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Reconstruction of Holocene environmental changes in two archaeological sites of Calabria (Southern Italy) using an integrated pedological and anthracological approach

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ABSTRACT

This paper focuses on the reconstruction of Holocene climatic and environmental changes in two archaeological sites of southwestern and north-central Calabria (southern Italy). It is based on a comparison of geoarchaeological, pedological and pedoanthracological data from soil profiles in the coastal hilly and inland mountainous surroundings of Palmi and Cecita Lake, respectively. At the Palmi site, the representative soil profile includes settlements and artefacts ranging from late Neolithic to late early Bronze Age and undifferentiated historical epochs. The archaeological record of soils at Cecita spans from late Neolithic/early Eneolithic to Roman ages. At both sites, surface A horizons are affected by repeated plough marks. All soils display some Andisol-like features, related to some volcanic input during soil formation originating from late Pleistocene to Holocene explosive eruptions of the Aeolian Islands. The occurrence of clay coatings, their relict nature and overall dominant phyllosilicate clay minerals in the Neolithic soil horizons of both sites, suggest warm climate conditions with high moisture availability and some seasonal contrast, during the late early-middle Holocene climatic *optimum*. The post-Neolithic soils show comparable or more abundant amounts of short-range order minerals than phyllosilicates, and no to scarce clay coatings. These features indicate a transition towards (probably cooler) prolonged humid conditions, intercalated by one or more drought episodes. Severe land degradation is recorded between these major climatic phases, indicated by human impact (deforestation and agriculture) and soil erosion. Soil charcoal analysis from Cecita soils provide evidence of these anthropogenic environmental changes, as indicated by the dominance of deciduous oak forest in Neolithic soils, followed by a transition to a mountain pine forest recorded in the Roman soils. A deciduous oak forest characterizes the vegetation at Palmi from the Neolithic onward.

1. Introduction

A prominent field of research in recent scientific literature is represented by the reconstruction of paleoclimatic and paleoenvironmental changes during the Holocene. Its relevance is based on its chronological continuity and direct relationship with modern climate and changing environments also under human pressure.

In this framework, the Mediterranean has peculiar climatic features that can be related to the orographic characteristics of the surrounding regions, to its complex outline which controls both marine and atmospheric circulations, as well as to its latitudinal and longitudinal location (Jalut et al., 2009). On the basis of pollen data, Holocene climate in this area can be considered as more or less stable, on the whole. A number of palynologists and phytogeographers mainly consider the present vegetation cover as a product of deforestation and agricultural practices rather than of natural eco-environmental dynamics (Reille and Pons, 1992; Pons and Quézel, 1998; Quézel, 1999). However, several proxies document important climatic variability during the Holocene at large to global scales (e.g. Allen et al., 2002; Davis et al., 2003; Dramis et al., 2003; Magny, 2004; Mayewski et al., 2004; Wanner et al., 2008). On the other hand, there is much debate concerning the relative roles of natural environmental changes versus effects of anthropogenic impacts (e.g. Sadori et al., 2004; Mercuri et al., 2011). The Mediterranean region was the cradle of western civilization and represented a crucial crossroad for land or

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maritime trades towards the continental east or westerly overseas destinations. As such it is likely to have been affected by human activities for a longer time and to a greater extent than northern European regions (cf. Allen et al., 2002), often promoting cause-effect mutual interactions between climate and cultural dynamics (Cremaschi and Di Lernia, 1999; Bernasconi et al., 2006; Frisia et al., 2006; Colacicchi and Bizzarri, 2008; Berger and Guilaine, 2009).

In this paper, archaeological, pedostratigraphic and anthracological approaches are integrated to reconstruct and compare local responses of some Holocene soil profiles in Calabria (southern Italy) to climatic and environmental changes, trying to evaluate the mutual role of natural and anthropogenic signals. They were excavated in two archaeological sites close to Palmi and Cecita Lake, in southwestern coastal and north-central inland Calabria, respectively, partly spanning the same time interval. In particular, archaeological finds and settlements of different epochs are used to fix chronological constraints; soil features and associated analytical data are interpreted in terms of climatic conditions and human activities; macroscopic soil charcoal content derived from *in situ* natural or anthropogenic fires provides information (complementary to traditional pollen-based reconstructions) about diachronic changes of vegetation on a local scale (Carcaillet and Thinon, 1996; Di Pasquale et al., 2008).

2. Geological and geomorphological settings

The study sites are located in two different geomorphological, environmental and climatic contexts in south-western and north central Calabria (southern Italy), respectively (Fig. 1).

The first site is located at “Piani della Corona”, close to the town of Palmi, on a wide terrace at about 500 m a.s.l., along the southern Tyrrhenian coast of Calabria (Fig. 1a). This area is characterized by a Paleozoic crystalline basement that represents the bulk of the Serre-Aspromonte mountain range, made of plutonic and medium- to high-grade metamorphic rocks (e.g. Bonardi et al., 2003; Ortolano et al., 2005; Cirrincione et al., 2008). It is covered by discontinuous Mesozoic to Miocene and Plio-Pleistocene sedimentary terranes (both carbonates and siliciclastics) (Cavazza et al., 1997; Bonardi et al., 2003). The landscape consists of a typical staircase sequence of Pleistocene marine terraces (Miyauchi et al., 1994; Bianca et al., 2011). Their evolution is strictly connected with strong Quaternary tectonic uplift and activity of high-angle normal faults affecting the Serre-Aspromonte massif (e.g. Galli and Bosi, 2002; Antonioli et al., 2006; Catalano et al., 2008). At Palmi, annual rainfall reaches mean values of about 980 mm, with mean annual temperature of 17.6 °C. At this site archaeological excavations exposed a pedostratigraphic succession including late Neolithic settlements and ceramic artefacts (Agostino and Tiné, 2008), superimposed by a widespread paleosurface of late early Bronze Age, in turn overlain by historical layers of undetermined epochs.

The second study site is located in the inland mountainous environment of the Sila Grande massif, namely around Cecita Lake (Fig. 1b). The Sila massif consists of Paleozoic high- to medium- and low-grade metamorphic complexes of the Calabrian Arc (e.g. Amodio Morelli et al., 1976; Van Dijk et al., 2000), intruded by a batholith made of plutonites (Messina et al., 1991). This crystalline basement, discontinuously covered by Mesozoic to Pleistocene

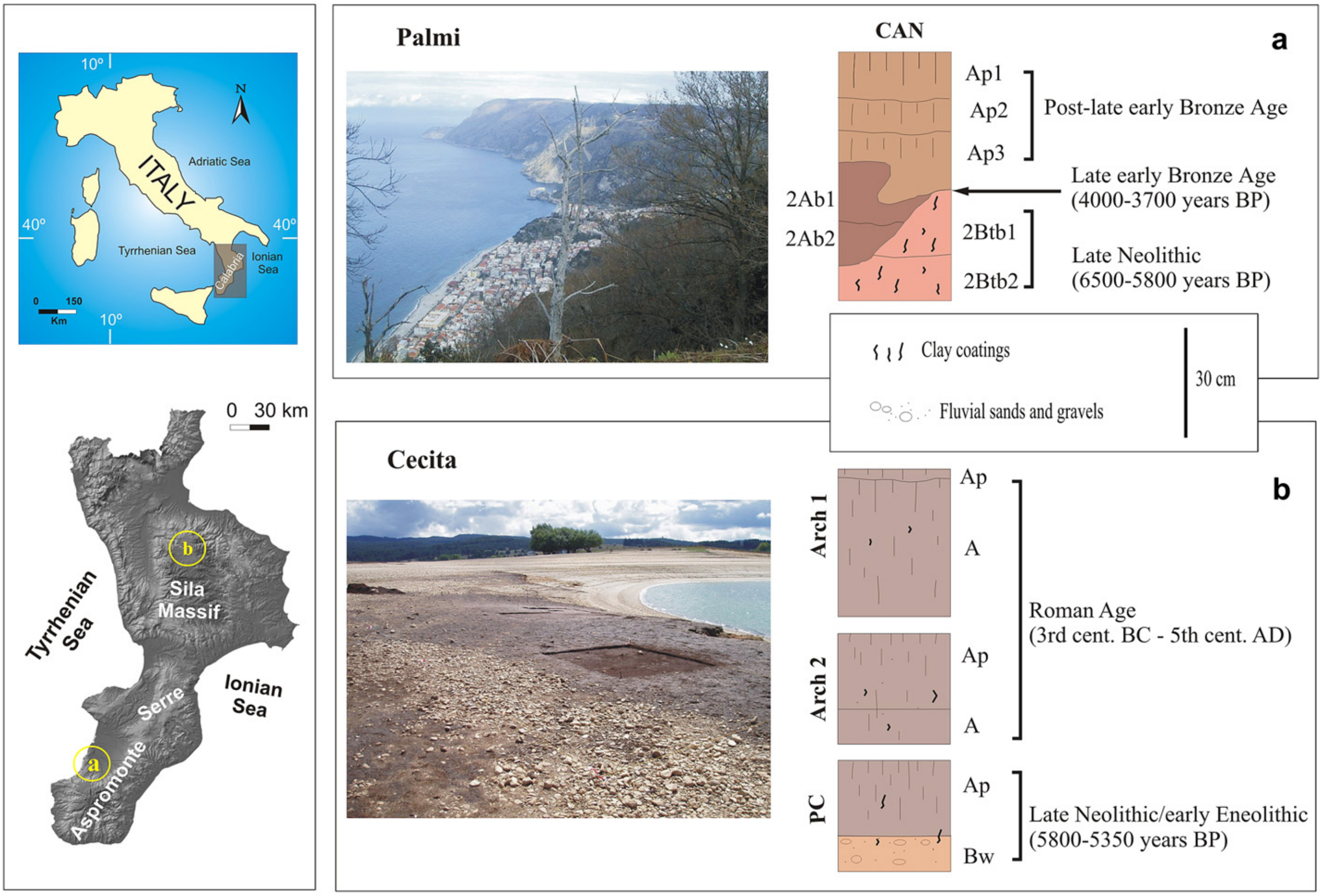

Fig. 1. Location of the study sites. General views of landscape contexts and schematic logs of representative soil profiles of Palmi (a) and Cecita sites (b), with archaeological and chronological information.

sedimentary units (e.g. Critelli, 1999; Van Dijk et al., 2000), was subsequently exhumed by erosion initiated by extensional tectonic phases. Cecita Lake is an artificial lake (created in the 1950s), which occupies an intramontane tectonic depression filled with Pleistocene terraced fluvio-lacustrine deposits of a paleo-lake (e.g. Scarciglia et al., 2005, 2008). In particular, on top of some terraces along the southeastern shores of Cecita lake, at about 1130–1140 m a.s.l., soils in an archaeological context were excavated. They include settlements, lithic and ceramic artefacts, spanning from late Neolithic/early Eneolithic to Greek and Roman times (Marino and Taliano Grasso, 2010). This study focuses on late prehistoric and Roman soils, because the Greek archaeological site (referred to the 6th–3rd centuries BC) is submerged to more than 6 m below present lake level. This site is characterized by mean annual rainfall exceeding 1600 mm and mean annual temperature of 10.1 °C.

3. Methods

3.1. Soil analyses

Representative soil profiles were described in the field at each archaeological site and sampled for chemical, mineralogical and micromorphological analyses. In particular, ammonium-oxalate extraction and atomic absorption spectroscopy (AAS) were applied on the fine earth fraction (<2 mm) to estimate aluminium and iron forms occurring in amorphous (and poorly-crystalline) soil materials (Schwertmann, 1964; MiPAF, 2000), i.e. entering metal-humus complexes and/or short-range order (aluminosilicate) minerals (SROM). On this basis the ICOMAND index ($Al_o\% + 0.5\ Fe_o\%$) proposed by the International Committee on the Classification of Andisols (ICOMAND, 1988) was calculated, as an indicator of andic soil properties (IUSS Working Group WRB, 2007; Soil Survey Staff, 2010).

Fourier transformed infrared spectroscopy (FT-IR) was performed on the clay fraction (<2 μm) with a special focus on clay mineralogy and organic matter. A Nicolet 380 instrument equipped with a Smart Orbit accessory operating in ATR (attenuated total reflectance) mode, measuring absorbance spectra in the region of mid infrared (wavenumbers between 400 and 4000 cm^{-1}) was used.

Micromorphological observations were conducted under an optical polarizing microscope on thin sections (10 cm × 5 cm × 30 μm), prepared from undisturbed soil samples impregnated with a polyester crystic resin and consolidated (FitzPatrick, 1984). Scanning electron microscopy and microprobe compositional analyses (SEM-EDS) were performed on thin sections, to identify possible volcanic input as parent material and related source areas. A Stereoscan 360 scanning electron microscope (Cambridge Instruments), equipped with an energy-dispersive X-ray analyzer with a Si/Li-SUTW detector (EDAX, Philips Electronics) was used.

3.2. Charcoal analysis

Soil charcoal analysis complemented the pedological study in order to provide a reliable proxy for the local woody vegetation with high spatial detail (Thinon, 1978; Carcaillet and Thinon, 1996). Charcoal analysis followed Carcaillet and Thinon (1996): soil samples were taken through the pedological horizons in the soil profiles and sieved by water through a sieving column with 2 and 0.4 mm mesh size. After drying, all charcoal fragments were sorted under a dissection microscope and then botanically identified. Taxonomical determinations were made by an incident light microscope at magnification of 100×, 200×, 500× and 1000×, using literature, wood anatomy atlases (e.g. Greguss, 1955, 1959; Schweingruber, 1990) and the references collection of the Laboratory of Vegetation History and Wood Anatomy (Università di Napoli Federico II, Portici, Italy).

4. Results

4.1. Field soil features

The pedostratigraphic succession exposed at the Palmi site is rather homogeneous all over the archaeological excavations and is represented by soil profile CAN (Fig. 1a). It consists of three topsoil horizons, characterized by repeated ploughing traces of undifferentiated historical epochs (Ap1, Ap2 and Ap3). They exhibit typical field features of volcanic soils with andic properties (IUSS Working Group WRB, 2007; Soil Survey Staff, 2010), such as high porosity and water holding capacity, free drainage, friable consistence, low bulk density, weak to moderate thixotropy (e.g. Buol et al., 1989; Terribile et al., 1999; Cinque et al., 2000). The plough layers are separated from underlying horizons by a paleosurface referred to about 4000–3700 BP on the basis of archaeological finds of late early Bronze Age. It truncates well-developed, dark yellowish-brown, deep, buried argillic horizons (2Btb1 and 2Btb2). The latter include late Neolithic settlements and artifacts of about 6500–5800 BP. Some dark brown humus-rich infillings occur in the Bt horizons. A concave surface borders a human excavation (probably a ditch), filled with at least partly artificially reworked, dark brown Neolithic topsoil horizons (2Ab1 and 2Ab2). In the surroundings, the Bronze Age paleosurface seals other traces of Neolithic archaeological structures, plough marks, cultivation ridges and various excavations (pole holes, cisterns, ditches and trenches), often filled with dark brown, humus-rich soil material derived from overlying A horizons.

The soil profiles selected in the archaeological excavations at Cecita Lake show some andic-like field appearance (cf. Scarciglia et al., 2008). Two soil profiles (Arch 1 and Arch 2) with Roman remains (ranging between the 3rd century BC and the 5th century AD) were dug (Fig. 1b). They comprise a dark brown Ap horizons (extremely shallow in the first Roman profile), affected by repeated modern ploughing traces. Below the Ap horizon another A horizon occurs. Also a prehistoric soil (PC) was selected, that includes settlements and artefacts of late Neolithic/early Eneolithic colonization (about 5800–5350 BP). It is characterized by a brown A horizon (in places also showing plough traces) overlying a dark yellowish-brown Bw horizon (Fig. 1b).

4.2. FT-IR data

On the basis of FT-IR spectroscopy, a rough estimate of clay mineralogy was achieved (Table 1). In all IR spectra a broad band of absorbance of H_2O stretching vibrations occurs in the range between 3700 and 3000 cm^{-1}, which is large in Palmi samples, but rather poorly expressed in those from Cecita. It indicates the presence of adsorbed and hydration water, which is typical of both short-range order minerals (SROM) such as imogolite, proto-imogolite and allophane (Gustafsson et al., 1999; Karltun et al., 2000) and phyllosilicates. Also an absorbance band diagnostic of the Si–0 chemical bond vibration at about 1000 cm^{-1} occurs in all samples from the two archaeological sites, and characterizes both SROM and phyllosilicate clay minerals. It is generally broader and asymmetric towards lower wavenumbers (absorbance values around 990–970 cm^{-1}) in short-range order aluminosilicates, and tends to form a well-defined, sharp peak in phyllosilicates (mainly observed in the Neolithic soil horizons of Palmi and in Cecita samples). Therefore, the contemporary occurrence of both groups of aluminosilicate clays can be supposed in all samples. In addition, poorly-crystalline components are also suggested by the presence

Table 1
Clay minerals and organic matter content estimated with FT-IR spectroscopy.

Site	Archaeological ages	Soil profile	Soil horizon	SROM	Phyllosilicates			OM
					Halloysite	Kaolinite	Illite	
PALMI	Post-Bronze Age	CAN	Ap1-Ap2	xxx	(x)	(x)		xxx
		CAN	Ap3	xxx	x	(x)		xxx
	Neolithic	CAN	2Ab1	xxx	(x)	(x)		xxx
		CAN	2Ab2	xxx	(x)	(x)		xxx
		CAN	2Btb1	(x)	x	(x)	(x)	x
		CAN	2Btb2	(x)	xx	(x)	(x)	xx
CECITA	Roman Age	Arch 1	A	x	(x)	(x)		x
		Arch 2	Ap	x	(x)	(x)		x
		Arch 2	A	x	xx	(x)		xx
	Neolithic	PC	A	x	x	(x)		xx
		PC	Bw	x	xxx	xx		

Increasing abundance of different components: (x), x, xx, xxx.
SROM: short-range order minerals; OM: organic matter.

of small absorbance bands at 690, 570, 505 and 430 cm^{-1} (Gustafsson et al., 1999; Basile-Doelsch et al., 2005) especially in Palmi soil horizons. On the other hand, phyllosilicates are evidenced by the typical doublet of absorbance bands at 3696 and 3623 cm^{-1}, which are diagnostic of 1:1 phyllosilicate clays (kaolinite and halloysite), due to stretching vibrations of hydroxyl groups. The presence of kaolinite and/or halloysite is also supported by the band around 910 cm^{-1}, expressed to variable degrees in all samples, coupled with two further peaks at 796 and 742 cm^{-1}, the former being almost always lower than the latter and thus suggesting that halloysite more likely occurs (Russell, 1987). The occurrence of illite cannot be ruled out as some of its diagnostic bands of absorbance at 3622, 821 and 754 cm^{-1} (more easily detected in the lower Neolithic layers of Palmi) are probably masked by halloysite bands. As a whole, some of the diagnostic bands of such phyllosilicate phases are more expressed in the Neolithic horizons than post-Bronze and Roman ones. SROM components prevail over phyllosilicates in the post-Neolithic soils of Palmi and Cecita, although their abundance changes significantly between the two sites.

Also the presence of organic matter is supported by IR spectra: absorbance bands between 1550 and 1660 cm^{-1}, along with a broad band around 1400 cm^{-1}, as expected, are generally more expressed in all Palmi samples, and in Cecita A horizons of Roman age rather than in the older Bw horizon of the Neolithic.

4.3. Andic properties

The estimation of andic properties related to possible short-range order minerals was assessed in soil profiles from Palmi and Cecita, using the ammonium-oxalate extracted forms of aluminium and iron. Al$_o$ and Fe$_o$ show rather homogenous values ($0.63 < Al_o < 0.92\%$ and $0.35 < Fe_o < 0.66\%$) for Cecita samples, whereas values are more variable ($0.94 < Al_o < 2.82\%$ and $0.69 < Fe_o < 1.50\%$) for the Palmi site. The ICOMAND index Al$_o$% + 0.5 Fe$_o$% calculated on their basis, is always lower than 2% and ranges from 0.80% to 1.19% in Cecita soils (Fig. 2a), whereas it always exceeds 2% in Palmi profile, except for its lowest soil horizon, where it ranges between 1.69 and 3.22% (Fig. 2b). On the whole, the measured values are coherent with a different degree of Andisol-like properties observed in the field.

4.4. Selected micromorphological features

Micromorphological observations permitted to identify yellow to brownish-yellow microlaminated clay coatings around skeletal grains and within pores in Neolithic soil horizons of Palmi (Bt) and Cecita (A and Bw) (Fig. 3a, b). They also occur to a much lesser extent in Roman A horizons at Cecita (Fig. 3c). In all these soil horizons clay coatings display slightly grainy to intensely stippled extinction patterns in crossed polarized light (XPL), and fragmentation. These features indicate a different degree of degeneration (sensu FitzPatrick, 1984), i.e. a rearrangement of clay particles caused by post-depositional "disturbing" processes. Moreover, isolated, subrounded fragments of reworked clay coatings (papules, as defined by Brewer, 1976), with sharp bands to weakly grainy extinction in XPL, occur. Frequently, dark brown, humus-rich infillings are found in Bt horizons from Palmi.

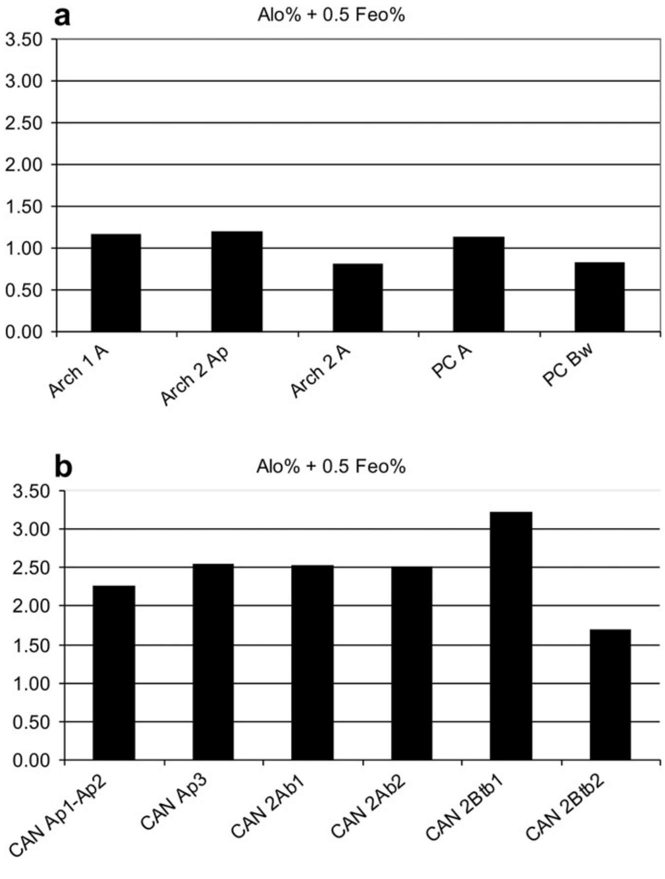

Fig. 2. Diagrams reporting the ICOMAND index for Cecita (a) and Palmi soil horizons (b).

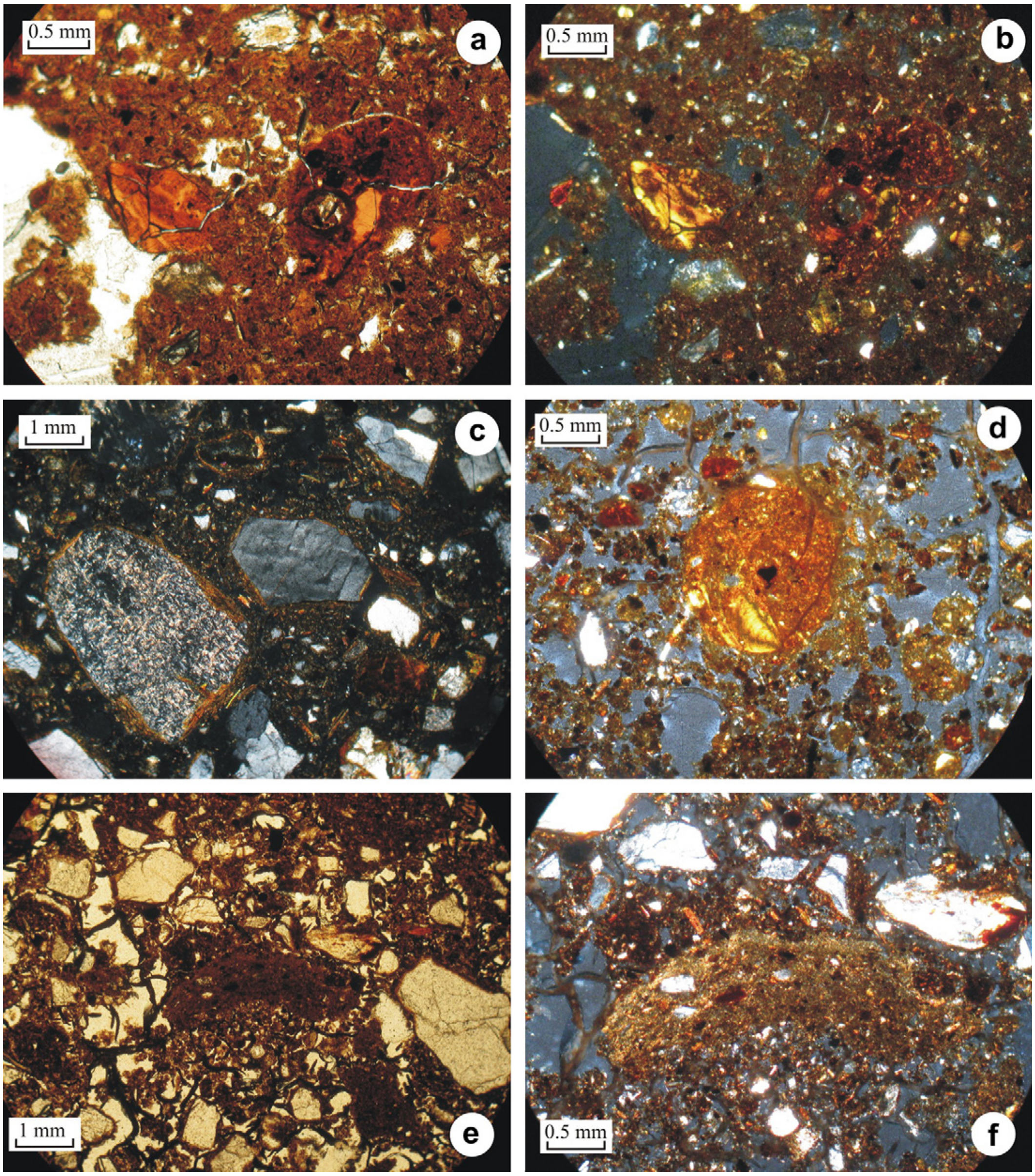

Fig. 3. Microphotographs of: fragmented and degenerated clay coatings in soil horizon 2Btb2 (profile CAN at Palmi) in plane polarized light (a) and crossed polarized light (b); clay coatings around skeletal grains in the Neolithic soil of Cecita (profile PC, horizon Bw, XPL) (c); dominant isotropic matrix surrounding a yellowish-red subrounded pedorelict which includes fragments of clay coatings (Palmi site, soil profile CAN, horizon 2Ab1, XPL) (d); elongated and curved laminated silt coating in horizon A (Cecita site, Neolithic soil profile PC), in plane polarized light (e); close-up of the same silt coating of Fig. 3e in crossed polarized light: optically anisotropic striated domains can be observed (f) (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Common subrounded pedorelicts, brownish-yellow to reddish-yellow and yellowish-red in colour, often including fragments of clay coatings, are present in various horizons of both Neolithic and post-Neolithic age at the Palmi site (Fig. 3d).

In all A horizons from both Palmi and Cecita, the soil matrix is dark brown and generally exhibits a dominant optically isotropic to poorly anisotropic behaviour between crossed polars (Fig. 3d). In Neolithic horizons it is moderately to highly anisotropic, with small, irregular to linear or curved anisotropic domains.

Occasionally, elongated and microlaminated silt coatings with linear to curved outline are observed in both Cecita and Palmi Neolithic soils (Fig. 3e, f). They appear sorted and graded, sometimes with cyclically alternated coarse and fine-textured laminae. They often exhibit optically anisotropic striated domains between crossed polars (caused by oriented clay particles), with parallel orientation to their elongation/lamination. Their continuity is locally broken by sharp fractures.

4.5. SEM-EDS analysis

SEM-EDS analysis permitted to identify very small amounts ($<1‰$) of volcanic glass (fine ash) dispersed within the matrix in all soil horizons from both sites, except for the Bw horizon of Cecita Neolithic soil. Volcanic fragments consist of very small pumices and shards, 20–200 μm in size (and therefore not observed in the field or under the optical microscope), characterized by vesicular structure with subrounded vacuoles. Their chemical composition is dominantly rhyolitic for both sites, with SiO_2 mainly ranging between 72 and 78% (only at Palmi also including a few samples with lower silica content) and the sum of alkalis ($Na_2O + K_2O$) close to or slightly higher than 8%.

4.6. Charcoal analysis

Charcoal analysis was carried out in the Neolithic (2Btb1) and post-Bronze Age (Ap1, Ap2, Ap3) horizons at the Palmi site and in the Neolithic (A from soil profile PC) and Roman horizons (Ap and A from soil profile Arch2 and A from profile Arch 1) at Cecita. Results are reported in Table 2.

Deciduous *Quercus* prevails in the samples from Palmi, indicating the presence of a stable deciduous oak forest from the Neolithic to the post-Bronze Age. *Arbutus unedo* detected in a post-Bronze Age horizon (Ap3) suggest the presence of stands characterized by evergreen shrub vegetation.

Data from Cecita show the presence of a mixed deciduous forest with deciduous *Quercus*, *Populus* and *Carpinus* in the Neolithic; scarce amounts of *Juniperus* (6.49%) and *Pinus sylvestris* group (5.19%) were also identified.

P. sylvestris group dominated charcoal assemblages in all samples dated to the Roman period. The *P. sylvestris* group includes *Pinus nigra*, *P. sylvestris* and *Pinus mugo*: this taxon is ascribed to *P. nigra* subsp. *laricio* because this species is an endemic and widespread tree in the mountain vegetation of Calabria, between 800 and 1800 m a.s.l. (Pignatti, 1982).

A minor proportion of deciduous *Quercus* (6.5%) is still present in the A horizon of the second Roman profile (Arch 2), whereas it disappears in the upper horizon (Ap) of the same Roman profile, where a less than 2% of *Prunus* and Rosaceae, and ca 4% of *Fagus sylvatica* were also identified in addition to more of 80% of *P. sylvestris* group. In the A horizon of the first profile (Arch 1) *P. sylvestris* group is the only identified taxon.

5. Discussion

Morphological field features and laboratory data of the studied soil profiles from both archaeological sites of Palmi and Cecita Lake revealed some similarities coupled with peculiar differences. In particular, their common but varying Andisol-like field appearance was demonstrated to be caused by some contribution of volcanic input as parent material concurring to soil formation and by the occurrence of some amounts of short-range order minerals as neogenic products. At both sites, very small pumice particles with high silica and alkali content were recognized at the microscale using SEM-EDS. On the basis of their dominant rhyolitic composition, they were likely emplaced mostly from the same source, namely the nearby Aeolian Islands (located to SW in the Tyrrhenian Sea), during late Pleistocene to Holocene volcanic explosive eruptions (Scarciglia et al., 2008; Bernasconi et al., 2010). Coherently, micromorphological observations showed a prevailing optical isotropic behavior of soil matrix in all A horizons between crossed polars, suggesting a low amount of phyllosilicates and conversely dominant poorly-crystalline and amorphous materials, namely SROM and organic matter. These data are also consistent with results of FT-IR spectroscopy and values of ICOMAND index, although clear differences between the two sites are evident. In particular, higher concentrations of short-range order minerals at Palmi site are supposed by $Al_o\% + 0.5\ Fe_o\%$ values higher than 2% in almost all soil horizons except the lowest horizon 2Btb2. In contrast, these components are always lower at Cecita, where the ICOMAND index exceeds the minimum threshold of 0.4% for andic properties but never reaches 2% (cf. IUSS Working Group WRB, 2007; Soil Survey Staff, 2010) and therefore can be considered as a proxy of moderately developed andic properties (Scarciglia et al., 2008). This difference between the more proximal (coastal) site of Palmi and the more distal (inland) one of Cecita, as well as further differences within various horizons of each soil profile, could have been caused first by a different primary amount of volcanic ash that reached each site, as a consequence of distance from source area and time. In addition, time could have also influenced a different degree of soil development and especially of andic properties, which are usually related to early stages of pedogenesis on volcanic ashes. Phyllosilicate clay minerals such as halloysite (and/or kaolinite) are on the whole more abundant in Neolithic B horizons than post-Neolithic layers from both sites. The concurrent presence of phyllosilicates especially in the Neolithic soils, also coupled with the occurrence of clay coatings, suggest an older stage of soil development than the post-Neolithic soils. These mineral phases could have been at least partly transformed from SROM over time. However, some paleoclimatic/environmental interpretation is also proposed. In fact, clay coatings and phyllosilicates in Neolithic layers suggest a warm climate characterized by high moisture availability and some seasonal contrast. In addition, the relict character of clay coatings, indicated by their degeneration patterns, points to their emplacement during the latest phases of clay illuviation in temperate mid-latitude and Mediterranean environments. They are well documented during the early-middle Holocene climatic *optimum* (Catt, 1989; Cremaschi and Trombino, 1998; Scarciglia et al., 2009; Bernasconi et al., 2010; Pelle et al., 2010). On the other hand, SROM phases associated with lower amounts of phyllosilicate minerals in post-Neolithic layers of both archaeological sites, suggest the weathering of volcanic glass under overall prolonged moisture availability, which is the most suited condition for their formation (Duchaufour, 1982; Parfitt et al., 1984; Buol et al., 1989). Such pedoenvironmental conditions are also supported by no to scarce clay coatings in the younger soil horizons/profile at Palmi and Cecita, respectively. Although no precise or continuous chronological information is available in these sites

Table 2
Results of soil charcoal analysis at Palmi and Cecita. *Taxa* percentages were calculated from the sum of analyzed charcoals in each horizon.

Site	Archaeological ages	Soil profile	Soil horizon	Taxa %										
				Deciduous *Quercus*	*Populus*	*Carpinus*	*Pinus sylvestris* group	*Juniperus*	*Prunus*	Rosaceae	*Fagus sylvatica*	*Arbutus unedo*	Monocotiledon	No id.
PALMI	Post-Bronze Age	CAN	Ap1-Ap2	50.00									37.50	12.50
		CAN	Ap3	33.33								11.11		55.56
	Neolithic	CAN	2Btb1		62.50									37.50
CECITA	Roman Age	Arch 1	A				96.97							3.03
		Arch 2	Ap				82.35		1.96	1.96	3.92			9.80
		Arch 2	A	6.52			80.43							13.04
	Neolithic	PC	A	71.43	7.14	1.30	5.19	6.49						8.44

Taxa Percentages were calculated from the sum of analyzed charcoals in each horizon.

for post-Neolithic soil development, the stop/decrease of clay illuviation could be related to drought phase/s, inhibiting water percolation downprofile and consequent clay translocation. Indeed, one or more drought phases (ca. 5.5, 4.7–4.0, around 3 and 2 ka BP) already known in the literature (e.g. Sadori and Narcisi, 2001; Allen et al., 2002; Hunt et al., 2004; Mayewski et al., 2004; Di Rita and Magri, 2009; Jalut et al., 2009; Swindles et al., 2010) could have been responsible for such an environmental change. It is important to underline that the effects of these drought episodes very likely were not the same and/or synchronous at both study sites, as clearly highlighted by the above quoted different response of clay illuviation after prehistoric times. Higher elevation and rainfall related to the mountainous environment of Cecita presumably permitted more prolonged water availability in the soil system than in the Palmi area, to promote reduced formation of clay coatings even until the Roman age. On the other hand, overall climate drying should have been not particularly strong and/or just temporary, as a restoration of overall prolonged humid conditions is suggested by SROM prevailing over phyllosilicates after the Neolithic period (specially in Palmi, see above). Such conditions, possibly coupled with lower temperature (Davis et al., 2003; Sauro et al., 2003; Mayewski et al., 2004; Di Donato et al., 2008), repeatedly alternated in the second half of the Holocene (e.g. Dramis et al., 2003; Magny, 2004; Giraudi, 2007). They could have promoted a minor seasonal contrast that could also explain well the decrease/disappearance of clay coatings during the Roman age at Cecita and after the Bronze Age at Palmi, respectively. At both sites, major changes in climatic conditions recorded by soil features between Neolithic and following periods, also correspond with pedo-archaeological evidence of severe land degradation. A clear superimposition and interfingering of natural environmental signals with anthropogenic modifications can be argued. In particular, surface and buried A horizons, appear variably affected by erosion to varying degrees, as indicated by their at least partial truncation. The dark brown natural infillings (recognized in the field and in thin sections) in late prehistoric Bt horizons at Palmi can be interpreted as cavities left by decomposed roots or bioturbation, filled with humus-rich material derived from old topsoil horizons (later eroded). The latter were probably once fertile and developed at the surface under particularly well-suited climatic conditions (the above Neolithic *optimum*) and vegetation cover. A similar explanation is proposed for artificial humus-rich fillings of cisterns, ditches and similar human-made structures. Also, the reddish-yellow pedorelicts found in A horizons, probably stripped off from underlying Bt horizons, represent further evidence for soil degradation and erosion. These results highlight that erosion processes were probably enhanced by human impact, which consisted of archaeological structures and various excavations, coupled with deforestation, performed to create arable land (even using fires) and/or to exploit wood as raw material. Although interpretation of silt pedofeatures is not univocal but often disputable, in such context the fragmented, laminated, sorted and striated silt coatings identified in Neolithic soil horizons from both Cecita and Palmi sites can be likely interpreted as agro-striated b-fabric (cf. Huisman et al., 2009): they probably represent illuvial and stress pedofeatures caused by agricultural activities, namely ploughing, as also suggested by plough marks and ridges described in the field.

Such an interpretation is strongly supported by soil charcoal analysis data, especially from Cecita Lake. In fact, whereas charcoal fragments indicate vegetation consisting of an oak-dominated deciduous forest in Neolithic soils of both sites, a major vegetation cover change is recorded in the Roman soils of Cecita, where a mountain pine forest replaces the deciduous forest. This transition can be only partly explained by mid- to late Holocene climatic changes discussed above, as their effects should not have been particularly drastic on vegetation dynamics in such cool and humid mountainous environment. In addition it is noteworthy that *P. nigra* subsp. *laricio* is a pioneer and heliophilous tree able to colonize open ground (Pignatti, 1982; Quézel and Médail, 2003); thus pine colonization must be preceded by severe deciduous forest degradation. These considerations rather point to a relevant role of anthropogenic degradation of the soil and vegetation cover, possibly superimposed on and enhancing the effects of a shift towards a drier climate.

On the other hand, the deciduous forest is maintained in the soil horizons overlying the Bronze Age paleosurface at Palmi. From a vegetation point of view, it is relevant to stress the different altitudes of the sites. In fact, any climatic shift towards drier conditions would have had a major impact on the vegetation at the lower altitude of Palmi; thus, the fact that oak forest is still present after the quoted early-middle Holocene climatic *optimum* reinforces the idea of human-induced degradation at Cecita. This different behaviour could be tentatively related to a more limited spatial extension of human impact for settlement and agriculture, without complete destruction of the surrounding forest cover. However further studies are needed to better constrain the chronology of the post-Bronze Age horizons at Palmi and to fill the time gap between Neolithic and Roman period at Cecita.

6. Conclusion

This paper successfully used the potential of combining archaeological, pedological and paleobotanical (pedoanthracological) approaches to reconstruct and compare local environmental responses of soil and vegetation in Calabria (southern Italy) to Holocene climatic changes and human activities. Two different archaeological sites with different geomorphological and environmental conditions (namely a hilly coastal one close to Palmi and another inland mountainous one around Cecita lake) were investigated in terms of soil features and genetic processes, (paleo) vegetation dynamics and effects of anthropogenic land-use and living practices. Results of pedological analyses are strongly consistent with those obtained from soil charcoal analysis, probably also due to the natural mutual feedback between soil and vegetation. They both fit well with archaeological evidence. In particular, evaluation of andic soil properties in several horizons from both sites with recurrent but varying Andisol-like field appearance revealed to be a reliable proxy for assessing climatic and (pedo)environmental changes. Warm-humid conditions (climatic *optimum*) were reconstructed both at Palmi and Cecita during the Neolithic, on the basis of relict clay coatings and dominant phyllosilicates in soils, under an oak-dominated deciduous forest cover. After the Neolithic, an overall increase of short-range order minerals and decrease or interruption of clay illuviation suggests a transition towards cooler and prolonged humid conditions, probably alternated with one or more drought phases. Such climatic changes are accompanied by a severe land degradation and soil erosion, promoted or strongly enhanced by human pressure (mainly forest clearance and agriculture). In fact, the oak forest is drastically replaced by a mountain pine forest at Cecita during (and possibly before) the Roman age. On the other hand, it is maintained at Palmi also after the Neolithic and the Bronze Age, likely as a consequence of less wide spatial extension of human impact.

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