Characterization of Microbial Induced Carbonate Precipitates formed through Denitrification

PI: Qingyun Li (Geosciences)

Co-PI: Xinwei Mao (Civil Engineering)

Overview/Abstract

Microbial induced carbonate precipitation (MICP) has been used widely for solving various environmental issues, such as improving soil mechanical properties, sealing concrete fractures, and wastewater treatment. Although MICP has been traditionally linked with ureolysis metabolism, in the last decades, an emerging MICP pathway through nitrate reduction, or denitrification, has been proposed for MICP applications. Denitrification is the last step in removing excessive nitrogen (N) from soil and groundwater through microbial activities, where nitrate (NO_3^-) is anaerobically reduced to nitrogen gas (N_2) by denitrifying bacteria. This process oxidizes carbon sources to carbonate species (CO_3^{2-} and HCO_3^-), leading to $CaCO_3$ precipitation when sufficient calcium (Ca^{2+}) is available. MICP through denitrification (MICP-DN) has advantages over other MICP pathways in that (i) it uses indigenous bacteria in soil, (ii) generates non-toxic products, (iii) is thermodynamically more favorable, and (iv) is suitable for subsurface systems where nutrients and oxygen are deficient. However, much remains unknown about the potential of MICP-DN in environmental remediation and treatment. More research is needed to explore the nature of $CaCO_3$ generated from MICP-DN and its potential in immobilizing contaminants.

Current knowledge on MICP-DN has mostly been focused solely on the applied outcomes of $CaCO_3$ products in soil improvement, fracture sealing, and to a less extent, industrial wastewater treatment. Limited information exists on the synergy between denitrification and MICP. Lack of such information presents a challenge to fully grasp contaminant transport and soil mechanical evolution. It also hinders the development of industrial waste treatment units that couple the two processes in one system for best performance. In this study, we hypothesize that MICP-DN can shift the structure of denitrification microbial community, and that the biomass produced by denitrification microorganisms alters $CaCO_3$ morphology, solubility, and precipitation rates. For this seed grant, we propose three tasks to gain preliminary understandings of MICP-DN.

Task 1: Explore mutual impacts between microorganisms and $CaCO_3$ precipitates. Batch reactors will be setup to compare two systems with and without addition of Ca^{2+} to promote MICP. Samples will be characterized for microbial abundance and structure, as well as mineralogy properties of $CaCO_3$.

Task 2: Explore the effects of silicate surfaces on MICP and biofilm formation in the system. Two environmentally abundant minerals, quartz and clay, will be submerged in the reaction solution during the MICP-DN experiments. The morphology and mechanical properties of biofilm and $CaCO_3$ formed on these silicate surfaces will be analyzed using atomic force microscopy.

Task 3: Introducing MICP to established denitrification columns. After gaining fundamental knowledge of the batch system, MICP will be introduced to more complex column systems. This system will provide insights into the role of large amounts of mineral surfaces, effects of complex flow conditions, and the reactive transport coupling of MICP and DN in porous media.

Results gained from the proposed research will be critical in pursuing external funding from the NSF program of *Geobiology and Low-Temperature Geochemistry*. Acquired knowledge will promote development in the fields of microbially induced mineral formation as well as soil remediation.