Magnetic Measurement as a Proxy for Investigating Microbial Anaerobic Oxidation in a Hydrocarbon-Contaminated Aquifer

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Biogeochemical transformation of iron at hydrocarbon-contaminated sites is linked to hydrocarbon biodegradation and critical to the removal of contaminants in groundwater and soils. In these environments, microorganisms play an important role in mediating the processes involved in iron cycling. At the National Crude Oil Spill Fate and Natural Attenuation Research Site near Bemidji, MN, US, geophysical measurements showed elevated magnetic susceptibility (MS) within the water table fluctuation zones of contamination sites, which demonstrate that MS can be used to investigate microbial mediated iron reduction linked with bioremediation. However, the elevated MS signals at the site were transient, and the iron mineral phases acting as transformation reactants and products associated with this long-term decrease in MS remain largely unknown. To address these ambiguities, we obtained detailed mineral magnetism measurements, including hysteresis loops, backfield curves, and isothermal remanent magnetizations on sediment core samples retrieved from different depths at the site and fresh magnetite packs installed within the contaminated and uncontaminated aquifer. Our results show that the saturation magnetization declines with time in the magnetite packs, this loss is more pronounced for samples located within the oil pool (90%) than for those located outside of the oil pool (20%). Bulk coercivity increases coincided with this decrease in magnetization, suggesting either a reduction in grain sizes or partial oxidation of the material. Low-temperature magnetometry on all core samples tested showed a Verwey transition, characteristic of magnetite. However, samples within the plume exhibited smearing of the Verwey transition and a greater remanence recovery during low temperature thermal cycling, which suggests maghemitization (magnetite transformation to maghemite). This explanation is reinforced by the presence of shrinkage cracks on the surface of the grains, as observed by scanning electron microscopy. Since the center of the plume is anoxic and would not support conventional abiotic oxidation, we propose that maghemitization is occurring within the anoxic portions of the plume via microbially mediated anaerobic oxidation. Microorganisms capable of such anaerobic oxidation have been identified at the Bemidji site.