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Weathering profiles in granitoid rocks of the Sila Massif uplands, Calabria, southern Italy: New insights into their formation processes and rates

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ABSTRACT

In this paper we characterized several weathering profiles developed on granitoid rocks in the Sila Massif upland (Calabria, southern Italy), integrating detailed macro- and micromorphological observations with physico-mechanical field tests and petrographic, mineralogical and geochemical analyses. We focused our attention on the main weathering and pedogenetic processes, trying to understand apparent discrepancies between weathering grade classes based on field description and geomechanical properties, and two common weathering indices, such as the micropetrographic index (Ip) and the chemical index of alteration (CIA). Our results showed that sericite on plagioclase and biotite chloritization, that represent inherited features formed during late-stage hydrothermal alteration of granitoid rocks, may cause an overestimation of the real degree of weathering of primary mineral grains under meteoric conditions, especially in lower weathering grade classes. Moreover, the frequent identification of Fe–Mn oxides and clay coatings of illuvial origin (rather than or in addition to those formed in situ), both at the macro- and microscale, may also explain an overestimation of the weathering degree with respect to field-based classifications. Finally, some apparent inconsistencies between field geomechanical responses and chemical weathering were interpreted as related to physical weathering processes (cryoclastism and thermoclastism), that lead to rock breakdown even when chemical weathering is not well developed. Hence, our study showed that particular caution is needed for evaluating weathering grades, because traditional field and geochemical-petrographic tools may be biased by inherited hydrothermal alteration, physical weathering and illuvial processes. On the basis of chronological constraints to soil formation obtained from a 42 ka-old volcanic input (mixed to granite parent materials) detected in the soil cover of the Sila Massif upland, a first attempt to estimate soil formation rates was achieved for different depths of corresponding weathering profile zones. Soil formation rates ranged from 0.01–0.07 mm a^{-1} for A and Bw horizons (weathering class VI) to 0.04–0.36 mm a^{-1} for the underlying saprolite (C and Cr layers; class V). By comparing these results with the corresponding erosion rates available in the literature for the study area, that range from <0.01–0.05 to 0.10–0.21 mm a^{-1}, we suggest that the upland landscape of the Sila Massif is close to steady-state conditions between weathering and erosive processes.

1. Introduction

Weathering studies cover a quite large variety of topics, often accomplished by applying multi- or trans-disciplinary approaches, in turn involving multi-scale and multi-analytical procedures. Available literature spans from morphological and visual investigations (e.g., Bourke and Viles, 2007) to climatic geomorphology and landscape evolution (Dixon and Thorn, 2005; Dixon, 2013; Migoń, 2013b; Pope, 2013b; Migoń and Vieira, 2014), to petrographic, mineralogical, micromorphological and/or geochemical approaches (e.g., Critelli et al., 1991; Blum and Erel, 1997; Kretzschmar et al., 1997; Taboada and García, 1999a, 1999b; Le Pera et al., 2001a, 2001b; Sequeira Braga et al., 2002; Zauyah et al., 2010; Mavris et al., 2012; Campodonico et al., 2014), hydrological or geotechnical characterization of weathering profiles (Chigira and Yokoyama, 2005; Pellegrino and Prestininzi, 2007; Heidari et al., 2013) or modeling of weathering processes (Buss et al., 2008; Apollaro et al., 2009, 2013a, 2013b; Perri et al., 2015), up to estimation of ages of regolith mantles and weathering rates (Migoń and Lidmar-Bergström, 2002; Heimsath, 2006; Dosseto et al., 2008; Dixon et al., 2009; Chabaux et al., 2013; Migoń, 2013b), implications for sediment generation and composition (Johnsson, 1993; Arribas et al., 2000; Critelli et al., 2003; Le Pera and Arribas, 2003; Caracciolo et al., 2012; Pope, 2013a), etc. Among these approaches, several papers aimed at defining a classification of weathering grades based on geochemical parameters and ratios (Nesbitt and Young, 1982; Harnois,

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1988; Birkeland, 1999; Darmody et al., 2005), petrographic indices (Lumb, 1962; Irfan and Dearman, 1978; Palomares and Arribas, 1993) and qualitative, visual observations coupled with physico-mechanical tests (Ruxton and Berry, 1957; GEO, 1988; Gullà and Matano, 1997; Arikan and Aydin, 2012; Perri et al., 2012a; Borrelli et al., 2012b, 2014). Although several papers highlight a general accordance between weathering grade classes and increasing or decreasing trends of weathering ratios and indices (e.g., Nesbitt et al., 1997; Arel and Tugrul, 2001; Haskins, 2006), in some cases a deeper examination of the analytical results suggests that these features are not always strictly coupled (Kirschbaum et al., 2005; Gong et al., 2013; Chiu and Ng, 2014; Perri et al., 2015). In this work we aimed at exploring apparent discrepancies between weathering grade classes (based on field description and geomechanical properties) and some petrographic or chemical weathering indices. We focused on a more detailed description of weathering features at the macro- and microscales, giving an emphasis on weathering and pedogenetic processes, including both in situ chemical weathering and translocation of secondary products. Moreover, a first attempt to estimate soil formation rates is proposed in this work, as weathered, loose and mobile materials represent potential sources of sediments entering the drainage river system. Hence, these results were discussed in the light of their interplay with erosion rates. To these purposes, novel morphological, petrographic, mineralogical and geochemical data on weathering profiles from large areas of the Sila Massif (Calabria, southern Italy) were integrated with some published results. The Sila upland represents a key site to a deeper understanding of weathering processes on plutonic rocks in the central Mediterranean basin, as a consequence of a combination of peculiar geolithological, tectonic, geomorphological and climatic factors, and their interplay with a number of morphodynamic processes (e.g., Le Pera and Sorriso-Valvo, 2000b; Scarciglia et al., 2005b, 2007; Borrelli et al., 2007; Terranova et al., 2007, 2009).

2. Materials and methods

2.1. Geological and geomorphological setting of the study area

The study area is located in the Sila Massif upland (Calabria, southern Italy) (Fig. 1), that represents part of an orogenic segment (Calabrian Arc) located between the Calabrian-Lucanian Apennines and the Maghrebian Chain, formed during the Paleogene, and overthrusted during the Miocene over the Apennine Chain (e.g., Bonardi et al., 2001). The bulk of the relief consists of a Paleozoic crystalline basement, which includes medium- to high-grade metamorphic rocks (amphibolite to granulite facies) intruded by late Hercynian granitoids (Sila batholith), and forming the highest tectonic units of the fold-and-thrust belt of southern Italy (e.g., Messina et al., 2004). The Sila batholith consists of tonalite, monzogranite and minor granodiorite (Messina et al., 1991; Liotta et al., 2008), discontinuously covered by unmetamorphosed Mesozoic to Cenozoic sedimentary rocks (e.g., Van Dijk et al., 2000; Critelli et al., 2011, 2013).

Since the Miocene the Sila Massif margins were covered by terrigenous sedimentary successions (Van Dijk et al., 2000; Barone et al., 2008; Zecchin et al., 2012, 2015; Muto et al., 2014; Perri et al., 2012b, 2014) and experienced brittle deformation. Strike-slip tectonics displaced the Sila Massif rocks and the Neogene-Quaternary basins (Critelli and Le Pera, 1995, 1998; Barone et al., 2008; Critelli et al., 2013; Fabbricatore et al., 2014), developing transpressional and

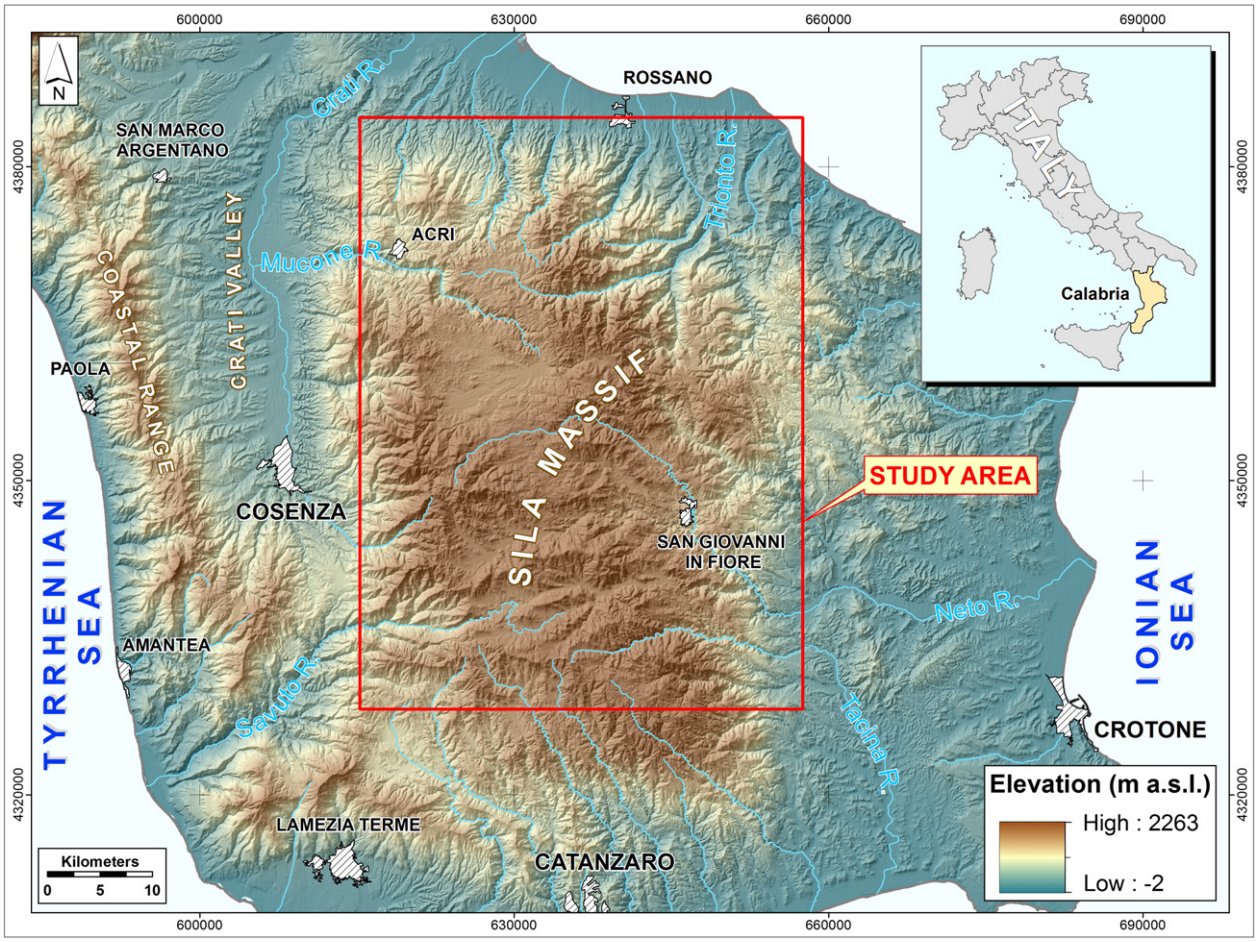

Fig. 1. Location map of the study area.