# Permafrost-related threats to alpine headwater lakes: evidence from integrating contemporary research

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## Abstract

Degrading permafrost in periglacial environments can produce acid rock drainage (ARD) and cause severe ecological damage in areas underlain by sulfide-bearing bedrock. Comparative research design was used in the integrating contemporary study to assess and compare ARDs generated by rock glaciers and their effects on alpine headwater lakes with similar morphometric features and underlying bedrock geology, but characterized by different intensities of frost action in their catchments. We argue that ARD and its effects on lakes are more severe in the alpine periglacial belt with mean annual air temperatures (MAAT) between −2 °C and +3 °C, where groundwater persists in the liquid phase for most of the year, in contrast to ARD in the periglacial belt where frost action dominates (MAAT < −2 °C). The findings clearly suggest that the ambient air temperature is an important factor affecting the ARD production in periglacial environments.

**Keywords:** acid drainage, aquatic invertebrates, frost action, metals, periglacial environments, rock glacier.

## Introduction

Despite the fact that changes in the mountain cryosphere are progressing rapidly, surprisingly little research has been devoted to studying the impact of meltwater from glaciated and perennially frozen areas on alpine aquatic ecosystems (e.g. Slemmons *et al.*, 2013). Extremely serious environmental problems associated with the generation of acid rock drainage (ARD) can arise in mineralized watersheds with sulfide-bearing bedrock (Thies *et al.*, 2007; Ilyashuk *et al.*, 2014). Changes in the location of glacier ice and ice-rich permafrost can greatly affect ARD in areas where the ice has been providing a cover to prevent oxidation of sulfide minerals (e.g. Todd *et al.*, 2012). As of today only a few studies exist which have been dealing with the investigation of ARD in periglacial environments.

In the present study, we hypothesized that ARD generated by a rock glacier and its effects on a lake in a crystalline-rock area are more severe in the alpine periglacial belt in which groundwater persists in the liquid phase for most of the year (MAAT between −2 °C and +3 °C; French, 2007), in contrast to the periglacial belt in which frost action conditions dominate (MAAT lower than −2 °C).

## Research Design

The study area is located within a crystalline-rock watershed in periglacial environments of the upper Vinschgau valley in the Central Eastern Alps, Northern Italy. Disseminated sulfide ore minerals are widespread in the bedrock of the valley (Spötl *et al.*, 2002) and are one of the key factors in generating ARDs. The present study aimed at testing the research hypothesis by assessing and comparing ARDs generated by rock glaciers and their effects on two alpine headwater lakes (RAS and POR) with similar morphometric features and bedrock geology, but characterized by different intensities of frost action in their catchments. A third lake (SAL1), not influenced by rock glaciers, was sampled as a reference site. The ARD effects were assessed through the determination of the concentrations of metals in water, sediment, and biota of the lakes.

## Results and Discussion

Chemical analysis of rock samples from the lake catchments showed that the geochemical composition of bedrock is rather similar between the lake catchments.

Chemical analysis of water samples revealed that the total concentrations of Al, Mn, Ni, and Zn are negligibly small in the circumneutral SAL1 compared to the acidic RAS and POR situated at the toes of rock glaciers. The concentrations of Mn and Ni exceed the appropriate EU limits for drinking water (The Council of the EU, 1998) ~16 and ~8 times, respectively, in the POR water and ~23 and ~15 times, respectively, in RAS. Speciation analysis performed with the Visual MINTEQ equilibrium model demonstrated that free $Ni^{2+}$ and $Mn^{2+}$ ions account for 88–91% of the total nickel and manganese concentrations in RAS and POR.

Geochemical analysis of surface sediments showed that the total concentrations of Cr, Cu, Ni and Zn in the deep-water sediments are significantly greater in RAS and POR than in SAL1. It is noteworthy that Ni and Zn concentrations are significantly less in POR whose catchment is governed mainly by frost action, compared to RAS, lying in the catchment dominated by melting of ground ice in the rock glacier.

The data provided evidence for the presence of natural ARDs in the catchments of RAS and POR situated at the toes of rock glaciers. However, POR and its catchment located in the periglacial environment with a MAAT below −2 °C are affected by less severe ARD than RAS and its catchment located within the periglacial belt with MAATs ranging from −2° C to +3 °C (Ilyashuk *et al.*, 2017).

Concentrations of five metals (Al, Cr, Cu, Mn, and Ni) in the chironomid body tissues are significantly greater in RAS and POR as compared to SAL1. The greatest concentration of Mn, Ni and Zn were measured in chironomids from RAS. The difference between the lakes in the metal body burdens observed in the invertebrates reflects the difference in the presence as well as in the severity of ARD.

It would be useful to test our hypothesis and obtained results on a broader set of lakes and in different mountain areas of the world.

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