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Silicon isotopes in alpine periglacial environments – New insights from experimental vs. natural hydroxy-aluminosilicate precipitation

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Active rock glaciers including permafrost ice in the Austrian Alps are susceptible to global warming. Acidic rock drainage due to bedrock weathering (i.e., oxidation of sulphide minerals and leaching of silicates) at active rock glacier springs and related streams has increased in recent years likely due to climate change. The mixing of these acidic waters with near-neutral waters from nearby streams lead to the precipitation of whitish coatings in the stream beds, which are found to be short-range-ordered hydroxy-aluminosilicates (SRO-HAS, i.e. allophane). The formation mechanisms of SRO-HAS under ambient conditions have been briefly addressed in recent studies[1], but currently we lack a thorough understanding of their formation in low temperature environments (<15 °C).

This study investigates the formation and associated Si isotope fractionation of SRO-HAS at low temperature by comparing data from batch experiments with natural samples from two locations in the Austrian Alps. The experimental results show that SRO-HAS precipitation follows three distinct stages: 1. An initial fast proto-SRO-HAS precipitation, 2. Almost complete SRO-HAS re-dissolution and 3. Slow SRO-HAS re-precipitation. The precipitation kinetics of SRO-HAS in stage 3 are significantly slower than observed in experiments conducted at 25 °C[1]. The experiments show a large magnitude Si isotope fractionation, expressed as $\Delta^{30}Si_{SRO\text{-}HAS\text{-}aq}$, of down to -2.82 ‰, reflecting the preferential incorporation of lighter Si isotopes (^{28}Si) into the precipitated SRO-HAS phase. The Si isotopic data from the field sites in the Austrian Alps show that all meltwater solutions are isotopically significantly heavier ($\delta^{30}Si \approx +0.91 + 0.10$ ‰ to $+1.88 + 0.16$ ‰) than the bedrock ($\delta^{30}Si \approx -0.36 + 0.20$ ‰) indicating mineral precipitation processes (i.e. SRO-HAS) preferentially remove the lighter isotopes, corroborated by the experiments. The results of this study show that the Si isotopic composition of SRO-HAS phases might be used to trace their ongoing formation and thus can shed light onto the impacts of climate change on natural water-rock interaction.

[1] Baldermann, A., Stamm, F.M., Farkaš, J., Löhr, S., Ratz, B., Letofsky-Papst, I., Dietzel, M., 2023. Chem. Geol. 646, 121911. 10.1016/j.chemgeo.2023.121911.