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COMPARATIVE STUDY OF TWO LATE PLEISTOCENE SEQUENCES WITH PALEOSOLS AND AEOLIAN DEPOSITS AT THE SOUTHERN ALPINE FORELAND

Abstract: Peresani M. & Nicosia C., *Comparative study of two Late Pleistocene sequences with paleosols and aeolian deposits at the Southern Alpine foreland*. (IT ISSN 0391-9838, 2015).

Two pedostratigraphic sequences located between the Euganean and Berici hills (Veneto region, north-eastern Italy) were investigated. In such sequences, morphogenic and pedogenic processes could be ascribed to the Late Pleistocene climatic evolution, based on pedostratigraphic characteristics and on archaeological finds. The series prove the degradation of the vegetation cover along the local slopes, followed by the truncation of paleosols due to widespread hillwash phenomena. The latter result in the concentration of coarser elements along an erosional surface, with successive displacement due to gelifluction. This process indicates climatic change towards glacial conditions, with an open environment that is characterized also by loess sedimentation.

Keywords: Paleosols, Loess, Late Pleistocene, Berici Hills, Euganean Hills, Northern Italy.

Riassunto: Peresani M. & Nicosia C., *Studio comparative di due sequenze del Pleistocene Superiore con paleosuoli e depositi eolici nell'avanpaese delle Alpi meridionali*. (IT ISSN 0391-9838, 2015).

Due serie pedostratigrafiche sono state analizzate nell'area posta tra le pendici occidentali dei Colli Euganei ed i Colli Berici (Veneto). Le due sequenze documentano eventi morfogenetici e pedogenetici che, sulla base delle caratteristiche pedo-stratigrafiche e del contenuto archeologico, possono essere inquadrate nell'evoluzione climatica del Pleistocene Superiore. Le serie documentano la degradazione delle coperture vegetazionali dei versanti, la conseguente troncatura dei paleosuoli per dilavamento diffuso ed accumulo di elementi grossolani sulla superficie di erosione, ulteriori processi di geliflusso che delineano una progressiva degradazione del clima in senso glaciale. Gli effetti di quest'ultima sulla riduzione della copertura vegetale si fanno sempre più evidenti fino a raggiungere le condizioni di ambiente aperto correlate anche alla deposizione del loess sui rilievi calcarei.

Termini chiave: Paleosuoli, Loess, Pleistocene Superiore, Colli Berici, Colli Euganei, Italia settentrionale.

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INTRODUCTION

In the Po plain and in the bordering hill complexes, different archives provide data on Middle and Late Pleistocene climate evolution (Cremaschi, 1987; Amorosi & *alii*, 2004; Massari & *alii*, 2004; Fontana & *alii*, 2014; Ferraro, 2009; Ridente & *alii*, 2009; Scardia & *alii*, 2010; Ravazzi & *alii*, 2012), occasionally with millennial-scale resolution (Monegato & *alii*, 2007; Pini & *alii*, 2010). Notwithstanding an increasing amount of contexts studied between the Alpine fringe and the northern Adriatic Sea (Fontana 2006; Fontana & *alii*, 2008; Pini & *alii*, 2009; 2010), some areas remain marginally investigated. Among these, we can include the Euganean and Berici hills, two isolated hill complexes that emerge from the Quaternary alluvial sediments deposited by the Bacchiglione, Brenta, Adige and other minor rivers (Zangheri, 1988-89; Mozzi, 2005; Fontana & *alii*, 2008; Monegato & *alii*, 2011; Fontana & *alii*, 2014). Especially in the Euganean hills, the effects of Late Pleistocene climate variability on landforms and slope evolution are still poorly known. These are in fact generally inferred on the basis of supra-regional evidences (Piccoli & alii, 1981), gathered in areas that were not directly affected by glacial advance or by fluvial morphogenesis, such as the central-oriental Alpine fringe. Sedimentary and palaeopedological slope sequences can be of key importance for the definition of the palaeo-environmental and climatic changes that took place in the Mediterranean area between the Middle and Late Pleistocene (Busacca & Cremaschi, 1998). Here, the main morphogenic processes include aeolian sedimentation, deposition of colluvium, solifluction, cryoclastic phenomena in caves and rock shelters, as well as pedogenesis (see Ferrarese & Sauro, 2005; Sauro, 2002; Cremaschi, 1987; 1990a; 1990b; 1990c). Aeolian dust sedimentation has been traced over the Northern Adriatic region until southern Dalmatia (Cremaschi, 1990a), including the margin of the Po plain and the pre-Alpine plateaus, where loess blankets thinner than one meter can be found. These are characterized by a marked granulometric sorting, by trends reflecting the distance from deflation areas, by the dominance of quartz as well as micas, and by mineralogical compositions reflecting those of the sediments of the main Po plain rivers.

A new contribution to this scenario is provided by the two pedostratigraphic sequences presented in this paper. The exposures ar quence, some of the processes will be also put in relation to an archaeological record of the Middle Palaeolithic (see Peresani, 2000-2001).

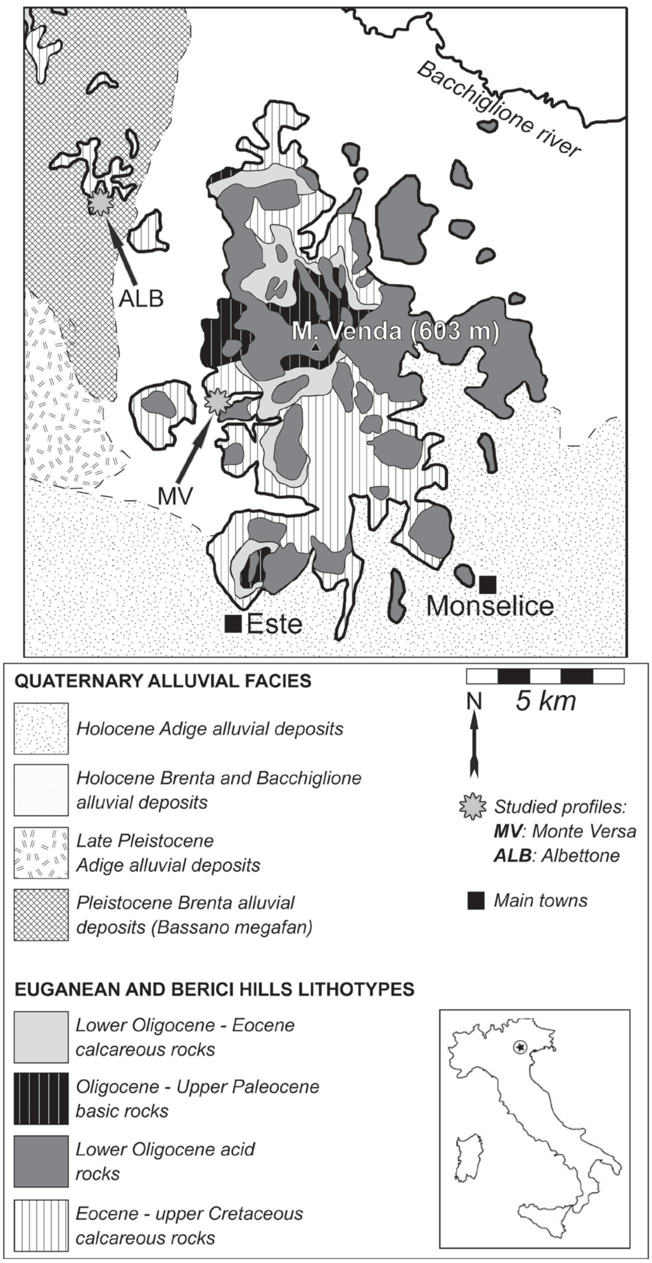


FIG. 1 - Position of the studied profiles between the Euganean and the Berici Hills (Based on: Regione del Veneto, 1990; Piccoli & *alii*, 1981; Mozzi, 2005)

PHYSICAL SETTING OF THE EUGANEAN HILLS AND SURROUNDING AREAS

The Euganean hills, and the ridges extending westward towards the foothill of the Berici, are isolated hills emerging from the floodplain with an area of more than 100 km². They occur as a rough ellipse with a N-S major axis, a main central nucleus and isolated outcrops located to its W and E (fig. 1). They include three main morphological domains. First, a group of lowlands located around the hill complex (Galzignano formation; see Cucato & *alii*, 2011). These occur 3 to 5 m below the surrounding floodplain and host palustrine environments. Their formation dates to the Last Glacial Maximum (LGM), when the Brenta megafan reached its maximum extension (Mozzi, 2005; Fontana & *alii*, 2008). The remaining portion of the floodplain, south of the Euganean and Berici hills, is the outcome of the Adige river activity. Sedimentary accretion led to the burial of the Euganean foothill and to the damming of many Euganean valleys. The alluvial sedimentation is also responsible for the rugged outline of the contact between the foothill and the plain and for the occurrence of scattered isolated hills or groups of hills.

The second morphological domain occurs between 100 m and 200 m a.s.l., where calcareous marls and marls prevail. These give rise to slightly undulating topographic profiles, with smooth ridges and short plateaus. This domain comprises slightly dipping surfaces occurring at different heights, interpreted originally as the remains of ancient piedmont surfaces (Schlarb, 1961), often difficult to identify on the ground (Donà, 1964). Their origin is nevertheless linked to structural or lithologic causes, but a review of their formation model appears still necessary (see Piccoli & *alii*, 1981; Zanferrari & *alii*, 1980). The existence of surfaces unrelated to structural control or to selective erosion is in fact well established. These occur on volcanic bedrocks, colluvia, strongly weathered stream deposits but also on thick blankets of alterites formed on acid volcanic bedrocks. The degree of weathering suggests a Middle or even Early Pleistocene age (Cucato & *alii*, 2011).

The third morphological domain occurs in the highest areas (400-600 m a.s.l.), and comprises basic and acid volcanic rocks formed as a consequence of two distinct volcanic cycles in the Upper Eocene and in the Lower Oligocene (Piccoli & *alii*, 1981). Here, the relief is characterized by marked topographic gradients, and conical and pyramidal morphologies are dominant.

Limited outcrops of Upper Cretaceous limestone occur along the foot of the eastern scarp of the Berici hills and in small isolated hills between the Berici and Euganean hills, among which the hills around the town of Albettone, where one of the studied profiles is located (Monte San Giorgio – fig. 1). These hills have an elevation of 70-100 m a.s.l. and are the relicts of a planation surface, possibly of Miocene age (Sauro, 2002). These upper Cretaceous limestones were deposited in a deep-sea environment and occur in lenticular stratified sets. They are termed "Scaglia Rossa" formation (Mietto, 1988; Cucato & *alii*, 2011).

The local landscape appears therefore rather articulated and is characterized by abrupt passages from one morphological style to the next. Beside slope processes, which contributed to the degradation of relief, the role of surface water erosion and mass wasting phenomena must be also noted. These processes led to the formation of gentle and small fans at the mouth of the valleys. No surface karst features are present.

Present-day climate

The meteorological station for the studied portion of the Euganean hills is located on Monte Venda (580 m a.s.l.; data series from 1923 to 1962 from ESAV, 1996). Here, the average annual temperature is 10.8 °C, with July being on average the warmest month (20.2 °C) and January the coldest (1.4 °C). Average rainfall is between 700 and 900 mm/yr, with absolute maximum values between 1200 and 1400 mm (spring and autumn) and minima between 450 and 600 mm (winter and summer). The annual average potential evapotranspiration in these higher parts of the hills is 668 mm, with an average excess of precipitation of ca. 200 mm.

Climate data for Albettone (24 m a.s.l) are derived from Veneto Agricoltura (2010) and are based on 1976-2005 data series. Mean annual temperature is 13.0 °C, with July being on average the warmest month (23.6° C) and January the coldest (2.4° C). Average rainfall is 925 mm/yr with maxima in spring and autumn and minima in winter and summer. Potential evapotranspiration amounts to 950-1000 mm/yr (slight water deficit).

According to the method of Thornthwaite & Mather (1957), in the study area the climate is humid (see also ARPAV 2005). For the classification system of Soil Taxonomy (Soil Survey Staff, 2010) the soil temperature regime is mesic with a predominant udic soil moisture regime.

MATERIALS AND METHODS

The studied sequences

Monte Versa

Monte Versa is a calcareous hill that makes up the SW end of the Monte Venda – Monte Vendevolo ridge. The hill is made up by calcareous marls of the Maiolica, Scaglia Variegata Alpina, and Scaglia Rossa formations (see Cucato & *alii*, 2011), all of which exhibit planar parallel stratification and occur in decimetre-thick units. The Maiolica formation outcrops in the lower portion of the SW hillside, with a plunging angle of about 10° and NW-SE direction. The Scaglia Variegata Alpina and Scaglia Rossa formations outcrop in the middle and upper portion of the hillside and make up the remaining part of the hill up to the Monte Vendevolo foothill to the north-east. Here, a belt of Euganean marls, tuffs and basaltic hyaloclastites outcrops (fig. 1).

The hilltop (136 m a.s.l.) is smooth and rounded. Beyond it, the hill is markedly asymmetrical with respect to the NE-SW axis, with the SE side being steeper than the NW one. The first break in slope is where the Monte Versa sequence is located. The foot of the hill is buried by a silty-clay deposit which gets thicker until as it reaches the alluvial plain.

In the upper portion of the hillside, an outcrop of ca. 1 m of thickness with slight planar parallel stratification can be observed. This is composed by an alternating sequence of gravels and silty gravels, varying from light brown (7.5YR 6/4) to light yellowish brown (10YR 6/4). The skeletal grains comprise subangular to subrounded gravels of Scaglia Rossa with frequent angular red chert fragments. Occasional flattened clasts of Scaglia Rossa show traces of secondary fracturing. Gravels are in general dominant on the fine fraction, even in the clast-supported silty gravel layers. They show variations in size, however, never exceed 5 cm. Layers are cm-thick and locally cemented, giving rise to veins oriented parallel to the topographic surface above. The overall thickness of these deposits is not known, as the contact with the underlying bedrock was not reached. The carbonatic matrix contains a subordinate amount of unweathered loess. This sequence can be compared with other deposits observed on the Euganean hills and interpreted as the result of colluvia and sheet flows which incorporated the weathering mantle formed on Scaglia Rossa and pre-existing soils, with intercalated solifuction deposits. The cemented horizons can be associated with the calcic horizons of a well-developed soil, now truncated, covered by more recent colluvia (Po synthem – see Cucato & *alii*, 2011). The pedo-sedimentary sequence that is analyzed in detail below rests on top of these deposits (defined horizon 4Cck).

Albettone

Similarly to Monte Versa, also Monte San Giorgio is a hill (101 m a.s.l.) formed on the calcareous marl substrate of the Scaglia Rossa formation, with plano-parallel stratifications and decimetre-thick beds (see fig. 1). The studied sequence was exposed along the SE hillside, characterized by a slope angle of ca. 10°. The foothill is linked to the alluvial plain by a colluvial cone. The south-eastern foot of the Monte San Giorgio hill is articulated in a series of ridges and smoothed valley that descend towards the floodplain.

Laboratory methods

The field description of profiles was carried out according to the guidelines of FAO (2006). Munsell colours were determined on the field on wet soil.

Sands (2000 mm - 63 mm) were quantified by wet sieving, while silts and clay by hydrometric analyses. Chemical analyses were performed on the <0.5 mm fraction. pH was measured with a potentiometer in H_2O with a soil to water ratio of 1:2.5. The amount of total carbonates was determined by means of a Dietrich-Frühling calcimeter, whereas organic carbon by the Walkley & Black method (Walkley & Black, 1934). The soil organic matter value was obtained by multiplying the organic carbon percentage by 1.72 (for the exact description of laboratory procedures see S.I.S.S., 1985).

Heavy minerals were determined on the sands between 250 µm and 63 µm, after removal of carbonates with 18% HCl and of iron oxides by boiling in oxalic acids with aluminium as catalyst (Parfenoff & *alii*, 1970; Cremaschi & Rodolfi, 1991; Mange & Maurer, 1992). The separation was carried out using sodium metatungstate ($Na_6O_{39}W_{12} \cdot H_2O$), with known density of 2.85 g cm^{-3}. Grains were mounted on a slide with Canada balsam and determined according to the guidelines of Parfenoff & *alii* (1970) and Mange & Maurer (1992), counting 150 grains for each sample. Weathering index in table 3 and 7 has been calculated as ratio of (%Zirc.+Tourm.+Ti Ox+Staur.+Garn./% Amph.+Pyr.+Epid.) according to Cremaschi (1987). Thin sections were manufactured from undisturbed and oriented blocks according to the methods exposed in Murphy (1986). The description of thin sections under the polarizing microscope followed the terminology and concepts of Stoops (2003).

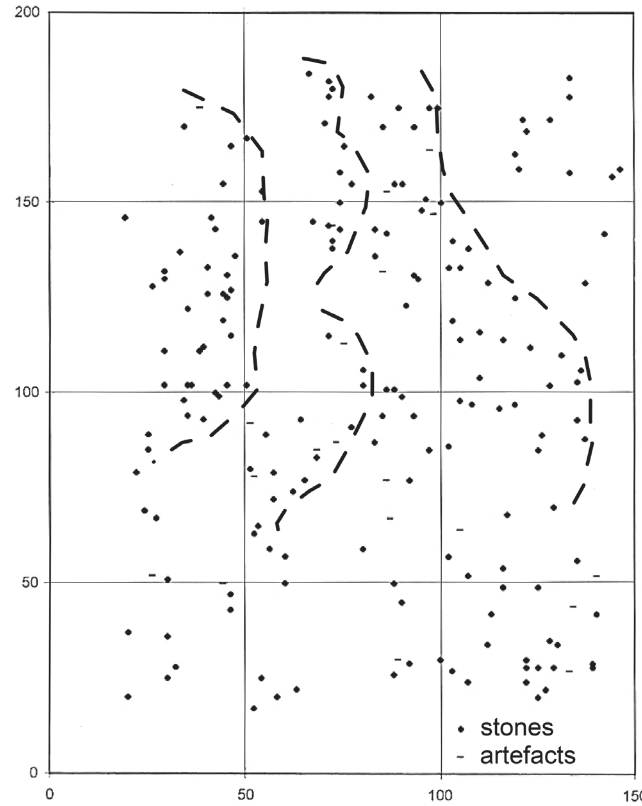


FIG. 3 - Monte Versa. Spatial distribution of stones and artefacts occurring within the stone line. Slope orientation is from left to right of the diagram. Grid measures expressed in centimetres (after Peresani, 2000-2001).

RESULTS

MONTE VERSA

Stratigraphic description

The pedo-stratigraphy of Monte Versa can be subdivided in three pedostratigraphic levels (sensu Costantini & Prioi, 2007) (fig. 2; tab. 1).

The present-day Ap horizon rests on an isopachous layer composed by unsorted chert clasts in a silty-clayey, non-calcareous, matrix (horizon C). Traces of re-organization of the coarse fraction can be observed. An abrupt lower boundary marks the passage to the second pedostratigraphic level. The latter is massive and composed of stones and dark brown decarbonated silty-clayey matrix (horizons 2Bt1 and 2Bt2). Scarce chert clasts and rare scattered Palaeolithic artefacts, which tend to increase in number towards the base, are present. Its lower boundary is abrupt and wavy, with a stone line dipping towards SW with an angle lower than that of the present-day surface. The thickness of this stone line is given by the degree of concentration of stones. These are clustered uphill, where this layer has a thickness of 10 cm, and are instead scattered over a thickness of 20 cm downhill. These stones are mainly blocks, plates and flakes of reddish chert with deep whitish-pinkish patinae. Secondarily, they comprise Mousterian flint artefacts with the same patinae, occasionally with worn edges. All these elements are distributed in rows or narrow bands dipping downhill that give rise to a series of 20 to 30 cm long and ca. 50 cm wide lobes (fig. 3). Due to the morphometry of the stones, no preferential orientation was observed. Nevertheless, an analysis of weight distribution revealed preferential concentrations of stones and lithic artifacts (see Peresani, 2000-2001). Heavy materials (³100 g) are clustered uphill, especially in the first 80 cm, while elements with weight ³10 g and £50 g, are more abundant down slope. This stone level rests on a truncated paleosol with clay-silty texture (third

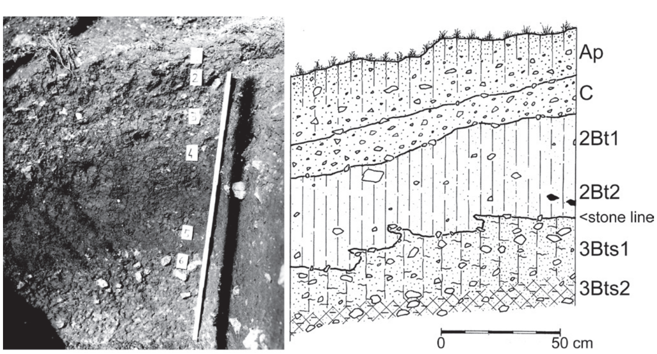


FIG. 2 - The Monte Versa pedostratigraphic sequence. The sequence rests on horizon 4Cck (not pictured).

TABLE 1 - Monte Versa profile description.

Horizon	Depth	Description
Ap	0-25	Silty clay; common medium and fine stones (chert); 10YR5/3; non calcareous; moderate angular blocky; moderately firm; non plastic; moist; weak porosity (fine pores, biogalleries, cracks); clay coatings and Fe-Mn coatings on peds and stones; abrupt lower boundary.
C	25-40	Silty clay; slope waste deposit
2Bt1	40-60	Silty clay; rare fine stones; 7.5YR3/4; non calcareous; strong medium angular blocky, weak medium prismatic; moderately firm; plastic; very moist; weak porosity (very fine pores, biogalleries, cracks); clay coatings and Fe-Mn coatings on peds and stones; shiny pressure surfaces on peds; abrupt lower boundary.
2Bt2	60-75	Silty clay; common fine stones (chert); 7.5YR3/3; non calcareous; strong medium and coarse angular blocky, strong coarse prismatic; moderately firm; plastic; vey mois; weak porosity (very fine pores, biogalleries, cracks); clay coatings and Fe-Mn coatings on peds and stones; shiny pressure surfaces on peds; abrupt lower boundary.
	75-80	Stone line
3Bts1	80-95	Silty clay; common heterometric fine stones (chert); 5YR3/4; non calcareous; strong medium and coarse angular blocky; moderately firm; plastic; moist; clay coatings and Fe-Mn coatings on peds and stones; shiny pressure surfaces on peds; gradual lower boundary.
3Bts2	95-110	Silty clay; common fine, medium and coarse stones; 5YR3/3; frequent mottles (10YR 5/4); strong medium and coarse angular blocky; moderately firm; plastic; moist; weak porosity (very fine porse; biogalleries); common clay coatings; discontinuous Fe-Mn coatings on peds and stones; many carbonate nodules; abrupt lower boundary.
4Cck	110-150+	Multi-layered gravels; lower boundary not reached.

pedostratigraphic level), chert stones, and rare lithics clustered mainly at the top. This paleosol is the result of the weathering of the rock substratum and of the stratified detrital fan on which the profile is set.

Physico-chemical analyses

The lithological differences across the pedostratigraphic sequence are well shown by the stone content. Percentages are higher in the topsoil, but decreases significantly in the 2Bt1 and 2Bt2 horizons, where stones almost disappear (tab. 2). In the 3Bts1 and 3Bts2 horizons the only stones are weathered and shattered flints contained in the limestone bedrock. Granulometries show the marked predominance of silt in the sequence, with slight decrease in 3Bts1 and 3Bts2 in favour of clay (fig. 4). The increase in sand in the lower part of the sequence can be ascribed to the presence of Fe-Mn oxides and to carbonatic sand in 4Cck. The pH values show no variations, remaining always in the sub-alkaline range. As expected, carbonate content is the highest in 4Cck.

Heavy minerals (tab. 3)

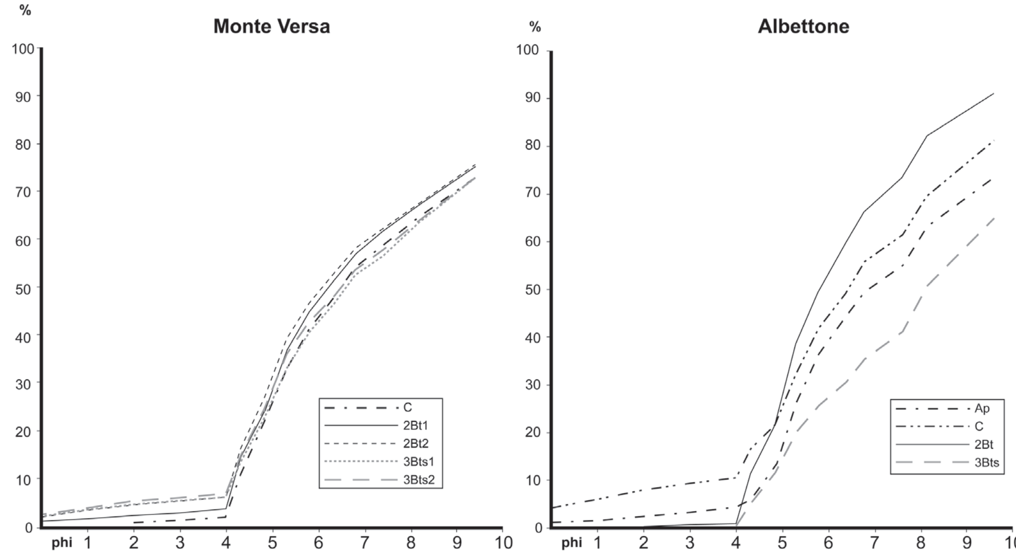
Transparent mineral species are predominant in comparison to opaque ones in the two topmost horizons. They decrease in the underlying ones, except in 4Cck. Here, transparent grains reach the highest frequency with respect to opaque ones (12%). Mica is most abundant in Ap and decreases in the underlying horizons, until it disappears in 4Cck.

Table 3 shows that pyroxenes are the most abundant transparent grains, largely dominating over amphiboles, followed by epidotes and garnets. All these groups exhibit some fluctuations. Pyroxenes decrease with depth, reaching a minimum in the third pedostratigraphic level and a peak in 4Cck. Amphiboles (among which basaltic hornblende is predominant) are scarce in 3Bts2 and get close to 6% in 4Cck. Epidotes decrease progressively until reaching a

TABLE 2 - Monte Versa physico-chemical analyses.

Horizon	Stones	Sand	Silt	Clay	Texture	pH	CaCO3
Ap	12.1	2.0	68.9	29.1	Silty clay loam	8.3	-
C	48.3	-	-	-	-	-	-
2Bt1	14.3	3.8	69.4	26.8	Silty clay loam/silt loam	7.8	2.9
2Bt2	17.8	6.2	67.3	26.5	Silty clay loam/silt loam	8.0	10.1
3Bts1	2.4	6.4	64.0	29.6	Silty clay loam	7.9	11.3
3Bts2	4.3	7.0	63.5	29.5	Silty clay loam	7.8	10.1
4Cck	61.1	49.3	37.2	12.0	Loam	8.2	84.4

FIG. 4 - Particle size distribution cumulative curves for the Monte Versa and Albettone sequences.



minimum in 2Bt2. They then increase over amphiboles in 3Bts2 and reach again a minimum in 4Cck. Garnets increase downwards and reach similar frequencies in both 3Bts1 and 3Bts2, while almost disappear in 4Cck. Ultrastable species (zircon, tourmaline, Ti-oxides – especially rutile and anatase) are frequent in 3Bts1 and 3Bts2

Micromorphology

Horizons 3Bts2 and 3Bts1

These horizons are characterized by a clay texture with silt and scarce very fine sand-sized grains (tab. 4). The dominant mineral species are quartz and chert, with subordinate quantities of mica (muscovite and biotite), and very rare pyroxenes. These occasionally show a pellicular alteration pattern, with release of iron (hydr)oxides in the adjoining groundmass. The microstructure is strongly separated platy juxtaposed to strongly separated angular blocky (fig. 5a). The groundmass appears yellowish red (5YR) with cross-striated, porostriated (along planar voids) and granostriated (around coarser grains) b-fabric types (fig. 5b). Birefringent striae are often interrupted by planar voids. Pedofeatures include frequent Fe and Fe/Mn orthic nodules, typic and dendritic, observed within the peds. Dense complete infillings and hypocoatings of micrite and of sparite, often with a feather-like arrangement of crystals, are frequent.

Horizons 2Bt2 and 2Bt1

The horizons of the upper pedostratigraphic level are characterized by a silty clay texture with quartz, micas (muscovite and biotite), and chert as dominant mineral species. Very rare pyroxenes with pellicular alteration and release of iron (hydr)oxides are also present. The microstructure is strongly separated angular and subangular blocky. The groundmass is decarbonated and the b-fabric shows markedly expressed cross-striations, with frequent granostriations around coarse clasts and Fe/Mn nodules.

TABLE 3 - Monte Versa physico-chemical analyses.

	Ap	2Bt1	2Bt2	3Bts1	3Bts2	4Cck
Mica	27.5	10.0	5.5	5.1	4.4	2.7
Transparent	54.0	64.2	47.6	51.4	53.5	85.5
Opaque	18.5	25.9	47.0	43.5	42.0	11.9
Zircon	1.3	2.1	4.1	2.6	1.9	0.8
Tourmaline	0.3	0.6	2.9	8.8	10.4	0.0
Rutile+Titanite	0.3	2.4	1.6	3.6	1.9	0.5
Anatase+Brookite	0.0	0.0	0.0	0.0	0.0	0.0
Amphiboles	9.8	11.3	12.1	10.1	7.9	5.7
Pyroxenes	76.2	74.1	68.9	57.1	58.9	89.8
Epidotes	8.1	6.0	2.2	5.8	10.1	2.2
Garnets	1.3	1.5	4.8	7.8	7.9	1.1
Baryte	0.0	0.0	0.0	0.0	0.0	0.0
Kyanite	0.0	0.3	0.3	2.6	0.6	0.0
Sillimanite	0.0	0.0	0.0	0.0	0.0	0.0
Corundum	0.0	0.0	0.0	0.0	0.0	0.0
Andalusite	0.0	0.0	0.0	0.0	0.0	0.0
Sphene	0.0	0.0	0.0	0.0	0.0	0.0
Spinel	1.3	0.6	2.9	1.0	0.0	0.0
Staurolite	0.0	0.6	0.3	0.6	0.3	0.0
Chloritoide	0.0	0.0	0.0	0.0	0.0	0.0
Altered	0.0	0.0	0.0	0.0	0.0	0.0
Weathering Index	0.05	0.10	0.21	0.36	0.32	0.03

TABLE 4 - Monte Versa and Albettone: micromorpholgocial descriptions

Hor.	Porosity1				MS2	Texture3	Skeletal Grains	Organic4	Groundm.	b-fabric5	c/f ratio	Related Distrib.6	Pedofeatures7		
	Ch	Vu	Ve	PV			>2mm						Fe nod.	Mn nod.	Calc. inf.
Monte Versa															
Ap	**			***	m/s AB	SiCl	*	5%	7.5YR strong brown	cs, ps, gs	30/70	dsp	5-10%		*
2Bt1	**			***	s AB/ SB	SiCl	*	5%	7.5YR strong brown	cs, gs, ps	35/65	dsp	2-3.5%		**
2Bt2	*			***	s AB/ SB	SiCl	*	3.5-5%	7.5YR strong brown	cs, gs, ps	25/75	op	3.5-5%		**
3Bts1	*	*		***	s P/ AB	Cl/SiCl	**	1-2%	5YR yellowish red	cs, ps, gs	20/80	op		5%	***
3Bts2	*	*		***	s P/AB	Cl/SiCl	*	<1%	5YR yellowish red	cs, gs, ps	15/85	op		2-3.5%	**
Albettone															
2Bt	**	*		***	m/s AB Ch	SCL		1%	7.5YR reddish yellow	ss	65/35	dsp	**	2-3.5%	**
3Bts	*	*	**	***	m/s AB	Cl/SiCl		<1%	7.5YR reddish yellow	gs, ps	10/90	op	**		

(1) Porosity: Ch = channels; Vu = vughs; Ve = vescicles; PV = planar voids. (2) MS = Microstructure. m/s AB = moderately/strongly separated angular blocky; s AB/SB = strongly separated angular blocky/subangular blocky; s P = strongly separated platy; Ch = Channel microstructure. (3) Texture: SiCl = silty clay; Cl = clay; SCL = Silty clay loam. (4) Organic: organic punctuations expressed as percent of the field of view at 200x magnification. (5) b-fabric: cs = cross-striated; ps = porostriated; gs = granostriated; ss = stipple-speckled. (6) Rel. Dist. = c/f related distribution pattern: dsp = double-spaced porphyric; op = open porphyric. (7) Pedofeatures: Fe nod. = Fe nodules, typic, orthic and anorthic. Mn nod. = Mn and Fe/Mn nodules, dendritic and typic, orthic. Calc. inf = calcite (sparite and micrite) dense complete infillings and orthic typic nodules. Frequency determinations: * = rare; ** = frequent; *** = dominant.

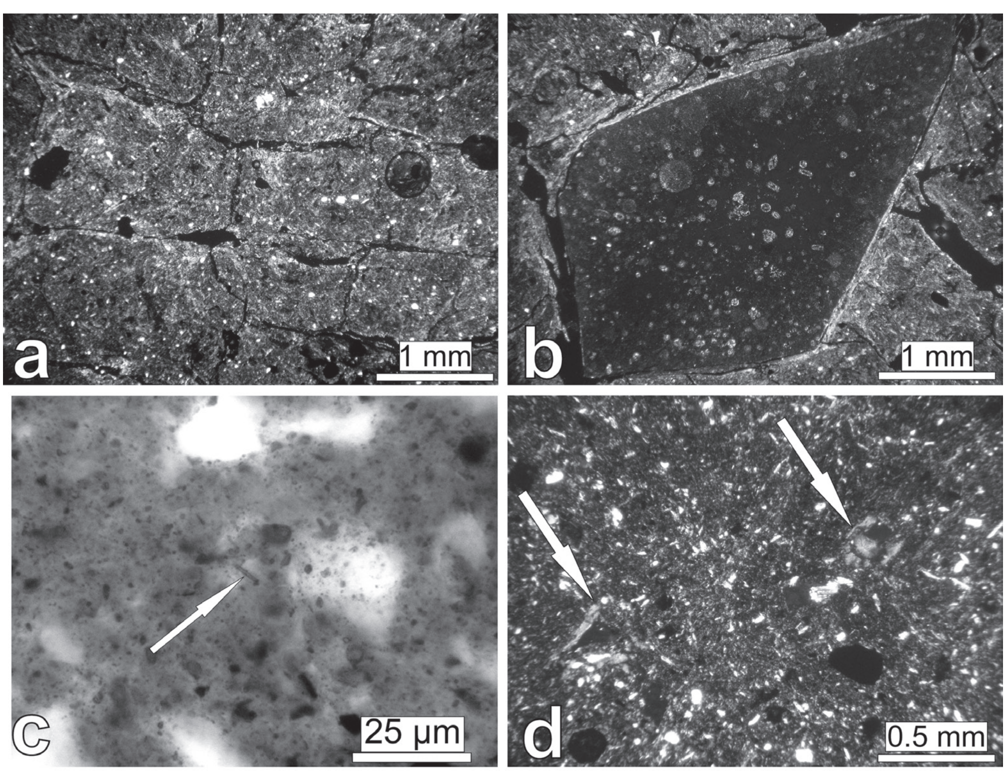


FIG. 5 - Monte Versa sequence, micromorphological features: (a) Horizon 3Bts2. Platy microstructure. 20x, XPL. (b) Horizon 3Bts1. Granostriation around chert fragment. 20x, XPL. (c) Horizon 2Bt2. Elongated non-articulated phytolith (arrow). 800x, PPL. (d) Horizon 2Bt2. Clay coatings along pore walls (arrows). 40x, XPL.

Elongated and square non-articulated phytoliths can be observed at high magnification (fig. 5c). At high magnification it is possible to observe finely comminuted opaque particles (10-50 μm), interpreted as organic punctuations, humified vegetal matter, manganese aggregates, and possibly charcoal and charred vegetal material.

Pedofeatures comprise rare laminated limpid clay coatings with sharp extinction lines (fig. 5d). These are often deformed along pore walls or reworked within the groundmass, giving rise to the "irregular" or "linear" clay concentrations (Bullock & Murphy, 1979) mentioned above.

Small (100-250 μm diameter), rounded orthic and disorthic Fe/Mn nodules are frequent. Dense complete infillings and hypocoatings of micrite and sparite are abundant, especially towards the top of the sequum, in horizon 2Bt1.

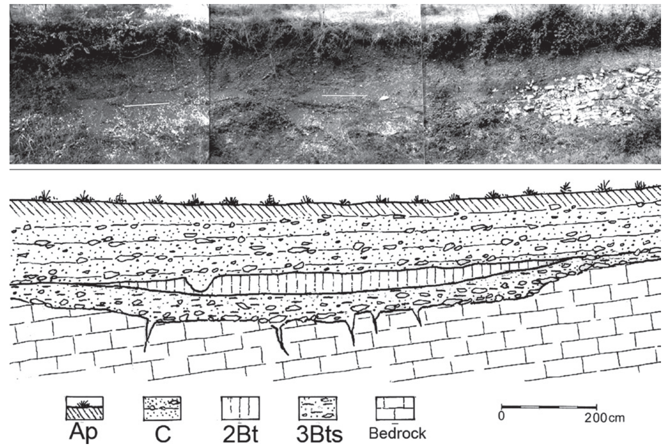


Fig. 6 - The Albettone pedostratigraphic sequence.

Discussion of the Monte Versa results

The variability in heavvy mineral associations and ratios reflects differences of provenance – namely local colluvium and aeolian inputs – and of pedogenesis. The prevalence of pyroxenes and amphiboles (basaltic hornblende) is connected with local colluvial processes, as such minerals derive from the weathering of basalts overlying the Monte Versa hill and occurring along the western Euganean flanks. The presence, yet limited, of mica and other minerals of metamorphic paragenesis contained in the alluvium of Po and Adige rivers (Cremaschi, 1990a), highlights the aeolian input. The increase in opaque grains, in stable minerals and the highest weathering indices in 3Bts1 and 3Bts2 can be attributed to pedological weathering.

The picture resulting from micromorphological analyses of Horizons 3Bts2 and 3Bts1 is that of a strongly weathered paleosol, formed upon alteration of the local Scaglia Rossa. The marked weathering is witnessed by the total decarbonation (the observed calcareous pedofeatures derive in fact from recarbonation), by clay illuviation, by rubefaction of the fine mass, and by the relative abundance of weathering-resistant species such as quartz and chert.

The observed platy microstructure can be interpreted as to be formed by deep seasonal freezing or ice lensing (Cremaschi & Van Vliet-Lanöe, 1991; Van Vliet-Lanöe, 1998), with ice segregation indicating availability of water (Van Vliet-Lanöe, 2010). Traces of strong shrink-swell phenomena are also present (b-fabric), but they cannot ascribed with certainty to frost activity, as they can be produced by any type of stress (Van Vliet-Lanöe 2010), especially in a clay-rich material like the one under examination. Whatever the origin of the shrink-swell processes, these led to the reworking and incorporation of former clay coatings in the groundmass (according to the mechanism described by Nettleton & *alii*, 1969) and around coarser elements. This gave rise to numerous elongated birefringent domains, also referred to as "irregular" or "linear" clay concentrations by Bullock & Murphy (1979).

Micromorphology of the second pedostratigraphic level highlighted a pedogenetic sequence comprising loess deposition, decarbonation, clay illuviation, vertic processes, and recarbonatation of the profile. Reduction and oxidation processes are proved by the frequent iron and manganese nodules, which are churned by the shrinking and swelling of expandable clays. The presence of phytoliths and of probable microcharcoal suggests that loess deposition could have taken place in conditions of dry cold steppe. This is hypothesized for the Veneto plain by both the pedo-sedimentary studies of Cremaschi (1990a, 1990b) and by palaeobotanical determinations from caves (Cattani, 1990). The phytoliths dispersed in the soil possibly relate to the presence of vegetation dominantly composed of grasses. The fine charcoal or charred vegetal fragments could derive from wildfires and transported by wind together with loess. Their presence reinforces the hypothesis of dry and cold conditions during loess sedimentation in the Pleniglacial (see Wang & *alii*, 2005; Huang & *alii*, 2006).

Recarbonatation is strongly evidenced all along the studied profile. At the base of the sequence (horizons 3Bts1and 3Bts2), nodules, hypocoatings and infillings appear to have undergone many re-crystallization cycles. The large sparite crystals that compose them can be interpreted as the result of crystallization at drying void surface (Wieder & Yaalon, 1982; Brewer, 1972), where over saturation preferentially takes place (Jongerius & Bonfils, 1964). Calcium is supplied from the weathering of colluvia containing Scaglia Rossa fragments (abundant in the upper pedostratigraphic level) but could also derive from the enrichment of the groundwater in Ca from the local calcareous bedrock. In the second pedostratigraphic level (horizons 2Bt1 and 2Bt2), recarbonatation is witnessed by the frequent micrite and, more rarely, sparite hypocoatings and infillings.

The top part of the profile appears truncated and reworked by agricultural practices. In thin section, the Ap horizon is in fact composed of reworked materials from horizons 2Bt1 and C.

Albettone

In this sequence (fig. 6, tab. 5), the present-day Ap horizon rests on the top of a layer with planar parallel stratifica-

TABLE 5 - Albettone profile description.

Horizon	Depth (cm)	Description
Ap	0-35	Silty-clayey; common medium and fine stones (carbonates); 10YR2/2; calcareous; moderate fine angular blocky; moderately firm; non-plastic; moist; weak porosity (fine pores, biogalleries, cracks); clear lower boundary.
C	35-140	Silty-clayey; common very fine and fine stones (carbonates); 7.5YR3/3; calcareous; strong fine and medium angular blocky; moderately firm; dry; porous (fine pores, biogalleries, cracks); abrupt lower boundary.
2Bt	140-185	Silty, 7.5YR4/4; weakly calcareous; strong coarse prismatic, strong medium and fine angular blocky; moderately firm; plastic; dry; strong porosity (biogalleries); abrupt lower boundary.
3Bts	185-220	Clayey-silt; rare stones (chert with patinae); 5YR3/3; weakly calcareous; strong coarse prismatic, strong medium angular blocky; moderately firm; moist; weak porosity (biogalleries); rare discontinuous Fe-Mn coatings on peds and stones; slickensides; abrupt lower boundary.

tion, slightly inclined downslope, composed of an alternating sequence of small calcareous flakes and brown gravelly silts (horizon C). Below its abrupt lower boundary, there is a decarbonated silty horizon devoid of skeletal grains (2Bt). The latter covers a truncated paleosol (3Bts) with a clay-silty texture and chert clasts, formed upon weathering of the local rock substrate.

Physico-chemical analyses

Stone content shows marked variations, being highest in the upper colluvium (horizons Ap and C) and disappearing in 2Bt. The scarce stones in 3Bts are fragments of chert with patinae. The silt fraction is prevalent in 2Bt and decreases slightly in 3Bts below, where clay reaches the maximum value in the whole sequence. Values of pH show limited variations and are in the sub-alkaline range throughout. Calcium carbonate content is the highest in horizon C, decreasing below 3.8% in 2Bt and to less than 1% in 3Bts. Organic carbon shows a decreasing trend moving from the top towards the bottom of the sequence (tab. 6).

Heavy minerals

The sequence shows a considerable mineralogical variability. Transparent mineral grains are predominant over opaque ones, with a variable incidence of micas along the profile. These are in fact at a minimum in C but above 50% in Ap and 3Bts. They reach a peak in 2Bt, suggesting an aeolian origin for the latter. Conversely, opaque minerals are at a minimum in 2Bt and increase in C and 3Bts, as the result of colluvial processes in the first and of pedogenesis in the second.

Table 7 highlights that pyroxenes, amphiboles, epidotes, and garnets are the most abundant transparent grains. All these mineral species show fluctuations, especially for pyroxenes, which are significantly less frequent in 3Bts. Amphiboles (mainly green amphiboles), become gradually the most abundant heavy mineral after pyroxenes towards the bottom of the sequence. Epidotes show no significant fluctuations in the top three horizons and increase noticeably in 3Bts. Garnets also show variations between 12.9% and 21.5%. Except for Ap, ultrastable species are around 8.5% in all the remaining horizons.

Micromorphology

Horizon 3Bts

This horizon is composed of reworked clay-textured pedorelicts, ranging in diameter between 0.5 mm and 15 mm and with rounded edges (fig 7a). The space between these reworked soil aggregates is filled by clays with strongly expressed granostriated and cross-striated b-fab-

TABLE 6 - Albettone physico-chemical analyses.

Horizon	Stones %	Sand %	Silt %	Clay %	Texture (USDA)	pH	$CaCO_3$ %	Org. C %
Ap	7.1	4.3	64.4	31.3	Silty clay loam	7.1	5.9	3.30
C	37.2	10.4	65.5	24.1	Silty clay loam/silt loam	7.0	28.8	2.84
2Bt	-	0.7	86.1	13.2	Silty loam	7.7	3.8	1.55
3Bts	1.3	0.2	58.3	41.5	Clayey silty loam	7.5	0.8	1.02

Table 7 - Albettone heavy mineral percentages.

	Ap	C	2Bt	3Bts
Mica	69.1	38.6	87.6	54.9
Transparent	22.0	44.7	10.2	33.8
Opaque	9.0	16.7	2.1	11.3
Zircon	2.2	1.6	2.0	0.9
Tourmaline	0.7	1.6	2.6	0.9
Rutile	0.4	0.0	1.0	0.9
Anatase+Brookite	0.4	1.9	0.3	0.0
Titanite	1.8	3.5	2.6	5.7
Amphiboles	10.0	13.4	16.5	24.4
Pyroxenes	44.3	36.0	26.4	4.1
Epidotes	17.0	12.7	15.2	31.3
Garnets	12.9	21.7	17.2	21.5
Baryte	0.0	0.0	0.0	0.0
Kyanite	0.7	1.3	2.6	2.5
Sillimanite	6.3	4.8	9.9	0.9
Corundum	0.0	0.0	0.0	0.0
Andalusite	0.0	0.0	0.0	0.9
Sphene	0.0	0.0	0.0	0.0
Spinel	1.1	0.0	0.0	0.0
Staurolite	1.5	1.0	3.0	5.4
Chloritoide	0.7	0.6	0.7	0.3
Altered	0.0	0.0	0.0	0.0
Weathering Index	0.26	0.47	0.42	0.57

ric. The groundmass of both the pedorelicts and the fine material between them is strongly weathered and rubefied.

Traces of vertic processes are discernible in the b-fabric and in the presence of elongated clay domains. These might derive from the reworking of former clay pedofeatures (similarly to horizons 3Bts1 and 3Bts2 of Monte Versa, where "irregular" or "linear" clay concentrations were found - see Bullock & Murphy, 1979) (fig. 7b).

Iron nodules, ranging in diameter between 50 µm and 200 µm appear to be orthic as well as disorthic and anorthic, with rounded edges. The allochtonous nodules were probably transported together with the pedorelicts.

Horizon 2Bt

The texture is silty clay loam, with more abundant silts grains (20-40 µm) than in the second pedostratigraphic level of the Monte Versa sequence. The mineralogy is similar, with quartz and micas (muscovite and biotite) as the dominant components. The microstructure is moderately to strongly separated angular blocky, with intrapedal porosity made up by frequent biogenic channels. The groundmass is decarbonated, and re-organization of the fine mass is witnessed by the stipple-speckled b-fabric (see Bullock & Murphy, 1979). Similarly to the upper part of the Monte Versa sequence, non-articulated phytoliths are scattered in the horizon. Finely comminuted (5-15 µm) opaque material is dispersed in the groundmass (fig. 7c). In addition to organic punctuations and decaying vegetal matter, part of it can be identified as microcharcoal and fine charred vegetal matter.

Traces of in situ clay illuviation are scarce. Nevertheless, the presence of aggregates of limpid clay with traces of microlaminations suggests that clay coatings existed and that they were probably fragmented and reworked (by bioturbation ? – see fig. 7d).

Part of the material that makes up the horizon is allochtonous. This is the case of rounded clay-textured pedorelicts and of fine sand-sized disorthic and anorthic iron nodules with rounded edges. Given the position of this profile, it can be supposed that these materials colluviated or were washed downslope from surrounding soils.

The orthic iron nodules, with weak degree of impregnation, suggest moderate hydromorphism. Micrite and sparite infillings and hypocoatings, similar to those observed in the upper pedostratigraphic level of the Monte Versa sequence, indicate recarbonatation of the profile.

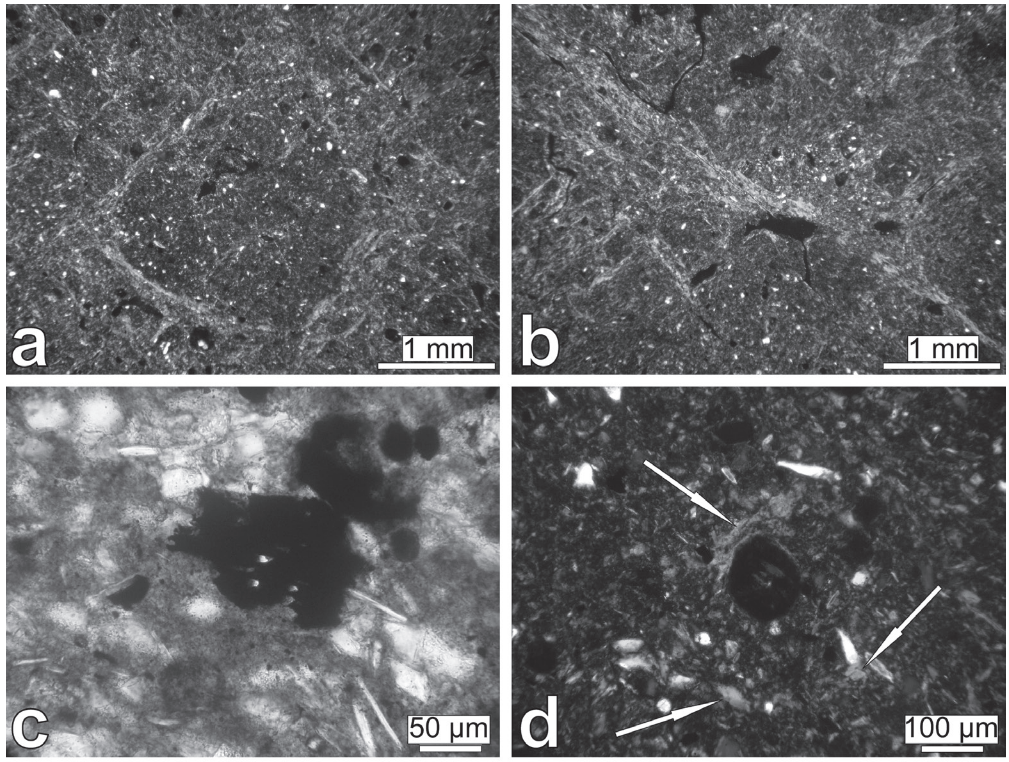
Discussion of the Albettone results

The presence of aeolian inputs in the parent material can be hypothesized based on: (a) the high amount of micas (especially in 2Bt), (b) the presence of minerals that are allochtonous with respect to the local carbonate substratum, (c) the presence of minerals of metamorphic paragenesis compatible with alluvial sands of the Po floodplain. The emerging picture is in accordance with the data from the Monte Versa profile (see above). The variations in mineral associations and in relative ratios probably derive from the different degrees of weathering of the parent material making up each pedostratigraphic level and by inwash and colluvial processes.

Given the micromophological signatures, we can interpret horizon 3Bts as the outcome of colluvium of strongly weathered soil material with continuing pedogenesis leading to clay illuviation and rubefaction. Vertic phenomena led to the homogenization of the horizon and to the disappearance of former clay coatings (see Nettleton & *alii*, 1969). Subsequent recarbonation of the profile is witnessed by rare micrite and sparite infillings (dense complete infillings).

Horizon 2Bt appears to have formed by the conjunct deposition of loess and by the inwash and colluviation of materials from the surrounding surfaces. Inwash processes might explain the higher quantities of silt and very fine sands recorded at Albettone with respect to Monte

FIG. 7 - Albettone sequence, micromorphological features: (a) Horizon 3Bts. Reworked pedorelict. Note strongly expressed granostriations and cross-striations. 20x, XPL. (b) Horizon 3Bts. Elongated clay domain, also termed "irregular" or "linear" clay concentrations (see Bullock & Murphy, 1979) and resulting from the churning of former clay pedofeatures. 20x, XPL. (c) Horizon 2Bt. Charred vegetal tissue fragment. 200x, PPL (d) Horizon 2Bt. Fragmented and reworked clay coatings (arrows). 100x, XPL.



Versa (see fig. 4). Decarbonatation and fine fabric re-organization followed deposition, with clay illuviation being attested although difficult to characterize precisely in thin section, most likely due to bioturbation. Afterwards, slight hydromorphy and recarbontaation characterized the horizon.

CONCLUSIONS

The observed textural, chemical, and morphological characteristics of the two studied sequences can be explained in the framework of the climatic variability of the Pleistocene and Holocene. The unit at the base of the Monte Versa sequence (horizon 4Cck) can be compared with ancient colluvial and slope deposits occurring at the Euganean foothill (Comezzara supersynthem; Cucato & *alii*, 2011). Such deposits rest with an erosive and irregular contact on the Scaglia Rossa and exhibit a marked degree of weathering, ascribed to the Middle to Late Pleistocene interval.

The formation of the strongly weathered paleosols at Monte Versa (3Bts1 and 3Bts2) and Albettone (3Bts) indicates a prolonged period of biostasy. The processes of total decarbonatation, clay illuviation, rubefaction, the increase in weathering-resistant mineral species, and the richness in Fe (hydr)oxides can all be ascribed to the fersiallitc weathering of Red Mediterranean Soils, particularly of Terra Rossa soils formed on calcareous substrata (Duchaufour, 1983). The pedological alteration suggests climatic conditions similar to those that led to the formation of fersiallitic soils on the Lombardy Prealps and in the Po plain during the interglacials between the Middle and the beginning of the Late Pleistocene (Cremaschi, 1987; Trombino, 1998).

Such pedogenic phase was not in equilibrium with the later climatic conditions. This is demonstrated by the truncation of the sequences and by colluviation of strongly weathered soil material, followed by the deposition of new sediments. Profile truncation reveals slope degradation processes that at Monte Versa led to formation of a stone line. The latter is the outcome of the washing of the finer matrix and of the resulting accumulation of coarser stones, among which lithic artefacts originally contained in the paleosol. This stone line is not the result of direct anthropic activity (see Peresani, 2000-2001), nor can be regarded as a simple deposition of slope debris. After its formation, the stone line underwent deformation processes proved by the embricated lobes aligned transversally to the direction of maximum slope. This patterned ground can be ascribed to a periglacial environment that triggered freeze-thaw processes, implying the deformation of the layers along the slope (Ballantyne, 2007).

The stratigraphic position, the massive nature, the sorting, and the abundance of micas suggest an aeolian origin for the 2Bt horizon at Albettone. At Monte Versa, instead, the scarcity of micas and the abundance of minerals of volcanic paragenesis in the second pedostratigraphic level, indicate a probable more mixed origin, comprising also colluvial inputs from the basic rocks that outcrop uphill. Comparisons can be drawn with the mineralogical spectra of the Middle and Late Pleistocene cave deposits of the Grotta di San Bernardino located along the eastern flanks of the Berici hills, 15 km west of Monte Versa (Peresani, 1987-88). Here, the proportions of the three groups of minerals of different paragenesis (and the scarcity of micas: 5-14%) can be compared with the Monte Versa spectrum. On the other side, the transparent mineral assemblage, with epidotes (21-36%), amphiboles (11-15% – among which basaltic hornblende), and pyroxenes (26-32%), correlate the loess of Grotta di San Bernardino with the 2Bt horizon of Albettone. The age of such sedimentation cannot be ascribed with more precision than generically to the Late Pleistocene. The Levallois lithic industry of Monte Versa, on the ground of its taphonomic and technological characteristics, provides a minimum age corresponding to the MIS5. MIS4 and MIS3 show in fact a more variable techno-typological framework for the Middle Palaeolithic in the region (Peresani, 2001).

The palaeo-environmental conditions of this period are rather generically outlined at the Grotta di San Bernardino (Cattani, 1990). However, higher resolution data for the Late Pleistocene are available in the lacustrine pollen archive of the Lago della Costa, located on the eastern flanks of the Euganean hills (Kaltenrieder & *alii*, 2009). This archive allows for a reconstruction of regional and extra-regional dynamics between 35 and 16.5 ky BP. Pollen associations show an unexpected persistence of temperate species during the full glacial phase, when a more open landscape would be expected. These rather thermophilous species belong to the mixed oak forest pollen association, with other mesophilous temperate species such as beech and white fir occurring alongside. The emerging picture is that of an environment with a marked variability, contrasting with the reduction in species' diversity determined by the climatic continentalization of the Adriatic basin (Ravazzi & *alii*, 2004).

The deposition of aeolian sediments, which encompassed also their syn- and post-depositional reworking, was followed by pedogenesis in a contrasted season regime during the Holocene. This comprised decarbonation and clay illuviation, resulting in the formation of *Sols Bruns Lessivés* (Duchaufour, 1983). Such soils were truncated, most likely due to agricultural impact that triggered slope instability and colluvial processes.

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