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Thickened tailings disposal at Musselwhite Mine

S. Kam *Golder Associates Ltd., Canada*

J. Girard *Goldcorp Canada, Canada*

N. Hmidi *Goldcorp Canada, Canada*

Y. Mao *Golder Associates Ltd., Canada*

S. Longo *Golder Paste Technology Ltd., Canada*

Abstract

Musselwhite Mine in Northwestern Ontario, Canada began thickened tailings disposal in May 2010. Surface disposal of thickened tailings for the 4,000 tpd gold mine was chosen following a series of studies beginning in 2002 to investigate options to expand the capacity of the tailings management area. This technology was considered most cost effective in maximising storage capacity within the existing site footprint. The elimination of a pond for closure will reduce the risk of dam failure. Further, the non-segregating tailings are expected to be relatively impervious and saturated. These characteristics will help inhibit tailings oxidation and reduce the likelihood of acid generating and metals leaching in the long term. Musselwhite Mine is currently planning to remove the sulphide minerals from the tailings stream using a flotation plant.

This paper discusses the design of the thickened tailings disposal system and presents preliminary observations on tailings deposition to date.

In preparation for thickened tailings disposal the tailings management area was partitioned by an internal dyke in 2008. This has allowed tailings to be 'stacked' using the upstream method of construction in the west cell and the east cell to serve as a water management pond.

The cold climate presents a special challenge to operating the thickened tailings system as there is very little precedent experience. The design has incorporated a number of contingency measures to facilitate tailings thickening and deposition in winter.

Field data have suggested that the thickened tailings system is performing very well to date. The thickening plant has consistently produced underflow at about 70% solids with minimal attention. The tailings beaches are steeper than expected. The deposited tailings are non-segregating and relatively saturated. The measured in situ dry density of the tailings is higher than expected. The performance of tailings deposition is being closely monitored.

1 Introduction

Goldcorp Canada's Musselwhite Mine is a 4,000 tpd underground gold mine located in northwestern Ontario, Canada. The mine began operation in 1997 and by end of 2009, has produced over 16 Mt of tailings.

The currently identified mine resource is expected to greatly exceed the capacity of the existing tailings management area (TMA), which was originally designed for 13.7 Mt. In 2002, Musselwhite initiated a series of studies to examine options for tailings disposal both within the existing project footprint and in a new tailings facility. The studies concluded that thickened tailings disposal would best meet the project objectives. A re-configuration of the existing TMA was undertaken in 2008. The thickened tailings plant was completed in 2009 and commissioned in May 2010.

This paper discusses key considerations that led to the selection of thickened tailings technology for surface disposal of tailings and presents the design of the thickened tailings system. A lack of precedent experience in similar cold climatic environment was a challenge for design. Preliminary field data are presented highlighting performance of the system to date.

2 Background

Situated about 2 km southwest of the mill complex, the existing TMA was formerly a small pond. The general area is underlain by extensive glacio-fluvial deposits. The TMA has a surface area of 133 ha and is bounded by topographic high ground to the north and west. A series of engineered embankment dams, up to 15 m high, provides containment along a ridge on the south and east sides of the TMA. The dams incorporate a low permeability central core that is keyed into the foundation. The starter perimeter dams were constructed in 1996 and subsequently raised in 2000 and 2005 to provide an intended capacity of 17.3 Mt with a shallow cover for closure.

The Musselwhite tailings contain about 1.5% sulphur primarily in the form of pyrrohite and have a NP/AP ratio between 0.2 and 1.2 indicating that it is acid generating (Yalcin et al., 2004).

Up until early 2010, the tailings had been disposed of as conventional slurry at about 50% solids. Deposition typically occurred along the TMA perimeter with a pond maintained in the interior of the basin. To date, there has been no water quality issue associated with tailings oxidation as a result of sub-aerial deposition.

Musselwhite uses a CIP process for gold extraction. An Air/SO_2 circuit is included to reduce cyanide loading in the process water.

Excess water in the tailings pond is pumped to the polishing pond before it is released to a wetland. Typically water is discharged in non freezing periods from May to November each year. Site discharge is also subject to satisfactory performance of the wetland in ammonia removal, which is temperature dependent.

Musselwhite is a region where sub zero temperatures prevail from November to March. The average monthly temperature for January is -20.7°C. Average annual precipitation in the region is 733 mm compared to lake evaporation of 410 mm.

3 Tailings properties

Gold mineralisation is hosted within iron formation within folded mafic volcanic rocks. The tailings have a specific gravity of 3.25 reflecting the iron content in the host rock. The tailings contain up to 70% particles passing the #200 sieve size. Figure 1 shows the particle size distribution of the Musselwhite tailings.

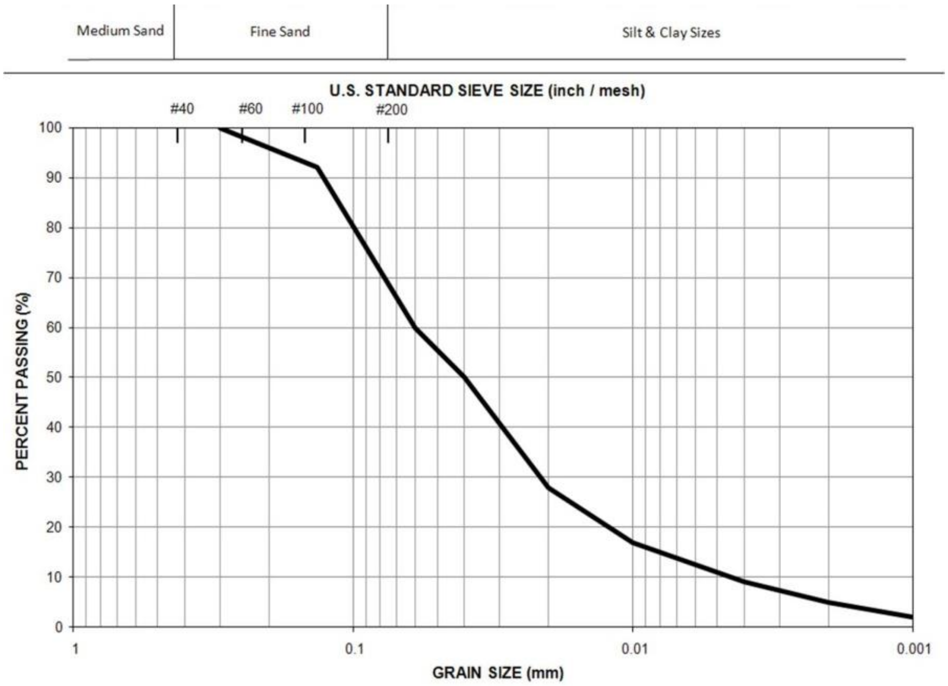

Figure 1 Particle size distribution of the Musselwhite tailings

The design average in situ dry density of the deposited tailings was assumed to be 1.6 t/m^3, which corresponds to an in situ void ratio of 1. The average deposited tailings dry density at end of 2008 was found to be 1.65 t/m^3.

4 Tailings expansion studies

On-going exploration efforts have significantly increased the ore resource beyond that originally anticipated. Currently Musselwhite is planning to extend the mine life to 2028 with a total tailings production of 32 Mt. The mill throughput is also expected to increase from 4,000 tpd to about 5,000 tpd in the near future.

In 2002, Musselwhite initiated a series of studies to investigate options to expand the tailings capacity. Different closure scenarios and tailings thickening techniques as well as feasibility to develop a new tailings basin north of the existing TMA were considered. It was concluded that expanding the capacity within the existing TMA footprint was the preferred option. A new TMA not only was inferior in total cost, it also presented much greater difficulty in managing the site runoff with uncertainty in permitting and meeting the environmental criteria for discharge.

Two possibilities exist for in basin expansion. The tailings can either be stacked, or the TMA depth increased by further raising the perimeter dams. The latter option was considered not viable because of a lack of topographic containment and that dam raising would be very challenging on the soft clay foundation that existed in part of the TMA.

Constructing a tailings stack above the existing dam level could provide the required storage capacity. However, a dry cover will be needed for closure. As an alternative, the sulphide minerals in the tailings could be removed. Test work completed by Musselwhite confirmed that it was feasible to reduce the sulphur content from 1.5% to less than 0.3% thus ensuring the tailings have an excess neutralising potential and acid generation would not occur (Yalcin et al., 2004). Removing the sulphide minerals from tailings has an added benefit of improving water quality in the TMA. For this reason, Musselwhite is committed to de-sulphur the tailings in the near future.

Conventional slurried tailings require a large pond for solids settling, which is a major constraint to increase the storage capacity of the TMA. Thickened tailings disposal was chosen because of the non-segregating nature of the tailings. This type of operation typically does not require a large settling pond. Compared to conventional slurried tailings, thickened tailings or paste tailings have the following benefits:

- reduced water use
- a smaller overall footprint
- improved water management (less overall water to manage)
- steeper tailings beach slopes
- better moisture retention and a higher degree of saturation (better able to inhibit tailings oxidation)
- lower potential for dusting
- less seepage (lower tailings permeability)
- conducive to reclamation (no slime pond)
- lower risk of failure (no sizable tailings pond upstream of dam).

The feasibility of thickening the tailings was confirmed in a series of test work completed (PasteTec, 2006, 2007; Outokumpu, 2006). Results of bench scale and mini-pilot scale thickener testing indicated that thickener underflow densities between 70% and 74% solids could be achieved.

5 Tailings deposition and closure considerations

5.1 Design criteria

The following criteria were selected for the thickened tailings system:

- The TMA is to accommodate 34 Mt of tailings.
- Design minimum beach slope is 2%.
- A tailings pond will be maintained to meet water management objectives. The pond will be of sufficient size to ensure water quality will remain acceptable.
- Tailings deposition must not interfere with pump barge operation.
- The TMA should include designated areas for the disposal of the sulphide concentrate, once the flotation plant is in operation.
- Contingency measures are provided for thickener upset.
- The TMA can be rehabilitated to meet stability and environmental protection requirements.

Thickened tailings disposal has a number of environmental benefits over the original design that required the tailings to be submerged below a shallow pond at closure. The TMA seepage will be reduced so will the risk of dam failure. The site will be aesthetically more compatible to the surrounding landscape and require less surveillance, care and maintenance than a flooded pond.

5.2 Deposition alternatives

Two general concepts for thickened tailings disposition were considered. The first involves discharging tailings from the centre of the TMA with one or more towers. Examples of this type of operation include Kidd Creek Metallurgical Site in Timmins, Mount Keith tailings area in Western Australia and Bulyanhulu Mine in Tanzania. Tailings discharge will result in a cone shaped TMA with the high point at the discharge locations. This type of deposition is simple to operate and is well suited to relatively flat terrain. In a relatively small TMA the lack of control on beach formation from a central discharge location could require frequent raising of the perimeter dams and present difficulty in managing site runoff. There are also technical challenges in establishing the discharge mechanism on saturated tailings in the centre of the existing TMA. Thickened tailings may also be discharged from the perimeter of the TMA as conventional tailings. This method was adopted because it provides a greater control on tailings deposition as discharge location and method can be adjusted based on field performance. Such a level of control was considered essential to maximise tailings storage in the existing footprint and to ensure that corrective action can be taken to meet the deposition objective.

5.3 Deposition plan

Thickened tailings will be deposited from the west end of the TMA from a discharge dyke. As the west cell fills, the dyke will be raised and progressively extended. Figure 2 shows a plan of the TMA at end of mining. The discharge dyke will be raised to a maximum elevation of 328 m in the upstream direction as illustrated in Figure 3. The overall slope will be maintained at a very gentle profile to ensure stability and to facilitate final reclamation. It should be noted that Musselwhite is located in a region with very low seismic risk. No liquefaction of the tailings was predicted under the 0.072 g, 1,000 year return earthquake event. The dyke raises will be typically 2 m in height. On the south side of the TMA 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 tailings stack.

The overall tailings beach slope is expected to be 2%. During the entire operating period, the pond downstream of the Separation Dyke will be maintained at a constant level.

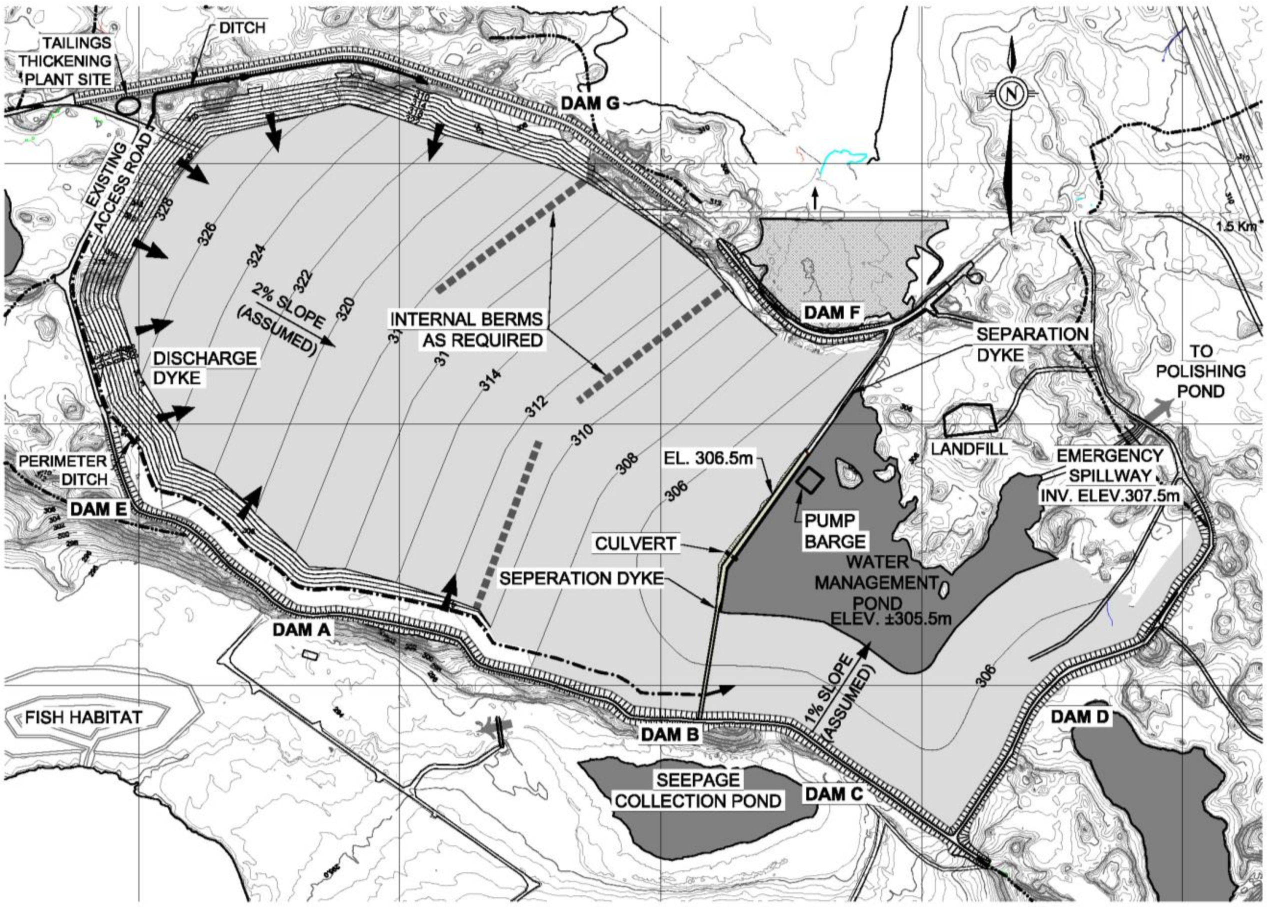

Figure 2 **Conceptual 32 Mt tailings deposition plan**

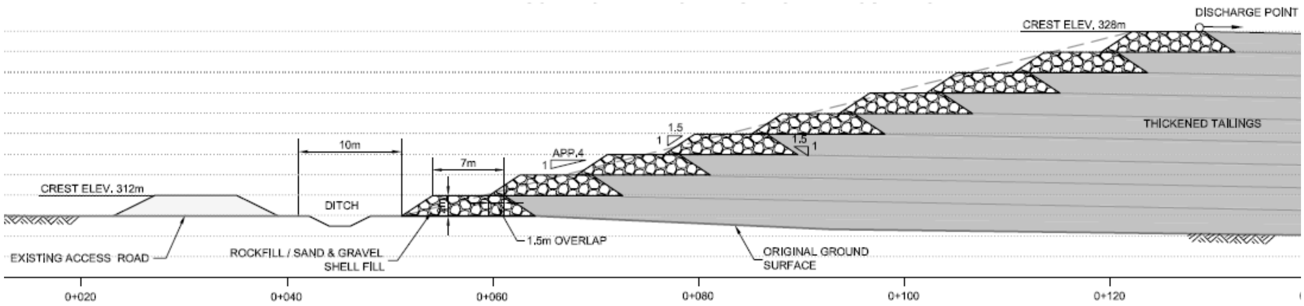

Figure 3 **Stacking of thickened tailings**

5.4 Closure and reclamation

On completion of mining, the tailings pond will be lowered by the provision of a spillway on the north side of the TMA. The de-sulphurised tailings are not expected to be an environmental concern for closure; the tailings surface will be covered with a growth medium and re-vegetated. The tailings in the east cell and downstream of the discharge dyke that will not be covered with the de-sulphurised tailings will be capped with a dry cover. Some of the dams and dykes will be contoured and re-vegetated.

6 Thickened tailings plant design

Musselwhite commissioned a laboratory testing program to confirm the feasibility to thicken the Musselwhite tailings, up to a paste consistency in 2002. Subsequently Outokumpu completed a mini-pilot plant dewatering test on the Musselwhite tailings (Outokumpu, 2006). On the basis of the available test data, a conceptual design of the surface paste tailings system was prepared (PasteTec, 2006) and pre-feasibility level engineering of the thickened tailings plant completed in 2007 (PasteTec, 2007). In addition, a trade off study was carried out to determine the optimum plant location between the mill site and the TMA. Detailed engineering of the thickened tailings plant followed in 2009.

6.1 Laboratory testing

Comprehensive material characterisation was completed to determine the properties of the tailings for surface disposal. The main objectives of the testing program were to determine:

- the dewatering characteristics of the tailings
- the ability of the thickened tailings to retain water
- engineering properties of the thickened tailings at various consistencies.

Bench test and field pilot test results indicated that the Musselwhite tailings could achieve an underflow density of 70% solids, at a feed density of 18% solids and with the addition of Magnafloc 351 at a dosage of 15 g/t (Outokumpu, 2006). These results were in general agreement with settling test results that suggested the optimal feed density was 15% with FA 920 VHM at a rate of 25 g/t (PasteTec, 2007).

The slump vs. solids content relationship was developed to investigate the sensitivity of the thickened or paste tailings to water content. The Musselwhite tailings had a measured slump of 250 mm at a solids content of 77.3%. At a density of around 70% solids, the tailings slurry essentially behaved as thickened slurry with no measurable yield stress as shown in Figure 4. A review of literature indicated that the proposed tailings density is higher than the Kidd Metallurgical Site at 61% (Kam et al., 2009) and an unnamed operation in South Africa at 53–55% (Addis and Cunningham, 2010). Both of these facilities produced non-segregating tailings with relatively steep beach slopes.

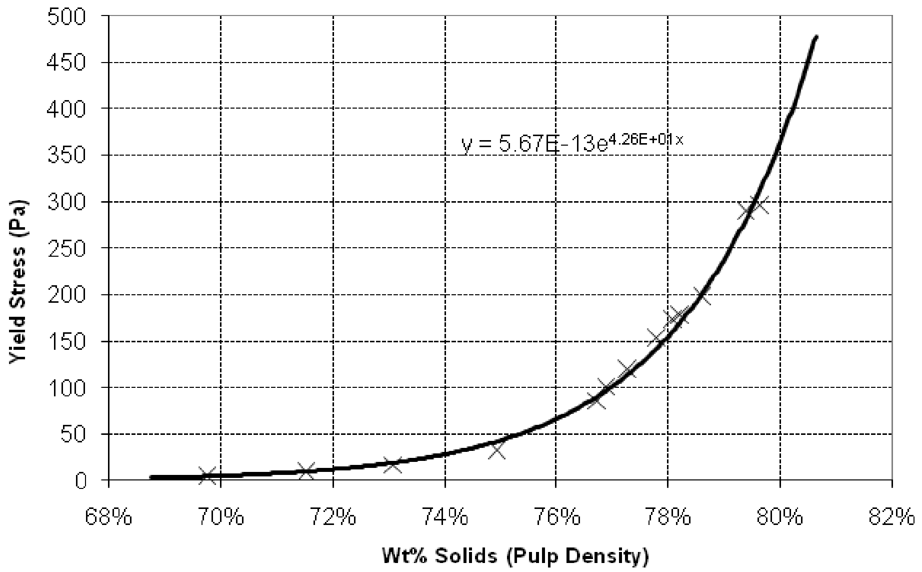

Figure 4 Yield stress – pulp density relationship

6.2 Plant process design

The tailings thickening system consists of a 16 m diameter high compression thickener (HCT) located adjacent to the thickening plant, as well as a flocculant system with assorted pumps and tanks located in a separate building. The thickener is fed from the mill via the existing tailings slurry pipeline. The slurry enters the thickener feedwell at approximately 50% solids where it is diluted to 18% solids using the thickener automatic dilution system. Flocculent at a dosage of 20 g/t was originally expected to be added to the tailings slurry but was subsequently reduced to 10–15 g/t after commissioning of the plant. The tailings then settle in the thickener tank, where they are dewatered to between 68–72% solids for deposition in the TMA. The operating range of thickener was chosen to provide some flexibility in varying the consistency of the underflow to suit field condition. In extreme cold weather, the underflow density may be lowered to reduce the risk of rapid tailings build up around the discharge pipe due to freezing. The plant was also designed to accommodate large fluctuations in the feed density and load.

6.3 Tailings distribution system

The tailings slurry may be discharged from one of the two 150 mm feeder pipes on the discharge dyke. The use of two separate lines allows tailings deposition to alternate between the north and south sections of the dyke. At each discharge line there are a number of spigots, spaced at approximately 50 m centres that can be operated independently. Typically tailings slurry is end discharged from a single spigot although multiple spigots can be operated at the same time. The thickener overflow is discharged into a ditch downstream of the discharge dyke. Options exist to direct the flow either to the north or the south side of the tailings stack.

7 Project implementation

Preparation for thickened tailings disposal began in 2008 with the construction of a starter discharge dyke for tailings deposition at the west end of the TMA, and the Separation Dyke to partition the TMA into a west cell for tailings deposition and a east cell for managing water. Construction of the thickened tailings plant followed in 2009. Musselwhite began thickened tailings deposition in May 2010. However, due to a delay in commissioning the thickened tailings system, the capacity of the starter discharge dyke was substantially exhausted by mid 2010. In summer of 2010, Musselwhite completed the second stage expansion of the dyke, which involved adding a 2 m raise in the starter dyke and extending it by 800 m. The construction is expected to provide one year of tailings storage capacity. Also in 2010, a protective dyke was completed upstream of the pump barge.

The overall cost of the thickened tailings plant was approximately AU$9M. Dyke construction between 2008 and 2010 amounted to approximately A$2.8M.

8 Field performance

8.1 Thickener

The thickened tailings plant has been operating well with no reported mechanical issues to date. Aside from periodical inspections four times a day, the plant has required very little attention. The underflow density is stable at about 70% solids (range 68–72%) over a wide range in feed densities from the mill. The thickener has been operating to specification with the plant having a throughput of about 4,000 t/day.

Reagent consumption is lower than expected. Due to thickening process for cyanide recovery in the mill, a flocculent dosage of 15 g/t was found to be satisfactory compared to the design rate of 20 g/t. It is expected that flocculent usage could be further optimised if overflow water was not being used as the water supply for gland water seals. Further investigation is underway to modify this situation.

8.2 Tailings deposition

Thickened tailings disposal was interrupted briefly between September and October 2010. During this period the tailings were discharged without thickening to allow construction of the toe ditch, which was required to convey the thickener overflow.

Since the commissioning of the thickening plant in May of 2010, thickened tailings have been discharged along the west and northwest perimeter of the TMA. Due to the shallow depth upstream of the starter dyke, the thickened tailings beach is relatively short (~100 m from dyke). A topographic survey plan showing the approximate extent of thickened tailings deposition (shaded) as of November 2010 is shown in Figure 5.

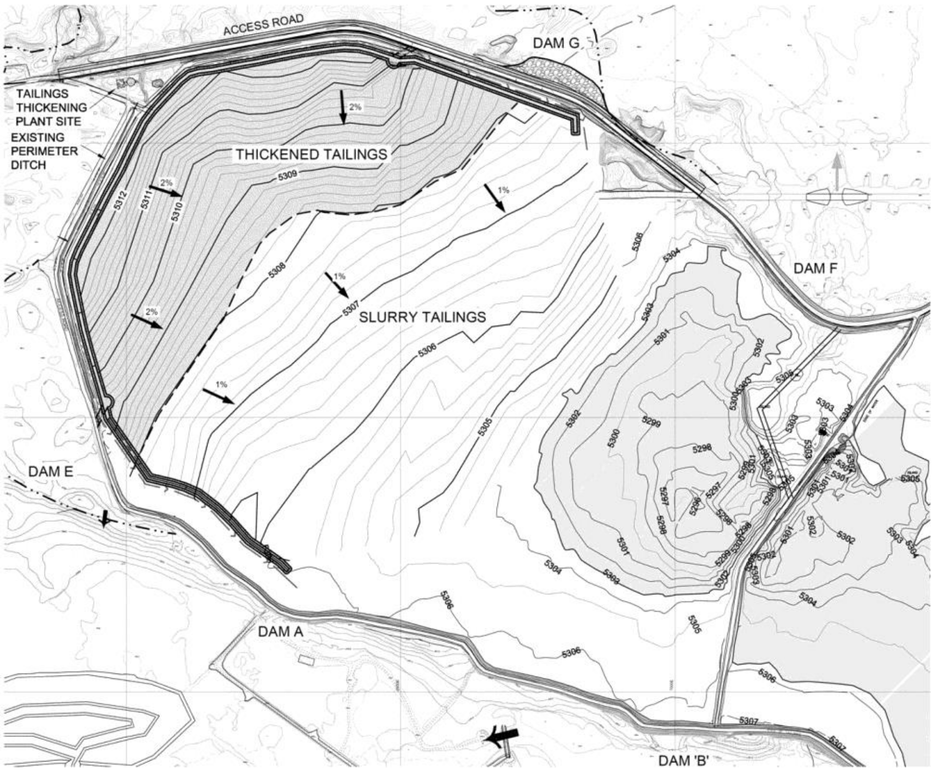

Figure 5 Approximate extent of thickened tailings deposition in November 2010

8.2.1 Beach slope

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 6 shows the beach slope as a function of distance from the point of discharge.

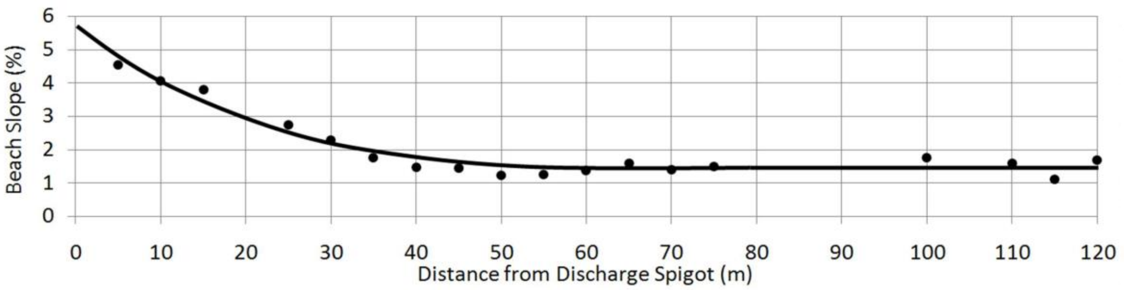

Figure 6 Slope profile of thickened tailings deposition

For comparison the conventional tailings beaches typically have a beach slope on the order of 1–1.5% within the same distance from the perimeter dams. It is noted that historical water level fluctuations in the tailings pond have had an influence on the beach profile along the shoreline.

8.2.2 Tailings sampling and in situ testing

A limited sampling program was completed on the thickened tailings beach. Samples of thickened tailings were collected from the west end of the TMA at distances ranging from 0–100 m from the discharge points. Sampling period started about two weeks following the end of thickened tailings deposition at a selected spigot and spanned from mid-September to late October during which no further deposition was carried out in the test area. Sampling areas remained in the general vicinity throughout the sampling period to maintain consistency for comparison purposes. Generally, it was found that accessing the tailings within the first two weeks of deposition was difficult as the surface was too soft.

Relatively undisturbed samples of tailings were collected using 3.5 and 6.9 cm sample tubes that were carefully pushed into the tailings. The tubes were then excavated for density and moisture content determination in Musselwhite's metallurgical laboratory. Bulk samples were also collected to determine particle grain size distributions. The samples were generally obtained at a depth of about 150 mm to avoid the surface material that might have been affected by exposure to the elements.

Shear strength of the deposited tailings were estimated using a hand-held vane (Geonor H-60). Vane tests were carried out in locations where cylinders and bulk samples were obtained.

Laboratory moisture content, measured and calculated densities, as well as field vane test results are summarised in Table 1.

Table 1 Summary of laboratory and in situ test results on deposited thickened tailings

Sampling Distance from Discharge Spigot	Date	Moisture Content, w	Dry Density from Cylinder Samples	Dry Density from S.G. & w	Vane Shear Strength
(m)		(%)	tonne/m^3	tonne/m^3	kPa
0	16/09/2010	26.03	1.82	1.78	34
	23/09/2010	23.85	1.83	1.85	58
	16/10/2010	23.08	1.92	1.87	54
	23/10/2010	21.37	1.97	1.94	50
10	16/09/2010	23.08	1.89	1.87	14
	23/09/2010	22.68	2.00	1.89	17
	16/10/2010	27.55	1.81	1.73	27.8
	23/10/2010	21.57	1.88	1.93	33.2
20	16/09/2010	25.97	1.79	1.78	8
	23/09/2010	25.07	1.85	1.81	10
	16/10/2010	27.14	1.83	1.74	14.6
	23/10/2010	23.36	1.83	1.86	25.4
30	16/09/2010	26.63	1.80	1.76	4
	23/09/2010	25.54	1.92	1.79	7
	16/10/2010	23.53	1.88	1.86	12.2
	23/10/2010	20.42	1.91	1.97	22
40	16/09/2010	29.40	1.83	1.67	N/A
	23/09/2010	26.02	1.85	1.78	5
	16/10/2010	27.50	1.80	1.73	9.76
	23/10/2010	22.75	1.84	1.89	11.2
50	16/09/2010	30.36	1.90	1.65	N/A
	23/09/2010	25.23	1.84	1.80	5.5
	16/10/2010	25.25	1.86	1.80	7.81
	23/10/2010	23.88	1.85	1.85	10.7

From the results, it was found that the deposited tailings experienced relatively slow drying throughout the 1.5 month monitoring period, with moisture contents dropping from 26–21% at the discharge location, and from 30–24% at a distance of 50 m from the discharge location.

The calculated dry density values for the deposited tailings ranged from 1.65–1.94 t/m^3, with an average of about 1.82 t/m^3. The measured densities from the tube samples were marginally higher at all locations indicating that the samples were highly saturated. There is a minute increase in densities within the 1.5 month of monitoring period at all sample locations; however, relationship between distances from discharge point and dry densities is not apparent.

Vane test results are plotted in Figure 7, which shows that strength gains were observed at all distances from the discharge point over the 1.5 month monitoring period. The exception is at the point of discharge where the tailings shear strength remained unchanged after initial drying. In general, the tailings shear strength reduces with distance from the point of discharge. This phenomenon appeared to have been associated with higher retained water content in the tailings (poor drainage in tailings). At a distance of 10 m from the discharge point the measured shear strength increased from 14 kPa in mid-September to 33 kPa by late-October. At 50 m distance the corresponding strength gain was about 10 kPa, up from less than 1 kPa during the same 1.5 month period.

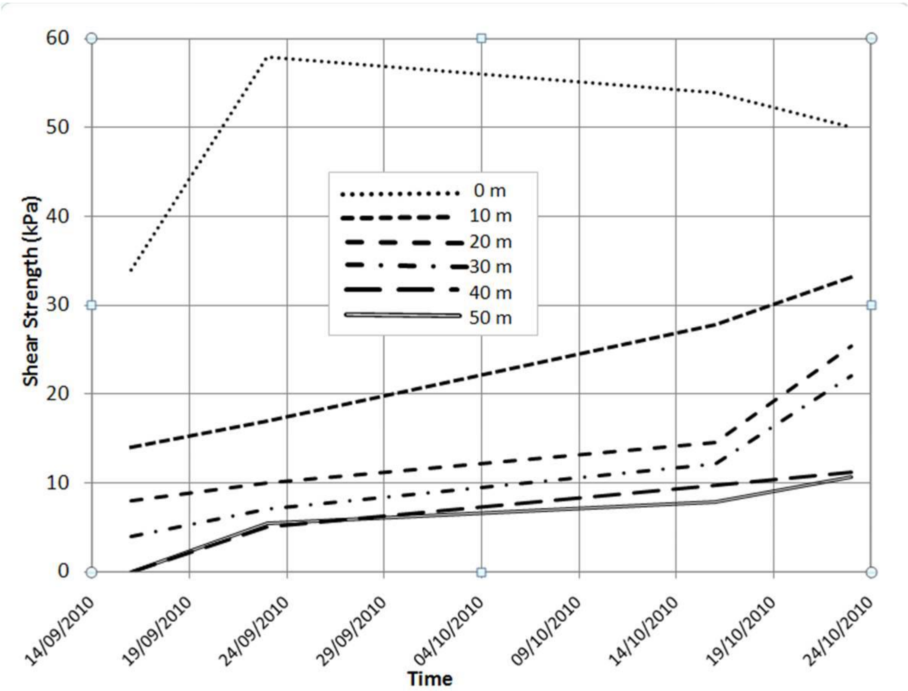

Figure 7 Shear strength variations with time

For the section of beach monitored, the tailings remained highly saturated immediately below the surface during the sampling period. This is consistent with the expectation that the tailings will be of relatively low permeability and highly saturated.

The bulk samples taken were analysed for grain size distributions using sieving and hydrometer methods. The results are shown on Figure 8. Test data for samples taken at a distance of 0, 30, 50 and 100 m from the discharge point confirmed that there was virtually no particle size segregation in the thickened tailings. Further, the tailings gradation is consistent with the full mill tailings shown in Figure 8.

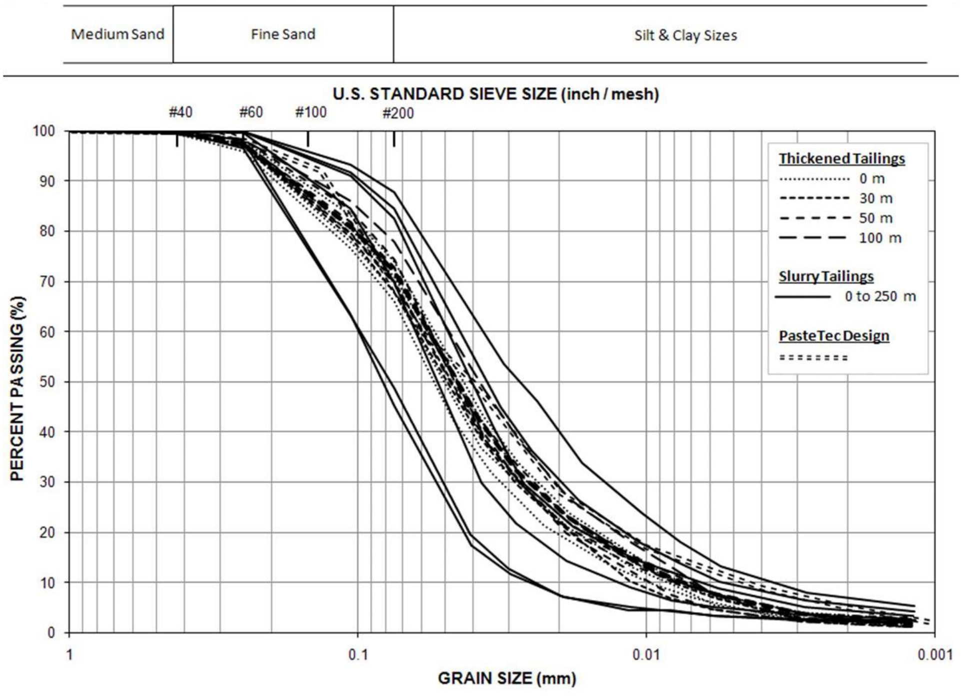

Figure 8 Grain size distribution curves for thickened and conventional tailings at various distances from the discharge points

In comparison, grain sizes of samples taken along the conventional slurry tailings beach clearly show signs of segregation as evident from the gradation envelope. As expected the coarser samples were obtained near the top of the beach. Within 50 m from the perimeter dams, the conventional tailings contained around 40–45% fines (passing #200 sieve). The fines content increased to up to 87% with distances between 100 and 250 m from the discharge point.

9 Cold weather considerations

Musselwhite is located in a cold region where tailings deposition under extreme temperatures can be challenging. The risk of freezing of pipelines can be minimised 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.

There is currently relatively limited experience in thickened tailings disposal in cold climatic condition. The performance of a similar system at the Kidd Metallurgical Site in Timmins has been good (Kam et al., 2009). 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.
- Provisions have been made to construct berms to intercept the tailings flow if necessary. Creating cells could prolong the service life of the tailings pond.
- Thickened tailings operation can be suspended on a temporary basis. This mode of operation will not adversely affect the overall TMA performance.
- 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 1–2 days ahead of time to thaw the valves.
- The use of a “lily pads” to insulate the top of the thickener was considered not necessary as long as the base of the thickener was insulated and the thickener remained in motion. This could be a contingency option should freezing of the thickener become an issue.
- The effectiveness of thickening and flocculent addition could be affected by ambient temperatures and should be monitored.

Field performance has been very good as of end January 2011. To date, no specific winter operation procedures have been required.

10 Conclusions

Musselwhite has adopted thickened tailings disposal to meet its needs for tailings management within the existing TMA. The added storage capacity was achieved through tailings stacking within the existing TMA footprint. This option is cost effective, more flexible and environmentally superior to other options considered. When fully developed the tailings stack will slope from the west to the Separation Dyke with an ultimate elevation of 298 m.

Tailings will be discharged from the TMA perimeter to maximise control on tailings deposition. This practice also required the least physical change in the TMA. The transition from conventional slurried tailings to thickened tailings disposal has been relatively easy.

To date the thickened tailings plant has performed to specification. The tailings underflow density has been relatively consistent at 70% over a wide range of feed densities from the process plant.

Limited field data collected since deposition started in May 2010 have indicated the overall beach slope is steeper than historical tailings beaches at Musselwhite and meets the design objective. Further, the tailings are non-segregating with a relatively high water retention capability. The tailings maintained a high water content over a five week monitoring period. The decrease in water content was accompanied with an increase in undrained shear strength. The measured tailings dry density values are about 10% higher than was previously observed for the conventional tailings (1.82 t/m^3 versus 1.65 t/m^3). On this basis, the actual capacity of the TMA is likely greater than predicted. These findings are preliminary and applicable to a relatively short section of the beach that may not have been fully developed. Further monitoring will be carried out in the coming years to assess the characteristics of the thickened tailings beach.

The Musselwhite thickened tailings system includes a number contingency measures to facilitate operation in extreme low temperatures. The thickener operation as well as tailings deposition will be closely monitored in winter of 2011 and appropriate field changes made to improve performance. The system has performed very well as of end of January 2011.

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