Pedological (micromorphological and chemical) investigation in an archaeological site of the Early Bronze Age: the case study of Palma Campania (southern Italy): Soil properties of the last 9000 years in a plain close to Vesuvius

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Keywords:	soil chronosequence, micromorphological features, Early Bronze Age, soil fertlity, climatic indicators

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Running head: soil properties of the last 9000 years in a plain close to Vesuvius

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ABSTRACT

Archaeological records from excavations of the last forty years in the Campania region (southern Italy) attest to an intense human occupation from the Early Bronze Age (EBA) until the present day. A soil study, aimed to the better understanding of fertility, use and environmental conditions of the land where these past communities lived, was carried out at Palma Campania (Naples) over an

Eneolithic to Modern Age chronosequence and an EBA paleosurface. The results shown that soils i) were Andosols, ii) differ markedly in terms of depth, degree of andic properties and chemical fertility, iii) had micromorphological features (e.g. silty coatings, laminar features, iron segregations, weathering rims etc.) indicating specific weathering environments. The comparison of the estimated pedogenetic times (EPT) and selected soil properties (Al and Fe ammonium oxalate extractable forms and organic matter) with climate evaluations from the literature highlighted a marked relationship between these properties and the humidity/aridity of the environment. Regarding the EBA paleo-surface, the organic-phosphorous content and the organic matter of some areas resulted consistent with both archaeological contexts and reconstructed agricultural uses (animal pasturing and crop cultivation), whereas the specific micromorphological pedo-features and chemical properties strongly suggest anthropic genesis for an ancient micro-topography of undefined origin.

1. INTRODUCTION

Recent archaeological and volcanological studies carried out in the Campania region (southern Italy) have shown that the activity of the Quaternary volcanic edifices (i.e. Vesuvius, Roccamonfina, Campi Flegrei and Isle of Ischia) along the Tyrrhenian margin of the Campania Plain graben have strongly influenced the growth and decline of many human settlements over the millennia (Marzocchella 2000; Albore Livadie et al. 2001, 2003; Talamo and Ruggini 2005; Albore Livadie 2007; Di Lorenzo et al. 2013). Evidence of the involvement of humans with volcanic activity has been found in many areas close to the eruption vents, as well as in locations several tens of kilometers further east and north-east. Interruptions in human occupation of these areas alternated several times with resettlement phases, following the periods of activity and quiescence of the local volcanism.

Numerous explosive and effusive eruptions have been produced by the volcanoes still active, but the events of greatest intensity are associated with Somma-Vesuvius and the Campi Flegrei caldera.

In detail, the Plinian eruptions known as Pomici di Mercato (8890 ± 90 ^{14}C yr cal BP, Santacroce et al. 2008), Pomici di Avellino (3945 ± 10 ^{14}C yr cal BP, Sevink et al. 2011) and Pompeii (AD 79, Sigurdsson et al. 1985) were produced by Somma-Vesuvius, while the Agnano-Monte Spina eruption (4625-4482 ± 70 ^{14}C yr cal BP, de Vita et al. 1999; Smith et al. 2011) had its origin in the Campi Flegrei. Among them, the Avellino Pumice eruption (PdA) had a very strong impact on a wide area, striking both the Campanian Plain and the surrounding Apennine Mountains. Before this eruption, the Campania region was densely inhabited by Early Bronze Age (EBA) communities of farmers and pastoralists (Albore Livadie 2007 and references therein), as testified by the discovery of numerous villages and cultivated fields. In particular, the PdA eruption dramatically interrupted and buried numerous remains of the notably well-developed socio-economic and demographic scenario (Talamo 1993a; Talamo 1993b; Di Lorenzo et al. 2013) belonging to the archaeological *facies* of Palma Campania. This *facies* is a cultural sphere developed in the EBA in the southern Italy, starting from the Campania region and principally involving the inner Tyrrhenian lands, even remains have also been found in Sicily, Aeolian Isles, Malta and northern Lazio region. The Palma Campania *facies* is of exceptional relevance due to the specificity of the ceramic forms (Albore Livadie, 1980) of Helladic derivation, therefore does not represent a simple evolution of the previous Eneolithic culture. The *facies* ranks temporarily between the protoappeninico A and B (Lo Porto, 1962) and is named after the place where in 1972 a new kind of pottery was found and described (Albore Livadie et al. 1998).

In spite of the *Campania felix* is wellknown for the fertility of lands, a real fertility evaluation based on the main chemical and physical properties of the soils inhabited by the past communities in the last 9000 years is not yet available in literature. The present study refers to the 1995 excavation (Albore Livadie 1999), conducted in the vicinity of the 1972 excavation. In 1995, a dig in Balle/Pirucchi locality at Palma Campania (Naples) brought to light i) a deep (approximately 9 m) soil chronosequence (*sensu* Hugget 1998), composed of pyroclastic deposits and buried soils, which started below the Pomici di Mercato (PdM) eruption (8890 yr cal BP) up to the present soil surface, along with ii) an extensive (approximately 4500 m^2) well preserved paleo-surface of the EBA. Archaeological remains from the soil chronosequence enabled the identification of soils of the Late Imperial Roman, Late Republican Roman, Middle Bronze and Early Bronze Age, Eneolithic and Mesolithic period. Moreover, the excavations have revealed traces left by human activity and domestic animals above the EBA paleo-surface, along with a peculiar soil topography of uncertain (natural or anthropic) genesis and use. Because of the exceptional degree of preservation and importance of the archaeological excavation, a detailed stratigraphic (volcanological) and pedological study was performed on both the entire soil chronosequence and the EBA paleosurface, with the aim: i) of contributing to a better understanding of environmental conditions and land use where these past human communities lived, by investigating the main chemical and micromorphological properties of the soils of different age; ii) of identifying relationships between particular soil properties (i.e. properties more sensitive to hydrological changes) and the estimated pedogenetic times (EPT), by the use of volcanological evidence and climatic phases reported in the literature, so as to enable the use of these properties as a proxy for the reconstruction of past climatic conditions, in association with other paleoclimatic records; iii) to document the distribution of the soil properties in three areas of the EBA paleosurface, previously subject to archaeological investigation, in order to better understand the use of the entire area and the genesis (natural or anthropic) of a debated micro-topography found in the South area.

2. MATERIALS AND METHODS

2.1 Environmental and archaeological setting

The modern village of Palma Campania (southern Italy) is located on flat ground between the western slopes of the Sarno hills (Apennine Chain) and the eastern slopes of the Somma-Vesuvius volcano (whose crater is 11 km away). Due to its position close to Somma-Vesuvius an abundant accumulation of Vesuvian pyroclastic deposits affected the area, and Phlegrean products are also found (Orsi et al. 2004; Di Vito et al. 2013 and references therein).

In autumn 1995, approximately 2 km south-west of the modern village of Palma Campania, an almost flat area of 4500 m^2 in Balle/Pirucchi location was investigated before the extension of an existing land-fill site. The site is 200 m distant from the first discovered hut, where more than a hundred vessels of the EBA Palma Campania *facies* were found in 1972, during the construction of the Caserta - Salerno highway (Albore Livadie 1980). Moreover, in a further survey (1978) for a highway lay-by construction at a distance of about 300 m, a burnt earth ("concotto") floor was sampled for the first ^{14}C analysis of the site (Albore Livadie 1980) and in 1987, wrought lens of a hut floor with pottery fragments were found in a side of the land-fill cut (Pozzi 1987). The three huts occupied a small hill (62 m asl) where the protohistoric village very likely stood, on the eastern side of the present study area (Fig. 1a) that is at a slightly lower altitude (50.5 -52.9 m asl). On the basis of the archaeological discoveries (Albore Livadie 1998), the EBA paleosurface was divided into three main areas (North, Central and South) (Fig. 1b). In the North area two long narrow NE-SW oriented trenches were found; they were 42 and 21 m long, both 35 cm wide, and 13 m apart. The longer trench intersected a third one that was 3.5 m long, forming a sketch of quadrangle. This arrangement suggested they were boundaries made by humans to demarcate plots of land allocated to different family groups (Albore Livadie 1998). Inside and outside this area, numerous animal hoof prints (238 tracks) were found, mainly belonging to adult cattle (*Bos taurus*) and also a few young, but the number of livestock is indeterminable. These tracks (Fig. 2a) indicate that part of the sector was used for pasturing animals and another part for animal transition, as shown by a predominant NE-SW track orientation. In the Central area a few bone remains (teeth, long-bone and skull fragments from adult cattle - *Bos taurus* - and an old pig *Sus scrofa*) were found, associated with pottery fragments (large jars, cups and plates); these were interpreted as waste from the nearby village. Moreover, a squared plot of land (12 x 13 m, 156 m^2) with parallel NE - SW oriented furrows 55 cm apart was also found (Fig. 2b). These furrows were interpreted as a "strip" cultivation (Albore Livadie 1999) ploughed in one single direction using a simple scratch plough. A riverbed 2 m wide, filled with redeposited volcanic pumice, separated the Central and South areas.

The analyzed soil chronosequence (section-a) was sampled in the Central area, very close to the riverbed. In the South area was found a slightly depressed zone (approximately 150 m^2) with an unusual micro-topography featuring ripples (micro-relief and micro-concavity), spaced at a distance of approximately 40 cm one from another (Fig. 2c). The genesis (natural or anthropic) of this soil micro-topography is still controversial. A soil trench (section-b) was dug in this area. Paired wheel ruts were also found in the South area, oriented parallel to the riverbed pathway.

Within the soil chronosequence, two areas rock dry wall built belonging to the Late Imperial Roman age were found in correspondence to the *sola LROM2* and *LROM3*. They had first been used as funerary enclosures in a Roman cemetery and successively for food storage and as stables. Moreover, 14 tombs of the Late Republican Roman graveyard were found in soils with the stratigraphic position of *MBLR1* and *MBLR2*, while ten tombs belonging to the Samnite burial ground were found in *MBLR4* and *MBLR5*.

2.2 Materials

Thirty bulk soil samples were collected from the chronosequence (section-a), located in the Central area of the excavation and 8 from the EBA paleosurface. In detail, for the EBA paleosurface, 1 sample was sampled from the North area (s1), 1 from the Central area (s2) and 6 from the South area where a trench (section-b) was dig till 1.5 m of depth. In this trench 2 soil profiles (P1 and P2) were described and sampled, with P1 crossing both MR and MC, and P2 approximately along a MR (Fig. 4a). The soil sampling for the P1 was carried out only in the MC. In general, the soils of the chronosequence were cultivated natural soils collected close to archaeological remains; they did not show clear evidence of marked anthropic activity due to settlements (i.e. huts, tombs, rooms etc.). On the basis of both volcanological deposits and archaeological remains (Albore Livadie 1998), 5 main groups of soils were identified within the chronosequence. The time-span in which each soil developed has been defined as Estimated Pedogenetic Time (EPT) and calculated as the time which elapsed between one eruption and another, using the age ^{14}C BP of the identified pyroclastic records (Table 1).

By the use of the Kubiena boxes (5 x 10 x 3.5 cm) (Kubiena 1938) and the sampling of soil aggregates, 37 undisturbed samples were collected from section-a and 9 from section-b for soil micromorphology analyses.

2.3 Methods

Bulk soil samples, dried at 40°C in an oven and sieved at 2 mm, were analyzed in accordance with Soil Survey Staff (2009). The analysis of the particle size distribution (PSD) was performed with the pipette method on samples dispersed with sodium hexametaphosphate (Na-HMP). This is the dispersant agent recommended by the ISO international standards of soil particle size distribution (PSD). Nevertheless, Na-HMP is known to fail in the complete dispersion of Andosols (Nanzyo et al. 1993; Mizota and van Reeuwijk 1989). Therefore, considering such colloidal dispersion problems, the sum of fine silt + clay was used as a parameter for discussing the soils' physical properties (Terribile et al. 2000). The soil reaction was measured potentiometrically on soil-H_2O (1:2.5 ratio) suspensions, the cation exchange capacity (CEC) was measured with $BaCl_2$-triethanolamine (pH 8.2), following Mehlich (1938), and the exchangeable cations (Ca, Mg, Na, K) content by ICP-AES. The organic matter (OM) content was determined following the Walkley and Black (1934) procedure and the carbonates using the Dietrich-Fruehling calcimeter, after addition of HCl 1M. The acid ammonium-oxalate extractable forms (Al_o, Fe_o and Si_o), used to calculate the Al_o+ 0.5 Fe_o index for the Andosol classification, were obtained as indicated by Schwertmann (1964) and Blakemore et al. (1987). The total P content was determined by the ignition method: a sulphuric acid extraction of soil samples ignited at a temperature of 550°C was performed. The inorganic phosphorous (IOP) was measured after sulphuric acid extraction on non-ignited samples. Both measurements of P content were carried out spectrophotometrically by the use of the ascorbic acid method. Then the organic phosphorous (OP) content was obtained by subtracting the inorganic P content from the total P (Bethell and Matè 1989).

All analyses were carried out on single soil horizons and then assembled in *sola* in order to better evaluate different pedogenetic phases. A *solum* (plural *sola*) is the upper and the most weathered part of the soil profile (i.e. A and B horizons) (*sensu* Soil Science Society of America 1987).

A scheme of Land Evaluation (FAO 1976), aimed to produce a comparative evaluation of soil fertility between *sola*, was set up. Such a scheme considered land qualities typical of the soil fertility classification such as: soil thickness, CEC, base saturation, OM content and particle size distribution (i.e. the clay + fine silt sum). The range for each land quality was divided into 4 classes (first class for the least fertile and fourth for the most fertile). The sum of indexes obtained from each class, assembled for each *solum*, enabled an empirical index of soil fertility (EIF) to be constructed. In the present case study, the index ranged from 6 (the lowest fertility) to 16 (the highest fertility).

Soil thin sections (30 µm) were prepared from undisturbed soil samples and described according to FitzPatrick (1993).

3. RESULTS AND DISCUSSION

Development and conservation of both soils and volcanic deposits in the archaeological site of Palma Campania were the result of accretive processes strongly enhanced by the geomorphological position in a gently sloping area where accumulation prevails over erosion. The following section lists soil properties (morphological, chemical and physical), soil micro-morphology and discusses environmental interpretation of i) the pedological/archaeological stratigraphic levels identified within the soil chronosequence (section-a) (Table 2) and ii) the different areas of the EBA paleosurface (i.e. North (s1) and Central areas (s2), along with section-b in the South area) (Table 3). As explained in the previous paragraph (2.1), the site investigated represented a territory outside the protohistoric village used for cultivation and animal pasturing activities, along with waste deposition.

3.1 Morphological, chemical and physical soil properties and soil micro-morphology

3.1.1 Mesolithic (MES) and Eneolithic (ENEO) soils

ENEO developed between PdM and Agnano-Monte Spina (AMS) eruptions, whereas *MES* was buried by PdM and was the oldest *solum* analysed from the chronosequence. *ENEO* and *MES* were very different in terms of OM content (41.9 - 36.0 *vs.* 14.1-12.2 g kg^{-1}, respectively) and thickness of the surface horizons (30 *vs.* 15 cm), whereas both soils were characterised by high CEC (36.5 - 30.1 *vs.* 29.2- 34.7 $cmol^{(+)}$ kg^{-1}) and moderate Al_o+0.5Fe_o index (1.2 – 1.0 %). These properties mean that these soils are highly fertile chemically and physically (EIF = 17 and 16 in *ENEO* and *MES*, respectively). The moderate Al_o+0.5 Fe_o index (which is diagnostic for andic and vitric properties) is in agreement with the vitric properties, therefore these soils can be classified in the Andosols Reference Group (IUSS Working Group WRB 2014). The OP content resulted low to moderate in all the upper horizons (120 and 307 mg kg^{-1}, in *ENEO* and *MES* respectively) and decreased weakly with depth, while the calculated ratio P tot/P inorg (then called P ratio) was low for both *ENEO* and *MES* (1.1 and 1.2-1.3) and compatible with low animal or anthropic frequentation in these soils. In such a framework, it must be considered that P ratios about 1.0 have been found in dwelling areas, with high phosphate inputs, and about 1.5 in locations of animal stabling and manured fields because of the association with a high organic matter content (Engelmark and Linderholm 1996; Macphail *et al.* 2000). In the Campania region a few settlements and cemeteries of Eneolithic age have been found in the area of Gricignano d’Aversa (Marzocchella 2000), a village 30 km from Palma Campania.

The micromorphology of *ENEO* showed clear signs of a high degree of weathering of the soil, such as fine granular structure, presence of weathered mineral fragments, brownish to reddish colour of the soil matrix (particularly in the Bwb horizons) and common (2-5%) iron segregations (Fig. 5i). In

MES the upper horizon exhibited a massive soil structure and frequent (5-10%) iron segregations, as well as occurrence of weathered minerals and clay and silty-clay coatings (Fig. 5l). The presence of this particular soil process, i.e. clay illuviation, is consistent with the specific climatic conditions (see paragraph 3.2) and the moderate to high degree of soil weathering.

3.1.2 Early Bronze Age (EBAS): the soil chronosequence and the paleosurface

EBAS developed in the period between Agnano-Monte Spina (AMS) and PdA eruptions and corresponds to the soil where much protohistoric archaeological evidence was found.

Within the soil chronosequence (section-a) *EBAS* showed a thin (12 cm) A horizon characterised by low OM (5.8 g kg^{-1}), moderate CEC (16.9 cmol kg^{-1}), low Al_o+0.5Fe_o index (0.2-0.4%) (below the limit for vitric properties) and low OP and IOP fractions (226 and 652, respectively), which imply a P ratio between 1.1 and 1.3. As a whole, the above data differed from measurements regarding the pasture zone (s1) and ploughed fields (s2) of the central area, where the OM content was significantly higher (13.5 and 9.8 g kg^{-1} in s1 and s2, respectively) and the Al_o+0.5Fe_o index slightly higher (0.5-0.6%)(within the vitric properties range).

Thin section analyses of the samples from the chronosequence revealed rare (0.5-2%) iron segregations and coatings, along with frequent (10-15%) calcium carbonate segregations (Fig. 5g and 5h); both of these soil features are consistent with water circulation and processes of periodic stagnation (hydromorphy) in the soil. Moreover, the presence of a sub-angular blocky structure and planar pores identify a moderate degree of soil development where natural (e.g. fluvial) and/or anthropic actions produced horizontal compaction. As reported in paragraph 2.1, archaeological investigation showed the presence of an ancient stream on the *EBAS* paleo-surface, whose pathway was very close to the analysed section-a (Fig. 1b). Therefore it is likely that during flooding events this watercourse eroded part of the A horizon, determining a loss of OM. This hypothesis is in agreement with the presence of $CaCO_3$ (1 g kg^{-1}) in the soil, the low values of organic and inorganic P fractions (indicating no anthropic or animal frequentation of the soil), and with its micromorphological features. On the contrary, in the Central and North areas were found the highest P ratios of the entire chronosequence (1.8 and 2.1 in s1 and s2, respectively), due to the significantly high organic phosphorus content of these soils. As stated above, similar P ratio values are reported in the literature for areas of animal stabling and manured fields (Engelmark and Linderholm 1996; Macphail et al. 2000). Indeed, P is the only persistent element that is a sensitive indicator of human presence, because the addition of P to the soil comes from human and animal waste, from the presence of burials or cattle and soil fertilization with organic material (Holliday and Gartner 2007). Therefore these results seem to confirm the land-use suggested by the archaeological remains (see paragraph 2.1).

Much more difficulty was encountered interpreting the microtopography found in the South area (Fig. 2c), made by micro-reliefs (MR) and micro-concavities (MC), approximately 20 to 60 cm distant from each other. Observations showed that the MR had a shallow mineral horizon (Bwb_1 *EBAS* section-b –P2 in Table 3), yellowish brown in colour (10YR5/4) at the top (Fig. 4b1). This horizon was horizontally discontinuous and had an abrupt boundary with the underlying organ-mineral horizon (Ab *EBAS* section-b – P2 in Table 3), which was dark brown (10YR 3/3) in colour. This Ab covered another Bw horizon (named Bwb_2), which was very similar in colour and morphology to Bwb_1. MC showed a different soil horizon sequence (Fig. 4b2), consisting of two organ-mineral horizons at the top (Ab_1 and Ab_2 *EBAS* section-b – P1 in Table 3) and an underlying Bwb. By the comparison of MC and MR chemical data, Ab of the former evidenced a higher OM (22.5-22.9 in P1 and 17.5 g kg^{-1} in P2, respectively), as well as a finer PSD (fine silt + clay = 356-400 g kg^{-1} and = 275-299 g kg^{-1} in MC and MR, respectively), whereas both OM and PSD of Bwb and Bwb_2 of MC and MR, respectively, were more similar (OM = 7.1 and 5.7 g kg^{-1}, fine silt + clay = 447 and 464 g kg^{-1}). The CEC was particularly high in all Ab horizons (28.0-29.4 cmol kg^{-1}), but decreased in the Bwbs. In the subsurface horizons of both MC and MR (i.e. Ab_2 and Ab respectively) the P ratios were very high (2.1 and 1.7) and surprisingly similar to those found for the pasture and ploughed fields (1.8 and 2.1 in s1 and s2, respectively). The soil micromorphology of

MR showed a combination of the following features: i) strongly heterogeneous matrix on the surface; ii) complex crumb/granular microstructure in the upper few millimetres (Fig. 6a), followed by a massive structure with frequent finer textured laminar aggregates, horizontally and vertically oriented (Fig. 6b); iii) main planar pores (Fig. 6a) and rare secondary vesicle pores; (iv) presence of organic residues mixed with charcoal (Fig. 6c) in the subsurface (Ab) and not in the surface (Bwb); (v) weathered, fragmented and strained charcoal embedded in the massive soil structure (Fig. 6d). In MC, compared with MR, (i) such heterogeneity of the soil matrix significantly decreased, because the microstructure was complex (crumb and massive) in the first few millimetres (Fig. 6e), but the porosity increased with depth (Fig. 6f); (ii) organic residues and charcoal also occurred on the surface, but in smaller amounts; (iii) the soil PSD was visibly finer and (iv) abundant fauna passages occurred at depth (Fig. 6f).

We therefore conclude that the vertical sequence of soil horizons found in MR is unusual, because in a natural soil sequence the organ-mineral A horizon overlies the mineral Bw horizon, especially in the local pedo-environmental conditions (rainfall, temperature, soil pH, clay minerals, etc.), which do not promote any translocation of OM, as in the case of Spodosols (WRB 2014) in which an inversion of the horizon position is possible. Hence, it is likely that in MR the original soil structure was broken and reworked, producing heterogeneity and mixing of the soil fabric, associated with soil compaction, as inferred from the presence of laminar aggregates, horizontal planar pores and the vertical orientation of laminar aggregates in the massive structure. The OM enrichment and high P ratio of the soil subsurface horizons of both MR and MC could be due to OM input, probably from waste, animal excrement and manuring practices, as already found in s1 and s2. The abundance of charcoal fragments, more in the subsurface than on the surface, is another anthropogenic feature indicating the practice of burning to prepare the underlying surface for a specific use (such as in Courty et al. 1989). It is likely also that wet conditions occurred in MC, due to the depressed morphology that also created a suitable environment for soil fauna, as indicated by the higher frequency of fauna passages and channel structure. The higher Al_o+0.5Fe_o index of the top of the microtopography (in Ab_1 and Bwb of P1 and P2, respectively), compared with the other parts of the paleo-surface, along with the presence of 'footprints' of *Phragmites*, a plant species typical of hydromorphic environments, (Albore Livadie 1998) strongly supports the interpretation of a wet environment, also favoured by the finer PSD of MC. Therefore, the probable explanation for this morphology is that only human activity could produce such a combination of morphological, chemical and micromorphological soil features. The area was first subjected to clearance by burning and then strongly reworked, creating MC and MR, and manured. The wet conditions of soils probably did not favour the use of the area for agriculture, so it was subsequently abandoned and colonized by wild plants. The hypothesis of abandonment is consistent with both the low P ratios of the upper horizons and the absence of traces such as ploughed furrows.

3.1.3 The soils after PdA and before Pompei: from the Middle Bronze Age to the Late Republican Roman era (MBLR)

The long period (approximately 1.5 kyr) that elapsed between two of the major Vesuvian eruptions (PdA and Pompeii) was influenced by the occurrence of low-energy or subplinian events called AP eruptions. For AP4 and AP5 there is not a certain chronology, while for AP6, AP3, AP2 and AP1 the dates (following Rolandi et al. 1998; Santacroce et al. 2008; Stothers and Rampino 1983) are reported in Table 1.

Within this group of *sola, MBLR1* and *MBLR2* showed the highest Al_o+0.5Fe_o index (1.2-1.8%) and OM content (13.5-21.0 g kg^{-1}), while *MBLR3* was intermediate (Al_o+0.5Fe_o = 0.7% and OM = 7.2 g kg^{-1}); a similar trend was found for the CEC (see Table 2). Except *MBLR6,* all *sola* met the vitric properties and can be classified as Andosols. Data of Al_o+0.5Fe_o index and OM content are strongly consistent with those found by Vogel and Märker (2011) in the Roman paleosols of Boscoreale. The soil fertility varied from high (EIF = 14-13) in *MBLR2* and *MBLR1* to low (EIF = 6 -7) in *MBLR4*, *MBLR5* and *MBLR6*, while intermediate (EIF = 10) was in *MBLR3*. Moreover, *MBLR1* and *MBLR2* had the highest P ratio of the sequence (1.3 and 1.6), as a consequence of high and very high OP contents (272-369 mg kg^{-1} and 543-727 mg kg^{-1} in *MBLR1* and *MBLR2* respectively), which is a strong indicator of human and/or animal frequentation of the soils. Therefore soil fertility and P data are in accordance with the archaeological remains that indicate an intensively inhabited landscape during the Roman epoch, a cemetery dating to which was also found associated with cultivated soils.

The micromorphological analyses showed a very fine granular microstructure and occurrence of thick weathering rims in both *MBLR1* and *MBLR2*, confirming the moderate to high degree of pedogenetic development indicated by the chemical properties. Moreover, the presence of rare fine laminar structures in *MBLR1* and the very dark brown matrix of *MBLR2* (see Table 2) could be considered signs of a higher degree of weathering in *MBLR2* than in *MBLR1*. A similar micro-structure, but nearly massive (i.e. primary volcanic ash structure), was found for *MBLR4*, in which rare laminar aggregates were also found. *MBLR5* and *MBLR6* were mainly massive, with strongly weathered areas containing iron segregations, very likely as a consequence of temporary waterlogging in this dense layer with low porosity.

As a whole, chemical and micromorphological properties of the *sola* before AP5 (*MBLR3, MBLR4, MBLR5, MBLR6*) evidenced a significantly lower degree of weathering than the *sola* after AP5 (*MBLR1* and *MBLR2*).

3.1.4 The soils after Pompeii: Late Roman (LROM) till Early Modern (EMOD) period

The *EMOD* and the *LROM sola* (*LROM1, 2* and *3*) formed in the time period between the AD 79 (i.e. Pompeii) (Santacroce et al. 2008) and AD 1631 eruptions. In detail, *EMOD* developed between AD 512 (Wulf et al. 2004) and AD 1631, *LROM1* between AD 472 (i.e. Pollena, Sulpizio et al. 2005) and AD 512, *LROM2* between AD 472 and AD 203 (Cioni et al. 2008), *LROM3* between AD 203 and AD 79 eruptions. Differently from the other eruptive events, ash lenses from AD 203 were not found in this excavation, but they were reported by Di Vito et al. (2013) in a nearby excavation (location: Via Isernia, approximately 3 km away). Among the above mentioned eruptions, the sub-

Plinian event of AD 472 produced the most widespread effects and sealed evidence of human activity (Di Vito et al. 2013).

EMOD showed elevated OM content (16.8-18.6 g kg^{-1}) and CEC (28.1-26.1 cmol kg^{-1}), whereas the Al_o+0.5 Fe_o index (1.8-2.7 %) was very high (the highest of the chronosequence) and met the andic properties requirements. On the contrary *LROM1* was very low in both OM (3.3 g kg^{-1}) and Al_o+0.5 Fe_o index (0.4%), the latter at the boundary of vitric-non vitric properties, whereas it showed moderate CEC (15.9 $cmol^+$ kg^{-1}). Both *EMOD* and *LROM1* had high total P content (P tot = 1652-1940 and 2185 mg kg^{-1}, respectively), mainly due to the inorganic fraction (P inorg = 1609-1759 and 2178 mg kg^{-1}, respectively). A renewed increase in OM (5.6-13.4 g kg^{-1}) and Al_o+0.5 Fe_o index (1.3-1.5 %) was found in the underlying *LROM2* and *3*, where the CEC was moderate to high (13.4-22.3 $cmol^+$ kg^{-1}), whereas the total P content (1360-1388 mg kg^{-1}) decreased. However, the P ratio was always low (around 1.0), indicating a low anthropic or animal frequentation in these soils, as well as in the more recent *LMOD solum*. In this group of *sola*, only *EMOD* showed a high fertility value (EIF = 13), whereas the lowest value was found for *LROM2 (EIF = 8)*.

In a comparison between *EMOD* and the overlying *LMOD,* the micromorphological analyses showed a relative loss of porosity and increase of mineral weathering in *EMOD,* as well as occurrence of frequent laminar pedofeatures and charcoal fragments (Fig. 5b and 5c). These pedo-features are related to anthropic activities, such as compaction, when associated with organic matter increase (Courty et al. 1989) and charcoal presence. A different microscopic arrangement was shown by *LROM1*, with higher porosity on the top and massive structure at the bottom, occurrence of rounded soil aggregates, iron segregations in the soil matrix and silty coatings around pumice and mineral fragments (Figs. 5d and 5e, respectively), with iron segregations inside probably due to weathering, reworking and erosion processes that occurred during explosive eruptions. These properties are very likely related to intense and frequent meteoric precipitation and alluvial events which occurred during and after the AD 472 eruption and are well documented in the volcanological literature (Sulpizio et al. 2006). These events created an unstable environment unfavourable to both pedogenetic processes and human activities, as demonstrated by the low Al_o+0.5 Fe_o index and OM content. In both *LROM2* and *3* the micromorphological analyses showed i) granular structure, ii) presence of poorly weathered fragments of minerals and scoria and iii) silty textural features (Fig. 5f)(i.e. ashy laminar structures) related to the deposition of volcanic materials on the soil surface. As a whole, these characteristics indicate a moderate degree of soil development.

3.1.5 The soils after the AD 1631 eruption: the Late Modern Age (LMOD)

LMOD1 and *2* developed in the time from the AD 1631 eruption (dated by Rolandi et al. 1993; Rosi et al. 1993) to the present; therefore, even if not clearly identified in field, pyroclastic materials from Vesuvius' recent activity following the 1631 eruption must have affected the genesis of this *solum*.

The *LMOD1* and *2* showed moderate to low OM content (15.2-6.2-g kg^{-1}) with respect to the entire soil sequence (Table 2), which is consistent with the cation exchange capacity (CEC = 24.3-2.1 cmol kg^{-1}). The Al_o+0.5 Fe_o index was moderate to weakly developed (from 1.5 to 0.9 %), but in accordance with the vitric properties and can be classified in the Andosols Reference Group. The total P (from 2150 to 1873 mg kg^{-1}) was generally high, likely as a consequence of the high IOP (1852 – 1986 mg kg^{-1}), while the P ratio was low. Therefore *LMOD1* and *2* were classified as being of high and low fertility (EIF = 12 and 7), respectively. The micromorphological analyses showed frequent occurrence of weakly weathered mineral crystals, pumices and scoria, associated with single grains and granular structure (Fig. 5a) with abundant pore space, which confirmed the moderate to low degree of soil weathering indicated by the chemical analyses.

3.2 Soil properties and climatic factors: possible relationships

In the literature, the use of multiproxy records (e.g. $\delta^{18}O$, pollen, $\delta^{13}C$, stable isotopes, etc.) has allowed a picture of climatic variability to be defined, in terms of temperature and rainfall, for the

Holocene period in many areas of Europe and Italy (Magny et al. 2009; Zanchetta et al. 2012; Regattieri et al. 2014). On the other hand, a knowledge gap exists regarding the relationship between climatic phases and soil properties, which could constitute key parameters when a territory is investigated in terms of human history. Indeed, soil properties are directly related to the fertility of the land and thus to the density of human occupation. The climate is one of the most important soil forming factors (Jenny 1947; Tardy 1986), since it determines rates of processes by controlling moisture availability and temperature, the identification of particular soil properties more sensitive to these two parameters and easy to measure in soils would be of great interest in archaeological contexts.

An attempt is therefore made here to evaluate the relationship between documented climatic changes and selected soil properties measured along the chronosequence, assuming that the geomorphological conditions of the site have not changed very much with the time, because the spatial distribution of soil properties could change with geomorphological position, as demonstrated for roman paleosols in neighbours areas (Vogel and Märker 2011). The time of pedogenesis has also been taken into account in this evaluation. The soil properties used for this purpose are the soil OM content and the Al_o+0.5Fe_o index, due to their high reactivity to climatic changes. Indeed, the amount of OM and humic substances in the soil depends on both the quantity and quality of residues and organic fertilizers which reach the soil, as well as the rapidity of mineralization and humification processes to which the residues are subject. The OM mineralization (i.e. the conversion of nutrients from organic to inorganic forms) is influenced by several factors such as temperature, availability of oxygen and humidity, pH, etc. On the other hand, temperature and precipitation also have a controlling influence on the formation of Andosols, according with the andic properties (Shoji et al. 1993), because higher temperature increases the rate of chemical weathering in tephras and higher precipitation intensifies the leaching of Si and bases, leading to the formation of allophanes instead of Si-rich clay minerals. In the case of the Al_o+0.5Fe_o index, since the Al_o, Fe_o and Si_o represent the active, short-range-order (i.e. allophane, imogolite, ferrihydrate) or amorphous (Al-humus complexes and opaline silica) Al, Fe and Si compounds in soils (Blakemore et al. 1987), this percentage is used here as a measure of all these forms.

The ages of tephras used for the EPT calculation of the *sola* are given in table 3, while the OM content, the Al_o+0.5Fe_o index and the EPT *vs.* the *sola* of the chronosequence are reported in figures 7a and 7b. *MES,* which is characterized by generally low Al_o+0.5Fe_o index and OM, was formed in the period preceding PdM (8.9 kyr cal BP), when phases of climatic improvement after the Last Glacial period alternated with cold episodes (e.g. the Younger Dryas), which interrupted the deglaciation before the beginning of the Holocene. We observe that the effects of these alternating climatic conditions were the moderately low development of soil properties and the activation of clay illuviation processes, as showed by the micromorphological analysis. As reported in the literature, this process typically occurs in soils when i) distinct dry periods are followed by high intensity rainfall and ii) fine clays (generally phyllosilicates) are present and move through non-capillary voids suspended in the percolating water. In general, phyllosilicates are scarce in Andosols, but periodic desiccation of allophanes may cause recrystallization to phyllosilicates (Buurman and Jongmans 1987; Jongmans et al. 1994). Due to the absence of the older chronological constraint, the EPT was not calculated to evaluate the influence of this factor on soil properties. Nevertheless, the soil properties suggest the presence of a stable geomorphological environment suitable for anthropic frequentation, without any catastrophic eruptive events.

The highest values of the Al_o+0.5Fe_o index + % OM of the chronosequence, associated with the highest EPT (see Figures 7a and b), are found for *ENEO*, which formed between PdM and AMS eruptions (8.9 - 4.5 kyr cal BP) in a period falling almost entirely in the Neolithic Climatic Optimum or Hypsithermal period (ca. 8.2-5.5 kyr cal BP) of the early Holocene. The largely stable warm and humid climatic conditions favored the greatest expansion of the oak forests in the eastern Mediterranean region (Cheddadi et al. 1991), in Greece (Bottema 1974) and on the southern Dalmatian islands (Beug 1975). Therefore the very high OM content (3.9%) found for *ENEO* is very likely due to plant residues, owing to the forest cover, which were incorporated into the soil

466 and poorly mineralized because of the humid climate. The $Al_o+0.5Fe_o$ index was expected to be
467 very high due to the very stable environment, but was found to be only moderate probably as a
468 consequence of i) recrystallization of allophanes as phyllosilicates or ii) inhibition of allophane
469 formation caused by perhumid, highly leaching climate, which removed all silica from the soil.
470 The overlying *EBAS*, which developed between the AMS and PdA eruptions (4.5 to 3.9 kyr cal BP),
471 showed a low $Al_o+0.5Fe_o$ index and low OM content, the latter being markedly lower than *ENEO*.
472 The very low developed properties do not seem to result from a short EPT, because approximately
473 600 yr could have been a sufficiently long period to produce moderate soil properties in favorable
474 (i.e., warm and moist) climatic conditions. The decrease of both $Al_o+0.5Fe_o$ and OM seems
475 therefore to be related to two essential environmental changes that occurred before the PdA event: i)
476 climatic: Jalut et al. (2000) identify an aridification phase at ca. 5300-4200 yr cal BP, Magny et al.
477 (2009) report a pronounced lowstand in lakes responsible for peat formation before PdA deposition,
478 as well as Zanchetta et al. (2012) who identify a prominent arid event at ca. 4100 – 4000 yr cal BP,
479 which is in agreement with other multi-proxy records (Drysdale et al. 2006) or the Spanish flood
480 history records (Thorndycraft and Benito 2006) and ii) vegetational (land use): the Campania region
481 was intensely occupied by the Proto-Apennine civilization and agriculture flourished during the
482 Bronze Age.
483 With regard to the subsequent period, we observed that: i) from *MBLR6* to *MBLR4* (formed after
484 PdA till AP4) the $Al_o+0.5Fe_o$ index and the OM are very low and their EPT varies from 173 to 534
485 yr (on average 220 yr), ii) from *MBLR2* to *LROM2* (after AP5 till AD 472) the $Al_o+0.5Fe_o$ index
486 and the OM are higher, always moderate (except for the OM in *LROM2*), with an EPT varying from
487 124 to 269 yr (on average 217 yr), iii) *MBLR3* has intermediate properties (between AP4 and AP5).
488 Due to the absence of a certain chronology for AP4 and AP5, the EPT of *MBLR4*, *MBLR3* and
489 *MBLR2* was assumed to be approximately 180 yr. Thus the soil before AP5 also formed in a similar
490 or longer EPT compared with the more recent soils, which showed less developed properties. In the
491 period after PdA until AP4-AP5 (i.e. *sola* from *MBLR6* to *MBLR4*), the studied area was affected

by frequent eruptions with ash emission and deposition (Di Vito et al. 2013) that played an important role in the low degree of soil weathering because they i) frequently interrupted the pedogenetic processes, decreasing the soil formation rate, ii) likely modified the local climate, increasing the water input into the atmosphere and meteoric precipitation which caused marked ash reworking after eruptive events. Moreover, two further significant phases of drier climatic conditions occurred at ca. 3500 and 3300 yr cal BP (Zanchetta et al. 2012), which correspond to the phase of cooling following the deposition of the Thera tephra (Rohling et al. 2002). A severe drought was found also by Bretscheider and Van Lerbeghe (2008) between ca. 3300 and 2700 yr cal BP, indicated by pollen evidence in alluvial deposits. With regard to this arid phase, Kaniewski et al. (2010) have suggested that this event may have produced region-wide crop failure corresponding to the Late Bronze Age collapse. However, after AP4 (starting from *MBLR3*) the soil properties show a gradual increase, except for a small decrease in correspondence to *LROM2*. No certain climatic references were found for the period from *MBLR3* to *MBLR1*, while evidence of wetter conditions during the Roman Empire (1800-1500 yr cal BP), which clearly favored the pedogenesis of *LROM3* and *LROM2*, were reported by Zanchetta et al (2012). At that time, the plains around Vesuvius were densely populated and intensely cultivated by Roman or Romanized populations. However, the increase of Al_o+0.5 Fe_o index (from 0.4 to 2.7 %) and OM content (from 3.3 to 18.6 g kg^{-1}) is surprisingly consistent with the EPT, which grew from *LROM1* to *LROM2*, *LROM3* (EPT = 40, 269 and 124 yr, respectively) and *EMOD* (EPT approximately 1100 yr), strongly supporting these soil properties as indicators of stability for these ancient paleo-surfaces. For the last two *sola* *EMOD* and *LMOD*, it is interesting to observe that the Al_o+0.5Fe_o index and the OM is higher for the first solum than the latter, consistently with the EPT (approximately 1100 and 380 yr, respectively). In this regard, two relevant phases of wetter conditions occurred at ca. 1350-1250 yr cal BP (600-700 AD, at the beginning of the Early Medieval period) and 1100-800 yr cal BP (850-1150 AD, during the subsequent Middle Ages) (Bradley et al. 2003) which could have improved the soil properties of *EMOD*, but one only wetter phase centered at ca. 90 cal BP (AD 1860) in the period of *LMOD*. Moreover, the time range of *EMOD* included the Medieval Warm Period (MWP) (Mann et al. 2009), a medieval climate optimum generally thought to have occurred from about AD 950 to 1250, during the European Middle Ages, while in *LMOD* the Little Ice Age (LIA) occurred, lasting approximately from AD 1300 to 1850 (Grove 2004; Matthews and Briffa 2005). In spite of the good relationship found between soil properties and EPT and climatic conditions, we prefer to be cautious in the case of *LMOD* because of its proximity to the surface, where recent ploughing practices and/or deposition of recent Vesuvius products might also have affected the soil formation.

4. CONCLUSIONS

The present case study at Palma Campania shows one of the better-preserved chronosequences of the Campania region, in a peri-volcanic environment. Vesuvius and Phlegrean products represent both the parent material from which the soils developed and the material that has covered, buried and preserved the pre-existing soils and evidence of human activity. As a whole, the results indicate that the choice by human communities to live in this particular area is due to the moderate to high potential fertility of its soils, which show different degrees of pedogenesis, according to the different weathering environments, geomorphological stability and time (duration) of soil processes. Regarding to ~~the~~ EBA paleo-surface, the soil properties demonstrated a good correlation with the land use documented by archaeological evidence in the North and the Central area. For the South area, we conclude that only human activity could produce such a combination of soil morphological (i.e. micro-relief and micro-concavities, disordered vertical sequence of soil horizons), chemical (i.e. high OM and organic P contents) and micromorphological (i.e. laminar aggregates, horizontal planar pores and vertical orientation of laminar aggregates) features. Indeed, we suppose that the area had been previously subject to clearance by burning and then strongly reworked and manured. The hypothesis of abandonment after this human intervention is supported by absence of specific shapes (like ploughing traces, etc.) probably due to hydromorphic conditions. A more interdisciplinary dataset (pollen, phytoliths, etc.) would help to better define the use of the area.

Against this background, the relationship found between both the OM content and some andic properties (i.e. the Al_o+0.5Fe_o index), and the EPT and climatic conditions reported in the literature, is of great interest. We are confident that these properties, in association with other paleoclimate data, may be used as a proxy to better identify the Holocene climatic changes (i.e. cold and/or dry phases) that occurred in volcanic environments.

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CAPTIONS

Table 1. Estimated pedogenetic time (EPT) of the sola from the chronosequence by the volcanological records (eruptions).

Table 2 Main morphological, chemical and physical soil properties of the chronosequence (section-a).

Table 3. Main morphological, chemical and physical soil properties of the EBA paleo-surface (section-b, s1 and s2 samples).

Figure 1. a) Location of the study site showing previous nearby archaeological discoveries; b) the three main areas of the EBA paleo-surface and the location of section-a and section-b.

Figure 2. a) Scattered animal tracks in the North area; b) traces of cultivation activity in the Central area; c) microtopography of the South area.

Figure 3. a) Sketch of the section-a: chronosequence of volcanic deposits and soils

Figure 4. a) Position of section-b with respect to the micro-topography of the southern sector; b) profile 1 crosses microreliefs (MR) and concavities (MC), profile 2 is along a microrelief.

Figure 5. Micrographs of *sola* from the chronosequence, in plane polarised light (PPL) and crossed polarised light (XPL) of a) granular structure of *LMOD1*; b) compacted laminar features in *EMOD* (PPL); c) charcoal fragment in *EMOD* (PPL); d) iron segregations in the soil matrix of *LROM1* (PPL); e) silty coatings around a pumice fragment, with internal iron segregations, in *LROM1* (PPL); f) silty textural features in *LROM3* (PPL); g and h) pore network filled by calcium carbonate segregations in PPL and XPL; i) weathered soil matrix in *ENEO* (PPL); l) iron segregations and clay coatings in *MES* (PPL).

Figure 6. Micrographs of the Early Bronze Age microtopography in PPL. Microreliefs: a) crumb/granular structure in the upper few millimeters, where 2 red arrows indicate planar pores b) progressively massive structure with depth, with finer textured horizontally-oriented laminar aggregates (indicated by the red arrow); c) organic residues mixed with charcoal in the soil matrix;

756 d) fragment of strained charcoal embedded in the soil matrix; Microconcavity: e) massive and
757 crumb structure on the surface, f) abundant fauna passages at depth.
758 Figure 7. For each *solum* of the chronosequence are reported in a) Al_o+0.5Fe_o index (red) and the
759 OM (pink), both in %; b) estimated pedogenetic times (EPT) (blue) in years. The *solum* age
760 increases from the bottom upwards.
761

^{14}C yr BP	^{14}C cal yr BP	Eruption	*Solum*	EPT
1747	1478		**LMOD**	384
470±55	520±40	**AD 1631**		
			EMOD	1119
1420	1420 varve age	**AD 512**		
			LROM 1	40
1530±70	1630±50	**AD 472**		
			LROM 2	269
1747	1747	**AD 203**		
			LROM 3	124
1871	1871	**AD 79**		
			MBLR 1	296
2167-2166 (217-216 BC)		**AP6**		
			MBLR 2	180
2347		**AP5**		
			MBLR 3	180
2527		**AP4**		
			MBLR 4	180
2710±60	2830±50	**AP3**		
			MBLR 5	534
3150±100 AP2 3500±60 AP1	3364 AP2 and 3818-3726 AP1	**AP1-AP2**		
			MBLR 6	173
3565±20	3945±10; 4310 varve yr BP	**PdA**		
			EBAS	608
4130±50	4625-4482±70	**AMS**		
			ENEO	4336
8098±71	8890±90	**PdM**		
			MES	

EPT = estimated pedogenetic time

Group of soils	Solum	Horizon	Depth (cm)	Colour (moist)	pH H_2O	OM g kg^{-1}	CEC cmol(+) kg^{-1}	OP	IOP mg kg^{-1}	Total P	P ratio	Al_o + 0.5 Fe_o %	Fine silt+clay g kg^{-1}	$CaCO_3$	Particle size classes[a]	EIF
EMOD-LMOD	**LMOD1**	A1	0-20	10YR3/1	7.2	15.2	24.3	164	1986	2150	1.1	1.5	125	0	loamy sand	12
	LMOD2	A2-A3	20-70	2.5Y3/2	7.2	9.9-6.2	2.1-6.8	154-40	1719-1852	1873-1892	1.1-1.0	1.4-0.9	93-99	0	loamy sand	7
	EMOD	3Ab1-3Ab2	85-130	10YR2/2	6.9	18.6	28.1	181-90	1759-1735	1940-1825	1.1	1.8-2.2	118-125	0	loamy sand	13
		3Bwb	130-145	10YR3/2	7.5	16.8	26.1	43	1609	1652	1.0	2.7	140	0	loamy sand	
LROM	**LROM 1**	5Bwb	225-265	10YR3/2	7.4	3.3	15.9	7	2178	2185	1.0	0.4	338	0	sandy loam	10
	LROM 2	6Bwb	320-335	2.5Y4/2	7.0	5.6	13.4	150	1210	1360	1.1	1.3	125	0	loamy sand	8
	LROM 3	7AB	335-345	2.5Y4/2	7.0	13.4	22.3	164	1224	1388	1.1	1.5	175	0	loamy sand	12
MBLR	**MBLR 1**	8Bwb1-8Bwb2	355-400	2.5Y4/2	7.4-7.1	15.2	24.3	272-369	1027-948	1299-1317	1.3-1.4	1.4-1.8	240-251	0	sandy loam	13
	MBLR 2	9Ab1-9Ab2	400-460	2.5Y3/2	6.9-7.0	13.5-21.0	19.0-26.4	727-543	1131-1216	1858-1759	1.6-1.4	1.8-1.2	205-259	0	sandy loam	14
	MBLR 3	9Bwb	460-485	2.5Y4/2	7.2	7.2	12.6	210	1135	1345	1.2	0.7	186	0	sandy loam	10
	MBLR 4	10Bwb	510-525	2.5Y4/2	6.8	1.4	7.8	126	1381	1507	1.1	0.5	187	0	sandy loam	6
	MBLR 5	10CBb	540-585	5Y 4/1	7.1	0.5	2.6	n.d.	n.d.	n.d.	n.d.	0.5	158	0	n.d.	7
	MBLR 6	11Bwb	610-620	2.5Y4/2	7.1	2.6	6.8	287	1359	1646	1.2	0.2	210	0	sandy loam	6
EBAS	**EBAS**	13Ab	680-692	10YR3/3	7.6	5.8	16.9	226	652	878	1.3	0.4	421	0	sandy loam	11
		13Bwb	692-705	2.5Y5/3	7.6	1.9	13.5	110	837	947	1.1	0.2	292	0	sandy loam	
ENEO-MES	**ENEO**	14Ab1	710-720	10YR2/2	7.6	41.9	54.5	120	1340	1220	1.1	1.2	431	1	silt loam	15
		14Ab2	720-740	10YR3/2	7.5	36.0	47.8	122	1220	1342	1.1	1.2	450	0	silt loam	
		14Bwb	740-755	10YR4/6	7.6	6.6	14.6	100	1002	1102	1.1	0.5	315	0	sandy loam	
	MES	15Ab	760-775	2.5Y3/2	7.6	14.1	29.2	307	1207	1514	1.3	1.0	385	0	sandy loam	15
		15ABb	775-785	2.5Y4/3	6.9	12.2	34.7	307	1253	1560	1.2	0.9	305	0	sandy loam	
		15Bwb1/Bwb2	785-840	2.5Y5/4	7.1-6.9	7.1-4.8	28.1-23.8	245-276	1140-1196	1385-1472	1.2	0.5-0.4	254-297	0	sandy loam	
		15Bwb3-Bwb4	840-875	2.5Y5/5 - 2.5Y6/3	7.5-7.3	1.2-0.5	18.6-13.9	260-120	1168-1286	1428-1406	1.2-1.1	0.3	296-238	0	sandy loam	

OM = organic matter; CEC = cation exchange capacity; OP =organic phosphorous fraction; IOP = inorganic phosphorous fraction; Total P = OP + IOP; P ratio = Total P / IOP; Alo + 0.5 Feo = ammonium oxalate Al and Fe extractable form; EIF = empirical index of fertility

Solum	Horizon	Depth (cm)	Colour (moist)	pH H_2O	OM g kg^{-1}	CEC cmol(+) kg^{-1}	OP	IOP mg kg^{-1}	Total P	P ratio	Al_o + 0.5 Fe_o %	Fine silt+clay	$CaCO_3$ g kg^{-1}	Particle size classes	EIF
P1	Ab1	680-705	10YR4/2	7.7	22.5	28.0	179	462	641	1.4	1.1	356	0	sandy loam	14
	Ab2	705-725	10YR4/2	7.5	22.9	29.1	501	457	958	2.1	0.7	400	1	loam	
	Bwb	725-745	10YR5/4	7.6	7.1	19.0	154	482	636	1.3	1.2	447	1	loam	
P2	Bwb	680-687	10YR5/4	7.3	5.8	23.2	157	540	697	1.3	1.2	275	0	sandy loam	16
	Ab	687-712	10YR3/3	6.9	17.5	29.4	388	524	912	1.7	0.6	299	0	sandy loam	
	Bwb2	712-732	10YR5/4	6.9	5.7	17.8	53	570	623	1.1	1.4	464	0	sandy loam	
s1	Ab	680-690	10YR4/2	8	13.5	22.4	528	680	1208	1.8	0.6	322	0	sandy loam	14
s2	Ab	680-690	10YR4/2	7	9.8	18.2	525	475	1000	2.1	0.5	334	0	sandy loam	11

OM = organic matter; CEC = cation exchange capacity; OP =organic phosphorous fraction; IOP = inorganic phosphorous fraction; Total P = OP + IOP; P ratio = Total P / IOP; Alo + 0.5 Feo = ammonium oxalate Al and Fe extractable form; EIF = empirical index of fertility

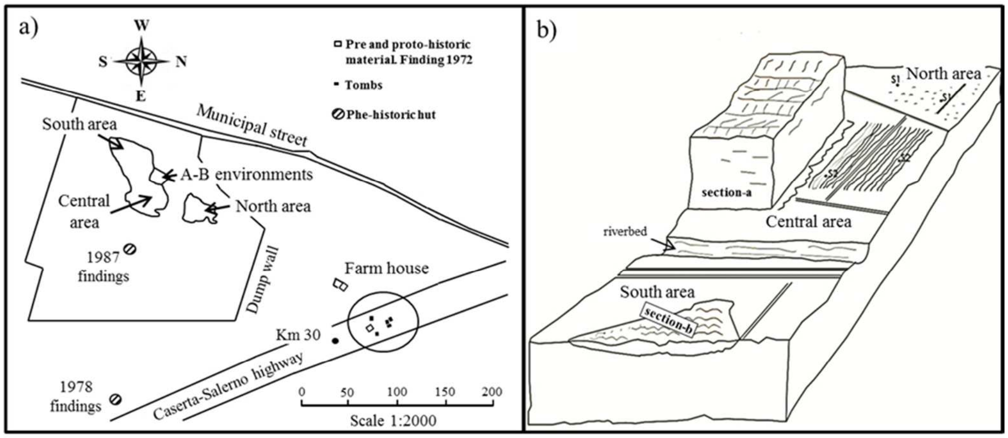

Figure 1. a) Location of the study site in the context of previous archaeological findings; b) the three main areas of the EBA paeosurface and the location of section-a and section-b.
161x72mm (150 x 150 DPI)

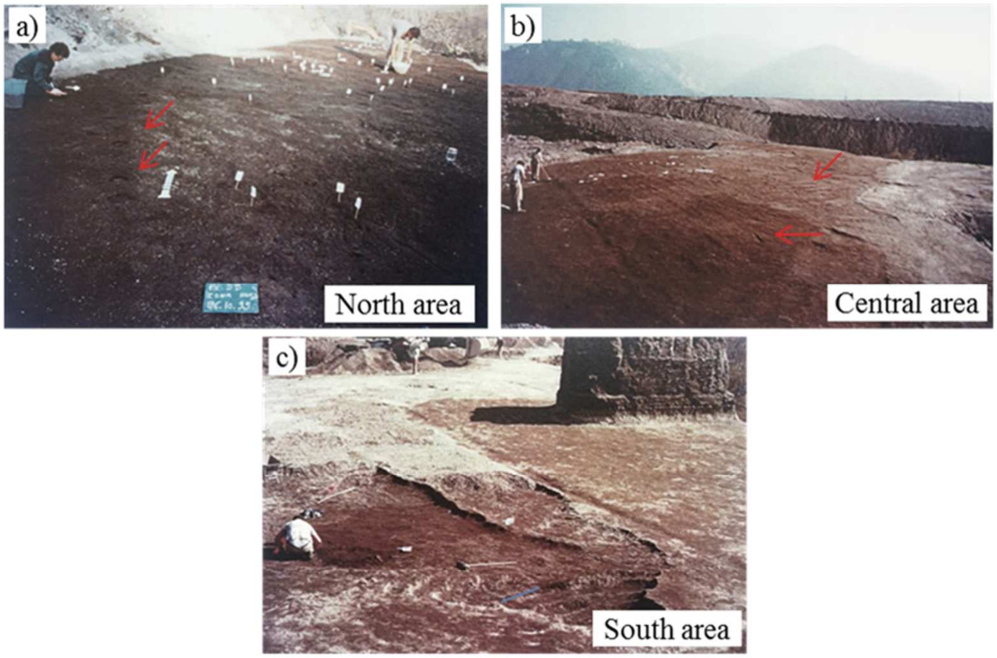

Figure 2. a) Chaotically scattered animal tracks in the North area; b) traces of agricultural activities in the Central area; c) microtopography of the South area.
160x107mm (150 x 150 DPI)

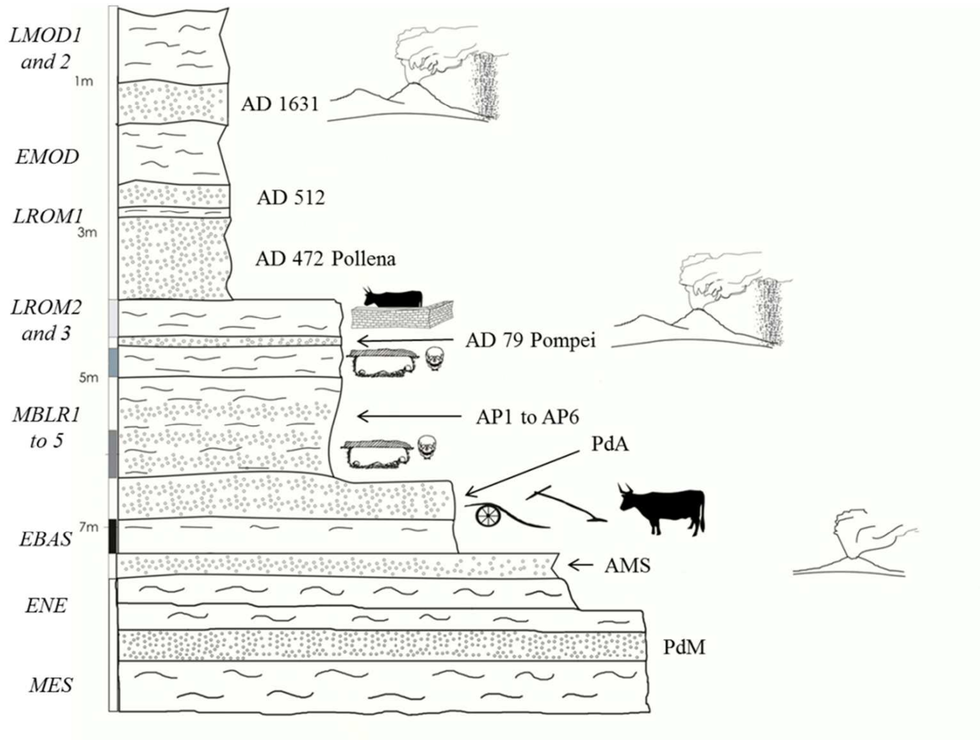

Figure 3. Sketch of the section-a: chronosequence of volcanic records and soils
222x166mm (150 x 150 DPI)

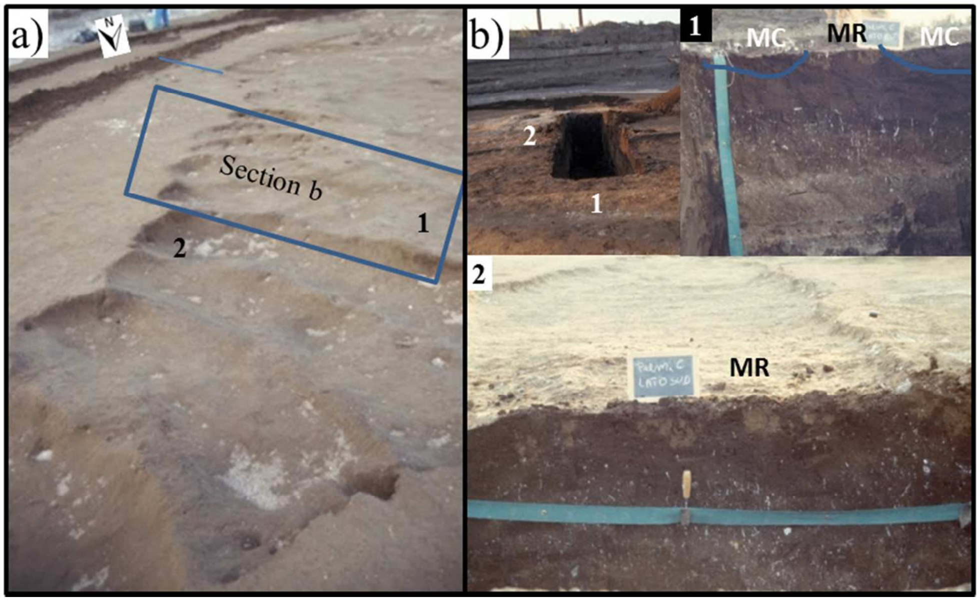

Figure 4. a) Position of the section-b with respect to the micro-topography of the southern sector; b) the profile 1 crosses microreliefs (MR) and concavities (MC), the profile 2 is along a microrelief.
149x90mm (150 x 150 DPI)

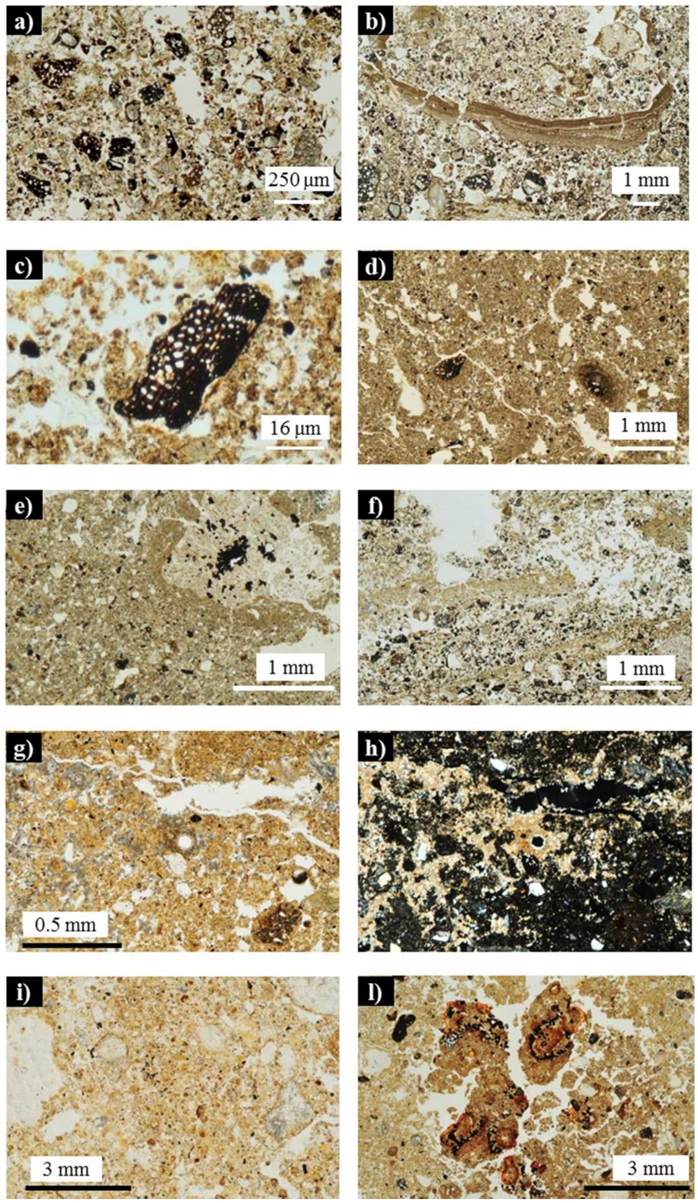

Figure 5. Micrographs of sola from the chronosequence, in plane polarised light (PPL) and crossed polarised light (XPL) of a) granular structure of LMOD1; b) compacted laminar features in EMOD (PPL); c) charcoal fragment in EMOD (PPL); d) iron segregations in the soil matrix of LROM1 (PPL); e) silty coatings around a poumice fragment, with internal iron segregations, in LROM1 (PPL); f) silty textural features in LROM3 (PPL); g and h) pore network filled by calcium carbonate segregations in PPL and XPL; i) weathered soil matrix in ENEO (PPL); l) iron segregations and clay coatings in MES (PPL).
120x208mm (150 x 150 DPI)

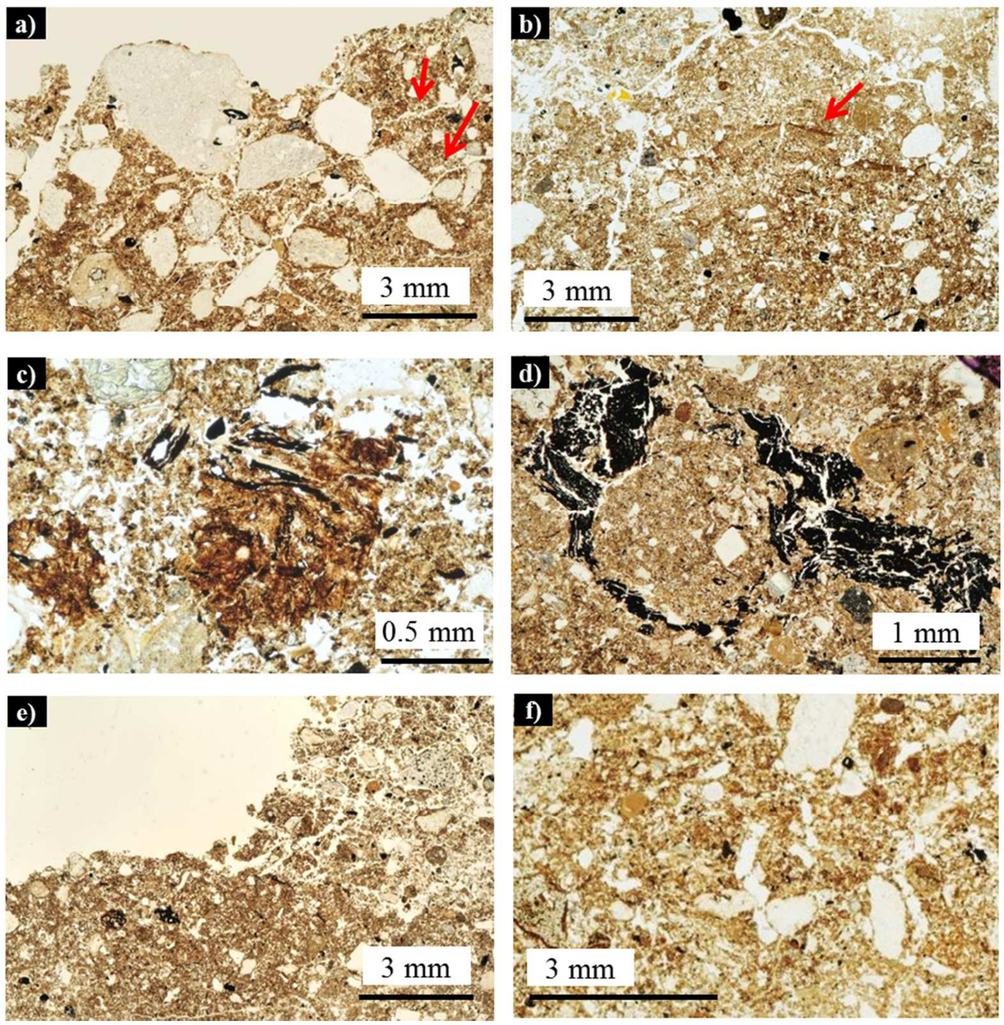

Figure 6. Micrograps of the Early Bronze Age microtopography in PPL. Microreliefs: a) crumb/granular structure in the first millimeters, where 2 red arrows indicated planar pores b) progressively massive structure with depth, with finer textured laminar aggregates horizontally oriented (indicated by the red arrow); c) organic residues mixed to charcoal in the soil matrix; d) fragment of strained charcoal embedded in the soil matrix; Microconcavity: e) massive and crumb structure on the surface, f) abundant fauna passages in depth.
159x162mm (150 x 150 DPI)

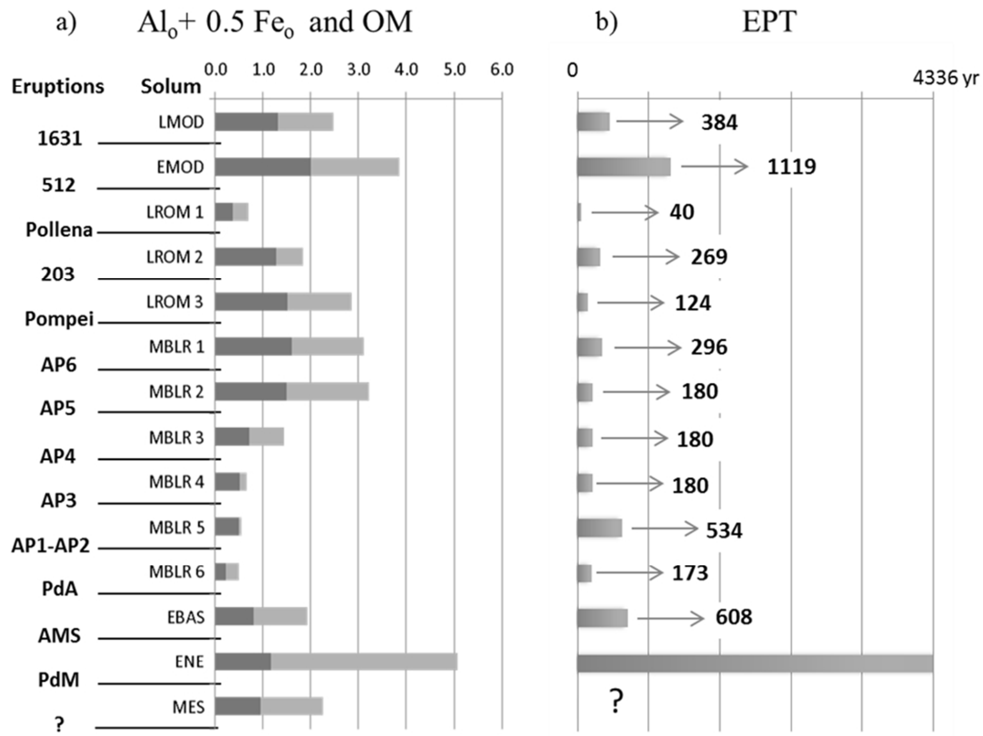

Figure 7. For each solum of the chronosequence are reported in a) Alo+0.5Feo index (dark grey) and the OM (light grey), both in %; b) estimated pedogenetic times (EPT) in years.
162x123mm (150 x 150 DPI)