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Basalt and rhyo-dacite weathering and soil clay formation under subtropical climate in southern Brazil

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ABSTRACT

The mineralogy of highly weathered soils is dominated by kaolinite-group clay minerals. However in the highlands of southern Brazil the subtropical climate (mean annual temperature ~15 °C, mean annual precipitation 1900 mm/yr) favored accumulation of organic matter and occurrence of 2:1 clay minerals. The objective of this work was to compare the weathering of the two main rock types in the volcanic plateau in the Rio Grande do Sul in southern Brazil in order to consider soil fertility and sustainability in this intensively cropped area. Two weathering profiles were sampled on basalt and rhyo-dacite at elevations ranging between 760 and 850 m a.s.l. The soil minerals were analyzed by X-ray diffraction, chemical extractions, and FTIR spectroscopy. Weathering intensity was inferred from bulk chemical analyses and calculation of weathering indices (Chemical Index of Alteration, CIA; Weathering Intensity Scale, WIS) and elemental mass balance. Mineralogy was dominated by kaolinite and crystalline iron and aluminum oxy-hydroxides and 2:1 clay minerals. The surface horizons contained hydroxyl-Al-interlayered minerals originating from aluminization of smectite present in the saprolite under acidic conditions, with the important accumulation of organic matter. Results of mass balance calculation showed extensive loss of all elements (high Δ4Si, WIS and CIA) with residual accumulation of Fe and Al oxy-hydroxides. The degree of weathering is higher on rhyo-dacite compared to basalt although rhyo-dacite rock is richer in SiO_2.

Given the importance of 2:1 clay minerals on soil properties (e.g. sorption, aggregation) a better understanding of their formation and transformation according to geochemical conditions is a key issue in the management of these sub-tropical soils.

1. Introduction

Because basalts occupy a large part of the earth surface weathering and soil formation from basalts constitute a key component of global weathering and biogeochemical cycling, and an important carbon sink through weathering induced CO_2 consumption. Mass balance calculations are means to quantify element transfers during weathering and to estimate mineral weathering rates and as so far been performed on a wide range of rock types and climates (e.g. Anderson et al., 2002, 2007; Braun et al., 2009; Heckman and Rasmussen, 2011; Price et al., 2005, 2013; Turner et al., 2003). Basalt weathering in tropical climates implies rapid loss of cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and relative accumulation of Si^{4+}, Al^{3+} and Fe^{3+} into secondary mineral assemblage (Chorover et al., 2004) such as kaolinite-group clay minerals and crystalline iron oxides. Formation of 2:1 clay minerals in volcanic rock-derived soils is a matter of debate because some authors consider 2:1 phyllosilicates as authigenic taking into account their absence in basaltic rocks (Rasmussen et al., 2010; Righi et al, 1999), while others attributed them to hydrothermal alteration during cooling of the lava flow (Bain et al., 1980; Curtin and Smillie, 1981; Pokrovsky et al., 2005) or eolian inputs (Rasmussen et al., 2010) or both. Volcanic rocks (basalt and rhyo-dacite) occupy an area of approximately 1.2 million km^{-2} in southern Brazil on the Paraná Basin. Soils developed on these rocks are intensively cultivated with cash crops, such as soybean, corn, apples, pines (*Pinus taeda* and *Pinus elliottii*), and ryegrass, due to the subtropical climate of the region. Weathering and pedogenesis in southern Brazil were investigated by several authors such as Kämpf and Klamt (1978). Pötter and Kämpf (1981), Curi et al. (1984), Kämpf and Curi (2003), and Kämpf et al. (2009). These studies were focused on the

Abbreviations: a.s.l, above sea level; CEC, cation exchange capacity; CIA, Chemical Index Of Alteration; EG, ethylene glycol; FTIR, Fourier transformed infrared; HIMs, hydroxy-aluminum-interlayered minerals; WIS, weathering intensity scale; XRD, X-ray diffraction.

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tropical region of Brazil, and established relationships between precipitation, temperature, and 1:1 clay minerals, and crystalline iron oxide formation. Specifically, more humid and cooler climates at elevation (mean annual temperature of about 15 °C and mean annual precipitation 1750–2150 mm/yr) in Rio Grande do Sul in south Brazil favored the accumulation of organic matter in topsoil and the coexistence of crystalline Fe oxy-hydroxides, kaolinite, and 2:1 clay minerals, especially hydroxy-aluminum-interlayered minerals (HIMs) (Bortoluzzi et al., 2008, 2012; Inda et al., 2010; Kämpf and Schwertmann, 1982a; Kämpf et al., 2009; Melo et al., 2001).

The objective of this study was to quantify the weathering processes and clay mineral formation in two major parent rock materials on the volcanic plateau of northern Rio Grande do Sul State in south Brazil by using elemental mass balance and clay mineralogy analyzes. Emphasis was placed on 2:1 clay minerals because although they are present in minor proportion, they control important properties of these soils such as cation exchange capacity (CEC), sorption properties, aggregation, and water holding capacities. The results were also discussed in terms of soil fertility and sustainability for this region with potential of intensive agricultural production.

2. Materials and methods

2.1. Location and profile description

The study area is located in the northern region of the Rio Grande do Sul State (RS) in southern Brazil (Fig. 1). The geological formation, called *Serra Geral*, formed in the Mesozoic era (volcanism). *Serra Geral* formation is composed by different lava flows with a thickness up to 1200 m with alkaline basaltic lava flows at the bottom of the formation and basaltic–andesitic, rhyolite and rhyo-dacite on the top of the formation. The region presents a wavy landform (*Campos Gerais plateau*) at an elevation between 800 and 950 m above the sea level (a.s.l.) (IBGE, 1986). The climate is subtropical humid with mean annual rainfall comprised between 1750 mm per year (profile 2) and 2150 mm per year (profile 1) and mean annual temperatures around 15 °C (IBGE, 1986; Moreno, 1961). The natural vegetation is a mosaic of permanent meadows and lowlands occupied by natural mixed rainforest composed by deciduous trees and the characteristic conifer *Araucaria angustifolia* (*Mata Atlântica*). Secondary pine (*P. taeda*, *P. elliottii* and *Pinus* sp.) forests, established after forest clearing, are also found. The two studied profiles are located at the vicinity of the cities of São Francisco de Paula (50°37′ W, 29°24′ S) and Canela (50°39′ W, 29°21′ S) (Fig. 1). Two representative soil profiles were selected after field observations: profile one (São Francisco de Paula) was located over rhyo-dacite rocks (850 m a.s.l.) and profile two (Canela) over basaltic rocks (760 m a.s.l.) which are the two main rock types present in this area. Rhyo-dacite presents a glassy texture with phenocrysts of pyroxenes, and phenocrysts and microcrysts of plagioclases. Patches of anhedral quartz are observed in the groundmass. Basaltic rocks have a porphyritic texture containing predominantly phenocrysts (0.5–2 mm) of plagioclases, pyroxenes (augite, pigeonite), and Ti-magnetite. Olivine is rarely observed.

Profile 1 was sampled under natural grassland close to a mixed temperate rainforest and profile 2 was sampled under natural grasslands next to a pine forestation. The two soil profiles were described using international horizon designation and classified according the World Reference Base for Soil Resources (IUSS Working Group WRB, 2007). The samples were collected from the horizons of soils, saprolite, and

Fig. 1. Location of Rio Grande do Sul and of the sampling sites (dot) in southern Brazil.