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Integrating mineral interactions with organic carbon in thawing permafrost to assess climate feedbacks

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Permafrost contains 1400-1660 Gt of organic carbon (OC), from which 5-15% will likely be emitted as greenhouse gases (GHG) by 2100. The soil organic carbon stock is distributed between a pool of particulate organic matter (POM), and a pool of mineral-associated OM (MOM). POM can be free, i.e., more readily available for microbial decomposition, or occluded within soil aggregates (involving clay minerals or Fe-Al (hydr)oxides), i.e., spatially inaccessible for microorganisms. MOM includes OC sorbed onto mineral surfaces (such as clay minerals or Fe-oxides) and OC complexed with metal cations (e.g., Al, Fe, Ca), i.e., stabilized OC. The interactions between OC and minerals influence the accessibility of OC for microbial decomposition and OC stability and are therefore a factor in controlling the C emissions rate upon thawing permafrost.

In the warming Arctic, there is growing evidence for soil disturbance such as coastal erosion, thermokarst and soil drainage as a consequence of abrupt and gradual permafrost thaw. These disturbances induce changes in the physico-chemical conditions controlling mineral solubility in permafrost soils which directly affect the stability of the MOM and of the occluded POM. As a consequence, a portion of OC can be unlocked and transferred into the free POM. This additional pool of freely available OC may be degraded and amplify C emissions from permafrost to the atmosphere. Conversely, the concomitant release of metal cations upon permafrost thaw may partly mitigate permafrost C emissions by stabilization of OC via complexation or sorption onto mineral surfaces and return a portion of freely available OC to the MOM. The majority of C is emitted as CO_2 but 1.5 and 3.5% of the total permafrost C emissions will be released as CH_4, with implications for the atmospheric radiative forcing balance. Importantly, the proportion CH_4 emitted relative to CO_2 is likely to increase with increasing abrupt thaw and associated anoxic conditions, but a portion of CH_4 emissions could be mitigated by the anoxic oxidation of methane mediated by the presence of Fe-oxides exposed by abrupt thaw of deep permafrost.

This contribution aims at assessing how changing soil physico-chemical conditions affect interactions between mineral surfaces and OC in thawing permafrost. Scenarios of mineral-organic interactions during gradual thaw, including changes in water drainage and talik formation, and abrupt thaw including shifting redox conditions associated with thermokarst will be presented. Approaches to quantify changes in mineral-organic interactions will be discussed. By integrating the most recent studies from the permafrost carbon community with soil mineralogy, soil chemistry and soil hydrology, this contribution demonstrates that the fate of mineral-organic interactions upon thawing must be considered given their potential implications for GHG emissions. If we do not include the role of mineral-organic interactions in this puzzle, the complexities involved in soil carbon decomposition may propagate large uncertainties into coupled soil carbon-climate feedback predictions.