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The big melt: how microbes, minerals, and ions change our planet today and in future warmer climates

Climate change enhanced melting of the Greenland Ice Sheet has long passed the 1.5˚ C threshold resulting in dramatic melt rates and a large contribution to global sea level rise. Worldwide glaciers and ice sheets occupy ~ 10 % of the total land surface and they harbour diverse and complex biological communities that play very distinct roles and that lead to complex interactions and feedbacks with their physical and chemical environment – the snow and ice. In these habitats the biological entities are dominated almost exclusively by microbes that separate into various habitats. Such microbial habitats include snow and bare ice are dominated by pigmented algae while cryoconite holes (small, water-filled cylindrical cavities on glacier surface) are dominated by cyanobacterial communities. For these microbes to be able to thrive in the summer, when temperatures reach above zero, melting has to be imitated so as to produce enough liquid water that will sustain microbial activity. Although not discussed here in detail, subglacial habitats, that are often oxygen poor, are also dominated by microbes – that are fuelled by chemolithotrophic processes linked to S, Fe and C cycles that drive chemical transformations under the ice (see more info for example in Anesio et al. 2017 or Stibal et al. 2020).

Quantifying the biogeochemical processes controlled by the microbiomes that dominate glacier and ice sheet surface habitats worldwide (snow, ice and cryoconite holes) it becomes clear that they all harbour a remarkable similar microbial composition, in particular in terms of their main primary producers and ecosystem engineers. Among these, various pigmented algae, that bloom on snow and ice surfaces play major roles in element cycles and these will be the main focus of this talk. Their pigmentation darkens snow and ice surfaces and reduces albedo between 13 and locally up to 25 % (e.g., Lutz et al. 2016, Tedstone et al. 2020, Cook et al. 2021, Chevrollier et al. 2023).

The algae bloom on snow and ice and this blooming is fueled by nutrients, which they derive either from melting snow and ice rot from solid mineral dust (Gill-Olivas et al. 2026; McCutcheon et al. 2021, 2016). We have shown recently through mass balance calculations that crucial nutrients (like nitrogen and phosphorous) that are released from melting ice each year may, in certain locations, even exceed the amounts needed by the pigmented glacier ice algal biomass that dominates bare ice surfaces (Gill-Olivas et al. 2026). This suggest that dissolved macronutrients may not be the limiting parameters when it comes to controlling glacier ice algal growth on the Greenland Ice Sheet. We further analyzed the molecular scale mineral – microbe interactions (McCutcheon et al. 2021, 2026) and show that these play a fundamental role in the landscape-wide processes that shape our planet today and importantly also in a warmer future world.

We know that algae blooms are triggered annually through the tight interplay between geochemical, mineralogical, microbiological and physical processes and we are slowly managed to unravel the biochemical and fundamental cellular processes that govern such blooms. For example, we recently documented the response of glacier ice algae that thrive on bare ice surfaces to extreme light and dark conditions (Feord et al. 2025). We identified high oxidative stress responses and evidence for high photosystem protein turnover in the blooms. This data heled us provide crucial evidence about how pigmented glacier ice algae cannot just survive but actually adapt and thus bloom in the harsh and extremely variable light environments on glaciers and ice sheet surfaces. We also show that these glacier ice-algae habitats have higher abundances of highly unsaturated and aromatic organic carbon compounds that are highly resistant to bio- and photo-degradation (Rossel et al. 2025). In contrast, snow-algae habitats, are more enriched in bioavailable and more photosensitive unsaturated aliphatics compounds and light exposure increased dissolved organic matter compounds, in both algae dominated habitats. Combining such detailed analyses of inorganic and organic components in snow and ice surface measurements and complementing them with drone and satellite data (e.g., Tedstone et al. 2020, Feng et al. 2023) we could now determine the role that microbes and minerals play in shaping landscape scale processes on Greenland and this helps parameterise global melt and sea level rise model predictions.

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Fig. 1. Bags filled with green and red pigmented snow algae; ***copyright Liane G. Benning***

Fig. 2. (left) Ice core covered with dark pigmented glacier ice algae and mineral particles (right) frozen in algae/mineral aggregates in an ice core slice; both images from S-Greenland; ***both copyright Liane G. Benning/ DeepPurple***

Fig. 3. Sampling pigmented snow and ice in S-Greenland; ***copyright L. Halbach/DeepPurple***

Fig. 4. (left) Melt zone transition between white clean(ish) snow and dark ice (humans for scale on snow) on the E-Greenland Ice Sheet
(right) Dark brown/ deep purple pigmented glacier ice algae; ***both copyright L. Halbach/DeepPurple***

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