WHEN A PEDOMARKER IS LACKING: PALYNOLOGICAL AND CHEMICAL MULTIANALYSIS OF A LATEGLACIAL-HOLOCENE BURIED SOILS SUITE (BOLOGNA, ITALY)

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Abstract

A thirteen-metres long sedimentary suite was recorded and sampled in the courtyard of Sant'Orsola Hospital in Bologna to reconstruct the surrounding area's paleoenvironmental evolution. Fourteen buried Soil Units (SU) were recognized, three of which were characterized by a peculiar darkening. Three stratigraphic markers allowed us to chronologically constrain the soil sequence between the Roman Age and 13230±70 calibrated years BP. The geomorphological study and the chemical multianalysis provided data for the understanding of the pedological palaeoenvironment, whereas the pollen analysis permitted to suggest the lowest buried soil (SU 14) to be a lateral equivalent of the lacking Bölling chronozone alfisol, proposed as a fundamental marker in the Emilia-Romagna regional chronostratigraphic scale. A small creek (Fossa Cavallina) was the main local morphosedimentary dynamic driver whereas the human settlement appears to have been a subordinate factor. These results highlight the importance of the integrated approach of geomorphology, pedology and palynology for the study of continental deposits.

Keywords: *pedology, geochemistry, palynology, Holocene, Bologna*

Introduction

A pedomarker is a buried or outcropping soil profile, hereon *Soil Uni*t (SU), that possesses its own intrinsic characters making it easily recognisable as a body distinct from the adjacent ones. Furthermore, it can possess a peculiar value as a chronostratigraphic unit of local or regional value. As a consequence, it can be used as a reliable geologic *guide-level*. In Emilia-Romagna region the youngest soil unit of such a kind is an intergrade between *Alfisol* and an *Inceptisol* (Cremaschi, 1979) with a soil profile *A-Bw/Bt-Bk-C* according to Martelli et al. (2009) dating back to the last Lateglacial period (about 14.5-14.8 ky BP). It shows a rubefaction degree indicating that it had to develop during a sufficiently warm but wet time

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lapse coinciding with the Bölling chronozone as suggested by the δ^{18}O-GRIP curve (NOAA, 1989). The soil developed mainly in fan areas characterized by an axial trenching able to prevent lateral sedimentation, that is under geomorphic stability conditions. A lot of literature exists dealing with the natural soil kind developed in the low alluvial plain, some tens of kilometres off the fan toe (Amorosi et al., 2014) but information concerning the transition zone between the fan toe and the upper alluvial plain are lacking. Here the pedomarkers gradually thin out and tend to disappear due to a progressive increase in sedimentation rates. This study aims to focus such a case showing the recognition of alternative evidences.

Geographical and geological setting

The city of Bologna lies at the Apennine fringe at a mean elevation of 53 m a.s.l. in a general tectonic setting that in recent times was able to generate seismic events of medium-high magnitude (Boschi and Guidoboni, 2003; Picotti and Pazzaglia, 2008). It was built at the foothill between Reno and Savena rivers. The study site is located outside the eastern side of Medieval walls. In this area Holocene fluvial sediments pertaining to the Upper Emilia-Romagna Synthem, Torre Stagni Subsynthem (AES 5) (Martelli et al., 2009) outcrop; they are mainly made of silts and clays with small channel bodies interspersed within. The lower boundary is marked by an unconformity surface above Quaternary marine units, whereas the upper boundary often coincides with the topographic surface, somewhere showing an alteration profile belonging to AES 7b Vignola Unit. This paleosol was recongnised at depth near the city (Vittori Antisari et al., 2016).
In such a kind of geological setting, sedimentary cycles of two different kinds take place: during cold periods, alluvial fans were aggrading, while during warm periods pedogenesis developed on their surface (Di Dio and Valloni, 1997; Valloni and Calda, 2007). Amorosi et al. (2014) suggested that Holocene soils were less developed than those of the previous interglacial. At and beyond the distal margin of the alluvial fan these soils disappear giving place to less developed soil types (Vittori Antisari et al., 2016).

Geomorphological setting

Between Reno and Savena, from E to W, Meloncello, Ravone, Vallescura, Aposa, Fossa Cavallina and Griffone creeks flow, shaping a complex pattern of surficial morphologies already widely studied in literature (Cremonini 1992, 2001, 2014; Cremonini and Bracci, 2010). Fossa Cavallina and Rio Griffone flow joined in a single channel (Fig. 1), today artificially covered by urban structures.
Fossa Cavallina erodes many different geological Formations (Pantano, Cigarello, Termina, Gessoso-Solfifera and Sabbie di Imola, all ranging from late Miocene to Pleistocene). Because of this, its alluvial deposits are rather fine and vary from clays to sands with some pebble interspersed. On the hill slopes arboreal cover is quite homogenous, although there are some uncultivated open fields. Its recent geomorphological behaviour is shown by the V shape of the valley.

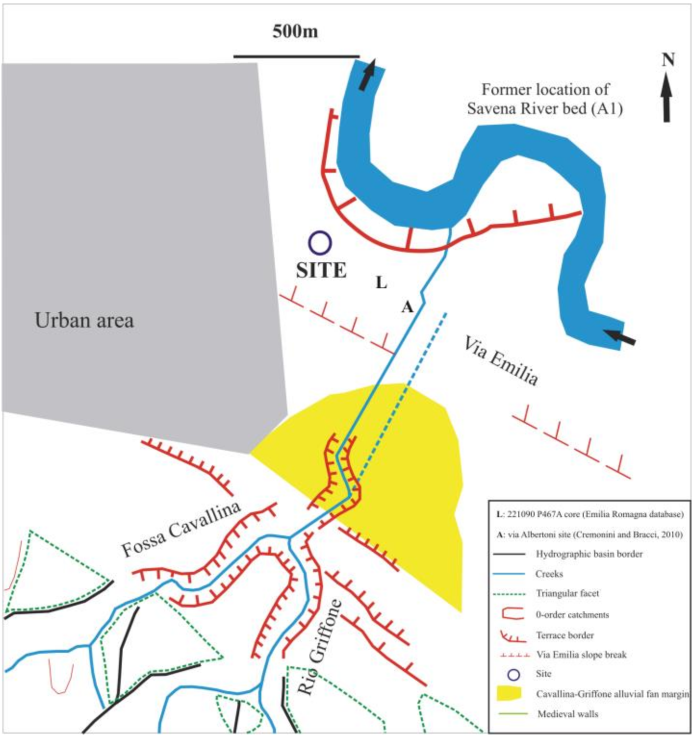

Figure 1
Geomorphological map of the lowland track of Fossa Cavallina and Rio Griffone from the foothills to the study site.
We have to remark that the whole area North of the foothill is completely urbanized.

Rio Griffone has a wider basin than its western adjacent counterpart (Table 1) and it crosses the same Formations except from Pantano F., thus originating finer deposits. Differently from Fossa Cavallina, here the arboreal cover is scarce because of the wide cultivated fields on the less steep valley sides; furthermore, a 10 cm to 1.5 m deep, 20 to 50 cm wide incision has been found all along the valley profile, witnessing an active, though limited, erosional behaviour. Finally, on the right side of the catchment, three fairly flat surfaces interpreted as fluvial terraces were found around the height of 130-140 m a.s.l.

Table 1. *Main characteristics of the catchments in study.*

CREEKS	A_b (km^2)	$A_{c>}$ (km^2)	$A_{c<}$ (km^2)	L (km)	Mountainous tract inclination	Q_{max} P=200
Fossa Cavallina	0,77	0,79	0,49	1,82	n.d.	n.d.
RioGriffone	1,68	1,58	0,99	2,6	n.d.	n.d
Cavallina + Griffone	2,45	2,37	1,48	4,43	43,1‰*	28,47 m^3/s*

A_b = basin area - $A_{c>}$ = upper limit of the estimated alluvial fan area - $A_{c<}$ = lower limit of the estimated alluvial fan area - L = main fluvial course's length - Q_{max} = maximum discharge estimated for basins with absolute maxima of 200 mm per 24 hours – n.d. = not determined.
* = data from Cremonini (2001)

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As shown in Figure 1, Fossa Cavallina and Rio Griffone (C-G system from now on) flow on the bottom of a trench extending from the mid alluvial fan area up to the Apennine foothill. In this area, three orders of terraces exist in a parallel direction to the chain margin.

Northward, C-G system maintains a straight track up until the confluence with paleo-Savena river. Here a uniform flat morphology can be observed due to the merging of the distal fan area and the alluvial ridge. Savena river (A1 channel, sensu Cremonini 1992) crossed normally the C-G system in a slightly NE position away from the study site, where the main landform is the left side of a 5 m deep meander in respect to via Massarenti road plan. While this road was built during the Roman Age, the fluvial channel was certainly active in Medieval times, when it eroded the original road track; as a consequence, the modern curved geometry can be the result of the restoration works during the Middle Ages. The study site is located between the Savena meander and the alluvial fan inside a small depression. The area has an 8‰ S-N gradient, originated from the C-G system aggradation.

Materials and methods

Geomorphological survey

A wide area around the site was geomorphologically surveyed to recognize the original landforms often masked by the pervasive urban structures. On a more restrict area around the study site a levelling survey was performed with a gradiometer and a levelling rod along five selected lines referred to a local benchmark (54.8 m a.s.l.) taken from *Carta Tecnica Regionale dell'Emilia Romagna*.

Site field observations

Two stratigraphic sections (Section A and B) were sampled for geopedological lab investigations: the sections lie 20 m away from each other and they can be vertically correlated. A further hand-borehole was made up to a depth of 4 m beneath the excavation bottom in order to reach the top of the Bölling soil pedomarker. The stratigraphic units were recognized according to their main features (grain size, colour, mottles, structures, $CaCO_3$ nodules and/or concretions, charcoal, bricks, Fe-Mn nodules) and sampled.

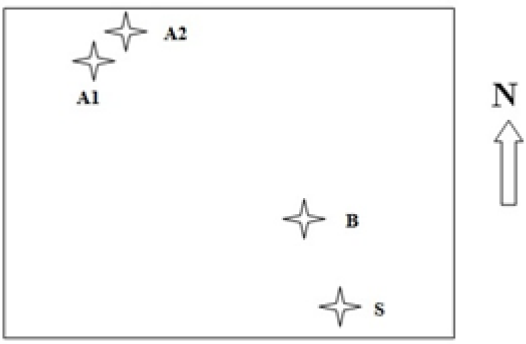

Figure 2
The site hole map showing the sampling point locations of section A and B and of the hand-borehole. For the correct topographic position of the site, see Fig. 1.
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Chemical analysis

Physical characteristics were determined both at dry conditions and at artificially reintegrated humidity at the Agrarian Chemistry's laboratory (at the University of Bologna's Agrarian Sciences Department). Then, samples were desiccated at 50°C, powdered, quartiled and sieved through a 2 mm mesh sieve in order to carry on chemical analyses. To determine the total concentrations of macro- and microelements (Al, Ca, Fe, K, Mg, Mn, Na, P, S, Ti and As, B, Ba, Be, Cd, Ce, Co, Cr, Cu, Li, Mo, Ni, Sb, Pb, Sb, Sn, Sr, V, Zn respectively) the Aqua Regia method was used after calibrating the instrument (ICP-OES optical spectrometer) with two multi-element standard solutions (CPI international Amsterdam peak-performance) in an Ar gas medium at 5000 °C. While the analysis was being carried on, control measures were made using bi-distilled water. TOC (Total Organic Carbon) was determined by the difference between the weight of the original desiccated sample and the weight measured after 10 hours in the muffle at 550°C. Total $CaCO_3$ and pH were also measured (MiPAF, 2000).
Interpretation of the results and final determination of SU werebeen made according to the WRB (IUSS, 2015) classification of soils, whereas geochemical values were compared to De Vivo et al. (2009).

Palynological analysis

After the pedochemical analysis, a palynological study was done at the laboratory of Centro Agricoltura e Ambiente "Giorgio Nicoli" in San Giovanni in Persiceto (BO, Italy) using the method elaborated by the Earth's Sciences Institute at the Bruxelles Vrije Universität and partly modified. The palynological content of 10 soil units was analysed after a selection made on the basis of their stratigraphic position and geochemical content; two of them are nearly barren and, therefore, were not included in the final analysis. About 10 g of dry sediment per sample were weighed, then a *Lycopodium* tablet was added (1 tablet = 20484 spores) to calculate APF (Absolute Pollen Frequency); after that, samples were mechanically disrupted in a 10% Na-pyrophosphate solution and filtered through a 0,5 mm mail sieve and a 5 µm mail nylon filter; each sample then underwent many 24 hour-long treatments in the following order: 10% HCl solution, acetolysis, enrichment with a Na-meatungstate hydrate heavy liquid, 40% HF solution, ethanol suspension and evaporation at 60 °C in a stove. In the end, microscope slides were prepared with glycerine jelly and paraffin.
Modern palynomorphs were recognised referring to Faegri et al. (1989), Moore et al. (1994) and Reille (1992, 1995, 1998), while for secondary grains many USGS publications were used as reference (Frederiksen, 1980 and 1984, Love et al., 1978, Tschudy 1973 and 1975, Tschudy and Scott, 1969, Tschudy et al., 1984, Tschudy and Van Loenen. 1970. The results were also controlled by comparing them to geographically constrained scientific works (Bertolani Marchetti, 1968; Paganelli, 1984; Tomaselli, 1987; De Marinis, 1997; Bertoldi, 2000: Mercuri et al., 2012 and 2013; Ravazzi et al., 2012; Vittori Antisari et al., 2013; Zanchetta et al., 2013).

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Where possible, at least 300 pollen grains were counted, although sometimes this sum could not be reached; in such cases we had to be satisfied with the statistical validity granted by counts higher than 100. For species ecological characterisation, reference to Pignatti (1982), Tutin (1993) and Zangheri (1976) was fundamental alongside with a huge miscellanea of pollen keys stored at the laboratory and with the online databases at www.actaplantarum.org, www.prodromo-vegetazione-italia.org, https://paleobiodb.org, https://paleobotany ru, http://fossilworks.org.
For each sample a pollen spectrum was elaborated after putting together plant species in Pollen Groups as follows: LD (deciduous trees), Cf (conifers), Q (oak woods), ar (shrubs), E (grasses), I+i (woody and herbaceous hygrophytes), Fe+ fe (woody and herbaceous edible plants), cc (herbaceous cultivated, only valid for 1_3 and 3_4 samples since other samples are too old to include cultivated species; in these ones cc merged into E), As (spontaneous anthropic), ce (cereals), leg (Fabaceae), pp (meadows and pastures) and Tg (cold-climate Lateglacial proxies). Because of the young age of geological Formations cut by Fossa Cavallina and Rio Griffone, secondary palynomorphs were subdivided in two pollen groups on the base of their timeframe: JO (Jurassic-Oligocene) and MP (Mio-Pleistocene).

Radiocarbon dating

SU 10 was radiocarbon dated at the CEDAD laboratory, University of Lecce (LTL15779A). The raw dating (11401±65) was calibrated by OxCal 3.10 (Reimer et al., 2009), indicating 11350 – 11210 BC (1σ = 68.2%. 13300-13160 cal. BP) and 11440 - 11150 BC (2σ = 95.4%. 13390-13100 cal. BP). $\Delta\ ^{13}C$ showed values of 27,1±0.4‰.

Results

Stratigraphic log and buried soils

Section A (Fig. 3) lacks the stratigraphic record of the uppermost 1.95 m due to the reworking practises linked to the modern times building works. Section B (Fig. 4) partially integrates the stratigraphic record of Section A. Below 1.95 m of depth the stratigraphic record shows poorly developed buried soils which can be subdivided in two: SU 1-9 (1.5-6.2 m of depth) are less than 1 m thick, whereas SU 10-14 (6.2-11.6 m of depth) are thicker. SU 14 (9.75-11.6 m) has a fluvial origin, weak pedogenesis and light CU trend; its boundary lies at about 43 m a.s.l., nearly coinciding to the top of the Last Glacial Savena gravels (http://geo.regione.emilia-romagna.it). The lowest 4 m of the suite were sampled by means of a hand borehole (9.75-13.6 m). Among these, the 2 m at the bottom were not drawn in Fig. 3 due to the fact that no evidence of pedogenesis was recorded; their FU sandy texture possibly suggest a crevasse-splay origin. At 13.4 m of depth a yellowish coarse-sand/gravel body without pedogenesis was interpreted as coming from Pantano Formation. SU 12, 11 and 10 are a suite of *A/AC* dark buried soils with only little bioturbation and Fe-Mn nodules.

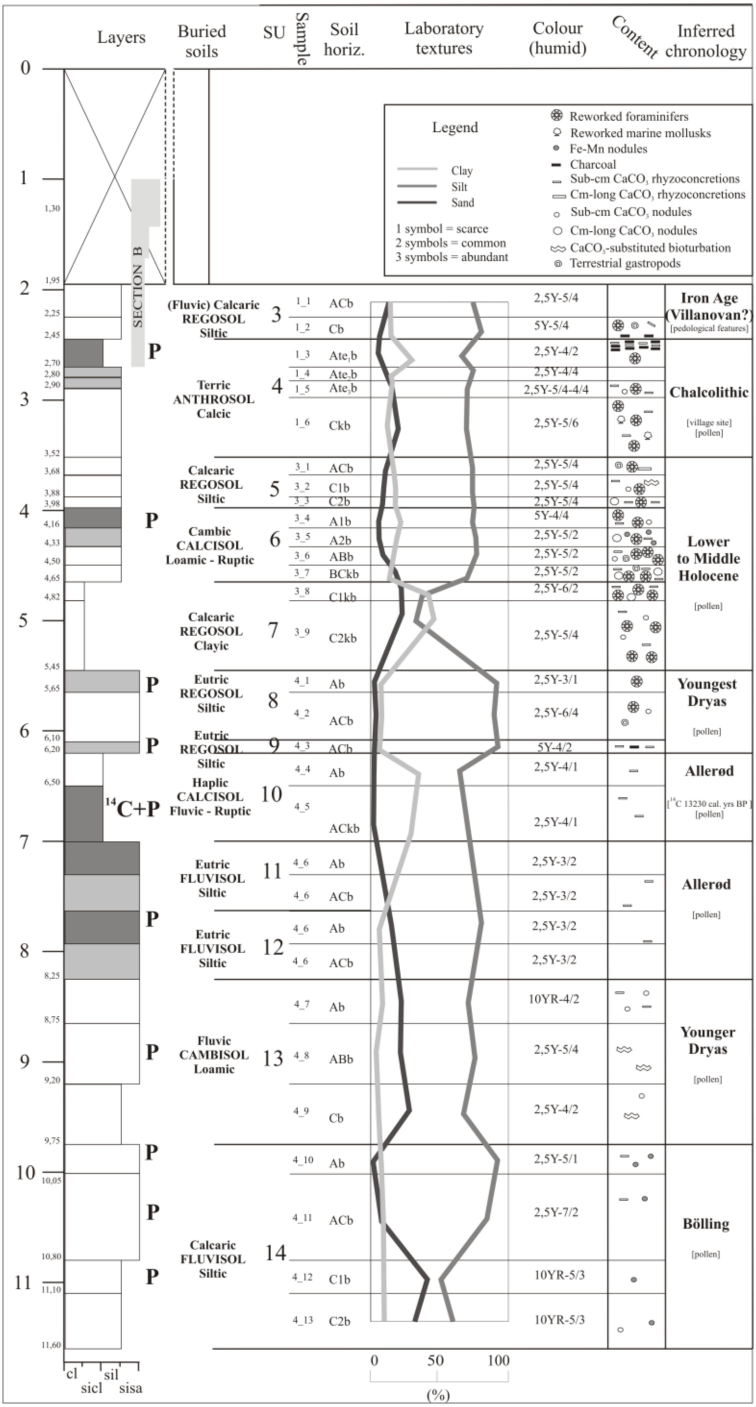

Figure 3
Section A. Pedological features and inferred chronology: on the right, in brackets there are the proxies used to infer the soil unit's age; on the left, P marks pollen analysed horizons.

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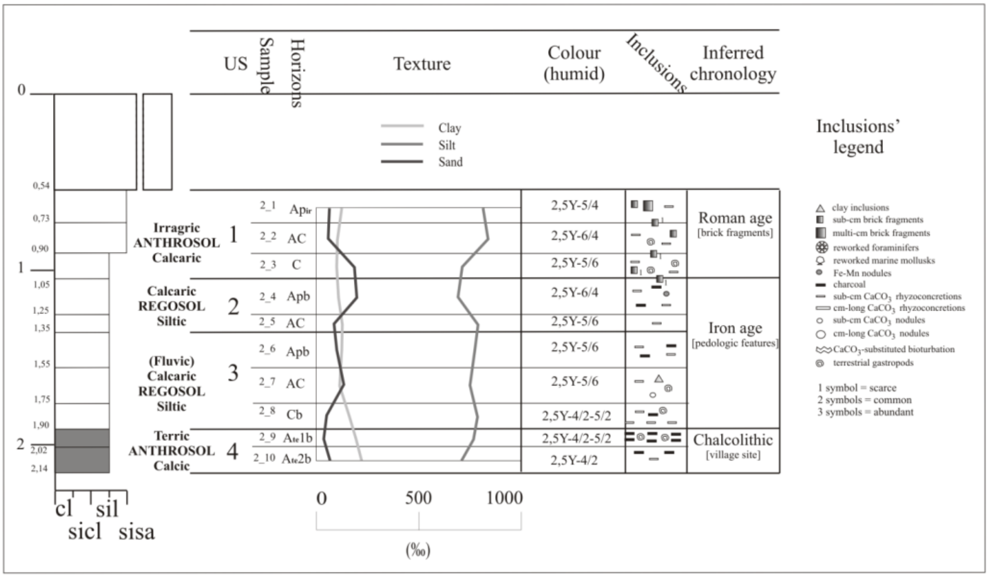

Figure 4. *Section B. Pedological features and inferred chronology: on the right, in brackets there are the proxies used to infer the soil unit's age; on the left, P marks pollen analysed horizons.*

Table 2. *Summary of the Soil Units and their classification.*

Pedological sequence		Depth (cm)	Soil classification (IUSS, 2015)
Soil profiles	Horizon samples		
------	n.c.	0-54	------
Ap_{ir}/AC/C	2_1/2_2/2_3	54-105	Irragric ANTHROSOL Calcaric
2Apb/AC	2_4/2_5	105-135	Calcaric REGOSOL Siltic
3Apb/ACb/Cb/	2_6/2_7/2_8/1_1/1_2	135-190	(Fluvic) Calcaric REGOSOL Loamic
$4A_{te}1b/A_{te}2b/A_{te}3b/C_k$	2_9/2_10↔1_3/1_4/1_5/1_6	245-352	Terric ANTHROSOL Calcic
5ACb/C1b/C2b	3_1/3_2 /3_3	352-398	Calcaric REGOSOL Siltic
$6A1b/A2b/6ABb/BC_kb$	3_4/3_5/3_6/3_7	398-465	Cambic CALCISOL Loamic Ruptic
$7C_k1b/C_k2b$	3_8/3_9	465-545	Calcaric REGOSOL Clayic
8Ab/ACb	4_1/4_2	545-610	Eutric REGOSOL Siltic
9ACb	4_3	610-620	Eutric REGOSOL Siltic
$10Ab/AC_kb$	4_4/4_5	620-700	Haplic CALCISOL Fluvic Ruptic
11Ab/ACb	4_6	700-750	Eutric FLUVISOL Siltic
12Ab/ACb	4_6	750-825	Eutric FLUVISOL Siltic
13Ab/ABb/Cb	4_7/4_8 /4_9	825-975	Fluvic CAMBISOL Loamic
14Ab/ACb/C1b/C2b	4_10/ 4_11/4_12/4_13	975-1160	Calcaric FLUVISOL Siltic
Crevasse splay		1160-1340	
Resimented Pantano Formation		1340-1360	

The upper part of the suite is an alternation of FU and CU (coarsening upward) units, whose base is a C1k-C2k Regosol, where clay amount reaches the maximum value of the section. Above it, another black soil (SU 6) was laying at the depth of

4 m. At 2.5 m of depth the dark Eneolithic Age Anthrosol topped by a charcoal layer was found. The three upper soil units each have an Ap horizon, the uppermost of which was dating back to the Roman Age thanks to artifact fragments.
SU 8 and 9 showed intermediate features between SU 1-7 and SU 10-14 (thin horizons, similar grain size and various content) like those of the upper SU 1-7 (charcoals, $CaCO_3$ nodules and resedimented foraminifers). On the contrary, they had a darkening and a stratigraphic position similar to SU 10-14. No clay coatings were seen throughout the suite, except for AC horizon of SU 3.
A simple evaluation of the sedimentary rates can be proposed by taking into account the available stratigraphic benchmarks, if an average error in the soil chronological definition is accepted. According to the depth shown in Fig. 3, the considered benchmarks are the following: i) the deepest (6.6 m) is the 13230 cal. yrs BP as medium value of the 1σ radiocarbon dating; ii) the Eneolithic top lying at 2.45 m of depth considered as dating back to about 4950 yrs BP (as mean value of the time lapse 3500-2500 BC); iii) the Roman Age agrarian soil buried surface lying at 1.54 m of depth considered as possibly dating back to 0 AD, i.e. 1950 cal yrs BP. According to these assumptions, the mean sedimentation rates can be assumed as: 0.5 mm/y between Allerød and Eneolithic periods and 0.3 mm/y between Eneolithic and Roman Ages, respectively. A further tentative sedimentation rate could be proposed for the post-Roman Age as 0.79 mm/y. It must be stressed that the previous ones are apparent values.

Geochemistry

In figure 5 organic matter shows high values in the two topmost SU 14 horizons, in SU 10 and 9; it also peaks in the three topmost SU 4 horizons and in Ap of SU 3-1. Another minor peak is found at the top of SU 6. Similar trends are followed by Al, B, Ba, Be, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, V and Zn throughout the soil suite, suggesting some kind of binding between them and organic matter. On the contrary, $CaCO_3$ generally shows a clearly opposite trend, marking its peaks where organic matter is lower and viceversa. In the same way $CaCO_3$, Ca and Sr showed similar variations. An exception is made by SU 14, where $CaCO_3$, organic matter and the aforetold elements all show similar trends. Other noticeable elements are: i) the high P concentrations between US 13 and 8 and in the Roman Age SU 1; ii) in SU 14, the Mg lowest concentration in C1b horizon followed by its maximum in AC horizon.

Palynology

Due to data provided by the pedological analysis, SU 4, 6 and 8-14 were investigated for their palynological content, while the first three soil units (recognised as agrarian soils) were not.

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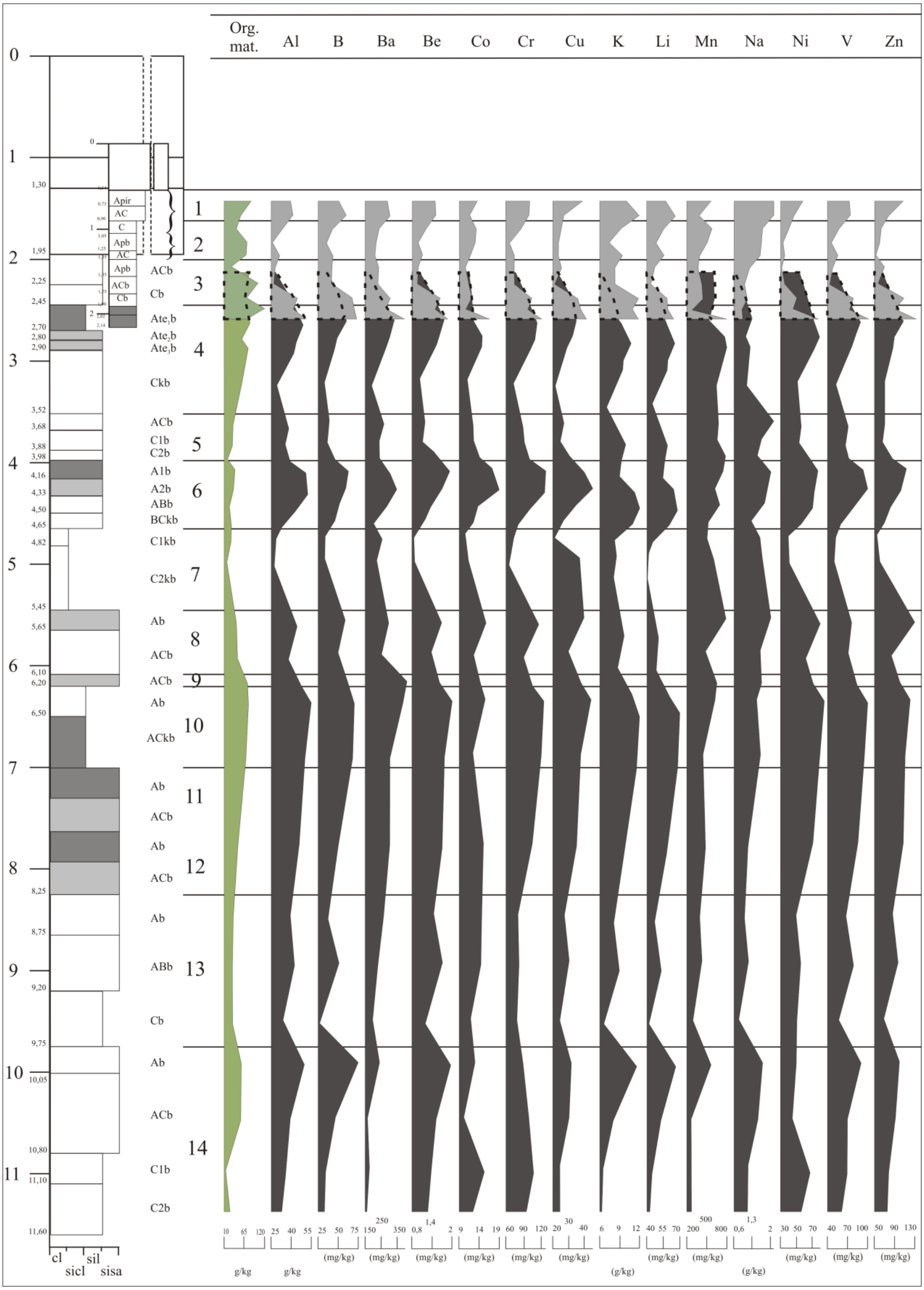

Figure 5. *Concentration of organic matter and of macro- and microelements that show similar trends.*

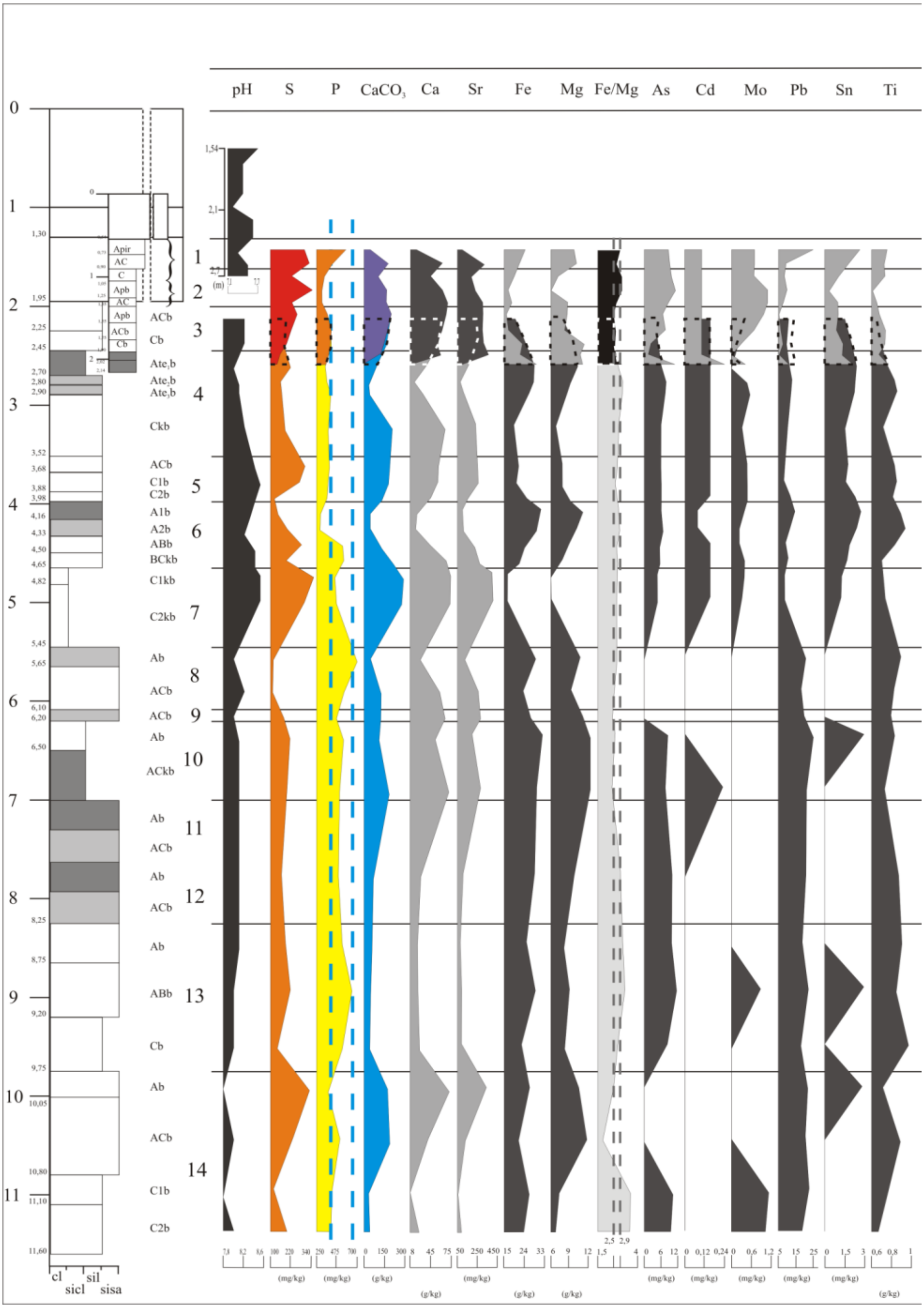

Figure 6. *pH trend and concentration of $CaCO_3$ and of other macro- and microelements showing particular trends*

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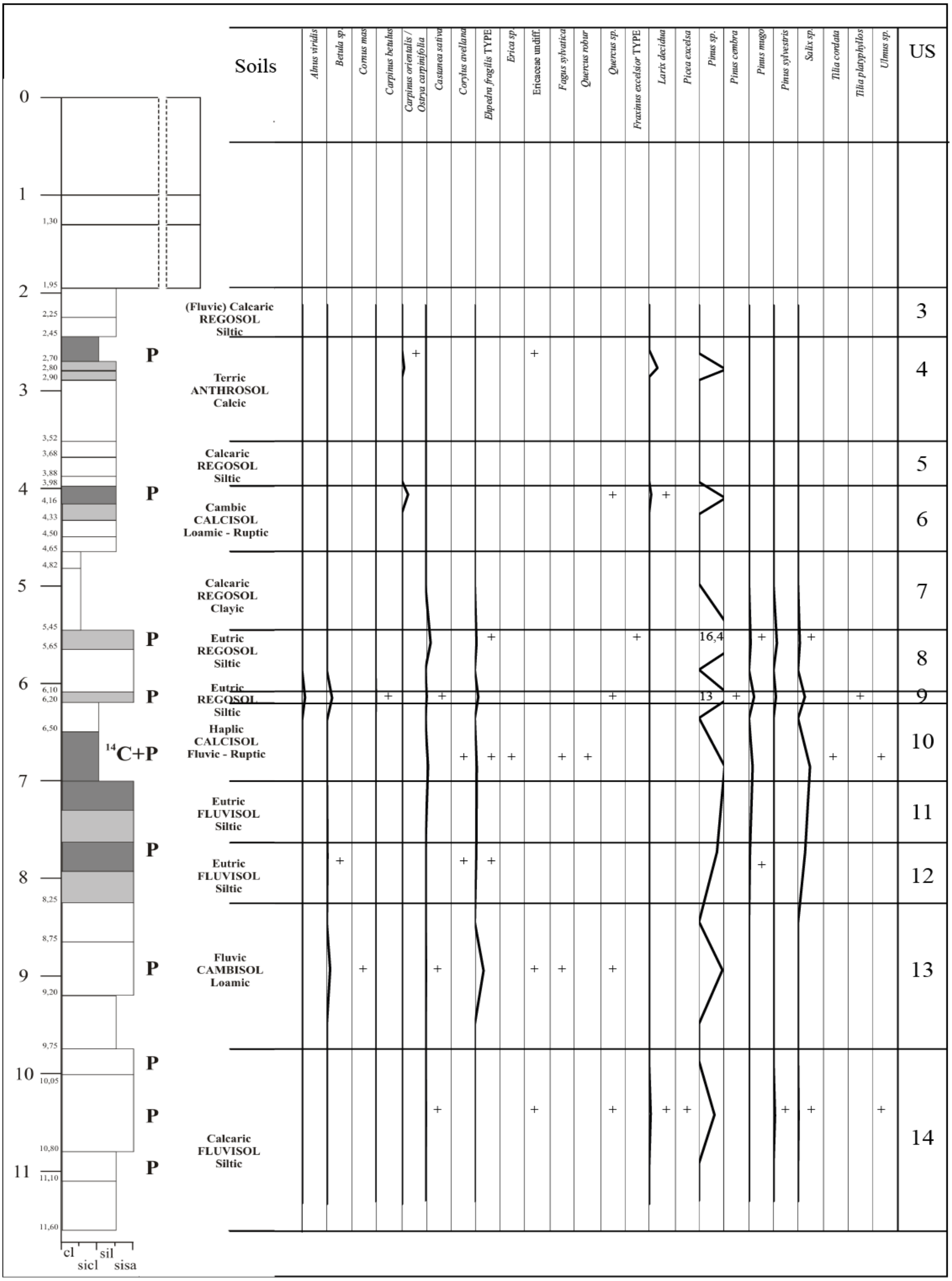

Figure 7. *Woody plants (A+ar+L) pollen content. Concentrations range 1-10%; when greater, a number shows it; when lower, a +.*

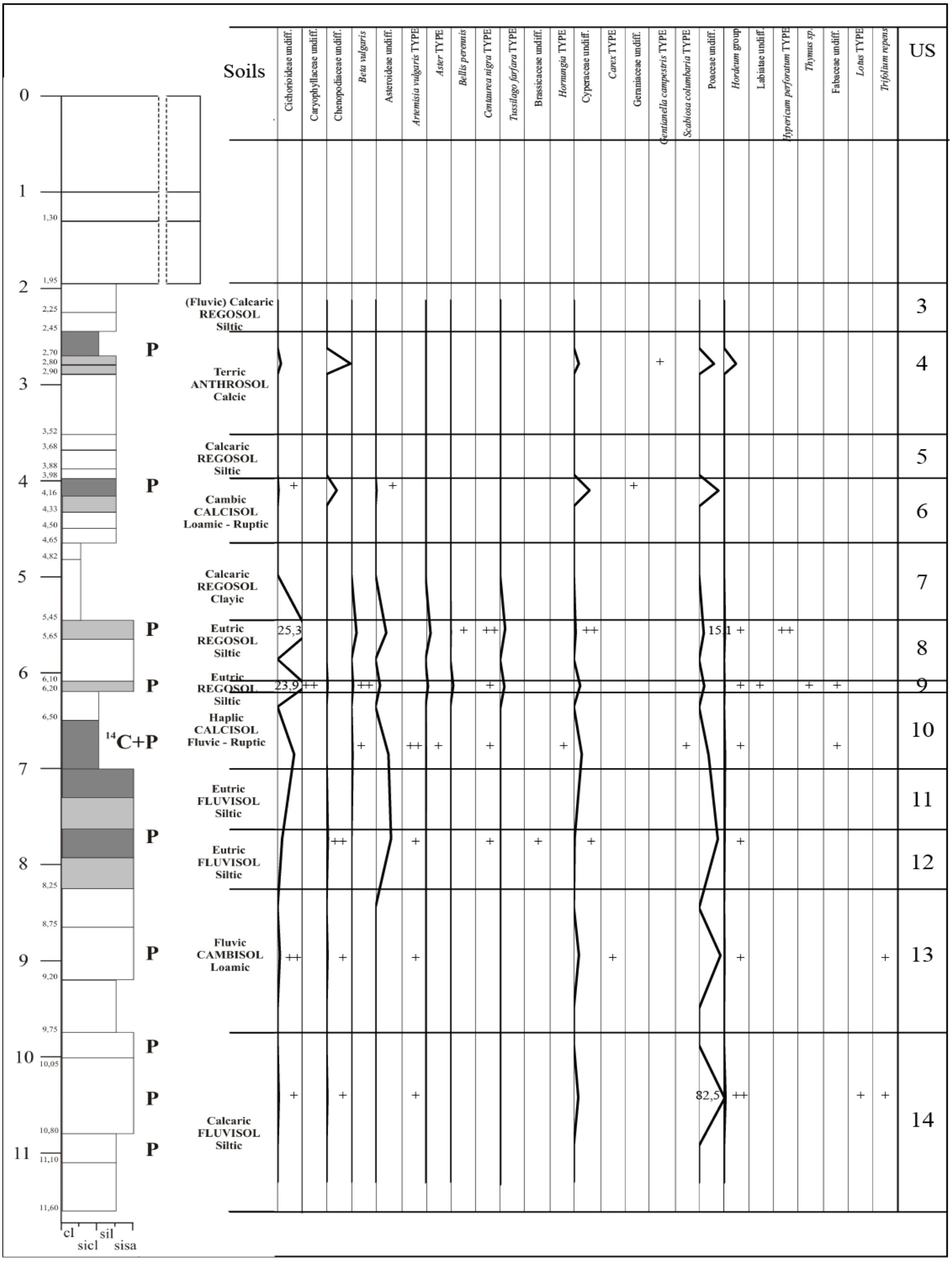

Figure 8a. *Herbaceous (E) pollen content. Concentrations range 2-20%; when greater, a number shows it, when 1-1.9%, a ++; when below 1, a+. An exception is made by Poaceae, whose scale is 0-80%, with minimum and maximum values expressed in numbers.*

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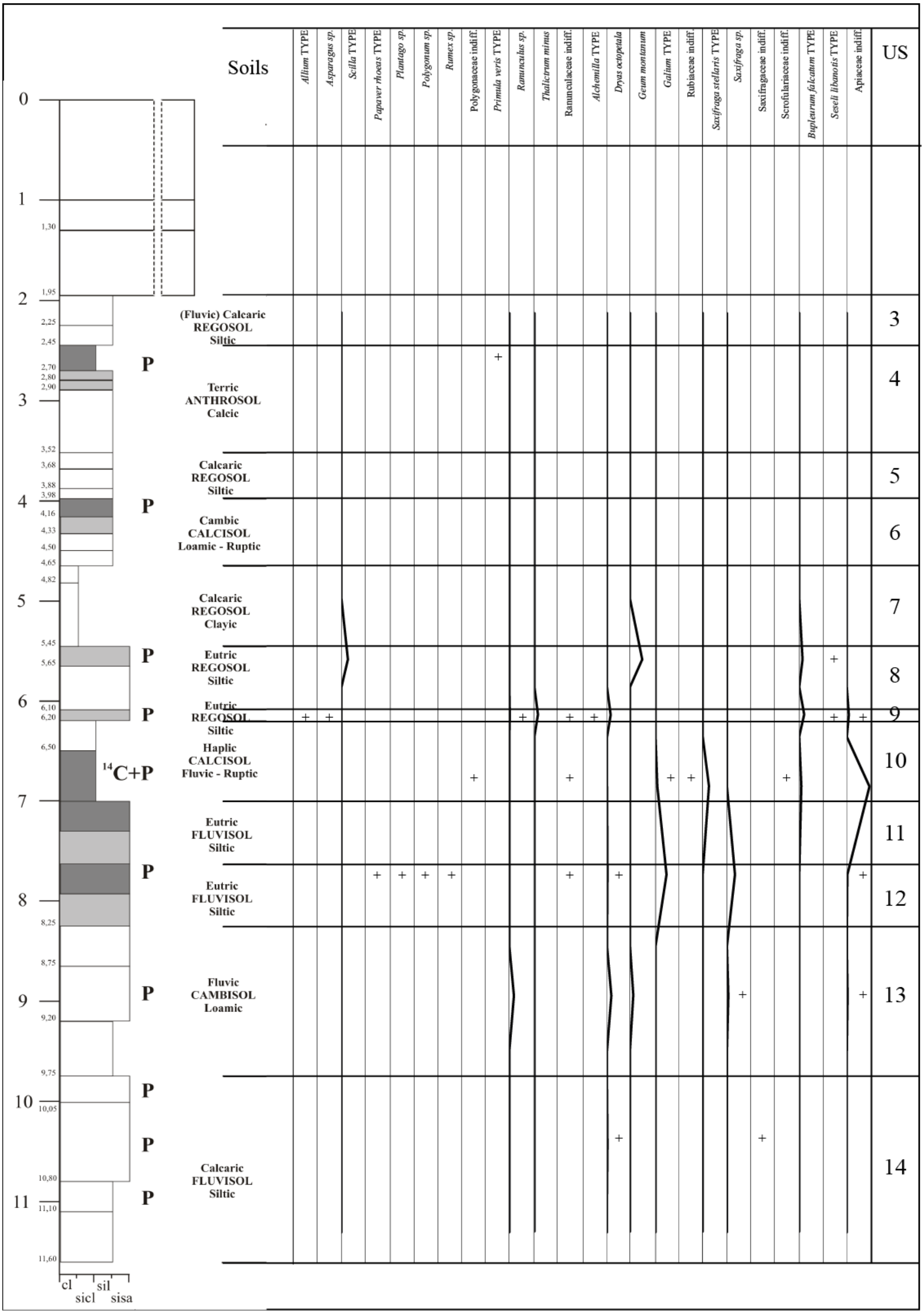

Figure 8b. *Herbaceous (E) pollen content. Concentrations range 1-10%; when lower, a + shows it.*

Arboreal plants. Woody plants are always subordinate to herbs in every sample. Among them, Conifers are dominant by the high *Pinus sp.* presence; very often its low preservation state has not allowed to refine the determination of species. Deciduous broad-leaved trees are present in every sample but subordinate to Conifers, even though with higher species richness; they altogether belong to the mixed oak forest group (*Cornus mas, Carpinus betulus, Corylus avellana, Carpinus orientalis / Ostrya carpinifolia, Quercus robur, Quercus sp., Fraxinus excelsior, Tilia cordata, Tilia platyphyllos* and *Ulmus sp.)* but, despite their high differentiation, they do not trespass the 2.5% peak of SU 6. Among woody hygrophytes there are *Salix sp.* and *Alnus viridis*.

Herbaceous plants. Herbaceous plants are always dominant in respect to woody plants, with a 73.8 – 90.7% range of presence; they are mostly represented by spontaneous species, since anthropic indicators are always low in numbers except in SU 4, where they reach 29.2% of total pollen concentration. The dominant family is Poaceae, alternatively followed or outclassed by Cichorioideae, Chenopodiaceae and Asteroideae. Cyperaceae locally assume a high importance but generally remain low in values.

Pteridophytes. Pteridophytes are present in every sample; although they generally remain a minor floristic component, in SU 14 and 4 they have a dominant or co-dominant position and are more abundant than Tracheophytes in SU 6; the poor preservation has often impeded species determination.

Alia. *Concentricystes* (green algae, indicators of water stagnation in a non-wetland context) are present only in SU 4 and 6 but with very high values (49.4% and 22.1% respectively); *Hystricosphaeridia* have been found in the lower part of the section with generally low values; fungal spores have been found everywhere but are significant only in SU 4 and 6 and abundant in SU 14.

Secondary palynomorphs. Secondary palynomorphs have been found all along the profile and they always show a rather fair diversity within each sample, although remaining below 13% in six samples out of eight but reaching 26.8% in SU 4 and 52.5% in SU 13. Since their age they were subdivided in two pollen groups: the group *JO* (Jurassic-Oligocene) and the group *MP* (Mio-Pleistocene). The issue of their chronological subdivision arose when the lacking of geological Formations older than the Miocene in the catchment area was taken into account. Thus, at the study site for the *JO* pollen grains a two-times secondary deposition was proposed coming from the former Miocene secondary deposition in Cigarello, Termina and Pantano Formations, which are roughly located on the catchment divides. Finally, pollen spectra have been elaborated for each sample as follows.

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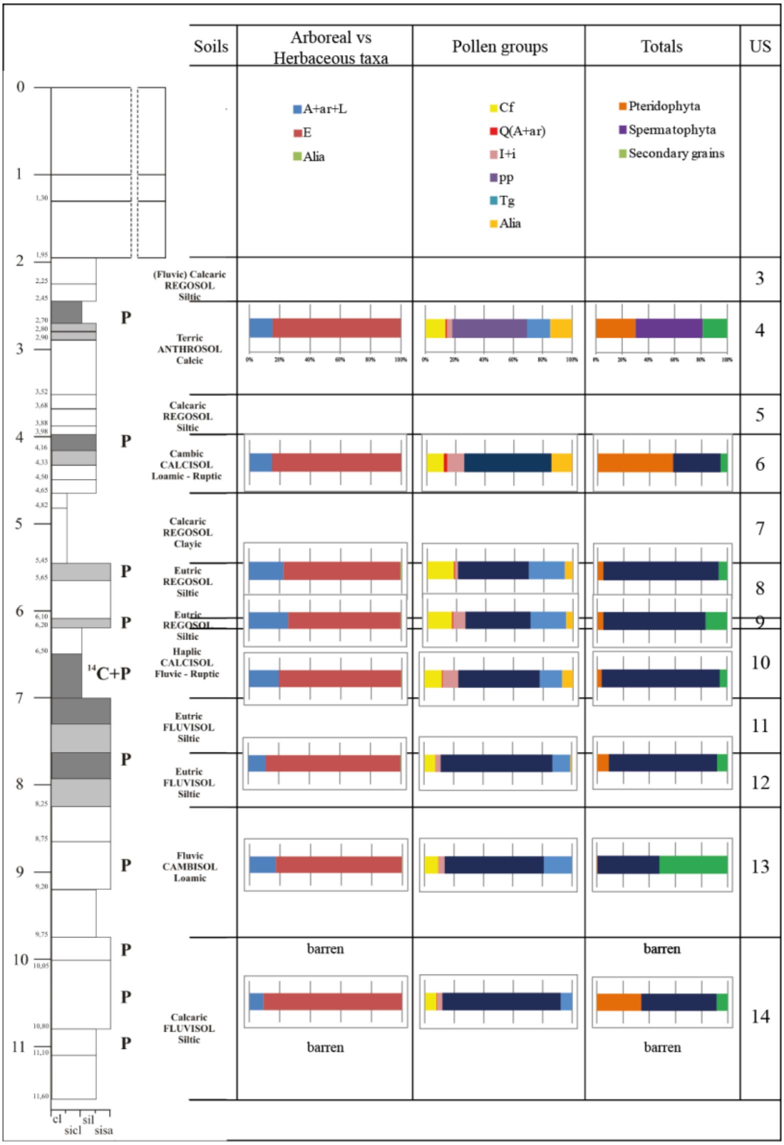

Figure 9 *Pollen spectra elaborated for each analysed sample.*

Discussion

Geomorphology

In Figure 10 the depth of the Iron Age (Etruscan) and Roman buried soils found at the site are compared with that studied in Albertoni road (Cremonini and Bracci, 2010) and with core 221090 P467A. In the latter, the FU silty interval at 3.2 m of depth was reputed to be an *Ap/C* soil profile of Roman Age because of its stratigraphic position and content. For the same reasons, for the underlying FU silty interval at 4 m of depth an Iron Age dating is suggested. As a consequence, we could correlate these stratigraphic sets with those of the study site and of Albertoni road, thus enabling the recognition of an Iron Age topographic gradient of 2.5‰ dipping eastward. During the Roman Age such a gradient had reduced to 1.25‰. This shows the possibility that C-G system maintained both the same position and channel as today (near Albertoni road) at least from the Iron Age onward. As a consequence, the modern 5‰ westward dipping gradient may have had a natural origin from the alluvial fan aggradation.

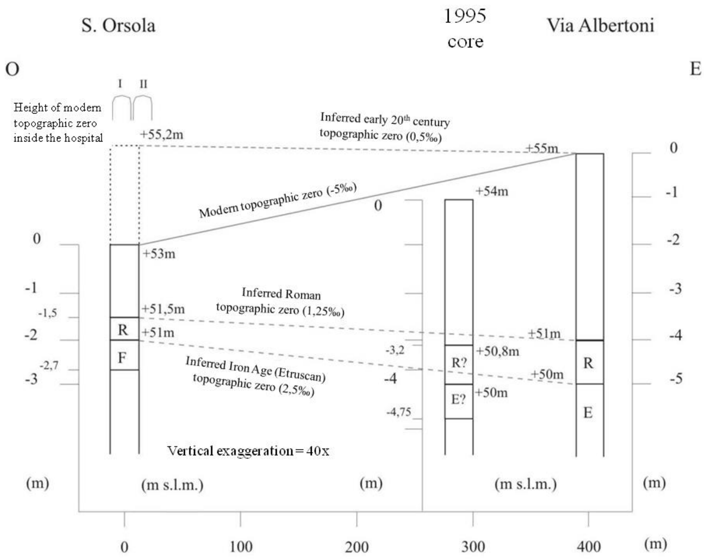

Figure 10 *Stratigraphic section from the study site to the 1995 core to the Albertoni road site (Cremonini, Bracci 2010).*

Furthermore, in this area it was possible to retrace the boundary between C-G and Savena depositional systems: indeed, on the bottom of core 221090 P467A at the depth of about 15 m lies the top of the LGM Savena gravels (http://geo.regione.emilia-romagna.it), while at the study site the top of the eroded gravels of Pantano Formation lies at 15.4 m of depth. This suggests that at the study site the sedimentation was exclusively generated by the *Cavallina-Griffone* system whereas, 300 m eastward, Savena river was still the main geomorphologic agent. Another proxy consistent with this interpretation is the absence of geochemical severe variations in heavy metals concentrations along the stratigraphic log: if Savena river was the main fluvial agent, a fraction of the mineral composition would have shown a consistent amount of sediments derived from ophiolitic rocks weathering. Finally, a further correlation can be stated for the three dark buried soils reported by Bruno et al. (2015) in the immediate surroundings of the study site to SU 4, 6 and 10-12 by their stratigraphic position.

Pedochemistry and Palynology

The geomorphological and field observations provided evidence for a partition of the stratigraphic section in two subsets: the lower part encompassing SU 14-10 and the upper part comprising SU 7-1; between them, SU 9-8 showed intermediate

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textural and pedological characteristics. Furthermore, the sediment provenance from the same geologic Formations has permitted to consider the soil units' geochemical content as independent from different sedimentary sources but due to paleoenvironmental conditions. Nevertheless, many factors point out to the persistence of the geochemical content within each soil unit such as: i) the poorly-developed pedogenesis affecting each buried soil; ii) the sufficiently quick burial of each soil; iii) the lacking of pedological features suggesting element translocation (Figs. 5 and 6). A brief appraisal concerning each soil unit is listed below.

SU 14 (Calcaric Fluvisol Siltic). In SU 14 a hot-humid climate grassland dominated by Poaceae and with Cichorioideae as an accessory group is represented. It indicates a natural pasture, where the arboreal component is scarce but well differentiated (*Salix*, *Ulmus*, *Quercus*, *Castanea sativa* and Ericaceae, while *Pinus* is low and, thus, referable to a regional pollen rain). For the considerations made in Chapter 3, the presence of the sole *MP* pollen group indicates an erosion limited to recent geologic Formations. Organic matter, $CaCO_3$ and metals (Figs. 5 and 6) all show similar trends and have high concentrations in the two topmost horizons. Despite of the yellowish colour, TOC concentration is fairly comparable to that of the dark horizons of SU 10-12 (53.1 g/kg in the A horizon, 51.5 g/kg in the AC). This could be ascribed to a different microbial fauna responsible for its degradation before the soil was buried (Van der Hejden, 2008), which in turn could reflect different environmental conditions; thus, the high abundance of fungal spores is very likely to be linked to organic matter degradation. Furthermore, (Sumner, 2000) since the topsoil is eutric, carbon fixation mainly depends on the chemical bonds it makes with Ca. In these conditions, at first organic matter decomposition proceeds rapidly but then it stops as the intermediate decomposition forms are produced. The result is that the soil still bears a good amount of organic matter but does not show any darkening. As a consequence it is very fertile and can host vegetal communities with high primary productivity. The 82.5% concentration of Poaceae pollen strengthens this inference. In Figure 6 the Mg peak is shown: indeed, contrarily to what is recorded in the rest of the section, in horizon AC Mg severely increases whereas Fe and most of other metals decrease. Since no dolomite-rich rocks are present within the catchments, this peak can be interpreted as reflecting environmental conditions rather than sedimentary dynamics, as follows: Mg is present in nature with high concentrations in many vegetal compounds (mainly chlorophyll, Buchanan et al., 2003), so it was interpreted as representing the primary productivity peak of the herbaceous community. To sum up, the Poaceae dominance, their high primary productivity and the continuous aggradation of the alluvial fan point out to a repeated superimposition of a non-climax vegetal association shaped by high levels of natural disturbance. While on one hand Mg was increasingly concentrated by plants from the subsoil in what time after time became the topsoil (and thus added to what already was its sedimentary content), on the other hand the organic matter's intermediate degradation operated by fungi, the scarce pedogenesis and the quick burial of each and every topsoil masked the single inundation events and shaped the internal uniformity of this AC horizon and of the upper A.

SU 13 (Fluvic Cambisol Loamic). In SU 13 a cold xerophilous steppe developed: the *pp* pollen group continues to be the dominant one, although slightly less; the cold climate indicators (*Tg* pollen group) are very abundant both as herbaceous (e.g.: *Dryas octopetala*, *Geum montanum* etc...) and as woody plants (mainly Conifers, although interpreted as a part of the regional pollen rain since their presence is below 20%). A major decrease in humidity is marked by the sudden drop in Pteridophytes, while Cyperaceae remained constant. An evidence pointing out to a sudden decrease in arboreal cover and enhanced erosion of the catchment divides is provided by the dominance of secondary pollen deposition (52.5% of the total pollen sum), where the *JO* group is more present than *MP*.
A remarkable feature is the high P concentration: 534 mg/kg (A horizon), 649 mg/kg (AB horizon) and 534 mg/kg (C horizon). These concentrations are consistent with mean values coming from a Neolithic both proximal off-site (416 mg/kg) and in-site with organic waste (649 mg/kg) in Germany (Gerlach et al., 2012), although the study site age is older. This environmental and chronological difference between the two sites excludes an anthropic cause for this anomalous concentrations and, since the lacking of peculiarly P-rich geological Formations in the catchment area, points out to a natural pasture where organic waste (dung) came from the persistence of wild animal herds on the territory. P concentrations remain higher than 416 mg/kg up until the basal horizons of SU 6, after which they drop and remain well below this threshold.

SUs 12-11 (Eutric Fluvisol Siltic) and SU 10 (Haplic Calcisol Fluvic-Ruptic). These two soil units are very similar to one another and on the field they appeared as almost fused in a single dark horizon. The internal difference in the darkening degree masks a triplet of A-AC Fluvisols possibly undergoing a rapid burial. The darkening increases from bottom to top as well as the TOC shows.
The 13230±70 cal. yr BP dating of SU 10 suggests that sediment was settled down during the Allerød. SU 11-12 have also been attributed to the same period because of their palynological content, whose pollen spectrum show a mesophilous prairie with a significantly developed hygrophilous component; the arboreal cover was still scarce, in comparison to SU 13, but well differentiated (mixed-oak forest taxa). Even though the vegetal landscape remained fairly similar, from SU 12 to 10 there is a sharp decrease in the *pp* pollen group (from 75,9% to 54,7%). By contrast, Conifers and *Tg* increase. As a whole, this sharp variation marks the shifting from the relatively warm onset of the Allerød chronozone to its cooler and drier termination. Furthermore, the *pp* pollen group inner composition varied significantly from an association dominated by Poaceae and, subordinately, by Asteroideae, to a more diversified one (Cichorioideae increase from 3,8% to13,6%, indicating the development a natural pasture near a water source). In such a pasture, the high P concentrations in the soil set can be considered dung-born. A slight decrease in environmental humidity can also be inferred by the replacement of Pteridophytes with Cyperaceae and *Salix sp.* (both also tolerant of cold climates)

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among the hygrophilous vegetation. However, the higher species richness in SU 10 (referable to a fragmentation of the ecological niches) could be due to both the recorded slight climatic worsening and to the disturbance effect of a moderate grazing. The secondary palynomorphs deposition suggests an erosion increase on the top of the hills from SU 12 to 10 due to the scarceness of *JO* pollen group in SU 12 and its abundance in SU 10, as well as the *Pinus mugo* increase.
Soils similar to the ones in study have been found in Texas, New Mexico, Arizona and Nevada (Harris-Parks, 2015) and in the Po Plain North of Bologna (Amorosi et al., 2014). Furthermore, Ravazzi et al. (2012) have shown a peak in organic matter accumulation during the Lateglacial – Holocene transition in Lombardy (Italy). A comparison between the Sant'Orsola black soils and the North American type I black mats shows striking similarities: i) a TOC varying 4.4 – 7.1 %; ii) a $CaCO_3$ concentration varying 7.1 – 11.6 %; iii) a variable coarse mineral composition made of terrigenous silicates and carbonate rhyzoconcretions (vegetal bioturbation); iv) the dominance of silts among the grain sizes; v) a well expressed pedologic microstructure with a strong degree of aggregation also due to carbonate coatings on the structure's facets. As a consequence, Harris-Parks (2015) defined the type I black mats as productive (type Ib) to very productive (type Ia) moist soils formed thanks to the superimposition of several wetting-drying cycles originating from water table oscillation on local highs. Then, the finding of the same characteristics at the Sant'Orsola site has led us to consider them as an equivalent originating from the crevasse splays of C-G system. As a consequence, we can state that the high thickness of these soil units hides several distinct episodes of inundation responsible of both the maintenance of similar ecological conditions and the alluvial fan aggradation.

SU 9-8: Eutric Regosol Siltic. Palynological analyses performed on SU 9 and 8 defined the palaeoenvironment as a natural pasture of a cold-climate steppe. The *pp* pollen group is still dominant, although the decreasing trend shown for previous soil units goes forth (being 48.6% and 44.5% in SU 9 and 8, respectively); the increasing presence of Cichorioideae and Asteroideae vs Poaceae is also persistent from SU 12 and marks at this depth the Cichorioideae dominance with respect to Poaceae, showing a temporal continuity of the natural pasture from the Allerød onwards: the 8.7% concentration of the *As* pollen group (mainly Compositae and Chenopodiaceae) and the P absolute maximum in the SU 8 A horizon (698 mg/kg) can be more easily interpreted as a consequence of the high levels of disturbance (grazing and a cooler climate) rather than as a first appearance of the anthropic settlement. The climate cooling is marked by the maximum concentration of the *Tg* pollen group (24.7%), summing up a pollen rain made of local- (*Alnus viridis*, *Betula pubescens* and *Ephedra fragilis* among the woody plants, *Dryas octopetala*, *Saxifraga sp.* and *Seseli libanotis* among the herbs), near-regional- (*Pinus mugo*) and far-regional taxa (*Pinus sp.* and *P. cembra*). This evidence, in turn, constrains these soil units to the Youngest Dryas, also thanks to the Allerød radiocarbon age of the underlying SU 10. As similarly observed for SU 13, the secondary deposition of the *JO* pollen group equals the *MP*, once again suggesting an erosion located on the hill tops. Consistent with the regional arboreal cover increase is the partial substitution of herbaceous hygrophytes with woody taxa and with Pteridophytes in SU 9 (I+i = 8,7%); the opposite behaviour is recorded by the SU 8, marking the onset of the coldest and driest climate conditions at the end of the Lateglacial (I+i = 2,7%). These considerations enable the comparison between the dark soils of SU 12-10 and 9-8: the vegetal association shifted from highly productive during the Allerød (dominated by Poaceae) to less productive during the cooler Youngest Dryas (dominated by Cichorioideae). Thus, the climate worsening can be positively linked to the weaker darkening of SU 9-8. Another local finding of an Upper Lateglacial blackened soil lies East of Bologna (Vittori Antisari et al., 2016).

SU 7, 5 (Calcaric Regosol Clayic) and SU 6 (Cambic Calcisol Loamic-Ruptic). This set of soil units defines the development of thin Regosols characterizing the upper part of the suite; furthermore, $CaCO_3$, Ca and Sr show an opposite trend with respect to organic matter and related elements (Chapter 3). SU 6 is the best developed buried soil among those considered here and shows a hygrophilous prairie with scarce arboreal cover. Among the *pp* pollen group, Poaceae return the dominant taxon, with Asteroideae and Cichorioideae both being very low. Arboreal cover remains low, even though the mixed-oak forest peaks at 2.5%. The hygrophilous component reaches its absolute maximum with Cyperaceae (11.7%) and Pteridophytes (61.5%), pointing to the proximity of the Cavallina-Griffone channel. Finally, a periodic highstand of local water table was indicated by the high concentration of *Concentricystes* (22.1%). This data chronologically constrains SU 6 to the Holocene climate-optimum. Human presence cannot be confidently hypothesized since the fairly high Chenopodiaceae concentration (8.3%) in A horizon is not a reliable enough evidence, more than ever if we take into account the sudden drop in P concentration well below the Neolithic threshold for the proximal off-site (Gerlach et al., 2012). On the contrary, in Vittori Antisari et al. (2016) an early Mesolithic human presence was suggested East of Bologna. No secondary pollen grain prior to the Miocene was recognised pointing out to a reduced erosion of the catchment hill slopes.

Furthermore, the darkening of SU 6 is similar to SU 8 and 9; in this case, though, the dark colour must mainly be ascribed to the abundance of Fe-Mn nodules rather than to the organic matter content. This evidence is particularly striking when comparing it to SU 14, in which TOC is double in spite of showing no darkening at all. Thus, the abundance of fungal spores found in SU 6 and the opposite geochemical behaviour of organic matter with respect to $CaCO_3$, could point out to a completely different path for organic matter degradation during the Holocene with respect to the Lateglacial.

SU 4: Terric Anthrosol Calcic. This SU is the only black soil of the whole suite having a sure anthropic origin: on the topsoil lies the Eneolithic archaeological site (personal communication of dr. Renata Curina). The upper technic horizons show a

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remarkable lateral variability from section A to B: in the former, the upper horizon shows an upper cm-thick concentration of charcoals. The two lower horizons are rather thinner and have a lower degree of darkening, thus representing the organic matter percolation consistent with the site occupation. At the bottom, the C horizon is strongly recarbonated. In section B the upper technic horizon is the only one present and is subdivided in $A_{te}1$ (corresponding to the charcoal accumulation) and in $A_{te}2$ (organic matter concentration). This ancient topographic surface is characterized by a 20‰ S-N topographical gradient. It seems reasonable that the strong dipping could have had an anthropic origin, particularly evident when comparing it to the 2,71‰ gradient of the Roman Age.
The palynological analysis showed a herbaceous in-site vegetal association dominated by spontaneous Poaceae (48.1%) and Chenopodiaceae (19.4%); the abundances of Pteridophytes (37%) and of Concentricystes (49.4%) suggest a humid environment with local water stagnation, very likely linked to anthropic management of the site. Finally, the 9.7% concentration of *Hordeum* pollen group can indicate its in-site storage and a local cereal cultivation near the site. The anthropic settlement during the Eneolithic period was also recorded in areas west of Bologna (Zanni, 2011).

SU 3, 2 (Calcaric Regosol Siltic) and SU 1 (Irragric Anthrosol Calcaric). The three uppermost soil units are Regosols with a ploughed A horizon. The Roman Age SU 1 has a stronger pedological evidence of cultivation than SU 2 and 3, thus the distinction among the younger Irragric Anthrosol and the elder Regosols. SU 2 and 3 were attributed to the Iron Age due to their strong similarities with other local soils of that period (Cremonini et al., 2013) and because their upper boundary with SU 1 is gradual, thus excluding the existence of a significant sedimentary hiatus. The geochemical characteristics mark a bottom to top noticeable increase of TOC, as well as of the associated micro-and macroelements (Chapter 3); furthermore, a very high amount of P in the Ap horizon of SU 1 indicates the topsoil fertilization during the Roman Age. This set of evidence points out to a constantly increasing land exploitation by agricultural means from the Iron Age to the Roman Period. As a general final remark, the radiocarbon age of the upper SU 10 (Allerød Chronozone) suggests a possible Younger Dryas age for the cold environment highlighted for SU 13. Consequently, SU 14 was recognised as the lateral equivalent of the lacking Bölling pedomarker. Furthermore, SU 9 and 8 were palynologically constrained to the Youngest Dryas. During this chronozone, a local shifting in pedogenesis was noticeable, consisting in the onset of thinner soil profiles and in the opposite geochemical behaviour of $CaCO_3$ with respect to TOC and related elements. These conditions persisted during the whole Holocene soil suite and are opposite with respect to the Lateglacial. Finally, from the Eneolithic to the Roman Age the anthropic settlement is recorded.

Conclusions

Fossa Cavallina and Rio Griffone are altogether the main geomorphologic local factor. Their sedimentary dynamics originated a deposit 12.5 m thick on which 14 buried soils developed. Geomorphologic and pedologic data permitted to distinguish a lower part of the suite, made of natural, thick but weakly-pedogenised soil units, from the upper part, mainly composed of thin soil units bearing evidence of anthropic impact from the Eneolithic period onwards. The palynological analysis allowed then to recognise the following chronostratigraphic intervals:

Bölling: even though no diagnostic pedological feature of the Bölling pedomarker was found, various considerations could enable its attribution to the Bölling interstadial as follows:

the lacking of cold-climate indicators and of taxa belonging to Late Pleistocene Laurasian flora (excluding an LGM or pre-LGM age); ii) the presence of mild-climate trees; iii) the high primary productivity of the herbaceous community coupled to the incomplete degradation of organic matter and to high fungal spores concentration; iv) the Mg absolute maximum; v) the presence of recent secondary pollen grains coming from the most recent geological Formations; vi) a continuous alluvial fan aggradation; vii) the finding at the bottom of the suite of Pantano Formation gravels as a lateral equivalent of the LGM Savena gravels; viii) the presence of cold climate pollen indicators in the overlying SU 13 and ix) the radiocarbon dating of SU 10 to the Allerød.

Younger Dryas: xerophilous cold steppe with scarce pedogenesis. The high P concentrations, in absence of phosphate-rich rocks in the catchment area, points out to the presence of wild herds around the fluvial channel during a period of harsh climate. The presence of *JO* secondary pollen grains indicates an active erosion on the catchment divides.

Allerød: mesophilous prairie gradually shifting to a natural pasture with decreasing temperature and moisture. Towards the end of the period the presence of *JO* secondary grains in SU 10 shows an increased erosion on the catchment divides than in previous SU 11-12.

The rapid alteration of organic matter led to the strong darkening with an upward increasing trend. The subsequent formation of dark soils can be paralleled to coeval dark soils of Lombardy and Po Plain (Italy) of and can be interpreted as environmental responses to rapid climate changes occurring in the Upper Lateglacial as shown in Harris-Parks (2015) for what concerns North America.

Youngest Dryas: natural pasture in a xerophilous cold steppe environment with progressing decrease in temperature and moisture. Major environmental changes are outlined by the onset of thin Regosols and an opposite geochemical behaviour of $CaCO_3$ vs TOC and related elements. Features typical of older buried soils still remain, the most important of which is the same kind of darkening.

Holocene climate optimum: hygrophilous prairie developed near the Cavallina-Griffone channel. A temporary water stagnation was recorded. Differently from older dark soils, in SU 6 TOC is low and thus its darkening is preferentially attributable to the high Fe-Mn concentrations.

Human presence was not confidently recorded, although East of Bologna (Vittori Antisari at al., 2016) an early Mesolithic human settlement was detected.

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Eneolithic period: in-site herbaceous association with stable human settlement and cereal cultivations. The anthropic presence was been recorded west of Bologna (Zanni, 2011).
Iron Age – Roman Period: increasing land exploitation by agricultural means.

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References

AMOROSI A., BRUNO L., ROSSI V., SEVERI P., HAJDAS I. (2014) Paleosol architecture of a late Quaternary basin-margin sequence and its implications for high-resolution, non-marine stratigraphy. Global and Planetary Change, 112:12-25.
BERTOLDI R. (2000) Storia del popolamento vegetale della pianura del Po. In: Ferrari C., Gambi L. (a cura di), Un po di terra. Guida all'ambiente della bassa Pianura Padana e alla sua storia. Ed. Diabasis.
BERTOLANI MARCHETTI D. (1968) Ricerche palinologiche in relazione agli eventi climatici in epoca storica. S.T.E.M. Mucchi, Modena.
BOSCHI E., GUIDOBONI E. (2003) I terremoti a Bologna e nel suo territorio dal XII al XX secolo. Editrice Cmpositori, Bologna.
BRUNO L., AMOROSI A., CURINA R., SEVERI P., BITELLI R. (2013) Human-landscape interactions in the Bologna area (northern Italy) during the mid-late Holocene, with focus on the Roman period. The Holocene, 23(11):1560-1571.
BUCHANAN B. B., GRUISSEM W., JONES RUSSELL L. (a cura di) (2003) Biochimica e biologia molecolare delle piante. Zanichelli, Bologna.
CREMASCHI M. (1979) Alcune osservazioni sul paleosuolo delle conoidi "wurmiane" poste al piede dell'Appennino Emiliano. Geografia Fisica e Dinamica Quaternaria, 2:187-195.
CREMONINI S. (1992) Il torrente Savena oltre i limiti dell'analisi storica. Un esempio di "archeologia fluviale". Atti e Memorie della Deputazione di Storia Patria per le province di Romagna, 12:159-205.
CREMONINI S. (2001) Il quadro geo-pedologico di via Foscolo – Frassinago. Indicazioni sull'evoluzione geomorfologica del pedecolle e del centro storico di Bologna negli ultimi 3000 anni. In: Jacopo Ortalli, Laura Pini (a cura di). Lo scavo archeologico di via Foscolo – Frassinago a Bologna: aspetti insediativi e cultura materiale. Quaderni di Archeologia dell'Emilia Romagna, 7:19-147.
CREMONINI S., BRACCI E.A. (2010) Problemi di paleoidrografia in ambito urbano. Bologna: rassegna storica di ipotesi e nuovi dati. Alla ricerca di Bologna antica e medievale. Da Felsina a Bononia negli scavi di via d'Azeglio, a cura di R. Curina et al., in Quaderni di Archeologia dell'Emilia Romagna, 25:167-178.
CREMONINI S. (2014) La transizione geomorfologica "catena-pianura" nella città di Bologna. Osservazioni per un'analisi evolutiva dell'areale del santuario etrusco di Villa Cassarini nell'arco cronologico pre-protostorico e classico. In: Romagnoli S. (a cura di), Il

Santuario etrusco di Villa Cassarini a Bologna. DISCI – Dipartimento Storia, Culture, Civiltà – Sezione Archeologia- 4, Bonomia University Press, 33-58.
CREMONINI S., LABATE D., CURINA R. (2013) The Late-Antiquity environmental crisis in Emilia regione (Po river plain, Northern Italy): Geoarchaeological evidence and paleoclimatic considerations. Quaternary International, 316:162-178.
DE MARINIS R. (1997) L'età del Bronzo nella regione benacense e nella Pianura Padana a nord del Po. In Bernabò Brea M., Cardarelli A., Cremaschi M. (a cura di): Le terramare. La più antica civilità padana. Electa, Milano, 405-422.
DE VIVO B., LIMA A., CICCHIELLA D., FRIZZO P., DI LELLA A., RACCAGNI L. (2009) Atlante geochimico-ambientale d'Italia. ARACNE Editrice, Roma
DI DIO G., VALLONI R. (1997) Unità di Crescita nei sistemi di conoide alluvionale del tardo Quaternario: la risposta dei corsi d'acqua ai cicli climatici e ai movimenti tettonici. Riassunti convegno AIQUA: Tettonica quaternaria del territorio italiano - conoscenze, problemi ed applicazioni. Parma 25-27/2/1997: 159-160.
FAEGRI K., IVERSEN J., KRZYWINSKI K. (1989) Textbook of pollen analysis. Blackburn
FREDERIKSEN N.O. (1980) Sporomorphs from the Jackson Group (Upper Eocene) and adjacent strata of Mississippi and Western Alabama. Geological Survey Professional Paper 1084.
FREDERIKSEN N.O. (1984) Stratigraphic, paleoclimatic and paleobiogeographic significance of Tertiary sporomorphs from Massachussets. Geological Survey Professional Paper 1308.
IUSS Working Group WRB (2015) World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.
LOVE J.D., LEOPOLD E.B., LOVE D.V. (1978) Eocene rocks, fossils and geologic history, Teton Range, Notyhwestern Wyoming. Geological Survey Professional Paper 932-B.
MARTELLI L., AMOROSI A., SEVERI P. (editors) (2009) Note illustrative della Carta Geologica d'Italia alla scala 1:50000, Foglio 221, Bologna. SystemCart, Roma.
MARTELLI L., BENINI A., DE NARDO M. T., SEVERI P. (editors) (2009) Note illustrative della Carta Geologica d'Italia alla scala 1:50000, Foglio 220, Casalecchio di Reno. SystemCart, Roma.
MERCURI A.M., BANDINI MAZZANTI M., TORRI P., VIGLIOTTI L., BOSI G., FLORENZANO A., OLMI L., MASSAMBA N'SIALA I. (2012) A marine/terrestrial integration for mid-late Holocene vegetation history and the development of cultural landscape in the Po valley as a result of human impact and climate change. Veget. Hist. Archaeobot., 21:353–372. DOI: 10.1007/s00334-012-0352-4
MERCURI A.M., BANDINI MAZZANTI M., FLORENZANO A., MONTECCHI M. C., RATTIGHIERI E., TORRI P. (2013) Anthropogenic pollen indicators (API) from archaeological sites as local evidence of human-induced environments in the Italian peninsula. Annali di Botanica, 3:143–153.
MiPAF (2000) Metodi di Analisi Chimica del Suolo. Franco Angeli Ed.
MOORE P.D., WEBB J.A., COLLINSON M.E. (1991) Pollen analysis. Second edition. Blackwell Scientific Publications, Oxford, 1991.
NOAA (1989) www.ncdc.noaa.gov/paleo/icecore/greenland/summit/document/gripisot.htm

DOI: 10.6092/issn.2281-4485/7599

PAGANELLI A. (1984) Storia climatico-forestale del Pliocene e del Quaternario. In: Bartolomei G. (a cura di): L'evoluzione dell'ambiente nel Quaternario. Ed. Banca Popolare di Verona.

PICOTTI V., PAZZAGLIA F.J. (2008) A new active tectonic model for the construction of the Northern Apennines mountain front near Bologna (Italy). Journal of Geophysical Research, 113:BO8412. DOI: 10.1029/2007/JB005307.

PIGNATTI S. (1982) Flora d'Italia. Edagricole – Edizione Agricole de Il Sole 24 Ore Edagricole S.r.l., Bologna.

RAVAZZI C., DEADDIS M., DE AMICIS M., MARCHETTI M., VEZZOLI G., ZANCHI A. (2012) The last 40 ka evolution of the Central Po Plain between the Adda and Serio rivers. Géomorphologie, 2:131-154.

REILLE M. (1992) Pollen et spores d'Europe et d'Afrique du nord. Laboratoire de Botanique Historique et Palynologie, Marsiglia.

REILLE M. (1995) Pollen et spores d'Europe et d'Afrique du nord. Supplément 1. Laboratoire de Botanique Historique et Palynologie, Marsiglia.

REILLE M. (1998) Pollen et spores d'Europe et d'Afrique du nord. Supplément 2. Laboratoire de Botanique Historique et Palynologie, Marsiglia.

REIMER P.J., BAILLIE M.G.L., BARD E., BAYLISS A., BECK J.W., BLACKWELL P.G., BRONK RAMSEY C., BUCK C.E., BURR G.S., LAWRENCE EDWARDS R., FRIEDRICH M., GROOTES P.M., GUILDERSON T.P., HAJDAS I., HEATON T.J., HOGG A.G., HUGHEN K.A., KAISER K.F., KROMER B., MCCORMAC F.G., MANNING S.W., REIMER R.W., RICHARDS D.A., SOUTHON J.R., TALAMO S., TURNEY C.S.M., VAN DER PLICHT J., WEYHENMEYER C.E. (2009) IntCal09 and Marine09 radiocarbon age and calibration curves, 0-50,000 years. Radiocarbon 51:372.

SUMNER M. E. (editor) (2000) Handbook of soil science. Taylor & Francis Group LLC.

TOMASELLI M. (editor) (1987) Guida alla vegetazione dell'Emilia Romagna. Collana Annali, Facoltà di Scienze MM., FF., NN. Università di Parma.

TSCHUDY R.H., SCOTT R. A. (a cura di) (1969) Aspects of palynology. Wiley-Interscience.

TSCHUDY R.H., VAN LOENEN S.D. (1970) Illustrations of plant microfossils from the Yazoo Clay (Jackson Group, Upper Eocene Mississippi). Geological Survey Professional Paper 643-E.

TSCHUDY B.D. (1973) Palynology of the Upper Campanian (Cretaceous) Judith river Formation, North-central Montana. Geological Survey Professional Paper 770

TSCHUDY R.H. (1975) Normapolles pollen from the Mississippi Embayment. Geological Survey Professional Paper 865.

TSCHUDY R.H., TSCHUDY B.D., CRAIG L.C. (1984) Palynological evaluation of Cedar Mountain and Burro Canyon Formations, Colorado Plateau. U. S. Geological Survey Professional Paper 1281

TUTIN T.G., HEYWOOD V.H., BURGES N.A., VALENTINE D.H. (1993) Flora europaea. Cambridge University Press.

VALLONI R., CALDA N. (2007) Late Quaternary fluvial sediment architecture and aquifer systems of the Southern margin of the Po River Plain. Memorie descrittive della Carta Geologica d'Italia, 76:289-300.

VAN DER HEIJDEN M. G. A., BARDGETT R. D., VAN STRAALEN N. M. (2008) The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecology Letters, 11:296-310.

VITTORI ANTISARI L., CREMONINI S., DESANTIS P., CALASTRI C., VIANELLO G. (2013) Chemical characterisation of anthro-technosols from Bronze to Middle Age in Bologna (Italy). Journal of Archeological Science, 40:3660-3671.
VITTORI ANTISARI L., BIANCHINI G., CREMONINI S., DI GIUSEPPE D., FALSONE G., MARCHESINI M., MARVELLI S., VIANELLO G. (2016) Multidisciplinary study of a Lateglacial-Holocene sedimentary sequence near Bologna (Italy): insights on natural and anthropogenic impacts on the landscape dynamics. J Soils Sediments, 14:230–242. DOI 10.1007/s11368-013-0791-2
ZANCHETTA G., BINI N., CREMASCHI M., MAGNY M., SADORI L. (2013) The transition from natural to anthropogenic-dominated environmental change in Italy and the surrounding regions since the Neolithic: an introduction. Quaternary International, 303:1-9.
ZANGHERI P. (1976) Flora italica vol. 1-2. Cedam, Padova.
ZANNI M. (2011) Studio stratigrafico e palinologico di una sezione olocenica a Casalecchio di Reno. Thesis in Natural Sciences, University of Bologna. (unpublished),

DOI: 10.6092/issn.2281-4485/7599