Systematic Investigation of the Biogeochemical Stability of Iron Oxide-Bound Organic Carbon: Linking Redox Cycles and Carbon Persistence

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Our core hypothesis is that the degradation rate of soil organic carbon (OC) during aerobic-anaerobic redox cycles is governed by the amount of iron (Fe)-bound OC, and the ability of microbial communities to utilize OC as an energy source and electron shuttle for Fe reduction that in turn stimulates reductive release of Fe-bound labile dissolved OC. We have been testing our hypothesis systematically using model Fe-OC complexes, natural soils, and microcosm system.

We have initiated studies of the dynamics of Fe and OC in hematite-OC and ferrihydrite-OC complexes during redox reactions. We found that hematite-bound aliphatic C was more resistant to reduction release, although hematite preferred to sorb more aromatic C. Resistance to reductive release represents a new mechanism that aliphatic soil OC was stabilized by association with Fe oxide. To the other side, pyrogenic OC can facilitate the reduction of hematite, by enhancing extracellular electron transport and sorbing Fe(II). For ferrihydrite-OC co-precipitates, the reduction of Fe and release of OC was closely governed by the C/Fe ratio in the system. Based on the XPS, XANES and XAFS analysis, the transformation of Fe speciation was heterogeneous, depending on the conformation and composition of Fe-OC complexes. Fe-bound OC was more thermally resistant compared to free OC, indicating the strong impact of association with Fe on the conformation of OC. Other experiments examining the mobilization and degradation of Fe-bound OC by natural wetland soil microbial communities are underway.

For natural soils, we investigated the quantity, characteristics, and reactivity of Fe-bound OC in soils collected from 14 forests in the United States. Fe-bound OC contributed up to 57.8% of total OC in forest soils. Under the anaerobic reactions, the reduction of Fe was positively correlated to the electron accepting capacity of OC. We also have collected tundra soil from Toolik (Alaska), and started microcosm experiment for studying the response of OC stability and Fe redox reaction to climate change.

Our findings so far highlight the closely coupled dynamics of Fe and OC, with broad implications on the turnover of OC and biogeochemical cycles of Fe. For our next step, we will investigate the transformation of Fe and OC and dynamics of microbial community, when the model Fe-OC complexes and natural soils are exposed to anaerobic-aerobic transitions. Furthermore, the molecular- to microcosm-scale experimental studies will be integrated with model simulations.