Title: Spatial Variation in Microbial Processes Controlling Carbon Mineralization within Soils and Sediments

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Approximately 3300 Pg of carbon (C) are stored in soils as organic matter, which is three-times the amount stored in the atmosphere. An important control on soil organic matter (SOM) storage is the mineralization (oxidation) rate, which is affected by climatic factors (particularly temperature and rainfall) influencing microbial metabolic rates as well as SOM chemistry, mineral-organic associations, and physical protection. What remains elusive is to what extent constraints on microbial metabolisms induced by the respiratory pathway, and specifically the electron acceptor in respiration, control overall rates of carbon mineralization in soils. The complex physical structure of soils and sediments results in an abundance of redox environments even within seemingly aerobic systems. Therefore, factors limiting oxygen diffusion and availability such as soil texture and aggregate size (soil structure) may be central controls on microbial C mineralization rates.

Combining micro-scale laboratory experiments with field-scale observations, we find that texture-induced oxygen diffusion limitations create anaerobic microsites within seemingly well-aerated soils, shifting microbial metabolism to less efficient anaerobic SOC oxidation pathways. In both saturated and unsaturated systems, microsensor measurements in combination with gas flux measurements showed that particle size exerts a strong control on the extent of the anaerobic volume, thereby causing an overall decrease in OM oxidation rates. In model aggregates, we determined the distribution of operative microbial metabolisms and their cumulative impact on SOM transformations and overall oxidation rates within anaerobic microsites.. Metabolic profiling showed that texture-induced anaerobic microsites reduced SOC oxidation rates by an order of magnitude relative to aerobic rates, with Fe reduction contributing more than 75% of the overall metabolism. Density separations in combination with C 1s NEXAFS spectroscopy and high-resolution FT-ICR-MS showed that texture-induced anaerobic microsites resulted in the preferentially preservation of reduced (electron-rich) organic carbon compounds (both dissolved and particulate), a result corroborated by field measurements across multiple sites.

Collectively, our results suggest that anaerobic microsites are an underappreciated OM protection mechanism in upland soils. Removing anaerobic metabolic constraints through increased soil aeration (e.g., through changes in precipitation patterns or land use) will stimulate microbial oxidation of this inherently bioavailable SOC pool. Models that attribute the effects of texture merely to ‘mineral protection’ may therefore underestimate the vulnerability of soil C to global change impacts.