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Chemistry of volcanic soils used for agriculture in Brava Island (Cape Verde) envisaging a sustainable management

Rosa Marques[a,*], Bruno J. Vieira[a], M. Isabel Prudêncio[a], João C. Waerenborgh[a], M. Isabel Dias[a], Fernando Rocha[b,c]

[a] Centro de Ciências e Tecnologias Nucleares (C2TN), Instituto Superior Técnico, Universidade de Lisboa, EN 10 (km 139.7), 2695-066, Bobadela, Portugal
[b] GeoBioTec, Universidade de Aveiro, Campus Universitário Santiago, 3810-193, Aveiro, Portugal
[c] Dep. de Geociências, Universidade de Aveiro, Campus Universitário Santiago, 3810-193, Aveiro, Portugal

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ABSTRACT

In order to acquire a better knowledge of iron forms, clay minerals and the content and distribution of trace elements in soils mostly used for agriculture in the semi-arid Brava Island (Cape Verde), iron speciation, mineralogy and chemical contents in the clay-size fraction (< 2 μm) of incipient soils developed on sediments and phonolitic pyroclasts was performed by Mössbauer spectroscopy, X-ray diffraction and neutron activation analysis. In contrast with the whole samples in the clay-size fraction of all the studied soils only Fe(III) was detected. Iron and chromium are depleted suggesting their occurrence as ferromagnesian and oxide minerals present in coarser particles. Rare earth elements are concentrated in the clay-size fraction, and significant differences are found in their distribution which may be partially due to oxidation, since Ce anomalies were observed. Among the other chemical elements studied, high concentrations of arsenic, bromine, and particularly antimony were found in the clay-size fraction of soils where all the Fe oxides are nano-sized, confirming the predominant adsorption of these elements on the nano-particles surface. The existence of significant amounts of these elements as well as of vitreous phases in fine particles of these soils may contribute to their mobility and accumulation in groundwater and in plants, both by absorption and by dust deposition onto the plant leaves.

1. Introduction

The knowledge of arid zone soils has become increasingly important since global warming has worsened the water resource crisis in many zones worldwide from Africa to Asia (Han, 2007).

Volcanic eruptions form part of the biogeochemical cycle of the elements and represent one of the natural ways in which significant amounts of chemical elements enter the atmosphere (Nriagu, 1989). The environmental impact of ash deposits, which contribute with considerable quantities of metals to sediments and soils, is also of the utmost relevance. As shown by several studies, major, minor and trace elements can quickly transfer from ash into the environment, leading to considerably high concentration of these elements in water and vegetation (Cronin et al., 2003; Frogner et al., 2001; Jones and Gislason, 2008; Martin et al., 2009; Watt et al., 2009). Thus, soils with contribution from volcanic eruptions, particularly those developed on oceanic volcanic islands, may have significant amounts of a number of chemical elements. Volcanic soils are rich in mineral nutrients being amongst the most fertile lands in the world and are intensively cultivated. Nevertheless they may have an imbalance of chemical elements that can impact on the health of plants and animals growing in or on the soils (Neall, 2007). This may be particularly relevant in the case of volcanic islands of recent and contrasting volcanism that are under semi-arid climate, which is the case of Cape Verde.

The Cape Verde archipelago is located in the Atlantic Ocean. The semi-arid climate of these islands gives rise to topsoils with low to moderate degree of weathering and development, in general with less than 30 cm depth. Although Brava is one of the islands with more frequent rainy periods in Cape Verde, the aridity associated with the rough topography leads to incipient soils (Madeira and Ricardo, 2013).

* Corresponding author.
E-mail addresses: rmarques@ctn.tecnico.ulisboa.pt (R. Marques), brunovieira@ctn.tecnico.ulisboa.pt (B.J. Vieira), iprudenc@ctn.tecnico.ulisboa.pt (M.I. Prudêncio), jcarlos@ctn.tecnico.ulisboa.pt (J.C. Waerenborgh), isadias@ctn.tecnico.ulisboa.pt (M.I. Dias), tavares.rocha@ua.pt (F. Rocha).

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Nevertheless, soils of alluviums and colluviums, the major areas for agriculture, can be found in valleys. Furthermore, high contents of trace elements may occur originated from imbalance of elements in the volcanic parent materials, which may be a threat to the environmental health (Marques et al., 2012, 2014a,b, 2016, 2017a,b,c). Detailed Fe speciation and chemical composition studies of Cape Verde soils, namely of Fogo and Brava Islands (Marques et al., 2014b, 2016, 2017c) have shown that oxidation is a major weathering mechanism. The global iron oxidation appears to be a good indicator of the weathering degree in these semi-arid islands. In addition to information on pedogenetic conditions Fe oxides may affect a number of soil properties, namely surface adsorption of numerous ions and molecules. Significant chemical content variations were found to occur as well as high contents of Mn, Co, Ga, Ba, rare earth elements (REE), Ta, W, Th and U in the whole sample ($\phi < 2$ mm) of soils (Marques et al., 2016). These results justify a more detailed study concerning fine particles, which have the highest surface areas, of soils used for agriculture in Brava, a crucial resource of this small island.

The soils mostly used for agriculture in Brava Island are those developed on phonolitic pyroclasts and sediments on a plateau between 300 and 976 m above sea level, and also on sediments occurring on terraces of fluvial incisions of the steep coastal cliffs (Fig. 1). In this work the clay-size fraction ($\phi < 2$ μm) of these soils were analysed by Mössbauer spectroscopy, X-ray diffraction and instrumental neutron activation analysis, in order to characterize the iron speciation, mineralogy and to determine the concentration and distribution of 29 chemical elements. Results are compared with those obtained for the corresponding whole samples (Marques et al., 2016).

The main objectives of this work are therefore: (1) the chemical characterization of the clay-size fraction of the surficial layer of soils developed on sediments and phonolitic pyroclasts in Brava Island (Cape Verde); (2) the iron distribution in mineralogical phases of the clay-size fraction of the soils; (3) the assessment of the $Fe^{3+}/(Fe^{2+} + Fe^{3+})$ ratio; and (4) the establishment of the geochemical patterns and the identification of chemical elements with high contents. Thus a better knowledge of soils used for agriculture in Brava Island is a major motivation of this work, contributing for the identification of potential risks to humans coupled with the need of the population of this island to produce food.

Fig. 1. Photographs of Brava Island (Cape Verde) with a view to agriculture soils developed on (A) phonolitic pyroclasts (Nova Sintra), and (B) terrace sediments (Tantum).