Crystal-size and shape distributions of magnetite from uncultured magnetotactic bacteria as a potential biomarker

BALÁZS ARATÓ,1 ZOLTÁN SZÁNYI,1 CHRISTINE FLIES,2 DIRK SCHÜLER,2 RICHARD B. FRANKEL,3 PETER R. BUSECK,4 AND MIHÁLY PÓSFAI1,*

1Department of Earth and Environmental Sciences, University of Veszprém, Veszprém, Hungary
2Max Planck Institute for Marine Microbiology, Bremen, Germany
3Department of Physics, California Polytechnic State University, San Luis Obispo, California 93407, U.S.A.
4Departments of Geological Sciences and Chemistry/Biochemistry, Arizona State University, Tempe, Arizona 85287, U.S.A.

ABSTRACT

We studied the sizes and shapes of magnetite nanocrystals produced by several types of uncultured magnetotactic bacteria to understand whether their size distributions can be used for identifying the biogenic origin of magnetite crystals in geological samples. The two-dimensional projections of the crystals were measured on transmission electron microscope (TEM) images, and features of crystal-size and shape-factor distributions (CSD and SFD, respectively) were analyzed. In agreement with previous results, most magnetite CSD curves are asymmetric and negatively skewed; however, one magnetotactic strain produced particles that have a normal size distribution. A statistical analysis of CSDs and SFDs (both from this and previous studies) reveals similarities among magnetite from magnetotactic strains from various locations. In particular, crystals in a cultured marine strain (MC-2) were indistinguishable from magnetite from a freshwater strain. We tested whether CSDs of distinct magnetosome types can be recovered from the shape and size data of all particles combined in samples that contain several types of magnetosomes; such samples can be used as models for rocks that contain magnetite nanocrystals of unknown and, presumably, various origins. If the SFDs of the distinct magnetosome types occurring in the same sample differ, the CSDs of individual magnetosome types can be retrieved from bulk data. In such cases the characteristic shape of the size distribution can be used for identifying magnetite as originating from magnetotactic bacteria.

INTRODUCTION

Magnetite (Fe₃O₄) crystals produced intracellularly by magnetotactic bacteria have well-defined and often unusual morphologies, narrow size distributions, and a high degree of chemical purity (Devouard et al. 1998; Bazylinski and Frankel 2000, 2004). The unique crystal habits and size constraints of bacterial magnetite offer the possibility of using such nanocrystals as biomarkers in geological samples (Kirschvink and Lowenstam 1979; Kirschvink and Chang 1984). Nanoscale magnetite crystals from ocean sediments and rocks of various ages were identified as biogenic magnetite populations for the determination of the biogenic or inorganic origins of crystals.

The shapes of CSDs carry information about the growth histories of crystal populations (Eberl et al. 1998). Various inorganically formed crystals, including quartz (Kile and Eberl 1999) and illite (Srodon et al. 2000), as well as biologically induced ZnS (Moreau et al. 2004) exhibit lognormal distributions. Such CSDs can result when the crystals grow in an open system, and their growth is controlled by either their surface area or the availability of nutrients (‘surface-controlled’ and ‘supply controlled growth,’ respectively; Eberl et al. 1998). In contrast to inorganically produced magnetite populations that show lognormal CSDs (Fig. 1b), magnetite particles from several cultured magnetotactic bacterial strains produce negatively skewed CSDs (Meldrum et al. 1993a, 1993b; Devouard et al. 1998; Eberl and Frankel 2000) (Fig. 1a). Based on the few CSDs that are available in the literature, the narrow size distributions and sharp cutoffs at large sizes may be a signature of bacterial magnetite. On the other hand, greigite (Fe₃S₄) crystals from a sulfide-producing magnetotactic microorganism (‘many-celled magnetotactic prokaryote,’ MMP) exhibit a symmetrical, Gaussian CSD (Fig. 1c) (Pósfai et al. 2001). The specific shapes of CSDs are likely related to specific biologically controlled crystal growth mechanisms.

In principle, the distinctly biogenic CSDs could be used for