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Mineral alteration and genesis of Al–rich soils derived from conglomerate deposits in Cabo Basin, NE Brazil

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ABSTRACT

In the Cabo Basin, NE Brazil, conglomerates have given rise to soils with attributes that are rarely observed in humid tropical climates and remain relatively unknown within the scientific community. These soils have high levels of Al in the exchangeable phase, diminishing their agricultural and environmental potential in an underdeveloped region of great socioeconomic importance. This paper presents the mineralogy and genesis of soils derived from conglomerates on a slope in the Cabo Basin, with the aim of meeting the demand for studies on Al–rich soils. Three soils were classified, morphologically described and sampled for the accomplishment of chemical, physical and mineralogical analyses, including the main exchangeable cations content, mineralogy of the sand, silt and clay fraction, differentiation of the Fe and Al forms, mineral micromorphology and chemical composition of mineral species. In addition, chemical and physical attributes were used in multivariate analyses. The soil mineralogy is associated with the weathering evolution of three mineralogical zones identified in the Cr horizons. Pathways of alteration followed by feldspars and micas resulted in kaolinite, smectite and hydroxy–Al interlayered smectite formation (argilification). The susceptibility of the conglomerate to weathering, constant releases of Al from the structure of aluminous minerals, low contents of exchangeable bases and consequent low pH values (< 5.3) were associated with high levels of exchangeable Al. At the highest position on the slope, a C/Cr transitional horizon provided evidence of the pedogenesis advance on the Cr horizon. Pedogenetic processes then resulted in morphological, physical and mineralogical differentiation between the A and Bt horizons. In addition, a cluster analysis showed similarities between attributes of the Bt and Cr horizons due to their genetic relationships.

1. Introduction

Soils derived from conglomerates are an important natural resource for agriculture and extractive industries in underdeveloped countries around the world (Frery, 2015). Such soils can be found in Oceania (Dobrzhinetskaya et al., 2014; Pirajno et al., 2015), Africa (McCarthy, 2011), Asia (Dubille and Lavé, 2015; Li et al., 2015), Europe (Jorand et al., 2015; Loperte et al., 2016) and the Americas (Frery, 2015; Mabesoone and Alheiros, 1988). Conglomerates have given rise to highly weathered soils with different chemical, physical, mineralogical and morphological attributes (McCarthy, 2011) as a result of variations in weathering grade (Li et al., 2015).

The genesis of highly weathered soils results in intense loss of exchangeable bases (Ca^{+2}, Mg^{+2}, Na^{+} and K^{+}), whereas less soluble Al accumulates in newly formed solid phases such as secondary phyllosilicates like kaolinite ($Al_2Si_2O_5(OH)_4$), or mineral forms of aluminum hydroxide, such as gibbsite ($Al(OH)_3$) (Lima et al., 2008). In these soils, the maintenance of aluminum in the exchangeable phase is favored in the pH range from 5.5 to 6.5 (Lima Neto et al., 2010; Marques et al., 2002). However, high levels of exchangeable Al and 2:1 clay minerals are attributes rarely observed in the same soil profile (FAO, 2014; Soil Survey Staff, 2014).

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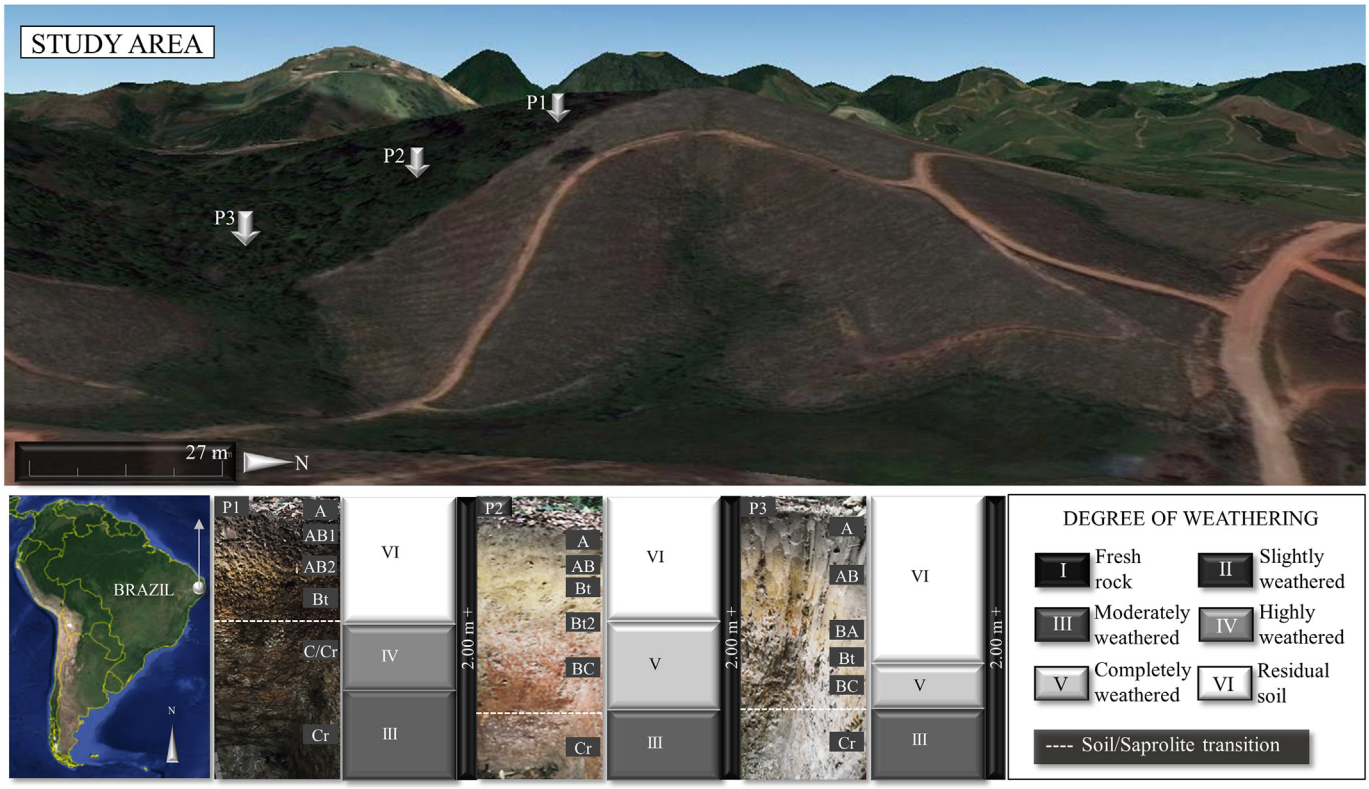

Fig. 1. Sampling soil locations, morphology and weathering grade of the soils derived from conglomerate on a slope in the Cabo Basin, NE Brazil (e.g., Irfan and Dearman, 1978).

In the Cabo Basin (NE Brazil), highly weathered soils are the result of strong dissolution of primary minerals in an environment conducive to high weathering rates (Marques et al., 2002). However, studies conducted around the world show that mineralogical variabilities of the conglomerates favor different pathways of mineral alteration and results in the formation of diversified clay minerals (Dubille and Lavé, 2015; Frery, 2015; Jorand et al., 2015).

Studies associated with soils derived from conglomerates in the Cabo Basin are scarce (Brasil, 1972), a tendency which is observed in other regions around the world (Dobrzhinetskaya et al., 2014; Dubille and Lavé, 2015; Frery, 2015; Loperte et al., 2016; McCarthy, 2011; Pirajno et al., 2015). The exploratory soil survey of Pernambuco State presented a taxonomic study of the regional soils in the Cabo Basin (Brasil, 1972), classifying them as equivalent to Ultisols (Soil Survey Staff, 2014) and Lixisols (FAO, 2014). Ongoing agricultural, industrial and economic expansion has intensified soil use in the area, so studies such as these are necessary to assess the potential lack of sustainability in long–term soil use (Santos et al., 2017).

Thus, more detailed knowledge on soils derived from conglomerates is essential, considering its economic and social importance (Li et al., 2015; Loperte et al., 2016). With the aim of meeting this scientific demand, the objectives of this research are as follows: a) to study the variation of morphological, physical, chemical and mineralogical attributes of soils derived from conglomerates along a slope in the Cabo Basin, seeking to understand the genesis of said soils and b) to describe the mineralogical, structural and chemical evolution of these soils, from the saprolite to the soil surface.

2. The Cabo Basin

Located in North East Brazil, the Cabo Basin encompasses sedimentary, metamorphic and volcanic rocks and extends along the southern coast of Pernambuco State (Assis, 1999). The Cabo Basin resulted from the rupture process of the Gondwana Supercontinent, which split South America and Africa and generated the South Atlantic Ocean (Nascimento et al., 2004). This tectonic event occurred in the Late Cretaceous period, when the deposition of fluvial–deltaic sediments occurred and filled the basin. The first sedimented material was the polymodal and polymictic conglomerates, with different diameters of granitic and gneissic clasts, deposited in alluvial fans by very dense flow (Mabesoone and Alheiros, 1988).

The geomorphology of the Cabo Basin is called the seas–of–hills domain. These environments are characterized by homogeneous fluvial dissection, smooth undulating convex slopes, dendritic drainage and U– and V–shaped valleys (Nascimento et al., 2004).

The Cabo Basin is included in the Litoral/Mata physiographic unit. The climate is predominantly hot and humid and classified as type As' (Köppen, 1931). The average annual temperature is 25 °C and the average relative humidity is 73%. Annual average rainfall is 2160 mm; occurring mainly between February and August, the rainiest months being June and July (Assis, 1999). The native vegetation is humid tropical rainforest, distributed in the Atlantic Forest and *Restinga* ecosystems, much of which has been replaced by cultivated and industrial areas (Nascimento et al., 2004).

The Cabo Basin region is of great socioeconomic importance for the development of Brazil because of the Port Suape Complex, a vast area being developed for an industrial and conjugate port system. This complex is strategically located in relation to the main global shipping sea routes. In addition, the cultivation of sugar cane is predominant in the region, Brazil being the world's largest producer (CPRM, 2005).

3. Materials and methods

3.1. Field sampling

The study area was defined in advance through identification of the occurrence of conglomerate derived soils on the geological map of Pernambuco State (CPRM, 2005). The selection of pits for sampling and