CHARACTERISTICS OF IMPOUNDED TAILINGS AT MOUNT NANSEN, YUKON TERRITORY – IMPLICATION FOR REMEDIATION

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ABSTRACT

The Mount Nansen gold property is located in southwestern Yukon, about 180 km north of Whitehorse. Less than two years of recent open-pit mining at the site has left approximately 250,000 tonnes of arsenic- and cyanide-bearing tailings impounded in a facility with questionable long-term physical stability. A recent characterization study has revealed the detailed physical and chemical properties of the impounded tailings and permafrost distribution in the impoundment. The current tailings system appears to be chemically stable with improving water qualities. Only the thiocyanate and ammonia levels in the ponded water and seepage may continue to be of concern in the medium term. However, there is a potential for remobilization of cyanide related or derived species and trace elements like arsenic, antimony and perhaps zinc if the tailings are disturbed. In the light of the newly acquired information, three options for final decommissioning of the tailings are examined. The options include retention in the existing but improved impoundment, relocation to the open pit and surface disposal as a cementitious paste. More detailed information, particularly on the hydrology and hydrogeology of the open pit area and the vicinity of the tailings impoundment, is required to devise an appropriate scheme for final closure of the site.

Key Words: Tailings characteristics, arsenic, cyanide, decommissioning alternatives, Mount Nansen, Yukon.

INTRODUCTION

The Mount Nansen property hosting epithermal gold mineralization is located approximately 60 km west of the Village of Carmacks and 180 km north of the City of Whitehorse in the Yukon Territory, Canada. BYG Natural Resources Inc. operated an open pit mine at the property between November 1997 and February 1999, using cyanidation for gold extraction. The operator went bankrupt in July 1999, leaving significant environmental liabilities, especially in terms of approximately 250,000 tonnes of cyanide- and arsenic-bearing tailings impounded in a management facility with doubtful physical stability. Since mine abandonment, the Water Resources Division of Indian and Northern Affairs Canada (INAC), Whitehorse, has assumed the task of site maintenance to reduce the risks and potential serious environmental impacts of tailings impoundment failure or uncontrolled discharge of potentially deleterious tailings water.

To facilitate developing proper strategies for final closure of the abandoned site, a detailed tailings characterization study has been completed at the CANMET Mining and Mineral Sciences Laboratories (Kwong et al., 2002). The detailed assessment work on the short- and long-term chemical stability of the impounded tailings has been presented and documented elsewhere (Kwong et al., 2003). This paper aims to highlight the relevant physical and chemical properties of the impounded tailings and discuss their implications for long-term safe placement of the tailings.

PHYSICAL CHARACTERISTICS OF THE MOUNT NANSEN TAILINGS

Tailings types and impoundment settings: Tailings generated from the recent mining operation at the Mount Nansen property are impounded in a tailings facility measured about 200 m by 200 m, which was constructed across a broad valley behind an earth dam keyed into the underlying permafrost. For systematic tailings sampling, 19 holes spread over the impoundment and varying from 2.4 to 9.7 m deep were drilled using a sonic device (Vibra-Corer). Based on their apparent contrasts in mineralogy, color and texture observed during field core logging, the impounded tailings are divided into four main types with their relative abundance by volume described as follows:

1. Oxide silt, 35.0%
2. Oxide clayey silt, 29.8%
3. Sulfide-rich silt, 16.5%
4. Sulfide-rich clayey silt, 18.7%

The coarser tailings (oxide and sulfidic silts) typically show a trimodal distribution with a mean particle size ranging from 30 to 119 μm and modes varying at 55-142, 6-7 and 0.4-0.5 μm, respectively. The finer tailings (oxide and sulfidic clayey silts) typically exhibit a bimodal distribution with a mean grain diameter ranging from 4.8 to 13 μm and modes varying at 4-8 μm and 0.3-0.4 μm, respectively. The sulfide-rich tailings are more widespread in the western half of the impoundment, where the most recent tailings were discharged. The finer tailings (silty clay) tend to be more concentrated in the middle portion of the impoundment where ponded conditions usually occur. In the tailings impoundment as a whole, the depth to permafrost appears to be shallower towards the north edge (3-4 m) rather than the south side (~ 7 m). However, the greatest depth to permafrost is apparently near the seepage return to the impoundment, where no frozen ground has been encountered at the drilled depth of 8.8 m. A typical north-south cross section of the impoundment is shown in Figure 1.

Amenability to form cementitious paste: Because of their fine grain size, most of the clayey tailings did not readily bleed water upon retrieval from the cores but exhibited a plastic behaviour. To investigate if they can be converted to a cementitious paste for surface disposal, samples of the oxide clayey tailings were mixed with 8% by weight of Portland cement (Type 10) and sufficient water and the mixtures were cast into paste cylinders for further physical and leach testing. Preliminary results showed that although the paste cylinders readily solidified within a week, it did not appear to develop any cohesive strength. Even after a curing period of seven weeks, subsamples of the paste cylinders became totally disintegrated upon gentle rolling overnight in distilled water during leach testing. Arsenic leaching from the paste material, however, was relatively insignificant compared to that observed in testing with raw tailings.

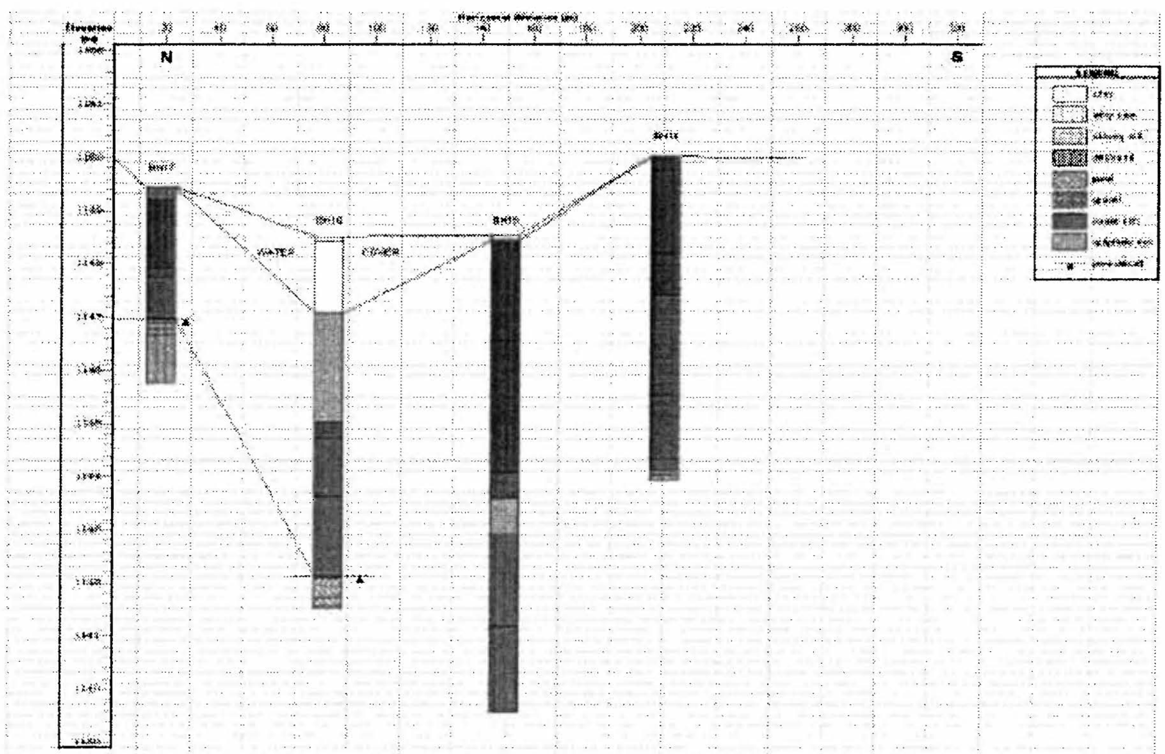


Figure 1. A north-south cross section of the tailings impoundment at Mount Nansen showing the distribution of tailings types and permafrost.

Chemical Characteristics of the Impounded Tailings

Geochemistry: The Mount Nansen tailings are heterogeneous in composition with anomalous contents of arsenic (up to 0.6%), copper (up to 0.06%), lead (up to 0.6%), antimony (up to 0.1%) and zinc (up to 0.3%). The total cyanide (Total CN) content ranges from 5 to 165 µg/g with most of the high values associated with the fine suflidic tails. Furthermore, the clayey tailings are more enriched in arsenic, manganese, lead, zinc and, to a lesser extent, in iron and potassium as well as slightly impoverished in total sulfur (Total S) than the silty varieties. The sulfidic tailings, on the other hand, are only marginally higher in Total S content than the oxide tailings regardless of grain size. The average concentrations of Total CN in the tailings solids and two CN species and selected dissolved metals in the porewaters of the four tailings types are depicted in Figure 2. The relatively high dissolved copper contents (averaging 3.6-6.5 mg/L) apparently correlate with the dissolved cyanide concentrations, indicating the occurrence of copper cyanide complexes in the tailings porewaters. The fact that little copper has been detected in the overlying water in the tailings pond suggests the natural disintegration of the complexes in an active oxidation environment, resulting in the precipitation or sorption of the released copper at the tailings surface.

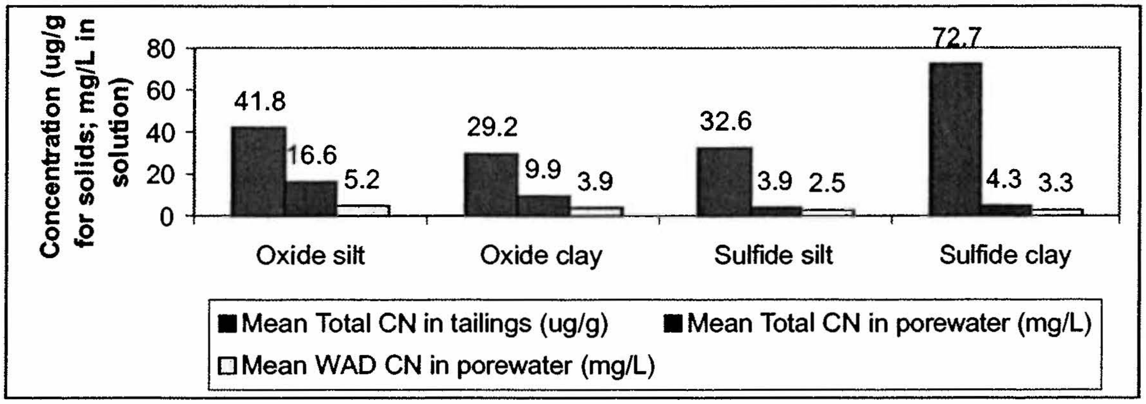
With regard to the potential for generation of acidic drainage, the impounded tailings can all be classified as moderately acid-generating with a net neutralization potential (NNP) ranging from -12 to -52 kg $CaCO_3$/tonne. The sulfide-sulfur content does not exceed 4 % by weight in any of the 40 samples analyzed. Apparently the oxide tailings, regardless of grain size, are relatively depleted in carbonates while the finer tails, especially the oxide clayey tailings, are relatively impoverished in sulfide-sulfur. The native sediments underlying the impoundment, with a NNP value up to 20 kg $CaCO_3$/tonne, appear to have some inherent acid buffering capacity.

Mineralogy: Mineralogically the tailings are also heterogeneous in their make-up. The coarser tailings generally contain more quartz and less sericite than the finer tailings. Alkali feldspar occurs in subordinate amounts, which tends to be more concentrated in the sulfidic tailings. The most abundant sulfide mineral observed in the tailings is pyrite, which amounts up to 5% by volume. Most of the minor arsenopyrite detected has been altered to scorodite. Because of the common encapsulation of sulfides in coarse quartz particles in all the tailings types, the sulfidic tailings show only marginally more sulfides than the oxide tailings. In addition to iron oxyhydroxide, jarosite occurs as a common secondary mineral in the tailings. Other minor to trace minerals identified include kaolinite, gypsum, calcite, ankerite, manganese oxide, albite, sphalerite, galena, chalcopyrite, covellite, argentite, bournonite, rutile, ilmenite, apatite, epidote, monazite, zircon and a couple of unknown sulfosalts.

Leachability: As detailed in Kwong et al. (2003), the impounded tailings at the Mount Nansen property appear to represent a relatively stable chemical system, the water quality of which is expected to improve with time. Column testing with the coarser tailings simulating four different tailings disposal scenarios has demonstrated a potential for mobilization of thiocyanate, ammonia and arsenic in the tailings porewater and overlying water at undesirable concentrations. Sequential batch leach testing of the clayey tailings using the procedure of Filipek (1999) has shown that arsenic and antimony are susceptible to be released. The results of a partial sequential extraction analysis of the four tailings types using a procedure modified after Hall et al. (1996) indicate that arsenic and zinc are the most readily released trace elements occurring in the tailings. However, as demonstrated by recent site monitoring results, only the thiocyanate and ammonia levels in the tailings pond water and porewater may remain a concern for the medium term if new technology cannot be developed to enhance their removal.

Decommissioning Alternatives

Upon reviewing the remnant economic potential of the Mount Nansen property and the outstanding environmental and reclamation issues, Strathcona Mineral Services Ltd. (2000) suggested two possible options for the long-term disposal of the impounded tailings. These are: (1) retention in the current impoundment with improvement made on the facility; and, (2) transfer and redeposition of the tailings in the nearby open pit. If the tailings can readily be converted to a stable cementitious paste, a third option that should perhaps be considered is surface disposal as a paste. These alternatives are discussed below in the light of the newly acquired information



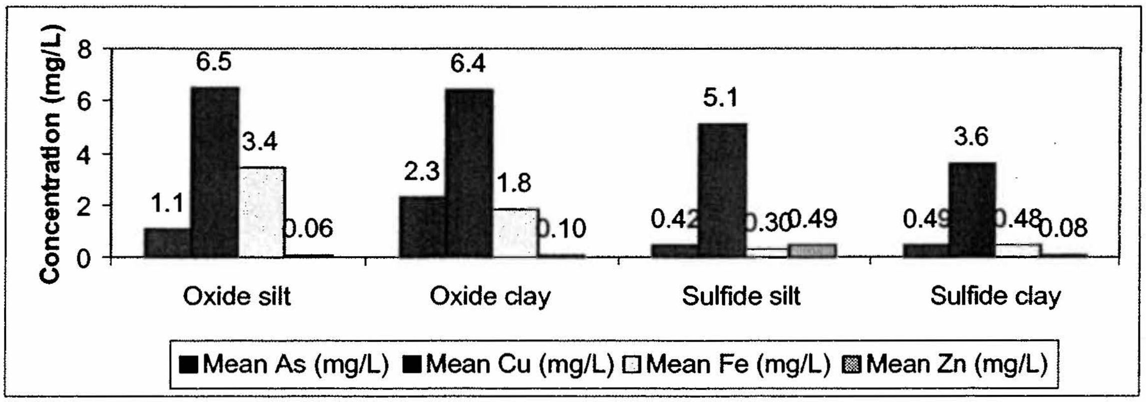


Figure 2. Average Total CN concentration in the tailings solids and selected porewater chemistry in the four types of tailings identified at Mount Nansen.

on the physical and chemical characteristics of the impounded tailings.

Retention in the current impoundment: The most recent tailings sampling campaign has shown that the impoundment is largely contained by permafrost except in the vicinity of portions of the tailings dam (Kwong et al., 2002). As such, the tailings impoundment is apparently isolated from the regional groundwater flow system. Contaminant transport from the impounded tailings is dominated by surface runoff, controlled discharge and limited local seepage. Although anomalous levels of ammonia and thiocyanate in the tailings pond water and seepage currently pose toxicity concerns, historic and on-going site monitoring data as well as the results of various recent laboratory testing suggest that the system is chemically stable and the water quality is improving (Kwong et al., 2002). For the two relatively mobile elements, arsenic and zinc, elevated concentrations of dissolved arsenic are restricted to the tailings porewater and there is no evidence of significant zinc leaching currently occurring in the impoundment. Given the relatively low acid generating potential of the impounded tailings, retaining them in the existing impoundment is a viable long-term solution from a chemical stability viewpoint. This is especially true if means can be devised to reduce ammonia and thiocyanate concentrations to acceptable levels in the tailings pond water and seepage.

The two primary concerns with respect to retaining the tailings in the existing impoundment are (i) the physical stability of the tailings containment dam and (ii) the rapid erosion of the diversion ditches (Water Resources Division, INAC, Whitehorse, personal communication, October, 2001). The tailings dam was designed as a compacted earth dam keyed into permafrost. Its physical integrity, according to the original design, required the initial emplacement of tailings to press a low-permeability geomembrane against the dam and no water resting directly against the dam structure for 50 m on the upstream side (Klohn Crippen Consultants Ltd., 1995). Both design criteria were apparently ignored when tailings were first placed in the impoundment. This has resulted in partial thawing of permafrost beneath the dam as is evidenced from recent coring and doubts if the dam can survive a relatively serious seismic event. Thus, unless innovative ways can be found to reinforce the tailings dam and to ameliorate erosion of the diversion ditches, the impoundment may not be safely maintained for perpetuity.

Transfer of the impounded tailings to the open pit: Although relocating the impounded tailings and redepositing them in the open pit will eliminate the concern of a potentially unsafe tailings dam, the process will expose the tailings to an entirely new environment. Both column studies with coarse tailings and batch leach tests with fine clayey tails have demonstrated potential mobilization of arsenic, antimony and some weakly sorbed cyanide-related species with disturbance of the tailings. While some free cyanide and weak acid dissociable cyanide may escape during tailings transport, additional loads of thiocyanate and ammonia are likely to be generated at the same time by continual oxidation of the contained cyanide. If the transport medium is eventually contaminated with excessive trace elements and potentially hazardous cyanide-related compounds and their derivatives, the medium has to be impounded and treated before discharge.

In the absence of detailed information on the local hydrology and hydrogeology of the open pit, the post-deposition environmental setting for the transferred tailings is largely unknown. If a relatively deep water cover eventually forms such that reducing conditions start to develop at the tailings/water interface, dissolution of the amorphous iron and manganese oxides and oxyhydroxides may occur, releasing the associated trace elements to the water column. If unsaturated conditions prevail, then oxidation of the remnant sulfides may occur, giving rise to acid generation and metal leaching. In contrast to the tailings impoundment, it is not known if the open pit is isolated from the regional groundwater flow system. If it is not and no measure is taken to prevent the interaction between the tailings porewater and groundwater, contamination of the latter with trace metals like arsenic and antimony as well as various cyanide-related species seems probable following the relocation of the impounded tailings.

Surface disposal as a cementitious paste: Although recent research has demonstrated that cementitious paste with designed cured strength can readily be prepared from cycloned tailings for underground backfill and surface disposal applications (Bloss, 1998; Landriault et al., 1997), paste making using fine tailings remains a challenge. Preliminary testing with clayey tailings from Mount Nansen has shown that while it is possible to cast them into any self-standing forms, the cementitious paste does not possess sufficient cohesive strength to withstand any significant agitation. Consequently, although converting the fine tailings into cementitious paste helps to suppress metal leaching, it is unlikely that the paste can survive mechanical weathering when placed in an unconfined environment. However, since the distribution of coarse and fine tailings in the impoundment has been fairly well delineated during the sampling campaign, the acquired information allows consideration of variations to the themes of maintaining the existing impoundment and in-pit disposal discussed above. For example, if it is technically feasible from an engineering perspective, the coarser tailings concentrated at the eastern and southern portions of the impoundment may be selectively excavated and made into cementitious material for disposal in the open pit or reinforcement of the upstream side of tailings containment dam. Alternatively, low-permeability cementitious paste can perhaps be prepared using the coarser tailings to line the open pit. Afterwards, the remainder of the tailings may be transferred there with or without cementitious amendments. In any case, a thorough understanding of the local hydrology and hydrogeology of the open pit area and the immediate vicinity of the tailings impoundment is required for further evaluation of various applicable options.

SUMMARY AND CONCLUSIONS

In recapitulation, less than two years of open-pit mining at the Mount Nansen has left the property with approximately 250,000 tonnes of arsenic- and cyanide-rich tailings impounded in a facility with questionable physical integrity. Although the existing tailings system appears to be chemically stable with improving water qualities, various chemical assessments have indicated potential mobilization of cyanide-related species, arsenic, antimony and perhaps also zinc if the tailings are disturbed. Options being considered for tailings management for final mine closure include retention in the existing impoundment with modifications, relocation to the open pit and surface disposal as a cementitious paste. Each option is beset with challenges. More detailed information, especially that on the local hydrology and hydrogeology of the pit area and the vicinity of the tailings impoundment, is required to devise an appropriate scheme for decommissioning the site.

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