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Soil genesis and evolution on calanchi (badland-like landform) of central Italy

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ABSTRACT

Calanchi are badland-like erosional landforms, common in the Mediterranean region, which form from accelerated erosion processes. The calanchi slopes, naked or differently vegetated, can be considered as formed by different ecological tesserae originated by the mutual interaction of several factors such as erosion, geomorphology, microclimatic conditions, vegetation, ground cover, and pedogenesis. However, information about pedogenesis is rather scarce mainly because the soils developing on calanchi slopes are incessantly disturbed by erosion processes. To understand the role of soil evolution on landslide erosion, we considered three land facets each one made up of four tesserae (T1 to T4), which represented the different steps of soil and vegetal evolution of calanchi. The soil of each tessera was described, sampled by genetic horizons, and the samples were characterized for their physical, mineralogical and chemical properties. Field observations and laboratory data suggest that pedogenesis in the calanchi badlands may progress until a critical threshold. Indeed, advanced plant colonization and *solum* development improve soil structure, increase soil organic matter, and favor redistribution of nutrients along the profile. The improvement of structure at depth fosters water storage and clay dispersion through soil leaching and reduction of ionic strength of the soil solution, making soil less stable. Depending on the slope gradient, the soil weight acquired during rainfall events may trigger landsliding, mudflows, or collapses that rejuvenate the surface.

1. Introduction

Badlands are worldwide erosional landforms represented by several types of geoforms such as rills, gullies, ravines, canyons, hoodoos, and pinnacles (Plummer et al., 2012). The formation of different badland morphologies is due to the type of sedimentary bedrock, especially texture and cementation degree, as well as climate. Among the types of badlands, “calanchi” are landforms mainly originated from accelerated erosion such as creep, landsliding, mudflows, slope collapse, and piping that form a network of rills and gullies with high internal disorder (Alexander, 1980, 1982; Battaglia et al., 2002). Further, they generally form on Miocene to Pleistocene soft to semi-coherent marine sediments (Battaglia et al., 2002). Calanchi occupy much of the Italian territory and are diffused across southern Europe and northern Africa.

The main factors inducing the formation or controlling the persistence of calanchi, as for the other badland-like morphologies, are 1) fine-grained and poorly consolidated or diagenized bedrock, 2) topography, and 3) climatic conditions such as high intensity rainfall events (e.g., Battaglia et al., 2002; Gallart et al., 2002, 2013; Godfrey et al., 2008; Alonso-Sarria et al., 2011; Martínez-Murillo et al., 2012). The diffusion of calanchi in the Mediterranean basin, in addition to these three factors, can be attributed to an intense soil use (Dramis et al., 1982; Guasparri, 1993; Torri et al., 1999, 2013; Corti et al., 2013). In this area, vulnerability to erosion was triggered by anthropogenic removal of evergreen oak woodland during the Holocene, so exposing erodible soils to climate rigors, favoring rain-splash and runoff, and activating processes of mass wasting such as creep, sliding, and flowage (e.g., Bryan and Yair, 1982; Imeson and Verstraten, 1988; King, 1990; Howard, 2009; Torri et al., 2013). Another key factor controlling the formation of badlands as well as calanchi is represented by pedogenesis. The presence of a relatively stable soil instead of a thin accumulation of unconsolidated material or “regolith” (e.g., Fairbridge, 1968; Gallart et al., 2002), derived from the weathering of the underlying mudrock, may prevent or limit badland formation (Gallart et al., 2002). Also mineralogical composition plays an important role in badland development as diverse clay minerals may differently affect soil dispersivity (Summa et al., 2007; de Santis et al., 2010) or mass movements (Kasanin-Grubin, 2012). However, as far as we know, there is no evidence about the importance of mineralogy on the formation of calanchi or other badland-like geoforms. As evidence of this, studying badlands from Dinosaur Park and Chinguacousy (Canada) and calanchi from an area across Tuscany and Marche (Italy), Kasanin-Grubin (2012) found that the Dinosaur Park badlands had a mineral composition

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very similar to the Italian calanchi, while it differed from that of Chinguacousy badlands because of the diverse composition of the parent material. Further, the Italian calanchi have often been remodeled or obliterated for agriculture purposes by the use of explosives (Pavari, 1911) or bulldozers (Calzecchi-Onesti, 1954; Rendell, 1986; Guasparri, 1993). Because of this, calanchi landscapes result from pedo-climatic and anthropic forces (Torri et al., 2013).

As for the other types of badlands, calanchi are subject to a geomorphic evolution that produces a mosaic of soil surfaces (Guàrdia et al., 2000; Lázaro et al., 2000; Regüés et al., 2000; Cantón et al., 2003). On calanchi slopes, the soil surface may be naked or differently vegetated, so that the landscape can be considered as formed by different ecological tesserae (sensu Forman and Godron, 1986). Indeed, each tessera originated by the mutual interaction of several factors such as erosion, geomorphology, microclimatic conditions, vegetation, ground cover, and pedogenesis. Among these factors, information about pedogenesis on calanchi is rather scarce. Consequently, little is known about the role of soil evolution on calanchi dynamics. This paucity in knowledge can be partly ascribed to the fact that in these landscapes the erosion processes responsible for soil removal are often rapid, while soil reformation on the scalped surfaces is very slow. Further, selection of the site where to accomplish pedologic study can be difficult as calanchi landscapes are often formed by many different tesserae, some of which, at sites, may lack or disappear as a result of erosion or pedogenesis. In some cases, tesserae appear to be linked among themselves so to form a system of soil and vegetal evolution that describes a so called *land facet*, namely a “combination of ecotypes forming a pattern of spatial relationships, being strongly related to properties of at least one attribute” (Bridgewater, 1993). We hypothesized that integrating pre-existing studies with new field observations and lab data may highlight the relationships among tesserae and improve the understanding of the role of pedogenesis on the processes of accelerated erosion that affect these landscapes. To test this hypothesis, this study was concentrated on soil genesis of calanchi *land facets* and assessing the role of soil evolution on landslide erosion.

2. Materials and methods

2.1. Background information

Most of central and southern Italy is made up of territories covered by calanchi (Fig. 1), which originated from Plio-Pleistocene marine sediments composed of alternating beds of clay, marl-clay, silt clay and silt (Alexander, 1982; Moretti and Rodolfi, 2000). In some cases the summit of the calanchi is occupied by forests, but more often it has been remodeled (leveled) and plowed to cultivate vines, olive trees, and cereals (Fig. 2). Deep plowing has been responsible for greatly increasing erosional processes that have left the calanchi slopes almost barren (Phillips, 1998). The steep slopes around the leveled summit show features of accelerated erosion with dissected bare terrain intersected by a network of gullies (Battaglia et al., 2002). Whether or not the summit is leveled and cultivated, it may host different soils in function of dip slope and exposition. The dip slope surfaces with an NNW to NNE aspect have rather developed soils (mostly Inceptisols) with a thick grass vegetation cover or cultivations, while the anti-dip slopes with an SSW to SSE aspect have poor soils (mostly Entisols) and are almost barren (e.g., Fascetti et al., 1990; Del Prete et al., 1997). If not artificially remodeled, the more or less vegetated slopes tend to form sharp pinnacles that are at the mercy of strong erosion (Fig. 3). Materials eroded from the slopes accumulate into, and at the side of, braided streams

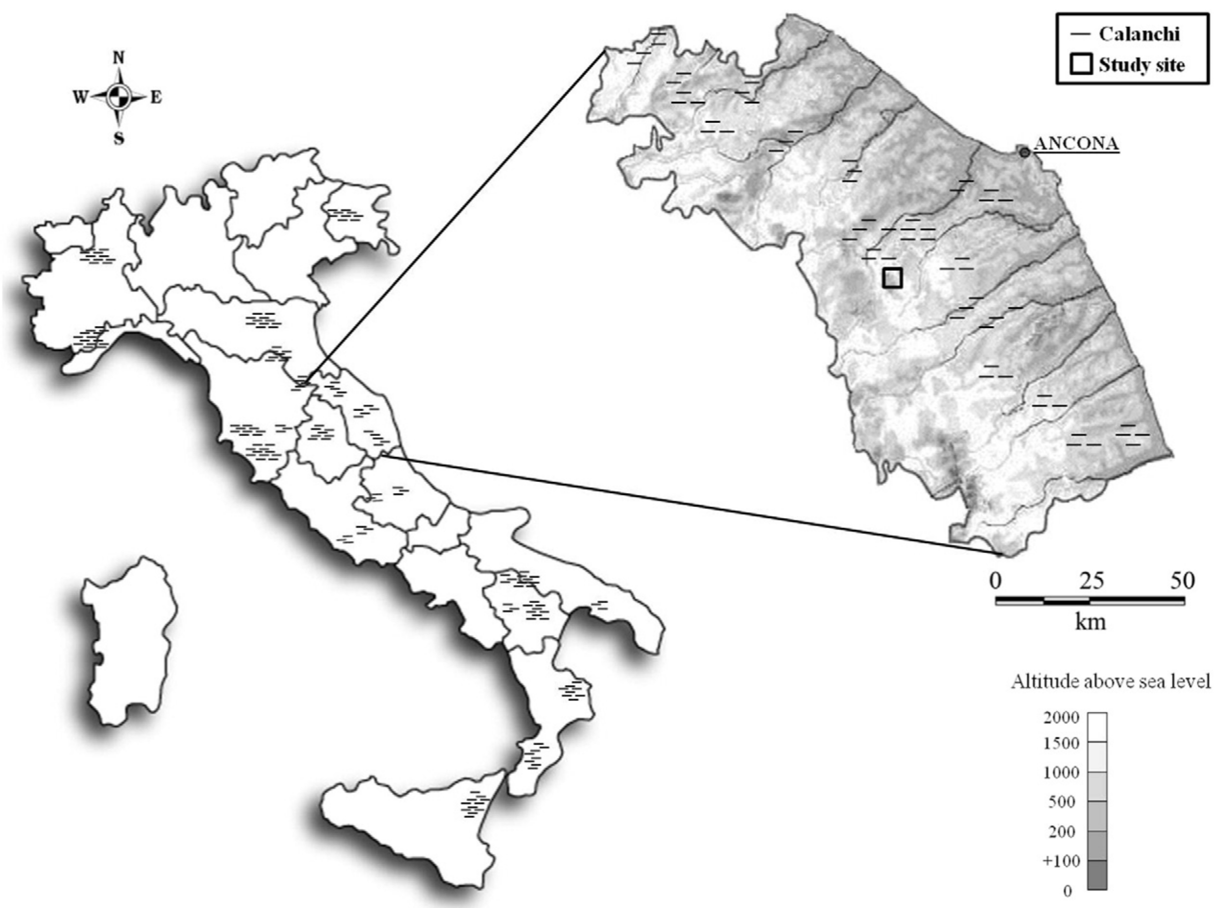

Fig. 1. Map of Italy with distribution of calanchi, magnification of the Marche region and indication of the study site.