AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Biogeosciences

RESEARCH ARTICLE

10.1002/2013JG002414

Key Points:
- Microbial mediated iron-reduction can result in the precipitation of magnetite
- Higher magnetic susceptibility occurs within zones of iron-reduction
- Magnetic susceptibility is a viable tool in iron and carbon cycling studies

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Citation:
Atekwana, E. A., F. M. Mewafy, G. Abdel Aal, D. D. Werkema Jr., A. Revil, and L. D. Slater (2014), High-resolution magnetic susceptibility measurements for investigating magnetic mineral formation during microbial mediated iron reduction, *J. Geophys. Res. Biogeosci.*, *119*, 80–94, doi:10.1002/2013JG002414.

Received 8 JUN 2013
Accepted 17 DEC 2013
Accepted article online 19 DEC 2013
Published online 16 JAN 2014

High-resolution magnetic susceptibility measurements for investigating magnetic mineral formation during microbial mediated iron reduction

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Abstract Disimilatory iron-reducing bacteria play an important role in the reduction of Fe(hydr)oxides and the production of secondary solid-iron mineral phases that can have magnetic properties. Magnetic susceptibility can therefore play an important role in identifying zones where microbial-mediated iron reduction is occurring. We investigated the magnetic susceptibility variations in a hydrocarbon-contaminated aquifer where methanogenesis and iron reduction are the main biogeochemical processes. Our objectives are to (1) determine the variability of magnetic susceptibility, (2) determine the hydrobiogeochemical controls on the magnetic susceptibility variability, and (3) evaluate the use of magnetic susceptibility as a viable technique for identifying zones where the coupling of iron and organic carbon cycling is occurring. Magnetic susceptibility data were acquired down 11 boreholes within contaminated and uncontaminated locations. We show that magnetic susceptibility values for boreholes within the free phase plume are higher than values for boreholes within the dissolved phase plume and background. Magnetic susceptibility values are highest within the zone of water table fluctuation with peaks predominantly occurring at the highest water table marks and are also coincident with high concentrations of dissolved Fe(II) and organic carbon content, suggesting that the zone of water table fluctuation is most biologically active. High magnetic susceptibility values within the vadose zone above the free phase plume are coincident with a zone of methane depletion suggesting aerobic or anaerobic oxidation of methane coupled to iron reduction. Our results suggest that magnetic susceptibility can be used as a viable tool in iron and carbon cycling studies.

1. Introduction

Iron is the fourth most abundant element on Earth and one of the most dominant redox active metals in the Earth's crust. Microorganisms reduce Fe(III) as ferrihydrite with either organic acids or H_2 as electron donor [*Lovley*, 1993; *Tuccillo et al.*, 1999]. Hydrocarbon-contaminated environments therefore provide excellent natural laboratories for investigating iron mineral biotransformations and the relationship between coupled carbon and iron biogeochemistry. Many studies have documented that iron-reducing bacteria can use hydrocarbon as a carbon source to reduce Fe(III) to Fe(II) [*Anderson and Lovley*, 2000; *Lovley et al.*, 1989] to form siderite [*Fredrickson et al.*, 1998; *Mortimer and Coleman*, 1997], magnetite [*Lovley*, 1990; *Lovley et al.*, 1987; *Mortimer and Coleman*, 1997; *Prommer et al.*, 1999; *Rijal et al.*, 2010], vivianite [*Fredrickson et al.*, 1998], ferroan calcite [*Baedecker et al.*, 1992], and green rust [*Fredrickson et al.*, 1998; *Parmar et al.*, 2001].

The bio-metallic minerals, in addition to other iron minerals, show a broad range of magnetic susceptibility (MS) responses between a highly positive response for ferrimagnetic minerals such as magnetite (513–1116 × 10^{-6} m^3 kg^{-1}), maghemite (410–440 × 10^{-6} m^3 kg^{-1}) [*Dunlop and Özdemir*, 2001], and greigite (320 × 10^{-6} m^3 kg^{-1}) to a low response for antiferromagnetic minerals such as hematite (1.19–1.69 × 10^{-6} m^3 kg^{-1}), goethite (<1.26 × 10^{-6} m^3 kg^{-1}), siderite (1.0 × 10^{-6} m^3 kg^{-1}), pyrite (0.3 × 10^{-6} m^3 kg^{-1}), and lepidocrocite (0.5–0.75 × 10^{-6} m^3 kg^{-1}) [*Dearing*, 1994]. Thus, magnetic susceptibility might be used as a tool to diagnose