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Evidence of rock glacier melt impacts on water chemistry and diatoms in high mountain streams

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ABSTRACT

A first study of high alpine freshwaters at Hochebenkar and Krumgampen (Oetztal Alps, Tyrol, Austria) revealed pronounced differences in the concentration of major ions, heavy metals, species composition and biodiversity of epilithic diatoms in streams emerging from two active (i.e. ice containing) rock glaciers and in adjacent unaffected reference streams. The clear-water streams impacted by active rock glaciers are characterized by high electrical conductivity (EC) values, but differ in acidity, heavy metal concentrations and by the proportion of circumneutral and acidobiontic diatoms. On the contrary, all reference streams exhibit low EC and circumneutral to slightly acidic pH values characteristic for surface waters on bedrock composed of paragneiss and micaschist, with no detectable heavy metals and a diatom composition typical for high altitude softwater streams. The high ion concentrations in streams emerging from rock glaciers are attributed to a seasonally increasing release of melt waters from active rock glaciers.

1. Introduction

Remote high mountain freshwaters are recognized as sensitive indicators of pollution and climate change and they gain rising importance for biodiversity conservation and as a freshwater resource (Battarbee et al., 2005; Brittain and Milner, 2001; Marchetto et al., 2009; Nickus et al., 2010; Rott et al., 2006). The Alps have experienced a pronounced increase in air temperature since the 1970s (Casty et al., 2005) and related effects of substantial warming on permafrost in several European mountains including the Alps have been reported (Harris et al., 2003). Active rock glaciers are a common form of permafrost in high mountain areas (Humlum, 1998) and were defined by Barsch (1996) as lobate or tongue-shaped bodies of perennially frozen unconsolidated material supersaturated with interstitial ice and ice lenses that move downslope by creep. Krainer and Ribis (2012) mapped more than 500 active rock glaciers in the Tyrolean Alps (Austria). Rock glaciers are situated near the local boundary of permafrost, and their mean annual surface temperature is therefore close to melting conditions (Haeberli et al., 2006), which underlines their sensitivity to climate warming. Studies on the effects of rock glaciers on hydrology and water chemistry of adjacent surface waters are still the exception (Baron et al., 2009; Krainer et al., 2007; Williams et al., 2006) in the field of permafrost research (Haeberli et al., 2010). But there is first evidence about a climate warming impact on high mountain lake water chemistry in the Alps driven by active rock glaciers (Thies et al., 2007), in particular regarding strongly rising concentrations of calcium, magnesium, sulphate and elevated heavy metal values. We are however not aware of studies on the potential effects of rock glacier melt waters on the ecological quality of alpine headwater streams. Effects of heavy metals on diatom species have been reported in a review (e.g. Falasco et al., 2009), but studies at the community level of headwaters are still rare (e.g. Furey et al., 2009) and have not been shown for freshwaters affected by rock glacier melt.

Here, we report on the first study of chemical and biological indicators from selected high mountain rock glacier streams in the Austrian Alps. Due to their remoteness these streams can be characterized as almost pristine without any direct anthropogenic impact like domestic sewage, mining, agriculture or settlements. Land use is restricted to alpine pastures grazed during summer by some sheep or horses. These rock glacier fed streams are typically clear-waters and differ from glacial streams emerging from ice glaciers, which are characterized by strong mineral turbidity due to glacial erosion (e.g. Füreder, 2012). We selected high altitude stream systems differing in acidity and metal concentration, which emerge from (i) an average size rock glacier and (ii) from the largest rock glacier in Tyrol (Krainer and Ribis, 2012). Additionally, we compare these affected streams with non-impacted reference streams, which have no contact to active rock glaciers.

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2. Material and methods

2.1. Study sites

The Hochebenkar rock glacier is an active, tongue-shaped glacier located at a northwest oriented cirque in the southern Ötztal Alps (Fig. 1; 11°00′ E, 46°50′ N). Hochebenkar rock glacier extends from 2360 to 2840 m altitude, is 1.6 km long, and has a surface area of 0.48 km^2 (Fig. 2). It represents the largest rock glacier in Tyrol and holds the most extended study record for rock glacier flow velocities (Haeberli and Patzelt, 1982; Krainer, 2010; Krainer and Ribis, 2012; Pillewizer, 1938; Schneider and Schneider, 2001; Vietoris, 1958, 1972). A clear-water stream emerging from Hochebenkar rock glacier was studied for water chemistry and epilithic diatoms at 2550 m altitude (HK-1) and at 2210 m altitude (HK-2) (Fig. 2). Water levels have been monitored at HK-1 since 2008 by a pressure sensor and a data logger (Logotronic Micro), and the stage–discharge calibration is performed using the salt dilution method and a Logotronic QTrace device. The reference stream HK-R1 (2560 m altitude) is situated northeast of Hochebenkar rock glacier (Fig. 2), while a second reference stream (HK-R2) is located at 1950 m altitude near the village of Obergurgl (11°01′ E, 46°51′ N) on the orographic left side of the river Gurgler Ache. Both reference streams are without contact to active rock glaciers.

The Krumgampen rock glacier is situated at a north facing slope in a side valley of the upper Kaunertal in the western Oetztal Alps (Fig. 1; 10°42′ E, 46°52′ N). It covers an altitudinal range of 2465 to 2700 m, is 440 m long and has an area of 0.1 km^2, thus representing an active and tongue-shaped average size rock glacier in the Tyrolean Alps (Krainer and Ribis, 2012). Sampling sites include three clear-water streams (KG-1, KG-2, and KG-3). They emerge at the front of the rock glacier at 2460 m altitude (Fig. 3) and are direct tributaries to the Krumgampen main stream. This main stream was sampled at 2405 m altitude at the site KG-S (Fig. 3) in order to assess potential downstream effects of the rock glacier streams KG-1, KG-2 and KG-3 on its water chemistry and epilithic diatoms. Water level and discharge of the Krumgampen main stream were monitored by a gauge as described for HK-1. The selected reference streams (KG-R1, KG-R2, and KG-R3) are located at the orographic left side of the valley opposite to the rock glacier and drain into the Krumgampen main stream at an elevation from 2465 m to 2420 m (Fig. 3).

The bedrock of both Hochebenkar and Krumgampen rock glaciers consists mainly of paragneiss and micaschist of the Oetztal metamorphic complex (Hoinkes and Thöni, 1993; Krainer, 2010; Purtscheller, 1978). Both rock glacier catchments are in almost pristine conditions with respect to land use (e.g. alpine pastures) and lacking direct anthropogenic impacts (e.g. no settlements, no agriculture, no mining).

2.2. Sampling and analysis

Water chemistry at Hochebenkar and Krumgampen streams has been studied since 2008 (Nickus et al., unpubl.). According to the scope of this explorative study, the biological and chemical sampling for the current study was performed at base low conditions in September 2010 at selected streams (Table 1, Fig. 4) in order to focus on a period of prevailing permafrost melt (cf. Krainer and Mostler, 2002; Krainer and Mostler, 2006; Krainer et al., 2007) and to minimize potential effects of high discharge by spring snow melt or summer rainfall. Studies on the seasonal variability of benthic algal communities of high altitude alpine streams (Rott et al., 2006; Uehlinger et al., 1998, 2010) identified the period from late summer to autumn as the most favourable ecological time window for maximum algal growth and diversity.

Water samples were transported in pre-cleaned polyethylene bottles and stored at 4 °C in the dark until analysis for less than one week. Temperature and electrical conductivity were measured on site with a WTW LF-92 meter. The pH was measured in the laboratory with a WTW pH-91 meter using a Hamilton flushtrode and Merck Titrisol pH 4 and pH 7 buffer solutions. Ion concentrations were analysed by ion exchange chromatography (Dionex DX 500/ICS 1000) applying suppressed conductivity detection. Analytical columns AS11 and CS12A were used for the separation of major anions and cations. The injected sample volume was 20 μL. Merck CertiPur individual stock solutions of 1000 mg/kg were diluted for mixed standard solutions. Elemental metal analysis was carried out using an Inductively Coupled Plasma Optical Emission Spectrometer ICP OES (Horiba Jobin Yvon Activa). The spectrometer was continuously purged with nitrogen to enhance the detection of emission lines <220 nm, i.e. here Al and Zn emission lines. Standard solutions for metal analysis were prepared by dilution of Merck CertiPur ICP multi-element stock solutions and AlfaAesar single element ICP stock solutions. Quality control was performed using certified reference solutions from Environment Canada (trace element fortified materials TM-15.2, TMDA-61.2 and TMDA-70). Deviation of measured values was generally <10% of certified concentrations. Detection limits were

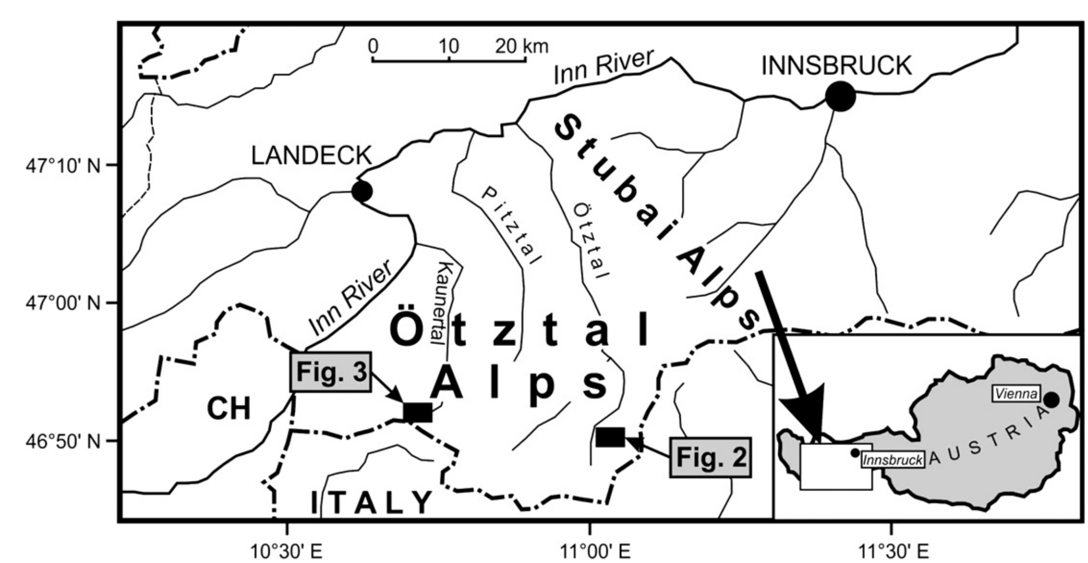

Fig. 1. Location of study sites in the Oetztal Alps (Tyrol, Austria).