Catena 83 (2010) 96–106

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Review

Weathering of basaltic pebbles in a red soil from Sardinia: A microsite approach for the identification of secondary mineral phases

S. Vingiani [a,*], F. Terribile [a], A. Meunier [b], S. Petit [b]

[a] Università di Napoli Federico II, DISSPAPA, Facoltà di Agraria, via Università, 100–80055 Portici (NA), Italy
[b] University of Poitiers, HYDRASA UMR 6532 INSU-CNRS, 40 avenue du Recteur Pineau 86022 Poitiers Cedex, France

ARTICLE INFO

Article history:
Received 30 November 2009
Received in revised form 17 May 2010
Accepted 2 July 2010

Keywords:
Basalt weathering
Soil genesis
Microsystems
Micromorphology
Clay minerals

ABSTRACT

Mineral weathering microsites in a basalt rock-derived soil were investigated in the Mediterranean environment of south-western Sardinia. An *in situ* approach, frequently used for saprolites and rock investigations, was employed to examine the weathering microsites of a soil system. This study compared clay phases that formed from the weathering of mineral-bearing rock pebbles and soil crystal chemical composition, with the goal of evaluating the evolutionary trends of the secondary minerals. Micromorphological, mineralogical (XRD and FT-IR analyses) and microscopic (SEM–EDS) analyses were carried out on: i) plagioclase, enstatite and glassy features (weathered volcanic glass) microsystems, in rock pebbles embedded in the soil, ii) clay coatings microsystem, connecting the soil–rock environment and iii) the soil itself. EDS data were plotted on phase diagrams to evaluate developmental and evolutionary trends of the weathered products. The weathering of enstatite and volcanic glass resulted in, primarily, Fe-bearing montmorillonites, while a mixture of Fe-bearing smectite and kaolinite developed from plagioclases. Our results indicated formation of secondary phases in open microsystems, where transfers of elements among primary minerals and glass occur by slow diffusion along the network of inter-mineral micropores. Cracks that developed inside the soil–rock pebbles acted as direct connections between microsystems and the soil environment. Clay and Fe–Mn coatings deposited in the cracks are an indication of clay migration. The mineralogy of these clay coatings was similar to that of the soil matrix and the fine clays. Since it is likely that the clay migration processes remain active in Guspini soils, the further mineralogical similarities of clay coatings and soil fine clays suggest that the transformation of Fe-smectites into K–S MLMs occurs in the clay phases during transport, prior to deposition into the soil environment. Indeed, the similar mineralogy of the *in situ* analysed soil matrix and fine clays (the youngest soil fraction) is interpreted as due to same soil processes, suggesting stable environmental conditions in the Guspini area.

Contents

* Corresponding author. Fax: +39 0812539186.
E-mail address: vingiani@unina.it (S. Vingiani).

0341-8162/$ – see front matter
doi:10.1016/j.catena.2010.07.001

1. Introduction

Over the last century, a consistent literature on rock mineral weathering has been produced, especially since the 1960s. It has been recently reviewed by Meunier et al. (2007). Topics of the works are variable, covering subjects such as mineral reaction mechanisms from atomic to macro scales, relationships between alteration processes and landscape geomorphology, experimental alteration of rocks and minerals (alteration rates calculated), thermodynamic of solutions, chemical mass balance (at profile, watershed and continent scales), using major and minor elements or stable isotopes.

Mineral weathering has been also studied from a soil genesis perspective and inferences on the secondary minerals' composition have been made. Nevertheless, recent reviews on minerals weathering rates evidence a substantial discrepancy between field and laboratory data for several mineral species (White and Brantley, 2003; Anderson et al., 2004). Mathematical models have demonstrated that traditional estimates (White et al., 1996) may diverge from the actual weathering rates by several orders of magnitude (Yoo and Mudd, 2008), revealing a gap in our understanding of the fundamental mechanisms related to soil formation.

Because basalts are relatively abundant (~5% of earth's land area) (Dessert et al., 2003), weathering and soil formation from these rocks play a key role in global weathering and biogeochemical cycling (Torn et al., 1997; Chorover et al., 2004; Dessert et al., 2003; Self et al., 2006). Several studies have investigated mineral weathering and secondary mineralogy of soil derived from basalts (Herbillon et al., 1981; Bhattacharyya et al., 1992; Weitkamp et al., 1996; Vingiani et al., 2004; Thanachit et al., 2006). Rasmussen et al. (2010) described a basalt mineralogical sequence of aluminosilicates, Fe-oxyhydroxides and dioctahedral smectite formation. The transformation rate and trajectory of these intermediate phases towards thermodynamically stable minerals are highly dependent on temperature, precipitation and the activity of soluble Al and Si in the soil (Dahlgren and Ugolini, 1989; Schwertmann and Taylor, 1989; Quantin, 1992). Authigenic formation of smectite and mixed-layer-smectite–kaolin clays has been reported in basalt-derived soils in tropical, subtropical and semiarid climates (Delvaux and Herbillon, 1995; Righi et al., 1999). Due to the general lack of primary phyllosilicates in basaltic rocks, the presence of soil phyllosilicates was attributed primarily to pedogenic processes. Alternative origins have been suggested, such as hydrothermal alteration of primary minerals (Bain et al., 1980; Curtin and Smillie, 1981; Mirabella et al., 2005; Pokrovsky et al., 2005) and/or eolian inputs (Porder et al., 2007). However, the traditional approach, based on the clay mineralogy, faces mineral weathering in soil environment mainly from a bulk perspective and does not provide direct, *in situ*, crystal chemical composition of secondary minerals formed by the weathering of individual mineral assemblages. The actual sources, therefore, of the phyllosilicatic phases remain in question.

Korzhinskii (1959) first used *in situ* measurements to investigate weathering processes in terms of "microsystems". A microsystem, found at each water–parent mineral interface, is composed of primary and secondary minerals and local solutions; with respect to the neighbouring regions, can be closed, semi-open or completely open (Meunier et al., 2007). This approach has since been applied to the analysis of mineral reactions in weathered granitic rocks (Meunier and Velde, 1979) and andesitic/basaltic saprolites (Ildefonse, 1987, Jongmans et al., 1999).

Despite the mineralogical variability at a micro- and nanometre scale is greatly important for the valid interpretation of macroscopical physical and physicochemical soil properties (Onchere et al., 1989; van Oort and Jaunet, 1990; Poss et al., 1991; Jongmans, 1994), there is a dearth of information regarding weathering microsystems in the soil environment and on the contribution of the specific rock mineral assemblages to the soil clay composition.

Therefore, using *in situ* analyses, this research investigated the weathering processes acting on primary minerals of basaltic pebbles embedded in a soil in a Mediterranean environment. The goal was to obtain data on the crystal chemical composition of the secondary minerals and evaluate how they contribute to the soil clay mineralogy. Micromorphological analysis focused on identification of the most significant mineral weathering microsystems and of the soil-features that connect them to the soil environment. *In situ* chemical composition was evaluated by SEM–EDS analyses and crystal chemical arrangement was defined by FT-IR and XRD analyses. Phase diagrams (Velde, 1977) were used to illustrate and describe the evolutionary trends of chemical composition of the secondary clays.

2. Materials and methods

2.1. Study area and main soil properties

The study area was located on the middle-slope of a soil catena studied by Righi et al. (1999) in Sardinia (Italy), near the Guspini (Oristano) village, at Serra Pubusa (Fig. 1). The soil catena is composed of three different pedogenetical environments that developed on an isolated basaltic hill (height of 130 m), originating from Plio-Pleistocene volcanism that produced hawaiite lavas (Lustrino, 2007; Lustrino et al., 2000). The mean hill slope gradient to the alluvial plain is roughly 15%. Mean annual temperature in the area is 16.7 °C. Mean annual rainfall and potential evapotranspiration are 521 mm and 808 mm, respectively (Aru et al., 1991); soil moisture and temperature regimes are xeric and thermic, respectively.

General chemical, physical and mineralogical properties of the selected soil profile (P2) are listed in Table 1 (data from Righi et al. (1999)). The P2 is a shallow (30 cm) clayey loam soil, with a slightly acidic pH (6.6–6.8) and partially unsaturated exchange complex (Base Saturation Percentage – BSP– is 92% in the Bw horizon). The fine clay mineralogy is dominated by 70% K–S MLMs (kaolinite–smectite randomly ordered mixed layers), in which the smectite layers are of beidellite and montmorillonite types, few I–S MLMs and kaolinite.

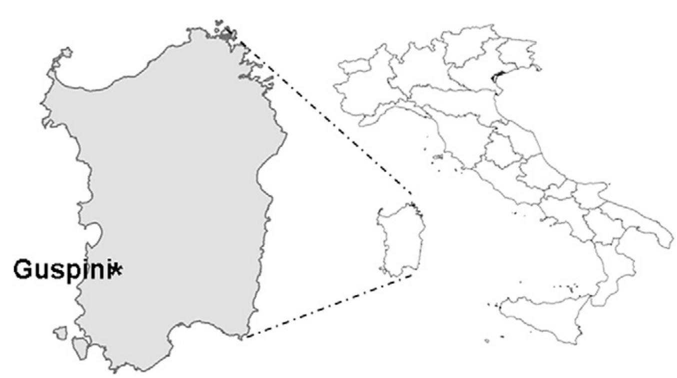

Fig. 1. Study area location. The Guspini village is indicated by the asterisk.