

Could siderite be a stable carbon sink in iron-rich polar soils in a future warming climate?

ZHENGZHENG CHEN^{1,2}, JEFFREY PAULO H. PEREZ¹,
CHRISTOPHER B. TRIVEDI¹, JESSICA ALEXANDRA
STAMMEIER¹, TOBIAS LINKE^{3,4}, SIGURDUR R.
GISLASON³ AND LIANE G. BENNING¹

¹GFZ Helmholtz Centre for Geosciences

²Freie Universität Berlin

³Institute of Earth Sciences, University of Iceland

⁴Institute for Geology, University of Hamburg

Northern high-latitude permafrost soils store a significant proportion of global carbon [1], much of which is associated with reactive iron minerals in a “rusty sink” [2], which influences carbon dynamics across Arctic landscapes. As global temperatures rise and permafrost thaws, these soils experience dramatic seasonal water level fluctuations, particularly in Iceland, where intense chemical weathering of basaltic rocks alters soil composition. Seasonal waterlogging drives Fe mineral (trans)formations and organic carbon (OC) cycling, a coupled process influenced by microbial activity. Earlier studies suggest that redox-driven Fe mineral recrystallization enhances OC degradation and release [3,4]. Among Fe phases, siderite (Fe(II) carbonate) naturally precipitates in these environments while potentially acting as a stable CO₂ sink [5,6], yet its formation and stability in permafrost-affected soils remain poorly understood.

To investigate natural siderite formation, we analysed the chemical, mineralogical, and biological variations in a seasonally waterlogged soil profile characterized by fluctuating redox gradients. Our results revealed that the redox transition zone exhibits distinct Fe speciation, OC composition, and microbial diversity compared to other horizons. Bulk X-ray diffraction confirmed siderite presence in this zone, while chemical extractions indicated a total iron content of ~29 wt.%, 2–4 times higher than in adjacent layers. Additionally, up to 84% of OC in this zone comprised low-molecular-weight fractions, suggesting enhanced OC degradation. Microbial community analyses via 16S rRNA gene sequencing highlighted the role of Fe-cycling and fermentative bacteria in regulating Fe and OC dynamics. More importantly, initial simulated redox oscillation experiments suggest the high resistance of this natural siderite against biogeochemical transformations and degradation. Together, these findings provide the first detailed insights into natural siderite formation in seasonally waterlogged soils, and their potential role in preventing future greenhouse gas emissions from iron-rich polar soils in a warming climate.

(1) Kramer & Chadwick (2018), *Nat. Clim. Change* 8 (12), 1104-1108.

(2) Lalonde et al.(2012), *Nature* 483 (7388), 198-200.

(3) Bhattacharyya et al. (2018), *Environ. Sci.Tech.* 52 (24), 14129-14139.

(4) Dong et al. (2023), *Nat. Rev. Earth Environ.* 4 (9), 659-673.