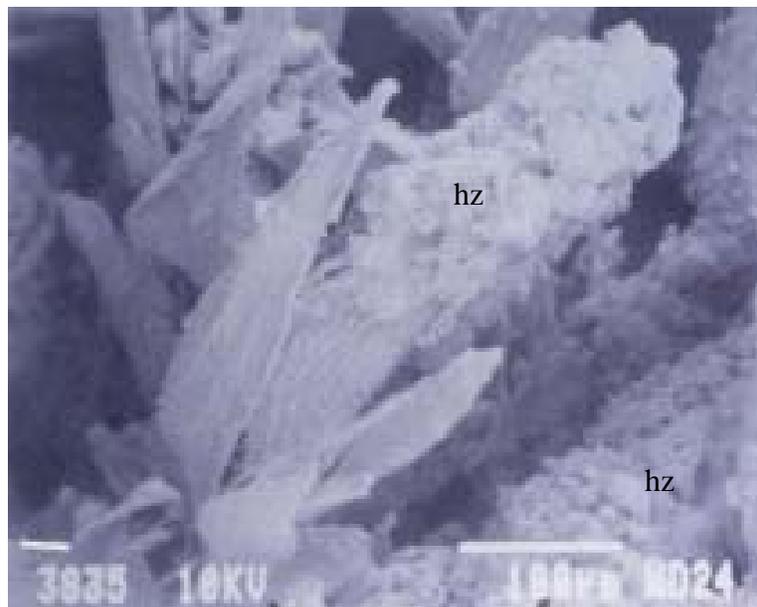


Figure 4. An electron micrograph of hydrozincite (hz) precipitated on organic litter along an abandoned streambed down-gradient of the Onek adit, Keno Hill mining district, Yukon.

Conclusion

It follows from the examples described above that proven technologies developed under southern conditions can only provide a starting point for devising suitable schemes for mine reclamation in the North. Total reliance on proven technologies without taking

local conditions into consideration can lead to ineffective and costly remediation endeavours in northern environments. From a chemical stability viewpoint, innovative solutions can be devised only if sufficient research is conducted to better understand the important mechanisms and processes controlling metal leaching and aqueous metal transport in the northern environment.

Acknowledgement

The authors would like to thank Bryan Tisch for reviewing this paper. Permission for its publication is granted by the Director of the CANMET Mining and Mineral Sciences Laboratories.

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