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Soil–geomorphology interactions and paleoclimatic implications of an ornithogenic soil toposequence on Rata Island, Fernando de Noronha Archipelago, South Atlantic

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ABSTRACT

The formation of highly phosphatized soils on sites of avian activity is a common feature of oceanic islands. We characterized a toposequence of phosphatic soils on Rata Island, to evaluate the soil genesis based on local topographic variations. For this purpose, four soils ranging from the upper hill down to the lowest landscape position on the island, representing a range of parent materials (basalt and calcareous sands), were analyzed. In the lowest landscape position a shallow Regosol was identified, strongly influenced by birds and marine sprays, developed on "karstified" Pleistocene calcarenites; the three other soils in the upper part of the toposequence are Ornithogenic Cambisols, ranging from a deep Cambisol profile on Basalt lava to intermediate Cambisols on mixed colluvial sediments of the basalt/calcareous. The lowermost Regosol is associated with a rugged landscape with strong calcarenite dissolution and karstification. The soil phosphatization is clearly an inherited process of the Late Quaternary age, when climate conditions were different. Initial weathering took place in the last interglacial period, under wetter conditions during which the Tertiary basalts were strongly weathered, leaving corestones in a saprolitic, oxidized mass. In the late Pleistocene, a gentle surface distributed these weathering products along the pediment slopes as colluvial materials, whereas in the coastal areas aeolian processes formed large sand dunes composed of reworked calcareous sands from marine sources during a time of very low sea level. During this time, widespread bird activity accounted for secondary apatite formation on the surface of calcareous oolites. Finally, the Holocene warming was accompanied by increasing sea level, enhanced tropical weathering, Fe and Al mobility and variscite formation superimposed on degraded Ca-phosphates, forming two phase phosphatic aggregates.

1. Introduction

Oceanic islands are environments characterized by soils that develop under conditions associated with geographical isolation, direct maritime climate influence, mainly volcanic lithology, disturbances in the basement structure by volcanic earthquake events and significant influences on soil formation by local fauna and flora. Due to these properties, the resulting soils are often considered endemic (Clemente et al., 2006). The archipelago of Fernando de Noronha, in the South Atlantic, is part of this context.

Although, in recent years, a very valuable stock of knowledge about the soils of this archipelago has been developed, only the soils of the main island Fernando de Noronha have been studied in detail (Batistella, 1993; Teixeira et al., 1993; Ribeiro et al., 2003; Marques, 2004; Schaefer, 2006). Pedological aspects of the other islands of the archipelago, particularly of Rata Island (Oliveira et al., 2009), are still almost completely unknown, especially in terms of the pedogenetic and morphogenetic processes forming them.

Known for its guano deposits, which were exploited by the U.S. Army during the North American occupation of the archipelago,

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Rata Island is the setting of a particular phosphatization process. This is a pedogenetic process that represents the interaction between a substrate, such as soil, with P-rich droppings of animals, mainly birds (Myrcha et al., 1985; Tatur and Barczuk, 1985; Tatur, 1989; Tatur and Myrcha, 1993; Tatur et al., 1997; Blume et al., 2002; Schaefer et al., 2004; Simas et al., 2007). Phosphatization results in the formation of soil environments consisting of ornithogenic soils with geochemical and mineralogical characteristics inherited from the source material mixed with features related to P input into the system.

Despite representing a fundamental process for understanding the biogeochemistry of adjacent marine and terrestrial environments influenced the return of P to the sea by leaching and/or erosion, the chemical, physical, mineralogical and morphological properties of phosphatized soils are still poorly studied. In addition, the soil phosphatization in island environments occurs mainly in dry climates, where the surface is poorly covered by vegetation and sea levels are lower, enabling colonization by birds. Thus, the study of phosphatization, with regards to distribution across the landscape, can provide important information about the soil–geomorphology interactions and paleoclimatic/eustatic oscillations.

This study aimed to characterize the phosphatized soils of Rata Island, with the main purposes of identifying phosphate forms in these soils and understanding their soil–geomorphological and paleoclimatic implications.

2. Materials and methods

2.1. Study area

Fernando de Noronha (FNA) is a Brazilian archipelago (lat 3°50′–3°52′ S, long 32° 32°24′–32°28′ W) (Fig. 1A), consisting of a set of 21 islands at a distance of approximately 345 km from the continent (Marques, 2004). The main island bears the name of the archipelago and the other 20 islets and rocks are spread over a shallow sea area of more than 20 km^2 in the South Atlantic. The main island is 17.6 km long, with an approximate width of 2.0–3.3 km (Batistella, 1993).

Rata Island is located in the far northeast of the FNA and is the second largest island of the group (Fig. 1A and B), with an approximate area of 6.8 km^2. Currently, the island is protected by the IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) and access is restricted and authorized only for surveillance, conservation and research. In the past, lighthouse keepers inhabited the island at times when the functioning of the lighthouse required human operators. It was also an agricultural production site of corn and an experimental field of guano exploitation by the Guano Company, which removed calcium phosphate in great quantities from various parts of the surface. This guano has been described as “the largest zoogenic phosphate deposit in Brazil” by Derby and Barros (1881).

The geology of the Rata Island is composed of ankaratrite lava flows alternating with pyroclastic components of the lava itself, called the Quixaba Formation (Almeida, 1955) and Pleistocene aeolian-sedimentary deposits composed of carbonates, forming the so-called calcarenites of Caracas (Fig. 1A and C). The first lithology is characterized by horizontal flows or flows inclined up to 30°, depending on the flow, massive within and vesicular or amigdaloidal at the base and top. The sandstone is pale cream in color, consisting mostly of subrounded to rounded grains from calcareous algae (*Corallinaceae*) and mixed with some magmatic rocks, in some places reaching up to 25% of the total mass (Almeida, 1955). When the sandstone rests on an ankaratritic area, as in part of Rata Island, it contains femic minerals. The relief of the island is low and tabular and is flanked by structural cliffs, some consisting of lava, some of sandstone. The mean annual rainfall is 1300 mm and the mean annual temperature is 25 °C (Oliveira et al., 2009).

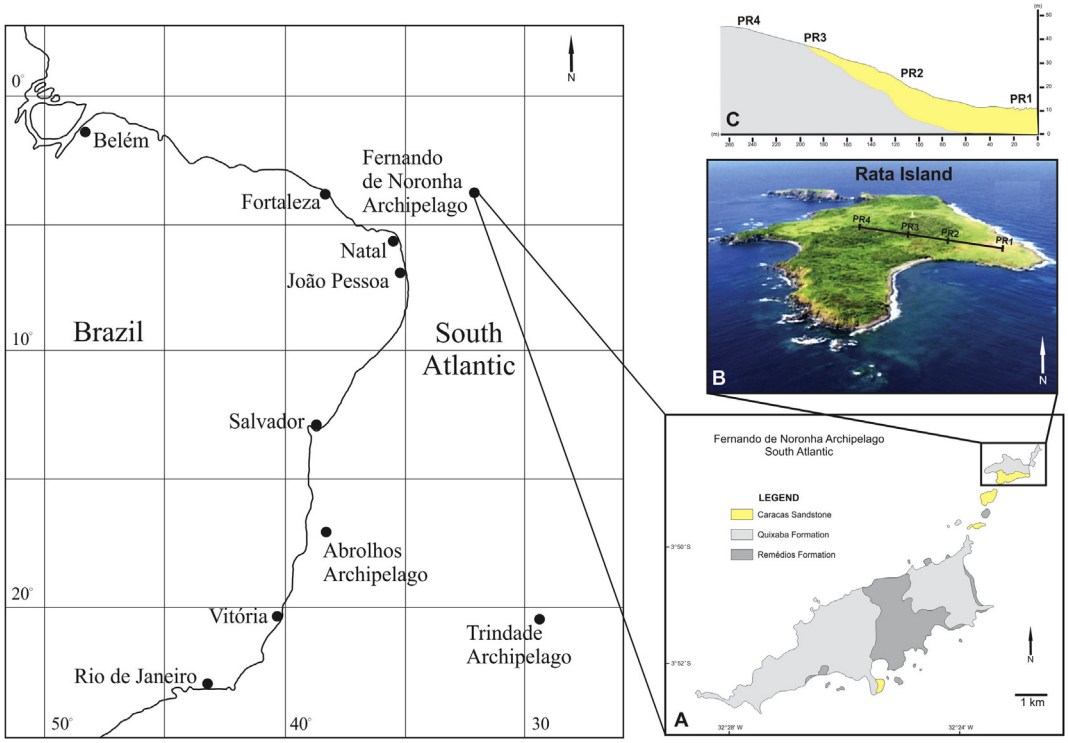

Fig. 1. A: Simplified geology of the Fernando de Noronha Archipelago (Oliveira et al., 2009 adapted from Almeida, 1955); B: Aerial photograph of Rata Island indicating the location of the sampling points, image source: Ecosphere (2007) C: Schematic geological section of the sampled profiles in the toposequence.