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Out-of-phase magnetic susceptibility as a rapid and efficient indicator of ultrafine magnetic particles in rocks, soils, and environmental materials

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The presence of ultrafine magnetic particles in rocks, soils and environmental materials is traditionally investigated by frequency-dependent susceptibility consisting of susceptibility measurement at two or more operating frequencies. In some instruments measuring the susceptibility in alternating magnetic field, the measured susceptibility can be resolved into a component that is in-phase with the applied field and a component that is out-of-phase. While the former component is widely used for solving various geological and environmental problems, the latter component is paid only minor attention. Néel (1949, Ann. Geophys.) found the theoretical relationship between the frequency-dependent in-phase susceptibility and the out-of-phase susceptibility, called the $\pi/2$ law, for materials in which the latter is due to the viscous phenomena (presence of magnetic particles on transition between superparamagnetic and stable single domain states). Consequently, the out-of-phase susceptibility, which is measured simultaneously with the in-phase susceptibility during one measuring process, can be used in indicating the ultrafine magnetic particles even the measurement is made at one frequency, only. Approximate formulas are proposed for conversion of the out-of-phase susceptibility into the frequency-dependent susceptibility. Their validity is tested on samples of various sediments. The correlations found seem to be acceptable from the practical point of view. In addition, simple test is proposed for checking that the out-of-phase susceptibility is solely due to the viscous phenomena and not due to electrical eddy currents or weak field hysteresis.