Rapid soil structure formation after deglaciation through accrual of organic matter –an image analysis of elemental distributions by NanoSIMS

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Global change contributes to the retreat of glaciers at unprecedented rate. At the Damma glacier (Switzerland) the deglaciation exposed barren glacial deposits to geochemical weathering and the establishment of vegetation and biological soil processes. The ongoing soil formation in the proglacial environment enables to study the spatial complexity of soil organic matter (SOM) at early stages of ecosystem development (chronosequence on ice-free deposit with 15 to >700 years since deglaciation). The spatial complexity of SOM is an important factor to understand soil carbon cycling and demands measurements at the microscale. To quantify SOM coverage and connectivity we developed an image analysis based on supervised pixel classification with a machine learning algorithm of the $^{12}C^-$, $^{12}C^{14}N^-$ (indicative for SOM) and $^{16}O^-$ (indicative for mineral surfaces) secondary ion distributions provided by nanoscale secondary ion mass spectrometry (NanoSIMS) at a lateral resolution of approximately 100 nm. With this technique we investigated mineral-associated SOM obtained from clay fractions (<2 µm) separated in two density fractions: light mineral (1.6 to 2.2 g cm^{-3}) and heavy mineral (>2.2 g cm^{-3}). We found increased coverage and a simultaneous development from patchy-distributed organic coatings to more connected coatings with increasing time after glacial retreat indicating soil biota shaping their own microenvironment. At the same time, fine particles found in the heavy mineral fraction at young soil development (15 years) shifted to the light fraction in the mature soil (>700 years). On the organic coatings we found a sequential accumulation of proteinaceous SOM in the medium-aged soils and carbonaceous compounds in the mature soils. Image analysis in combination with secondary ion distributions provides a powerful tool at the required microscale and enhances the mechanistic understanding of SOM retention in soils.