Supporting information

Controlled cobalt doping in the spinel structure of magnetosome magnetite: New evidences from element- and site-specific XMCD analyses

Jinhua Li, Nicolas Menguy, Marie-Anne Arrio, Philippe Sainctavit, Amélie Juhin, Yinzhao Wang, Haitao Chen, Oana Bunau, Edwige Otero, Philippe Ohresser, Yongxin Pan

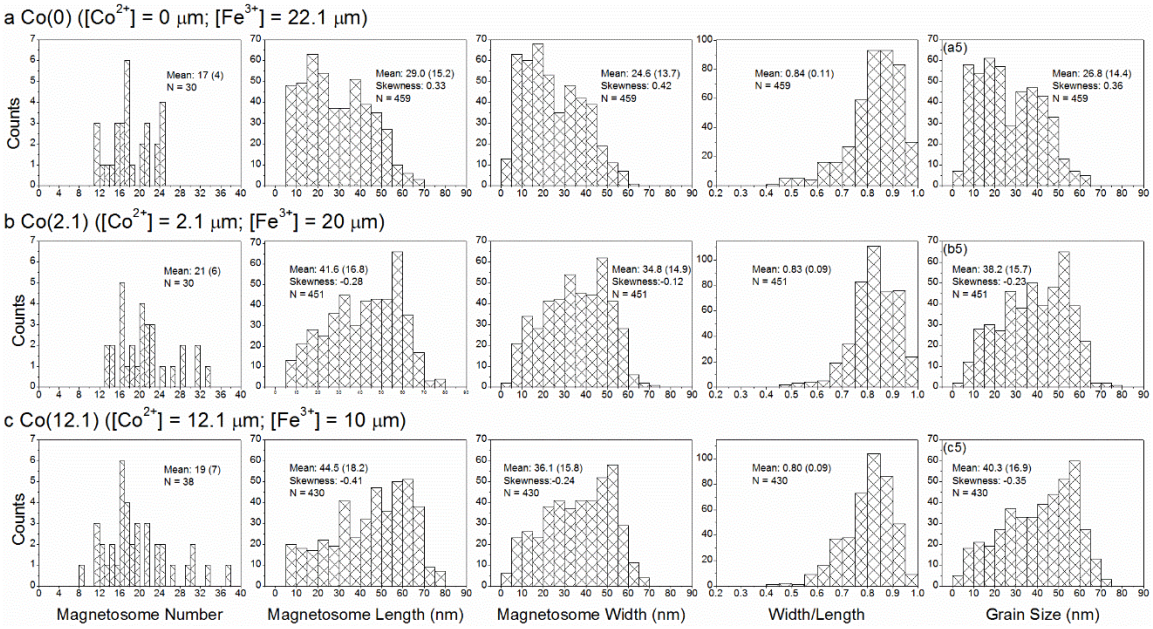

Figure S1. Histograms representing counts as a function of magnetosome number (first column), length (second column), width (third column), shape factor (i.e., width/length, forth column), and grain size ((length+width)/2, fifth column) for magnetosomes produced by AMB-1 cells within the Co(0) (a), Co(2.1) (b), and Co(12.1) (c) cultures.

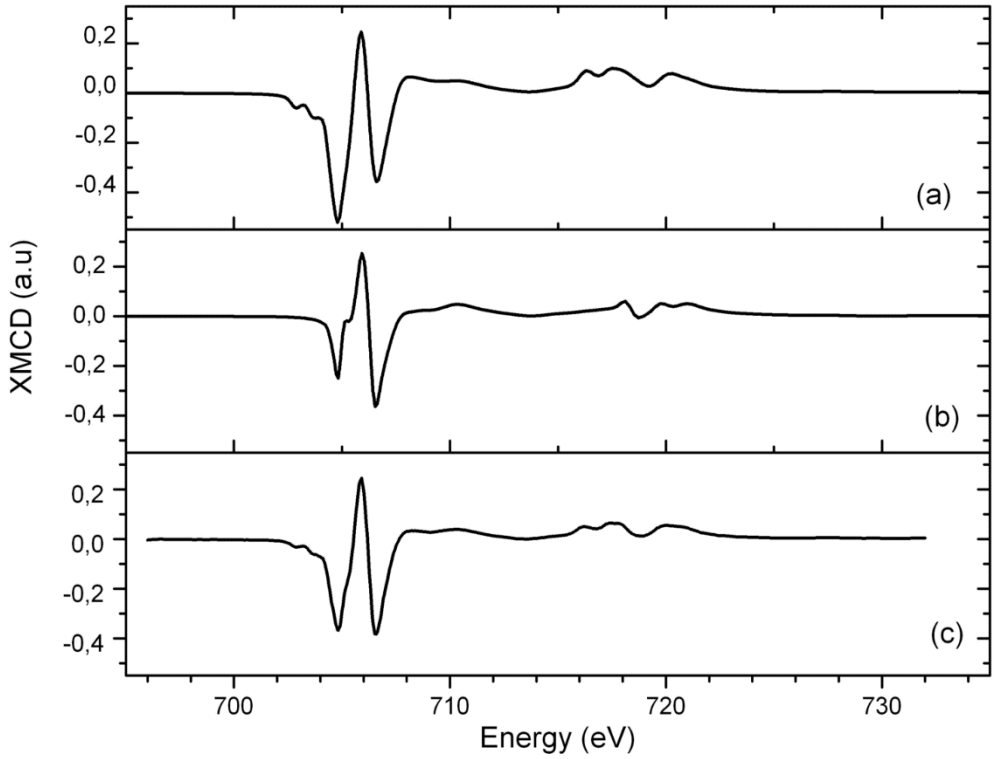

Figure S2. Experimental XMCD signals at Fe $L_{2,3}$ edges for (a) pure magnetite, (b) pure maghemite, (c) Co(12.1) sample

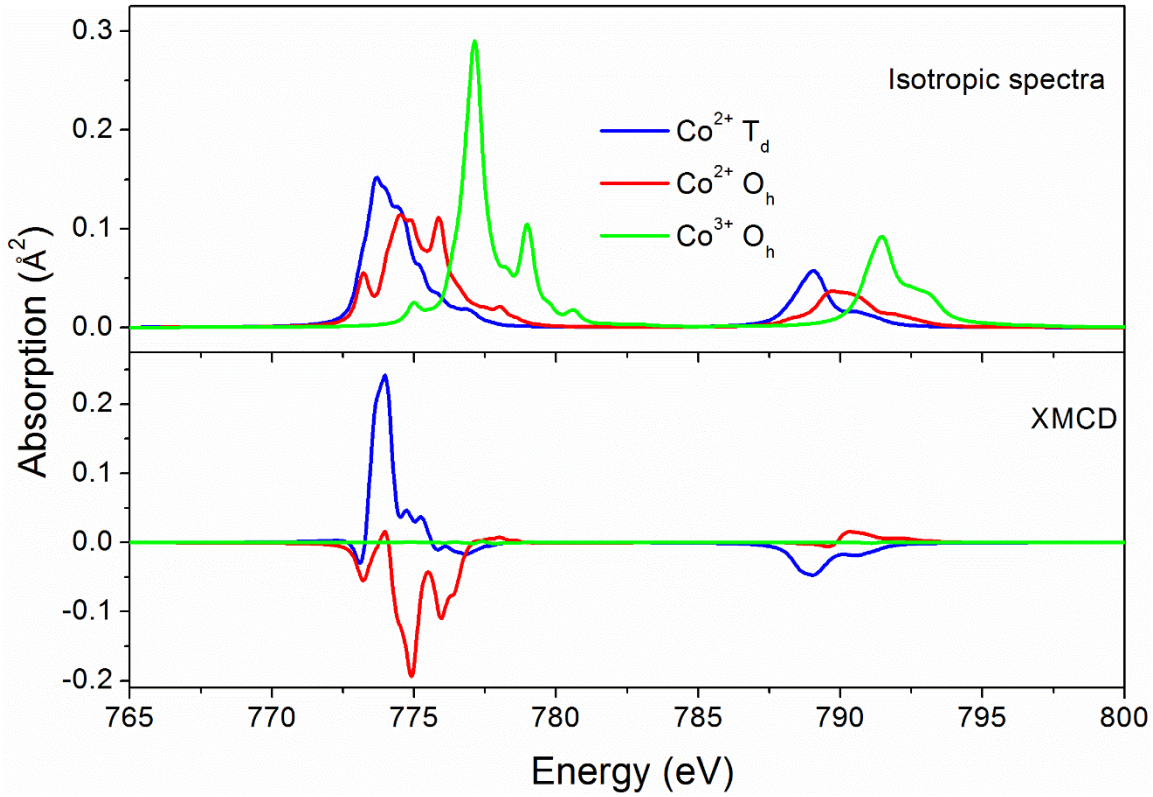

Figure S3. Calculated XAS and XMCD spectra for Co^{2+} and Co^{3+} in octahedral and tetrahedral coordinations.

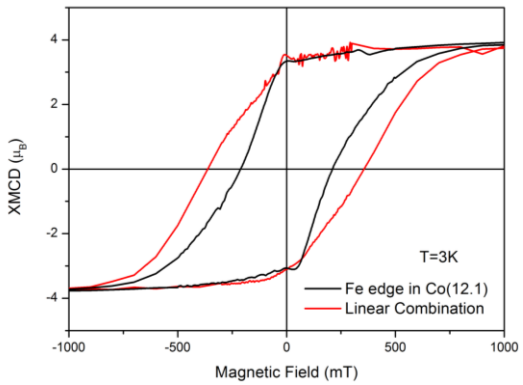

Figure S4. Magnetization curve (red line) calculated for a weighted average of the magnetization curves measured on the Co(0) magnetosomes at the Fe $L_{2,3}$ edges and on the Co(12.1) magnetosomes at the Co $L_{2,3}$ edges compared to the magnetization curve of the Co(12.1) sample (black line) at the Fe $L_{2,3}$ edges. Both curves are plotted in absolute units (μ_B) where we assumed 5 μ_B for Fe^{3+} ions, 4 μ_B for Fe^{2+} ions and 3 μ_B for Co^{2+} ions. From the comparison of the magnetization curves measured at the Fe and the Co edges in the Co(12.1) sample, we can conclude that there is more than one type of magnetosomes. For instance, the remanent magnetization M_r at the Fe edge is 82% of the saturation magnetization M_s, while at the Co edge M_r/M_s is 89 %. This represents a relative increase in M_r/M_s of ~10%. One assumes that there are, on one side, magnetite particles (slightly oxidized as in Co(0) sample) and, on the other side, Co-bearing nanospinels where Co / Fe+Co = 6 %. If the distribution of Co in the latter is homogeneous between the core and the surface, then the magnetization curve of Co in Co(12.1) is representative of the magnetization curve of the Co-bearing particles. From what precedes, one concludes that the magnetization of Fe in Co(12.1) should be the weighted sum of 10% of Fe magnetization in Co(0) and 90% of Co magnetization in Co(12.1). As expected, the remnant magnetizations of both curves are the same, but the coercive fields are very different, with a larger coercive field for the linear combination. This indicates that Co is not homogenously distributed within the Co(12.1) particles. We guess that the Co concentration is higher close to the surface compared to the core, and surface anisotropy adds to the magneto-crystalline anisotropy of cobalt.

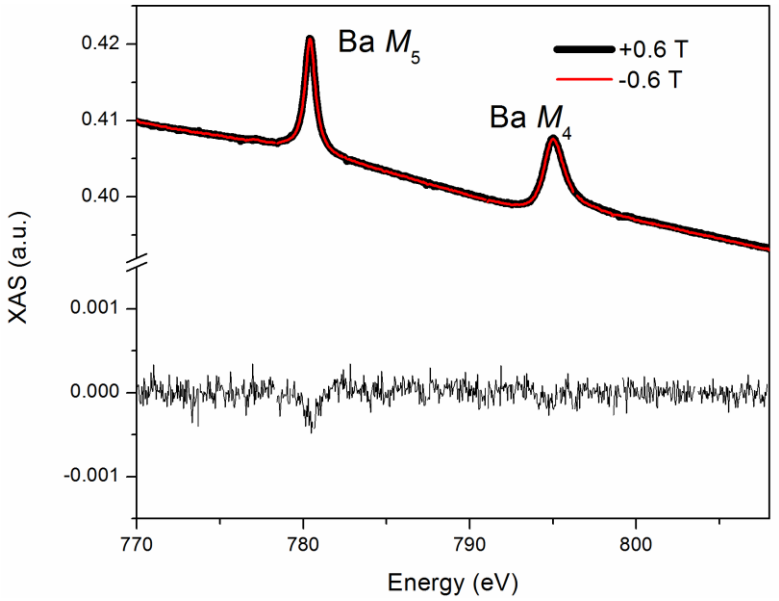

Figure S5. XAS spectra of the Si wafer on which the magnetosome samples have been prepared. X-rays are circularly left polarized. Black thick curve is for +0.6T external magnetic field and thin red cirve is for -0.6T external magnetic field. Features at 780 eV and 795 eV are due to the $M_{4,5}$ edges of Ba impurities present in the silicon wafer. The thin black line is the XAS difference for the two opposite magnetic fields. As expected, the difference is less than 3% of the Ba XAS spectrum and Ba impurities do not contribute to any significant XMCD signal.

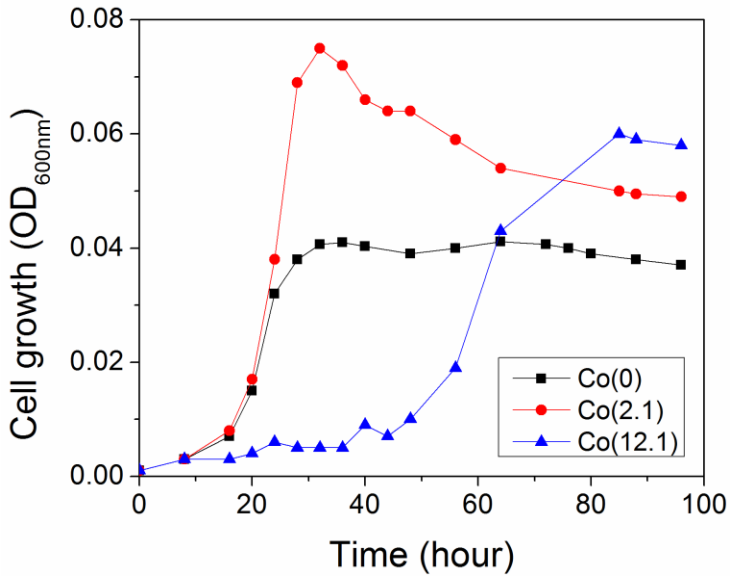

Figure S6. Temporal variations of cell growth (OD_{600}) of AMB-1 within the Co(0), Co(2.1) and Co(12.1) cultures.