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CRYSTAL SIZE AND SHAPE DISTRIBUTIONS OF MAGNETITES FROM MAGNETOTACTIC BACTERIA

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Magnetite crystals from magnetotactic bacteria are typically characterized by sizes within the single magnetic domain range, growth habits that can differ from equidimensional morphologies, and structural perfection. It is of great interest to find criteria that could unambiguously distinguish such bacterial magnetites from inorganic ones when crystals are no longer organized in chains, as can be the case in ancient rocks.

We showed (DEVOUARD et al., 1998) that "structural perfection" should not be considered a valid criterion for distinguishing magnetite from magnetotactic bacteria, since both biological and synthetic crystals of magnetite can display similar twinning according to the spinel twin law, also known in macroscopic magnetite.

The size and shape of magnetite crystals from magnetotactic bacteria appear to be statistically different from those of synthetic crystals (DEVOUARD et al., 1998). We studied four samples of cultured magnetotactic bacteria (*Magnetospirillum magnetotacticum*, strains MV-1, MV-4 and MC-2) and compared their size and shape distributions with those of synthetic crystals similar mean size. The crystal size distributions (CSDs) of bacterial samples appear to be species dependent, narrower than that of synthetic crystals, and their skewness is inverted compared to the synthetic sample (Fig. 1a, c). The anisotropy (elongation) of the crystals was estimated from the ratio of their measured width over length (W/L). Those "shape" distributions differ from those of synthetic material for the strains that show consistently elongated morphologies (strain MV-1, Fig. 1b, and less markedly strain MC-2), while cubooctahedral crystals from *M. magnetotacticum* are indistinguishable from synthetic ones (Fig. 1d).

Two questions remain to be addressed in order to apply this size and shape criterion to unknown samples. (i) The CSD from a mixture of species of magnetotactic bacteria can be estimated by summing those of pure species: in most cases, the resulting distributions could still be distinguishable from those of non-biogenic samples. (ii) The synthetic sample we used for this study can not be considered as representative of all possible non-biogenic samples. However, observed CSDs of various non-biogenic crystals are properly described by lognormal distributions similar to that of Fig. 1c (EBERL et al., 1998). These authors show that crystals evolved from supply-controlled Ostwald ripening (i.e., volume diffusion being the limiting process) can display negatively skewed CSDs similar in shape to the one observed in magnetite from magnetotactic bacteria.

Analyzing CSDs with the desired accuracy raises two additional problems. The first one is that it is difficult to define width and length for a non regular shape (Fig. 2a). This issue can be addressed by approximating the crystal shape by a best-fitting ellipse of same area (Fig. 2b), and taking the mean of minor and major axis lengths as the size, and the ratio of these lengths as the W/L ratio. These calculations are easily performed by image analysis softwares. The second problem in quantifying CSDs of crystals observed by TEM is that the observed distribution can strongly differ from the real one. If one considers a set of identical but randomly oriented cubes (Fig. 3), the CSD obtained from measuring the different projections of the cubes will lead to an overestimation of the mean size, while the apparent W/L ratios will be less than 1. Because we know of no way to infer the real CSD from the observed one, we conducted numerical simulations of CSDs for randomly oriented simple shapes (cubes, octahedra, and parallelepipeds). The results show that for most shapes, the CSDs are significantly biased and show a larger spread than the real distributions. The shape distributions are affected in similar ways.

Although problems remain, crystal size and shape distributions seem to be a useful criteria for distinguishing magnetites from magnetotactic bacteria from non-biogenic ones. However, we suggest that studies using quantitatively CSDs should try to take into account the measurement bias.

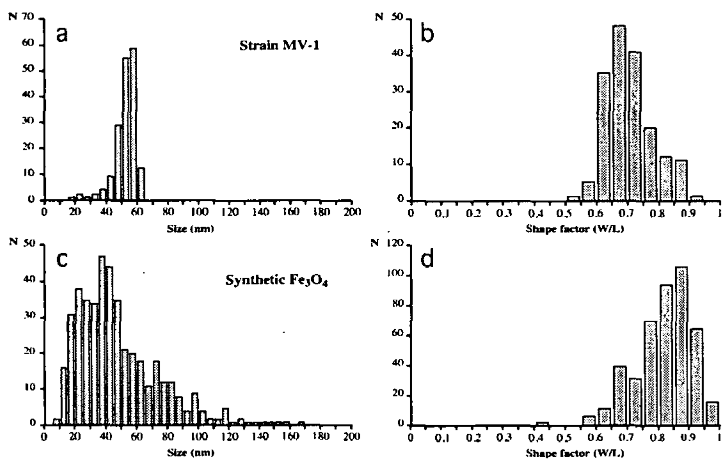

Figure 1: CSD and shape (W/L ratio) distribution for (a, b) strain MV-1 magnetotactic bacteria and (c, d) synthetic magnetites.

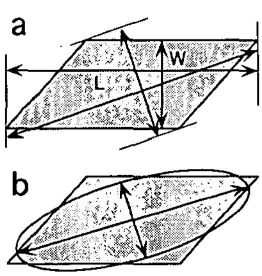

Figure 2: Measurement of an irregular shape

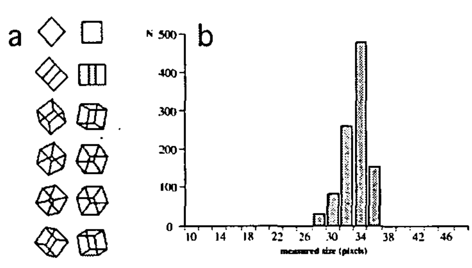

Figure 3: Measured CSD of randomly oriented cubes

References

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