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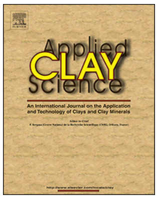

Research paper

Alteration of olivine in volcanic rocks from Trindade Island, South Atlantic

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ABSTRACT

The alteration of olivine (forsterite) phenocrysts in three soil profiles that were developed on similar pyroclastic rocks from Trindade Island, at different altitudes and degree of development, were investigated in this study. Optical microscopy, Electron Probe Microanalysis (EPMA), Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD) and Differential Thermal and Thermogravimetric Analysis (DTA-TGA) were used to determine the mineralogical, micromorphological and geochemical transformations resulting from the alteration process. Micromorphological analyses showed fractured phenocrysts of colorless olivines with high relief at plane polarized light. These crystals are euhedral and irregularly shaped, and distributed in a dark reddish brown matrix constituted by pyroxenes, magnetites, ilmenites, kaolinite, hematite and anatase. At crossed polarized light, the olivine phenocrysts display a rim of reddish brown material in the fractures and in the borders that extinguishes parallel to their extinction direction. This reddish brown material appears to invade the crystal progressively until a complete replacement towards the top of the soil profile of higher altitude and degree of development. The olivine was identified as forsterite type and the reddish brown material has a chemical composition of Si, Fe, Mg, Al, Ca, Na, K, Mn and Ti, with predominant and variable contents of Fe, Si and Mg. The chemical composition and optical features are consistent with that found in iddingsites which may form through the incipient alteration of olivines due to the oxidation of ferrous iron to ferric iron, and with the coordination of magnesium with hydroxyl groups. The microscopic features of olivine did not allow us to identify any previous alteration by either deuteric or hydrothermal processes. However, the advance of the alteration towards the soil profile, leaving only relicts of olivine crystals or reaching their total transformation in the upper horizons, shows that weathering is the main process of iddingsite formation. This finding is corroborated by the presence of greater alteration of olivine crystals in the topmost soil at the highest altitude on the same lithology.

1. Introduction

Iddingsites are formed from the alteration of olivines and are very common in rocks of basic volcanism. The first studies about the iddingsites were portrayed in the 19th century. Lawson (1893) proposed the name iddingsite in honor of the geologist and petrologist Joseph Paxson Iddings, for phenocrysts found in basaltics rocks of the region of California. According to Lawson (1893), the iddingsites in hand samples are soft, brittle, with well developed cleavage and, under optical microscopy, show colors varying from brown to light yellow with pronounced pleochroism in transversal position to their cleavage. The chemical formula of iddingsite, $MgO{\cdot}Fe_2O_3{\cdot}3SiO_2{\cdot}4H_2O$, was deduced by Ross and Shannon (1925). They concluded that iddingsite would be a deuteric mineral formed at the end of the lava cooling and not a weathering product. Edwards (1938) also proposed that iddingsite was formed during and after the magma consolidation. Through XRD analyses, Sun (1957) showed that the iddingsites are a complex product of olivine alteration and not a single mineral. Haggerty and Baker (1967), Champness (1970), Goode (1974) and Gualtieri et al. (2003) observed the formation of hematite, magnetite and orthopyroxene during high-temperature oxidation experiments on olivine. Additionally, several authors have studied high-temperature iddingsite (HTI) with similar composition (orthopyroxene, maghetite, hematite, cristobalite and amorphous silica) within continental and oceanic basalt flows (Goff, 1996, 1977; Caroff et al., 2000, 1999, 1997) and in gabbroic intrusions (Clément et al., 2007). Tschegg et al. (2010) observed a systematic HTI-like corrosion phenomenon of olivine phenocrysts in alkaline lavas and because they did not observed real iddingsite formation they called this phenomenon high temperature corrosion (HTC) of olivine. The low-temperature iddingsite (LTI) present composition different from that of

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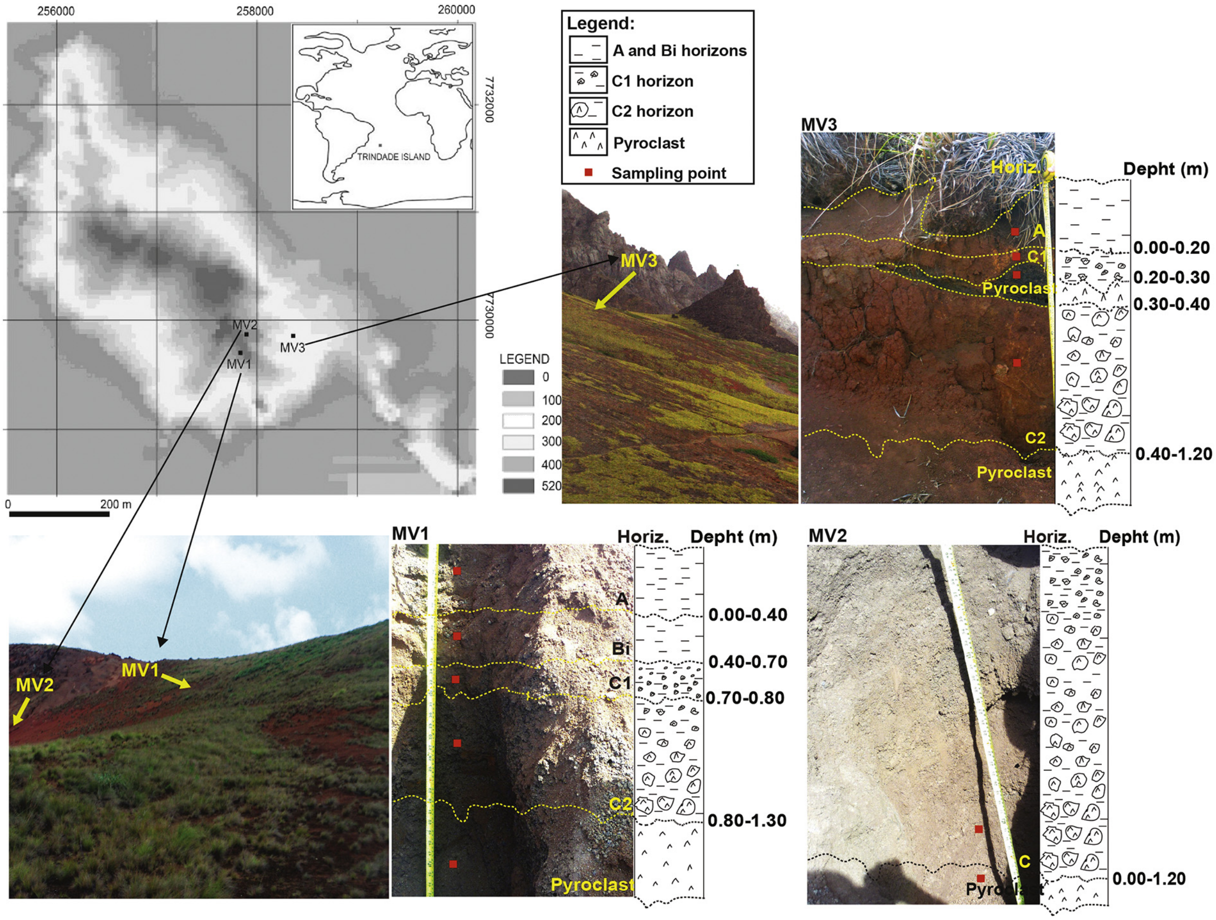

Fig. 1. Digital elevation model of Tindade Island showing the location of the three soil profiles, MV1, MV2 and MV3 and their respective horizons.

HTI, a intimate mixture of hydrous iron and magnesium silicates (goethite, montmorillonite, illite, chlorite) as described by Gay and Le Maître (1961), Fawcett (1965); Le Maître et al. (1966), Baker and Haggerty (1967), Schandl et al. (1990), Schenato et al. (2003), Talbi and Honnorez (2003). Gay and Le Maître (1961) described the XRD standard of several phases that occur in LTI: as olivine-like, goethite-like, hematite-like, spinel-like and silicate structures. Baker and Haggerty (1967), observed that in alteration under oxidizing conditions at low temperature, probably below 140 °C, produces iddingsite with goethite and smectite. Delvigne et al. (1979) also proposed that the iddingsite is composed by a mixture of cryptocrystaline goethite and possibly hematite, with smectite, chlorite, micas and rarely talc. Talbi and Honnorez (2003) described an orange or reddish material with intermediate composition between Fe-oxyhydroxides and phyllosilicates, chemically similar to iddingsite, in tholeiitic basalts that were affected by low temperature alteration. Through the transmission electronic microscopy, Eggleton (1984) showed saponites and goethites in iddingsites in olivine borders of basanites in Germany. A few years later, Smith et al. (1987) demonstrated that the olivine alteration model in iddingsites proposed by Eggleton (1984) was applicable to olivine alterations from Australia region. Gerard et al. (2007) described the presence of iddingsite in basaltic pyroclasts on Faial and Pico islands (Azores). Recent studies performed on meteorites with iddingsitized olivine (Kuebler, 2013; Lee et al., 2015) showed iddingsite formed during the final stages of magma consolidation.

In the volcanic islands of the Brazilian territory, specifically in the island of Trindade, object of this study, Antonello et al. (2009) described basaltic composition rocks with partially or totally altered olivines to serpentine, carbonates and iddingsites. However, these studies dealt with an essentially petrographic description, without involving a detailed microscopic and microchemical analysis that allowed to investigate the processes of alteration of the olivines and the evolution of this alteration along the soil profiles. In order to overcome this lack of research in Trindade, the present work aims to investigate the alteration of olivines into iddingsite in the pyroclastic rocks, to define the composition of iddingsite and to understand low temperature conditions of its formation, by using optical microscopy, X-Ray Diffraction (XRD), Differential and Thermo Gravimetric Analysis (DTA-TGA), Electron Probe Microanalysis (EPMA) and Scanning Electron Microscopy (SEM).

2. Materials and methods

Trindade Island, with a surface of 13 km^2, is located in the South Atlantic at 1140 km from the Brazilian coast (Fig. 1). The island is part of an extensive submarine volcanic chain of east-west orientation, denominated Vitória-Trindade, and constitutes the superior portion of a volcanic building rising 5,2 km from the ocean floor (Almeida, 2002; Alves et al., 2006).

The study area is located in the south-eastern part of the island in three soil profiles developed on pyroclastic rocks, MV1, MV2 and MV3, respectively at 460, 351 and 258 m of elevation (Fig. 1). The MV1 is from the Vulcão do Paredão and, MV2 and MV3 from the Morro Vermelho Formation. Macromorphological descriptions and samplings of pyroclastic rocks and soil horizons were performed on all three profiles (Fig. 1).

Particle size was determined by the total dispersion method according to Donagema et al. (2011). After vertical shaking for 16 h with sodium hexametaphosphate solution as a dispersant, the clay content was determined by the pipette method, the gravel, coarse and fine sand