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Microspatial patterns of organic matter accrual in microaggregates govern the rapid soil formation after glacial retreat

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The retreat of glaciers due to climate change leads to initial soil formation including a rapid sequestration of soil organic matter (SOM) in the proglacial environment. The underlying mechanisms shaping the association of SOM with soil mineral particles are still unclear and require further investigation of the spatial heterogeneity of organic matter accrual at the microscale. In this study, we analyzed the microspatial arrangement of SOM coatings on intact soil microaggregate structures during an ecosystem development from 15 to >700 years since deglaciation at the Damma glacier (Switzerland). We separated the clay-sized soil fractions from four development stages (<2 μm) into a light (1.6-2.2 g cm^3) and a heavy (>2.2 g cm^3) density fraction with different amounts of organo-mineral associations. Based on images from nanoscale secondary ion mass spectrometry (NanoSIMS), we quantified how SOM extends across the surface of mineral particles (coverage) and if SOM coatings are distributed in fragmented or connected patterns (connectivity). We classified SOM and mineral areas depending on the ^{16}O, ^{12}C, and $^{12}C^{14}N$ ion distributions, using a multi-channel machine-learning algorithm. Our results show that, over time after glacial retreat, the microspatial coverage and connectivity of SOM increased rapidly. On soil microaggregates, we found a succession of patchy distributed to more connected SOM coatings. Even >700 years after deglaciation, the SOM coatings covered the mineral surfaces to an extent of 55 % and revealed direct evidence for a decoupling of SOM sequestration from the mineral surface, as it was not completely masked by SOM and retained its functionality as an ion exchange site. The chemical composition of SOM coatings indicated an increase of the CN:C ratio already at 75 years after glacial retreat, which was associated with microbial succession patterns reflecting high N assimilation. We concluded that rapid SOM sequestration drove the microspatial succession of SOM coatings in soil microaggregates, that can stabilize SOM for the long-term.