Characterization of organic carbon-mineral interactions within a megaslump headwall and potential evolution following material export: case study in Batagaika crater, northern Yakutia, Siberia

Maxime THOMAS[1*], Loeka JONGEJANS[2], Jens STRAUSS[2], Chloé VERMYLEN[1], Sacha CALCUS[1], Arthur MONHONVAL[1], Thomas OPEL[2], Sophie OPFERGELT[1]

[1] Earth and Life Institute, Université catholique de Louvain, Louvain-la-Neuve, Belgium
[2] Permafrost Research Section, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany

*Speaker: Maxime Thomas: maxime.thomas@uclouvain.be
Croix du Sud, 1 bte L7.05.10, B-1348 Louvain-la-Neuve, Belgium | Phone: +32 (0)10 47 36 29

Arctic is warming close to four times faster than the global average and, as a direct outcome, permafrost temperatures have increased by up to 0.39 ± 0.15 °C in the years 2007-2016. This increased warming is expected to generate a permafrost carbon feedback on the climate by promoting permafrost thaw and by emitting additional volumes of greenhouse gases into the atmosphere. Still, it is estimated that between 30% and 80% of soil organic carbon (OC) in permafrost is stabilized by geochemical interactions with mineral elements such as iron and thus less likely to be emitted as greenhouse gases. Quantifying the nature and controls of mineral-OC interactions is necessary to better frame permafrost-carbon-climate feedbacks, particularly in ice-rich environments that result in rapid thawing and the development of thermokarst landforms. Thaw slumps are amongst the most dynamic forms of slope thermokarst and expand through the years due to the ablation of an ice-rich headwall each summer. These phenomena are important to consider in the permafrost carbon budget since they expose a deep OC pool that may reach tens of thousands of years old and that would not have re-entered the modern carbon cycle if these disturbances had not occurred. Here, we collected samples from the Batagaika crater, Siberia, on a headwall reaching locally 55 m high - every half a meter for the upper 10 m of the headwall and then every meter. We present total element concentrations, mineralogy, and mineral-organic carbon interactions in the different stratigraphic units, i.e., from the top to the bottom, i) the organic surface layer, ii) the Holocene cover, iii) the upper ice complex, also called Yedoma, which is dominated by large ice wedges, iv) the woody debris layer which consists of macroscopic terrestrial plant remains, v) the lower sand unit of pore-ice-cemented aeolian-sourced fine sand, and vi) the lower ice complex which reveals ice-rich deposits of ice-wedges and provides access to ancient permafrost up to ~650 ka old. Our data show that the main mechanism of organic carbon stabilization through mineral-OC interactions is the complexation with metals, which stabilizes 35 ± 18% of the total organic carbon (TOC) pool. Associations to poorly crystalline iron oxides do not have a significant role in OC stabilization as we estimate a maximum of 5 ± 2% of TOC to be stabilized by this mechanism, with the exception of the Holocene cover which stabilizes up to 29 ± 14% of the TOC via associations with poorly crystalline iron oxide. From a budget perspective, we estimate that a mass of 1.65×10^7 kg of OC is exported annually downslope of the headwall with ~ 38% being geochemically stabilized by complexation with metals or associations to poorly crystalline iron oxides. Climatic and geochemical conditions at the time of deposition appear to be the key parameters influencing OC geochemical stability as the mineralogy in the deposits is very similar despite a sedimentary depositional series spanning ~650 ka old.

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