Mine Waste Management in a Changing Climate

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Abstract

A five-year research project on mine waste management in the Canadian North under a changing climate was conducted. Based on field and laboratory work, it is evident that permafrost does not degrade as fast as expected without human disturbance. Consequently, permafrost-based mine waste management practices still apply in Nunavut, need some modification in the Northwest Territories, but may require significant changes in the Yukon. Direct application of southern technologies such as wetland or bio-treatment may not be practical under Northern conditions. To develop or operate an environmentally-friendly mining project at a lower cost, the principles of an environmental ore deposit model that emphasizes communication and co-operation of all functional groups cannot be avoided.

Introduction

As climate change would invariably have impacts on the natural resources sector (Warren and Lemmen, 2014), CanmetMINING has started a five-year (2011-2016) project - Mine Waste Management in a Changing Climate - to explore adaptation alternatives for northern mining to minimize environmental impacts often observed in many old abandoned mines. The key objectives of the project are: 1) to assess foreseeable impacts of a changing climate on current practices of mine waste management and effluent treatment in the three territories; and, 2) to explore and/or develop adaptive technologies to reduce vulnerabilities to drastic climatic events. With project progression, it becomes clear that pertinent environmental ore deposit models should not be overlooked. Thus, this short paper will focus on the following key issues:

1) Observed and predicted temperature changes in the three territories in the Canada North;
2) Causes of permafrost degradation;
3) Implications for mine waste management in the North; and,
4) Role of a practical environmental ore deposit model for developing or operating a northern mine.

Temperature Changes in the Three Canadian Territories

Recent research has demonstrated that there is little doubt of global warming, particularly in the Canadian North (Furgal and Prowse, 2008; Troop et al., 2012; Warren and Lemmen, 2014). Occupying forty per cent of the Canadian land, the three territories are largely underlain by permafrost (Figure 1). The frozen ground has been relied upon for mine waste management in many past and current mines. It is important to determine whether a changing climate would significantly affect the permafrost distribution and whether the temperature records could reflect the extent of permafrost decay. To explore these potential relationships, temperature changes in a few selected towns in each territory (names underlined in Figure 1) are briefly reviewed and their impacts on mining will be illustrated with a few examples in the next section.

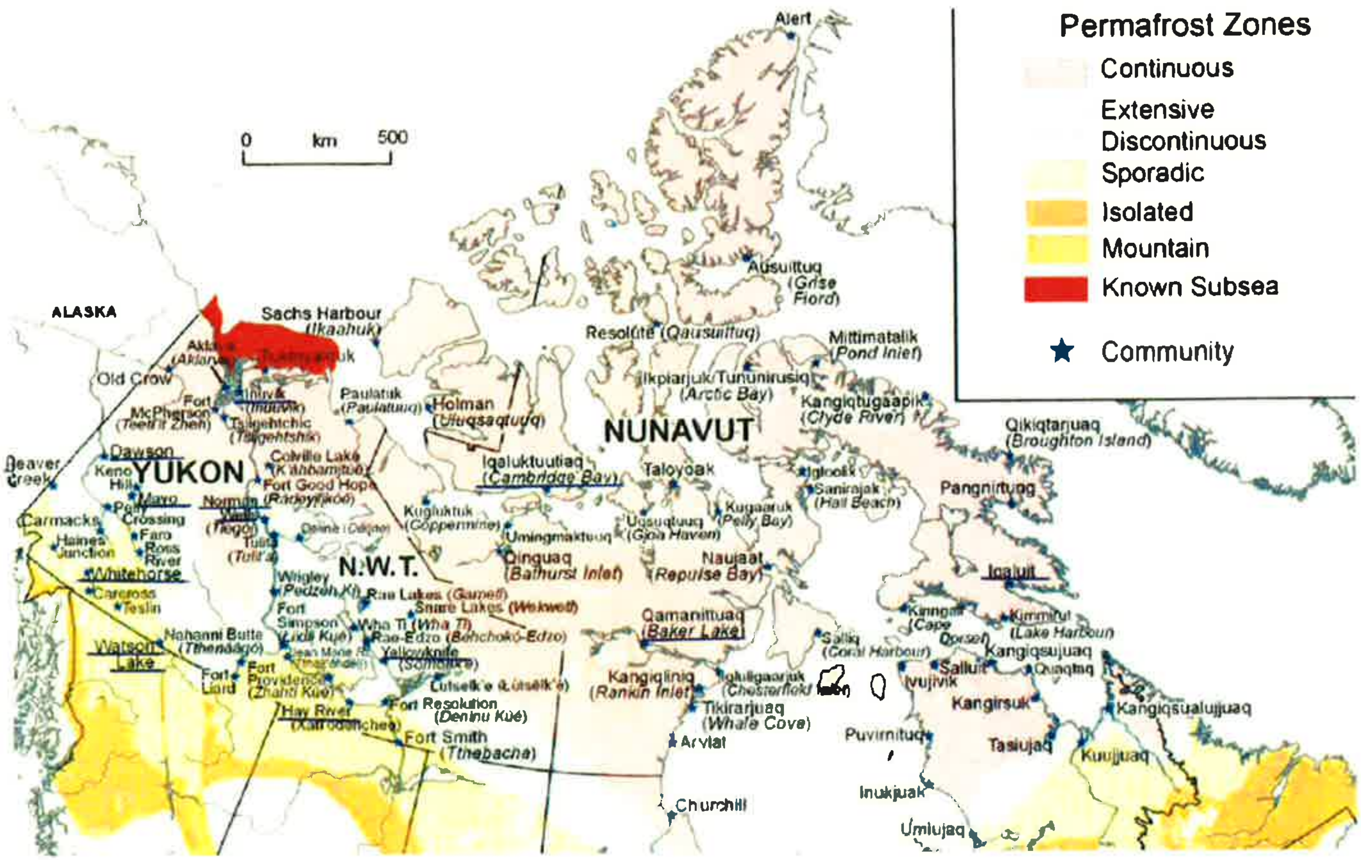

Figure 1. Permafrost distribution in the Canadian North (modified from Furgal and Prowse, 2008).

Recent changes in mean annual air temperature (MAAT) at four selected towns in the Yukon Territory (Dawson, Mayo, Whitehorse and Watson Lake) are depicted in Figure 2. Located further north, Dawson and Mayo have a significantly lower MAAT than Whitehorse and Watson Lake. While all four towns show an increase in MAAT with time, Dawson and Mayo have a larger increase than the two southern towns (~2°C versus 0.5°C). As mean annual ground temperatures (MAGT) are only slightly higher than MAATs in permafrost areas and cold permafrost is relatively stable at MAGT < -1.5°C (Throop et al. 2012), it is not unexpected that Dawson and Mayo are still underlain by continuous permafrost. On the other hand, Whitehorse is underlain by sporadic permafrost and Watson Lake likely by extensive discontinuous permafrost.

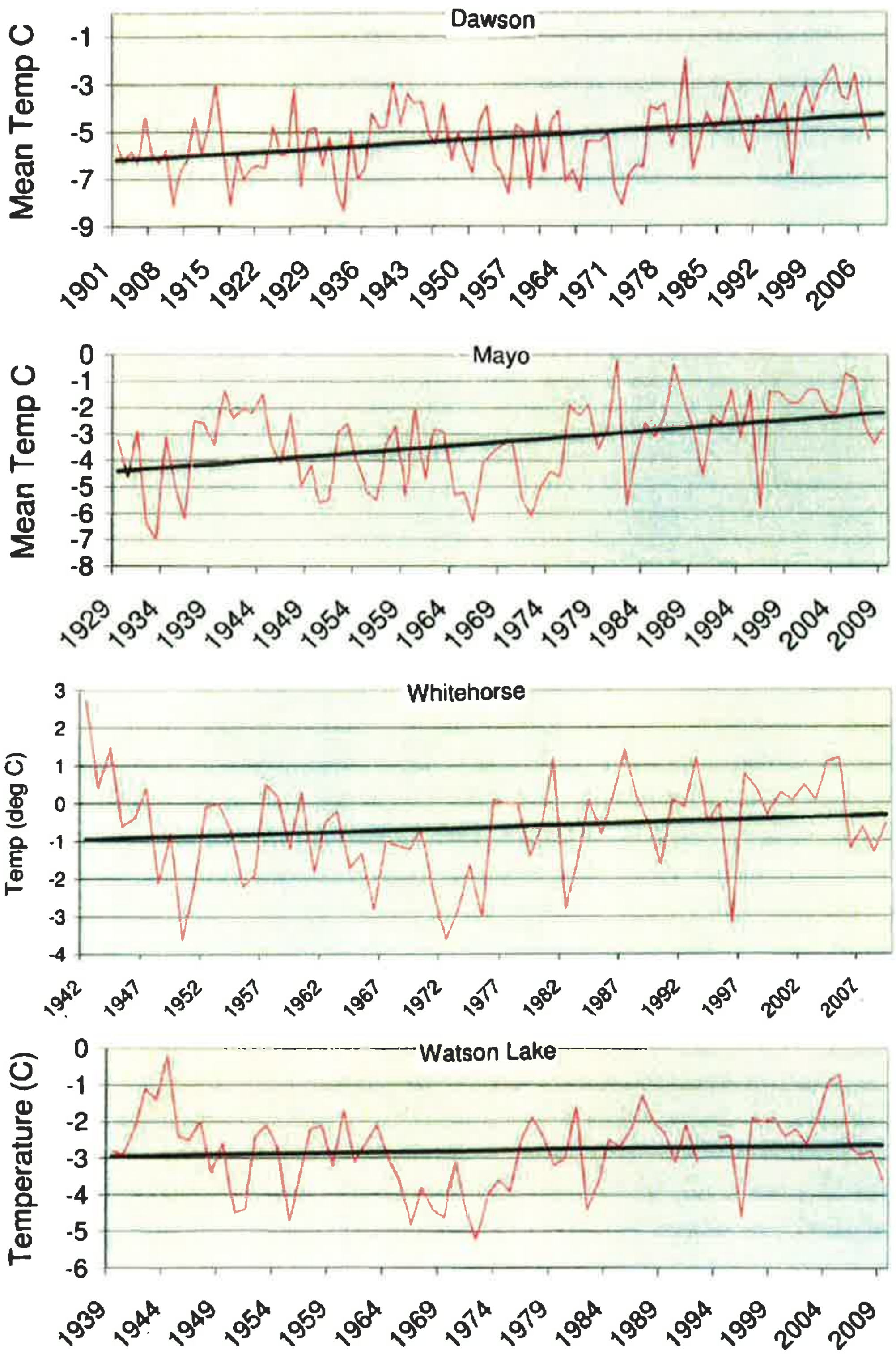

Figure 2. Mean annual air temperature (MAAT) recorded at selected towns in the Yukon Territory (modified from appended data in Northern Climate ExChange 2012).

The recently recorded MAAT and predicted increase in the future at four selected locations (Inuvik, Norman Wells, Yellowknife and Hay River) in the Northwest Territories are depicted in Figure 3. As observed in the Yukon Territory, despite the increasing MAAT trend, the two northern towns (Inuvik and Norman Wells) are underlain by continuous permafrost. Even if a significant increase in MAAT materializes in the future as predicted, it is unlikely that continuous permafrost in the two towns would degrade significantly in fifty years. With higher MAATs and continual increasing trends, permafrost degradation is likely to occur in the two southern locations (Yellowknife and Hay River).

Changes in MAAT in three Nunavut towns (Baker Lake, Cambridge Bay and Iqaluit) in 1971-2010 are depicted in Figure 4. Compared to the selected towns in the Yukon Territory and Northwest Territories, they have considerably lower MAATs and are underlain by continuous permafrost. Even though an approximately 2°C increase in MAAT has occurred in all three towns over the past forty years, natural permafrost degradation is unlikely to occur to a significant degree over the next 100 years.

In summary, while increases in MAAT are noted throughout the three territories, significant permafrost degradation is less likely to occur in Nunavut than in the Yukon and Northwest Territories. This is understandable for northern regions in Nunavut, which lie in higher latitudes. However, in addition to minor differences in natural environments, there must be other factors involved for towns at similar latitudes in the three territories to have different extents of permafrost degradation. Possible reasons are explored in the next section.

Causes of Permafrost Degradation

In addition to climate warming, permafrost degradation is often related to and/or accelerated by human activities. For example, both Whitehorse and Watson Lake lie in the sporadic permafrost zone (Figure 1) but less permanent frozen ground remains in Whitehorse, which has a higher population and more year-round human activities. The disappearance of isolated permafrost in the region extending from northern Alberta to Yellowknife in the Northwest Territories was identified in the early 1990s by Kwong and Gan (1994). Increased industrial development, particularly south of the provincial-territorial border, is no doubt a primary cause. In comparison, Nunavut has a much smaller and scattered population. The largest city in the recently established territory (in 1999) contains less than seven thousand people. An obvious effect of increasing temperature on continuous permafrost is often just an increasing depth of the active zone.

Mining is an essential industry in all three territories. Permafrost has long been relied upon for effective mine waste management in northern mines. With continual increase in air temperature across the Canadian North, reliance on frozen ground for mine waste management should be reviewed and suitable adjustments made so that unacceptable environmental impacts would not be generated.

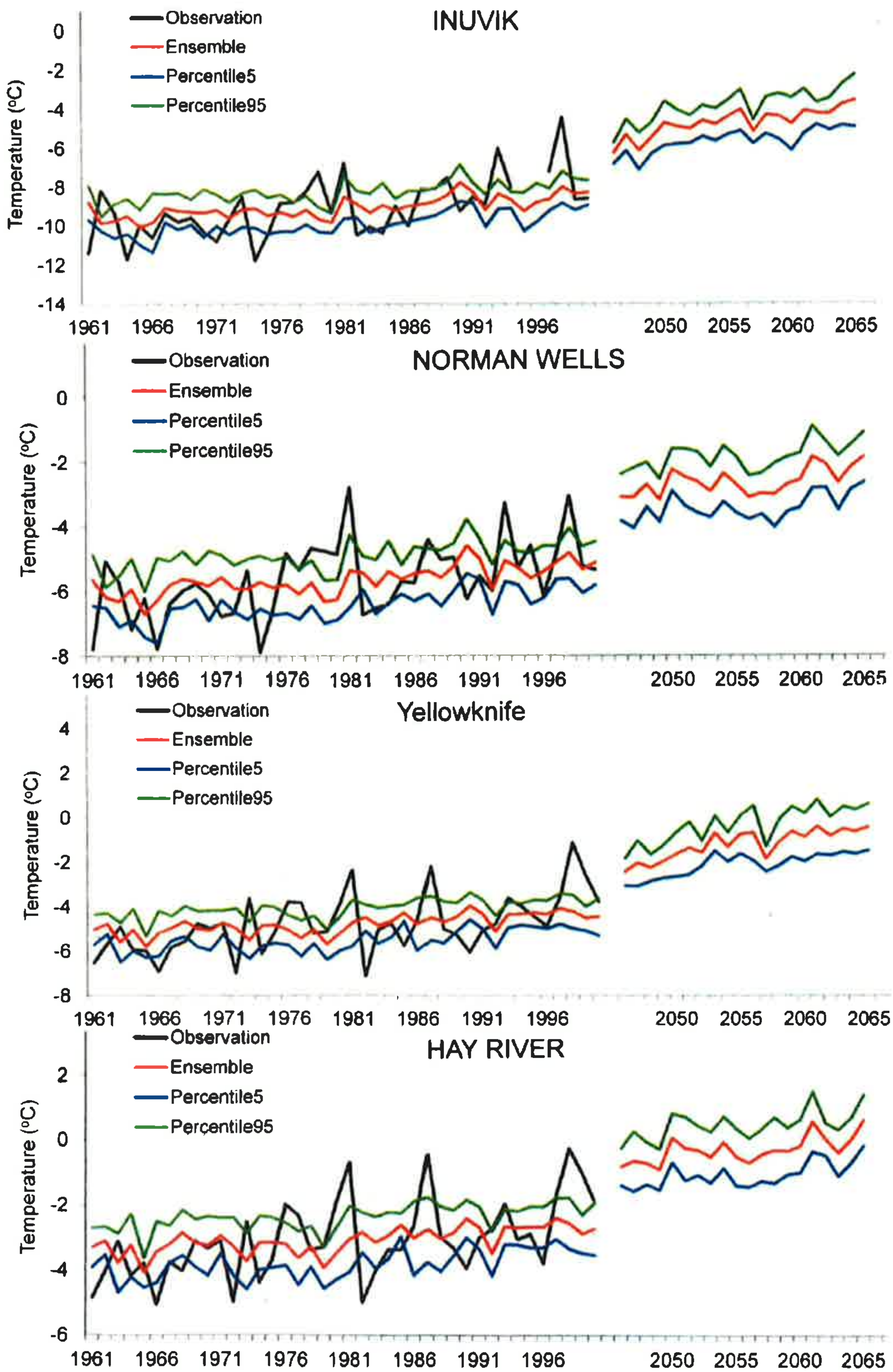

Figure 3. Mean annual air temperature (MAAT) and predicted increase in future years at selected towns in the Northwest Territories. (Data provided by NWT Department of Environment and Natural Resources in March 2013.)

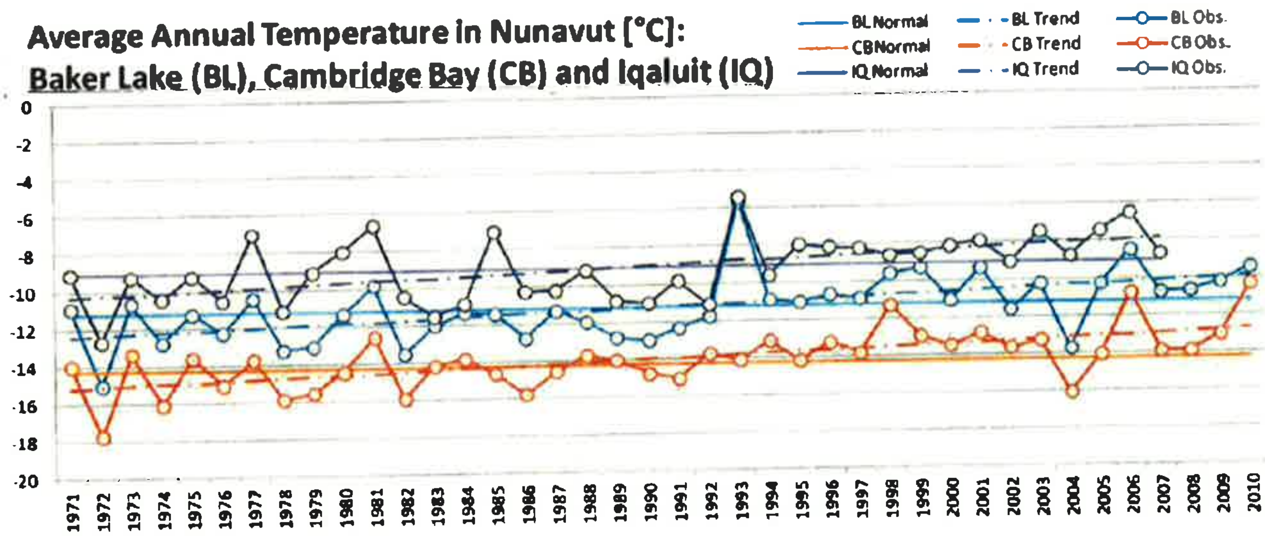

Figure 4. Mean annual air temperature (MAAT) at three selected towns in Nunavut (modified after IMG-Golder Associates Ltd., 2012).

Implications for Mine Waste Management in the North

Low average temperatures of most permafrost regions in Nunavut mean that it will take many decades or centuries for the permafrost to thaw completely. Consequently, permafrost-based mine waste management still applies in Nunavut. In southern Northwest Territories, permafrost degradation appears to be unavoidable. Modified mine waste management and treatment approach may have to be developed. For example, at the abandoned Giant Mine in Yellowknife, the original plan during mining operation was to permanently store the arsenic trioxide underground in permafrost; this is no longer applicable. With average air temperatures continually increasing with time (Figure 3), even the currently contemplated use of thermosyphons to maintain frozen ground may not work in the future. In-situ conversion of the arsenic trioxide into more stable forms may be a more practical long-term solution.

In the Yukon Territory, disappearance of permafrost has frequently been observed particularly in the southern regions. For example, permafrost degradation around the tailings impoundment in the abandoned Mount Nansen Gold Mine near Carmacks has been identified in the last decade (Kwong, 2010). The disappearance of frozen ground beneath the tailings dam renders the dam unstable. To avoid tailings spill into a down-gradient stream, moving the tailings to the open pit for long-term disposal is currently considered as a potential decommissioning option. In other proposed, operating and/or abandoned mines across the Yukon Territory, bio-treatment of contaminated discharge using southern technologies is being considered. However, even with gradual permafrost degradation as a result of climate warming, environmental conditions in the Yukon Territory still are not the same as those occurring further south. Preliminary testing of bio-treatment in an open pit in the abandoned Faro Mine has not produced, so far, any positive reports. Recent work in the Keno Hill area further north by Lawrence et al. (2014) demonstrates that inorganic reactions are more important than microbial interactions in preventing contaminant transport. Perhaps a more comprehensive approach as described by Plumlee and Logsdon (1999) should be put into practice.

Role of Environmental Ore Deposit Model

In addition to the earth-system toolkit as described by Plumlee and Logsdon (1999), use of an environmental ore deposit model as briefly explained by Kwong (2003) would facilitate environmentally-friendly mineral resources development in the North. The essential components of a practical environmental ore deposit model are shown in Figure 5. In addition to deposit geology and mineralogy, the model contains information on pertinent mining, mineral processing and mine waste management alternatives as well as their interrelationships. The essential functions of the model include the following:

1. Facilitate communication and engagement among all stakeholders;
2. Assist adaptive planning and mine management;
3. Allow field geologists to look for potential solutions during exploration;
4. Aid with making development decisions; and,
5. Accelerate permitting.

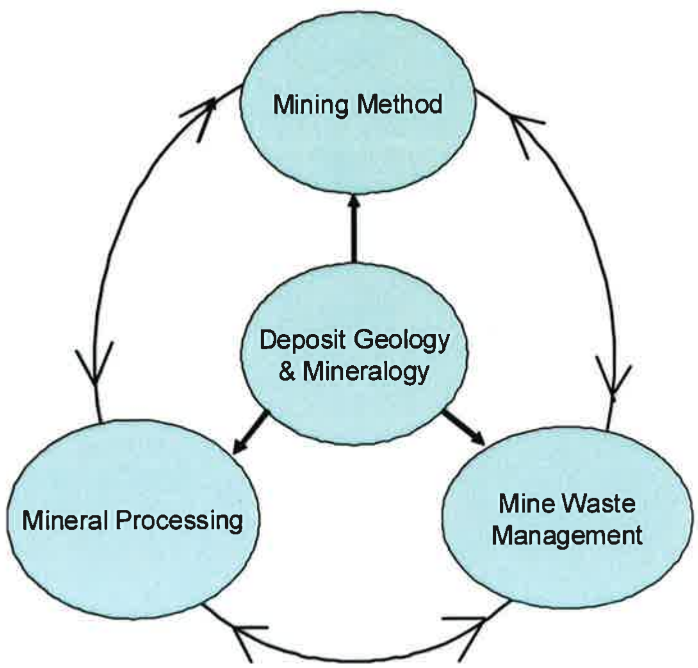

Figure 5. Components of an environmental ore deposit model.

As an example, Kwong (2011) described the potential applications of such a model for future mining of a skarn deposit at the border of the Yukon and Northwest Territories. In essence, simultaneous mining of the two identified ore zones with different mineralogy would avoid a necessary change in mineral processing if they were mined in sequence, and only one stream of non-acid-generating tailings instead of two with different qualities would be produced for easier disposal. The net result would be a less costly mine with reduced environmental impacts.

Conclusions

In summary, a brief review of recent average air temperature records in the three territories indicates that in the near future, permafrost degradation will occur to negligible degree in Nunavut, more in the Northwest Territories, and significantly in the Yukon Territory. Thus, traditional northern mine waste management techniques still apply in Nunavut but need modification to various extent in the other two territories. However, direct application of southern technologies such as bioreactors may not be applicable as yet. Broader use of appropriate environmental ore deposit models may help to develop and operate environmental-friendly mines in the North with least impacts.

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References

Furgal, C. and Prowse, T.D. (2008): Northern Canada. In: D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush (Eds.) From Impacts to Adaptation: Canada in a Changing Climate 2007, Government of Canada, Ottawa, ON, p.57-118.

IMG-Golder Associates Ltd. (2012): Vulnerability Assessment of the Mining Sector to Climate Change Task 1 Report. Report Number 11-1334-0029, prepared for the Government of Nunavut, Department of Economic Development and Transportation, 100p.

Kwong, Y.T. J. (2003): Comprehensive environmental ore deposit models as an aid for sustainable development. *Journal of Exploration and Mining Geology,* **12**(1-4):31-36.

Kwong, Y.T.J. (2010): Tailings decommissioning options at Mount Nansen, Yukon, Canada. In: A.B. Fourie and R.J. Jewell (Eds) Mine Waste 2010 – Proceedings of the First International Seminar on the Reduction of Risk in the Management of Tailings and Mine Waste, 27 September – 1 October 2010, Perth, Australia, p.91-102.

Kwong, Y.T.J. (2011): Role of environmental ore deposit models in resources development. Proceedings of the Eighth International Mining Geology Conference 2011, 22-24 August 2011, Queenstown, New Zealand, The Australian Institute of Mining and Metallurgy, p.437-441.

Kwong, Y.T. and Gan, T.Y. (1994): Northward migration of permafrost along the Mackenzie Highway and climate warming. *Climate Change* **26**(4): 399-419.

Lawrence, J.R., Swerhone, G.D.W., Dynes, J.J. and Kwong, Y.T.J. (2014): Metal attenuation and microbes in a northern mining area. CanmetMINING 13-058(TR), 39p.

Northern Climate ExChange (2012): Yukon Mine Waste and Climate Change. Northern Climate ExChange, Yukon Research Centre, Yukon College, Whitehorse, YT, 160p.

Plumlee, G.S. and Logsdon, M.J. (1999): An earth-system science toolkit for environmentally friendly mineral resource development. In: G.S. Plumlee and M.L. Logsdon (Eds.) The Environmental Geochemistry of Mineral Deposits, Part A: Process, Techniques, and Health Issues, Reviews in Economic Geology Volume 6A, Society of Economic Geologists, Inc., p.1-27.

Troop, J., Lewkowicz, A.G. and Smith, S.L. (2012): Climate and ground temperature relations at sites across the continuous and discontinuous permafrost zones, northern Canada. *Can, J. Earth Sci.* **49**:865-876.

Warren, F.J. and Lemmen, D.S. (Eds., 2014): Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation; Government of Canada, Ottawa, ON, 286p.