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Inversion of magnetic susceptibility measurements: quantitative characterization of ferri- and antiferromagnetic superparamagnetism

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A quantitative reconstruction of the magnetic properties of weakly interacting superparamagnetic (SP) particles is obtained from measurements of the low-field magnetic susceptibility as a function of temperature and applied field frequency. The inversion method developed for this purpose is used to obtain (1) the temperature dependence of the magnetic moment and the microcoercivity of the particles, (2) the effective magnetic field produced by magnetostatic (exchange and dipole) interactions between the particles, and (3) the distribution of energy barriers related to the size of the particles. The inversion of susceptibility measurements of samples containing dispersions of well characterized iron oxide nanoparticles shows a clear and systematic difference between ferri- and antiferromagnetic minerals: Magnetite and maghemite nanoparticles are characterized by a weak temperature dependence of the magnetic moment and microcoercivity between 3 and 400 K, as predicted by theoretical models. The reconstructed microcoercivity of both equidimensional and elongated magnetite nanoparticles is characterized by a weak local minimum at temperatures close to the isotropic point, indicating a small crystalline anisotropy contribution. On the other hand, the magnetic moment and microcoercivity of ferrihydrite and goethite nanoparticles depends strongly on the temperature between 3 and 400 K. The magnetic moment increases typically by a factor 5 upon cooling from 400 K to 3 K. The inversion method has also been applied to susceptibility measurements of several samples taken from different soil profiles, allowing following interesting observations: (1) the susceptibility enhancement in soils is produced by both ferri- and antiferromagnetic nanoparticles, (2) the ferrimagnetic component is produced by non-interacting maghemite parti-

cles with a very broad distribution of grain sizes, (3) the antiferromagnetic component is extremely similar to synthetic ferrhydrite or goethite nanoparticles, (4) the ferrimagnetic component is sharply confined to the range of depths where organic matter is present, (5) outside of this depth range, 50-100% of the magnetic susceptibility is produced by the antiferromagnetic component, (6) both the ferri- and the antiferromagnetic components are characterized by consistent and well-constrained properties in a variety of soils analyzed. The results obtained with the soil samples show that the susceptibility inversion method is an effective tool for the characterization of complex magnetic mineral mixtures containing SP particles.