The role of parent lithology in nanoscale clay-mineral transformations in a subtropical monsoonal climate

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ABSTRACT

Clay minerals are among the most important reactive components of soil systems, acting as a bridge linking organic and inorganic components. Lithology is a key factor in clay-mineral genesis and transformation, yet it has received scant attention to date at the nanoscale. Inferences regarding pedogenic clay-mineral transformations based on X-ray diffraction (XRD) are sometimes speculative, whereas mineralogic relationships documented by high-resolution transmission electron microscopy (HRTEM) are more robust due to direct evidence from lattice-fringe observations. In this contribution, the mineralogical and geochemical characteristics of four soils derived from different parent rock types (a gneiss, an Fe-rich siltstone, a sandstone, and a dolostone) from subtropical China were determined using HRTEM, XRD, and geochemical elemental data. The predominance of 2:1 clay minerals and kaolinite in the investigated soils is typical of subtropical climatic settings. Lattice-fringe images suggest the prevalence of topotactic transformations during clay-mineral alteration. Two distinct alteration pathways were observed in the investigated soils, one starting with chlorite and the other with illite, with convergence of mineralogic compositions toward kaolinite and crystalline iron and aluminum (oxyhydr)oxides. In the early stages of weathering, chlorite transformed into expandable clays through a continuous, solid-state mechanism with corrensite and/or randomly interstratified chlorite-vermiculite/chlorite-smectite as intermediate products. Unlike chlorite, which tends to form a 1:1 regularly interstratified phase, the weathering of illite commonly starts at layer edges. Under subtropical monsoonal climates, the precursor minerals in host rocks and aeolian materials determine the starting composition and, to a certain extent, the trajectory of clay-mineral transformation over time. With advanced weathering, mineralogic convergence toward kaolinite and Fe/Al-(oxyhydr)oxides tends to obscure the initial substrate composition. This study advances our understanding of the role of parent lithology in clay-mineral evolution at the nanoscale.

Keywords: Pedogenesis, chemical weathering, HRTEM, smectite, chlorite, corrensite

INTRODUCTION

Clay minerals represent an important component of the near-surface crustal environment of Earth and Mars (Hazen et al. 2013; Schroeder 2018). In the surficial weathering zones, primary minerals may transform into other clay species through a sequence of intermediate phases prior to the formation of end-member products (Churchman and Lowe 2012; He et al. 2017; Weil and Brady 2017). Clay minerals are naturally abundant in temperate and subtropical climates, and 2:1 clay minerals are oftentimes enriched in nutrients essential for plant growth (e.g., potassium and magnesium) (Velde and Meunier 2008; Cuadros 2017; Churchman 2018; Bakker et al. 2019). Clay minerals also play a key role in the preservation of natural organic carbon and influence global carbon cycling (Hemingway et al. 2019; Kleber et al. 2021). Unraveling the mechanisms and driving forces of clay-mineral neoformation and transformation is of vital importance for understanding the evolution of geological and pedogenic environments and mineral-environment interactions through time (Wilson 2004; Ryan and Huertas 2009; Cuadros 2017).

Neoformation and transformation of clay minerals are strongly dependent on the lithology of parent materials (Churchman and Lowe 2012; Yousefifard et al. 2015; Watanabe et al. 2017; Egli and Mirabella 2021). Yousefifard et al. (2015) investigated soils developed on various plutonic rocks and found variation in soil physicochemical properties but no significant differences in clay mineralogy, which was attributed to their similar arid/semiarid climate background. Watanabe et al. (2017) investigated the B horizons of soils developed under a humid tropical climate from various parent materials (i.e., felsic, intermediate and mafic igneous as well as sedimentary rocks) and found that parent lithology plays an important role in controlling secondary-