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Partially Saturated Granular Cover for Reactive Tailings in Permafrost Lupin Mine Experience, Nunavut, Canada

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Abstract

Rehabilitation of reactive tailings surfaces is a challenge worldwide and becomes even more so in the Arctic regions. A frequently proposed tailings rehabilitation concept for arctic mines is to encapsulate the tailings in permafrost that requires considerable cover thickness. Thick covers are, however, difficult to vegetate because of a lack of moisture near the cover surface. Published information shows that thick granular pads/covers do not support vegetation because of dryness at their surfaces. Exploration companies working in the National Petroleum Reserve of Alaska have adopted a practice to use thin gravel pads, less than 1 m, that encourages early natural revegetation.

Kinross Gold Corporation (formerly Echo Bay Mines Ltd) has covered some of the tailings cells with about 1 m of esker sand material at the Lupin Mine (Lupin) starting in 1995. Temperature, water level and water quality have been monitored to the present date. It was observed that the sand cover over tailings: a) maintained a saturated zone in the lower 0.3 m depth of the cover during the thaw season; b) water quality within the saturated zone is near discharge limits and is improving, and c) in areas where the cover thickness varies between 0.6 to 1.0 m it is supporting natural revegetation.

Research and field tests in southern climates have shown that a water depth of 0.3 m provides an oxygen barrier. Therefore the 1 m sand cover that is saturated in its lower part provides an oxygen barrier for the tailings. Whereas quite thick granular covers are required to provide complete permafrost encapsulation. Water cover research in southern climates and the seven-year monitoring data at the covered cells demonstrate the validity of a partially saturated granular cover design for the Lupin tailings closure. The attractiveness of this cover design is that it is not sensitive to yearly temperature fluctuations and global warming and can promote natural revegetation.

Introduction

Some mines produce waste rock and tailings that contain sulphide minerals that may lead to acid generation and metal leaching when they are exposed to oxygen and water (AMD). Many mines, past, present or planned, are located in permafrost regions. This is common in Canada where about 50 percent of the total land surface is located within permafrost. Permafrost has been defined as "a thermal condition in soil or rock having temperatures below 0°C persisting over at least two consecutive winters and the intervening summer" (Brown and Kupsch 1974). In the 1980's AMD was recognized as being environmentally detrimental. The mining industry and governments initiated the Canadian Mine Environmental Neutral Drainage (MEND) program for the understanding of AMD and to develop prevention and remediation measures. Most of the studies concentrated on the prevention and control of AMD in non-permafrost regions.

Permafrost regions provide an attractive environment for using the cold climate to construct frozen containment structures and encapsulate the sulphide bearing waste rock and tailings within permanently frozen ground. However, the development of effective preventive and control measures is complex in permafrost because the effect of air and ground temperatures, presence of ice within the ground, limited availability of construction materials and challenging construction seasons that have to be added to the design considerations applicable in non-permafrost regions. Furthermore, only limited case history information is available because many mines in the Canadian permafrost were closed before AMD was identified and some mines ran into financial difficulties leaving the sites in receivership

(Lauer 2001). The operating or just closed mines and two diamonds mines that have started operating recently are addressing metal leaching and are developing preventive and control measures. These mines are in various stages of developing reclamation plans, or are in the state of applying reclamation measures. This paper presents an attractive cover design for potentially metal leaching tailings in permafrost that is based on a concept proposed by Holubec (1993) and now supported by Lupin mine field data collected from a sulphide tailings cell that has been covered for about 7 years. The Lupin tailings operation is explained in a paper presented by Wilson (1989).

Tailings Cover Designs

Two basic cover designs for reactive tailings have been developed in the non-permafrost regions and one for permafrost regions (MEND 5.4.2d, 2001). For non-permafrost regions the two cover designs consists of 'dry' covers and 'water cover' and for permafrost regions it is proposed to cover the tailings with a sufficiently thick 'clean' (non-reactive) material that will encapsulate the tailings permanently within permafrost. Three covers and a range of their thicknesses are illustrated schematically in Figure 1 and are discussed in the next sections.

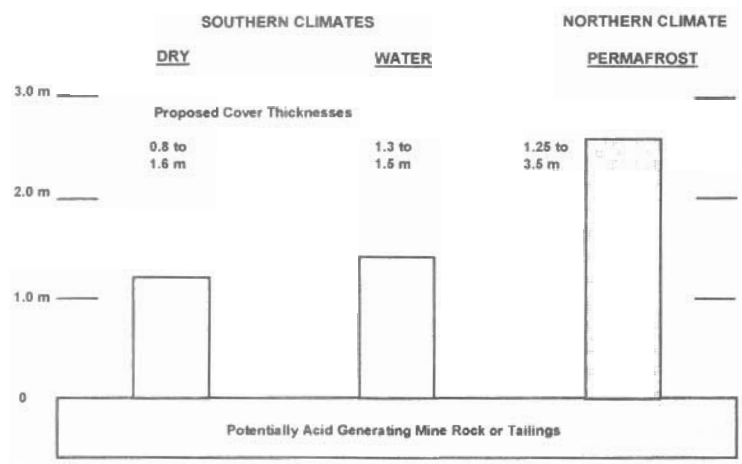

Figure 1: Schematic presentation of cover design to prevent or control AMD

Dry Covers

Dry covers have been widely used as an AMD preventive and control technique around the world. The objectives of the dry covers are to minimize water infiltration and provide an oxygen barrier. In most cases they do not stop sulphide oxidation and metal leaching completely and AMD seepage exits at the slope toes. They also are expected to resist wind and water erosion and provide a medium for vegetation. A wide range of cover designs have been used in the past; varying from a single layer of non-compacted soil to establish vegetation, dust suppression and control water infiltration to a multi layered cover that provides capillary control and decreases oxygen and water infiltration into the tailings (MEND 5.4.2d, 2001). The cover designs varied from a two-layer 0.8 m thick clay cover used at Equity Silver Mine (Aziz 1997) to reduce seepage, to more complex multi layer cover design studied at Waite Amulet (MEND 2.21.1, 1992) and Les Terrain Auriferes (MEND 2.22.4, 2000).

Most of these covers have used a clayey sandy gravel material (till) that is not commonly available in permafrost regions. It should also be noted that many of the mine sites where these covers were used continue to collect and treat water. This latter is not suitable for remote permafrost regions where access is not readily available after closure.

Water Covers

Research (MEND 5,4,2d, 2001) and actual mine site case histories (Davé and Vivyurka 1994) have demonstrated that water covers inhibit AMD. The depth of water over tailings is not governed by a criterion to create an oxygen barrier but to prevent tailings mobilization by wave action and ice scour (Atkins et al 1997). From theoretical studies that were also confirmed by field observations at Equity Silver tailings pond, it was determined that a water depth of 1.3 to 1.4 m is required (Atkins et al 1997) to combat wave and ice scour action. It is difficult to maintain a water cover in permafrost regions because the evaporation of water at the pond water surface is greater than normal precipitation in most Canadian permafrost regions (Latham 1988). Also it is costly to maintain the structural components of a water retention system in remote areas.

An important finding for the proposed partially saturated granular cover for permafrost regions is the research work done at Noranda Technology Centre that assessed the depth of water required to prevent oxidation of sulphide tailings under various conditions (Li et al 1997). They found that 0.3 m depth of 'stagnant' water is sufficient to inhibit tailings oxidation. This depth is supported by the results of two test-cells constructed adjacent to Louvicourt tailings pond (MEND 2.12.1c, 1992).

Permafrost Encapsulation Strategies

Encapsulation of reactive tailings within permafrost appears to be an attractive prevention and control option and has been pursued for some time. However, conclusive case histories are lacking because of the complexities permafrost poses and the lack of field information. Information is starting to become available from Rankin Inlet (Meldrum et al 2001), Nanisivik (Elberling 2001), and from Closure or Restoration Plans submitted to the respective Water Boards by Ekati Diamond Mine (2000), Diavik (2001), Nanisivik Mine (2002) and now Lupin. The development of a tailings cover design for permafrost and supporting monitoring results from Lupin where reactive tailings were covered about 7 years ago and dams and tailings temperature data have been collected for over 20 years (Geocon, 1990) are presented in this paper.

Conceptual or final designs for covers are in varied states of development. Cover design concepts that have or are being submitted to regulatory agencies are as follows:

- *Ekati* – A layered cover consisting of fine grain soils to retain moisture overlain by granitic waste rock. Anticipated thickness of 1.5 to 2.0 m.
- *Diavik* – A composite cover of 0.5 m of silty sand till overlain by 3 m of clean mine rock. Anticipated that the active zone will extend into the silty sand but the silty sand, being fully saturated, will form an oxidation barrier.
- *Nanisivik* – One meter of shale (sandy gravel sizes) covered with 0.25 m of esker sand and gravel. Permafrost is anticipated to stay within the cover.
- *Lupin* – Tailings to be contained within cells and covered with about 1 m of esker sand. Covers will be designed so that at least 0.3 m of the esker cover will remain saturated and thereby provide an oxygen barrier.

The proposed cover concepts are illustrated in Figure 2.

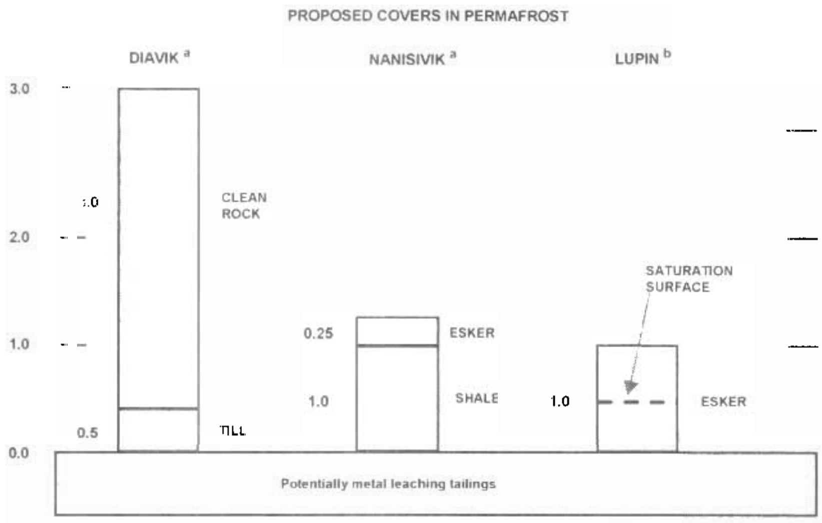

Figure 2: Proposed Cover Concepts of Reactive Tailings in Permafrost

Permafrost

The presence of permafrost and the depth of the active zone (depth to which the ground will thaw during the summer) are dependent on many factors and therefore are greatly variable. These are affected by the climate and terrain factors; such as, vegetation cover, overburden (soil or rock) and its saturation, snow cover, slope orientation and human disturbance or construction (Johnston 1981). The effect of these variables on the permafrost, and therefore also on the cover design are illustrated by the Geological Survey Canada compilation of the relationship between Mean Annual Air Temperatures versus Mean Annual Ground Temperature (GSC 2000) shown in Figure 3.

The scatter of data illustrates that for a given mean annual temperature there can be a range of mean annual ground temperatures. For a typical continuous permafrost location that has a mean annual air temperature of minus 10°C the mean annual ground temperature may vary from –3°C to –8°C. This range of mean annual ground temperatures is also indicative of the likely variation to active zone depth.

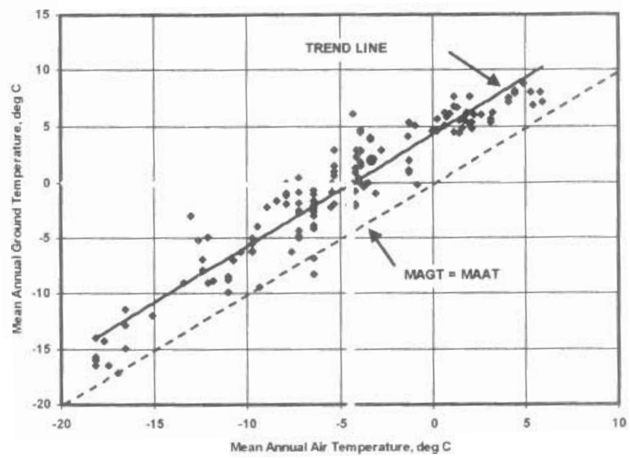

Figure 3: Relationship between mean annual air temperature and mean annual near-surface ground temperature (GSC 2000)

Extensive temperature monitoring over many years at the Lupin Mine illustrates a large variation of the depth of the active zone. The range of active zone depth for 4 stratigraphic conditions is illustrated on Figure 4.

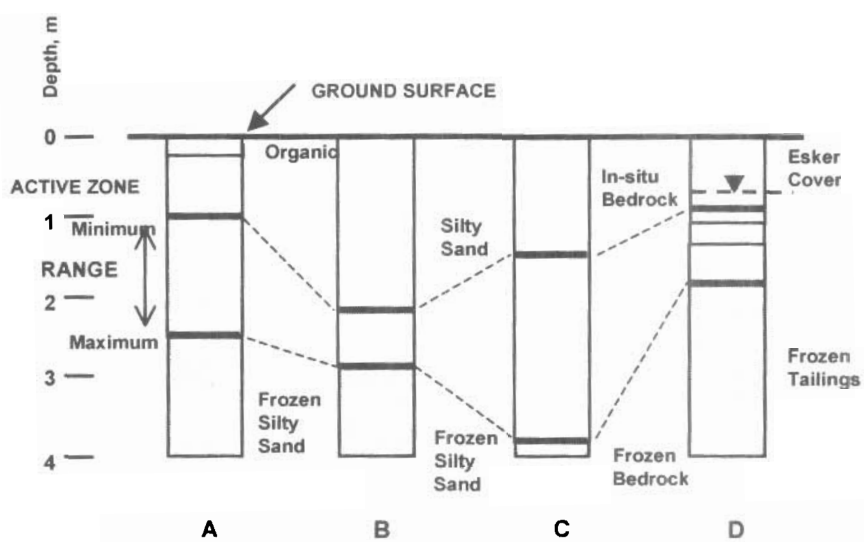

Figure 4: Depth of active zone for 4 stratigraphies.

A) Natural ground with variable vegetation cover thickness.
B) Moist silty sand below dam crest.
C) Local fractured bedrock.
D) Tailings covered with 1.1 m of esker sand and gravel.

The above illustrates that the depth of the active zone in natural ground with varied thickness of vegetation cover varied from 1 to 2.5 m (A); under the dam crests that are underlain by moist silty sand the active zone was observed to vary between 2.5 and 3.2 m (B); at local bedrock exposures with minimal or no soil cover and with local bedrock being fractured the active zone varied between 2.5 to 4 m (C) and finally at reclaimed tailings cells that have an average of 1.1 m of esker sand cover, and the bottom 0.3 m of the esker sand being saturated, the active zone was observed to be between 1.2 and 1.8 m (D). This variation of the active zone in the esker sand covered cell was observed across six locations within the reclaimed tailings cell.

While the depth of thaw varied across the covered tailings, the depth of thaw also changed over the 7-year monitoring period. The thaw depth changes during the summer at one thermistor monitoring station are illustrated in Figure 5.

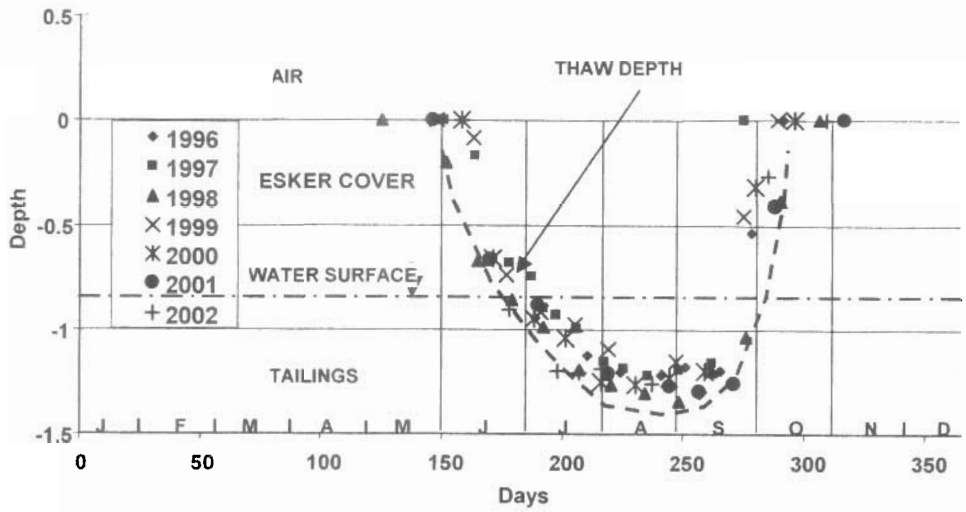

Figure 5: Variation of thaw depth in esker cover tailings

Figure 5 illustrates that at one location with the same stratigraphy the thaw depth can vary from year to year depending on the year's climate. At this covered cell location the thaw depth varied from 1.15 to 1.35 m during the 7 years of monitoring.

The data collected from Lupin shows that the active zone can vary from a maximum of 3.3 and 4.0 m within moist silty sand and fractured bedrock respectively to a minimum of 1.2 to 1.8 m in tailings covered with 1.1 m of esker sand. The first range would be representative of a 'dry' permafrost cover while the second range would be representative of a sand cover with saturation at its base.

It is concluded that the active zone depth at the Lupin Mine studied locations varied from 1.2 to 4 m. In areas with thick peat cover, the active zone would be smaller. The variation is predominantly dependent on the degree of water saturation or ice content. It is based on the conditions at the measured locations with normal snow covers appropriate for these locations. It does not take into consideration orientation of the cover, such as a sloping cover over mine rock dump, temperatures during higher temperatures that may occur for instance over a 100 year period or global warming. All these factors would increase the depth of the active zone.

Lupin Mine Cell Monitoring Experience

Lupin Mine is located in a low relief undulating topography underlain by continuous permafrost approximately 400 km northeast of Yellowknife and 285 km southeast of Kugluktuk. The tailings disposal was constructed within a relatively small watershed area located about 5 km south of the plant. The poor availability of suitable core construction material and the existence of cold mean annual air temperature of –11.8°C resulted in the decision to develop the tailings containment by constructing dams from thawed local overburden with the anticipation that they would freeze over one to two years. A liner, that was keyed into permafrost, was provided within the dam to hold the water until the dams froze. The dams were constructed in the summer of 1981 and the plant was put into operation in 1982. The design basis of using frozen dams required extensive temperature monitoring from 1982 to this date.

The tailings facility was developed based on total water containment for the first 4 to 7 years. This would provide time to evaluate the tailings water quality and develop water treatment method if this was found to be necessary. Increased production of ore resulted in the adoption of a tailings management strategy to deposit the tailings within cells and provide two ponds for water quality improvement before discharge. Since 1985, water was discharged from a downstream polishing pond to control water level based on the dam requirements to keep them frozen.

Internal partitioning of the tailings area in 1985 and the covering of filled tailings cells in 1995 provided an opportunity to add temperature measurements to the dam temperature monitoring. These developments resulted in the acquisitioning of extensive temperature data that support the development of the proposed partially saturated granular cover for Lupin's tailings. Figure 6 illustrates Lupin tailings facility with the numerous cells used to store the tailings and ponds to manage the water.

Figure 6: Lupin Mine tailings facility

Progressive reclamation of the filled tailings cells was started in 1995 to combat tailings oxidation. The tailings were covered with a nominal one-meter of esker sand containing some gravel. In November 1995, five strings of thermistors were installed to measure the temperatures within the esker cover, through the tailings and into the underlying natural ground. The length of the thermistor strings was 13 m. The thermistor strings became gradually in-operative with only one string providing readings to this date. Aside from the temperature monitoring, water sampling wells were installed at 3 locations besides each thermistor installation to monitor water levels and take samples for water quality determination within the cover pores.

An evaluation of the covered cell performance provided support for a partially saturated granular cover design proposed earlier by Holubec (1993). As a result of this positive evaluation, additional monitoring was decided upon and the construction of control cells are planned.

In 2002 nine pipes were installed within Cell 1 to establish more accurately the thickness of the esker cover, monitor the water level within the esker and to obtain samples for water quality testing. An aerial view of Cell 1 is shown on Figure 7.

Cell 1 has approximate dimensions of about 600 m by 700 m. The tailings were discharged from perimeter dikes, shown on Figure 6, resulting in beaches being developed adjacent to the dike crests and a depressed tailings surface was formed in the centre of Cell 1. The 9 pipes and the earlier 1995 thermistor strings show that the esker cover thickness is about 1.1 m over the beaches and 0.6 m in the central portion of the cell. At the beaches the water saturation level within the esker was observed to be 0.3 m and within the central portion the water level was near the top of the esker.

Two water wells installed during 1995 showed the water quality within the cover material was improving with time. Water samples obtained from 9 pipes installed in the esker in 2002 and the ponded water from the central portion of Cell 1 showed the water quality to be near discharge limits.

Figure 7: Air view of esker covered Cell 1

Ground temperature monitoring within Cell 1 (illustrated in Figure 5) is representative of the results obtained from other thermistor data. The information of interest in this figure is that the active zone penetrated a maximum of 0.3 m into the tailings, stayed unfrozen for only a period of about 2.5 months and the maximum temperature of the thawed zone (just at the esker/tailings interface) was less than 4°C. Average temperature at 1.0 m depth was 2.7°C. This means that even if the tailings were unsaturated, the oxidation process at this lower temperature for a period of 2.5 months in a year would reduce considerably the oxidation of the tailings.

A final observation from Cell 1 was that in areas with less than 1 m of esker cover, vegetation started to develop on top of the cover without any seeding or fertilizing (Figure 8). The vegetation originated from organics growing in the esker deposit from where the cover material was obtained.

Revegetation of disturbed areas with thin granular material was also observed at an abandoned airstrip at the Lupin site. Parts of an abandoned airstrip where the granular was stripped for use at other places supported more vegetation than in the remaining undisturbed section of the airstrip with a thicker granular pad. The observation that thinner granular pads support vegetation more readily was observed at the Alaska National Petroleum Reserve. They observed that the areas with thinner pads retain sufficient moisture to enable grasses to establish and the pads recede more quickly into the surrounding landscape. As a result the oil exploration companies have adopted a practice to use thin gravel pads, 0.5 m thick, for winter exploration to minimize impact on the ground and foster quicker revegetation (Brewer 1983).

Proposed Partially Saturated Granular Cover

Information presented in this paper leads to three major conclusions directed towards the design of covers for potentially leaching tailings in permafrost regions; namely:

Figure 8: Vegetation developed on Cell 1 esker cover without assistance.

1) Active zone depth. In the absence of vegetation cover, moisture level within the surface material is the dominant factor determining the depth of the active zone. The depth of the active zone can vary from 3.5 m in rock cover, 3.0 m in low moisture sands to 1.3 m in sands that are saturated to within 0.5 m of the ground surface.

2) Active zone depth fluctuation. Depth of the active zone will fluctuate over time due to climatic changes, snow cover thickness and will vary between points within a covered area. The fluctuation of the active zone increases in drier covers.

3) Influence of water cover.
Research into water covers has shown that 0.3 m water depth over reactive tailings, if the water is stagnant, is sufficient to provide an oxygen barrier.

Based on 20 years of ground temperature monitoring and 7 years of monitoring of sand covered tailings at Lupin and a literature review of performance of gravel pads on permafrost (Holubec 1994), Lupin is proposing to use a partially saturated granular cover over the tailings as a reclamation option. This cover is based on the above three conclusions.

A requirement for the partially saturated granular cover is that a saturation level within the esker cover is naturally maintained so that a closure 'walk-away' is attained. A 0.3 m open water cover over the tailings surface would be difficult to maintain at Lupin, and most permafrost regions, because of high evaporation during July and August. However, a saturated zone at the base of a granular cover should decrease the rate of evaporation to maintain a saturation zone. Preliminary water level measurements within the existing Lupin's covered cells support this concept. More rigorous study of the water balance within the partially saturated cells will be made by the installation of designed test pads within the existing covered tailings and on newly covered tailings.

Conclusions

Reclamation of potentially leaching tailings requires covering of the tailings surface to prevent wind erosion and the leaching of metals. In non-permafrost regions, dry and water cover approaches are employed. Dry covers are normally used to limit erosion, promote vegetation and reduce oxidation. Elimination of seepage is difficult to attain with these covers. Water covers are very effective in preventing oxidation of the tailings. But water depths of at least 1.3 m are required to prevent tailings being disturbed by wave action or ice scour. Without these disturbances, water depth of 0.3 m would be sufficient to provide an oxygen barrier.

In permafrost regions the designs considered in non-permafrost regions are not suitable because of a lack of appropriate cover materials, likely disturbance of the covers by frost action and the need to have maintenance free covers due to the inaccessibility of most mine sites.

A common cover design approach for the reclamation of tailings is intended to provide sufficient cover material that will encapsulate the tailings within permafrost. The main challenge in the design of this type of cover is to establish an economic cover thickness that will contain the active (thaw) zone within the cover using site available materials. The depth of the active zone is governed by many factors, such as climate, cover orientation, material type, saturation, snow depth aside of vegetation that is normally absent for long time in the cold regions. In the design of cover to encapsulate the tailings, or waste rock, within permafrost, temperature fluctuations over the years and global warming have to be taken into consideration.

'Dry' covers in permafrost regions would require cover thicknesses of 3 to 4 m to permanently encapsulate tailings or mine rock in permafrost if clean rock or relative dry sand and gravel material are used for the cover. The required thickness decreases as the saturation within the base of the cover is increased. A cover thickness in the order of about 2.0 m is required for 'moist' or ice rich covers to permanently encapsulate the tailings within permafrost. Both these covers require a large quantity of material to reclaim tailings and waste rock surfaces.

An alternative cover design for permafrost is a partially saturated granular cover that is presented in this paper. The principle of this design is to maintain a 0.3 m saturated water level within the granular cover to provide an oxygen barrier over the tailings.

The proposed thin partially saturated granular cover has many positive attributes, such as:

- Provides a water oxygen barrier that is not dependent on having permafrost within the tailings.
- Is not sensitive to annual temperature changes or global warming.
- Will support vegetation because of the proximity of the water surface to the top of the cover.
- If esker material is used for cover material, it decreases the required volumes and thereby reduces the disturbance of the esker deposits. Eskers serve as a preferable animal habitat.
- Is more economical to construct since less material is used.
- Provides a more easily constructible cover for use in remote locations.

This cover design is applicable for tailings surfaces that are nearly level. Since beached tailings have a minor slope, occasional internal baffles within the cover may be required to limit water migration where the deposited tailings surface have a minimal slope. The need for the baffles on sloping tailings surfaces depends on the permeability of the cover material.

This cover design is not suitable for steeply sloping surface, such as in the case of dams and waste rock dumps. Since 'dry' covers require a considerable thickness of cover material, especially if the slopes face towards the south, it may be preferable to design tailings pond and waste rock dumps with minimum slope areas and maximum horizontal surface areas to maximize the use of the partially saturated granular cover.

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