APPENDIX C

Technical Memorandum 3

Technical Memorandum 3

To: Montana Department of Environmental Quality

From: Environmental Resources Management

Date: December 21, 2017

Subject: Black Butte Copper Project - Full Sulfide Separation Prior to Tailings Disposal

BACKGROUND

Tintina Resources, Inc. is the owner of the Black Butte Copper Project (the Project), a proposed underground copper mine located approximately 15 miles north of White Sulfur Springs in Meagher County, Montana. The project is currently in the permitting phase and a Mine Operating Permit Application was submitted to the Montana DEQ's Hard Rock Bureau in July 14, 2017 (Tintina Montana, Inc. 2017). A number of tailings management alternatives were evaluated by a large working group of scientists and engineers to decide on the best approach (Geomin Resources 2016). Further assessment of the depyritized tailings approach is specifically warranted.

Montana DEQ has requested that Environmental Resources Management (ERM) assess the feasibility of using the flotation/separation process to remove all sulfide minerals from the tailings prior to disposal. Both raw and cemented paste tailings were assessed under subaqueous and subaerial weathering conditions in laboratory tests as part of a baseline geochemical evaluation for the Project. Static and kinetic testing indicated the potential for acid generation in both the raw and the cemented paste tailings. Kinetic testing indicated elevated sulfate and metals concentrations in leachate, including exceedances of groundwater standards for arsenic (As), nickel (Ni), and thallium (Tl).

Sulfide-S composition was 17.7 to 29.9 percent in raw tailings and 21.6 to 21.9 percent in paste tailings. Pyrite was a primary mineral constituent in tailings. Stripping out sufficient pyrite to render the rest of the tailings mass non-acid-generating would be technically challenging and yield large volumes of pyrite concentrate. Stripping out sulfide minerals creates a more hazardous waste than tailings; while being smaller than the original tailings, the volume of the depyritized tailings is substantive and poses a challenge for disposal and long-term storage. In addition, the use of acid is required for depyritizing of tailings, which comes with associated costs (Benzaazoua and Kongolo 2003; Bois et al. 2004).

CURRENT MOP

Feasible alternatives for tailings management and storage were evaluated (Appendix Q to the MOP; Geomin Resources 2016). Cemented paste tailings using 0.5 to 2 percent cement was selected as the preferred management method in an impoundment (cemented tailings facility [CTF]) located just south of the mill site. The current MOP does not propose to remove non-ore sulfide materials from the tailings prior to disposal.

In the Tailings Management Alternatives Evaluation (Appendix Q to the MOP), two alternatives involving depyritized tailings were considered:

1. Depyritized ultra-thickened subaqueous tailings deposition; and
2. Two-cell ultra-thickened depyritized tailings and pyrite concentrate.

These two alternatives received the lowest score in the Tailings Management Method Alternatives Working Group Rankings.

Key challenges associated with depyritization included the following:

- The need to adjust the pH of the process downward for pyrite flotation, followed by further pH adjustment for copper flotation, increasing lime consumption and issues in the pyrite circuit operation.
- Higher chemical consumption, which also increases:
  - Cost and complexity of flotation;
  - Tracking materials held onsite;
  - Transportation logistics; and
  - Potential for spills/leaks/errors in handling.
- The requirement for an additional circuit in the mill.
- The need for additional mining to provide sufficient space for underground disposal of the pyrite concentrate. More waste rock would result from this additional mining.

EIS ENVIRONMENTAL ISSUES

IMPACT OF NOT REMOVING SULFIDE MINERALS FROM TAILINGS PRIOR TO DISPOSAL

Potential for Acid Generation

Tailings that have not been stripped of their sulfide minerals have a higher acid potential (AP) compared to depyritized tailings. As a result, the requirement for capture and treatment of tailings seepage becomes necessary at the surface. Underground backfill has a lower potential to impact groundwater if it is adequately sealed and less permeable to groundwater flow as saturated conditions develop.

Higher Source of Acid Potential

Sulfide minerals typically represent the largest source of acid generated at mine sites. The oxidation of sulfide minerals in the presence of water is responsible for the generation of sulfuric acid. A simplified reaction for the oxidation of pyrite is as follows:

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 16H^+ + 8SO_4^{2-}$$

Where: Fe = iron; S = sulfur; O = oxygen; H = hydrogen

It is assumed that two moles of acid will be produced for each mole of sulfur. The AP is calculated by multiplying the percent of total sulfur or sulfide sulfur in a sample by a conversion factor (AP = 31.25 * %S). Units for AP are kilograms (kg) $CaCO_3$ /t (EPA 1994; INAP 2009; Price 2009; Sobek et al. 1978), where Ca = calcium and C = carbon.

AP in rock or tailings samples are potentially offset by minerals providing neutralization potential (NP). Units for NP are kg $CaCO_3$ /t. The acid rock drainage (ARD) potential of a sample is determined by acid-base accounting (ABA), where NP/AP less than or equal to 1 is considered potentially acid generating (PAG), NP/AP greater than 1 and less than or equal to 2 has an uncertain acid-generating potential, and NP/AP greater than 2 is not PAG (nPAG) (INAP 2009; Price 2009). The ratio of NP/AP is often referred to as the net potential ratio. Clearly, not removing pyrite from a sample renders it with a higher AP compared to a sample that has been depyritized.

Environmental Management

Management practices considered at the Project if pyrite was not removed from the tailings are described in Appendix Q of the MOP and include:

1. Conventional tailings slurry deposition;
2. Dry stack tailings;
3. Paste tailings with underground paste cement content (approximately 4 percent); and
4. Paste tailings with underground reduced paste cement content (approximately 2 percent).

The pros and cons of each option are summarized in Appendix A of this memo and represent the results of the tailings management alternatives evaluation (Geomin Resources 2016).

The preferred management option selected by the working group was the cemented paste tailings using 0.5 to 2 percent cement in an impoundment (CTF). This method was preferred since the potential environmental impacts would be minimized (e.g., facility stability, environmental risk, and impacts to wetlands). The paste tailings method using reduced 0.5 to 2 percent cement was recognized to have the lowest impact to nearby designated wetlands in terms of total disturbed area. The impact to the wetlands is described in Appendix K of the MOP application. Furthermore, the CTF location alternative is associated with the smallest catchment area footprint. Despite the markedly higher total cost of paste tailings disposal relative to other evaluated methods, the cemented tailings paste and CTF site location were selected as the preferred alternatives.

IMPACT OF DEPYRITIZATION PROCESS AND DISPOSAL OF SULFIDIC BYPRODUCT

The removal of the sulfide minerals from a PAG tailings sample yields two products: (1) refined nPAG tailings, and (2) PAG tailings with much higher sulfide content compared to the original tailings sample. The amount of sulfidic byproduct is less than the total amount of the original tailings material; therefore, the required capacity for disposal is lower (Bois et al. 2004). An added benefit of removing sulfide minerals from tailings is that the depyritized tailings product is nPAG and fine grained with a high surface area to volume ratio. This makes for useful cover material overtop of PAG waste rock/tailings because the depyritized tailings do not generate acid, and will limit the ingress of water and oxygen to the material underneath; this is particularly true if applied as a cover with capillary barrier effects (CCBE) (Bussiere and Aubertin 1999).

Environmental Management

Management practices considered at the Project if pyrite was removed from the tailings are described in Appendix Q of the MOP and include:

1. De-pyritized and ultra-thickened subaqueous tailings deposition; and
2. Two-cell ultra-thickened depyritized tailings and pyrite concentrate.

The pros and cons of each option including those not removing pyrite from the tailings are summarized in Appendix A of this memo and represent the results of the tailings management alternatives evaluation (Geomin Resources 2016). Despite there being some clear environmental advantages to removing pyrite from tailings, these two tailings management options were ranked lowest by the working group in the alternatives evaluation. The associated costs of pyrite removal with current technology and additional costs related to handling and disposal for long-term storage weighed in heavily on the working group’s rankings, although practical limitations were also considered.

TECHNICAL APPROACH

DE-PYRITIZED TAILINGS

The technical approach under investigation is the use of a flotation/separation process to remove all sulfide minerals from the tailings prior to disposal. While the de-pyritized tailings represent a relatively benign waste product from an ARD perspective, the concentrated pyrite product has a much higher potential for acid generation compared to the original tailings material. Therefore, disposal options have to be considered for this technical approach.

Case Histories

Several cases exist where sulfide removal was applied as a tailings management practice. Six are listed below and are summarized briefly in the following subsections for context:

- Strathcona Mine, Ontario, Canada
- Musselwhite Mine, Ontario, Canada
- Detour Lake Mine, Ontario, Canada
- Kemess Mine, British Columbia, Canada
- KSM, British Columbia, Canada
- Thompson Creek Mine, Idaho, USA
- Aitik Copper Mine, Sweden

Strathcona Mine, Ontario, Canada

Low-sulfur (less than 1 percent) scavenger tailings combined with lime kiln dust or reject material from lime production were used to cover the high-sulfur (30 percent) tailings at the Strathcona tailings facility near Sudbury, Ontario. The low-sulfur tailings cover was produced as the cyclone overflow from the scavenger flotation units that generate a sandy material for mine backfill. The overflow contains a fine-grained fraction and therefore has the value-added property of moisture retention capacity and reduction of oxygen ingress. The minimum thickness of the cover is 1.5 meters, which is considered sufficient for moisture retention in the lower zone of the cover layer. The area of high-sulfur tailings exposed to the atmosphere, and therefore oxidation, was reduced by at least 50 percent since the cover was applied.

Musselwhite Mine, Ontario, Canada

A pilot study was carried out to assess the suitability of froth flotation for desulfurization of reactive mine tailings at the Musselwhite Mine in Northern Ontario to prevent acid mine drainage (AMD). The effects of operating conditions such as froth depth, air flow rate, impeller speed, and pulp density on desulfurization of Musselwhite tailings were investigated. Results indicated that all of these parameters have effects on the flotation kinetics, recovery of sulfur, and concentrate grade. The most important operating parameters were identified as the air flow rate and froth depth. Environmental desulfurization was demonstrated to be technically feasible for Musselwhite tailings. Based on the data presented for the Musselwhite tailings, the maximum recovery of total sulfur was achieved when the operational parameters were set to the froth depth of 5 centimeters, air flow rate 125 liters per minute, impeller speed 1300 revolutions per minute, and pulp density 35 percent. Under these conditions, the froth flotation produced a satisfactory NP/AP ratio within 12 minutes.

Detour Lake Mine, Ontario, Canada

A single-layer desulfurized tailings cover 1 to 1.5 meters thick was installed over the Detour Lake mine tailings facility. The material was unlikely to produce acidity, and retained oxygen consumption potential. However, the cover materials were coarser grained than originally designed and were confirmed to desaturate in some locations. The cover material was intended to compose of finer material than the tailings, which would create a capillary barrier, high saturation, and low oxygen diffusion. Regardless, near-neutral pH conditions were recorded at the Detour Lake facility.

Kemess Mine, British Columbia, Canada

The Kemess gold mine in north-central British Columbia contains one of the largest earth filled dam structures for tailings storage. In order to meet engineering and regulatory requirements the original construction design called for a 1-kilometer-wide rock dam made with 30 million tons (MT) of non-acid generating waste rock. Instead, the dam was built from suitable quality tailings sand as a cost saving measure. The tailings sand was subjected to cycloning and flotation to reduce pyrite concentration and meet the neutralizing potential ratio specifications for dam construction. Grain size of the sand had to be consistent with less than 15 percent passing through 200 mesh sieve (75 micrometers). In addition to environmental benefits, the economic benefits of using cycloned sands for dam construction include lower dam height and reduced construction costs.

KSM, British Columbia, Canada

Depyritization of tailings is planned for the KSM project in British Columbia with Seabridge having already received permits (September 2014) authorizing early-stage construction activities at the Mine Site and Tailings Management Facility (TMF). The Treaty Process Plant will produce two tailing streams: the bulk rougher flotation tailing representing approximately 90 percent of the ore and a fine, sulfide-rich cleaner tailing comprising the remaining 10 percent. The sulfide stream will be cyanide leached using the carbon in leach (CIL) method followed by processing for gold recovery. A two-stage cyanide destruction circuit is proposed, using the Inco sulfur dioxide process followed by hydrogen peroxide treatment.

Cyclone sand produced from the KSM tailing was deemed suitable for construction material in the TMF. The flotation tailing is classified as nPAG and will be cycloned to produce sand fill for construction of the tailing dams during the summer months. The CIL residue tailing is classified as PAG. This material will be deposited under water in the CIL Residue Storage Cell in the center of the TMF and kept saturated to mitigate the onset of acid generation.

Thompson Creek Mine, Idaho, USA

Desulfurized tailings were produced at the Thompson Creek mine in Idaho for use as covers and in reclamation. ARD from these facilities is not an issue since the sulfide mineral content was removed and the pyrite concentrate was disposed in an offsite location.

Aitik Copper Mine, Sweden

The use of desulfurized tailings as a cover material was investigated at the Aitik Copper mine in Sweden. After desulfurization, the pyrite-depleted tailings can be used to cover water saturated tailings with higher pyrite content, and the pyrite enriched tailings have to be disposed of separately under an engineered dry cover or water cover. The thickness of the depyritized tailings cover is predicted to be 15 to 20 meters. Flotation pilot test results indicate that there is difficulty achieving the target limit less than 0.3 percent sulfides, if only flotation is used in depyritization. The problem is associated with the concurrent presence of both magnetite and pyrrhotite in the tailings, in addition to pyrite. A combination of flotation and magnetic separation has been suggested as a solution.

Environmental Impact

There is a potential for a reduced environmental impact by removing pyrite from tailings (i.e., depyritization) as a method to control AMD. In depyritization, the acid forming sulfide mineral fraction (i.e., pyrite) is either partly of fully separated from the tailings by froth flotation prior to final deposition into the tailings storage facility (Bois et al. 2004).

In complete desulfurization, all tailings are desulfurized by froth flotation. As a result of the separation, an acid generating high sulfur fraction with a reduced volume and a high volume of nPAG low sulfur fraction are formed. Low sulfur nPAG tailings do not represent a long-term liability, which is the most important advantage of the method (Bois et al. 2004).

Partial desulfurization represents the tailings fraction that is desulfurized only during a few years period prior to mine closure. nPAG tailings can be used as an inert dry cover material over top of acid generating tailings. The layer of 1 to 2 meters of desulfurized material acts as an elevated water table and keeps sulfide rich tailings saturated. The saturation of tailings is accompanied by the formation of an oxygen barrier, thus limiting oxygen diffusion to the underlying PAG tailings (Bois et al. 2004).

Storage or Disposal Options

Separation of sulfide minerals generates a small volume of sulfide-rich concentrate and a large stream of tailings with low sulfur content. The two streams can be handled differently. The low sulfur content tailings are relatively non-reactive and do not require as comprehensive decommissioning measures and can be deposited in large-volume repositories, or alternatively used for construction purposes (e.g., cover material, dams, roads, etc.). The sulfide-rich concentrate could be stored underwater in a tailings pond covered with depyritized tailings in a surface facility, or stored underground as paste backfill (Benzaazoua and Kongolo 2003; Sjoberg Dobchuck et al. 2003; Bois et al. 2004; INAP 2009). The most commonly used additive for paste backfill is a pozzolanic binder (e.g., cement, slag, fly ash). These provide significant strength underground at addition levels of 3 to 6 percent by weight. Cement addition also serves to increase the NP, raise the pH, and potentially immobilize metals by mineral precipitation. Other additives include specialty chemicals, resins, and surfactants that can enhance metal adsorption, as well as organic carbon and bacteria to aid biofixation (Newman et al. 2001). The pyrite concentrate would require more cement to raise NP compared to the currently proposed tailings disposal alternative. However, the risk of oxidation is typically limited to a thin upper layer.

Costs

The use of depyritization can reduce reclamation costs at a mine site due to the reduced transportation and material costs. Low sulfur tailings can potentially be used as cover material, which reduces transportation costs if the cover material has to be sourced from offsite. The costs of separating the sulfide minerals from the tailings can be high. The viability of the method depends on the amount of sulfide minerals that have to be removed because negative cost impacts are generated if the sulfide content is too high.

Site-specific conditions and scale of waste also influence how tailings are managed. Partial depyritization can generate cost savings if the tailings pond is located in a flat topography site with a soft base, as the costs for dam construction in these cases are typically high. The operational costs for partial depyritization are lower because only a fraction of the tailings is treated. Complete depyritization of tailings is economically viable if the construction of low permeability tailings dams becomes expensive (Bois et al. 2004).

CONCLUSIONS AND RECOMMENDATIONS

In spite of the environmental advantages associated with depyritized tailings, depyritization was not selected as the best tailings management strategy for the Project. Depyritization of tailings generates a larger volume of nPAG tailings and smaller fraction of PAG concentrated sulfides; however, the management costs of the PAG concentrated sulfides remain too high to be considered feasible compared to other alternatives. These alternatives also pose a number of technical challenges that includes the requirement for large amounts of acid in the processing (which increases lime consumption and potentially poses issues to the pyrite circuit operation due to scaling), and the need for an additional circuit in the mill, which presents a risk to copper recovery. It was also suggested that additional mining of host rock would be necessary to provide sufficient storage space for the underground pyrite disposal. Ultimately, the technical challenges and costs associated with these alternatives resulted in the working group’s low ranking in the tailings management alternatives evaluation.

The preferred management option selected by the working group was the cemented paste tailings using 0.5 to 2 percent cement in an impoundment – a CTF located just south of the mill site. Approximately 45 percent of the total tailings or 5.8 MT would be returned back underground as paste backfill in the mine workings. The claim for selecting this option was that the potential environmental impacts would be minimized. Compared to the depyritized tailings alternatives, there would be less impact to wetlands in terms of total disturbed area. The impact to wetlands is described in Appendix K of the MOP application. The potential for oxidation on the surface of the impoundment materials during the time a deposit lift is laid down prior to depositing the next layer was identified as a risk. However, the group dismissed this concern using the rationale that acidification would be decelerated by the cement to the point of preventing acidic conditions from developing before the next lift is deposited.

It is recommended that more consideration be given to technical feasibility and the pros/cons of the various tailings management alternatives rather than cost feasibility. Based on the material presented in the MOP, it is not clear how much more underground volume would be needed to dispose of the concentrated pyrite fraction if the tailings were subject to pyrite removal. The requirement for a tailings disposal facility at the surface was not eliminated in any of the alternatives presented. The nPAG tailings fraction would provide a useful source of cover material for any of the surface facility designs considered for storage of PAG tailings. There appears to be an increasing number of success stories for the application of desulfurized/depyritized tailings material as a clean cover component of a CCBE.

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Technical Memorandum 3: Appendix A

Table 1. Method Alternative Matrix

Method Alternative	**Pros**	**Cons**
1 Whole Tailings Slurry Deposition (subaqueous disposal)	Proven method for controlling acid rock drainage (ARD)	Requires pond management
	Flexible to take paste when it is not needed	Does not provide for pyrite recovery
	Water storage capacity	Tailings could acidify if they dry
	Lower cost	Largest embankment
	Simplicity	Long-term monitoring
2 Dry Stack Tailings	Can be located on slopes/uplands away from wetlands	Air quality issues
	Reduced site footprint	Higher capital costs
	Reduced water treatment costs	Higher operating costs
	Provides for segmented closure/reclamation	Complex operating plan
	No additional access roads required	Requires 4 full-time equivalents
		Requires Process Water Pond (PWP)
		Requires storage of contaminated process water
3 De-pyritized and ultra-thickened subaqueous tailings	Placing pyrite back underground	Storing waste rock for closure
	Established tailings management methods for safety purposes and environmental risk	Cost of pyrite removal
		Uses more functional wetlands
		Requires road relocation
		Potential for tailings seepage

Method Alternative	**Pros**	**Cons**
4 Thickened de-pyritized tailings and pyrite concentrate in two cells	No large pond required	Complicated process
	Requires less make-up water	Depends on pyrite flotation and removal at closure
	Removes ARD potential following closure	Requires storage of contaminated process water
	Pyrite separation	Run-off management
5 Paste Tailings - Cement content 4% same as underground paste	Non-flowing tailings	Requires road relocation
	Reduced embankment construction costs	Higher construction costs
	Reduced dust potential	Higher operating costs
	Reduced water loss to evaporation	Higher process and storm water costs
	Limits short-term ARD potential	
	Facilitates placement of closure cover	
6 Paste Tailings - Reduced cement content (2%)	Non-flowing tailings	Requires road relocation
	Reduced embankment construction costs	Higher construction costs
	Reduced dust potential	Higher operating costs
	Reduced water loss to evaporation	Higher process and storm water costs
	Limits short-term ARD potential	
	Facilitates placement of closure cover	

Source: Geomin Resources 2016