*Rend. Online Soc. Geol. It.*, Vol. 21 (2012), pp. 557-559, 4 figs.


# Investigation of weathering rates and processes affecting plutonic and metamorphic rocks in Sila Massif (Calabria, southern Italy)

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Key words: *Calabria, metamorphic rocks; mineralogy; plutonic rocks; Sila Massif; weathering.*

## INTRODUCTION

Climate (in terms of rainfall amount and temperature), parent rock composition (in terms of mineral stability), plant and animal activities, morpho-tectonic features and time are the most important factors affecting degree of chemical weathering. Generally, weathering of rocks involves several processes such as deposition of authigenic minerals, dissolution of primary phases, ionic exchange and sorption. Chemical weathering indices evaluate the chemical processes associated with weathering so as to understand their influence on geotechnical behavior. Furthermore, weathering produces mineralogical and petrographical transformation and, thus, a considerable decay of the physical-mechanical properties of the original rock, predisposing the slope instability processes (e.g., CASCINI & GULLÀ, 1993; GULLÀ *et alii*, 2008; BORRELLI *et alii*, 2012).

This study is focused on the western Sila Massif, one of the main mountainous massifs of the Calabria region (southern Italy). This area is characterized by crystalline rocks which have undergone intense weathering processes. For this reason, the Sila Massif is ideally suited to study relationships between landscape evolution and the genesis of clastic sediments and soils.

The results of our study regard the mineralogical, petrographical, physical, mechanical changes of the parent/fresh rocks and their weathered products of plutonic and metamorphic rocks characterizing significant cut slopes of the Sila Massif. The interdisciplinary approach used and the results proposed in this paper provides an important support for the study of mass movement phenomena related to different geological contexts mainly characterized by weathered crystalline rocks, and for the physical/mechanical characterization of weathering profiles.

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Lavoro eseguito nell'ambito della Commessa CNR-TA.P05.012 (Responsabile G. Gullà)

## GEOLOGICAL SETTING AND FIELD FEATURES

The studied area, located on the western side of the Sila Massif (Fig. 1), represents a section of the Hercynian orogenic belt of western Europe, where allochthonous crystalline basement rocks are exposed to form the highest tectonic units (Calabrian Arc) of the southern Italy fold-thrust belt (AMODIO-MORELLI *et alii*, 1976).


*Fig. 1* – Geologic sketch map of the Sila Massif (modified from MESSINA *et alii*, 1994) with location of the study area. Legend: 1) predominantly clastic deposits (Recent to Tortonian). 2 to 6 = Sila Unit: 2) Mesozoic to Tertiary sedimentary cover; 3) plutonic rocks (Sila Batholith; Carboniferous-Permian); 4) low-grade metamorphic rocks (Bocchiglero Complex; Late Cambrian to Early Carboniferous); 5) low - to medium-grade metamorphic rocks (Mandatoriccio Complex; Late Cambrian to Early Carboniferous); 6) medium-to high-grade metamorphic rocks (Monte Gariglione-Polia-Copanello Complex; pre-Triassic); 7) Lower Alpine thrust nappes of the Sila Massif including Castagna, Bagni and Ophhiolitic Units (phyllite + schist and ophiolitic rocks); 8) thrust fault; 9) stratigraphic contact; 10) studied area.

The Sila Massif consists of Paleozoic intrusive and metamorphic rocks, covered in places by unmetamorphosed Mesozoic sedimentary rocks.

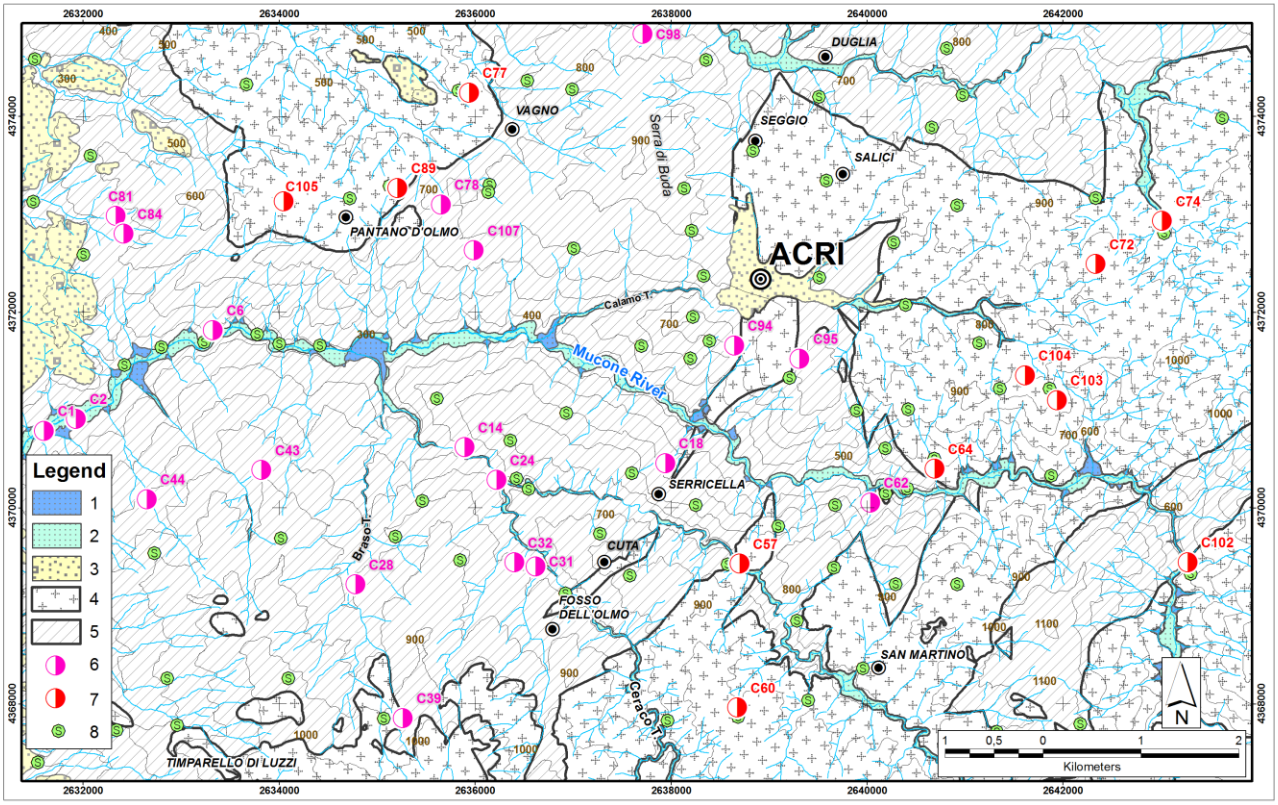


*Fig. 2* – Simplified geological map of the west-central side of the Mucone River Basin (northern Calabria, Italy). Legend: 1) alluvial fan and debris fan (Holocene); 2) alluvial deposits (Holocene); 3) matrix-supported conglomerates (Lower-Middle Pleistocene); 4) granitoid rocks (Paleozoic); 5) gneissic rocks (Paleozoic); 6) sampling from cut slope weathering profiles of gneissic rocks; 7) sampling from cut slope weathering profiles of granitoid rocks; 8) studied weathering profiles.

The sampling area (Fig. 2), ranging in elevation from 200 to 1100 m a.s.l. for about 100 $Km^2$, is located in the west-central side of the Mucone River basin, on the north-western slope of the Sila Massif (northern Calabria). The Mucone river borders are characterized by several landslides and deep-seated gravitational deformations, where high relief energy and steep slopes are commonly associated with severe tectonic fracturing. Rock-slide, soil-slips and debris-flows are the slope movements commonly affected the sampling area.

The Palaeozoic crystalline lithologies, that outcrop in the studied area, is mainly represented by rocks of the Sila Unit (MESSINA *et alii*, 1994), including medium-to-high-grade metamorphic, and plutonic (granitoid) rocks. The plutonic (granitoid) rocks, outcropping in the eastern part of the studied area, are mainly composed of tonalite, passing locally to granodiorite, and minor granodiorite with K-feldspar phenocrysts. The granitoid rocks are also composed of plagioclase, quartz, biotite and muscovite. The high-grade metamorphic rocks are composed by medium- to coarse-grained biotite-garnet and sillimanite gneiss, outcropping along the Mucone River, and medium- to coarse-grained biotite-muscovite migmatitic gneiss, outcropping close to the contact with the granitoid rocks. In the western portions of the studied area, plutonic and metamorphic rocks are unconformably overlying by Pleistocene successions.

The several structure complexities, such as fault gouge zones, thrust planes and joint fractures, mainly related to neotectonic activity of the massif uplift, are predisposing factors for chemical weathering and physical degradation processes which both play an important role in the evolution of landslide phenomena.

## DISCUSSION AND CONCLUSIONS

The geo-structural, geomorphological, compositional and textural features and the climatic characteristics of the studied area, associated with good drainage conditions favour the chemical-physical weathering and outcrops of plutonic and metamorphic masses that often display different degrees of weathering.

The field scale observation on the significant cut slopes allow us to reconstruct the typical weathering profile for both plutonic and metamorphic rocks. The cut slopes have been examined to get information about the thickness and features of weathering profiles. Generally, the weathering profile of plutonic rocks is simple whereas the weathering profile of metamorphic rocks is complex and irregular. Thus, the transition from fresh/slightly weathered rock to completely weathered rock is commonly gradual for the weathering profile of plutonic masses. The metamorphic rocks show weathering profile characterized by irregular and complex vertical and lateral transition. Near the most important discontinuities, metamorphic rocks change their texture and become soil-like in character (completely weathered rocks). The main weathered minerals observed on the studied plutonic and metamorphic rocks are plagioclase feldspar, biotite and potassium feldspar. Fine-grained sericite often occurs within plagioclase, preferentially along twin planes. As weathering advances, clay minerals replace fine-grained sericite, preferentially along mineral rims (Fig. 3).

*Fig. 3* – Photomicrographs of highly weathered sample (class IV) (10X, crossed polarized light).

Biotite, vermiculite, and mixed-layer clay minerals are major constituents of altered biotite grains; illite, illite-smectite mixed layers, kaolinite and halloysite are also present in various amount as showed by XRD analyses. Unaltered biotite is often present in some specimens in association with mixed-layer clay minerals. Generally, the initial stage of weathering produces precipitates of Fe-oxides along biotite cleavage planes. This favours the combination between ferrous iron of the iron-bearing silicates with oxygen to form ferric iron oxides (e.g., hematite). Furthermore, newly formed clay minerals (chlorite and vermiculite), replacing biotite along rims and lamellae, has also been observed in a later stage of biotite weathering. The completely weathered samples are characterized by fractured quartz grains that usually form with the detrital feldspars, the sckeleton of saprolite (Fig. 4).

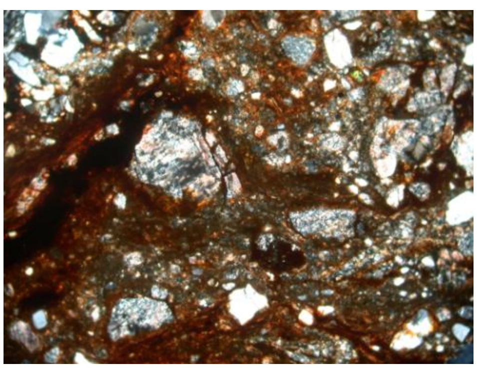

*Fig. 4* – Photomicrographs completely weathered sample characterized by clasts in an oxidized and argillaceous matrix (class V-VI) (10X, crossed polarized light).

The relationship between weathering state and mass movement regards the presence of neoformed clay minerals; among these, the presence of abundant expandable phases (e.g., swelling clay minerals) in the completely weathered rocks and residual soils, may decrease slope stability (e.g., CASCINI *et alii*, 1994 and references therein).

The tectonic uplift mainly related to important regional fault systems, played an important role in the Neogene-Quaternary geodynamic evolution of the central Mediterranean area (e.g., TANSI *et alii*, 2007). The presence of these fault systems may influence the morphology and the features of the weathering profiles. In particular, many fractured zone associated to fault planes and completely degraded rocks associated to thrust planes have been observed along the borehole logs studied, where physical and chemical weathering produce argillified levels. The association among fractured zones and completely degraded rocks with argillified portions represents a predisposing factor to the development of mass movements such as, in particular, DSGSD (Deep Seated Gravitational Slope Deformation) and deep landslides.

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