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GEOMORPHOLOGICAL CONTEXT OF "PLINTHITIC PALEOSOLS" IN THE MEDITERRANEAN REGION: EXAMPLES FROM THE COAST OF WESTERN LIGURIA (NORTHERNITALY)

Plinthitic paleosols in the Mediterranean Region

Contexto geomorfológico de "paleosuelos plintiticos" en la Región Mediterránea: ejemplos en la Costa oeste de Liguria (Italia del norte)

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Resumen: El principal objetivo de este estudio es el de caracterizar las propriedades micromorfológicas y mineralógicas de dos paleosuelos plintiticos y de deducir los procesos de formación relacionados con la posición geomorfológica. El primer paleosuelo descrito se sitúa en el altiplano de Mànie y presenta caracteristicas geomorfológicas parecidas a las de los actuales suelos tropicales, siendo caracterizado por la presencia de un profundo y espeso horizonte plintitico encima de la roca madre. Sin embargo, el segundo paleosuelo está caracterizado por un espeso horizonte petroplintitico y está relacionado con antiguos accidentes geográficos de terrazas de origen marino con depósitos marinos y continentales fuertemente alterados en las superficies preservadas. Las pruebas micromorfológicas, apoyadas por los análisis mineralógicos, sugieren un origen poligenético de estos paleosuelos, en el cual un diferente contexto geomorfológico jugó un papel importante para el desarrollo del suelo y la conservación del perfil.

Palabras clave: Paleosuelos; Plintite; Micromorfología; Paleosuperficie; Geomorfología; Liguria.

Abstract: The main objectives of this study were to characterize the micromorphological and mineralogical properties of the two plinthitic paleosols and to deduce their formation processes in relation to the geomorphological position. The first described paleosol is located on High Plain of Manie and shows morphological characteristics comparable to present-day tropical-area soils, being characterised by the presence of a deep and thick plinthitic horizon overlying a saprolite. Instead the second paleosol is characterised by a thick petroplinthitic horizon and it related to relic terraced landforms of marine origin with very weathered marine and continental deposits on their preserved surfaces. The micromorphological evidence, supported by the mineralogical analyses, suggests a polygenetic origin for this paleosols, in which different geomorphological context played a role both on soil development and profile preservation.

Key words: Paleosols; Plinthite; Micromorphology; Paleosurface; Geomorphology; Liguria.

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AEQUA

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1. Introduction

Italian coastal regions are usually considered typical Mediterranean areas, and their pedogenesis results strongly influenced by this kind of climatic, environmental and geomorphological conditions (Stoops *et al.*, 1994). But in the same regions there are also Late Tertiary (Cremaschi y Ginesu, 1990) or Middle Pleistocene (Bartolini et al. 1984, Magaldi *et al.* 1985, Magaldi y Bidini 1991) palaeosurfaces characterised by deep soils (relict palaeosols, Ruellan 1971) which show plinthitic features, under brown or red-brown horizons of the top soils.

The characteristics of those plinthitic paleosols are not only related to the climatic conditions in which they were formed, but also to the geomorphological history of the areas: in fact they occur mainly on old preserved surfaces. In this light, the geomorphological context of these evidences has to be taken in account, in order to clarify their origin, development and, of course, preservation.

2. Geological and geomorphological setting

The study areas are located along the coastal zone of western Liguria (NW Italy) (Fig.1), bordering the Tyrrenian basin in eastern sector of the Ligurian Alps. The basement of those areas are constituted by metaophyolite complex and crystalline basement and volcano-sedimentary sequence (paleo-european continental margin), covered by an mesozoic sedimentary sequences (Vanossi *et al.*, 1984). Moreover, part of the latter are unconformably overlapped by some marine late and post orogenic deposits, as Oligocene deposits of the Tertiary Piedmontese Basin and the Pliocene deposits due to a transgression from the Tyrrhenian basin. This sector of coast, with watershed very close to the sea, is generally high and abrupt with promontories, alternating with plains of limited amplitude. The study areas are characterised by the presence of marine and continental palaeosurfaces, having various elevations and ages, which are generally related to the repeated transgression/regression cycles due to the Late Quaternary tectonics and climatic fluctuations.

3. Methods

The studied soil profiles have been characterised by field description, bulk and undisturbed sampling, routine physical and chemical analyses, x-ray diffraction and micromorphology and heavy mineral analyses. Field description have been carried out according to the methods and terminology of ISSDS (2002).

Soil samples were air dried, particle size distribution analysis was carried out by sieving for the fraction > 63 µm, the composition of fine fraction (< 63 µm) was determined by SediGraph 5100. PH was measured in a 1:2.5 soil:water suspension and

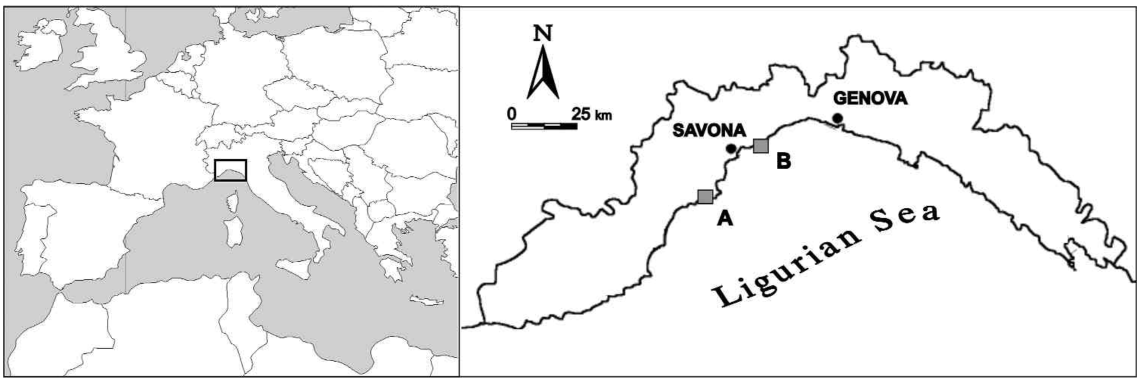


Figure 1. Location of the two study areas. A: Mànie Plateau, B: Celle Ligure terraces.
Figura 1. Sitio de dos áreas del estudio. A: Sitio Plateau Mànie, B: Sitio terrazas de Celle Ligure.

electrical conductivity in a 1:5 soil:water suspension.

Soil thin sections were carved by "Servizi per la Geologia" Piombino, (Li) Italy. Thin sections were observed by Optical Microscopy and described using the terms and methods of Stoops (2003) except that some terminology of Bullock *et al.* (1985) and Brewer (1976) in order to emphasise some concepts.

Mineralogical analyses were conducted by X-ray diffraction techniques (XRD) on randomly oriented powders, using diffractometer equipped with Ni-filtered Cu radiation generated at 40 kW, 20mA(Philips Analytical PW3710); X-ray patterns were interpreted according to Berry (1974) and Brindley y Brown (1980).

Heavy minerals were separated from the fine sand fraction (63 µm – 125 µm) (Parfenoff et al. 1970, Mange y Maurer 1992) using a natrium metawolframate [Na6O39W12 (H2O)] solution (2.9 g/cm3 density).

Finally plinthite samples were subjected to the test of Wood y Perkins (1976) with immersion for two hours in water to check the persistence of aggregates.

4. Soil Profiles

The first soil profile (Trombino, 1996) is located along the eastern side of the Mànie Plateau, elevated at an approximate height of 300 m a.s.l. The high plain is mainly formed by carbonate lithotypes (dolomite, limestone), subjected to a considerable karst process, outcrop next to quarzites and schist rocks. While the small-scall karst formations can be reffered to the dynamic of the present day slope, the large-scale formation (cockpits-like) are similar to formation which are typical of the tropical karst landscape (Sweeting, 1972). The top of Plateau is shaped by a palaeosurface which involves both lithotypes (carbonatic and quartzitic) and which is geomorphologically dated to Plio-Pleistocene age (Biancotti y Motta, 1988). The studied profile was sampled at the top of a depositional glacis which appears clearly polycyclic, with a sharp erosional discontinuity displayed in some incisions and truncating the oldest deposits. The erosional discontinuity separates two different sedimentary bodies: a weakly pedogenised, stratified slope deposit, with coarse gravel and pebbles to sand texture, overlying a well-structured and ticker buried paleosol, developed on bedrock formed

Table 1. The main morphological features.
Tabla 1. Las principales características morfológicas.

Profile	*Horizon*	*Depth (cm)*	*Clour*	*Mottles*	*Struct.*	*Stones*	*Clay coatings*	*Fe-Mn concretion*
P1	A	0-10	7.5YR 4/4	-	mSB	++	-	-
	Btc	10-40	7.5YR 5/6	(+)	mAB	+++	+	+++
	Bt	40-90	10YR 7/6	+++	fAB	+++	++	++
	2Btg	90-160	2.5YR 4/6	+++	mAB	(+)	+++	-
	2Bt	160-210	2.5YR 4/6	++	mAB	(+)	+++	(+)
	$2Bv_1$	210-270	2.5YR 4/6	++	cAB	(+)	++	++
	$2Bv_2$	270-360	2.5YR 4/6	++	cAB	(+)	++	++
	$2Bv_3$	360-440	5YR 4/6	++	mAB	-	++	-
	$2Bv_4$	440-515	2.5YR 4/6	++	mAB	(+)	++	++
	$2Bv_5$	515-710	2.5YR 4/8	++	gAB	(+)	++	+++
	2Crt	710-750	2.5YR 6/4	++	M	-	+++	-
	2Cr	750+	2.5YR 6/4	+	M	-	-	-
P2	AB	0-20	7.5Y5/8	+++	mAB	++	-	-
	Btg	20-80	5YR 6/1	++	mAB	-	+++	-
	2Bvm	80-150	2.5YR 3/6	++++	M	-	-	-
	2Bt	150-220	2.5YR 4/6	+++	cAB	+++	++	-
	2BtC	220-370	2.5YR 3/6	+++	mAB	++++	++	-

Aggregation: AB: angular blocky; SB: subangular blocky; M: massive; m: medium; c: coarse; f: fine
-, (+), +, ++, +++, ++++ indicate increasing abundance of some soil features: absent, rare, frequent, common, abundant, very abundant.
Agregación: AB: bloques angulares; SB:bloques subangulares, M: masiva; m: mediana; c: gruesa; f: fina
-, (+), +, ++, +++, ++++ indíca el aumento de abundancia de algunas características del suelo: ausente, raro, frecuente, abundante, muy abundante.

Table 2. The main physical and chemical features.
Tabla 2. Las principales características físicas y químicas.

Profile	*Horizon*	*Depth (cm)*	*Particle size*				*Silt/sand*	*pH (H_2O)*	*Ç$CaCO_3$*
			gravel	*sand*	*silt*	*clay*			
P1	A	0-10	Not sampld						
	Btc	10-40	7.05	24.98	55.10	12.87	2.20	4.8	0.46
	Bt	40-90	12.37	28.57	41.46	17.60	1.45	5.2	0.57
	2Btg	90-160	1.77	23.20	44.59	30.44	1.92	5.0	0.44
	2Bt	160-210	0.35	18.26	35.39	45.70	1.93	4.6	0.57
	$2Bv_1$	210-270	1.12	15.28	36.64	46.97	2.39	5.1	0.88
	$2Bv_2$	270.360	0.50	15.26	39.54	44.70	2.59	4.7	0.58
	$2Bv_3$	360-440	0.95	12.31	39.69	47.05	3.22	4.9	1.00
	$2Bv_4$	440-515	2.51	18.44	45.74	33.31	2.48	4.8	0.75
	$2Bv_5$	515-710	5.07	18.88	47.57	28.48	2.51	4.5	0.56
	2Crt	710-750	Not sampled						
	2Cr	750+	Not sampled						
P2	AB	0-20	4.17	24.81	43.11	27.9	1.73	4.5	1.1
	Btg	20-80	0.80	19.38	50.13	30.3	2.60	4.5	0.7
	2BVm	80-150	Not sampled						
	2Bt	150-220	3.41	43.9	34.9	17.8	0.79	4.6	1.8
	2BtC	220-370	18.6	42.65	28.11	10.3	0.66	4.9	0.3

by schists (quarzitic and sericitic). The soil description and the main results of routine analyses are summarised in Table 1 and 2. As the reconstructed type-section shows (Fig.2), at the top of the sequence, below the A horizon, two horizons (Btc, Bt) showing typical illuvial features have been distinguished; they overlain an horizons sequence that shows distinct plinthite characteristics (USDA, 1998); at the bottom of the sequence, a deeper argillic horizon cover an intensely weathered and fragmented saprolite

The second soil profile was observed along the

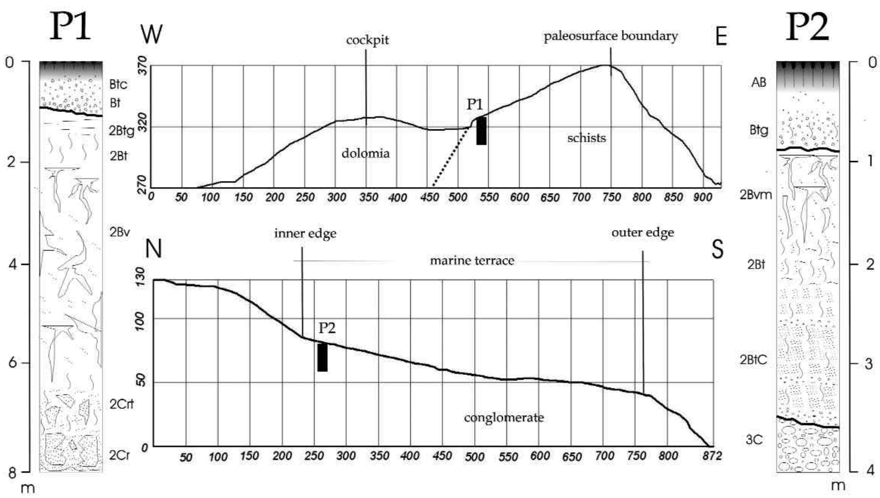


Figure 2. Schematic rapresentation of the studied paleosols and their topographic position.
Figura 2. Representación esquemática y posición topográfica de los paleosuelos estudiados.

Table 3. Mineralogical composition of selected horizons based on X-ray diffraction
Qz = Quartz; Gt = Goethite; Mv/Il = Muscovite/Illite; Nt = Nontronite; Mm = Montmorillonite; Ka = Kaolinite; Ta = Talc;
Cc = Clinochlore; Cs = Chrysotile; Hm = Hematite; Ab = Albite; Rt = Rutile.
Tabla 3. Composición mineralógica de los horizontes seleccionados basada en la diffración de rayos-X
Qz = cuarzo; Gt = Goethite; Mv/Il = Muscovite/Illite; Nt = Nontronite; Mm = Montmorillonite; Ka = Caolinita; Ta = Talco; Cc = Clinocloro; Cs = Crisotilo; Hm = Hematita; Ab = Albita; Rt = Rutilo.

Profile	*Minerals*											
horizon	*Qz*	*Mv/ll*	*Nt*	*Mm*	*Ka*	*Ta*	*Cc*	*Cs*	*Hm*	*Gt*	*Ab*	*Rt*
Profile 1												
Btc	X	.	.	X	X	.	.	.	.	X	.	.
Bt	X	X	.	X	.	.	X	.	.	.	.	X
2Btg	X	X	.	X	X	.	.	.	.	.	.	.
2Bt	X	X	.	.	.	.	.	X	.	.	.	.
$2Bv_1$	X	X	.	.	X	.	X	.	.	.	.	.
$2Bv_2$	X	X	.	.	.	.	.	X	X	.	X	.
$2Bv_3$	X	X	.	.	.	.	X	.	X	X	.	.
$2Bv_4$	X	X	.	.	.	X	X	.	.	.	.	.
$2Bv_5$	X	X	.	.	.	.	X	X	X	.	.	.
Profile 2												
Bt(g)	X	X	X	.	.	.	.	.	.	.	X	.
2Bv	X	.	X	.	.	.	.	.	.	.	X	.
2Bt	X	X	.	.	.	.	.	.	.	.	X	.
2BC	X	.	X	.	.	.	.	.	.	.	X	X

inner margin of marine terrace, which have height of 75 m above sea level, near Celle Ligure (SV). The estimated age of the terrace, calculated on the base of morphological data, is Early-Pleistocene (Carobene y Firpo, 2002). On this palaeosurface is possible to observe both marine and continental deposits that cover the poligenic conglomerate bedrock, which is constituted by quartz, heavy minerals (e.g. amphibole, epidote) and high percentages of lithic fragments (gneiss, serpentinite, metabasalts) (Gelati y Gnaccolini, 2003).

The profile involves a paleosol developed on marine sand overlain by fine colluvial layers. The profile description and the main results of routine analyses are summarised in table 1 and 2. The top of profile is characterised by a yellowish brown AB horizon overlaying a grey argillic horizon with clear hydromorphic features. The lowest part include also a thick petroplinthitic horizon which shows clear dark red redox concentrations with reticular and platy pattern.

5. Analitical data

5.1 Particle-size analysis

Particle size results are summarized in table 2. The particle-size analyses for profile 1 are in agreement with the hori-zon descrip-tion: there is a gap in the clay content between the surface material and the deeper horizons, correspond-ing to opposite trends for the coarser fractions. As re-gards the stone content (ø > 2mm), it seems to be signifi-cant only for the upper horizons.

The second profile is characterized by presence of a strongly indurated plinthitic horizon which was not analyzed. Stones are very scarce to absent in the upper part of the profile (AB, Btg) while there is a increase with the depth that reflect the proximity of conglomerate bedrock. Sand percentages are greatest in the deeper horizons (2Bt1, 2Bt2C) for the presence of old marine sand layers. Notwithstanding the marine origin for the parent material, those horizons show significant values of

Table 4. Heavy minerals assemblage of the two profiles (expressed in %).
Tabla 4. Ensamblaje de minerales pesados de los dos perfiles (exprimido en %).

	P1	*Btc*	*Bt*	*2Btg*	*2Bt*	*2Bv$_1$*	*2Bv$_2$*	*2Bv$_3$*	*2Bv$_4$*	*2Bv$_5$*	*P2*	*AB*	*Btg*	*2Bt*	*2BC*
Opaque		88,3	68	75	74,5	76,6	74	78,2	81	76,5		55,8	55,2	31	26
Transparent		11,7	32	25	25,5	23,4	26	19,8	19	23,5		44,2	45,8	69	74
Anatase		1,6	0	0	0	1,2	0	0	0	0		0	0	1,7	0
Amphibole		15,4	19,6	18,1	14,7	9	4,3	1,9	7,1	6,7		28,3	30,5	36,4	27,7
Apatite		0	0	2,3	0	0	1,6	0	1,1	0,7		0	0	1,7	1,5
Baryte		1,7	0	0,8	0	0	0	0	0	0		0	0	0	1,5
Brookite		4,1	3,1	5,4	3,8	0	2,4	1,2	2,3	2,8		0	2,3	1,6	4,6
Kyanite		0	0	1,2	0	0	0	0	0	0		7,5	5,5	5,8	5,4
Chloritoid		1	0	3,1	0,8	0,8	0	0,2	0	0		0	0	0	0
Epidote		7,1	5,1	4,6	1,9	0	0	0,6	0	0		5	25,8	10,7	4,6
Garnet		4,1	2,2	4,6	0	0	0	2,9	0,6	0		0	0,8	0,8	0,8
Pyroxene		23	26,2	21,9	25,1	18,9	17	11,1	13,4	10,8		30	22,6	33	33,8
Olivine		0	0	0	0	0	0	0	0	0		2,5	0	0	0
Rutile		3,1	2,9	1	0	0	0	4,3	3,9	3,8		0,8	3,1	0,8	5,4
Sphene		0	0,7	4,4	0	1,2	1,6	0	2,1	1,8		2,5	2,3	2,5	3,1
Tourmaline		5,6	4,2	6,2	8,9	17,5	21,9	9,1	11,7	15,8		12,6	2,3	0,8	0,8
Zircon		33,3	36	25,7	42,8	51,4	51,2	68,3	57,8	56,4		10,8	3,9	4,2	9,2
others		0	0	0,7	2	0	0	0,4	0	1,2		0	0,9	0	1,6

the clay and silt fraction, to indicate a pedogenic weathering. The textural characteristic of the superficial soil represents typical colluviated material.

5.2 Soil mineralogy

Preliminary investigation on randomly oriented powders of smear slides of the bulk samples was performed on two profiles (Tab.3). The results in soil profile P1 showed a dominance of quartz, muscovite, clinochlore in all horizons; the mineralogical composition of the plintithic horizons (Bv1-Bv5) is characterised by strong presence of hematite and minor amounts of goethite, besides traces of talc and chrysotile were detected. Montomorillonite mainly occurs in superficial horizons (Bt,Btc) while illite and kaolinite in the deeper (2Bv).

The XRD patterns of the profiles 2 horizons shows a composition with a dominance of quartz, muscovite and albite and a number of reflections probably indicating the presence of nontronite. These results are consistent with the bedrocks, its weathering products and slope sediments outcopping in the two areas.

The depth trends of heavy minerals may provide information to help understand the pedogenetic weathering history of the profiles. The heavy mineral assemblages are shown in table 4. As regards to the heavy minerals percent composition of the profile 1, the opaque mineral are dominant even if the most important observa-tion results from the determination of transparent minerals: in the plinthite horizons, weathering-resistant mineral species show higher values (zircon + tourmaline -_from 67% to 78%), whereas unstable minerals amphibole, garnet and epidote present low percentage or disappear. Afterwards the weathering index values (Brewer 1976, Cremaschi 1978) increase with depth in this profile indicating a strong weathering depletion in the deeper horizons (Fig. 3).

Within the profile 2, only slight difference in heavy mineral composition are observed. The profile can be further subdivided on the base of the opaque and transparent different trends. In the upper part (AB, Btg) the trasparent are dominant while they decrease in abundance with depth (2Bt, 2BtC). Ultrastable minerals are represented only in low percentages, while amphibole and pyroxene (nearly 60%) are more frequent and constant. Moreover, mineralogical composition of deeper horizons (presence of barite, anatase, apatite) is more complex than that of the top horizons, which show a significant increase of the percentage of tourmaline and epidote. The weathering index of

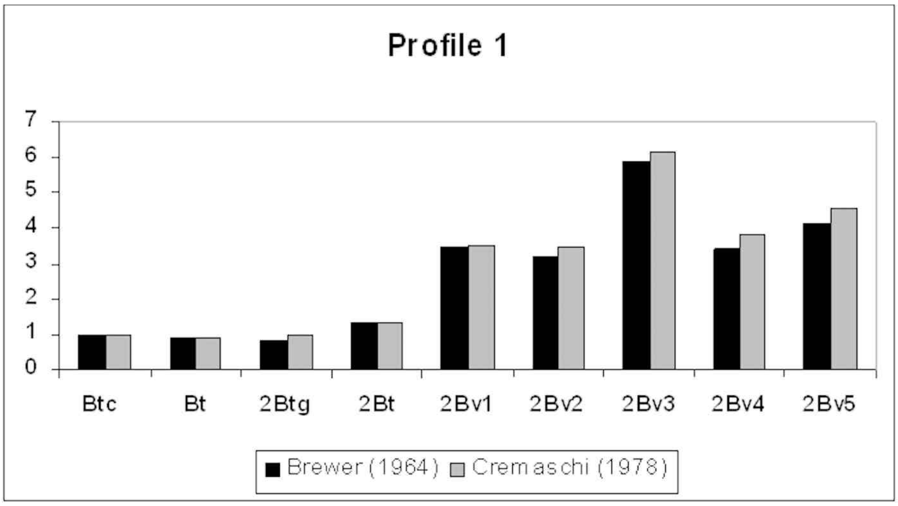


Figure 3. Depth trends of alteration index in the profile 1.
Figura 3. Tendencia en profundidad del índice de alteración en el perfil 1.

the profile 2 is not significant, due to the lack of samples of the 2Bvm horizon, the nature of the parent material of the deeper unit and the polygenetic origin of the parent material of the upper unit. However, the results suggest that the strongest weathering in the entire section occurs in deepest horizon.

5.3 Micromorphology

Micromorphology is the better way to understand the pedological history of those profiles. The main micromorphological results obtained from thin section are summarized in tables 5, 6.

5.3.1 Profile 1

The main micromorphological features of surface soil are frequent limpid yellowish clay coatings and dense infillings, which are usually with clear lamination and with crescent shape. We recognized some dusty clay coatings alternated with silt and fine sands coatings that indicate phases of coarse illuviation. Some isolated fragmented clay coatings with sharp extinction lines have been observed (papules, Brewer 1976). Pedoturbation may be responsible for this dislocation. We observed tipic iron nodules both orthic weakly impregneted and disorthic strongly impregnated which present sharp boundaries and spherical shape (Fig.4, micrographs 1). The coarse fraction of the groundmass is dominantly composed of subangular quartz grains, quartz aggregates (coarse sand) and common muscovites flakes of silt size, but there also few rounded quartzite grains strongly weathered (lithorelicts, Brewer 1976), with intermineral pores containing amorphous iron oxides. Besides irregular charcoal fragments are randomly distributed in the groundmass, as results of repeated burns of the scrub. Organic material consists of few tissue residues and common fine amorphous organic material. The yellowish brown fine fraction, mainly composed of clay, shows stipple-speckled b-fabric and locally a dotted limpidity.

The top horizons (2Btg-2bt) of the buried paleosols also have frequent clay coatings and/or infilling but they show a yellowish brown colour and they often are fragmented with diffuse extinction lines. The quartzites grains with hematite-filled pores always are present in the coarse fraction while the fine fraction consist of a yellowish brown or reddish brown clay. The planar voids produces a well developed angular blocky and slightly prismatic microstructure. Iron depletion hypocoatings are

Table 5. Summary table of micromorphological characteristic of the profile 1.
Tabla 5. Tabla resumen de las características micromorfológicas del perfil 1.

P1 Horiz.	Voids	Microstructure	c/f (limit; ratio; rel.distrib.)	Coarse material	Fine material	Organic material	Pedofeatures
Btc	Common planes (m.a.); common intrapedal smooth channels (m.a.) and very few mammillated intrapedal vughs (f.a.)	Highly separated and strongly developed angular blocky with accomodating peds	10 µm; 1/3 (1/2): double spaced (single) porphyric	Frequent angular quartz grains (c.s - f.s); very few angular quartz aggregates (c.s); few rounded quartz aggregates with intermineral pores containing amorphous Fe oxides (c.s) and muscovite flakes (silt)	Yellowish brown; speckled, locally dotted, limpidity; stipple-speckled b-fabric	Very few tissue residues and amorphous organic material	Few orthic Fe-nodules weakly impregnated (m.a.) and few disorthic rounded Fe-nodules strongly impregnated (c.a.); very few fragmented layered clay coatings; yellow concentric limpid or dusty clay coatings (2%); silt and clay infillings (1%)
2Btg	Frequent smooth planes (m.a.); few interpedal smooth channels (c.a. - m.a.) and very few mammillated vughs (m.a)	Highly separated and strongly developed angular blocky with partially accomodating peds	5 µm; 1/4; open porphyric	Common angular quartz grains (m.s - f.s); very few subrounded quartzite grains (f.g - c.s) with intermineral weathering, hematite-filled pores; very few muscovite flakes (silt)	Yellowish brown; speckled, locally dotted limpidity; stipple speckled, locally porostriated b-fabric (30%); Reddish brown dotted limpidity, speckled, locally undifferentiated, b-fabric (70%)	Amorphous organic material	Microlaminated of limpid, locally dusty, yellowish brown clay (2%); dense complete infillings of yellow and reddish dusty clay (5%); very few disorthic Fe-nodules strongly impregnated
[illegible]	Very few planes (m.s - f.s); very few intrapedal mammillated vughs (m.s. – f.s.) and common undulating channels (m.a.)	Highly developed primary angular blocky and weakly separated and moderately developed secondary angular blocky with partially accomodating peds	5 µm; 1/4; open porphyric	Common angular quartz grains (m.s – f.s) and subangular quartz aggregates (c.s - f.g.) with Fe-hydroxides filling on clinotore [illegible]; few muscovite flakes (silt) and very few calcite grains	Reddish brown; dotted limpidity, speckled locally undifferentiated, b-fabric (70%) Yellowish gray; dotted limpidity; stippled-speckled or cross-striated b-fabric (30%)	-	Two juxtaposed clay coatings (reddish + yellow); yellow and reddish dusty clay infillings (2%), locally fragmented; strong iron segregation in the groundmass or around voids (Fe-depletion and Fe-hypocoatings); few typic and concentric Fe nodules (m.a)
[illegible]	Frequent planes (m.s. - f.s.); few intrapedal smooth channels (m.s.) and very few irregular vughs (m.s - f.s.)	Highly separated and strongly developed angular blocky with accomodating peds	5 µm; 1/4; open porphyric	Common angular quartz grains (m.s - f.s) and few subrounded quartz aggregates (c.s - m.s.) with intermineral pores containing amorphous Fe oxides; very few calcite grains (c.s.)	Yellowish gray; speckled limpidity; stippled-speckled and parallel striated b-fabric (25%) Reddish brown; dotted limpidity; speckled locally undifferentiated, b-fabric (75%)	-	Thick, convolute reddish and yellow clay coatings and dense infillings (3%), locally compound (silt + clay); Fe-depletion around planes; few typic or concentric Fe nodules, moderately and strongly impregnated (m.a. - c.a.)
2Crt	Frequent irregular or rounded vughs and few channels (m.a.)	Apedal (highly separated angular blocky with accomodating peds, probably artificial) Vughs microstructure	5 µm; 1/20; open porphyric	Few angular sericitic rock fragments (c.s); common angular quartz grains (f.s) from disintegration of individual quartzitic grains	Brownish gray; clouded limpidity; parallel striated sericitic crystallitic b-fabric	-	Dominant thick and convolute reddish clay coating and dense infillings in fissures parallel to the old rock foliation; common iron-oxide segregation in the fissures or microgranular (silt) segregation in the groundmass

Table 6. Summary table of micromorphological characteristic of the profile 2.
Tabla 6. Tabla resumen de las características micromorfológicas del perfil 2.

P2 Horiz.	Voids	Microstructure	c/f (limit; ratio; rel.distribution)	Coarse material	Fine material	Organic material	Pedofeatures
AB	Common planes (m.s.), some subparallel; few intrapedal smooth channels (f.g. - c.s.) and very few mammillated interpedal vughs (m.s.)	Moderately separated and weakly-developed angular blocky with accommodating peds	10_μm; 1/4 ; double spaced porphyric	Common angular quartz grains (m.s - f.s); few subangular quartz aggregates (c.s - f.g.) with intermineral weathering; very few angular grains of plagioclase (c.s.) and muscovite flakes (silt)	Brown; dotted limpidity; undifferentiated b-fabric (40%) Gray; speckled limpidity; pore-granostriated b-fabric (60%)	Few fresh roots; very few tissue residues and common amorphous organic material	Very few passing features; cas pedorelicts, very strongly iron impregnated, including quartz grains with hematite-filled fissures; few orthic and disorthic Fe-nodules (m.s.); yellowish clay coatings, locally stress deformed
Btg	Common smooth planes (m.s. - f.s.); very few intrapedal mammillated vughs (c.s.) and smooth channels (c.s.)	Moderately separated and well-developed angular blocky with accommodating peds	10_μm; 1/1 and 1/4; close porphyric (bottom) and open porphyric (top)	Very common angular quartz grains (c.s. - f.s); few subangular quartz aggregates (c.s) and very few angular grains of plagioclase (m.s) and muscovite flakes (silt)	Yellowish gray; speckled limpidity; cross-granostriated and porostriated b-fabric	Very few reddish brown tissues and organ residues (m.s)	Crescentic coatings (50_μm thick) and dense complete infillings of dusty yellowish clay (2-3%); orthic aggregate nodules of Fe-hydroxides (10% of groundmass)
2Btv	Very few smooth planes (f.s.); very few intrapedal mammillated vughs (m.s.) and smooth channels (m.s.)	Weakly separated angular blocky with accommodating peds	10_μm; 1/4; open porphyric	Common angular quartz grains (m.s - f.s) with hematite-filled fissures; few subangular quartz aggregates (c.s. - f.g.) with intermineral weathering; very few subrounded grains of quartzites (c.s) and muscovite flakes (silt)	Reddish brown; dotted limpidity, undifferentiated b-fabric (70%) Gray; speckled limpidity; stippled-speckled b-fabric (30%)	-	Very few dense complete infillings and fragmented coatings of limpid reddish clay in pores; common Fe hypocoatings strongly impregnated around channels; common anorthic Fe-Mn nodules (c.s., m.s) strongly impregnated
2Bt	Very few planes (m.s. - f.s.); common intrapedal smooth channels (m.s.) and few mammillated vughs (m.s)	Weakly separated and moderately developed angular blocky with partially accommodating peds peds; Channel intrapedal microstructure	10_μm; 1/1; close porphyric	Frequent subangular and subrounded quartz aggregates (c.s - f.g.) with intermineral weathering; very few subangular quartz grains (c.s - f.s); very few opaque mineral (m.s.) and biotite grains strongly weathered	Gray; speckled limpidity; stippled-speckled b-fabric (50%) Reddish brown; speckled limpidity; speckled b-fabric (50%), locally undifferentiated	-	White and red crescentic coatings (m.s.) of limpid clay (2%); dense infilling of limpid clay in pores (3%); juxtaposed coatings of limpid red clay and yellowish white dusty clay with Fe-hydroxides hypocoating
2BtC	Frequent planes (f.s.); common inter-intrapedal smooth channels (m.s.)	Highly separated and well-developed angular blocky with partially accommodating peds	10_μm; 1/1; close porphyric	Dominant subangular and subrounded quartz aggregates (c.s - m.s.); few subangular quartz grains (m.s - f.s); very few opaque mineral (m.s.) and mica flakes.	Yellowish brown; speckled limpidity; speckled b-fabric (50%) Reddish brown; dotted limpidity; speckled b-fabric (40%), locally undifferentiated	-	Yellow and red microlaminated limpid clay coatings (f.s - m.s.), locally fragmented, sometimes with juxtaposed ferruginous silt coatings (2%); common dusty clay infilling in pores (m.s.)

frequently observed around the main conducting voids (planes-channels) as result of reduction. In plithitic horizons clay coatings and infillings occur in pores, these consist of fine clay, locally fragmented, without layering and with colour changes. Their colour varies between yellow and red. In some cases two juxtaposed clay coatings can be identified (Fig. 4, micrographs 2): a younger yellow limpid clay generation characterised by a sharp or diffuse extinction lines and other older reddish dusty clay coatings showing different degrees of assimilation into soil groundmass. The deeper plinthitic horizons (Bv4, Bv5) correspond to the highest clay accumulation in the profile in fact show very thick and convolute reddish clay coatings and /or dense infillings. Iron impregnation is common throughout the plinthitic horizons, hypocoating on voids and concentric orthic nodules are described. The fine fraction always is dominant over coarse fraction (open porphyric C/F relative distribution). The colour of the micromass may vary from reddish brown to yellowish grey and the micromass may contain very fine muscovite flakes. Poro/cross-striated b-fabric can occur in the grey zone, while the reddish zone mainly show speckled, locally undifferentiated, b-fabric.

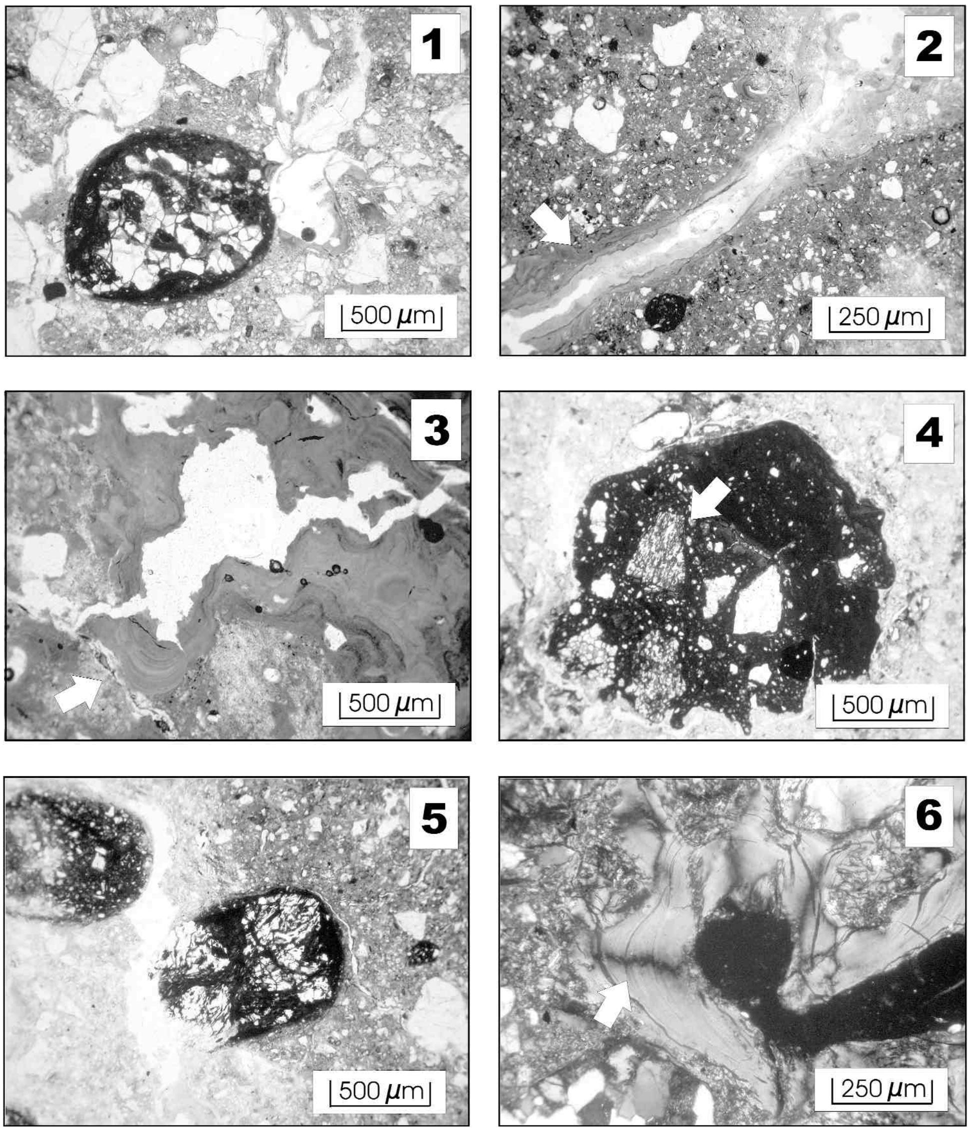
The underlying saprolite is characterised by a massive structure with frequent irregular and interconnected vughs and few channels in upper part. The saprolite is overlain by a slightly pedoplasmated material (2Crt) with evidence of soil formation (passage features). Illuviated clay is observed as very thick coatings and dense infillings in fissure and voids (Fig. 4, micrographs 3). The deeper part is completely serecitized (sometime the sericite is transformed to kaolinite), but the schist original foliation still remain visible and sometimes quartz veins are preserved. The coarse fraction (sand) consists mainly of quartz and quartzite fragments progressively disintegrate to individual grains. Dark reddish brown microgranular iron-oxide segregation occur in groundmass and especially in voids and fissures (plinthitic hematite according to Schmidt-Lorenz, 1978).

5.3.2 Profile 2

Profile 2 also has frequent yellowish dusty clay coatings and/or infillings even in the surface horizons (AB, Btg) but they often are stress deformed. The fine fraction mainly consist of yellowish grey clay showing a well developed poro-granostriated b-fabric, even if it often is brown in the upper part the profile, with dotted limpidity and undiferrentiated b-fabric, because of high amorphous organic material content. Smooth and accommodated planes are dominant among the other voids, mainly due to a shrinkage of the soil material on drying. The most striking pedofeature is the presence of large and rounded pedorelicts (Fig. 4, micrographs 4), very strongly iron impregnated, including quartz grains with hematite-filled fissure described as runiquartz by Eswaran *et al.* (1975). The coarse fraction is essentially composed of angular quartz grains and subangular quartz aggregates but considerable quantities of weatherable minerals grains may be present (mica, plagioclase). Besides a open (double space) porphyric related distribution grade into close porphyric ones with the depth. The petroplinthite below is characterised by intense iron oxide segregation in the groundmass: a dotted dark reddish brown fine material with a undifferentiated, locally speckled, b-fabric and common hypocoatings on pores and grains. When the clay fine material is greyish (iron depletion), it has a speckled limpidity and stipple-speckled b-fabric. In the petroplinthite layer the number of iron-rich nodules increase, they are characterized by a different fabric (chalcedony small grains), fragments of weathered rocks, sharp boundaries and rounded shape (Fig. 4, micrographs 5). The coarse fraction of groundmass comprise common large quartz grains with hematite-filled fissure (runiquartz) and subangular quartz aggregates with intermineral weathering. Illuvial features are present also in this horizon, where they consist of scant fragmented reddish clay coatings and dense infillings, often assimilated into groundmass. In the successive horizons the coarse sandy fraction become dominant (close porphyric relative distribution) and it mainly consist of subrounded quartz aggregate. Frequent illuvial features are observed. Limpid clay coatings and infilling occurs in pores (channels). They have crescentic shape, microlaminated internal fabric and show sharp extinction lines in crossed polarised light (Fig. 4, micrographs 6).

Figure 4 . Micrographs from profiles: 1 – Btc (profile 1): disorthic and nucleic Fe nodule. Plain-polarized light; 2 – 2Bv1 (profile 1): two juxtaposed clay coatings (white arrow). Plain-polarized light; 3 – 2Crt (profile 1): General view of clay illuviation. Note the thick crescentic clay coatings (white arrow). Plain-polarized light; 4 – AB (profile 2): Pedorelict strongly impregnated with hematite. Note the presence of runiquartzs (white arrow). Plain-polarized light; 5 – 2Bvm (profile 2): rounded disorthic Fe nodules in reddish and gray micromass. Plain-polarized light; 6 – 2Bt (profile 2): thick laminated clay coating. Note the sharp extinction line (white arrow), indicating strongly oriented, very fine clay particles. Crossed polarizers.

Figura 4 . Imágenes de micrógrafos de los perfiles: 1 – Btc (perfil 1): disorthic y nodulos de Fe nucléicos. Luz plano-polarizada ; 2 – 2Bv1 (perfil 1) : dos capas de arcilla yuxtapuestas (flecha blanca). Luz plano-polarizada ; 3-2Crt (perfil 1) : Vista general de arcilla iluvial. Se noten las espesas capas de arcilla (flecha blanca). Luz plano-polarizada ; 4 – AB (perfil 2) : « pedorelict» fuertemente impregnado de hematita. Se note la presencia de « runiquartzs » (flecha blanca). Luz plano-polarizada ; 5 – 2Bvm (perfil 2) : Nodulos de hierro «disorthic» y redondeados, en una micromasa rojiza y grisa. Luz plano-polarizada , 6- 2Bt (perfil 2) espesas capas de arcilla laminadas. Se note la marcada linea de extinción (flecha blanca) que indíca particulas de arcilla fuertemente orientadas y muy finas. Polarizadores cruzados.



6. Discussion and Conclusions

The described profiles show clear bisequence characteristics. In both cases an erosional sur-face separate two units: the deeper is truncated and lacks surface horizons, the upper seems to be evolved from different parent material. This hypothesis is supported by macro and micro-mor-phological evidences and by the results of the analyses carried out.

The deeper unit of profile 1 was affected by strong pedogenetic phases that lead to the development of a complex profile which shows characteristics like actual tropical areas soils on deeply weathered, rather oversaturated rocks:

-the horizon sequence (fresh rock, saprolite, pedoplasmation front, plinthite) is alike classical lateritic type-sections (Stoops *et al.* 1994, Stoops et al. 1990);

-the composition of the heavy minerals (it do not contain weatherable minerals) in the plinthite (Stoops *et al.* 1994, Stoops y Buol 1985);

-the micromass is characterised by high degree of homogeneity, a red brown colour, a cloudy limpidity, a very weakly developed speckled or undifferentiated b-fabric and it have a pronounced porphyric c/f-related distribution; all characteristic of an oxic material (Stoops 1994, Stoops y Buol 1985);

-Hematite-rich groundmass together with clear amount of plinthitic hematite (as defined by Schmidt-Lorenz, 1978) occur in saprolite and deepest horizons;

-the textural pedofeatures of the plinthite show differences in colour in relation with the degree of bleaching (Fedoroff y Eswaran, 1985);

-the presence of kaolinite-type and kaolinitization traces on saprolite fractures (Hamilton, 1964).

The deeper unit of the profile 2 is still affected by a strong pedogenetic phase, as for instance:

-its development started with the formation of plinthite under impeded drainage conditions, which hardened upon exposure.

-The petroplinthite shows micromorphological characteristics of an oxic material (Stoops 1994, Stoops y Buol 1985).

In the meanwhile, also shows a relative abundance of primary minerals which probably are related to external sedimentary inputs interrupting the regular soil development, by a rejuvenation of the parent material.

The upper unit of both profiles, even if very different from the pedogenetic point of view, are similar as regards as a weak evidence of a Holocene recent pedogenesis under a temperate humid climate (yellow clay coatings) and as the occurrence of reworked lithorelicts and pedorelicts (Brewer, 1976), exhibiting features different and incompatible respect those characterising the soil in which they are included.

In this light, both soil profiles can be regarded as polycyclic pedocomplexes (Bronger y Sedov, 2003), i.e. paleosols, because they show evidence of relict properties and transported materials: the presence of runiquarts and rounded anorthic and disotric Fe-nodules in the superficial layers points to a material derived, at last partially, from the destruction of older surfaces (Eswaran *et al.* 1975, Stoops 1989).

Moreover, the frequent illuvation features in the lower layers (thick reddish clay coatings and/or infillings) and the presence polycyclical clay illuviation with juxtaposed clay coatings (Catt 1989, Fedoroff 1997) in profile 1 are incompatible with the present day climate and related to climate warmer and more humid than today. In fact, from the palaeoclimatic and chronological point of view, the development of plinthitic soils (typical of present day tropical areas) needs specific climatic and environmental conditions ranging from tropical subhumid climate with strong seasonal dry/wet cycles, compatible with cementation of Fe oxides or Fe oxyhydrates in the profile 2 features, to higher temperature and higher water deficit in dry periods (Schwertmann y Taylor, 1989), compatible to the presence of hematite in the profile 1 (Tardy *et al.* 1995, Tardy 1993, Nahon 1991). In the past, similar condition in Italy, can be connected to warm periods, like the ones occurred in Italy before the glacial Pleistocene (Late Tertiary and Early Pleistocene, Cremaschi 1987, Cremaschi y Ginesu 1990) or during the Middle Pleistocene interglacial phases (Magaldi *et al.* 1985, Magaldi y Bidini 1991). Besides this hot and wet period may be also responsible for the cockpit shape of the biggest karst sags on Maniè Plateau. Biancotti and Motta (1988) have used a model which included an erosion factor related to the dissolution of carbonate rocks, to estimate the beginning of the karstification process of the carbonate plateaux of Manie. The cockpit karst formation mainly commenced during the interglacial alpine periods Early Pleistocene. Consequently, this date may be connected to the beginning of the weathering of the whole palaeosurface.

As far as the geomorphological context is concerned, both the described paleosols profiles are related to a palaeosurface. First of all, each described paleosol unit is strictly associated to a specific palaeosurface, characterised by morphological stability and flat landform enabling rates of weathering to exceed those of erosion: the formation of these paleosols might be directly related to the development and preservation of a geomorphologic palaeosurface. Furthermore, strong weathered paleosols pertain to long cycle pedogenietic bodies (*sensu* Duchaufour, 1977), which can acquire pedogenic inertia and operate as a protection for the palaeosurface itself, preserving the latter from erosion.

Moreover, palaeosurface occurrence is not the only geomorphological signature related to the pedogenesis of described profiles: also the different geomorphological position has played a role in the genesis of the described paleosols. Going into detail, the deeper unit of soil profile 1, located on the top of the high plain originate by weathering in situ of a relatively homogeneous parent material derived by schists (presence of saprolite) and show less evidences of external sedimentary inputs and rejuvenation of the parent material, than the soil profile 2, located on low position and thus strongly influenced by morphodynamics of the steep slopes at its back. In fact it shows clear input of debris slope and a strong iron enrichment probably connected to the accumulation from external upslope source (horizons of higher adjacent old soils). This is shown by the sharp bed contact of the parent material, and the absence of a saprolite horizons or leaching zone in the bedrock. Moreover the 2Bvm horizon may be cemented and indurate by post depositional reprecipitation of iron oxides from the dissolution iron rich detrital laterite fragments or from groundwater ferruginization under a marine highstand influence (Tardy *et al.* 1995, Wang 2003). Therefore, the formation and conservation of such paleosols is strongly associated with the landscape evolution.

Finally, the work on plinthitic profiles of the western Liguria substantiate once more the relevance of paleosols as palaeoclimatic and palaeoenvironemntal indicator in the continental areas from the Late Tertiary to the whole Quaternary. Notwithstanding the discontinuity of the pedological record, the scarce preservation of the older evidences, due to the erosion and/or deposition of materials during cold stages of the Quaternary, pedogenetic bodies are a very useful tool to reconstruct the past, thanks to their sensibility to variation of the lithosphere, biosphere and atmosphere. This potential can be enhanced when paleosols are placed in their geomorphological context: in this case, the integration of both disciplines allows a more detailed reconstruction of the environmental dynamics affecting the study area.

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