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Biogeochemistry of a degrading ice-wedge polygon in the High Arctic

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Rising air temperatures and melting ground ice in the High Arctic can cause marked changes in the hydrology and redox conditions in the active layer of ice-wedge polygons. As the ice wedges melt, the polygon rims collapse into the troughs, and the ice-wedge polygons degrade from low-centred to high-centred. This degradation drains water from the polygon centres, with implications for the soil biogeochemistry. We compared the active layer and upper permafrost (transient layer) of a high-centred polygon at Revneset, Svalbard, to ascertain the impact of ice-wedge polygon degradation on the biogeochemical processes. We highlight ice wedge polygon degradation to be associated with controlling methane release dynamics to the atmosphere.

We obtained replicate cores from the high-centred polygon, extracted the porewaters of the cores, measured the aqueous and solid phase chemistry, and incubated the sediments anaerobically for 111 days. Our results revealed that both the active layer and the upper permafrost were rich in organic carbon (up to 38 % of the dry sediment mass). This is characteristic of peat formed under anaerobic conditions, implying that these sediments were deposited in a stagnant, low-centred ice-wedge polygon. The upper permafrost sediments supported the prevalence of anaerobic conditions; methane concentrations in the porewaters were high (up to 560 μmol l^{-1}), and the low concentrations of aqueous iron and sulphate coupled with higher pyrite concentrations were indicative of iron- and sulphate-reduction. Concentrations of carbon dioxide were relatively low ($\sim$2000 μmol l^{-1}). This implies that the upper permafrost has preserved the stagnant, anaerobic conditions present during peat formation.

In contrast, the active layer was hydrologically-flushed, with a low or fluctuating water table preventing the maintenance of a highly-reducing environment. Carbon dioxide concentrations were high ($\sim$4000 μmol l^{-1}). The low concentrations of iron and sulphate, and high ∂^{34}S values of sulphate, provide evidence for iron-reduction and sulphate-reduction. Methane was not detected in the active layer porewaters, indicating that conditions were not conducive to methanogenesis, or that methanotrophy predominated. Despite the absence of methane in the active layer porewaters, the thawed incubated upper permafrost and active layer sediments produced up to 15 nmol CH_4 ml^{-1} day^{-1}, suggesting that methanogenesis exceeded methanotrophy under anaerobic conditions.

Permafrost thaw is predicted to cause poorly-drained, low-centred polygons to degrade to well-drained, high-centred polygons. Our biogeochemical data from a high-centred polygon active layer support decreased net methanogenesis upon degradation, with continued iron- and sulphate-reduction. This is in contrast to the reducing methanogenic environment preserved below in the upper permafrost.