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Porosity and genesis of clay in gneiss saprolites: The relevance of saprolithology to whole regolith pedology

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A R T I C L E I N F O

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A B S T R A C T

Weakening of the rock texture in a saprolite by weathering and further pedoplasmation results in the formation of a porous network and neoformed clays, which are the initial stages of pedogenesis, but the saprolite is likely the least studied compartment of the regolith. In this paper, the genesis of clays and their associated pore system was studied in gneiss saprolites. We investigated the saprolites of three regoliths in the Atlantic Forest Biome in northeast Brazil and used optical and electron microscopy to depict the clay–pore morphology. To assess the mobility of clays, we also determined the amounts of water–dispersible and total clay. The total chemical composition (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2 and P_2O_5), exchangeable cations (Al^{+3}, Ca^{+2}, Mg^{+2}, K^+ and Na^+), available P, capacity for saprolites to exchange cations and secondary forms of iron (Fe_d and Fe_o) were also measured. Micromorphological analyses showed that the most frequent pore types were channels and fissures. Channels occurred in the more weathered saprolite layers, which were identified according to the weathering indexes, and the clay–sized minerals found in the saprolite were illite, kaolinite, iron oxides, feldspar and quartz. The weathering of biotite and green hornblende formed an Fe–rich clay, and the weathering of feldspars formed an Al–rich clay. Secondary clays were accumulated at the mineral surfaces, pseudomorphs, clay infillings and clay coatings. The clay coatings are formed by two layers, i.e., the first clay layer was formed by an Fe–rich clay, and the second layer was formed by an Al–rich clay. Peculiar features named “doughnut–shaped holdfasts” were described in the clay cutans. The capacity for saprolites to exchange cations was similar to that in the shallower soils, which was environmentally relevant to the adsorption of plant nutrients, e.g., Ca^{+2}, Mg^{+2} and K^+, and potentially toxic elements, e.g., Al^{+3}.

1. Introduction

Saprolites perform several ecological services, including the transfer of chemical elements from mineral to soluble forms, i.e., plant–available forms, which allows the elements to cross the membranes of living cells and enter the biosphere; the buffering of the water available to plant roots and other soil organisms during annual climate fluctuations; and the filtering of excess soil water entering groundwater reservoirs. Although saprolites have largely been ignored in classical soil science studies (Santos et al., 2017), the number of publications using the “whole regolith pedology” approach has increased in recent decades (e.g., Driese and McKay, 2004; Wysocki et al., 2005; Lorz and Phillips, 2006; Juilleret et al., 2016).

In this paper, we consider the saprolite to be the friable and isovolumetrically weathered rock and the regolith to be the weathered lithosphere column encompassing the soil and the saprolite (Santos et al., 2017). Regoliths with near–surface saprolites (< 1 m deep) are common in several ecosystems around the world (Wen et al., 2004; Bétard, 2012; Ndjigui et al., 2013; Borrelli et al., 2014), allowing the soil–saprolite transition to be examined in regular regolith profiles.

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Saprolites interact with almost all the water transferred from the atmosphere into terrestrial ecosystems (Li et al., 1997). Hence, understanding the porosity of saprolites is fundamental to studies of the Earth's ecospheres and critical zone (Taylor et al., 2010; Pope, 2015). Several studies have shown that microscale processes in saprolites influence the macroprocesses of the surrounding environment (Le Pera et al., 2001; Scarciglia et al., 2005).

The water dynamics throughout the saprolite are associated with the amount, type, interconnectivity and morphology of the pores (Schoeneberger and Amoozegar, 1990; Vepraskas et al., 1991, 1996), and mineralogical changes due to saprolite weathering imply potential inputs of bioavailable chemical elements into the ecosystem above and the aquifers below (Ndjigui et al., 2013). Pedoplasmation processes in the transition zone between the soil and saprolite as well as the genesis of clays and the pore network are strongly related to the modifications of the mineral assemblage by the dissolution of primary minerals (Schoeneberger et al., 1995; Santos et al., 2017). However, the genesis of clay in the saprolite is poorly known, although its relevance to the regolith is paramount (Williams and Vepraskas, 1994; Li et al., 1997; Taylor et al., 2010; Tsuji, 2012).

In the northeast region of Brazil, extensive areas of soils that originated from gneissic substratum are covered by urban areas, native forest and sugar cane plantations (Jacomine et al., 1973; Silveira Neto and Azzoni, 2011). Therefore, the genesis of clays and their associated pore system in regoliths can be investigated in this region of the Atlantic Forest Biome (Araújo Filho and Carvalho, 1996; Santos et al., 2017). The general objective of this paper was to relate the characteristics of the gneissic saprolite to the pedoplasmation processes in this region as follows: (a) differentiate the primary types of pores in saprolites, (b) describe the modifications of the primary minerals and the formation of the associated clay minerals, and (c) measure the cation exchange capacity (CEC) of the saprolites.

2. Characteristics of the study area

The study area is in the Atlantic Forest Biome in northeastern Brazil (Fig. 1). The climate is tropical humid (Am) (Köppen, 1931); the average annual precipitation is 1234 mm yr^{-1}; the mean maximum temperature is 31 °C; and the average monthly evapotranspiration (ET_0) in dry years is 112 mm (da Silva et al., 2013). The geomorphology consists of hills characterized by fluvial–dissected landscapes and gentle undulated relief with convex slopes and good drainage, i.e., U–shaped and V–shaped valleys (e.g., Bétard, 2012; Santos et al., 2017). The area belongs to the Salgadinho geological complex that is composed of hornblende and biotite migmatitic orthogneisses of sienogranitic–tonalitic composition with leucocratic bands, oriented parallel or perpendicular to melanocratic bands (Neves, 2003).

Three regoliths with shallow soils in a back–slope position in the gentle undulated local relief were chosen as representative of the local geomorphology. The regolith P1 was in a sugarcane plantation; P2 was in an urban area; and P3 was in a forest reserve. These are the three most common land uses in this region of the Atlantic Forest Biome. The selection of the saprolite in an urban area was necessary to evaluate the influence of saprolite attributes, e.g., porosity and CEC, on the transport and sorption of contaminants in urban areas.

3. Materials and methods

3.1. Field sampling and classification

For descriptive and sampling purposes, we subdivided the regoliths according to soil and saprolite zones. Saprolite layers Cr1, Cr2 and Cr3 were sampled for all analyses, and soil horizons A and Bt were only sampled for exchangeable bases and CEC analyses (Fig. 1). The soils above the saprolites were Typic Argiudolls, according to the Soil Taxonomy (ST) (Soil Survey Staff, 2014), and Haplic Chernozems (Clayic) according to the World Reference Base (WRB) (IUSS Working Group

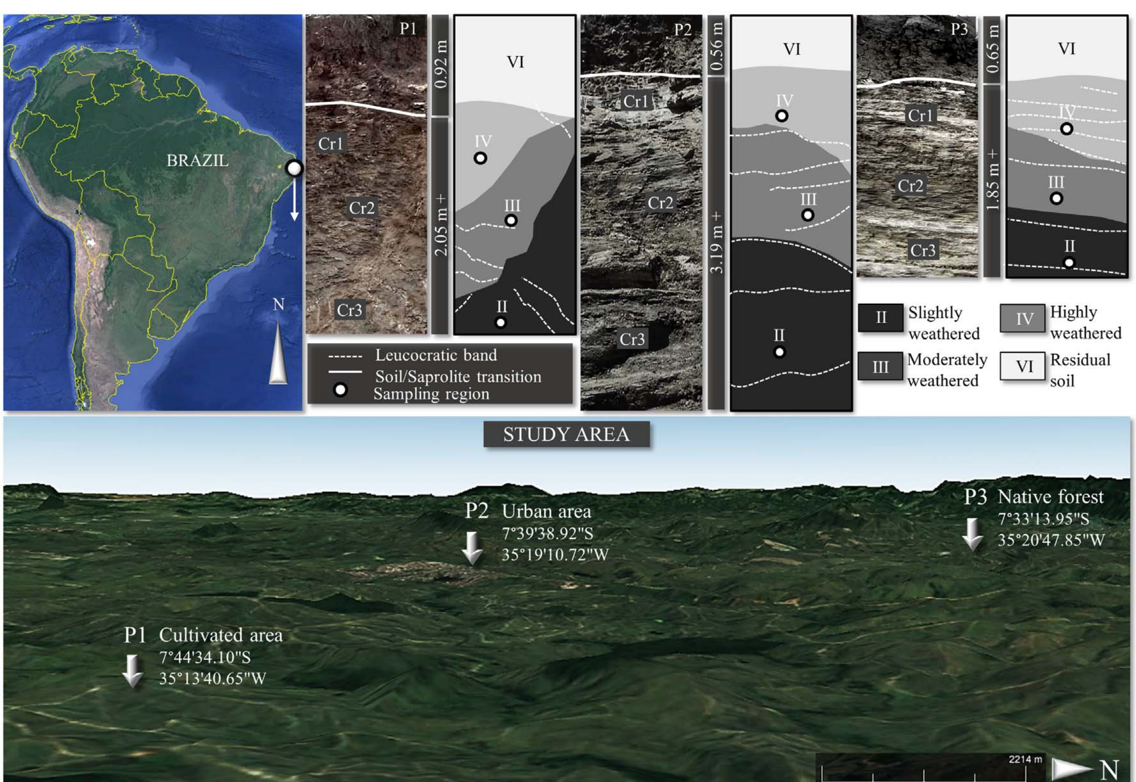

Fig. 1. Locations, morphology and weathering grade of the regolith samples from the Atlantic Forest of Brazil (e.g., Irfan and Dearman, 1978; Borrelli et al., 2014).