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Investigating the Microscopic Location of Trace Elements in Glacier Ice

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Past changes in atmospheric pollution can be reconstructed from high-alpine ice core trace element records (Schwikowski et al., 2004). Eichler et al. (2001) suggested that the preservation of major ions with respect to meltwater percolation depends on their location in the ice crystal lattice. Species predominately segregated at grain surfaces during snow metamorphism were more efficient scavenged by percolating meltwater compared to others incorporated into the ice lattice. Here, we present for the first time a comprehensive study on the microscopic location of anthropogenic, dust and volcanic related trace elements in glacier ice using two different approaches. Moreover, we link the outcome of the study to the tendency of crystalline ice to embed dopants.
On the one hand we assessed the microscopic location of trace elements indirectly by analyzing their concentration records in a high-alpine ice core from Grenzgletscher in the southern Swiss Alps using inductively coupled plasma mass spectrometry (ICP-MS). A 13 m w.eq. part of the ice core has been shown to be affected by an inflow of meltwater. Our results demonstrate for the first time that a variety of trace element records, such as Fe, Pb or Cu are not significantly altered by meltwater percolation, indicating a higher solubility of these species in ice. Other trace elements (e.g. Cd, Mn or Zn) are significantly depleted in the affected section of the ice core, presumably due to their initial segregation at grain boundaries.
In a second approach we examine the outcome of the indirect analysis by direct spatial analysis of trace elements in Grenzgletscher ice samples. We developed a method based on cryocell laser ablation (LA) ICP-MS, which is the method of choice for the direct in situ chemical analysis of trace elements at a sub-millimeter resolution in glacier ice (Della Lunga et al., 2014, Sneed et al., 2015). The setup is currently tested to analyze concentrations differences of accessible trace elements (e.g. Al, Fe, Pb or Mn) within grains and along grain boundaries in ice core samples from Grenzgletscher.
Results of both approaches will be presented. Based on these findings we will discuss possible driving forces causing the observed incorporation of trace elements (such as size and concentration levels) and address how the capability of the ice crystal to form solid solutions responses to size and concentration levels of solutes. This will not only help to evaluate the potential of trace elements as environmental proxies in glaciers partially affected by melting, but also involves the fundamental aspect of how dopants are incorporated into an ice lattice.

Significance statement

The microscopic location of trace elements is a key factor for their potential post-depositional relocation in glaciers affected by melting. Our study provides new insights into the nature of impurity location in glacier ice and into the solubility of dopants in single crystalline ice.

Primary author: Mr AVAK, Sven Erik (Laboratory of Environmental Chemistry, Paul Scherrer Institute, Switzerland)

Co-authors: Dr EICHLER, Anja (Laboratory of Environmental Chemistry, Paul Scherrer Institute, Switzerland); Dr GUILLONG, Marcel (Institute of Geochemistry and Petrology, ETH Zurich, Switzerland); Prof. SCHWIKOWSKI, Margit (Laboratory of Environmental Chemistry, Paul Scherrer Institute, Switzerland); Dr LAURENT, Oscar (Institute of Geochemistry and Petrology, ETH Zurich, Switzerland); BARTELS-RAUSCH, Thorsten (Laboratory of Environmental Chemistry, Paul Scherrer Institute, Switzerland)

Presenter: Mr AVAK, Sven Erik (Laboratory of Environmental Chemistry, Paul Scherrer Institute, Switzerland)

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