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Microbial-induced pedogenesis: Microaggregates as nucleus for initial soil formation

Soil formation in Antarctica begins immediately after the retreat of ice and snow. Because the continent is almost completely devoid of higher plants and burrowing animals, these processes are shaped primarily by microorganisms. This unique setting provides an opportunity to study the direct role of microbial communities in the earliest stages of pedogenesis. Previous studies have shown that microorganisms respond rapidly to changing environmental conditions and that the formation of soil microaggregates is an initial step in soil development. These aggregates have distinct physical boundaries, suggesting that early soil formation is spatially heterogeneous, with different microhabitats forming inside and on their surfaces. The aim of this project is to investigate interactions between microorganisms, aggregate structure, and soil chemistry using approaches that overcome the limited spatial resolution of conventional bulk soil analyses. To achieve this, we will analyse different microaggregate size fractions and separately examine their interiors and exteriors. Microorganisms will be differentially fluorescently labelled, and flow cytometry will distinguish surface-associated from interior microbial communities. First experiments developing this labelling technique and establishing a protocol for aggregate fractionation are already ongoing. In addition, complementary methods such as micromorphology, fluorescence microscopy, μCT, SEM-EDX, and NanoSIMS will provide structural and chemical data across multiple spatial scales, which will be integrated into a spatially resolved picture of aggregate architecture and microbial distribution. These methods will then be applied to samples from climate-change simulation experiments, designed to mimic shifts in moisture availability, temperature regimes, and freeze–thaw dynamics, in order to assess their impact on early soil development and to clarify microbial interactions with organic matter, soil moisture, clay content, and microaggregation under changing climatic conditions. Finally, all datasets will be merged and analysed using machine learning to model, for the first time, the earliest stages of soil formation.

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