Biogeochemical processes affecting Arctic tundra soil organic matter degradation and greenhouse gas emission

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Organic carbon (C) stored in Arctic permafrost accounts for approximately 25% of the total organic C on Earth that may rapidly degrade with warming climate, releasing greenhouse gases (CH4, CO₂) to the atmosphere. As part of the Next Generation Ecosystem Experiment (NGEE) Arctic project, we seek to better understand the rates and mechanisms of soil organic matter (SOM) transformation, including the relevant physical, chemical, and biological processes that lead to both C decomposition and/or preservation below ground. We examine spatial and seasonal patterns in aqueous geochemistry and SOM characteristics across an area of tundra landscape in the Arctic to identify factors that increase or decrease rates of organic matter degradation.

Soil and porewater samples were obtained from the Barrow Environmental Observatory (BEO) in northern Alaska. A suite of wet-chemical and spectroscopic analyses including high resolution mass spectrometry (HR-MS), X-ray absorption spectroscopy (XAS), Fourier transform infrared spectroscopy, and high performance liquid chromatography was used to determine (1) CO₂ and CH4 formation, (2) the abundance of terminal electron acceptors, (3) vertical transport and spatial variability of both organic and inorganic compounds, (4) soil organic C composition and functional groups, and (5) their interactions with soil minerals. We observe a pH gradient from acidic surface water (as low as 4) to near neutral pH in pore-water 20 cm below surface. Dissolved organic C and Fe are dominant ionic species in both surface waters and soil pore fluids. Ferrous Fe(II) increases with depth and positively correlates to dissolved CH4 in porewater, from which we infer that Fe(III) reduction may serve as a primary metabolism, driving organic respiration in oxygen-depleted areas. Additionally, dissolved concentrations of CH4, CO₂, and Fe(II)/Fe(III) vary with soil moisture at locations, indicating that geochemistry differences induced by water saturation may determine microbial products of organic matter degradation. HR-MS and XAS analyses of soil and pore water samples indicate highly heterogeneous composition of natural organic matter, with distinct peaks representing aromatic, aliphatic, and carboxylic functional groups and their associations with soil minerals. We discuss potential implications of these findings in understanding sources, rates, and geochemical controls of C fluxes from tundra soils, which form the basis for a computational modeling framework in predicting feedbacks to warming climate.