Soils and soilscapes of the Upper Volturno basin: a detailed survey of a large intermontane basin in the Central-Southern Apennines, Italy

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ABSTRACT

Soils of the Upper Volturno basin in the Central-Southern Apennines (Molise, Italy) were surveyed in detail. Trends in development are described with focus on the contrast between the mountain soils and the soils of the basin. Mountain soils are shallow and poorly developed. Topsoils in the central and eastern areas and on N-facing slopes have a large Late Pleistocene tephra component (Campi Flegrei) and are Andic. Basin soils from a distinct chronosequence: early Mid-Pleistocene deep highly weathered Chromic Luvisols/Nitosols in old surfaces of the fluvio-lacustrine fill, less developed soils in Late Pleistocene terraces and fans, and recent Fluvisols in the Holocene sediments of the Volturno River and tributaries. In the basin, Mid-Pleistocene Roccamonfina tephra play an important role. In the SW, it occurs as thick layers, blanketing the fluvio-lacustrine/fan deposits. The soil pattern clearly reflects the complex geological history of the basin, with prominent subsidence in the SW.

Introduction

In the 1970s, physical geographers from the University of Amsterdam (the Netherlands) executed a large series of soil surveys in Central Italy. For the Upper Volturno basin several soil maps were produced (see Figure 1). Some results were published in connection with the discovery by the Dutch team of the famous Isernia La Pineta site, described in Coltorti (1983). These include the first K-Ar datings for its tephra (Sevink et al., 1981) and a concise description of the Quaternary evolution of the Upper Volturno basin, with soil data and a generalized soil map (Van Otterloo & Sevink, 1983).

A recent impulse for integration of the several unpublished soil maps into a single map and explanatory report was generated by the archaeological studies executed in the Molise region by the Leiden University (The Netherlands). This is exemplified by recent papers in which soil maps of the Isernia area play an important role (Casarotto, 2018; Casarotto et al., 2018; Stek et al., 2015). For these publications we reviewed the existing earlier maps and integrated the soil maps mentioned above into one single soil map (at scale 1:25,000) that covers a major part of the Upper Volturno basin (‘Main Map’). Additionally, we assembled the existing soil data and relevant literature and translated these into a concise description of the genesis and characteristics of the soils and landscape in the area concerned, with emphasis on the important role played by the Campanian volcanism. A full set of basic background data and extensive reviews of the current state of knowledge in relevant topics is available as a supplement to the main text. The topics include the geology, the history of the Campanian volcanoes and their tephrochronology, and soil formation and weathering in the Central Mediterranean. It also contains a full set of all references cited.

This study is one of a small number of detailed studies of soils and soilscapes in the Apennine range and its intermontane basins in Central/Southern Italy. It illustrates the complex soil patterns that are encountered in Mediterranean mountain ranges where the basins were beyond the reach of periglacial denudation and mass wasting during the colder phases of the Quaternary. They hold soil chronosequences that reach far back into that period and reflect the important role of parent material in the so-called long cycles of soil development (Duchaufour, 2012). Our study also contributes to knowledge of Quaternary landscape genesis of the Upper Volturno Basin, which holds major archaeological sites amongst which the well-known and famous Lower Palaeolithic Isernia La Pineta site (Coltorti, 1983), and the Lower/Middle Palaeolithic key site at Guado San Nicola (Pereira et al., 2016; Peretto et al., 2016).

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Materials

The Upper Volturno basin is mountainous and includes major peaks and ranges reaching to between 1800 and 2000m asl. In addition to a large central basin, which is drained by the Volturno river and its tributaries and runs from Isernia in the NE to Venafro in the SW. There are several smaller intermontane basins between 300 and 700 m asl (see Figure 1). Within this area, because of its strong relief, temperature and precipitation vary considerably. The basins and adjacent lower terrains have a distinctly Mediterranean Cfa climate (Köppen, 1936) with a mean annual temperature between 16°C and 14°C and a mean annual precipitation between 800 and 900 mm, whereas higher parts have a Cfb climate, with mean annual temperatures of 12°C and lower, and mean annual precipitation increases to over 1000 mm (Aucelli et al., 2007).

Figure 2 provides a general picture of the geological structure of the area, which forms part of the Apennines. Meso–Cenozoic carbonate platform and slope-basin units, which include the Matese and Montagnola di Frosolone units, dominate the SW sector of the Molise region. Less common are upper Miocene siliciclastic foredeep deposits (Molise Flysch; e.g. Speranza et al., 1998) overlying the older carbonate units. In Figure 2, Plio-Quaternary deposits are indicated as a single unit, composed of continental, marine and volcanic deposits and dated as Middle Pleistocene pp – Holocene. In the area concerned (Isernia province) these are predominantly continental deposits. The earliest Pleistocene deposits and associated land surfaces date back to the early Middle Pleistocene, while the youngest are of Holocene age. A series of intermediate phases can be distinguished, resulting in a complex soil pattern and gradational history.
Moreover, the area was repeatedly affected by Campanian vulcanism, largely in the form of deposition of tephra from its major three volcanoes, the Roccamonfina, Campi Flegrei and Vesuvius.

Methods

The soil survey was based on a physiographic approach. Following a reconnaissance of the area to identify representative sample areas, the latter were systematically surveyed for their soils. This was followed by the interpretation of stereo air photographs at scale 1:30,000 for the preliminary identification and delineation of land units (see, e.g. Gessler et al., 1995 and Zonneveld, 1989). Subsequently, units and their boundaries were systematically checked in the field. Soil profiles were described using the FAO Guidelines for soil profile description (Jahn et al., 2006). Soils were first classified according to the FAO/Unesco soil classification system and more recently were reclassified according to the IIUS WRB (2007). Correlations between these systems are given in appendix 1.3.1.

Results and discussion

The soil map (Main Map) depicts the soil units distinguished at scale 1:25,000, based on a physiographic approach (Burrough et al., 1997; Gerrard, 1981). In its legend, at the highest level ‘major landscapes’ are distinguished, which are further subdivided into landscape units and, at its lowest level, soilscape (Hole, 1978; Lagacherie et al., 2001) based on such criteria as slope steepness, soil development, parent material.
etc. The full legend and descriptions of the soil mapping units are given in appendix 2 and 3, respectively. For descriptions of representative soil profiles and their location see appendix 4. Representative major soils were sampled for physical and chemical analyses. For results and analytical methods used, reference is made to appendix 5.

Two major types of landscapes were distinguished with marked differences in soil development and soil properties. These are the mountains with steep slopes and weakly developed soils with mostly Ah/C profiles (Landscapes C, D, and M), and the basins and associated lower mountain footslopes with far stronger developed soils (Landscapes B, F, G, L, P, and T). In the latter types of landscape, there are soil chronosequences that exhibit major differences in soil development, linked to the age of the soils concerned. These range from the early Middle Pleistocene to the Late Holocene. Its earliest members are the deep and highly weathered complex soils of well-preserved surfaces of the early Middle Pleistocene basin fill and associated footslopes (units L1). Less developed members are encountered in the more recent Middle Pleistocene to Holocene sedimentary units (units L2, L3, F3, F2, F1, successively).

First, attention will be paid to the trends in soil formation in the mountains, which are largely linked to the nature of the parent material, but also very much depend on the presence or absence of Late Pleistocene tephra, followed by a description of the soils of the basin. Throughout the area and irrespective of their age, topsoils contain smaller or larger amounts of Late Pleistocene tephra, which may be present in the form of a distinct tephra layer or as admixture and weakly developed soils with mostly Ah/C profiles (Landscapes B, F, G, L, P, and T). In the latter types of landscape, there are soil chronosequences that exhibit major differences in soil development, linked to the age of the soils concerned. These range from the early Middle Pleistocene to the Late Holocene. Its earliest members are the deep and highly weathered complex soils of well-preserved surfaces of the early Middle Pleistocene basin fill and associated footslopes (units L1). Less developed members are encountered in the more recent Middle Pleistocene to Holocene sedimentary units (units L2, L3, F3, F2, F1, successively).

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**Soils of the mountains (Landscapes C, D, and M)**

The soils of the mountains are marked by their limited development, with AC or A/Bw/C profiles in which the Bw horizon may show some clay illuviation features on relatively stable slopes, but rarely enough to classify these horizons as argic B horizons. Weathering and calcification – in case of calcareous parent material – is limited. Remains of more deeply weathered residual soils may be encountered in the form of clayey reddish (5YR) fills of fissures and pockets in limestone rocks, often with a significant component of highly weathered tephra. In the literature such soils are described as terra rossa (see, e.g. Merino & Banerjee, 2008; Spaargaren, 1979), even though the aeolian component (tephra, Sahelian dust, etc.) may be considerable. Outside the limestone areas, such remains of earlier formed soils are scarce and were hardly encountered.

Topsoil characteristics very much depend on the presence of a relatively recent tephra component or even true tephra layer. These can be linked to the eruptions of the Phlegraean Grey Campanian Ignimbrite and Yellow Neapolitan Tuff by their mineralogical composition (abundant sand-size sanidine crystals and, in case of the YNT, pumice fragments). Topsoils having a large tephra component are dark coloured and have a low bulk density and relatively high organic matter content, meeting the criteria for Andic properties. Truly dark topsoils with very low bulk densities are encountered particularly on forested N-facing slopes at altitudes above 500 m asl (e.g. units C121 and C122), while on south facing slopes and at lower altitudes this andic nature is less well developed (e.g. units C112 and C113). Bulk densities and colours of these various soils are reported in Table 1, while Figure 3 gives examples of Mollic Andosols from N-facing slopes at (~900 m asl).

The current distribution patterns of these tephras are complex. At regional scale, a relatively thick cover was found to the east of the line Vallelunga-Macchia d’Isernia, whereas to the west this layer is less prominent, suggesting that the successive large eruption plumes deposited most of their load to the east of this line. However, at more detailed scale, other factors play a role, such as the aspect, with N-facing slopes having overall a much more continuous and thicker cover than south facing slopes. Moreover, slopes underlain by marls and other low permeability rocks exhibit thinner tephra layers than slopes in limestone, which can be attributed to differences in runoff-caused erosion of the tephra. For further information on the tephra, reference is made to appendix 4.

### Table 1. Bulk densities of A horizons on the ash covered N-facing mountain slopes (forested).

| Location                  | Altitude (m asl) | Color (Munsell) | Facies           | Bulk density (g/cm²) | Classification (FAO, 1974) |
|---------------------------|------------------|-----------------|------------------|----------------------|-----------------------------|
| Forested N. slope of the Felgara la Selva (S.of Castelpizzuto) | 820               | 10YR3/4 (d) 10YR2/3 (m) | A-C prof.       | 0.73                 | Mollic Andosol             |
| Forested N. slope of the Felgara la Selva (S.of Castelpizzuto) | 1000              | 7.5YR3/3 (d) 7.5YR2/3 (m) | A-C prof.       | 0.70                 | Mollic Andosol             |
| Forested N. slope of the Felgara la Selva (S.of Castelpizzuto) | 1200              | 10YR3/4 (d) 10YR2/2 (m) | A-C prof.       | 0.83                 | Mollic Andosol             |
| Forested N. slope of the Monaco (S.of Longano)                | 845               | 7.5YR3/3 (d) 7.5YR3/2 (m) | Phase slope     | 1.26                 | Calcaric Phaeozem           |
| Forested N. slope of the Monaco (S.of Longano)                | 900               | 5YR2/3 (d) 5YR2/1 (m) | A-C prof.       | 0.79                 | Mollic Andosol             |

(d) = dry; (m) = moist.
Soils and their chronosequences in the basins (Landscapes F, L, P, B, G, and T)

The overall trends and pattern were clearly depicted in the earlier published small scale (1:113,500) physiographic soil map of the Upper Volturno basin (Figure 4) by Van Otterloo and Sevink (1983). Units to which reference is made in the following text refer to the 1:25,000 soil map and its legend.

The oldest members of the sequences are encountered in association with the non-eroded surface of the Pleistocene basin fill (units L1) and can be described as deeply weathered and decalcified residual soils with a very thick reddish-brown (5YR) argic B horizon, where the basin sediments are derived from geological units containing chert-rich gravel beds (e.g. units L11, L121, L124), or with a more yellowish coloured vertic argic B horizon in sediments, derived mainly from calcareous marls that are low in or free of chert containing beds (e.g. units L122, L123). Soils in chert-rich sediment generally have a completely decalcified residual chert-rich layer in their lower solum, with an overlying reddish to reddish-brown argic B that has more or less prominent nitic properties. A typical example is depicted in Figure 5 (see appendix 4, profiles K001 and O363). The Luvisols with more yellowish-brown vertic argic B horizons often have secondary calcium carbonate nodules in their lower solum, lack the residual chert-rich layer, and it is only incidentally that their upper solum has a more reddish-brown colour and nitic properties. Profile K110 (see Figure 6) provides an example of such soil, whereas profile K377 (Figure 7) represents a truncated soil where the vertic and calcic B horizon is now exposed (L122).

Chemical and mineralogical analyses of the topsoils suggest that the nitic argic B has a large tephra component, which can be identified as Middle Pleistocene Roccamonfina tephra (Van Otterloo & Sevink, 1983). This material is highly weathered and betrays its volcanic origin by the presence of traces of rather weathering-resistant heavy minerals (e.g. magnetite) and its specific chemical composition (e.g. higher K-content than in the subsoil). Descriptions and analytical data for these soils can be found in appendices 4 and 5. The nitic layer is susceptible to erosion and where eroded, the residual cherty subsoil is exposed, in which case the soil is classified as a Chromic Luvisol, or the vertic argic B horizon is exposed. In the latter case, soils may be close to Vertisols because of the prominent vertic nature of the argic B, but more commonly soils are classified as Vertic Calcic Luvisols (see Figure 6).

Whether still intact or more or less eroded, the most striking feature of this earliest member is the pronounced soil development reflected in a deep solum, absence of any weatherable rock fragment (e.g. limestone or marl) and residual accumulation of silicate rocks (in particular chert). The yellowish
brown vertic argic horizons are marked by stagnogley features with hard iron-magnesian concretions and hard secondary carbonate nodules. In deep exposures it is often evident that these ‘early soils’ are complex paleosols, reflecting an alternation of periods of soil formation, all marked by strong weathering and clay translocation, and with intermittent sedimentation of generally minor magnitude. Typical examples of such complex soils have also been described for the Isernia La Pineta site (e.g. Coltorti et al., 2005; Peretto et al., 2015). As to the age of these soils, given the age of the earliest tephra from the Roccamonfina, confirmed by the dates of the early tephra layers at Isernia La Pineta, these soils date from the early Middle Pleistocene (Coltorti et al., 2005). With decreasing age of the land surfaces, i.e. erosion terraces in the primary basin fill (L2 and L3), younger fluvial accumulation terraces (F3) and alluvial fans (P2), a decline in redness, thickness and clay content of the argic B horizon, and extent of weathering is observed. However, colours also depend on the origin of the material in which the soil is formed, with generally redder colours when more colluvial in origin and derived from older limestone and tephra soils.

Soil chronosequences are best developed in the various fluvi-lacustrine and fluvial deposits, whether terraces or alluvial fans, if not covered by reworked or in situ younger tephra. This is exemplified by the soils in the Monteroduni area, where the fluvial terraces and associated alluvial fans often have a thick cover of reworked or in situ Middle Pleistocene tephra layers. The soils can be characterized as deep Chromic Luvisols, exhibiting the characteristics of paleosol complexes, such as those frequently encountered in the outer proximal slopes of the Roccamonfina and fans (see units P2). Soilscapes in such tephra dominated...
surficial layers of the Pleistocene terraces and fans exhibit well-developed deep Chromic Luvisols/Nitisols irrespective of their age.

Figure 5. (a) Chromic Gleyic Luvisol (O363) and (b) detail.

Figure 6. Deep Calcic Gleyic Luvisol (K110).

Figure 7. Calcic Vertic Luvisol in eroded top of fluvio-lacustrine plain near Macchia d’Isernia (K377).
Thick covers of Middle Pleistocene tephra are most common in the Monteroduni area, whereas in the northern and western parts of the Isernia basin thick covers are far less common. Exceptions are the small karstic basins to the west (e.g. Croce Piana, Filignano) with also deep reddish brown Luvisols, which are largely developed in reworked older tephra.

In the basin, pre-Holocene soils commonly have a dark topsoil with a significant component of Late Pleistocene tephra, like the mountain soils, unless they are eroded or the sediments are of Holocene age. This is the case in the Venafro plain, where the younger Volturno deposits lack an Andic topsoil, although Late Pleistocene tephra are intercalated. In particular, tephra layers are present in the travertine terraces forming the NE border of the Venafro plain. The deposition of Late Pleistocene tephra is most prominent to the east of the line Vallelunga/Macchia d’Isernia. A typical example of such an Andic topsoil, which is superficially eroded resulting in residual accumulation of sand-size sanidine, is given in Figure 8.

**General discussion and conclusions**

In the handbook on the soils of Italy (Costantini & Dazzi, 2013) general trends in soil formation and soil pattern are extensively described. More detailed regional studies on soil chronosequences, i.e. soil development over time, include Cremaschi and Sevink (1987), Arduino et al. (1989), Busacca and Cremaschi (1998), Scarciglia et al. (2006, 2015), and Sauer et al. (2010). For details see appendix 8. The soils and their pattern in the upper Volturno basin clearly conform to the trends described at national and regional levels, and only a few characteristics stand out as specific for this area.

Remarkable is the prominent impact of sub-recent (Late Pleistocene) distal tephra on the topsoil characteristics throughout the area. Smaller or larger amounts of tephra occur in virtually every topsoil that either has not been truncated during the Holocene or developed in materials and/or on land surfaces of Holocene age, and often the A horizon has distinct Andic properties (see, e.g. Adamo et al., 2001; Arnalds et al., 2007). This implies that the areal distribution of Andic soils and Andosols is far greater than suggested by geological maps, which generally register only more proximal tephra deposits. It is highly probable also that further north and east in the Molise region these sub-recent tephras of Campanian origin form an important topsoil component.

Older, Middle Pleistocene tephra, presumably largely linked to the Roccamonfina volcano, had a similar impact. Soils of relatively stable land surfaces, such as those of the early Middle Pleistocene basin fill and associated fans, are often partly or fully developed in this older tephra and are marked by prominent nitic properties. This is due to the high weatherability of the tephra and the formation by weathering of mainly kanditic secondary clay minerals, accompanied by residual accumulation of iron (and manganese) hydroxides. Deep complex paleosols, in the upper part of the solum in such tephra and the lower part in highly weathered fluvio-lacustrine or fluvial deposits, often with abundant residual chert, are common on the oldest relict land surfaces, i.e. the surface of the fluvio-lacustrine fill of the Isernia basin and associated alluvial fans.

In the Venafro plain tectonic movements led to a far simpler pattern in which transitional stages of the soil chronosequence are rare. Here the oldest land surface with deep complex paleosols dips beneath Holocene deposits, and in places in the Volturno plain strongly developed soils (deep Nitisols) were encountered next to Late Holocene highly calcareous Fluvisols, as evidenced by the soil map.

Lastly, particularly in the older strongly developed soils the role of parent material in soil development is very clear, notably the effect of internal soil drainage and associated trends in weathering and clay formation. In coarse textured, siliceous parent material – often containing significant amounts of coarse chert fragments – the soils can be described as classic reddish brown fersiallitic to ferruginous soils (Duchaufour, 2012; Girard & Baize, 2009) while in marls and other fine-grained sediments soils exhibit distinct vertic properties.

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**Figure 8.** Rill erosion with sanidine minerals washed out.
Software
QGIS, an open source geographical information system, was used to produce the soil map. A standard GPS (Garmin) was used to establish coordinates in the field.

Map design
The maps can be found in the Figshare depository as: Appendixes 1.1. and 1.2. https://doi.org/10.6084/m9.figshare.12609125.v1. These are 2 pdf’s that can be opened and are readable using Adobe Acrobat Pro DC, provided that in Page Display (in Preferences) ‘smooth line art’ is activated and ‘enhance thin lines’ deactivated. The maps are based on the 1:5,000 topographic maps of Italy. Relevant details on these maps are given in both pdfs.

The soil boundaries have been projected on the topographic maps, which are a mosaic of individual digital maps obtained from the various regions of Italy (including permissions to use these), using the QGIS-software package.

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Disclosure statement
No potential conflict of interest was reported by the author(s).

Note
1. https://doi.org/10.6084/m9.figshare.12609125.v1

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