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Quantification of magnetic nanoparticles with broadband measurements of magnetic susceptibility in the frequency domain

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Measurement of low-field magnetic susceptibility over a wide band of frequencies spanning four orders of magnitude is a useful method for the assessment of the grain size distribution of ultrafine magnetic particles smaller than the SP/SSD boundary. This method has been applied to a loess/paleosol sequence at Luochuan in the Chinese Loess Plateau. The studied succession consists of sequences from the latest paleosol unit to the upper part of the loess unit, spanning the last glacial–interglacial cycle. Reconstructed grain size distributions (GSDs) consist of volume fractions on the order of 10^{-24} m^3, and the mean GSDs are modal but with distinctive skewness among the loess, the weakly developed paleosol (weak paleosol), and the mature paleosol. This indicates that the mean volume of SP particles in this sequence tends to increase during the transition from the loess to the paleosol. An index, defined as the difference between χ_{130} at the lowest (130 Hz) and χ_{500k} at the highest (500 kHz) frequencies normalized to χ_{130}, is judged to be a more suitable index than previous frequency dependence parameters for the concentration of SP particles. This index has a strong correlation with χ_{130}, showing a continuous 'growth curve' with the rate of increase being highest for the loess, moderate for the weak paleosol, and saturated for the paleosol. The characteristic curve suggests that smaller SP particles are preferentially formed in the earlier stage of pedogenesis rather than the later phase when even larger particles are formed in the mature paleosol. These results demonstrate that the broad-band-frequency susceptibility measurement will be useful for the quantitative assessment of magnetic nanoparticles in soils and sediments. Additionally, we point out that the measurement in the frequency domain generally requires time and may not be most suitable to routine measurements. We thus propose an alternative manner, the measurement in the time domain that can be performed by measurement of transient magnetization induced by a pulsed field. Results from preliminary measurements, coupled with simulation based on the linear response theory, suggest that the transient response in the time domain can be converted into the spectrum in the frequency domain.