

Mapping soil carbon from cradle to grave: C transformations from roots to organo-mineral associations

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Carbon cycling in the rhizosphere is a nexus of biophysical interactions between plant roots, microorganisms, and the soil organo-mineral matrix. Plant roots provide 30-40% of soil organic C inputs, accelerate the rate of organic matter mineralization by ~10X, and support an active microhabitat for microbial transformation of soil C. Our research on how roots influence decomposition of soil organic matter in both simplified and complex microcosms uses geochemical characterization, molecular microbiology, isotope tracing, metabolomics and novel imaging approaches ('ChipSIP' and 'STXM-SIMS') to trace the fate of isotopically labelled root exudates and plant tissues. Our work in synthetic rhizospheres suggests root exudates drive O₂ limitation, alter metal chemistry and mineralogy, and influence the availability of SOM. Using a combination of X-ray spectromicroscopy and NanoSIMS, we have imaged the deconstruction of ¹³C/¹⁵N-labeled ligno-cellulose in model plant cells *in situ*, and mapped associations of plant cell-derived decomposition products with specific soil minerals. In the more complex rhizospheres surrounding roots of the annual grass *Avena fatua*, the microbial community undergoes a compositional succession as the plant grows, senesces, and dies. We have developed an isotope array that allows us to follow root C into bacterial, fungal, and microfaunal communities. The presence of root detritus significantly alters the soil microbial community over short time spans, leading to a higher proportion of eukaryotic microbes and Bacteroidetes. Finally, we have characterized the molecular cocktail of compounds exuded by *Avena* roots, and showed that increased belowground C allocation and root biomass driven by elevated CO₂ correspond to a greater amount of root-derived ¹³C in the 'heavy' soil fraction, commonly assumed to reflect longer term stabilization.

CO₂ mineralization in percolated olivine-rich rocks: Control of olivine crystallographic orientation and fluid flux

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In situ carbonation of ultramafic rocks is potentially an effective means for mitigating atmospheric CO₂ concentrations. CO₂ mineralization reactions in sub-surface conditions are controlled by the coupling of flow and transport processes and of chemical reactions occurring at the mineral-fluid interfaces. To better understand the roles of the structure of rocks and of fluid fluxes on the reactivity of ultramafic systems, we performed a reactive percolation experiment using a sintered olivine core (ø 6.35 mm × L 13 mm) in which CO₂-rich fluid was injected at P-T conditions similar to that expected for *in situ* storage. The sample was then characterized by EBSD and FIB-TEM.

EBSD analyses indicate a weak crystal preferred orientation (CPO) of the olivine (ol) aggregate resulting from sintering, with [010]_{ol} parallel to the axis of cylinder. We observe the development of a dense network of microcracks parallel to (100)_{ol}. Symmetrical etch pits indicating olivine dissolution are observed on (010)_{ol} surfaces. Two reaction products were identified: dolomite (dol) and magnesite (mgn). EBSD analyses revealed a statistical relationship between the olivine fabric and the direction of carbonate (carb) growth, marked by (10-14)_{carb}: (10-14)_{mgn} is parallel to (001)_{ol} and (10-14)_{dol} is parallel to (100)_{ol}. FIB-TEM analyses indicate however that carbonate growth is non-topotactic.

At all scales, [10-14]_{carb} is systematically oriented parallel to the main direction of fluid flow. In our sample, sintering induced the localization of (001)_{ol} and (100)_{ol} and the development of microcracks parallel to the cylinder axis, which is also parallel to the main direction of fluid fluxes. As a consequence, fluid fluxes and chemical transport were promoted and the olivine-fluid surface area was larger in that direction compared to that perpendicular to fluid fluxes. In turn, these conditions facilitated the development of local concentration gradients and the growth of carbonates at the olivine surface, where local fluid velocity tends toward zero, thus explaining that (10-14)_{carb} is statistically parallel to (001)_{ol} and (100)_{ol}.

Our results suggest that carbonate growth is controlled by the hydrodynamic conditions rather than by the olivine CPO during *in situ* carbonation of ultramafic rocks.