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Weathering of the Madeira world-class Sn-Nb-Ta (Cryolite, REE, U, Th) deposit, Pitinga Mine (Amazon, Brazil)

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ABSTRACT

The paper deals on the laterization of the Madeira deposit associated with the albite-enriched granite facies of the A-type Madeira granite (~1.82 Ga). The Madeira deposit is located in the Amazon rain forest, where chemical weathering is intensive and lateritization is a major process of ore deposit formation. This deposit represents a particular case, where the parent rock is an ore deposit; thus primary mineralization and lateritic mineralization occur in the same profile. The parent rock has an unusual mineral association, which includes quartz, albite, k-feldspar, zircon, cryolite (Na_3AlF_6), fluorite, polylithionite, Zn-rich riebeckite, Zn-F-rich annite, thorite, cassiterite, pyrochlore, columbite, xenotime, gagarinite-(Y), fluocerite-(Ce), and genthelvite. An important feature of the rock is the F richness (2 to 6 wt%) mainly in the form of cryolite or fluorspar in the matrix. We first investigated the micromorphological changes of these minerals throughout the soil profile and then focused the geochemical studies in selected profiles. The chemical data were converted into volumetric proportions to quantify the variations in element contents in samples with different degrees of lateritization, and we performed mass balance calculations with Al as the reference element. In this way, we obtain many new constraints on the processes that formed the weathering profile from the Madeira deposit. The parental rock was a clearly aluminous system with lower amounts of Fe. The total loss of alkalis and partial loss of SiO_2 created kaolinitic clay minerals. The SiO_2/Al_2O_3 molar ratio ≈ 2 was suitable for generating aluminous clay minerals with 1:1 structures, such as kaolinite. Greater losses of SiO_2 occurred and gibbsite formed at the top of the weathering profiles. The leaching of alkaline elements led to relative enrichment in some economically important elements, such as Sn, Nb, and REEs, in the lateritic profiles. However, the distribution of some of the metals, such as Pb, Zn, and REEs, in the weathering profile is very unusual and may be explained by some special characteristics of the paragenesis and the richness of F in the solutions, which greatly influenced the weathering processes in two different ways. The intense corrosion of even very resistant minerals due to the presence of HF in the system and relative enrichment of HREE in the profile due to the formation of complexes with F^- and the downward movement of these elements.

1. Introduction

This paper focuses on the laterization of the Madeira deposit, which is associated with the albite-enriched granite (AEG) facies of the A-type Madeira granite (Fig. 1). This deposit is a world-class deposit with 130 million tons of disseminated ore with a Sn grade of 0.17%. Niobium and Ta (pyrochlore and columbite) are exploited as by-products. F (cryolite - Na3AlF6), HREE (xenotime and gagarinite-Y), Zr and U (zircon), Th (thorite), and Li (polylithionite) are potential by-products of this disseminated ore. In addition, in the central portion of the Madeira granite deposit, there is a massive cryolite deposit, with 10 million tons with a grade of 31.9% of Na_3AlF_6. This association of cryolite with tin, niobium and several other rare metals in the same peralkaline rock that hosts a massive cryolite deposit is unique in the world (Bastos Neto et al., 2009).

The AEG is located in the Amazon region, which is characterized by the development of deep chemical weathering, including widespread lateritic covers and soils. Lateritization is a major process of ore deposit formation in the region (Horbe and Costa, 1997). The Madeira deposit represents a particular case, in which the parent rock is an ore deposit;

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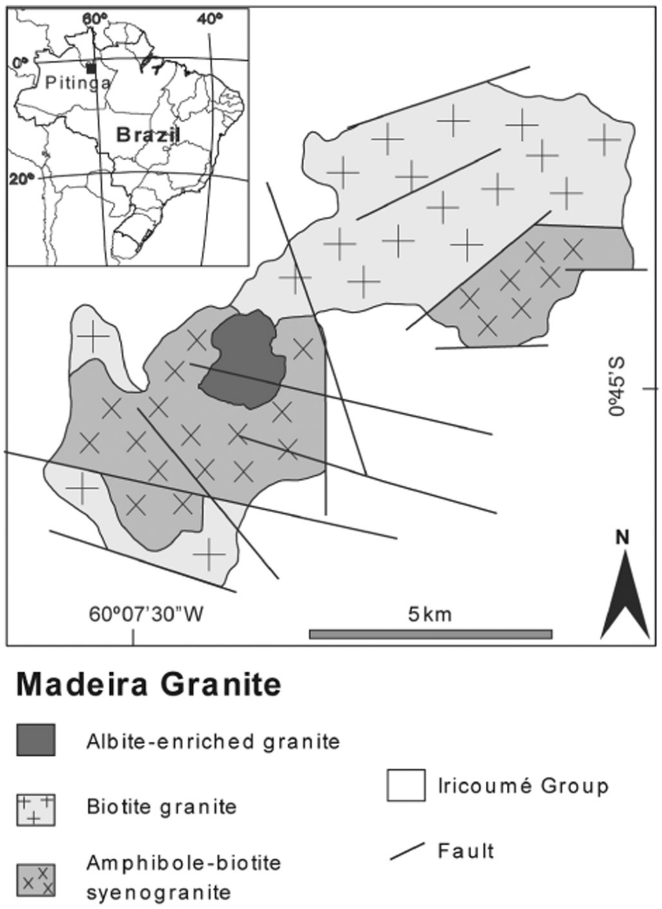

Fig. 1. Location and geological map of the Madeira granite (modified after Costi, 2000).

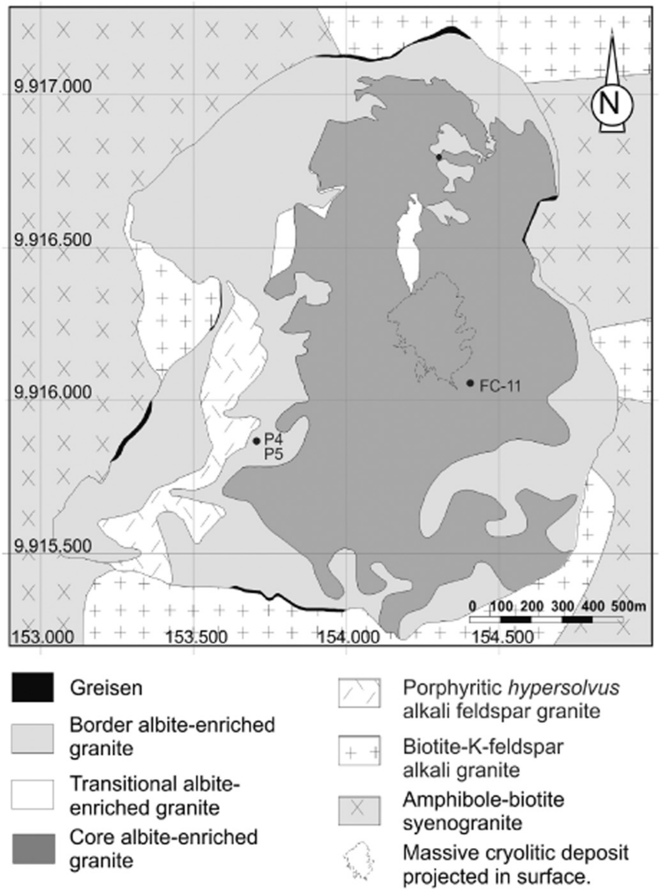

Fig 2. Geological map of the albite-enriched granite (modified after Minuzzi, 2005).

thus, primary mineralization and lateritic mineralization were preserved in the same profile.

Horbe (1991) and Horbe and Costa (1997) (integrated into Horbe and Costa, 1999) performed the only existing studies on the lateritic profile that developed in the AEG, which were based on 220 geochemical analysis of samples from 17 pits, and proposed a comprehensive model for the geochemical evolution. At that time, the primary rock was classified as apogranite and had not been thoroughly studied. Many studies on the bedrock have since revealed a number of characteristics to be considered in the study of this lateritization: (1) the very uneven distribution of zircon, which does not recommend the use of Zr in mass balance calculations; (2) the matrix's richness in F (Costi, 2000; Bastos Neto et al., 2009), a subject to be investigated if it could influence the lateritization process; and (3) the mineralogical distribution and geochemical evolution of elements such as Pb, U, Th, Nb, Zn, and REE, which are much more complex than previously supposed. We focus this investigation on selected soil profiles to examine these and other features of the AEG, in which we perform detailed mineralogical studies and analyze a larger number of samples per profile. We quantify the variations in the element contents in samples with different degrees of lateritization, convert these data into volumetric proportions, and perform mass balance calculations with Al as the reference element. In this way, we obtain many new constraints on the processes that formed the soil from the Madeira deposit.

2. Background information

2.1. Climate, landscape, and geological setting

The Pitinga region is located in the Amazon rain forest. The climate is tropical-humid with a long wet season (avg. annual rainfall of 2000 mm and temperature of 26 °C). The relief is dissected, with plateaus in interfluvia and altitudes around 450 m, but lower regions next to drains exhibit surfaces with altitudes around 100 m. The plateaus are defined and sustained by surface lateritic alteration and are usually capped by bauxite. The drainage system in the Madeira granite area is adapted to the structures.

The Pitinga region (Fig. 1) is located in the southern portion of the Guyana Shield (Almeida et al., 1981). The predominant rocks in the region are the volcanic rocks of the Iricoumé Group ($^{207}Pb/^{206}Pb$ zircon ages between 1881 ± 2 and 1890 ± 2 Ma), which are reminiscent of a caldera complex (Ferron et al., 2006, Ferron et al., 2010; Pierosan et al., 2011) and are cross-cut by the granitic bodies of the Madeira Suite, among them the Madeira granite (Fig. 1). The Madeira granite (Figs. 1 and 2) contains four facies (Costi, 2000). The metaluminous amphibole-biotite syenogranite facies ($^{207}Pb/^{206}Pb$ zircon age of 1824 ± 2 Ma, Costi et al., 2000) and the peraluminous biotite-alkali-feldspar granite facies are equigranular. The alkali feldspar hypersolvus porphyritic granite facies ($^{207}Pb/^{206}Pb$ zircon age of 1818 ± 2 Ma, Costi et al., 2000) and the albite-enriched granite were emplaced simultaneously and intrude the older facies.

The Madeira deposit corresponds to the AEG, the parental rock in this study. The massive cryolite deposit in the central part of the AEG (Fig. 2) has not been affected by weathering processes, so this deposit is not considered in this work. The AEG is subdivided into two subfacies (Fig. 2), whose contact is gradational: the core albite-enriched granite (CAG) and the border albite-enriched granite (BAG); locally, a transitional subfacies (TAG) can be identified. All these subfacies are mineralized.

The CAG is gray with a porphyritic to seriate texture and essentially consists of quartz, albite and K-feldspar (microcline) in approximately