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# Soil development in a Quaternary fluvio-lacustrine paleosol sequence in Southern Italy

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A B S T R A C T

The aim of this paper is to enrich our knowledge of an important paleosol succession located in Bojano basin of the southern Apennines (Italy), with new pedological, geochemical and magnetic data. The studied area consists of alluvial and fluvial-lacustrine sequences (>160 m) dating from the Middle Pleistocene (0.5 Ma). The study area shows the presence of recent soil consisting of well-developed Andosols (RS), and several clastic sedimentary levels alternating with four layers (Solum I, II, III and IV) of paleosols. Soil and paleosols were analyzed by laser grain size distribution (GSD), diffuse reflectance spectroscopy (DRS), trace elements, and magnetic properties in order to evaluate the relative contributions of pedogenic and detrital components. Results showed that the finest pedogenic ferrimagnetic grains exhibit two trends with respect to the degree of pedogenesis indicate two different pedoclimate formations. The paleosol sequence consists of highly-weathered Vertisols (Solum I and IV) and of less weathered Entisols (Solum II, III). The recent soil (Andosol) has a strong bimodal distribution formed mostly by coarse silt-size particles related to the volcanic parent material. Solum I showed a sharp unimodal clay GSD while Solum III and IV were composed of bimodal GSD with high percentages of fine silt-size particles. On the basis of the trace element content and Gt/$\chi_{fd}$ ratio, all Solum (I, II, III, IV) exhibited low weathering pedogenesis compared with RS and negligible contribution to the magnetic properties of the coarse fractions. This occurs in Vertisols which developed under humid temperate climates (Solum I and SIV) and formed below the layer of Neapolitan Yellow Tuff, developed after 12–15 ka BP. In Solum, II, III the finest sedimentary levels, the low rate of pedogenesis could have developed under more cold climatic conditions after the last eruption (Campanian Ignimbrite, 39 ka) in the Late Pleistocene.

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## 1. Introduction

The spatial distribution of volcanic soils in southern Apennines and in other mountain ecosystems is especially important in Italy (Iamarino and Terribile, 2008; Vacca et al., 2009). Volcanic activity in Central-Southern Italy during the late Pleistocene and the Holocene produced large amounts of pyroclastic deposits that covered wide areas of the Central and Southern Apennines (Italy) (Scandone et al., 1991; Scarpati et al., 1993; Vacca et al., 2003; Magliulo et al., 2006; Colombo et al., 2007), including the Matese Massif where an intermontane basin was located (Colombo et al., 2014). The Phlegraean Fields have produced two important eruptions since ~39 ka. These eruptions produced the Campanian Ignimbrite and the Neapolitan Yellow Tuff (Rolandi et al., 2003). The eruption which produced the Campanian Ignimbrite occurred as a large-volume pyroclastic flow associated with a pyroclastic fall deposit and resulted in the formation of a large amount of volcanic material throughout the central-southern Apennines (Lulli, 2007). The last eruption occurred 12–15 ka and produced and the locally-named Tufo Giallo Napoletano (Neapolitan Yellow Tuff, Di Vito et al., 1999). Despite the importance of these pyroclastic deposits (Santacroce et al., 2008), not much is known about their importance in terms of soil development and soil properties in the central-southern Apennines (Lulli and Bidini, 1980; Quantin et al.,

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1988; Quantin and Lorenzoni, 1992). Moreover, little is known in terms of the association between specific volcanic soils and the source of their volcanic ash parent material (Mileti et al., 2013).

This lack of knowledge is related to the specific difficulties dealing with these soils. Among these are rapid weathering and erosion, typical of andic soils, which hinder their preservation and their study over the landscape (Wada, 1985; Kimble et al., 2000). This is unfortunate because a detailed understanding of the relationships between volcanic parent material, soil processes, and the distribution of volcanic soil and buried soil would also be very important in terms of paleoenvironmental landscape reconstruction (Malucelli et al., 1999). The reasons for the repeated alternation of stages dominated by alluviation or pedogenesis are of particular interest. The presence of buried soil sequences poses a problem of the relationship between syngenetic and epigenetic soil formation related with the weathering of the pyroclastic parent material. In this sense, due to its conservative geomorphic setting, the Bojano intermountain basin offers a great opportunity to study these relationships.

Therefore the aim of this paper is to enrich our knowledge of the outcropping fluvial succession Bojano intermontane basin, located in the southern Apennines (Italy), with new pedological, geochemical and magnetic data. This is in order to improve our understanding of the Quaternary paleosol evolution of the colluvial layers present in this part of the sequence. Russo and Terribile (1995) studied the paleosol succession (3 m thick) in the steep cliffs of the Bojano basin and attributed it to the Upper Pleistocene-Holocene. This research aim to complete this observation with more information on the relationship between debris-flow source and the age of the involved pyroclastic deposits, as is the possible correlation for paleoclimatic reconstructions and soil development occurred in the southern Apennines (Italy).

## 2. Geological settings and previous studies

The Bojano intermontane basin (about 500 m a.s.l.) is located in the Molise sector of the Apennines (Southern Italy). It is a large Quaternary morphotectonic depression, approximately 22 km NW–SE long and 4 km wide which is formed of tectonized Meso-Cenozoic limestones and terrigenous sediments about 2–3 km thick (Fig. 1).

The Biferno River drains (towards Adriatic Sea) the intermontane basin, and, for a few of meters, partially cut its Pleistocene fluvial-lacustrine filling (Rosskopf and Scorpio, 2013). The basin was probably generated in the Lower and Middle Pleistocene due to strike-slip and extensional tectonics (still active), following the Mio-Pliocene compressive deformations of the south-Apennine orogen (Corrado et al., 1997, 2000; Blumetti et al., 2000; Galli et al., 2002; Di Bucci et al., 2005; Amato et al., 2010, 2012). The Bojano basin is between the northern edge of the Matese Mountains and the southern edge of the Sannio Mountains (Southern Italy) (Fig. 2). It is a large morphostructural depression produced by tectonic movements which occurred during the Pleistocene. Its original morphology of gentle sloping topographical surfaces is almost intact. The infilling sediments, about 20 m thick, can be observed in the southeastern portion of the basin (at Campochiaro limestone quarries) and consists of coarse alluvial fan and silt lake sediments (Aucelli et al., 2011b, 2013). Basically thin pedogenic, pyroclastic and epiclastic levels are interbedded with the alluvial sediments. The sediments are interbedded with levels of paleosols with different types of pedogenic features (Russo and Terribile, 1995; Guerrieri et al., 1999). They apparently show no signs of tectonic deformation, although synsedimentary and active tectonic movements have been documented (Galli et al., 2002; Amato et al., 2010, 2012), which are connected to the bordering slopes.

Russo and Terribile (1995) studied the exposed part of the paleosol succession in the Bojano basin and attributed it to the

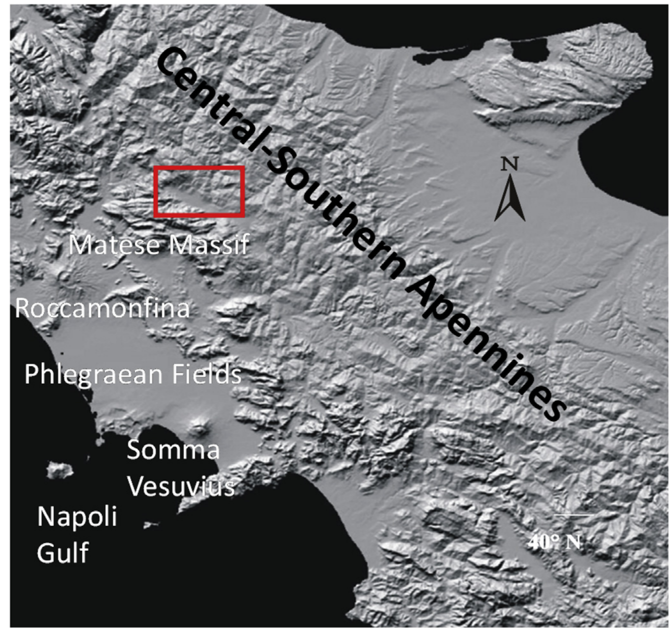


**Fig. 1.** Map of the study area in Southern Italy. General overview of the study area showing the Matese Massif in relation to volcanic centres (Roccamonfina, Phlegrean Fields and Somma Vesuvius) to the southwest. Rectangle indicates the location of the Bojiano Basin.

Upper Pleistocene-Holocene. These authors attributed the remaining part (160 m thick), to the Middle Pleistocene. This is coherent with observations (lake sediments at Basin of San Massimo) of Brancaccio et al. (1979a) attributing the lacustrine sediments of the San Massimo to the Lower Pleistocene (about 0.97/1.13 Ma). Di Bucci et al. (2005) have recently dated the same sediments through the $^{40}Ar/^{39}Ar$ method to Middle Pleistocene (0.6 Ma) origin. In this framework, Amato et al. (2010, 2011, 2012) and Aucelli et al. (2011a; 2011b) provide further and more detailed chrono-stratigraphic knowledge, unfortunately without reaching the pre-lacustrine bedrock. The drill core in the Bojano territory reaching the depth of 160 m allowed the authors to reconstruct a detailed chrono-stratigraphic and paleoenvironmental succession of the basin (Fig. 3). Overall, this succession consists of three litho-stratigraphic units; the first two (UQS1 and UQS2), the oldest, are buried below the present basin surface and the, more recent, third (UQS3) is partly cropping out. These three units are separated by a clear erosional surface (Es). The oldest unit (UQS1), which is approximately 80 m thick, consists of layers of clay, silty/clay and carbonaceous clay with reworked volcanoclastic levels. The examination of lithofacies reveals a clear sedimentation of limno-marsh environments with infrequent flood episodes. Two pyroclastic layers in this unit, from the Roccamonfina Volcano, have been dated, using the $^{40}Ar/^{39}Ar$ method, to 426 ± 5.5 ka and 437.9 ± 5.5 ka. Bio-stratigraphic and pollen data of this unit suggest that has been deposited between 500 and 400 ka during the development of an Interglacial-Glacial-Interglacial cycle lasting about 100 ky. The intermediate unit (UQS2), about 40 m thick, consists of sands and silty limno-marshy layers stratified with frequent peats. The upper part is almost entirely made up of alluvial fan sand and gravel layers. In the UQS2 unit, from the Roccamonfina Volcano, has been dated to 331 ± ka, using the $^{40}Ar/^{39}Ar$ method. The exposed (partially), youngest unit (UQS3) is approximately 30 m thick and consists of alternating layers of limno-marshy sandy, silty and carbonate-rich clay as it passes upwards to more frequent levels of alluvial fan sands and gravels with reworked volcanoclastic and pedogenic levels. The UQS3 contains a paleosols

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