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Hydrologic regulation of clay-mineral transformations in a redoximorphic soil of subtropical monsoonal China

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Abstract

Clay-mineral evolution in supergene environments is commonly a complex process subject to hydrologic influences on clay-mineral transformations, yet these influences remain insufficiently investigated to date. A quaternary red soil profile with evident redoximorphic features in subtropical monsoonal China was investigated with a focus on processes of secondary clay-mineral transformation. Evidence provided by soil physical and chemical descriptions, clay-mineral analysis, spectroscopic characterization, extractions of pedogenic Al and Fe species, and geochemical compositions reveals a complex relationship of clay minerals and iron phases to pedogenic weathering conditions as a function of depth in the studied soil profile. The soil profile can be divided into a homogenous horizon (HH; 0–2.0 m), a redoximorphic horizon (RH; 2.0–6.0 m), and a basal layer (BL; 6.0–7.2 m), and these three horizons are dominated by various intermediate clay phases. The HH is characterized by moderately acidic conditions (mean pH = 5.2) and low total organic content (TOC; TOC $\leq$2.1 g kg^{-1}). More importantly, compared with the lower horizons, the HH contains significantly more active acid-forming cations, as reflected by a greater abundance of Al phases and higher aluminum saturation levels. We infer that the occurrence of hydroxy-interlayered vermiculite (HIV) in the HH is tightly coupled with the nature of the soil acidic pools, which include both H^+ ions (i.e., pH) and active acid-forming cations (e.g., Al^{3+} and Fe^{3+}). The reaction pathway from primary minerals to final weathering products appears to be highly sensitive to dynamic hydrological processes. HIV is favored in generally oxic, well-drained soil systems with adequate acidic cations to maintain acidic weathering. When soils are more waterlogged and the aqueous solution is dominated by base cations, primary minerals tend to transform to smectite group minerals. Therefore, discrete smectite, interstratified illite-smectite (I-S), and interstratified kaolinite-smectite (K-S) were observed only in the RH and BL. We present a novel framework that links clay-mineral transformation pathways to soil hydrological disturbances, providing new insights into understanding the kinetics of water-mineral interactions in natural soil systems.

Keywords: Pedogenesis, chemical weathering, vermiculite, iron oxides, redox reactions, water-rock interaction