Water-related Issues in Permafrost Mining, with Special Emphasis on the Coal Mining of Spitsbergen (Norway)

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ABSTRACT

Aspects of mining in permafrost regions are described, with emphasis given to water issues. Most of the mines discussed are Spitsbergen coal mines. In general, when mining within the permafrost zone, problems include supplying water for the operational processes, the explosivity of the very dry coal dust and hoar frost formation due to humidity introduced by ventilation. In the non-frozen rocks below the permafrost, the technical problems are largely the same as encountered while mining elsewhere in the world. However, special care must be taken in the transition zone between the permafrost and the non-frozen rocks. Groundwater intrusions are possible and methane may accumulate below the impermeable permafrost.

INTRODUCTION

Permafrost is a special geological condition that critically influences the behaviour of water both on and under the Earth's surface. This article describes the impact permafrost has on the mining industry, specifically coal mining in Spitsbergen. Spitsbergen is the largest island within Svalbard, which is a high-Arctic Norwegian archipelago area of 62,050 km² (38,540 mi²), located between 74° and 81° N and between 10° and 35° E. Spitsbergen supports a year round population of 2,500 individuals in five major settlements. The capital and administrative center is the settlement of Longyearbyen. Coal in Longyearbyen and Svea is mined by the Norwegian company, Store Norske Spitsbergen Kulkompani AS (SNSK). The Russian Trust Arktikugol (TA) has mining operations at Barentsburg and Pyramiden. Mining at Ny-Ålesund ceased in 1963. Figure 1 shows the location of Svalbard and the coal mining communities on the west coast of Spitsbergen.

GENERAL REMARKS ON PERMAFROST

The depth of the permafrost on Spitsbergen varies from 100 m at the sea coast to 200–350 m near the coasts of the inner fjords (which are not affected by the relatively warm sea currents, e.g. near Longyearbyen) to 500 m inland. No permafrost is found beneath glaciers, large lakes, fjords and the sea bottom. These areas can be important sources of fresh potable water.

During the warmer summer months, only the top layer of soil (active zone, 0.5–3.0 m deep), thaws. During this time, surface and rainwater cannot percolate into and through the permafrost, and the active zone becomes an impenetrable morass, especially on the valley floors. Permafrost-specific geological phenomena include pingos (hills raised by residual water lenses or ascending groundwater), frost heaving (gradual ascending of objects within the active zone), polygonic floors and solifluction. The nature of the terrain is diagrammed in Figure 2. The transitory nature (freezing and thawing) of permafrost requires special construction techniques for roads and buildings and of course for mining operations. Pipes (e.g. potable water, sewage) must be placed on stilts approx. 1 m above ground or buried, using flexible pipes.

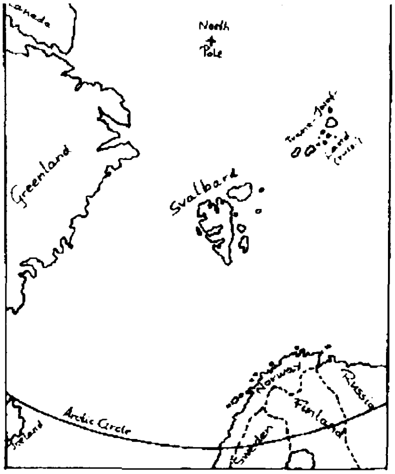

Figure 1. Left: position of the archipelago Svalbard in the Arctic Ocean. On the right: position of the settlements and mines on the west coast of Spitsbergen.

MINE WATER IN PERMAFROST MINING

General

Mining at Svalbard still takes place partially within the permafrost zone, though more and more mining activities extend to areas with larger rock overburden or at greater depths in non-frozen layers below the permafrost. At the onset of mining operations at Svalbard, many of the necessary techniques for mining in permafrost had to be developed by the companies operating there. SNSK were important pioneers in this aspect during their 80 years at Svalbard.

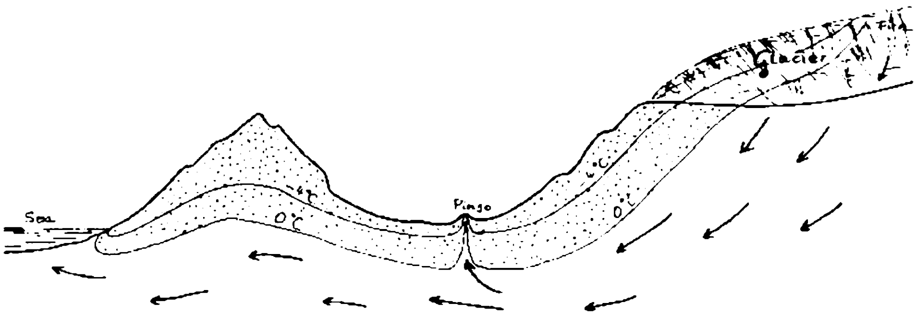

Figure 2. Vertical profile of permafrost zone (dotted) with indication of the –4 °C and 0 °C isotherm and groundwater movement from a glacier out to the coast. A pingo is shown in the center of the figure.

As long as the mines are operated within the permafrost zone, the frozen rock influences mining activities positively. In addition to increased roof stability and a somewhat reduced degassing, the mines are almost free of groundwater intrusion. Also, the extracted raw coal contains little moisture, an important prerequisite for the dry coal preparation plants with air jigs that are essential in the Arctic. In addition, at the very low temperatures, wood timbering is kept from rotting nearly indefinitely.

On the other hand, the use of water as a coal dust retardant in the mines requires complex precautions, since the average underground temperature within the permafrost zone is about -4 °C, and immediately below this area, scarcely over 0 °C. Pipes must be insulated and heated, or the incoming fresh air has to be heated. Therefore, mechanisation of production is complicated, and mines must deal with the coal dust, which is highly explosive due to its low moisture content.

If a mine advances to greater depths, the lower "limit" of permafrost will be passed. This is a broad transition zone in which the rock temperature gradually rises to about 0 °C (32 °F). In this transition zone, "boundary problems" develop; e.g. the encountering of liquid water pockets and the danger of sudden flooding or bothersome water intrusion.

In addition, since the permafrost zone acts as an impermeable cap-rock, methane gathers in the fissures and natural pockets of the non-frozen rock directly below the frozen layers, increasing the danger of explosion. The presence of methane in the transition zone must always be assumed and exhaust ventilation systems installed accordingly.

Mine Water within the Permafrost Zone

Because of the sealant effect of the permafrost, surface water cannot penetrate into the rock fissures, and so within the permafrost zone, the mines are almost free of water intrusion and largely dry. Therefore, there is less wear and tear on the mechanical equipment. Joy Sullivan coal cutting machines bought in the 1920's as well as locomotives from the late 1930's are still in use in SNSK's mines. However, permafrost does not mean that there is no unfrozen water within this zone. Approximately 1 km north of Olsokbreen (Sørkapplandet), a watercourse flows out of a small cave entrance in the limestone (Orvin, 1944). A similar water-filled karst cave is believed to be the reason for the huge 1929 water-break-in in the Ester mine (Ny-Ålesund, Spitsbergen).

Humidity Influx by Ventilation

At an ambient temperature of the rocks within the permafrost zone from approx. −10 °C to −12 °C, the incoming fresh air will be cooled in summer and warmed in winter. The underground air temperature within the permafrost zone during the whole year will therefore vary between −2 and −4 °C in fresh-air-ways, and in mine roads close to the surface down to −12 °C. Therefore, hoar frost formation is a typical phenomenon in permafrost mines. When the temperature rises above the freezing point, the humidity carried by the fresh air stream into the mine condenses, mainly within the first 500–1,000 meters of the mine road, starting at the adit as a glittering hoar frost layer on the side walls and the roof. Rarely "crystal palaces" may form, particularly if air with high moisture content meets cooler air. These hoar frost layers are always relatively thin and cannot in any case replace mine supports, as sometimes has been suggested in technical writings (e.g., Boldt, 1944). Ventilation must be properly regulated; too strong an air stream increases the danger of hoar frost accumulation.

Moisture can also accumulate in the approximately 50 m long depressions of the mine roads, which follow the wavy coal seam. The humidity mixes with the rock dust used to prevent coal dust explosions and then covers the floor with a slippery layer so that the ascending sections of the main roads will be difficult for trackless mine vehicles to traverse.

As only heated pipes can be used in the mine dewatering process, pumping the unfrozen mine water into tanks and removing it with those tank cars from the mine was for many years the only economical possibility. This form of dewatering is still used by SNSK during the summer break, when the transportation of personal and material is interrupted. If the dewatering is inadequate, ice forms in the mine floor depressions and does not melt, even during the next summer. In abandoned mines, this ice continues to accumulate, reducing the headroom in the tunnels.

Mandated security precautions dealing with closing the entrances of abandoned mines are facilitated by the accumulation of ice. In due course, a rock-hard snow and ice plug up to 20 meters in depth blocks the adit.

Mine Water in the Transition Zone

The rock directly below the permafrost zone is usually dry, though large accumulations of water are sometimes encountered. This situation can cause major dewatering problems. In the summer months, ground water intrusion through the floor of a mine road may be observed in a mine close to Longyearbyen. This water probably comes from a glacier situated directly above the mine. An extreme example of water intrusion occurred in the mid-1980's in the Black Angel Mine (Pb) in northwestern Greenland. A drift heading had to be stopped and a water dam built in a roadway that had passed through the transition zone because the seepage of water could not otherwise be effectively handled (Olsen, personal communication, 1996). Efficient dewatering is indispensable in such situations.

SUPPLYING WATER IN PERMAFROST MINES

Supplying the Mines with Processing Water

Many problems arise in supplying industrial water to mines in permafrost areas because underground temperatures range from -12 °C to +2 °C. The use of processing or industrial water, e.g. as drilling fluid, is only possible with large expenditures of money and time due to the freezing of pipes and the lack of sufficient unfrozen water nearby. To address such problems, mining companies have used, either individually or in combination: anti-freeze agents; transporting water in tankers; heating the water pipes; or air heating

Before the large scale mechanization of mine 7 (Longyearbyen) in 1978, mine face dust had been suppressed experimentally with water. The water was heated to 25 °C at the power plant of Longyearbyen and shipped the 18 km to the mine in tankers. Transportation of the water from the adit to the active face, however, could not be done satisfactorily because of permafrost conditions. Today, Arctic mines are generally supplied from lakes (artificial, if necessary) via pipe.

Within the permafrost zone, all water supply pipes must be heated and insulated. In the mines of Svalbard, the pipes are heated electrically by self-regulating heating wires with an electrical coefficient of 9–20 Watts along the pipe. The main supply pipes are 102 mm in diameter, and the two secondary pipes are 50 mm and run in a closed loop to prevent ice accumulation. 20-30 L of water are needed per ton of raw coal. At the end of the work week and before periods of prolonged production interruptions, water is exhausted from the pipes using dry compressed air. This prevents residual water in the pipes from freezing.

Use of Water for Dust Suppression and as Drilling Fluid

Coal dust suppression in permafrost mines is a constant concern because of health problems and the high explosive quotient of coal dust. The tertiary coal in Longyearbyen contains up to 40% explosive material. The dryness of permafrost mines increases the risk of explosion. Free air coal dust is measured periodically and it has been shown that dust creation and ambient air temperature are inversely proportional; as the temperature decreases, the amount of dust increases. A critical point is registered when the temperature approaches 0 °C; the creation of dust rises significantly.

In addition to the danger of ice forming in water supply pipes, using water to retard dust can also cause a problem with the coal preparation (cleaning) process. Spraying of the coal face would increase the moisture content from its natural levels of 4-6%, which does not cause a problem with the dry cleaning process, by at least 0.6%, which might cause problems.

The use of fresh water as drilling fluid pumped through the drilling rod by compressed air has not proven successful. Water may only be used as drilling fluid in the permafrost environment with anti-freeze additives, e.g. sodium chloride. At Spitsbergen, the best results have been obtained with solutions of 20% NaCl (Utsi and Hagen, 1996). In other Arctic mines, e.g. the Canadian Nanisivik mine, good results have been achieved with a calcium chloride solution. For drilling (at –12 °C rock temperature), a solution with 17 mass % $CaCl_2$ is sufficient, but, in fact 25–35% $CaCl_2$ is used in order to keep the solution liquid in the above ground storage bunkers at outside temperatures around –40 °C (McNeil et al., 1993).

A better way of handling industrial water in permafrost underground mines is air heating. Air heating was installed some years ago in the Svea mine on Spitsbergen. Air preheated to +5 to +10 °C, however, causes faster fragmentation of the roof due to frost action. Roof bolting proved to be insufficient and the roof over the mine roads must be sealed with sprayed concrete.

In order to avoid reduced roof stability because of frost damage, the Polaris mine in the Canadian Arctic achieves good results with a method that is initially surprising. Despite an annual average temperature of approximately –10 °C, the fresh air entering the mine is cooled (!) during summer, since an air temperature of only few °C over the freezing point is sufficient to accelerate fragmentation of the roof by frost (Myrvang, 1996).

OTHER ASPECTS OF PERMAFROST MINING

Dust Suppression Without Water: Dust Evacuation

Another procedure for dust suppression is "dust evacuation". First attempts to use this method in the early 1960's, using a special English rock drilling machine for the evacuation of the dust through the drilling rod, were unsuccessful. Probably because of the serious mine explosion in Ny-Ålesund in 1962, new attempts were made in 1965 to improve dust evacuation when drilling. Satisfactory results have been achieved evacuating the dust and particulates through the drilling rod and collecting it with a vacuum cleaner-like filter (Myran & Rafdal, 1987; Berge et al., 1963). Today this dry procedure is used with good results, especially when drilling roof bolting holes.

Snow as Explosion Barriers in the Coal Mining

In very early literature about mining at Spitsbergen, a remarkable, though dubious, explosion barrier is described. In order to extinguish coal dust explosions as quickly as possible, the floor of mine roads were covered with snow at the beginning of mining at Svalbard. It was hoped that the snow would immediately melt due to the heat generated by the explosion, and extinguish any flame-up (Klees, 1925). Nothing is reported about the effectiveness of such snow zones.

Use of Hydraulic Oil in the Permafrost

In longwall faces with hydraulic shield support, one must be concerned about the hydraulic fluid freezing during permafrost mining. The oil used for this purpose remains operational to –35 °C. However, it is always mixed with water to create an emulsion. A 20% oil with 80% water mixture will be effective to –6 °C. A mixture of 30% oil and 70% water prevents the emulsion from freezing down to –10 °C. According to the operating conditions, applicable emulsions can be mixed (Whitworth, 1978).

Use of Frozen Water

Ice under pressure of more than 2 bar is a highly viscous fluid that will slowly flow into and fill mine cavities at a controllable rate (~80–100 m/year). This phenomenon, well known from glaciology, can also be used outside of permafrost areas. Ice deposited in old mine roads and extraction cavities will relieve the side walls and roof because of the hydrostatic pressure, depending on the height of the ice. The movement rate at which the ice penetrates into the cavities corresponds to the average extraction rate in ore mines. The pit has to be supplied with sufficient amounts of ice. If no natural sources of ice are available in close proximity to the mine (glaciers or frozen lakes), the ice production may be accomplished by the use of snow cannons. Sufficient supplies of water and cold winters are prerequisites (Fangel, 1996).

CONCLUSION

Mines that operate correctly within the permafrost zone can be considered to be safe. The positive effects of the frozen permafrost rocks on the operations of Arctic mines are demonstrated by the excellent man-shift-results of SNSK. In 1994, SNSK achieved an average man-shift performance of 12 t per man-shift. If the operation is advancing into the non-frozen zone below, the same security and technical problems are to be expected as in other coal mines of the world. Special attention must be directed to the transition zone between permafrost and non-frozen rocks. To manage industrial water in permafrost mines, local experience is essential.

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