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Low temperature identification of an iron titanium oxide in a Vertisol

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Low temperature magnetic analyses provide an excellent tool for the identification and characterization of Fe-Ti-oxides which can be used as proxies to deduce soil genesis. We investigated the magnetic properties of a Vertisol in the Bafini River flood plain in southern Mali. The catchment area of the Banfini River comprises of Late Proterozoic sandstone series and dolerite intrusions of Permian age.

The Vertisol at Kabogora has a thickness of about 1.2m and can be subdivided into horizons: topsoil A_p, A_2, A_3, and a gley horizon A_g. Montmorillonite and quartz are the major mineral components; kaolinite, feldspar and ilmenite ($FeTiO_3$) are minor ones. The Fe-Ti-oxide phase as detected by SEM exhibits μm–sized particles.

Isothermal remanent magnetization acquisitions at room temperature (RT) show for all horizons a dominance of a low-coercivity component. Since the IRM acquisition reveals a drastic increase at 77K, the low temperature magnetic properties were analyzed in detail.

The ac susceptibility measurements were conducted on a Quantum Design PPMS with amplitudes (Hac) between 1 and 17Oe, and in a frequency range of 10 to 10000Hz. The magnetization was measured on a MPMS-5S. Untreated samples and samples after chemical treatment with dithionite, which is known to dissolve selectively ferric iron oxides, were analyzed. The in-phase susceptibility (χ') of the treated and the untreated samples starts to increase at about 150K with a peak between 43 and 45K followed by a drastic increase below 20K. The out-of-phase (χ") component is characterized by a broad peak around 65K and a sharp one at 38K. Both χ' and χ" exhibit an amplitude and a frequency dependence, which is indicative of low-field hysteresis and time-dependent viscous relaxation, respectively. The linear increase of χ' and χ" with Hac indicates a weak-field hysteresis. The frequency dependence for χ' (10Hz and 1000Hz) between RT and 5K is generally less than 8% but exhibits a cusp of 15% at 38K.

An applied DC field rounds off the peaks in the ac susceptibility curve. The peaks at 45 and 65K are vanished in a 1T field and no out-of-phase is observed. The disappearance of χ" in a 1T field is due to saturation of ferromagnetic fractions. Below 38K, a frequency dependence out-of-phase is found with χ"$<$0 at 10Hz and χ"$>$0 at higher frequencies.

The hysteresis loops of all samples between 40 and 300K reveal a low coercivity phase which is saturated in fields up to 0.3mT. At higher fields, components with identical ascending and descending portions and no saturation at 5T are found. This part of the hysteresis exhibits an increasing departure from linearity with decreasing temperature. The hysteresis behaviour can be attributed to magnetite, and a mixture of paramagnetic and superparamagnetic phases. At 5K the hysteresis loop reveals an additional magnetic phase which saturates at 3.5T.

Considering the mineral composition of the Vertisol, the low temperature magnetic properties can be attributed to a Fe-Ti-oxide in a matrix of paramagnetic and diamagnetic minerals. The onset of magnetic ordering at about 150K, the frequency and amplitude dependence of the in-phase, the cusp at 38K and the simultaneous occurrence of a frequency dependence of χ" in a 1T dc field argue in favour of an ilmenite with a Fe^{3+} for Fe^{2+} and/or Ti^{4+} substitution. Such a substitution can lead to magnetic clusters and the coupling of the clusters can considerably influence the magnetic properties of the host mineral.