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# Gneiss saprolite weathering and soil genesis along an east-west regolith sequence (NE Brazil)

Jean Cheyson Barros dos Santos [a], Emilia Le Pera [b], Valdomiro Severino de Souza Júnior [a], Marcelo Metri Corrêa [c], Antonio Carlos de Azevedo [d,*]

[a] Departamento de Agronomia, Universidade Federal Rural de Pernambuco (UFRPE), 52171-900 Recife, Pernambuco, Brazil
[b] Dipartimento di Biologia, Ecologia e Scienze della Terra, Università della Calabria, Cosenza 87036, Italy
[c] Departamento de Ciência do Solo, Universidade Federal Rural de Pernambuco (UFRPE) - Unidade Acadêmica de Garanhuns, Garanhuns, Pernambuco 55292-270, Brazil
[d] Departamento de Ciência do Solo, ESALQ, Universidade de São Paulo, Piracicaba, São Paulo 13418-900, Brazil

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ABSTRACT

The pressure to increase biomass production worldwide has pushed the boundaries of agricultural lands towards fragile soils. This process is particularly intense in Pernambuco State, NE Brazil. Pernambuco features a moisture gradient, with soils developed from similar gneisses. Resistant structures within the rock influenced the internal movement and distribution of water, consequently influencing regolith genesis. This paper presents the mineralogical characteristics of three regolith profiles with shallow soils (here assumed to be soils in which the top of the Cr horizon is at a depth of 1.5 m or less) along a transect at 8°S and discusses their weathering and pedogenetic processes. Samples were investigated via optical microscopy and scanning electron microscopy (SEM), X-ray diffraction (XRD) and total chemical analysis by inductively coupled plasma - atomic emission spectrometry (ICP-AES). The presence of weathering-resistant quartz veins and planes in the rock structure played a central role in controlling the water dynamics and the advancement of the weathering front. Therefore, desilication was dominantly controlled by the pore network. Hence, the weathering indexes did not differ appreciably among the climatic zones, and both 1:1- and 2:1-type clays were found in all profiles, although the amount of clay minerals that formed and the degree of dissolution of the primary minerals varied among the climate types. From an agricultural perspective, the thinness of these soil profiles and the presence of leucocratic layers are the main drawbacks of the regoliths, whereas the capacity to supply plant nutrients via primary mineral dissolution near the root zone can be an advantage.



## 1. Introduction

Brazilian agriculture ranks first in the export of sugar, orange juice and coffee, and second overall worldwide in the export of agricultural goods. It continues to expand towards unexplored arable land (Miranda, 2012), and the whole country, particularly the Northeast Region, is consequently experiencing intense agricultural development (Silveira Neto and Azzoni, 2011).

Land use change will pressure regolith resources towards degradation and possibly desertification if not well planned, particularly in semi-arid climates. Regoliths formed by shallow soils are the most endangered by such scenarios (Jacomine et al., 1973).

Regolith is a weathered bedrock and can be composed of sediments, soils and/or saprolites (Buol and Weed, 1991). Saprolites differ from soils because they preserve the same volume as the parent rock, known as the isovolume concept (Becker, 1895).

Knowledge of the characteristics of the regolith of the Northeast Region of Brazil is essential for preventing degradation and providing better solutions to land use changes and planning. This region is crossed by the 8°S parallel and exhibits a climate gradient, ranging from humid to intermediate to semi-arid over a few hundred kilometers (da Silva et al., 2013).

Several regoliths that crop out along this transect are developed on gneissic rocks characterized by similar geomorphic surface ages

*Abbreviations:* SEM, scanning electron microscopy; XRD, X-ray diffraction; ICP-AES, inductively coupled plasma-atomic emission spectrometry; Db, bulk density; Dp, particle density; P, total porosity; OC, organic carbon; V, base saturation; CEC, cation exchange capacity; Feo, poorly crystalline forms of iron oxides; Alo, poorly crystalline forms of aluminum oxides; AAS, atomic absorption spectroscopy; $X_d$, decomposition index; $I_p$, micropetrographic index; ε, strain parameter; *Z*, loss of elements; *CIA*, Chemical Index of Alteration; *CIW*, Chemical Index of Weathering; PIA, Plagioclase Index of Alteration; α*AlE*, geochemical ratio.

* Corresponding author at: Av. Pádua Dias, 11, Cx. Postal 9, Piracicaba, SP, Brazil.
*E-mail addresses:* jeancheyson@yahoo.com.br (J.C.B. Santos), emilia.lepera@unical.it (E. Le Pera), valdomiro.souzajunior@ufrpe.br (V.S. Souza Júnior), marcelometri@yahoo.com (M.M. Corrêa), aazevedo@usp.br (A.C. Azevedo).

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(Ab'Saber, 2003; Araújo Filho and Carvalho, 1996; Neves, 2003). Thus, by comparing regoliths from the three climatic belts, it is possible to evaluate how climate and rock structure control the genesis of gneissic regolith.

The objectives of this research are as follows: a) to discuss the physical, chemical, and biological processes acting upon gneissic regoliths along an east-west profile sequence, b) to characterize potential mineralogical changes and zonation as a function of the observation scale along a regolith profile, and c) to highlight the implications of weathering with respect to the agricultural potential of the regoliths.

## 2. Characteristics of the study area

The rocks studied and sampled along the 8°S transect are undifferentiated orthogneisses of Paleozoic age from the Borborema Province, which encompasses most of the Northeast Region (Neves, 2003; Vauchez et al., 1995).

Regoliths P1, P2 and P3 developed from biotite gneiss, varying from granodiorite gneiss for P1 and P2 to syenogranite gneiss for P3 (Neves, 2003).

The gneisses in this area have leucocratic sialic portions (Ferreira and Sial, 1986) and melanocratic mafic masses (Bétard, 2012).

The climate along the 8°S transect is distributed along belts (Köppen, 1931). These belts are illustrated in Fig. 1 and summarized as follows: a tropical humid climate (Am) in region 1 in the east, including the Atlantic Ocean shoreline; a transitional climate (Aw) in region 2 in the center; and a semi-arid climate (Bsh) in region 3 in the west. The average precipitation values in these regions are 1233.6 mm $yr^{-1}$, 742.8 mm $yr^{-1}$ and 648.3 mm $yr^{-1}$, respectively, and the mean maximum temperatures are 31 °C, 32 °C and 34 °C, respectively. The average evapotranspiration ($ET_0$) in dry years is 112 mm $month^{-1}$ in region 1, 142 mm $month^{-1}$ in region 2 and 176 mm $month^{-1}$ in region 3 (da Silva et al., 2011).

The climatic variation in the east-west direction is enhanced by the Borborema plateau, which was uplifted during Meso-Cenozoic tectonic events (Neves, 2003).

Consequently, the highlands intercept the moist air masses moving inland from the Atlantic Ocean, concentrating rains along the coastal area. The winds that reach the westernmost regions are therefore dry. This climatic gradient strongly affects the distribution of biomes, with tropical rain forests dominant in the east and thorn scrub forests dominant in the west (the semi-arid interior). The intermediate area features transitional vegetation (Ferreira and Sial, 1986; Neves, 2003).

## 3. Materials and methods

### 3.1. Field sampling

The sampled regolith profiles were labeled P1, P2 and P3 from east to west in the three climatic regions of NE Brazil (Fig. 1). Profiles were sampled in equivalent slope gradient positions, i.e., the intermediate point of the slope, to exclude any potential topographic control on the duration and intensity of weathering processes (e.g., Johnsson, 1993).

The sampling profiles were located in gentle rolling topography, and the profiles were classified according to the World Reference Base for Soil Resources (WRB) (FAO, 2014). From fieldwork analyses, the gneissic bedrock was divided into six different and progressive weathering stages, ranging from I to VI (Irfan and Dearman, 1978). The desert pavement, typical of Brazilian semi-arid regions, was not considered here due to its colluvial nature (Fig. 2).

### 3.2. Laboratory methods

Disturbed samples from soil and saprolite were collected in plastic bags, and undisturbed samples were collected in Kubiena boxes. Unconsolidated samples were impregnated with polyester resin, cut and thin sectioned until quartz yielded the characteristic extinction pattern. Thin sections were observed under a petrological microscope (an OLYMPUS model BX51 coupled with an OLYMPUS model SC20 imaging system) using natural and polarized light. Slides were also examined in a Quanta 200 scanning electron microscope.

The mineralogy of the silt and clay fractions was identified by XRD in a Rigaku Miniflex II system, using Cu K-alpha radiation, a Ni filter and a graphite monochromator. Samples were previously treated to eliminate carbonates, iron oxides and organic matter.

The interpretation of the XRD patterns was performed according to Jackson (1975), Brown and Brindley (1980) and Moore and Reynolds (1997). Minerals in gravel and sand fractions were identified by optical microscopy.

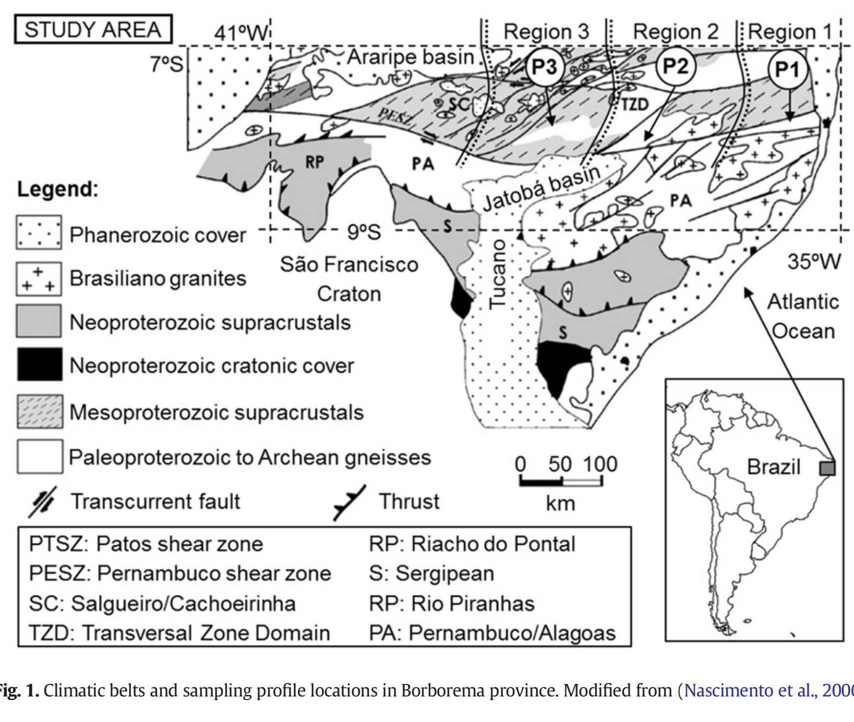


**Fig. 1.** Climatic belts and sampling profile locations in Borborema province. Modified from (Nascimento et al., 2006).