TECHNICAL MEMORANDUM

DATE	February 8, 2012	**PROJECT No.**	09-1373-1004
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CO-DISPOSAL PRACTICES IN MINE WASTE MANAGEMENT

1.0 INTRODUCTION

1.1 Co-disposal Terminology

In mine waste management, "co-disposal" refers to the disposal of tailings and mine rock streams in one integrated disposal facility. There are various forms of co-disposal, depending on the degree of mixing of the waste streams. Co-disposal can be generally divided into three forms:

- Co-placement
- Co-deposition
- Co-mingling

The use of these terms is somewhat inconsistent in the literature; however for the purpose of this report, the terms will be used as described below:

In **co-placement**, the waste streams are placed in an integrated disposal facility with very little mixing. This is the most common type of co-disposal. Typical examples of co-placement are: tailings facility contained by mine rock containment dams, the inclusion of a tailings cell within a mine rock dump, or the inclusion of mine rock in a tailings disposal facility.

In **co-deposition**, the waste streams are deposited together so that some degree of mixing takes place by virtue of the deposition process. This type of co-disposal has been used in few mine sites. Typical examples of co-deposition are: layered co-deposition of tailings and mine rock, discharge of tailings on active mine rock dump face, co-deposition of tailings and crushed mine rock using a conveyor belt, or co-placement of tailings and mine rock in voids (such as an open pit). The NICO project is proposing to use a layered co-deposition.

In **co-mingling**, the waste streams are actively mixed with the intention of filling the void space of the mine rock with tailings (fully or partially). Mechanical equipment is generally required to facilitate the mixing process. Methods of co-mingling include using a mixing plant (e.g., a concrete mixer) to blend paste tailings and crushed rock, using conventional loaders and bulldozers to actively mix thickened tailings and mine rock in a disposal cell, or pumping of mixed fine waste stream. There are few mines that have adopted co-mingling.

1.2 Selection of Type of Co-disposal

The selection of a particular type of co-disposal may be influenced by a number of factors, including:

- Tailings characteristics (geochemistry, density, viscosity, grain size distribution, mineralogy, etc);
- Mine rock characteristics (geochemistry, degree of weathering, grain size distribution, mineralogy, etc);
- Maximum rock size (coarse rock cannot be pumped);
- The mass ratio of mine rock to tailings;
- Site topography;
- Ease of construction and operation;
- Climatic condition (cold climate, extreme dry and wet, etc);
- Life cycle costs of the co-disposal facility; and
- Risk minimization potential (wind and water erosion, slope stability, liquefaction, closure, etc).

1.3 Benefits of Co-disposal

Co-disposal has the following benefits:

- The inclusion of tailings reduces oxygen flux and infiltration through mine rock (i.e., to control acid mine drainage and metal leaching)
- The inclusion of mine rock improves the stability (static and dynamic) of a tailings disposal facility
- Co-disposal generally reduces the footprint area requirement for the disposal of the two waste streams
- Having a single facility simplifies water management, monitoring and closure
- Layers of rock accelerate tailings consolidation and facilitate earlier closure
- Inclusion of rock reduces the erodability of tailings (by water and wind)
- Co-disposal generally reduces closure cost by reducing the footprint area

In general, co-disposal is advantageous when the mine rock is potentially acid generating (PAG) and/or susceptible to leaching metals at problematic levels. In such an instance, the introduction of tailings, (whether it is co-mingled with the rock or deposited in discrete layers) can reduce the access of oxygen to the rock, thus reducing the rate of acid generation. By contrast, layered co-deposition is not well suited to the opposite situation, where the tailings are PAG and the mine rock is innocuous. In that case the layers of mine rock may actually increase the access of oxygen to the tailings and thus augment the acid generation.

2.0 NICO CO-DISPOSAL FACILITY

2.1 Background

The proposed NICO Project is located at an altitude of 63°33'N and a longitude of 116°45'W in the Northwest Territories, approximately 160 km northwest of Yellowknife. The annual average precipitation, lake evaporation, and temperature are 344 mm, 479 mm, and -4.7 °C, respectively. The average freezing index in the region varies between 3,500 to 4,000 °C.

The mine has 31 Mt of proven reserve, of which 2.2 Mt will be accessed via underground and the remainder 28.9 Mt will be accessed via an Open Pit. The mine will generate 29.9 Mt of tailings. The tailings contain are classified as SILT with approximately 85% passing #200 sieve (75µm). The average specific gravity of the tailings is 3.32. The tailings have potential for metal leaching and have low potential for acid generating. Prior to deposition the tailings will be dewatered to 73-77% solids to produce non-segregated thickened tailings. The thickened tailings will be pumped to the disposal facility using a positive displacement pump.

The mine will generate a total of 96.9 Mt of mine rock, of which 6.5 Mt is classified as sub-economic mineralized rock that may become economic if parameters used in the reserve estimate change. All of the mine rocks have metal leaching potential. Approximately 45% of the sub-economic mineralized rock and 10% of the reminder of mine rock have acid generating potential.

2.2 Concept of NICO Co-disposal Facility

The thickened tailings and the mine rock will be co-disposed in a facility situated in close proximity to the Open Pit and the Process Plant. The general arrangement plan of the Co-Disposal Facility (CDF) and associated water management facilities is shown in Figure 1.

The co-disposal of the thickened tailings and mine rock was the preferred mine waste management system for the NICO Project for the following reasons:

- Reduces the footprint area requirement and hence reducing environmental impact and closure cost;
- Increases the rate of consolidation of the tailings;
- Improves the stability of the disposal facility;
- Reduces metal leaching and acid mine drainage from mine rock;
- Minimizes freeze drying of tailings and dusting;
- Reduces the mine hauling distance and tailings pumping length; and
- Facilitates progressive closure.

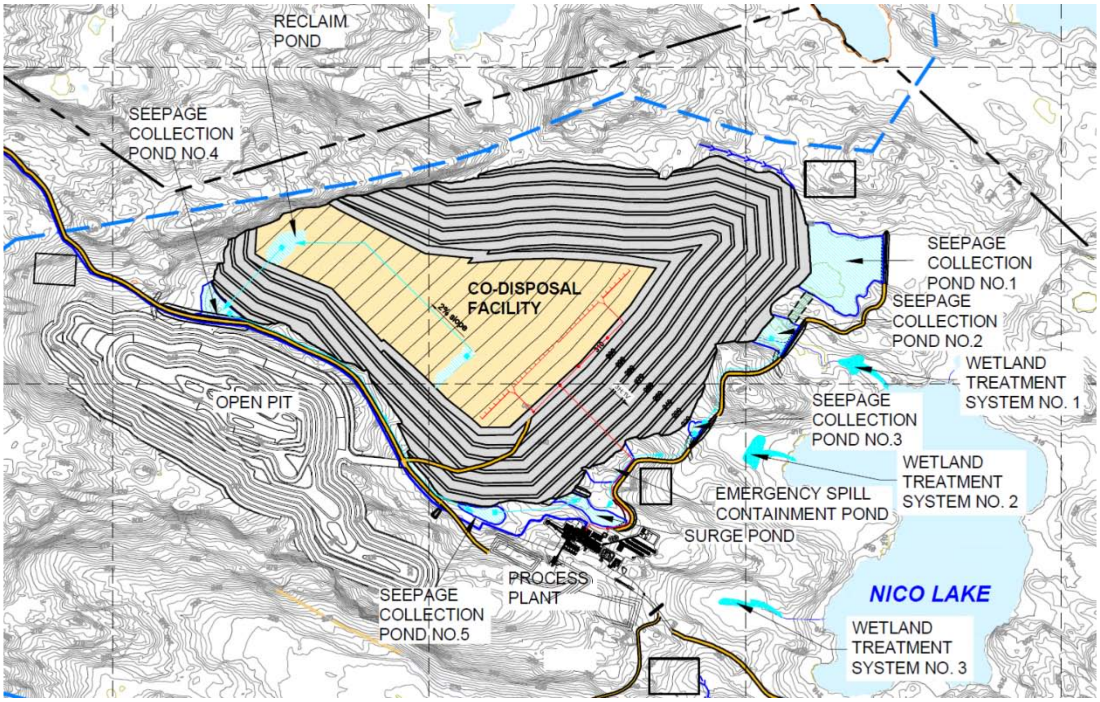

Figure 1: General Arrangement Plan of NICO Co-Disposal Facility

The CDF will be contained by a perimeter dyke comprising a prism of mine rock at least 25 m thick. With an overall slope flatter than 3H:1V, this dyke is very stable. The perimeter dyke will be raised continually in 5 metre lifts using the upstream construction method. A typical cross-section showing 5 m lifts is shown on Figure 2.

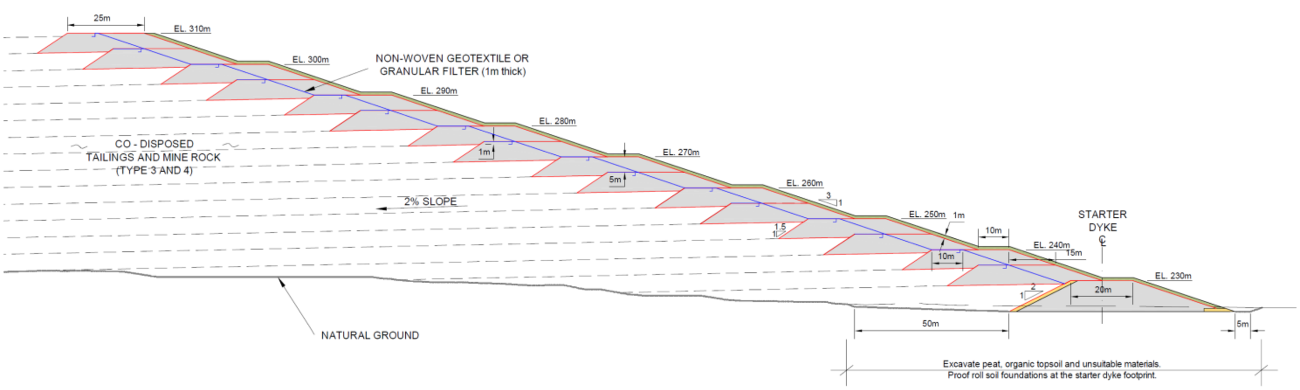

Figure 2: Cross-Section of NICO Co-Disposal Facility Perimeter Dyke

The perimeter dyke lifts will have three zones: an interior zone, a central filter zone and an exterior zone. The interior zone will be constructed earlier to provide containment for either tailings or co-disposed tailings and mine rock using select mine rock (Type 2). The interior zone will have a crest width of 10 m, an upstream slope of 1.5H:1V, and downstream slope of 3H:1V. The filter zone is placed downstream of the interior zone. The filter zone will prevent tailings from passing through the perimeter dyke to the downstream face. The filter could comprise Type 2 mine rock crushed down to a gravelly sand size range, or natural sand and gravel material, or a heavy weight non-woven geotextile (≥600 g/m^2). The exterior zone will be constructed of select (i.e., Type 2) mine rock. The zone will reliably depress the phreatic water level of the CDF. The zone will be 15 m wide and its exterior slope will be 3H:1V. Construction of the exterior zone, as well as the filter zone, could follow slightly behind if sufficient select mine rock is not readily available. The final exterior slopes will have 10m wide benches on every second 5m lift (i.e., at 10 m of intervals of height). This configuration will allow concurrent reclamation of the exterior slopes. The construction schedule of the perimeter dyke will be planned to be ahead of the co-disposal area to provide containment, not only for the tailings and mine rock, but also for the design storm event.

Inside the Perimeter Dyke, the CDF will comprise a “layer cake” of alternating layers of mine rock and thickened tailings about 5 m thick. The tailings layers will be created by constructing a series of tailings disposal cells. Typically, each tailings disposal cell will be a nominal square of 200 m by 200 m (Figure 3). The cell perimeter berms will be constructed by end dumping mine rock (Type 2 or 3). The berm will have a nominal crest width of 6 m to allow vehicle access. The downstream and upstream slopes will be at the angle of repose of the mine rock, which is approximately 1.5H:1V. The thickened tailings will be discharged through a series of spigot discharge points from the eastern berms of the tailings disposal cells. Since the cell perimeter berms will be permeable, tailings bleed water and run-off will seep through them. The water will eventually report to an active Reclaim Pond. The active Reclaim Pond will move westward over time as the CDF raises in elevation. From the Reclaim Pond, the water will be pumped to the Surge Pond, from where it will either be reclaimed into process water or treated in the Effluent Treatment Facility and released.

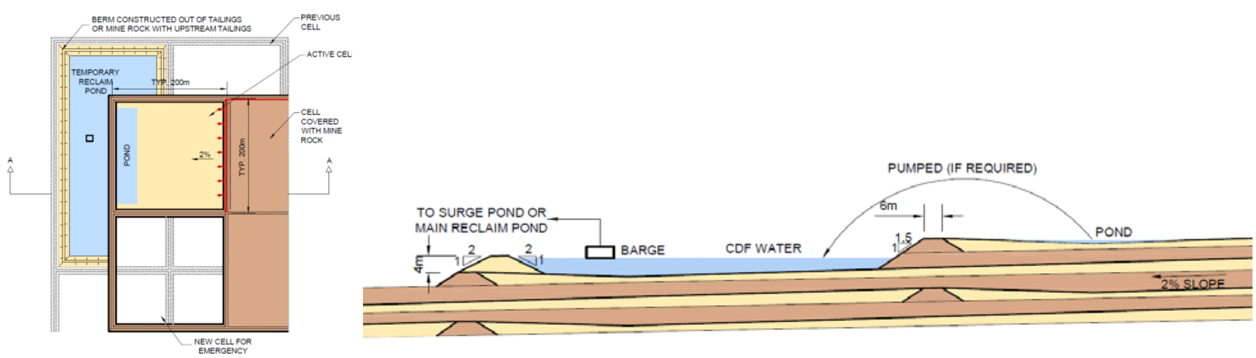

Figure 3: NICO Co-Disposal Facility Layered Co-disposal

The Perimeter Dyke and the CDF itself are both designed to be free draining, so that elevated water tables and excess porewater pressures will not build up. During operations, the pond of water will be small, largely confined to the active deposition cell(s), or to the current Reclaim Pond. After closure, the CDF will shed water into the Open Pit and there will be no pond at all.

The CDF has been designed to be physically stable in an unfrozen condition. It does not rely upon freezing conditions in any respect; subsequent freezing would only increase its stability. The CDF design is inherently more stable and presents a lower risk of failure than a conventional low permeability dam which would contain saturated tailings and likely a sizeable pond of water during operations and possibly after closure as well.

At closure a soil cover will be placed over the entire area of the CDF, effectively encapsulating the co-disposed tailings and mine rock.

3.0 CO-DISPOSAL OPERATIONS IN THE NORTH

Co-disposal is a relatively new technique for mine waste management. There are a number of co-disposal facilities in operation internationally, and the experience at these operations has influenced the design of the NICO CDF.

One of the more northerly applications of co-disposal is at Green's Creek in Alaska (see Section 5.2). This site is not completely comparable to NICO however because it has a warmer climate. On the other hand, Snap Lake (see Section 5.8) and Nunavik (proposed – see Section 5.5) are in even colder climatic conditions than NICO.

It is important to note that the deposition techniques that are proposed for the NICO CDF are all in common usage in many mines around the world and in the north. These techniques include:

- Using mine rock to construct perimeter dykes and internal berms;
- Pumping and deposition of thickened tailings in the winter;
- Staged raising of perimeter dykes; and
- Reclaiming water in the winter, etc

In that respect, the proposed operation of the NICO CDF will use a combination of well-established techniques.

4.0 THICKENED TAILINGS IN COLD CLIMATES

Most tailings facilities in the cold climate involve conventional tailings impoundments. These tailings impoundments are developed to store tailings slurry which is typically deposited at 25- 50% solids content. Large retention dams are often required to store both the tailings and the significant quantities of water disposed with the tailings slurry. These retention dams require continuous maintenance, even post-closure, to ensure their integrity. Supernatant water recovery from the tailings slurry facilities is challenging during the winter months. Some of the slurry water may freeze on the beach before it reaches the pond. Depending on the climate and deposition procedures, some of the resulting entrained ice may never melt, resulting in lost storage capacity. For this reason, some tailings impoundments are sized to accommodate a certain amount of entrained ice in addition to the tailings.

If it is extensive, ice entrainment could potentially pose stability issues. Construction of tailings impoundments with large pond can lead to the degradation of underlying permafrost. The degradation of the permafrost could lead to substantial settlement of the facility (which could delay closure) and it could potentially cause movement of the facility.

Potential problems related to the entrainment of ice can be avoided by reducing the volume of ponded water on top of the tailings disposal facilities. To achieve this tailings are being dewatered to form a non-segregating thickened tailings (typically 55 to 75% solids content), or paste tailings (typically 75 to 80% solids) or a filtered cake (>80% solids content). A summary of mines that are currently using or planning to use thickened, paste and filtered tailings in a northern climate are presented in Table 1.

Tailings thickening has high capital and operational costs which could in some instances be offset by lower cost of dam construction and water management compared to slurry tailings facility. Other benefits of dewatered tailings disposal include:

- Reduced environmental risk because a large tailings water pond is not required;
- Minimal liquids / solids separation during deposition;
- Minimal particle segregation which increases the deposited density and reduces storage volume;
- Smaller impoundment footprint resulting in less area of disturbance
- Less tailings contact water to manage, treat and discharge;

- Less water loss through evaporation and seepage;
- Promotes water conservation by allowing more water to be recycled to the mill;
- Typically less risk of groundwater impact due to lower hydraulic head and less seepage;
- Typically less risk of wind erosion due to reduced segregation of particle sizes;
- Greater chemical stability (unsegregated tailings typically retain water better than segregated coarse tailings beaches, reducing the ingress of oxygen);
- Less ponded water can facilitate progressive closure before the end of mine life;
- Can reduce the loss of storage due to water freeze-up within the tailings;
- Suitable for co-disposal with mine rock (providing improved stability);
- Facilitates progressive closure; and
- Typically has reduced long-term care and maintenance requirements.

Considering the above mentioned benefits, the NICO Project has selected to dewater the tailings to generate non-segregating thickened tailings for co-disposal with the mine rock.

Table 1: Summary of Tailings Thickening and Co-Disposal Projects in Cold Climates

Mine	Owner	Location		Resource	Production (Tonnes/year)	Surface Disposal Method	Underground Includes
Vaudreuil	Rio Tinto	48°30'	Jonquiere, Quebec	Al	0.45 million	Filtered tailings	
Kidd	Xstrata	48°34'	Timmins, Ontario	Cu/Zn	3 million	Thickened Tailings	Paste Backfill
Myra Falls	Breakwater	49°39'	Vancouver Island, BC	Zn/Au	1.3 million	Paste tailings	
Ajax**	Abacus Mining	50°36'	10 km SW of Kamloops, BC	Cu, Au	13.6 million	Thickened tailings co-disposed with waste rock	
Musselwhite	Goldcorp	51°28'	500 km N of Thunder Bay, Ontario	Au	1.3 million	Thickened Tailings	
Red Mountain**	Seabgridge	55°57'	18km E of Stewart, BC	Au, Ag	0.35million	Filtered tailings	
Eskay Creek	Barrick	56°39'	80km N of Stewart, BC	Cu	0.1 million	Filtered tailings	
Greens Creek	Kennecott	58°05'	30km SW of Juneau, Alaska	Au	0.8 million	Filtered tailings co-disposed with waste rock	Paste Backfill
Cluff Lake***	AREVA Resources	58°22'	700km NW of Saskatoon	Uranium	0.32 million	Thickened tailings	
Blagodatnoye*	Polyus Gold	60°04'	600km N of Krasnoyarsk, Russia	Au	6 million	Thickened Tailings	
Julietta	Kinross	61° 09'	250 km NE Magadan, Russia	Au	0.1 million	Paste tailings (previously), Slurry (present)	
Raglan	Xstrata	61°10'	Deception Bay, Quebec	Ni	0.7 million	Filtered tailings	
Nunavik*	Canadian Royalties	61°32'	Deception Bay, Quebec	Ni/Cu	1.7 million	Thickened tailings co-disposed with waste rock	
Minto	Capstone Mining	62° 37'	240 km NW Whitehorse, Yukon	Cu-Au	0.6 million	Filtered tailings	
Nixon Fork	Mystery Creek	63°14'	56km NE of Mcgrath, Alaska	Au	0.06 million	Filtered tailings	
Nico**	Fortune Minerals	63°33'	160km northwest of Yellowknife	Au,Co,Bi,Cu	1.7million	Thickened tailings codisposed with waste rock	
Snap Lake*	De Beers	63°34'	220 km NE of Yellowknife	Diamonds	1.1 million	Thickened Tailings	Paste Backfill
Pogo Mine	Sumitomo Metal	63° 48'	145 km SE Fairbanks, Alaska	Au	0.9 million	Filtered tailings	
Bellekeno**	Alexco Resource	63°55'	54 km north of Whitehorse, Yukon	Ag/Pb/Zn	0.1 million	Filtered tailings	
Kittila	Agnico Eagle	67°39'	50 km NE of Kittila, Finland	Au	1.1 million	Slurry	Paste Backfill

Notes

* Commissioning
**Feasibility
*** Closed

5.0 CASE STUDIES OF CO-DISPOSAL

5.1 Neves Corvo Mine, Portugal

5.1.1 Background

Neves Corvo is an underground Cu-Zn mine located in the south of Portugal, at about 220 km south of Lisbon. The mine has been operating since 1988. The mine has proven mineral resources to continue with mining operations until 2026. The pyritic slurry tailings (with 40-50% pyrite) have been placed subaqueous to control oxidation of the sulphides in a large tailings disposal facility (190 ha) created by a rockfill dam (42 m high) across a natural river valley. The subaqueous tailings disposal facility is almost at full capacity. A tailings and mine rock co-disposal facility is proposed to be placed over the subaqueous tailings disposal facility. The co-disposal facility will have a storage capacity for 12.5 Mt of future paste tailings and 5.5 Mt of existing and future mine rock. The co-disposal facility will allow maintaining the existing perimeter dam at its current elevation.

The local climate is semi-arid, with average annual precipitation of 484 mm, mostly occurring between October and April, and evaporation of about 1,313 mm per year.

5.1.2 Conceptual Design of Paste and Mine Rock Co-Disposal Facility

The paste and mine rock co-disposal facility is planned to be developed in a modular approach. It will involve sequential construction of 15 cells on top of the flooded slurry tailings disposal facility using mine rock (Figure 4). The development of the paste disposal facility will start construction of four cells at the south and progressing in a general counter clockwise fashion, displacing and directing the existing water cover towards the final cell at the southeast corner, which will act as a sedimentation pond before the water is discharged to a new water reservoir that will be constructed outside the facility.

The internal dykes that form each cell will be built from the existing mine rock stockpiled on site and new mine rock produced from the mining activities. The dykes will be built with a crest width of 7 m, variable elevation and side slopes of 1.5H:1V. Dyke construction will proceed in a progressive manner as new cells are required. A central berm or spigot, to support paste pipeline, will be progressively constructed from mine rock, stretching out to the centre of each cell, as the cell fills with paste, elevating the paste discharge pipeline in the process, to create the necessary paste slope.

Once paste placement ceases in any particular cell as its storage volume is depleted, construction of the cover can begin. Once suitable access onto the paste is achievable, and the first desiccation cracks begin to develop, the mine rock layer can be started. The duration between cessation of paste placement and cover construction will also depend on the climatic conditions. Experience from a pilot trial done on site highlighted the varying desiccation rates between summer and winter, and its influence on trafficability.

It is proposed that, for the final cover, a layer of at least 1.0 m of mine rock be placed over the paste deposit, overlain by a 0.5 m layer of capillary break material, and topped with a final 0.5 m layer of engineered subsoil, allowing the growth of native vegetation.

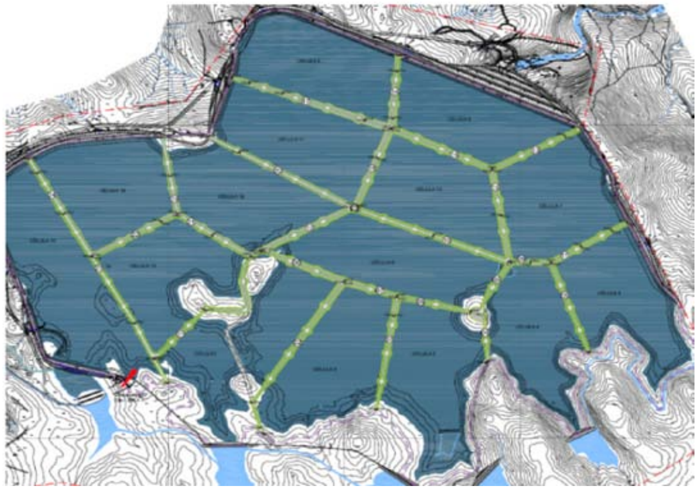

Figure 4: Neves Corvo Co-Mingling Facility General Arrangement Plan

The deposition of a paste instead of slurry tailings allows and ensures:

- Maintain the existing perimeter dam at its current elevation;
- Provided sufficient storage capacity for the tailings that will generate from the currently reserves in the existing subaqueous facility;
- Minimization of environmental impacts (reduction in sulphide oxidation and leachate generation);
- Optimization of geochemical, geotechnical and hydrogeological stability;
- Progressive filling and concurrent closure;
- Progressive management of the water cover of the existing tailings disposal facility; and
- Co-disposal of the paste tailings and the acid generating mine rock.

5.1.3 Construction of Mine Rock Cells Over Sub-aqueously Deposited Tailings Slurry

In 2009 and 2010, four cells were constructed. The construction of the cells used-up 0.5 Mt of mine rock obtained from the existing mine rock stockpile, which is located about 4 km from the facility. The mine rock was trucked and unloaded directly in the alignment of the perimeter dykes (Photo 1). The mine rock is then pushed and spread by bulldozer (Photo 1), leaving lateral berms of material for roadside safety (Photo 2). The slopes are then corrected using excavator and the dykes are locally breached to promote water drainage.

For safety reasons, the dykes were constructed in one layer, the dyke was constructed a minimum of 1.5 m above the water level and the bulldozers were always were kept away a good distance from the advancing edge of the dyke. Since the foundation material is sub-aqueously deposited loose tailings, a significant volume of the tailings is being displaced as mine rock is being placed. The movement of the dykes were monitored using internal survey. A maximum cumulative settlement of 47 cm and horizontal movement of 29 cm was measured.

In locations of dyke construction were significant settlement and horizontal displacement encountered, the unloaded mine rock was left overnight in the advancing front to promote dissipation of pore water pressure. Longitudinal cracks were common, mostly along the edges of the dike crest, due to the differential settlement rates between the center, which is more subjected to the truck movement and weight, settling faster than the edges. The cracks were inspected and repaired to minimize the water infiltration.

5.1.4 Paste Deposition

Paste deposition started in October 2010. Paste deposition is taking place in the four cells concurrently. The typical deposition plan allows for three consecutive days of deposition at each spigot and five days of desiccation. The tailings are currently deposited at average solids content of 61%. The beach slope achieved to date ranges from 1.5% to 2%. Aerial photo of the co-disposal facility that shows the nearly filled paste disposal cells is shown in Photo 3.

Photo 1: Truck off-loading mine rock and dozer spreading at Neves Corvo

Photo 2: Final aspect of a dyke at Neves Corvo

Photo 3: Paste Disposal at the Initial Four Cells at Neves Corvo

5.2 Greens Creek, Alaska, USA

5.2.1 Background

The Greens Creek Mine is an underground metal mine near Hawk Inlet on northern Admiralty Island, Alaska. The mine produces concentrates containing Zn, Ag, Au, and Pb from volcanogenic massive sulfide ore which is hosted by Triassic calcareous argillite and meta-volcanic rock (phyllite). The annual average precipitation, temperature, and wind speed at the mine site are 1,450 mm, 5.8°C and 5.0 m/s, respectively.

The mine has been operational since 1989. Presently, the mine is milling at an approximate rate of 2,000 t/d tons of ore per day and the tailings generation rate is approximately 1,500 t/d. The tailings are filter-pressed to 12% moisture content (88% solids content). Approximately 50% of the filtered tailings are returned underground for use as structural backfill and the remaining tailings are trucked 13 km to a filtered tailings disposal facility. The filtered tailings disposal method, which has considerably higher operational costs, was selected because of its environmental and economical advantages. When compared to conventional tailings slurry disposal facility, the filtered tailings disposal facility required approximately 78% less footprint area and more than seven times less capital cost. The reduced footprint area means reduced contact water and hence reduced water treatment cost during operation and post closure.

5.2.2 Tailings and Mine Rock Characteristics

As shown in Figure 5, the filtered tailings are classified as SILT with 80-85% passing the #200 sieve and less than 5% clay-sized particles. Because the tailings are placed mechanically, no particle segregation occurs. The average Standard Proctor density, specific gravity and optimum gravimetric moisture content are 2.2 t/cm^3, 3.5

and 13%, respectively. Atterberg limits tests indicate that the tailings are cohesionless to very low-plasticity silt. The average liquid limit, plastic limit and plasticity index are 19%, 16% and 3, respectively. The average in-situ gravimetric moisture content of compacted tailings is 16% and the porosity is about 40% (which is equivalent to void ratio of 0.67). The average in-situ hydraulic conductivity of the compacted tailings is 1.9×10^{-8} m/s. The friction angle for compacted tailings is approximately 40°.

The tailings consist primarily of quartz, sericite, pyrite, dolomite, magnesite, calcite, and chlorite. The tailings are potentially acid generating, but have a substantial neutralization potential. Analyses of weathered tailings demonstrate that carbonate minerals produce a long lag time to acid generation. Despite the long lag time, oxidation of sulfides and neutralization of acidity by carbonate minerals in the tailings produce pore water that is alkaline but high in $SO4^{-2}$, Ca, Mg, Zn, As, and Se.

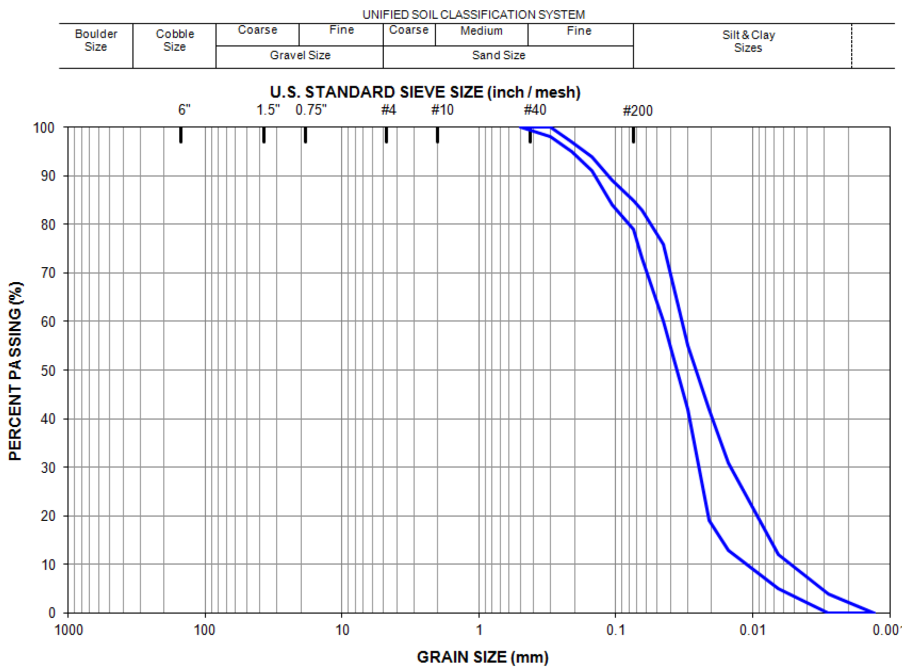

Figure 5: Particle Size Distribution of Filtered Tailings of Greens Creek

5.2.3 Filtered Tailings Disposal

According to current ore reserves, by the end of operations the mine will have generated a total of 6 Mt of tailings. Currently, 3.5 Mt of tailings have been deposited and the facility covers a total footprint area of 13 ha and it is about 25 m high. The outer slopes of the filtered tailings stack are at 3H:1V. The filtered tailings are transported from the mill to the filtered tailings disposal facility using 40 tons off-highway lidded trailered trucks. The tailings are dumped, spread out in thin lifts with a CAT D6 bulldozer and compacted with a CAT CS563 smooth drum vibratory roller to a target of greater than 90% of the Standard Proctor Maximum Dry Density of the tailings. Compaction checks are often carried out using a nuclear densometer.

During long periods of heavy rainfall, it becomes difficult to maintain access to placement areas, to manage erosion and runoff and to achieve target densities. The tailings are close to optimum moisture content when they arrive at the tailings pile, but quickly gain moisture from rainfall as they are spread and compacted. Areas away from outer-pile surfaces are utilized during inclement weather to minimize the risk of creating soft zones in areas that are critical to stability. Additionally, the mill has been equipped with a capacity to store 2 days of dry stack for contingency.

Access to the placement area is possible via a road with a rock surface. The silt-sized tailings erode easily and gullies form rapidly on exposed slopes. Gullies that form on slopes are either cut and re-compacted or filled with compacted tailings or rock. Tailings washed from the gullies are problematic because they are often too wet to place conventionally. They are typically mixed and placed with fresh tailings during dry periods.

Controlling fugitive dust is also a challenge during prolonged dry periods, particularly under freezing conditions. Use of synthetic covers, mine rock or a thin layer of ice may be necessary to control dust when conditions are not suitable for water application.

5.2.4 Mine Rock Dump

By the end of operations the mine will generate a total of 1.7 Mt of mine rock. There is already approximately 0.6 Mt of the mine rock stored in a dump adjacent to the mill (Photo 5). The mine compared the relative costs of re-contouring and covering the existing mine rock dump versus consolidating it with the filtered tailings disposal facility, and found that relocating is the most economical and environmentally protective solution. Relocation of the mine rock started in 2009.

The mine rock contains a mixture of acid generating and acid neutralizing rock. The existing inactive mine rock dumps have drainage dominated by near-neutral waters having sulphate and metals concentrations consistent with exposed production rock.

5.2.5 Co-Mingling of Filtered Tailings and Underground Mine Rock

Co-mingling of filtered tailings and mine rock started in the filtered tailings disposal facility. The major reasons for the co-mingling are to:

- Reduce area of environmental risk;
- Minimize impact on receiving waters; and
- Reduce reclamation (cover) cost.

Laboratory tests conducted in a large scale permeameter cell measured the hydraulic and strength properties of tailings only, production rock only, and various blends of production rock and tailings. Based on the results, the following main conclusions were drawn:

- The difference in permeability between compacted production rock and compacted saturated tailings is at least 33 times. Blend ratios of 2:3 (production rock to tailings by volume) and 3:2 resulted in lower values of permeability as compared to the tailings only sample. The 2:3 blend exhibited the lowest value of permeability. This behaviour is mainly attributed to the elongated length of the seepage path (and reduced seepage flow area) through the tailings dominated soil matrix and around the larger rock fragments.
- Friction angle of the 2:3 blend was similar to that of the tailings-only sample showing that the tailings were dominant in the blend. As expected, the friction angle improved with the addition of more production rock in the 3:2 blend. Addition of production rock generally increased the overall strength of the compacted tailings with all blend ratios.
- Relatively uniform mixing of the tailings and production rock was very easily obtained in the laboratory in all cases.

- A mine rock to tailings ratio of 3:2 (60% production rock by volume) with a permeability of 5 x 10^{-8} m/s and a friction angle of 43° is recommended as the limiting blend for blended co-disposal of mine rock and filter pressed tailings. The tailings alone have permeability of 3.4 x 10^{-7} m/s and internal fraction angle of 36°.
- Field trials confirmed that the mine rock and tailings mixed well when pushed with a bulldozer. This is consistent with the findings of the laboratory mixing experiments.

A geochemical assessment was carried out on the co-mingled material, the key findings of which are summarized below:

- Drainage quality at the mine rock dump will improve significantly following relocation and co-disposal.
- Reduced oxidation of the mine rock by blending with tailings will extend the duration over which the rock is able to neutralize acidity (extended lag period).
- The co-mingled waste material will have a lower acid generation potential than tailings alone.
- Comparison of metals and trace element contents between samples of mine rock dump and tailings show that the co-mingled blend will have a lower metal content than the tailings.
- Co-mingling of mine rock with tailings exhibited improved pore water chemistry similar to that of tailings and mine rock disposed of separately (see Figure 6).
- Dissolution of oxidation products, including reductive dissolution of iron and manganese oxides/oxyhydroxides will occur in response to the change in redox environment with co-mingling. Consequently, increases in iron, manganese, arsenic and co-precipitated or sorbed metals are expected. However, pore water compositions are not expected to be significantly different than those that develop when oxidized tailings surfaces are buried as the pile expands. Microbial sulphate reduction observed below the water table in the tailings pile and in carbon amended, unsaturated test cells produces alkalinity and sulphide. This has the potential to remove much of the dissolved load caused by reductive dissolution.
- Co-mingling of unamended, acidic rock with tailings significantly reduced metals leaching relative to the acidic rock control and demonstrated that the tailings are capable of neutralizing the acidity present in the acidic rock. This positive result also suggests that addition of lime, though protective, is not an essential component of the co-mingling process.

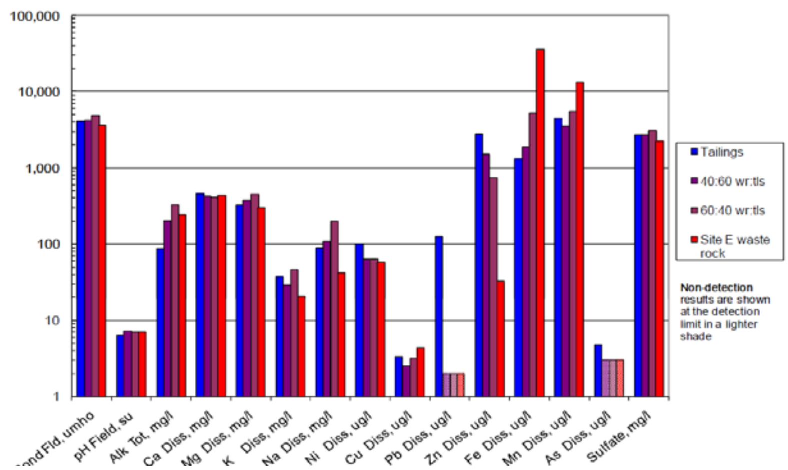

Figure 6: Geochemistry of Co-mingled Filtered Tailings and Mine Rock of Greens Creek

The co-mingling process involves end dumping of both filtered tailings and mine rock approximately at one to one ratio and spreading with the bulldozer and compacting with smooth vibratory roller (Photos 6 and 7). The co-mingled material typically gets compacted by at least two back and forth passes with the dozer and at least one back and forth pass with the roller. The same compaction technique was used when the filtered tailings was disposed separately. Filed tests could not be carried out on the compacted co-mingled materials as it is not possible to use nuclear densometer to measure compacted density and moisture content.

Photo 4: Greens Creek Filtered Tailings and Mine Rock Co-mingling Facility

Photo 5: Greens Creek Inactive Mine Rock Dump Near Mill

Photo 6: Greens Creeks Co-mingling of Filtered Tailings and Miner Rock

Photo 7: Greens Creeks Compacted Surface of Co-mingled Surface

5.3 Cerro de Maimon, Dominican Republic

5.3.1 Background

Cerro de Maimon Mine is an operational open pit mine located 75 km northwest of Santo Domingo in Dominican Republic. The mine produces Au and Cu concentrates. The nominal milling rate of the mine is 2,500 t/d. The mine will produce 14 Mt of inert overburden waste, 4.8 Mt of potential acid generating mine rock, 27.2 Mt of inert mine rock, and 5.2 Mt of potentially acid generating tailings. The principal lithological units in the open pit limit are chlorite schist, quartz-chlorite schist, massive sulphide (ore body), tuffs, and limestone. The thickness of the weathered zone within the open pit area varies from 10 to 40 m. At the ultimate configuration the open pit will be approximately 137m deep.

The site is seismically active. The mean annual precipitation and pan evaporation at the mine site are 2,012mm and 1,710mm, respectively. The average annual temperature is 26 $^{\circ}$C, with summer temperature varying from 21 to 35 $^{\circ}$C and winter temperature varying from 17 to 32 $^{\circ}$C.

5.3.2 Tailings and Mine Rock Management Concept

The overburden and inert mine rock are disposed in separate dumps. The PAG mine rock is planned to be co-disposed with the PAG tailings (Wislesky and Li, 2010). Some of the inert mine rock is also planned to be placed over the co-disposed surface (Figures 7 and 8). Co-disposal of the potentially acid generating tailings and mine rock has been selected to minimize AMD and ML from the PAG mine rock. The site also has limited space for separate disposal facilities for the two waste streams. The original conceptual design was to co-mingle the two waste streams to maximize the filling of the void spaces of the mine rock. Field test trials were carried out to assess whether tailings could fill the PAG mine rock void spaces, and methods for implementing this co-disposal strategy.

5.3.3 Characteristics of Thickened Tailings and PAG Mine Rock

The tailings will be dewatered to solids content of 55-60% to form non-segregating thickened tailings before sent for disposal. The beach slope of the deposited thickened tailings is approximately 2%. The grain size distribution of samples taken across the desiccated thickened beach is presented in Figure 9. Results show that the tailings are composed of 20-30% fine sand sized particles and 70-80% silt and clay sized particles. The average liquid limit, plastic limit and plasticity index are 25%, 19% and 7, respectively. The average specific gravity of the tailings is 3.13. The average void ratio of the deposited thickened tailings was 1.1. The peak undrained shear strength of the desiccated thickened tailings (after two weeks of deposition) was approximately 5 kPa.

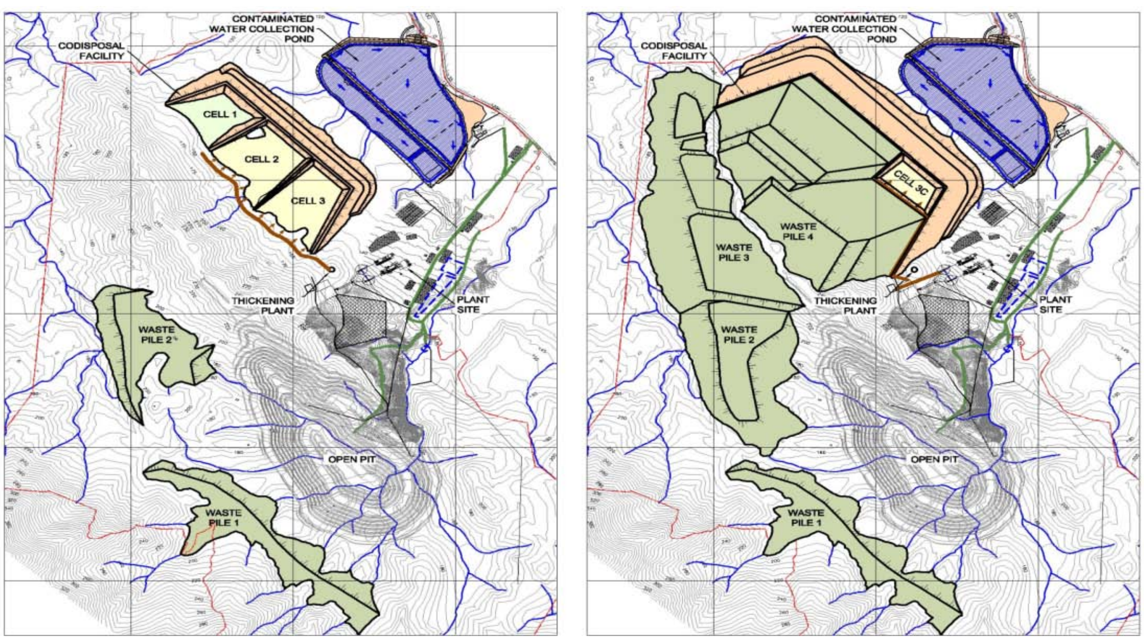

Figure 7: The General Arrangement Plan of the Cerro de Maimon Co-disposal Facility at Two Stages

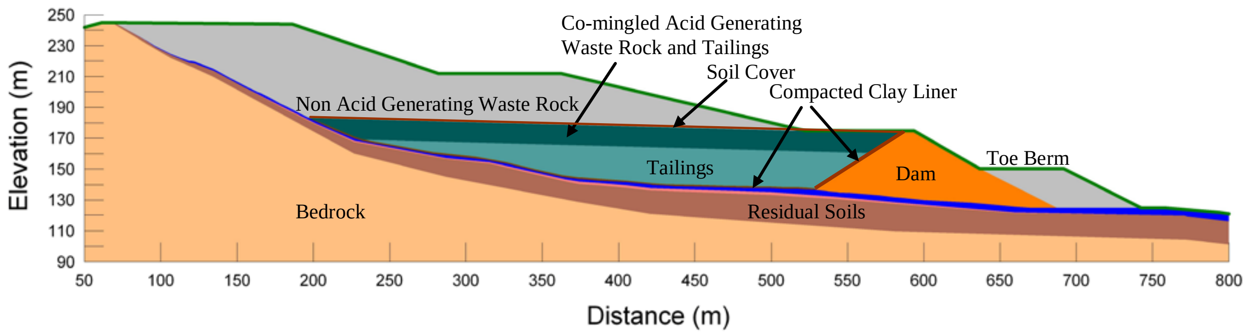

Figure 8: Cross-Section of the Ultimate Cerro de Maimon Co-disposal Facility

The PAG mine rock has 7-16% of fines as shown in Figure 9. The approximate void ratio of the PAG mine rock was measured in the field (see Photos 8 and 9). Tests done on two PAG mine rock samples showed that the void ratio varies from 0.29 to 0.41. The PAG mine rock was moderately weathered and has high fines content.

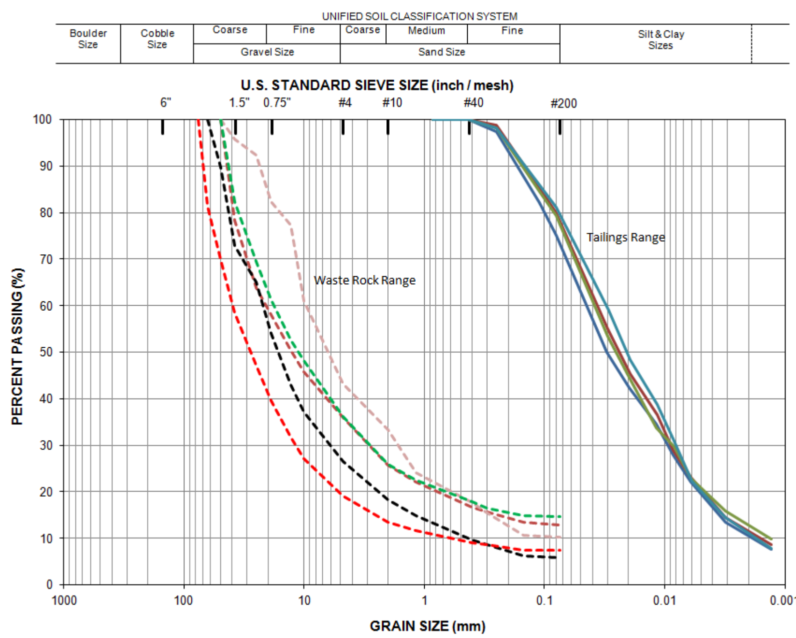

Figure 9: Particle Size Distribution of Cerro de Maimon Thickened Tailings and PAG Mine Rock

Photo 8: Typical PAG mine rock

Photo 9: Measuring void ratio of PAG mine rock

5.3.4 Co-disposal Field Trail

An investigation was undertaken on site to determine the optimal co-disposal strategy for the PAG thickened tailings and mine rock. The field investigation consisted of two stages. The first stage involved testing the effectiveness of various types of co-disposal, with the objective of identifying an optimal strategy. The second stage involved detailed testing of the performance of the preferred co-disposal strategy.

The following types of co-disposal were evaluated as part of Stage 1 evaluation:

- Type 1: Placing a layer of PAG mine rock using dozer over desiccated tailings
- Type 2: Placing a layer of PAG mine rock using dozer over freshly deposited tailings
- Type 3: Dropping PAG mine rock from excavator over freshly deposited tailings

Type 1 co-disposal involved hauling the PAG mine rock to a desiccated thickened tailings beach using articulated trucks, and PAG mine rock was spread in thin layer using a CAT D6 dozer (Photo 10). Following placement of the PAG mine rock pad, a wetted heave zone developed around the pad (Photo 11). A test pit was excavated in the co-disposed materials 2 days later to investigate if any mixing of the tailings and mine rock had occurred. Results of the test pit are shown in Photos 12 and 13. The photos clearly indicated that no mixing took place between the two waste streams. However, the presence of water in the test pit (Photo 10) could be an indication of a significant consolidation of the tailings due to the weight of the mine rock placed over it.

Type 2 co-disposal first involved creating a containment berm on freshly deposited thickened tailings to facilitate the field trail (Photo 14). Then about 1m thick PAG mine rock was pushed into the freshly deposited thickened tailings (Photo 15). During the spreading of the PAG mine rock large displacement of the tailings was observed, indicating that little mixing of the tailings and mine rock had occurred. A test pit was dug through the PAG mine rock pad to confirm if any mixing had occurred (see Photos 16 and 17). The dry conditions observed in the test pit (Photo 16) shows that no significant compression of the tailings had occurred. As shown in Photo 10, the tailings- mine rock interface was discrete, and no mixing of the two materials had occurred.

Type 3 co-disposal was tested at the containment cell constructed for Type 2 co-disposal. The test involved dropping PAG mine rock from an excavator bucket into the freshly deposited thickened tailings. The purpose of this investigation was to attempt to provide a co-mingled mass of tailings and mine rock. Photo 18 shows the placement technique. The following day a test pit was excavated through the mine rock, shown in Photos 19 and 20. The photos clearly showed that the co-disposal method will not provide significant levels of co-mingling. As shown in Photo 18, some minor co-mingling was observed in the test pit walls which are likely due to splashing during PAG mine rock placement. The floor of the test pit (Photo 19) showed a distinct tailings-mine rock boundary. As with the Type 2 co-disposal method, the dry conditions in the test pit show that the PAG mine rock had simply displaced the tailings.

The results of the above tests clearly indicated that co-mingling of the PAG mine rock and thickened tailings is not possible. This is more likely due to the high fines content of the PAG mine rock. Layered co-disposal of PAG mine rock over desiccated thickened tailings was found to be the optimal co-disposal strategy.

Photo 10: Spreading PAG mine rock over desiccated thickened tailings beach

Photo 11: Completed Type 1 Co-disposal Pad

Photo 12: Standing water test pit excavated through PAG mine rock pad in Photo 3

Photo 13: Tailings/PAG mine rock interface, no mixing (co-mingling) has occurred

Photo 14: Advancing containment berms out into freshly deposited thickened tailings

Photo 15: Spreading PAG mine rock over freshly deposited thickened tailings

Photo 16: No standing water after excavation, indication tailings displacement

Photo 17: Tailings/PAG mine rock interface, no mixing (co-mingling) has occurred.

Photo 18: Dropping PAG mine rock into freshly deposited thickened tailings using an excavator

A Stage 2 investigation was carried once a preferred co-disposal scheme was identified from Stage 1 testing. The purpose of the investigation was to determine how to implement the layered co-disposal strategy. Two deposition test cells were constructed, roughly 9m x 9m, one to be filled with 1m of tailings and the other with 2m of tailings. The tailings would be allowed to desiccate, and then spread over with 2 m x 1 m thick lifts of PAG mine rock. Test cells were instrumented with moisture sensors connected to a data logger, a staff gauge, and a settlement plate. Photos 21 to 24 below show the experimental setup.

The tailings were allowed to settle and the perimeter containment was opened to allow for decanting of the clear supernatant. During the desiccation phase, which lasted for 13 days, the tailings were monitored daily. Development of shear strength, suction, moisture content, and beach settlement were measured. Shortly after suction began to develop, the cells were covered over in a 1 m thick lift of PAG mine rock, placed by excavator.

Photo 19: Spreading PAG mine rock over desiccated tailings beach

Photo 20: Completed PAG mine rock pad

Photo 21: Deposition test cell prior to filling

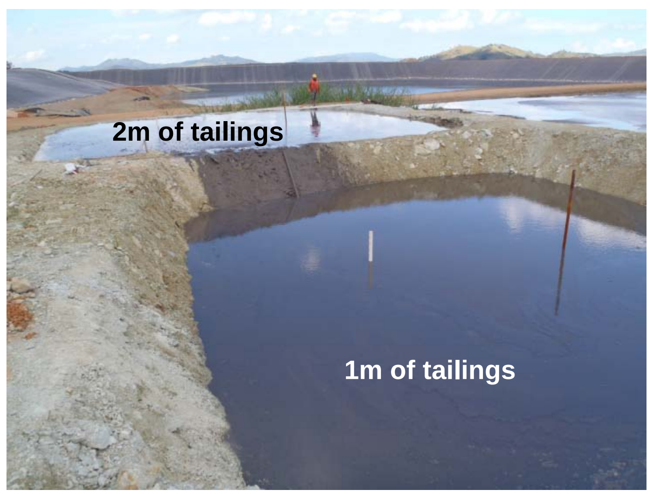

Photo 22: Deposition test cells after initial filling

Photo 23: Placing PAG mine rock lift over cell with 1m depth of tailings

Photo 24: Placing PAG mine rock lift over cell with 2 m depth of tailings

Surface settlements were measured by reading the staff gauge installed in each test cell. Settlement readings were taken throughout the test duration to correlate tailings property changes with consolidation of the material. Figure 10 shows the observed settlement of Cell 1 and Cell 2 tailings surfaces prior to PAG placement. In both test cells, the majority of settlement occurred within 4 days of deposition. The tailings were then allowed to desiccate for 10 to 15 days, after which point no significant settlement of the tailings surface was measured.

A hand held QuickDraw tensiometer was used to measure the suction developed after the tailings had undergone moderate desiccation (i.e. shortly after desiccation crack formation). Figure 11 represents the suction profiles at various stages of desiccation. As is shown in Figure 11, the depth of the desiccation occurred with the upper 10 to 20 cm with measureable suction.

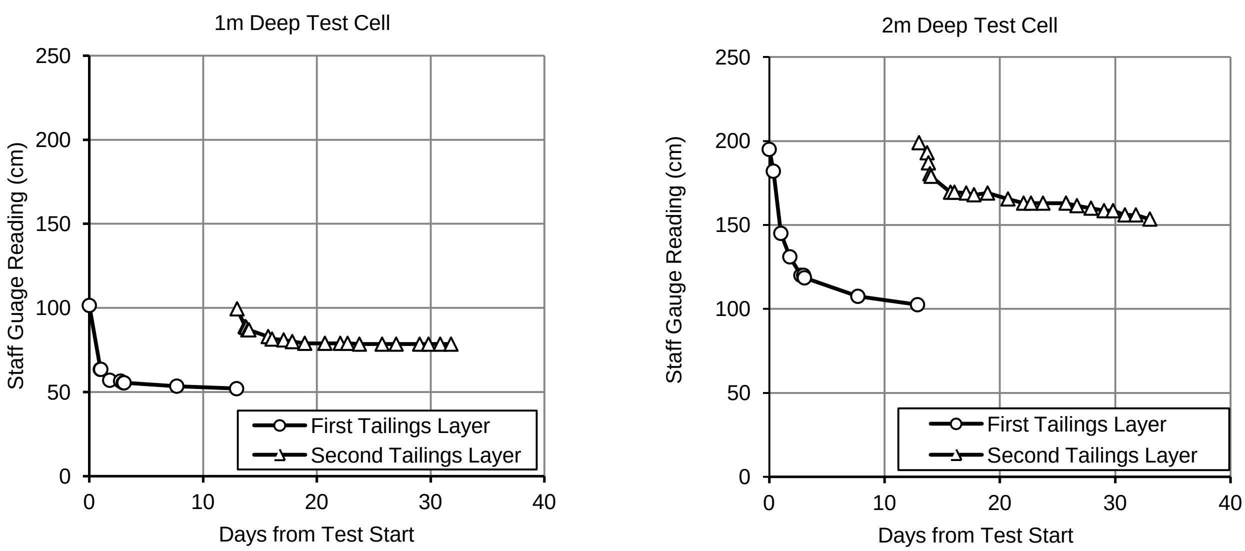

Figure 10: Tailings Surface Settlement Prior to PAG Mine Rock Placement

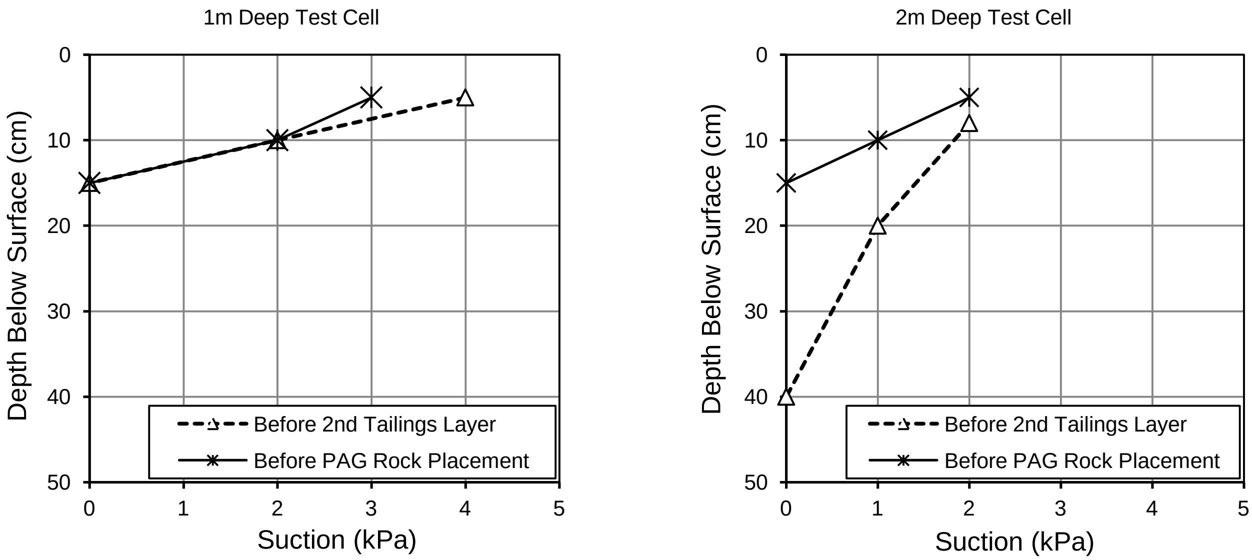

Figure 11: Measured Suction Profiles

The compressive settlement of the tailings due to PAG rock loading was estimated using survey data of the settlement plates installed at the top and bottom of the tailings layers. Significant consolidation of tailings resulting from PAG placement was observed within 1 day of placement. Placement of the 1st PAG lift resulted in 5.7 cm and 14.6 cm of settlement for Cells 1 and 2 respectively. Consolidation beyond the first day was negligible. This indicates that the consolidation of the tailings took place fast as a result of two way drainage provided by the mine rock. The total settlement was approximately 7.4 cm and 16.6 cm (i.e. approximately 10% strain) for the tailings in Cells 1 and 2, respectively.

Moisture content profiles were determined in the laboratory on the samples taken from each deposition test cell during each stage of the experiment: preceding 1st PAG lift placement, preceding 2nd PAG lift placement, and a final sampling at the end of the test. Shelby tube samples taken from Cell 1 after the 2nd PAG lift and from Cell 2 prior to the 1st PAG lift were damaged during transportation. Figure 12 shows the measured moisture content profiles.

Prior to PAG rock deposition, the moisture content profile exhibited a decreasing trend in the upper zone due to desiccation, increasing with depth in the middle zone and decreasing with depth in the lower zone due to self weight consolidation. Following placement of the 1st PAG lift, Cell 1 tailings underwent an average moisture content reduction of approximately 11%, corresponding to a reduction in void ratio of approximately 0.35. Moisture content profiling in Cell 2 exhibited similar trends. Placement of a 1 m thick PAG lift over 2 m of tailings resulted in an average moisture content decrease of 7.5%, corresponding to a void ratio reduction of approximately 0.23. Placement of the 2nd PAG lift yielded slightly additional changes in moisture content. The results of the moisture content profiling suggested that layered deposition of PAG and tailings significantly reduces the void ratio of the tailings. As is anticipated, the 1 m thick lift of tailings experienced a greater decrease in moisture content than the 2 m thick lift of tailings. The inferred dried density of the tailings increased from approximately 1.3 t/m^3 to 1.5 t/m^3 for the tailings in the test cells.

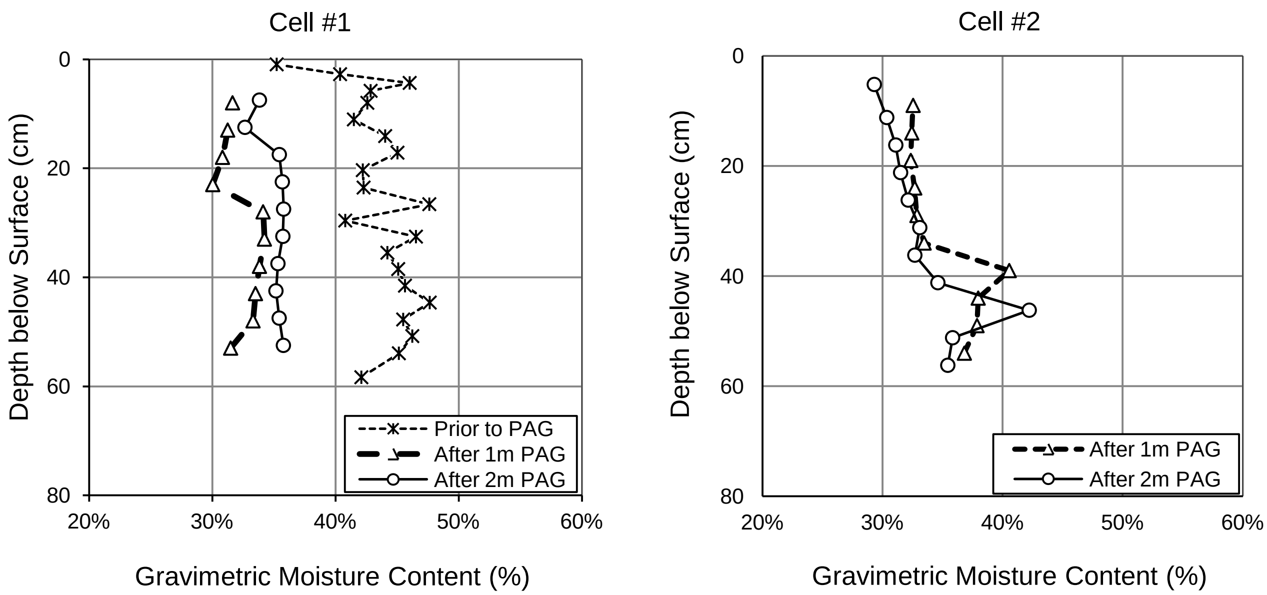

Figure 12: Measured Moisture Profiles

Shear strength profiles of the tailings in the test cells were measured prior to and after PAG mine rock lifts and the results are presented in Figure 13. It is evident that placement of the PAG surcharge loads resulted in significant increases in the undrained shear strength of the tailings deposit. Placement of the 1 m thick lift resulted in a strength increase of 62 - 210% from the surface to the bottom. Placement of the 2nd PAG lift resulted in a net strength increase of 25 - 42% from the surface to the bottom.

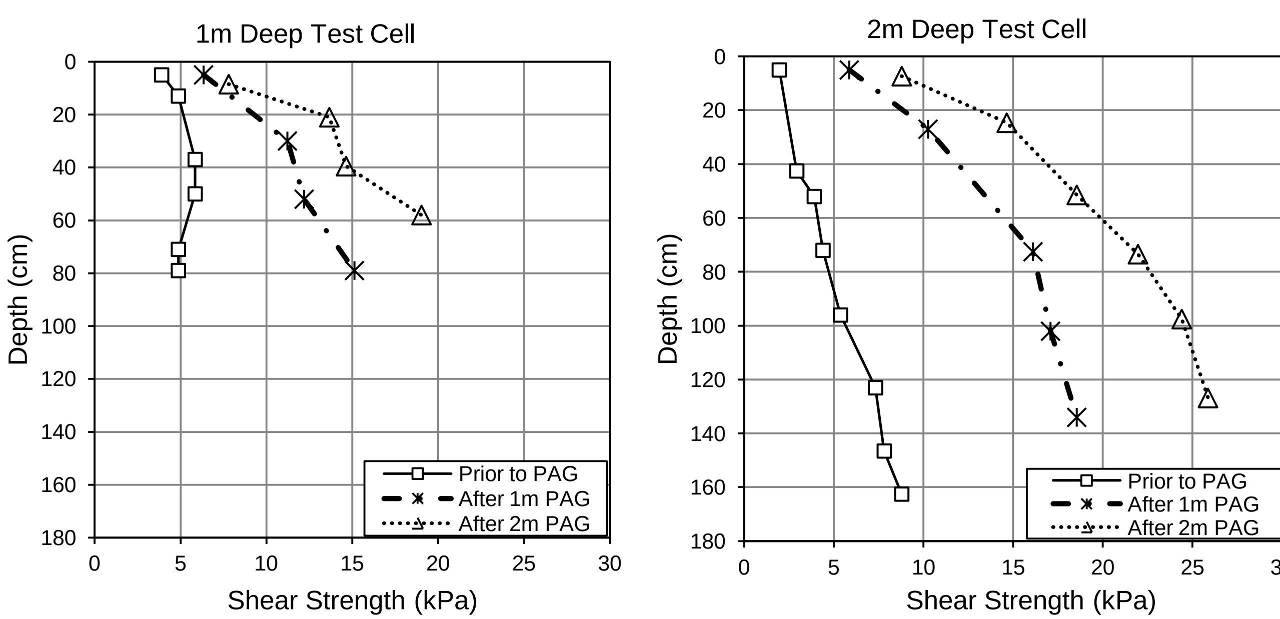

Figure 13: Shear Strength Profile of Test Cells

5.3.5 Co-Disposal at the Cerro de Maimon Mine Site

The main driver for co-disposal of PAG with tailings at the Cerro de Maimon mine site was the limited area available for construction of separate disposal facilities and the effectiveness of management of potential acid generating wastes. The other considerations for the use of the layered co-disposal method include improvement in stability of the facility, reducing liquefaction potential of the tailings deposit under possible seismic events and ease of water management. Co-disposal deposition can keep mine rock saturated and prohibit acid generation during operation. After closure, the compressed tailings layers will hinder oxygen diffusion and reduce ARD reaction.

The results of the deposition tests showed that layered deposition of tailings and mine rock is feasible, after allowing for consolidation and moderate desiccation of the tailings deposit, and that an increase in density and shear strength of the tailings can be realized shortly after placement of a mine rock layer. The increase of the storage volume was significant for both the 1 m and 2 m thick mine rock lifts. For the strength gain and void ratio change, the 2 m thick mine rock lift scheme was comparable to the 1 m thick lift scheme. To provide flexibility in operation, 1.5 m to 2.0 m lifts of tailings and PAG mine rock are considered favourable.

5.3.6 Operational Challenges

Layered deposition of mine rock and tailings can be a challenging procedure that requires specific operating characteristics to be successfully implemented. Layered deposition requires careful planning to ensure that the design objectives are met. The production of mine rock and deposition schedules are two key factors in this regard. At the Cerro de Maimon mine, the CDF is internally divided into three distinct cells which provide the required flexibility for successful tailings and mine rock co-disposal.

Consideration also needs to be given to techniques for mine rock placement. Shear strength of the tailings and grain size of the mine rock will dictate the minimum thickness of mine rock lift required for safe equipment access. For this specific site, the minimum mine rock lift was found to be 1.3 m thick to safely operate the equipment; however this could vary depending on the accelerated strength gain of the underlying tailings resulting from the placement of mine rock layers. Placement of mine rock on the tailings beach should be at controlled rates allowing for consolidation of the tailings to take place during deposition. Equipment access into the facility must also be maintained to allow for trucking and dozing PAG mine rock. If the tailings management facility is lined with geosynthetic liners, special consideration must be given to protect the liners. For the Cerro de Maimon CDF, the access roads were designed with careful material selection and required careful construction to minimize damage to the liner system.

5.3.7 Summary

The field deposition trials carried out at the Cerro de Maimon mine demonstrates that layered co-disposal of PAG mine rock and tailings is feasible to increase the storage capacity and to reduce environmental impact of, the tailings management facility for the project. Co-disposal employing layered deposition of the waste materials was observed to provide significant quantifiable benefits including significant increase in density and shear strength of the tailings deposit, and acceleration of tailings consolidation by shortening the drainage paths. The increase in density of the tailings due to layered co-disposal deposition would also decrease liquefaction potential of the tailings during seismic events. Thickened tailings also facilitates development of uniform tailings beaches, which require moderate desiccation over relatively short periods of time so that the placement of the PAG rock can be carried out using trucks and dozers for PAG mine rock placement.

5.4 Krumovgrad, Bulgaria

5.4.1 Background

The Krumovgrad Project is located approximately 3 km south of the town of Krumovgrad in the southern-most part of Bulgaria. The project has a 7.2 Mt gold-silver ore body which is being prepared for development as an open-pit truck and shovel mining operation. The mill throughput is 2,500 t/day. The mining process will generate 7 Mt of tailings and 15 Mt of mine rock. The average annual precipitation for the project site is 704 mm while the average annual pan evaporation is 1,052 mm. During winter, the average temperature varies between 1.3°C and 5.5°C and during the summer months the average temperature varies between 12.3 and 23.7°C. The average annual wind speed in the project site is 1.8 m/sec.

5.4.2 Characteristics of Tailings and Mine rock

The mine rock will comprise weathered to fresh conglomerate. The pit will be approximately 127 m deep. The mine rock generated from the first 40 m of the pit is expected to be highly weathered (oxidized). The mine rock mined below the weathered zone is expected to be predominantly fresh (but exhibiting variable degrees of clay (argillic) alteration). The mine rock is non-potentially acid generating.

The tailings are extremely fine with almost 100% passing the # 200 sieve as shown in Figure 14. The tailings is non-plastic with a Shrinkage Limit of 25%, specific gravity of 2.74, air entry value of greater than 100 kPa, peak and residual friction angles near 30°, and peak and residual cohesion values of near 25 kPa and 14 kPa, respectively. The tailings are non-potentially acid generating.

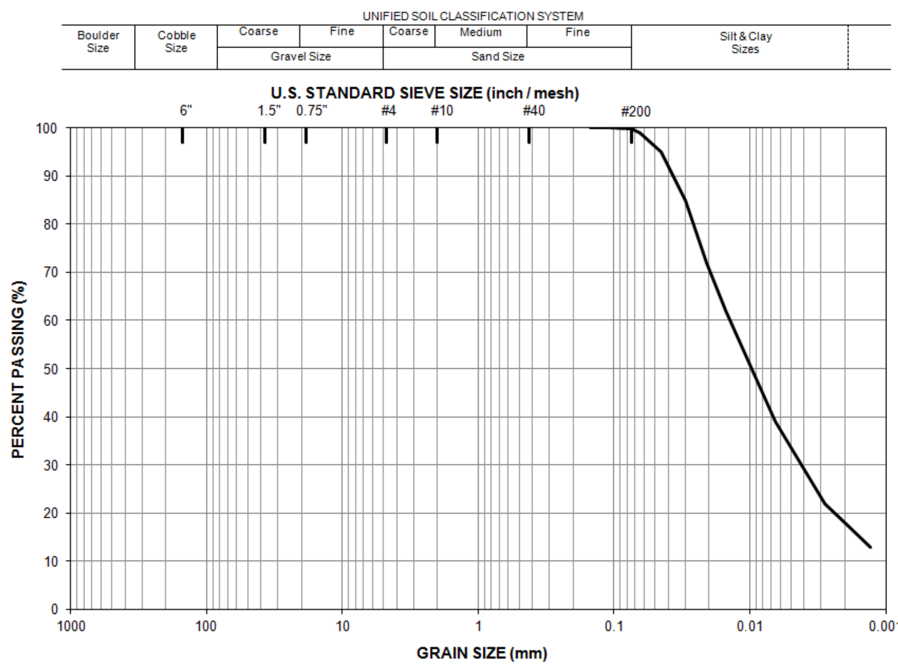

Figure 14: Particle Size Distribution of Thickened Tailings

5.4.3 Design Drivers for Tailings and Mine Rock Co-Disposal Facility

The project description in 2005 included an open pit, a mine rock facility, a carbon-in-leach process plant, a cyanide destruction circuit, a tailings management facility comprising a fully geosynthetic lined impoundment behind a cross valley dam, water supply reservoirs and the associated roads between the various mine facilities. A detailed review of the project revealed the following:

- Environmentally sensitive habitats were identified within the tailings management facility footprint area;
- There were small land holdings within the project area with absentee land-owners;
- Presence of downstream community water supplies; and
- The potential European Union ban on the use of cyanide in mining.

These prompted the re-design of some mine facilities, including:

- The use of cyanide has been eliminated; instead flotation will be used as the primary recovery process.
- The tailings management facility has been eliminated; instead the tailings will be co-disposed (Eldridge et al, 2011) with the mine rock at the previously mine rock facility footprint area.

5.4.4 Co-disposal Facility Concept

The concept for the co-disposal is that tailings dewatered to paste consistency will be placed within cells constructed from mine rock. The outer face of the facility will have a continuous face of mine rock. Mine rock not needed for construction of the outer face will be placed as internal berms to allow mine equipment access.

To prevent tailings being carried through the outer mine rock berm, a two zone filter system will be placed. This will consist of a heavy, non-woven geotextile directly against the mine rock and covered by a layer of sand. The sand will contain the tailings and the geotextile will prevent movement of the sand into the mine rock.

A schematic of the conceptual layout of the co-disposal facility is presented in Figure 15. The external faces of the completed portions of the co-disposal facility will be covered with topsoil and vegetated. This means that the co-disposal facility can be almost completely covered and reclaimed prior to the end of the mining operations.

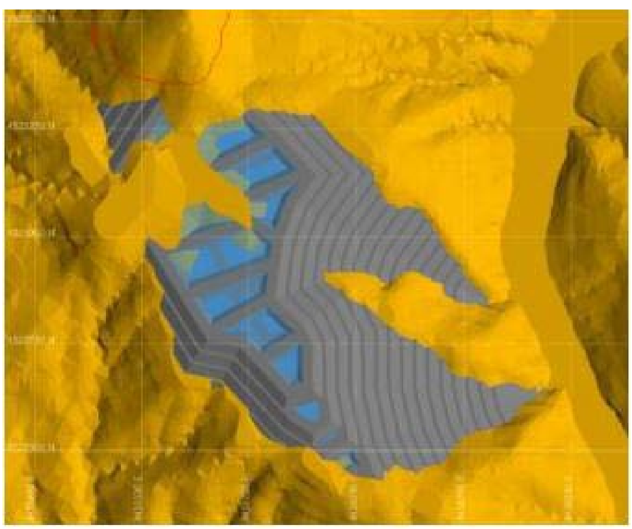

Figure 15: General Arrangement Plan of Krumovgrad Co-disposal Facility

The co-disposal facility development will involve placement of mine rock and tailings over previously placed tailings. The tailings will have little strength at deposition and will only gain strength with consolidation. The mine rock will promote drainage and consolidation of the tailings. The fine grained tailings require longer times to consolidate and have the potential to cause instability if rate of rise is too fast. The progress of tailings consolidation was predicted using void ratio versus hydraulic conductivity and void ratio versus effective stress relationships of the tailings. The tailings production rate and lift thickness were then used to define the minimum required footprint of working areas in the co-disposal facility.

The mine rock cells will provide containment to freshly placed tailings, but the overall stability of the co-disposal facility requires consolidation and gain in shear strength of tailings in the lower layers. Sensitivity analyses conducted to examine the effect of tailings strength on overall stability indicated that the outer rockfill berms should not be constructed over more than 20 m of undrained tailings. Stability is achieved by consolidation of the tailings and dissipation of excess pore water pressures. In operation, the progress of consolidation can be monitored using vibrating wire piezometers buried in each lift of tailings. Operation in multiple cells will allow flexibility to switch deposition between working areas to allow time for consolidation.

Water produced by consolidation of tailings and also from precipitation falling on the co-disposal facility will drain into the perimeter mine rock and then to the collection sumps located at two topographically low downstream of the co-disposal facility. Water collected in the sumps will be pumped to a water pond adjacent to the mill for use in process or treatment, if required, prior to release to the environment. The size of the water pond is relatively small as the water recovered from the dewatering of the tailings is directly circulated back to the mill.

5.4.5 Benefits of Co-disposal

The following are some of the benefits gained by switching to co-disposal of tailings and waste streams in the Project:

- The footprint area of the mine waste disposal facilities has been reduced by 57%, reducing the cost of land purchase and environmental impact.
- It reduced the closure cost and it minimized post closure water management requirements
- It provided an opportunity for placing the final cover on a large portion of the co-disposal facility
- It eliminated the need for tailings dam and the use of synthetic liner as low permeability barrier
- It eliminated the long-term liability associated with water retaining dams and unconsolidated cyanide tailings.

5.5 Nunavik Nickel Mine, Québec

5.5.1 Background

The mine is located at 61°32'N latitude and 73°28' W longitude in Nunavik, northern Québec. The mine has five ore bodies, four of which will be mined out through open pit operations and one through underground operation. Based on the current estimate, the mine has about 14.7 Mt of ore which will be milled at an average rate of 4,500 t/d. The mine will generate approximately 12.2 Mt of tailings and 46.2 Mt of mine rock. The mine rock generated from each ore body will be deposited adjacent to its source and the ore from each ore body will be trucked to the Expo site for processing. Tailings generated from the milling process will be co-disposed with the Expo Pit mine rock.

The mine lies within the Arctic zone of continuous permafrost extending up to 400 m below ground surface with a thin active layer at the surface that thaws seasonally. The thickness of the active layer during the seasonal thaw is limited to the first 2-3 m. The average annual precipitation in the site is 600 mm and evapotranspiration is 222.5 mm (including sublimation). The average annual wind speed is 5.6 m/sec. The mean annual temperature of the site is -9 ºC.

5.5.2 Tailings and Mine Rock Characteristics

The particle size distribution of the blended tailings stream is shown in Figure 16. The tailings consisted of 18.8% of fine sand sized particles, 31.8% of silt sized particles, and 49.6% of clay sized particles. The average specific gravity of the tailings was 3.22. Both the tailings and the mine rock are potentially acid generating.

5.5.3 Tailings and Mine Rock Co-Disposal Concept

The tailings and the Expo mine rock will be disposed in an integrated facility close to the Expo Open Pit and the Process Plant (Figures 17 and 18). The mine rock generated by the Expo pit will be used to construct two tailings disposal cells, sharing an internal dyke. The tailings disposal cells will be constructed in stages as mine rock becomes available from the Expo open pit development. The excess Expo mine rock will be disposed in a standalone cell adjacent to one of the tailings disposal cell. The ultimate crest elevation of the tailings and mine rock disposal cells will be maintained below the nearby ridge elevations.

The two tailings disposal cells will be capable of storing all of the tailings that generate from the Project, with the exception of tailings generated during the last 7 months of mine operation which will be deposited in the Expo pit.

This slurry will be dewatered in a deep cone thickener to a target solids content of 72%. The water recovered from the dewatering process will be circulated back to the Process Plant. Thickened tailings will be transported from the thickener to the Tailings disposal cells for disposal through carbon steel piping and pumped using a positive displacement piston pump. A standby pump and an emergency tailings delivery pipeline will be available to account for maintenance or unscheduled downtime of the operating piston pump and tailings pipeline system. The emergency tailings delivery pipeline will end discharge at the active tailings disposal cell. Both tailings pipelines will be heat traced and insulated. A backup heat trace line will also be installed.

The base and the side slopes of the tailings disposal cells will be fully lined with a low permeability geomembrane. The co-disposal facility will be progressively closed with a geomembrane cover as each cell is filled. The geomembrane will be covered with a protective layer of coarse granular material. The Expo pit will be flooded at closure to provide a water cover over the deposited tailings.

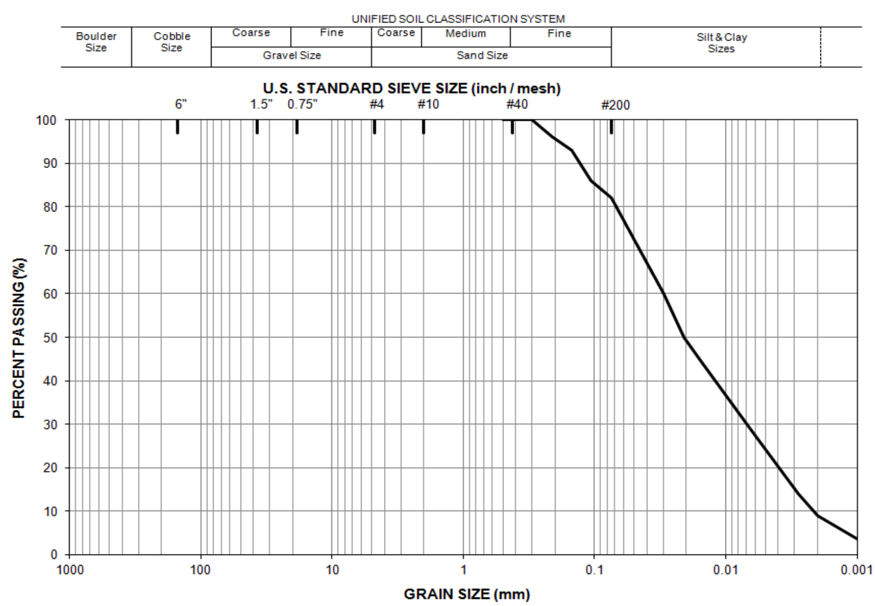

Figure 16: Particle Size Distribution of Nunavik Thickened Tailings

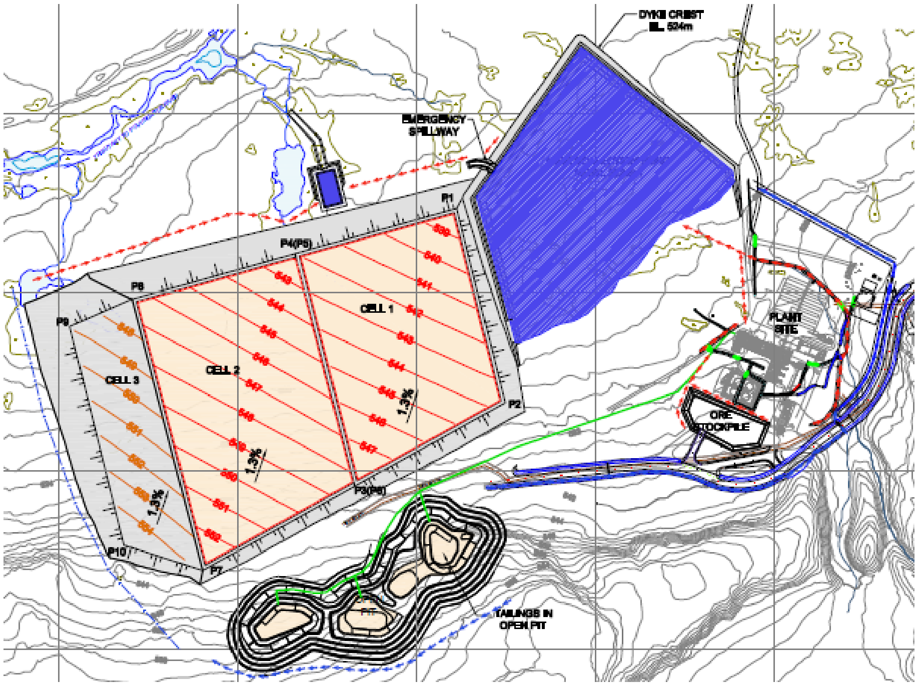

Figure 17: Expo Thickened Tailings and Mine Waste Co-disposal Facility

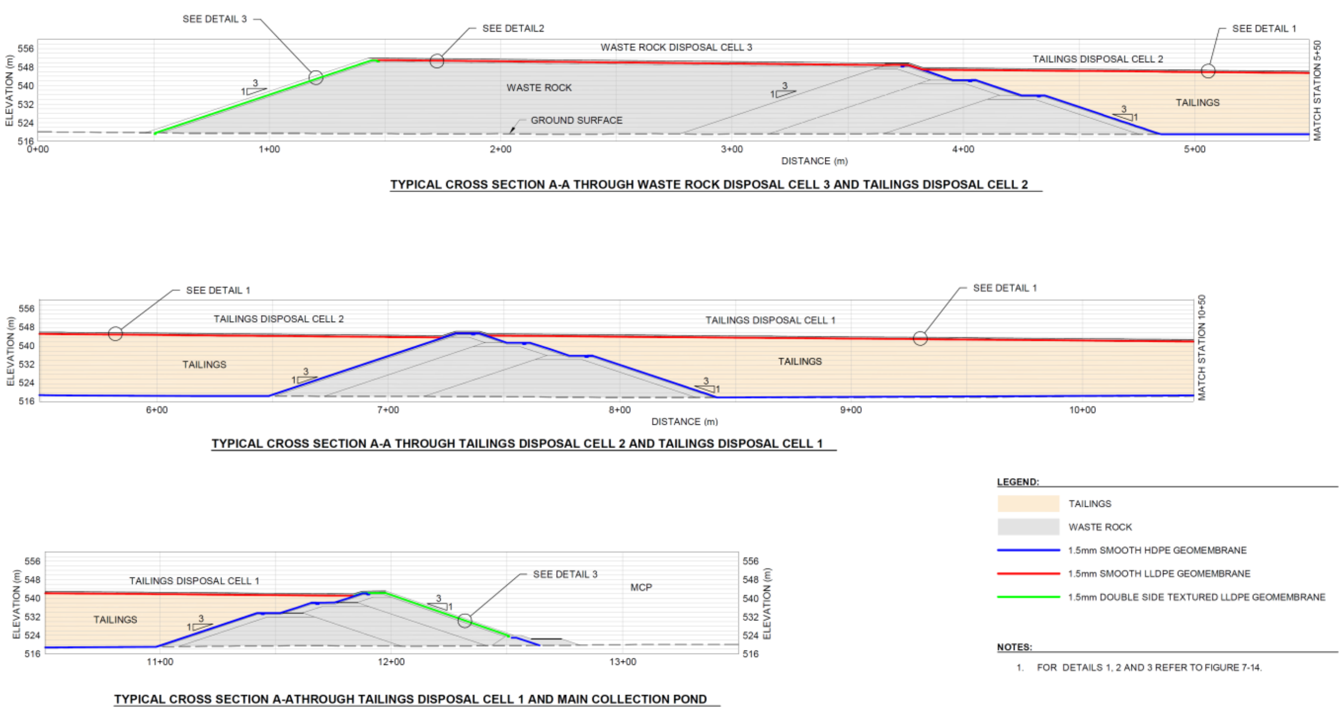

Figure 18: Cross-Section of Expo Thickened Tailings and Mine Waste Co-disposal Facility

5.6 Unnamed Mine, South Africa

5.6.1 Background

An operational polymetallic mine in east of South Africa started a major expansion in 2006. The proposed expansion of the mine will produce 125 Mt of tailings. The life of the mine is 19 years. The mine will have three tailings disposal facilities. The main tailings disposal facility is constructed about 12 km away from the mill and it will have a capacity to store 105 Mt of the tailings. A small lined sulphide tailings disposal facility, with an approximate storage capacity of 2 Mt, is constructed near the mill adjacent to old tailings disposal facility. The reminder of the tailings, 18 Mt, will be co-disposed with the overburden waste adjacent to one of the open pits near the mill.

5.6.2 Concept Design of Co-disposal Facility

The co-disposal facility involves construction two cells using overburden waste and mine rock for disposal of tailings slurry. The tailings will be pumped to the disposal cells at about 45% solids content. The tailings have 85% passing #200 sieve and 2% of clay sized particles (<0.002mm). The average specific gravity of the tailings is 3.21. The estimated dry density and permeability of the tailings are 1.85 t/m^3 and $1x10^{-7}$ m/s, respectively.

The general arrangement plan of the co-disposal facility is shown in Figure 19 and Photo 25. The cross section of the co-disposal facility is shown in Figure 20. The co-disposal facility is located in a valley. The initial stage of the co-disposal facility involves construction of the central dam. Subsequently, the central dam will be raised in a downstream construction method. Once the tailings level starts to get high, a dam will be constructed upstream of the central dam to its ultimate height. At a later stage, a dam will also be constructed downstream of the central dam. Tailings deposition will eventually burry the central dam. The downstream dam will be raised in a downstream construction method.

Surface flows occur along the co-disposal valley during the summer rainfall season. None of the streams are completely dry during low rainfall periods. Blasted mine rock was placed along the valley to channel out the spring water from the facility. A series of drains were also installed at the basin of the tailings disposal cells to remove tailings consolidation water. A water diversion ditch was also constructed to divert away clean water from reporting to the co-disposal facility.

The dams were constructed from bottom up in 1-1.5 m lifts (Photo 26). The overburden waste was hauled using CAT 785C mine haul trucks. Dozers and graders were used to prepare the surface for compaction using 10 t sheep foot and smooth drum vibratory rollers.

Tailings were deposited from spigot points along the dams. The tailings deposition aimed at pushing the tailings against the natural topography. A floating barge was used to pump the supernatant water for re-use to the mill.

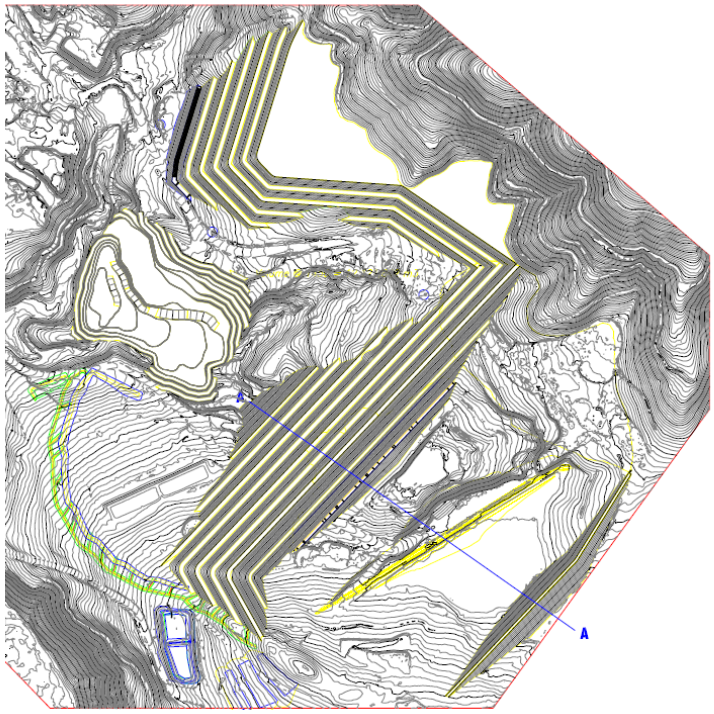

Figure 19: Plan View of South African Tailings Slurry and Overburden Waste Co-disposal Facility

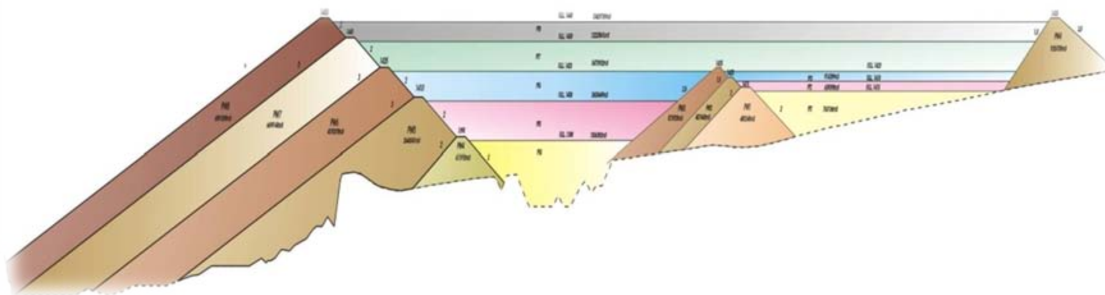

Figure 20: Cross-Section of South African Tailings Slurry and Overburden Waste Co-disposal Facility

Photo 25: South African Tailings Slurry and Overburden Waste Co-disposal Facility

Photo 26: South African Tailings Slurry and Overburden Waste Co-disposal Facility Construction

5.7 Brukunga Remediation Project, Australia

5.7.1 Background

The Brukunga mine is an abandoned mine located 40 km east of Adelaide in South Australia (Figure 21). The mine was a source of pyrite for fertilizer manufacturing during the mid twentieth century. The mine generated approximately 8 Mt of mine rock and 3.5 Mt of tailings during its operational years. The legacy of the mine is acid mine drainage with elevated concentration of sulphate and dissolved metal requiring continuous collection, treatment with lime and disposal of sludge. The acid mine drainage is collected from the tailings disposal facility, mine rock dumps, mine benches, and exposed ore body.

Figure 21: Brukunga Mine General Arrangement Plan

5.7.2 Characteristics of Tailings and Mine rock

The tailings facility has an oxidized surface, the thickness of which varies from 0.9 to 1.7m. The oxidized tailings are underlain by un-oxidized tailings. The tailings are estimated to comprise an average of 1.7% sulphide sulphur, predominantly as pyrrhotite. The pH of the tailings ranges from 3.2 to 5.8. The measured in-situ dry density of the tailings ranged from 1.35 to 1.45 t/m^3, which equates to porosity of about 0.45 to 0.55, assuming the range of specific gravity from 2.7 to 3.0. In-situ hydraulic conductivity of the tailings ranged from 1 x 10^{-5} to 1 x 10^{-6} m/s and 5 x 10^{-5} to 1 x 10^{-7} m/s for the oxidized and un-oxidized tailings, respectively.

The mine rock is estimated to comprise an average of 2% sulphide sulphur, predominantly as pyrrhotite. The pH of the mine rock ranged from 2.7 to 3.7. The average in-situ dry density and moisture content of the mine rock are 1.7 t/m^3 and 10%, respectively. The average porosity of the mine rock is approximately 0.2. The hydraulic conductivity of the mine rock was found to be approximately 1 x 10^{-6} m/s.

The grain size envelope of the tailings and the mine rock are shown in Figure 22.

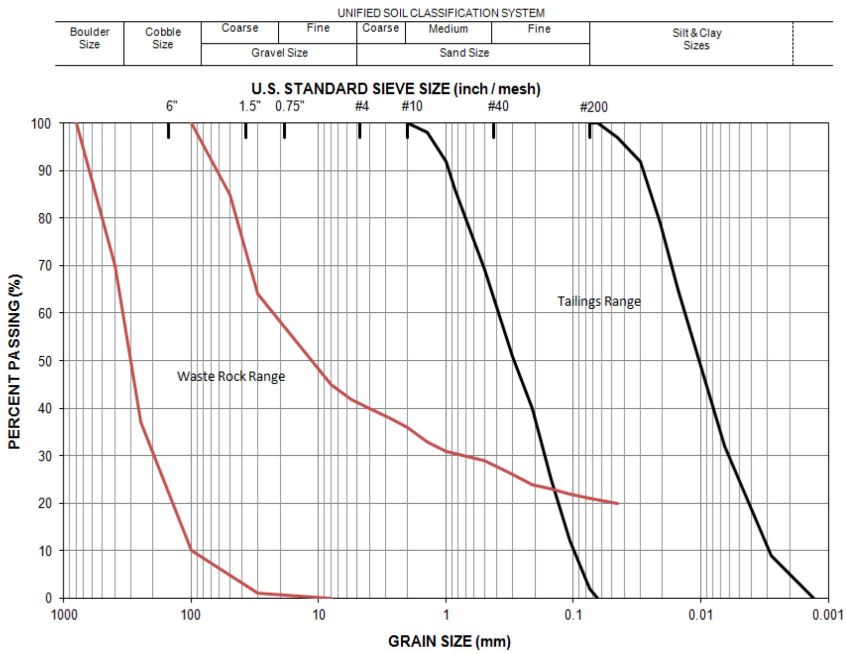

Figure 22: Particle Size Distribution of Brukunga Mine Tailings and Mine Rock

5.7.3 Co-disposal Concept

A number of options were evaluated to remediate the site completely to minimize the ever- increasing treatment, intervention, and maintenance requirements. The preferred concept was to co-dispose (Brett et al, 2011) the majority of the tailings and the mine rock by co-mingling and compacting them in areas where local stream flows can be diverted to maintain the saturation of the co-disposed material. Crushed limestone will also be added during co-mingling to neutralize oxidation products. The co-disposal facility will have a containment dam with low permeability element to ensure that seepage does not escape from the facility. The co-mingled waste would be covered with horizontal layer of permeable crushed rock overlain by soil cover suitable for vegetation growth, with recreated creeks over the final surface, able to feed water into the permeable rock layer to maintain the saturation of the co-mingled waste.

5.7.4 Co-mingling Trials

Laboratory and field tests were carried out to assess the effectiveness co-disposal for the remedial works. The particle size distribution of the tailings and the mine rock are shown in the figure below. For the tests the mine rock was mixed with the tailings at a dry mass ratio of 1.7:1 plus 1% of crushed limestone (Photos 27 and 28). The grain size distribution of the blend is shown in Figure 23. The blend is somewhat better graded than the mine rock and much better graded than the narrowly graded tailings, which facilitates achieving a high compacted density.

The results of the laboratory tests are summarized in the table below. This shows a weighted increase in density of the co-mingled waste of 15% and a halving of the permeability.

Waste	Moisture Content (%)	Dry Density (t/m^3)	Saturated Hydraulic Conductivity (m/s)
Scalped (<4.75 mm) trial waste rock	10.3	1.62	4.8 x 10–7
Trial tailings	12.8	1.43	8.2 x 10–7
Co-disposed WR:T = 63:37	14.0	1.78	3.0 x 10–7

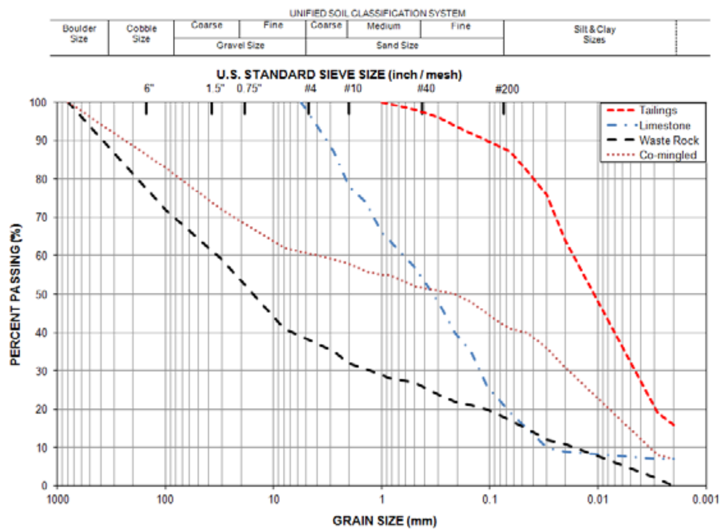

Figure 23: Particle Size Distribution of Brukunga Mine Co-mingled Tailings, Mine Rock and Lime Stone

Photo 27: Mine Rock used from Co-mingling

Photo 28: Tailings used from Co-mingling

Two field trials, each measuring about 15 m long by about 4 m wide by about 0.5 m high, were carried out. This comprised the compaction of mixed waste using a 10 t, smooth-drum, self-propelled roller. The co-disposal trial indicated that a compacted dry density of up to 1.85 t/m^3 (up to 97% of laboratory standard maximum dry density) is achievable at a moisture content of 16.5%, which is 3.2% wet of laboratory Standard optimum moisture content. This corresponds to a calculated degree of saturation of 90% (assuming a specific gravity of 2.8). Hence, at the as-placed gravimetric moisture content, the compacted mine rock/tailings mixture achieved near-saturated conditions. To fully saturate the compacted mine rock/tailings mixture would require only a 3.3% addition of water on a volume basis. Due to the higher dry densities achieved in the field, permeability testing gave saturated hydraulic conductivities an order of magnitude lower than was achieved in the laboratory (about 1.0×10^{-8} m/s in the field).

Oxidation tests on the compacted materials showed that:

- The low hydraulic conductivity, reasonable air-entry value, high water storage capacity and relatively small drying/wetting hysteresis of the compacted mine rock/tailings mixture suggest that it would have a high capability to hold water and remain saturated (or tension saturated) between rainfall events.
- The oxidation rate of a compacted co-disposed waste decreases approximately linearly with an increase in the moisture content of the mixture over a range of moisture contents from 5 (representing desiccated conditions with a degree of saturation of only 24%) to 19% (near-saturated at a degree of saturation of 93%), from 1.54%/year to zero.
- The higher dry density and hence higher degree of saturation achieved in the field for a compacted mine rock/tailings mixture would be expected to lead to lower oxidation rates than those achieved in the laboratory using scalped mine rock, and an oxidation rate of close to zero would be achievable in the field following compaction.
- Full saturation of the compacted mine rock/tailings mixture in the field would ensure an oxidation rate close to zero.

In summary, the co-disposal trials confirmed that it is technically and practically feasible to co-dispose and compact the mine rock and tailings to achieve a significant increase in dry density and a much reduced permeability. In addition, sulphide oxidation rates could be reduced to effectively zero if the wastes remain near-saturated.

5.8 Snap Lake, Northwest Territory

5.8.1 Background

Snap Lake is an operational underground diamond mine located about 220 km Northeast of Yellowknife, Northwest Territories at a latitude of 63°36’N and a longitude of 110°52’W. The mine has been in operation since 2007. The nominal daily processing rate of the mine is 3,150 t/d. The mine will generate about 22.8 Mt processed kimberlite (PK) and 1.73 Mt of mine rock over the 22 year mine life.

The climate is characterized by short, cool summers and long, very cold winters. The average annual temperature is approximately -7.5°C. The mean summer temperature is 9°C and the mean winter temperature is -24.5°C. Annual rainfall and snowfall totals are about 148 mm and 225 mm, respectively. The average thickness of the active layer is about 6 m. The permafrost thickness is expected to be at least 100 m.

5.8.2 North Pile Co-Disposal Facility

About 50% of the total PK generated during the life of the mine will be used as paste backfill. PK not required for underground paste backfill (about 12 Mt) and the mine rock (about 1.73 Mt) will be disposed in the North Pile Co-disposal Facility (Figure 24). The process plant produces PK materials in three size fractions: coarse (1.5-6mm), grits (0.125-1.5mm), and fines (<0.125mm). About 8.5Mt of the PK will be coarse and grit and the remaining 3.5 Mt will be PK fines. The PK materials are not potentially acid generating. Only about 20% of the mine rock is potentially acid generating.

The North Pile Co-disposal Facility (CDF) is planned to be about 90 ha in area with a maximum thickness of about 40 m. The North Pile will be sequentially developed in three phases: the Starter Cell, the East Cell and the West Cell. This will allow progressive closure of the CDF; as each cell is developed and filled, it will be covered with non-reactive rock. The PK materials and the non PAG mine rock will be used for the perimeter embankments of the CDF.

To date, the PK fines have been deposited as a slurry at 43-53% solids content in the Starter Cell and East Cell. The coarse and grits are dewatered to a solids content of about 84% at the process plant and are hauled and placed in the North Pile CDF using conventional earth moving equipment. Following start-up, the process plant will produce a paste stream by co-mingling the PK materials, comprising fines, coarse and grits fractions, which will then be pumped to North Pile for co-disposal. The co-mingled PK is anticipated to be pumped at 70-72% solids content. Currently field trials are being carried out to optimize the paste production. Paste pumping is planned to start at the first quarter of 2012, pending on the outcome of the field trails.

The North Pile Co-disposal Facility is not designed as a water retaining facility. The facility is operated to promote drainage of water through the perimeter embankments for routing and collection by the perimeter water control structures. Water collected in the perimeter sumps is transferred to the water management pond on an ongoing basis. Should water pond inside the North Pile CDF, it will be transferred to the water management pond.

Mine rock will be placed within the North Pile CDF. Depending upon the schedule of material, the mine rock may be used to construct the perimeter embankments. Rock type and geochemistry (i.e., non-acid generating or potentially acid generating) will dictate where within the North Pile the mine rock will be placed. Once paste is produced the perimeter dyke of the North Pile Co-disposal facility will be constructed out of deposited paste.

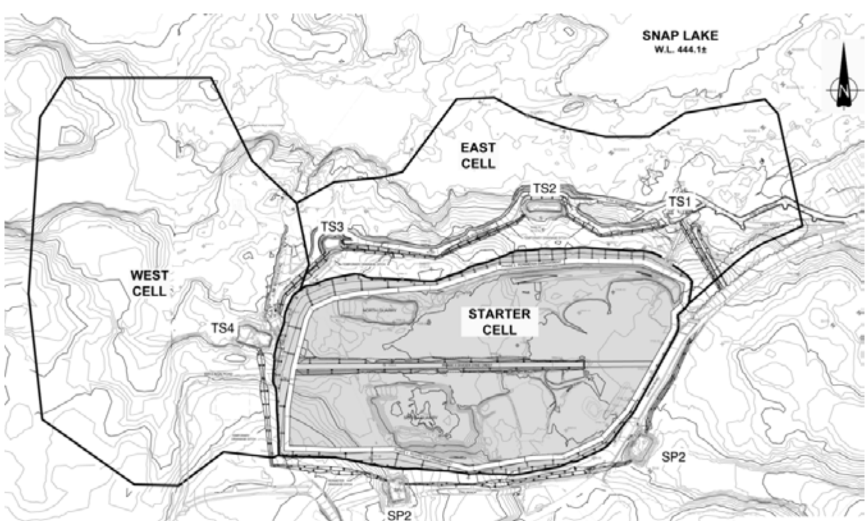

Figure 24: General Arrangement of North Pile Co-disposal Facility

6.0 CASE STUDIES OF SURFACE THICKENED TAILINGS FACILITIES

6.1 State of Practice

Tailings thickening technology has improved and tailings dewatering costs have decreased significantly over the years. Since the beginning of the 1990's the number of mines using surface disposal of non-segregating thickened tailings and paste tailings has increased exponentially (Williams et al., 2008). Mines in the cold climate that have used surface thickened tailings disposal include Kidd Creek, Musselwhite, Myra Falls, Cluff Lake, Snap Lake, Ekati, and Blagodatnoye. The experience gained from Kid Creek and Musselwhite surface thickened tailings will be discussed in greater details in the following sections.

6.2 Kidd Creek Thickened Tailings Facility

6.2.1 Background

The Kidd Mine is an underground base metal (Cu and Zn) mine located in the city of Timmins, Ontario at 48°41' N latitude and 81°22' W longitude in northern Ontario. The ore from Kidd mine is processed at the Kidd Creek Metallurgical site, located 17 km southeast of the mine.

The climate of the Timmins can be characterized by warm summer and cold winters with average temperature of 1.3 °C. Temperatures below -30°C are common in the winter. The average annual precipitation in the area is 873 mm, which consists of 581 mm of rainfall and 352 mm of snow. It generally rains from May through October and snows from November through March. The snow cover, which accumulates during winter, melts mostly during April. The average annual evapo-transpiration is 420 mm. The freezing index in the area is 1800 °C-days.

6.2.2 Thickened Tailings Disposal Facility

The Kidd Creek Metallurgical Site was one of the first mines to adopt surface disposal of thickened tailings (Robinsky, 1999). This mine has been operational since 1967 and thickened tailings have been deposited since 1973, with few problems in spite of the severe winters. The thickened tailings facility is currently receiving 8,000 tonnes of tailings per day at 61% solids content. A 35 m diameter high compression thickener is used to thicken the tailings.

At present, the tailings disposal facility is estimated to contain approximately 130 Mt of tailings (Kam et al., 2011). The facility covers a total footprint area of 1,250 ha, of which the active tailings deposition area is about 600 ha (Figure 25). The thickened tailings are deposited from a central cone. The cone is currently about 25 m above the perimeter dyke that retains the tailings. The radius of the deposited cone is about 1.2 km. The perimeter dyke is typically 3-4 m high and constructed of granular materials.

The tailings are acid generating with 10-14% of sulphide. The lag time to onset of oxidation ranges between 1 and 1.5 years.

The tailings contain over 80% silt and clay sized particles. The variation of the grain size distribution of the tailings obtained from different location of the cone is shown in Figure 26. It is evident from the figure that the tailings generally have similar gradation characteristics and remains non-segregating despite minor variations in the grind of the tailings over the time.

The hydraulic conductivity of the in-situ thickened tailings ranges from 1×10^{-7} m/s to 1×10^{-8} m/s with a decreasing trend with depth. Porosity of the deposited tailings is about 46% (which corresponds to 0.85 void ratio), varying by ±7% with depth owing to alternating summer and winter deposition. In summer the evaporation dewaters the surface of the tailings, thereby increasing the matric suction and consolidating to a lower porosity. The dry density of the deposited tailings is 1.58 t/m^3 and specific gravity is 3.1.

The tailings surface has an average slope of 2%. The tailings beach exhibits a concave surface with beach slopes varying between 4.5% at the point of discharge and under 1% at the perimeter dykes (Figure 27).

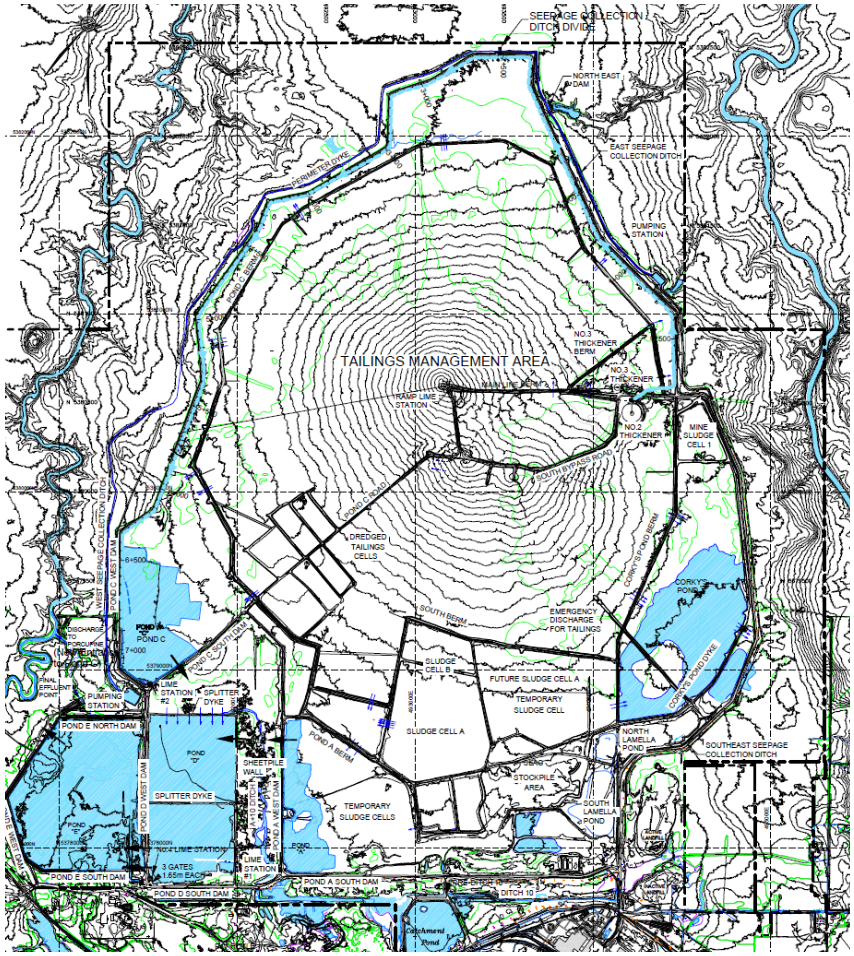

Figure 25: Kidd Creek Thickened Tailings Facility General Arrangement Plan

6.2.3 Performance Evaluation

The thickened tailings are discharged from the centre of the cone along the south by pass road. Typically, 3 to 4 spigots are used. Tailings deposition is changed typically between 3 and 6 weeks to ensure that the entire tailings deposition area is covered with fresh tailings on an annual basis. Maintaining the tailings beach wet helps reduce the potential for acid generation. The low hydraulic conductivity of the deposited tailings maintains a high degree of saturation, which limits the entry oxygen for acid generation.

The deposition method has also been effective in reducing channelization in the beach and promoting a steep slope profile, which minimizes tailings storage in the upper part of the cone and reduces the need for raising the perimeter dykes. The thickened tailings settle well with sheet flows observed a short distance from the source. Under freezing conditions and in the presence of snow, the thickened tailings have a greater tendency to channelize the tailings and travel a greater distance from the source. The winter discharge points are chosen to allow maximum settling on the beach.

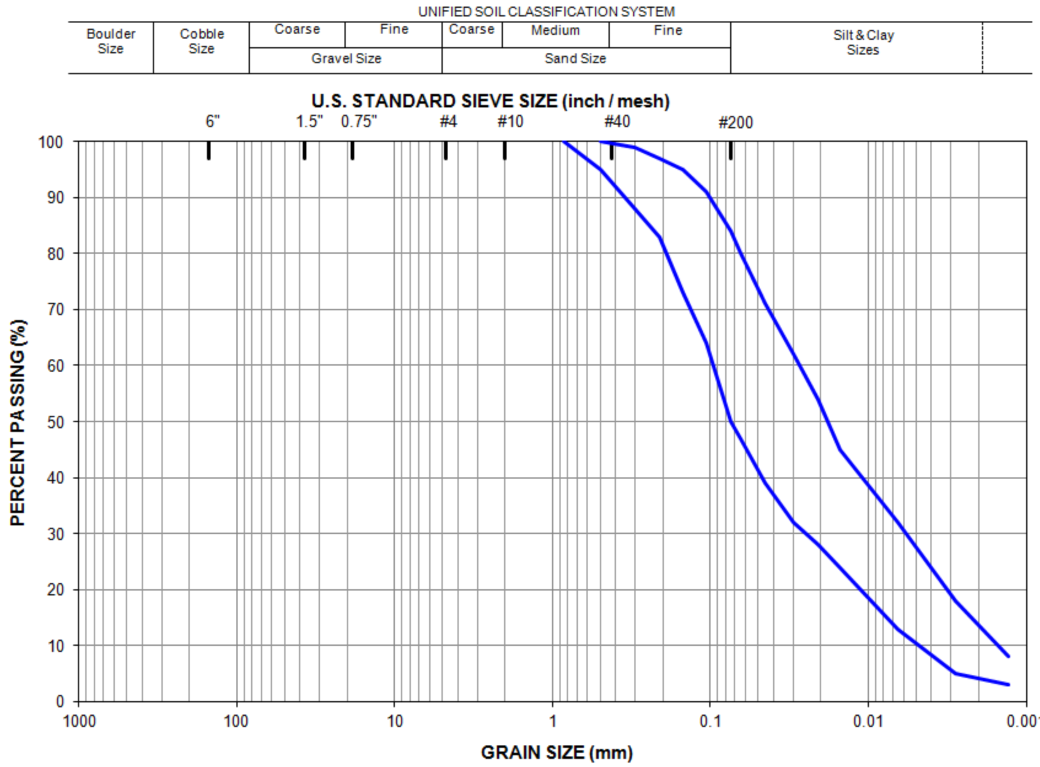

Figure 26: Particle Size Distribution of Kidd Creek Thickened Tailings

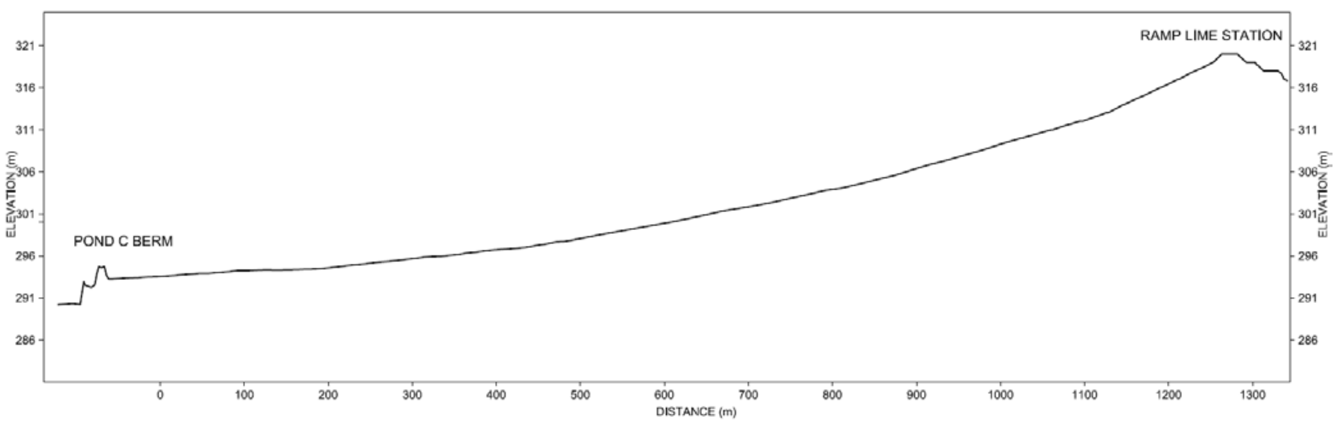

Figure 27: Musselwhite Thickened Tailings Facility Beach Slope

The potential for tailings erosion is relatively large. Flow channels should be stabilized to reduce requirements for pond maintenance and effluent treatment. Generally, the surface of the tailings cone is relatively free of erosion gullies. Keeping the tailings surface wet significantly reduces the potential for dusting (wind erosion). Robinsky (1999) showed that thickened tailings have a lower potential for dusting than conventional tailings.

The water table is generally at shallow depth in the tailings and it significantly fluctuates with the weather conditions. Generally, the water table is high after snowmelt and during the fall and low during the summer and the winter. Lower summer water tables rise in response to precipitation and a declining evaporation rate, to remain at high level through the autumn and early winter. Water table readily responds to individual rainfall storms, only to fall again during the dry period that followed the storm. This characteristic is typical of fine grained soils and it is related to the fact that the water table can rapidly rise through the capillary fringe (i.e., the tension-saturated zone) after an infiltration event of minor intensity. This is because capillarity maintains a hig degree of saturation well above the water table. The air entry value for thickened tailings at the Kidd Creek Metallurgical Site was found to be approximately 60-70 kPa. This means that the maximum thickness of the capillary fringe, above the water table, is about 6-7 m. Within the capillary fringe the tailings are cable of remaining saturated. Observation at the top of the thickened tailing facility cone, where unsaturated zone is more developed, indicated near-saturated condition within 1 m from the tailings surface. Within this upper 1 m zone, where the top of the capillary fringe fluctuates oxygen diffusion is predicted to be very slow owing to the water saturation.

On average year, approximately 42% of the precipitation will run-off, 51% will evaporate, and the remaining 7% will infiltrate through the thickened tailings stack.

6.2.4 Comparing Thickened With Conventional Tailings and Filtered Tailings

Thickened tailings provide several environmental performance advantages compared to conventional slurry tailings. Thickened tailings form a somewhat denser deposited mass because fine particles fill the void spaces between larger particles. In contrast, deposited slurry tailings segregate with the small-sized particles migrating to the toe of the beach and the coarse-sized particles remain near the deposition point. Coarse sand beaches become unsaturated allowing oxygen ingress and acid generation. Acid generation potential for thickened tailings is reduced due to high water retention characteristics and the maintenance of full saturation under negative porewater pressure. Oxygen diffusion into the matrix of the thickened tailings is minimized when saturation levels remain greater than 85%. The low hydraulic conductivity of the Kidd Creek tailings was found to maintain saturated conditions and to limit oxygen entry for acid generation.

Dusting can be a serious issue on sub-aerial deposited tailings in cold climates. Freezing temperatures tend to dehydrate exposed tailings and facilitate wind erosion of tailings. Moisture content and particle size distribution of the tailings, weather and wind speed all contribute to dust generation. Filtered tailings are deposited at very low moisture content and are therefore more prone to freeze-drying and dusting. Slurry tailings deposition results in segregation of coarse and fine particles, which also contributes to freeze-drying and dusting. However, the susceptibility of thickened and paste tailings to freeze-drying is reduced relative to slurry tailings since they are both non-segregating and have high moisture retention characteristics (Robinsky, 1999). The thickened tailings facility at Kidd Creek has performed well. Problems associated with freezing of thickened tailings during winter conditions have not been encountered and dusting due to wind erosion has not occurred (Kam et al., 2009).

6.3 Musselwhite Thickened Tailings Facility

6.3.1 Background

Musselwhite Mine is a 4,000 t/d underground gold mine located in northwestern Ontario, Canada. Gold mineralization is hosted within iron formation within folded mafic volcanics rocks. The mine uses a CIP process for gold extraction.

Musselwhite is located in a region where monthly air temperature can fluctuate from a maximum of 18°C in July to -21°C in January. The average annual air temperature is -0.5°C. Winter in the region begins in November and lasts for five months. Typically, the snow cover melts completely by late May. The average annual precipitation is about 733 mm and lake evaporation is about 410 mm. Musselwhite is located in a region with very low seismic risk.

6.3.2 Conventional Tailings Slurry Disposal Facility

The mine began operation in 1997 and by end of 2009, has produced over 16 Mt of tailings. During this period the tailings had been disposed of as conventional slurry at about 50% solids content in a facility situated about 2 km southwest of the mill complex. The tailings facility has a surface area of 133 ha and is bounded by topographic high grounds to the north and west. A series of engineered embankment dams, up to 15 m high, provided containment along a ridge on the south and east sides. The dams incorporated a low permeability central core that is keyed into the foundation. Deposition typically occurred along the perimeter of the tailings disposal facility with a pond maintained in the interior of the basin. Excess water in the tailings pond was pumped to a Polishing Pond before it is released to a wetland. Typically water was discharged in non freezing periods from May to November each year.

The tailings are acid generating with about 1.5% sulphur primarily in the form of pyrrhotite. However, there was no water quality issue associated with tailings oxidation as a result of the sub-aerial deposition.

Musselwhite increased its ore reserves that will extend the mine life to 2028. The expansion will generate an additional 32 Mt of tailings.

6.3.3 Thickened Tailings Disposal Facility over Existing Tailings Slurry Facility

Constructing a thickened tailings disposal facility above the existing tailings slurry was found to provide the required storage capacity for the 32 Mt tailings. Thickened tailings will be deposited from the west end from a discharge dyke. As the west cell fills, the dyke will be raised and progressively extended. Figure 28 shows a plan of the thickened tailings facility at end of mining. The discharge dyke will be raised, typically 2 m in height, in the upstream direction as illustrated in Figure 29. The overall slope will be maintained at a very gently profile to ensure stability and to facilitate final reclamation. On the south side, the discharge dyke will be offset about 50 m upstream from the perimeter dams. This buffer zone is needed to convey the thickener overflow to the tailings pond and to protect the perimeter dams from loading of the thickened tailings stack. During the entire operating period, the pond downstream of the Separation Dyke will be maintained at a constant level.

Construction of the discharge dykes of the thickened tailings disposal facility started in 2008 and deposition of thickened tailings started in 2010. The discharge dykes are constructed using sand and gravel. The crest width is 7 m and the downstream and upstream slopes are 2H:1V. The downstream is dressed with riprap to minimize erosion. In areas where the tailings surface was too wet, geogrid was placed over the slurry tailings prior to construction of the discharge dykes (Photo 29). Relatively, the construction of the discharge dyke over the deposited thickened tailings seems to be easier as it is not as soft as the slurry tailings (Photo 30). The discharge dykes are compacted in 0.5 m lifts using 10 t smooth drum vibratory compactors to 95% of the Standard Proctor Maximum Dry Density of the sand and gravel.

A 16 m diameter high compression thickener was used. The thickener is able to produce non-segregating thickened tailings at an average solids content of 70% (range 68-72%). The thickened tailings contain up to 70% particles passing the #200 sieve size (Figure 30). The tailings have a specific gravity of 3.25. The average dry density of the deposited tailings is 1.85 t/m^3. The deposited thickened tailings achieved an average slope of over 2 %. Beach slopes range from over 4% along the discharge perimeter to around 1.7% as it flows toward the interior. Figure 31 shows the beach slope as a function of distance from the point of discharge.

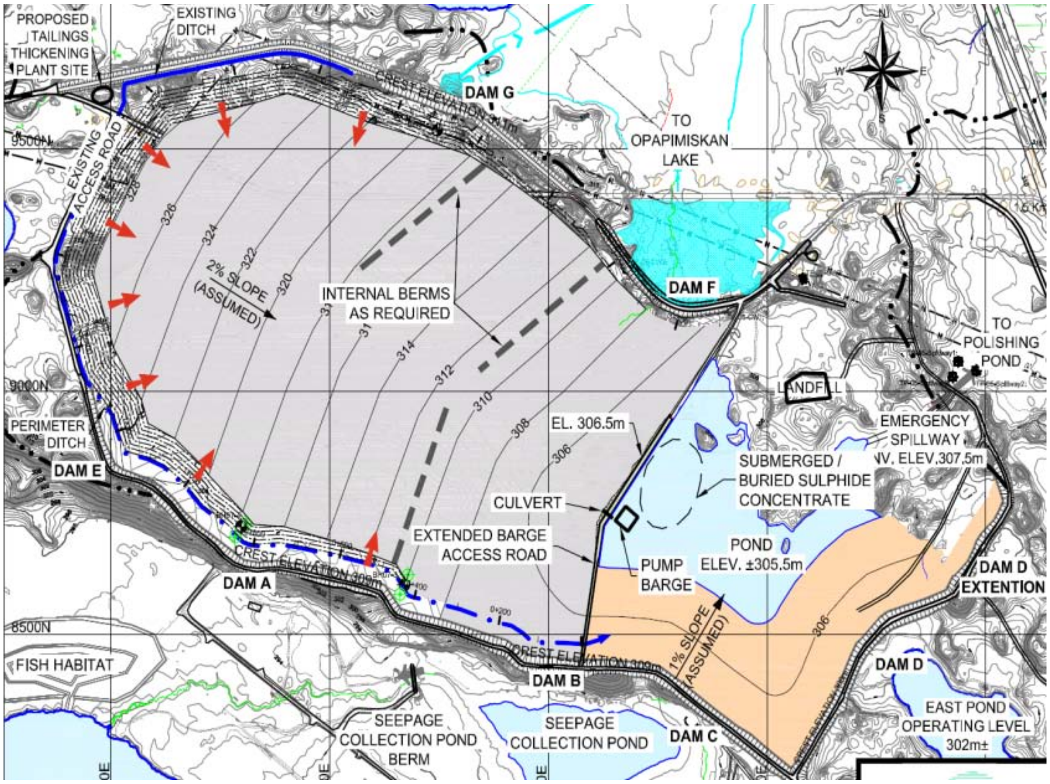

Figure 28: Conceptual Plan for 32 Mt Thickened Tailings Disposal Facility over Existing Tailings Slurry

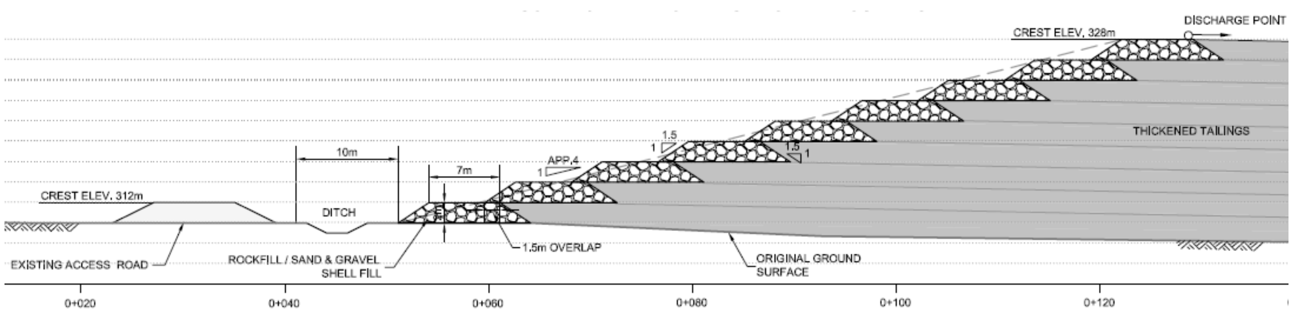

Figure 29: Cross Section of Conceptual 32 Mt Thickened Tailings Disposal Facility over Existing Tailings Slurry

6.3.4 Operation of Thickened Tailings Disposal Facility in Cold Weather

Musselwhite is located in a cold region where tailings deposition under extreme temperatures can be challenging. The risk of freezing of pipelines can be minimized by maintaining flow and in some cases, using heat tracing pipelines. Experience has shown that with the presence of snow, the tailings could have a greater tendency to travel a long distance in a stream and settling could be poor. It has also been observed that freezing may cause the tailings to form mounds on the beach.

From an operation perspective, the risk of tailings freezing near the point of discharge could be high because thickened tailings tend to settle more quickly compared to conventional tailings. The reduced water content in the slurry also means there is less latent heat. Given the uncertainty on the behaviour of the tailings, the current design contains a number of measures to improve operability in the winter. They include:

- Tailings will be end discharged in the winter;
- There will be an increase surveillance effort on tailings deposition;
- Thickened tailings operation can be suspended on a temporary basis;
- As a precaution against tailings mounding around the spigot, the underflow density could be decreased to 68 % solids to make the tailings more fluid;
- For the thickening plant, issues related to the design of the pipeline, the spigot arrangements and the prevention of freezing valves or pipelines to the ground. It was recommended to use heated doghouses up to 1 to 2 days ahead of time to thaw the valves; and
- The effectiveness of thickening and flocculent addition could be affected by ambient temperatures and should be monitored.

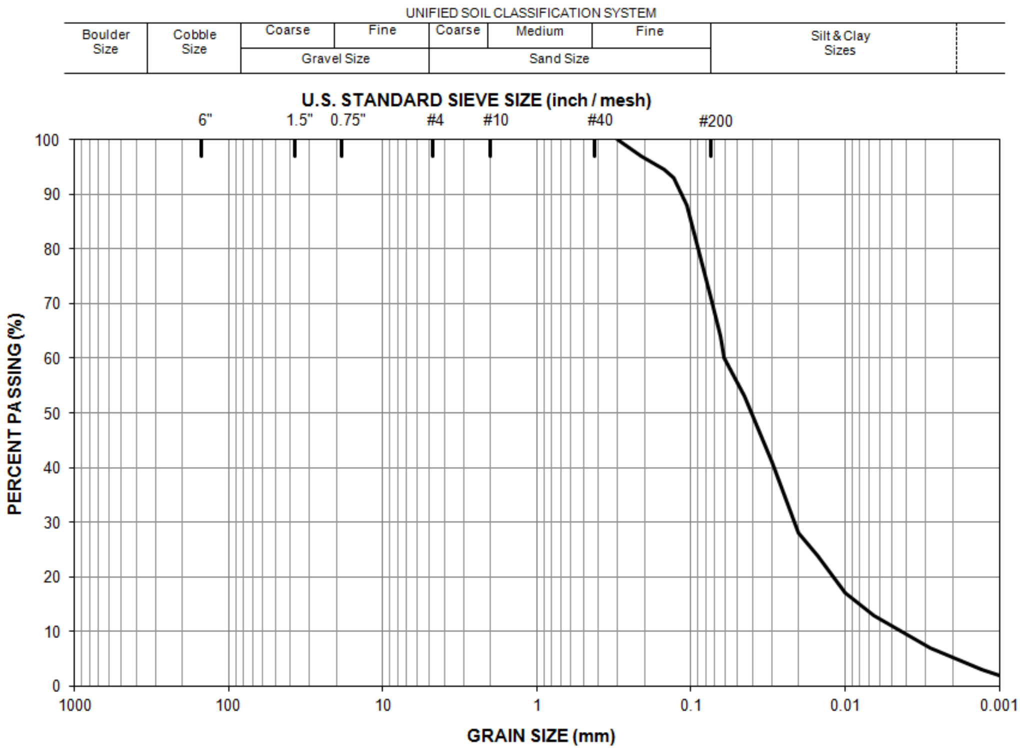

Figure 30: Particle Size Distribution of Musselwhite Thickened Tailings

Photo 29: Musselwhite Thickened Tailings Deposition

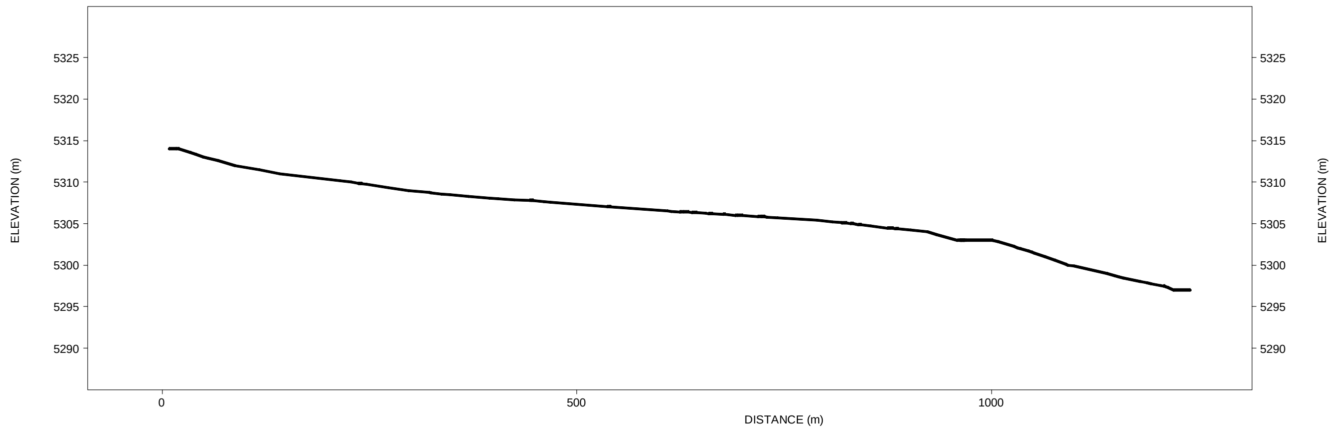

Figure 31: Slope Profile of Musselwhite Thickened Tailings

Photo 30: Typical Start-up Discharge Dyke Construction with Geogrid over Soft Tailings Slurry

Photo 31: Typical Raise 1 Discharge Dyke Construction without Geogrid over Thickened Tailings

7.0 CONCLUSIONS

The case histories provided demonstrate that the deposition techniques that are proposed for the NICO Co-disposal Facility have been used successfully at a number of sites around the world, and further that they have been applied in cold climates.

Yours very truly,

GOLDER ASSOCIATES LTD.

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Principal

KH/KAB

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