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How to avoid permafrost while depositing tailings in cold climate

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ABSTRACT

Managing tailings deposition in cold climate requires specific measures not to create permafrost. The risk of generating permafrost due to tailings deposition exists even in regions where permafrost would naturally not occur. Material being frozen during winter might not fully thaw in the following summer due to added height of the tailings on the surface. Such embedded layers of permafrost should be avoided especially close to tailing dams. Main reasons are to prevent impermeable layers in tailings facilities, and to reduce the risk of having implications if such layers thaw during warmer summers causing increase in pore water pressure, reduced effective stress, and increased water content.

This paper presents a numerical study on the effects of tailings deposition in cold regions in relation to the potential formation of permafrost. Various deposition rates, schedules and tailings properties were evaluated. One-dimensional heat conduction analyses were performed with a temperature scenario representing a mine district in northern Sweden. Results show, that the thickness of permafrost layers increase with increased deposition rate and with increased water content. It was also shown that wet and loose tailings must be deposited in short periods during summer to avoid permafrost generation. In the case of dry and dense tailings more time is available for deposition in order not to cause aggradation of permafrost in the deposit.

These findings can help mining operation to set up deposition schedules for tailings facilities in cold climate. For known tailings properties, results can be used to identify periods of the year when, and how much, tailings can be deposited in critical areas of a deposit in order to avoid permafrost formation.

1. Introduction

There are extensive research documented on tailings deposition methods and their corresponding effects on tailings properties. With the purpose to increase storage capacity and to enhance consolidation, density and strength, views on deposition methods have evolved with time (Gipson, 1998; Robinsky, 2000; Caldwell and Van Zyl, 2011). The so-called sub-areal deposition method (Knight and Haile, 1983) with systematic discharge in thin layers is a well-used technique where tailings settle, drain, partially air-dry and increase in density. For this, the storage facility is normally divided into sections, facilitating rotational deposition (Gipson, 1998). By rotational deposition the tailings in one section of the tailings storage facility is allowed to air dry and consolidate, while deposition of fresh tailings occur in the next section. Details on how to optimize tailings deposition with respect to sedimentation, consolidation and desiccation are given by Qiu and Sego (2006a,b, 2007).

However, little emphasis has been given to tailings deposition methods in cold regions, where effects of freezing and thawing have to be taken into consideration. Managing tailings deposition in cold climate requires precautions to prevent the generation of permafrost. Tailings are normally delivered to a mine's tailings facility continuously throughout the year. There is therefore a need for robust delivery systems and appropriate deposition schemes in order to avoid disturbances in tailings management.

Lighthall (1987) concluded that sub-areal deposition is less suitable in cold and damp weather compared to warm, arid regions. He also gave an example with sub-areal deposition for a restricted time of the year. During winter, the tailings were discharged into a special part of the facility. Further sub-areal deposition continued after the thaw period. Nixon and Holl (1998) modeled the geothermal regime in tailings with deposition and concurrent freezing/thawing and they showed that generation of layered permafrost in tailings impoundments might take place. Indications of embedded frozen layers have been observed in tailings facilities in northern Sweden during summer, even though the facilities are located in regions with no natural permafrost.

Due to thaw consolidation of fine tailings, dewatering and enhancements in consolidation (Proskin et al., 2010) and increasing stability (Beier and Sego, 2009) have been reported. Design considerations on preventing acid mine drainage by developing permafrost, and to

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keep sulfur rich tailings in a frozen state, have been studied (MEND, 1993). However, no literature has been found on the behavior of tailings deposits where layers remain frozen. With embedded impermeable layers, the vertical drainage capacity is affected. The intended merits from the deposition method might therefore be lost. Other aspects of frozen layers in a tailings deposit are the consequences if, and when, such layers thaw. Excess pore water pressure (Morgenstern and Nixon, 1971), large settlements (Wang et al., 2014) and thaw stability issues (McRoberts and Morgenstern, 1974) might develop. These can have significant influence on the tailings dam safety (Knutsson et al., 2016; Korshunov et al., 2016). The generation of permafrost layers should therefore be prevented in tailings facilities.

This paper presents a numerical study of the effects of tailings deposition on permafrost generation. Various deposition rates and schedules were considered. Different tailings properties in terms of degree of water saturation and dry densities were taken into consideration. This was studied for a climatic scenario representing a mine district in Sweden, located north of the Arctic Circle. The aim of the study was to find periods of the year when tailings can be deposited without generating permafrost. The findings can aid in the set-up of deposition schedules, winter planning and related topics for managing tailings in cold climate.

2. Method

Simulations in this study were conducted with a one-dimensional geothermal model developed by Knutsson et al. (2018). The model simulates the temperatures in the tailings when the surface elevation is increased due to deposition. At the tailings surface the temperature changes according to ambient air temperatures. Air temperatures, tailings deposition rate (height increase with time), tailings properties, tailings slurry temperature and n-factors are given as input to the model (Knutsson et al., 2018).

The study was conducted for climatic conditions representing a mine district in northern Sweden, Fig. 1. Air temperatures used for simulations are presented in Fig. 2. The average yearly air temperature for this location is +0.1 °C. No ground surface temperatures for calibration were available. Simulations were performed to represent a period of 10 years. The ratio between air temperatures and ground surface temperatures (n-factors) (Andersland and Ladanyi, 2004) were set to 0.9 (freezing) and 2.0 (thawing). No consideration was taken to potential snow on the tailings surface. The temperature of the new tailings added on the surface due to deposition, was set to +15 °C. This temperature has been shown to have very low impact on freezing and thawing depths (Knutsson et al., 2018).

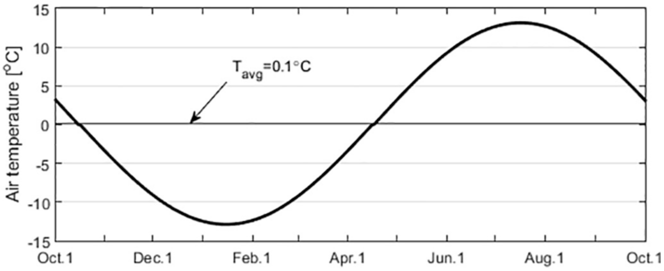

Fig. 2. Air temperatures used as input for the simulations, idealized for a normal winter and summer respectively.

Initial tailings depth, before any new tailings were added on the surface, was set to 8 m. The element size, in which temperatures were computed, was set to 0.025 m (Knutsson et al., 2018).

2.1. *No deposition*

To get a reasonable temperature condition in the tailings before any tailings were deposited, a case without tailings deposition was studied. 10 years with freezing and thawing were simulated with constant tailings height. As initial condition, all tailings were assigned a temperature of +0.1 °C which corresponds to the yearly average air temperature, see Fig. 2. This temperature was also kept constant at the bottom of the model.

Simulated temperature profiles at October 1st are presented in Fig. 3. After 3 years, no differences were seen on the temperature profile. The final temperature profile was later used as initial profile before tailings were added on the surface.

2.2. *Tailings deposition*

In the simulations, tailings were added on the tailings surface with time. For this, it was assumed that the in-place properties (given as input, see section *Tailings properties)* were present immediately after the tailings were added. Neither ponding water, nor drying/wetting interactions were included in the model.

Different scenarios of tailings deposition were studied. Firstly, three deposition rates were simulated, i.e. increase in yearly tailings height. These were 1, 2 and 3 m per year. Secondly, the time period for which the tailings were deposited were studied for 12 months deposition per year (i.e. continuous height increase), 8 months deposition per year and

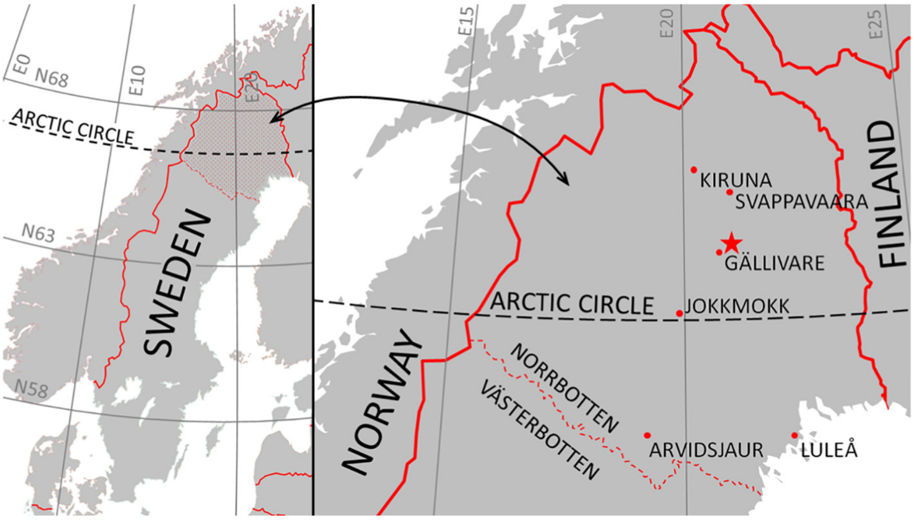

Fig. 1. *Left:* Scandinavian peninsula. *Right:* Norrbotten county (Sweden) with location of the mine district (star).