Formation of single-domain magnetite by a thermophilic bacterium

CHUANLUN ZHANG,1,* HOJATOLLAH VALI,2 CHRISTOPHER S. ROMANEK,3
TOMMY J. PHELPS,1 AND SHI V. LIU4

1Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, U.S.A.
2Electron Microscopy Center, McGill University, Montreal, Quebec H3A 2B2, Canada
3Department of Geology and Savannah River Ecology Laboratory, University of Georgia, Aiken, South Carolina 29802, U.S.A.
4Department of Microbiology and Immunology, Allegheny University of the Health Sciences, Philadelphia, Pennsylvania 19129, U.S.A.

ABSTRACT

Magnetite is a common product of bacterial iron reduction and may serve as a potential physical indicator of biological activity in geological settings. Here we report the formation of single-domain magnetite under laboratory conditions by a thermophilic fermentative bacterial strain TOR-39 that was isolated from the deep subsurface. Time-course analyses were performed at 65 °C to study the effect of bacterial activity on solution chemistry and magnetite formation during the growth of TOR-39. Run products were examined by transmission electron microscopy. Magnetite particles formed exclusively outside of bacterial cells and exhibited octahedral shapes having relatively equal length and width (<15% difference). Tiny magnetite particles (<12 nm) nucleated between 10 and 11 h of incubation and increased to average lengths of 55.4 ± 26.8 nm after 24 h of incubation. Between 24 h and 22 d of incubation, magnetite particles maintained average lengths of 56.2 ± 24.8 nm. Based on size constraints, greater than 85% of the particles observed fell within the magnetic single domain. Little to no magnetite was detected in abiotic controls at 65 or 95 °C, or in TOR-39 cultures whose activity was suppressed. Unlike mesophilic iron-reducing bacteria (e.g., GS-15), TOR-39 produced crystals having shapes and sizes similar to some particles produced intracellularly by magnetotactic bacteria. Thus the single-domain magnetite produced by thermophiles such as TOR-39 may represent a heretofore unrecognized biological contribution to natural remanent magnetization in sedimentary basins and other geothermal environments.

INTRODUCTION

The geosciences community has increasingly recognized the importance of bacteria in geological processes (e.g., Banfield and Nealson 1997; Skinner and Banfield 1997). It is now known that microbes inhabit nearly every portion of the Earth’s crust, including the most extreme environments such as permafrost in Antarctica (e.g., Gilichinsky 1997), hot geothermal vents (e.g., Brock 1978; Stetter 1995), and the deep subsurface (Phelps et al. 1989; Boone et al. 1995; Stevens and McKinley 1995; Fredrickson and Onstott 1996; Liu et al. 1997; Pedersen et al. 1997). Microbes participate in a variety of geochemical processes such as weathering of rocks (Ferris et al. 1994; Sillitoe et al. 1996), formation of mineral ores (Juniper et al. 1995; Vasconceios et al. 1995; Tebo et al. 1997), and cycling of organic matter (Ehrlich 1990; Lovley 1991; Nealson and Saffarini 1994).

Iron-reducing bacteria are widespread in the Bacteria domain (Coates et al. 1996; Lonergan et al. 1996), and have been found in various natural environments including freshwater and marine sediments (Lovley and Phillips 1986; Caccavo et al. 1992; Nealson and Saffarini 1994), pristine or contaminated aquifers (Lovley et al. 1990; Coates et al. 1996), geothermal vents (Slobodkin and Wiegel 1997; Slobodkin et al. 1997), and the deep subsurface (Boone et al. 1995; Liu et al. 1997; Pedersen et al. 1997; Onstott et al. 1997). Because of their wide occurrence, iron-reducing bacteria may have global significance in the geochemical cycling of mineral-forming elements such as carbon, oxygen, sulfur, and iron. Nealson and Myers (1990) suggest that bacterial iron reduction may have played an important role in the genesis of Precambrian banded iron-formations, and that the enzymes responsible for iron reduction may have preceded many of the more common enzymes present in modern oxic environments. Lovley (1990) suggests that at the pH, temperature, and pressure of most sedimentary environments, Fe³⁺ reduction is mainly the result of microbial enzymatic activity, and that Fe³⁺ reduction may have been the first globally important mechanism for microbial oxidation of organic matter in the Archaea biosphere.

Magnetite is a common end product of bacterial iron reduction and may serve as a potential physical indicator of biological activity in geological settings.