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Climate change versus land management in the Po Plain (Northern Italy) during the Bronze Age: new insights from the VP/VG sequence of the Terramara Santa Rosa di Poviglio

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Abstract

The sedimentary infilling of the moat surrounding the *Villaggio Piccolo* of the Terramara Santa Rosa di Poviglio was analysed in order to obtain palaeoenvironmental inferences from sediments and pollen assemblage. The high-resolution stratigraphic sequence preserves evidence of the environmental changes that occurred in the Po Plain, in Northern Italy, during the Late Holocene. Our interdisciplinary approach permitted to study climatic and anthropic contributions to the environmental changes in this region. The relationships between these changes and land-use changes were investigated focusing on adaptive strategies of the Terramare people during the Middle and

Recent Bronze ages (1550-1170 yr BC). The Terramare are archaeological remains of banked and moated villages, located in the central alluvial plain of the Po river. The Terramara of Santa Rosa consists of two adjoining settlements (*Villaggio Grande* and *Villaggio Piccolo*); the moat that separates the two parts of the site is c. 23 m large and reaches a maximum depth of 4 m from the extant ground level. The stratigraphic sequence VP/ VG exposed by archaeological excavation inside the moat was sampled for pedosedimentary, thin section, and pollen analyses. Chronology is based on archaeological evidence, stratigraphic correlations and radiocarbon dating. Pedosedimentary features and biological records (pollen of aquatics and algal remains) demonstrate that shallow water, probably subjected to seasonal water-level oscillations, has always been present in the moat. In the lower units of the sequence, the laminations indicates standing water, while occurrence of reworked pollen testified the supply of sediments to the plain from catchment zones located in the Apennine. Open vegetation was widespread; economy was based on wood management, fruit collection on the wild or from cultivated woody plants, crop fields with a fairly diversified set of cereals especially increasing in variety during dryness or phases of water crisis. Probably, grapevines were cultivated near the moat, where the wet habitat was favourable to the growing of wild plants. The extraordinary high-resolution of this sequence makes visible the management of woods (including coppicing) at the Middle Bronze and early Recent Bronze ages. The economy of Santa Rosa di Poviglio should have been probably less based on animal breeding than it was in the other Terramare villages already studied for pollen. This research also confirms the chronological correspondence between an environment stressed by dry conditions and the collapse of the Terramare civilization.

Key-words

Terramare culture; Middle–Recent Bronze Age; Site forming processes; Pedosedimentary processes; Wood management; *Vitis;* Wet habitats; Climatic changes; Human impact; Po Plain; Northern Italy

1. Introduction

The joint action of climate and cultural variables has been found to be responsible for the trajectories of ancient people, whose survival relied on a responsible interplay with the natural resources available in lands hosting settlements (e.g., Galop, 2000; Brooks, 2006; Roberts et al., 2011; Mercuri, 2014; see for a contrasting position: Magny et al., 2012). This is the case, for instance, of the Terramare culture of the Po Plain, in Northern Italy, dating back to the Middle and Recent Bronze ages (Cremaschi, 2014). The crisis of this early European society is reasonably related to a regional climate change. This coupled with the incapacity of the Terramare people to manage natural resources that were progressively reduced (Cremaschi et al., 2006; Mercuri et al., 2011).

The availability of water played a crucial role for the Terramare culture, which was based on irrigated agriculture, and developed some rituality connected to water procurement and storage (e.g., Bernabò Brea and Cremaschi, 2009). Climatic crisis, including depletion of water, is among the claimed causes of the disappearance of the Terramare settlements in Northern Italy (Cremaschi et al., 2006; Cardarelli, 2010; Cremaschi, 2010). From this, it is evident that climate change took a critical part in the determination of the cultural trajectory of the Terramare villages of the Po Plain. Climate possibly represents one of the main motors of the expansion of the Terramare civilization, initially triggering it for the positive evolution of the settlement pattern, and then largely contributing to its collapse.

In the present paper we investigate the sedimentary fill of the moat that separates the *Villaggio Piccolo* from the *Villaggio Grande* of the Terramara Santa Rosa di Poviglio (**Figs. 1, 2**). The interdisciplinary study has been carried out in order to obtain palaeoclimatic and environmental inferences from sediments and pollen assemblage. The moat and its fill played an outstanding role in the local hydraulic system of water collection and re-distribution at this Terramara (Mele et al., 2013). But its importance goes beyond this interest. In fact, thanks to its distinct pedosedimentary and palynological evidence, it represents a paradigmatic feature owing supra-regional palaeoenvironmental significance. The stratigraphic sequence that we identified therein preserves evidence for the environmental changes that occurred in the Po Plain during the Late Holocene (*sensu* Walker et al., 2012). Our interdisciplinary study permitted to investigate climatic and anthropic contributions to environmental changes in this region, and their relationships with the different land-use adopted by Terramare people during the Middle and Recent Bronze ages (1550-1170 yr BC).

2. The Terramare culture and its climatic context

The Terramare are the archaeological remains of banked and moated villages of the Middle and Recent Bronze ages (1550-1170 cal yr BC), located in the central alluvial plain of the Po river (Cremaschi, 2014; **Fig. 1**). This culture reached its apogee at the beginning of the Recent Bronze Age and suffered, at the end of this period, a societal collapse that led to the abandonment of the villages in a few generations (Cardarelli, 2010). The Terramare villages are evidence of a complex society, whose subsistence was based on intensive agriculture, pastoralism, and long distance trade (Barfield, 1994; Cardarelli, 1997).

The Terramare-type villages were squared in shape with houses on posts, distributed in regular rows and enclosed inside earthen rampart. They were surrounded by moats connected to the local fluvial network with the purpose to collect water and distribute it to cultivated fields by means of irrigation ditches (Balista, 1997; Cremaschi and Pizzi, 2007, 2011). This was necessary to sustain the irrigated agriculture, a subsistence strategy on which the Terramare culture was based. As confirmed by palynological studies, villages had performed a complex and diversified land-use, involving crop field (cereal/ legume) rotation, alternation of fields and pastures, manuring and wood management since their establishment (Mercuri et al. 2006a,b).

Referring to the Alpine systems, by the palaeoclimatic point of view the development of the Terramare (1550-1170 cal yr BC) is fairly coincident with a period of generalized cooling (the Lobben glacier advance; e.g., Magny, 2004; Magny et al., 2010; Pelfini et al., 2014).

The collapse of the Terramare culture occurred just at the beginning of the following warm period, often indicated as the Bronze Age Warm Period (BAWP) or Bronze Age Climatic Optimum (with reference to the spread of sites on piles of the Final Bronze Age to the North of Alps; Holzhauser, 2007, Magny, 2004; Leroy et al., 2015). This collapse was coincidental (Cremaschi et al., 2006; Cremaschi, 2009) with one or more short dry episodes, which are recorded from different proxies in the Italian sub-alpine lakes (Baroni et al., 2006; Valsecchi et al., 2006), and may also be observed as a prominent warm spell in the residual $\Delta^{14}C$ curve (Blaauw et al., 2004; see also the conclusion section of this paper).

3. General background

3.1. The site of Santa Rosa di Poviglio, geomorphology and archaeological structure

The Terramara Santa Rosa di Poviglio (Lat. 44°52'21''N; Long. 10°34'31''E) is located in the alluvial plain, about 3 km southward from the present-day course of the Po River (**Fig. 2**). A swamp has occupied the site area until the 15th century AD. Also today, this area is poorly drained (Cremaschi, 2004). Geomorphological evidence suggests that the site was located near a palaeochannel of the Po river, which was active during the lifetime of the Santa Rosa village (Cremaschi et al., 1980; Cremaschi, 2004).

More than 30 years of archaeological excavations of the site and a recent geophysical survey (Mele et al., 2013) have revealed the archaeological structures of the settlement (consisting of an earthen rampart, wood fences, and dwelling areas) and their relationship with the surrounding moats.

The site consists of two dwelling areas indicated as "*Villaggio Piccolo*" (that in Italian means 'Small Village'; therein: VP) and "*Villaggio Grande*" ('Large Village'; therein: VG), dating back to the Middle Bronze Age and to the Recent Bronze Age, respectively (**Figs. 2, 3**). The moat separating the VP from the VG was investigated during the field season 2012 (**Fig. 4**); it appeared to be exceptionally deep (4 meters) in the context of the hydraulic structures of the site (Cremaschi and Pizzi, 2010, 2011).

Its high-resolution sedimentary sequence, with well-preserved pollen content, covers the entire chronological span of the Terramare civilization. The aim of this paper is to report on geoarchaeological and palynological data obtained from the sequence of the VP/VG moat to understand the main landscape transformations that occurred at the Middle and Recent Bronze Age phases considering climate, vegetation, and human activity changes in the area.

3.2. Local environmental settings

The climate of the area is semi-continental with 12–14 °C mean annual temperatures, minimum in January (between −2 °C and 0 °C, on average), and maximum in July (between 24 °C and 26 °C). Mean annual rainfall varies between 600 and 800 mm, with snowfalls in winter. Human environments have replaced the natural potential vegetation. In the plain, woods consisting with dominant *Quercus robur* L. and *Carpinus betulus* L., mixed with *Acer campestre* L., *Fraxinus excelsior* L., *Ostrya carpinifolia* Scop., *Ulmus minor* Mill. and *Tilia cordata* Mill. represent the most common tree cover recorded from past pollen diagrams in the region (Valsecchi et al., 2006; Vescovi et al., 2010; Bosi et al., 2011, 2015; Mercuri et al., 2012). Hygrophilous woods are actually the only 'natural' woods in the region, and are still spread near rivers and fresh-water habitats. The mature status of riparian woods of the plain prevalently includes *Salix alba* L., *Populus nigra* L., with *Sambucus nigra* L. as main shrubby species, and the herbaceous species *Agrostis stolonifera* L., *Artemisia vulgaris* L. and *Urtica dioica* L. They all belong to the *Salicetum albae* association (Alessandrini et al., 2010; Blasi, 2010).

Today, the plain is characterized by intensive industrial agriculture, which is dominated by animal breeding (especially pigs for meat, and cattle for milk, cheese and meat production), crop fields for food, fodder (especially *Medicago* and other legumes), biofuel, and remarkable fruit production (Rosaceae-Prunoideae including cherries, plums, apricots, and grapes for wine production).

4. Material and methods

4.1. Pollen and sediment sampling

The stratigraphic sequence exposed by archaeological excavation inside the moat was sampled for pedosedimentary analyses (**Figs. 4, 5; Table 1**). Bulk and block of sediments were collected from each Stratigraphic Unit (SU; Barker, 1977) identified during the excavation.

A total of 31 pollen samples (from P1, at the top, to P31 at the bottom) were collected from 2.5 meters below the ground level to further 150 cm deep, at about 5 cm intervals, taking into account both stratigraphy and archaeological phases.

4.2. Pollen treatment and analysis

About 2 grams of sediment were subjected to pollen extraction. Laboratory treatments included heavy liquid separation according to van der Kaars et al. (2001) and Florenzano et al. (2012). *Lycopodium* spores were added to calculate concentrations, expressed as pollen (or non-pollen palynomorphs) per gram = p/ g (or NPP/ g). Residues in glycerol were mounted in permanent slides. Pollen and NPPs were counted in the same samples. Identification was made at 400× and 1000× magnification on permanent and labelled slides. Cerealia type pollen was identified according to Beug (1964), and Fægri et al. (1989). Sacs, bodies and fragments of pollen of *Pinus* or *Abies* were counted as parts of entire pollen grains, and summed to obtain the unit. Reworked pollen grains are pre-Quaternary opalescent-dark rearranged pollen grains with a particular toughness of sporopollenin (Traverse, 1988). They may derive from the erosional action of rivers detaching pollen grains from the rocks on their banks and redepositing them in a more recent sediment: they mark the input of alluvial deposits in sediments (Mercuri et al., 2012). According to Ravazzi et al. (2004), the 'not reworked / reworked' pollen ratio may be an index of the influence that fluvial processes had on the sedimentation in ditches during different phases of their development. Pollen nomenclature mainly follows Moore et al. (1991). The NPPs, mainly consisting of algae but also animal remains, were identified according to van Geel (2001).

On average, about 520 pollen grains per sample were counted. The percentage pollen diagrams were basically calculated from pollen sums including all pollen counted (PSum). Ferns, NPPs and reworked pollen were calculated on different sums, each of them including PSum plus themselves. To avoid masking effects of riparian vegetation and very local plants growing close or in the channel, an additional diagram was provided with percentages calculated on a pollen sum that excludes pollen from wet environments (hygrophilous woody plants such as *Alnus*, *Salix* and *Populus*, *Vitis*, and herbaceous hygro- and hydrophytes).

The pollen diagrams were drawn with TGView; zonation was based on CONISS (Constrained Incremental Sum of Squares; Grimm, 2004), and visual examination. The Principal Component Analysis (PCA) distribution of samples was elaborated with XLStat. Taxa were grouped into main sums useful for environmental reconstructions: i) oak wood, including pollen from broadleaved *Quercus*, *Acer campestre* type, *Carpinus betulus*, *Ostrya*/ *Carpinus orientalis*, *Tilia* and *Ulmus*, to which the shrub *Corylus* may be added; ii) wet environments, including pollen from hygrophilous trees (*Alnus*, *Populus* and *Salix*), herbaceous limno-telmatophytes (Cyperaceae, *Lythrum*, *Sparganium emersum* type, *Thalictrum*, *Typha latifolia* type), and hydrophytes (*Alisma-plantago aquatica* type, *Butomus*, *Hydrocharis*, *Lemna*, *Myriophyllum verticillatum* type, *M. spicatum* type, *Nymphaea alba* type, *Potamogeton*, *Ranunculus* cf. *fluitans*, *Sparganium erectum* type); iii) human environments, including pollen from synanthropic plants (*Beta*, Chenopodiaceae indiff., *Convolvulus*, *Galium* type, *Linaria*, *Orlaya grandiflora*, *Papaver*, *Polygonum aviculare* type, *Rumex*, *Solanum nigrum* type; Bosi et al., 2015), and particularly Anthropogenic Pollen Indicators (API). According to Mercuri et al. (2013a), the API taxa that are ubiquitous in archaeological contexts of Italy are *Artemisia*, *Centaurea*, Cichorieae, *Plantago*, cereals, *Urtica*, and *Trifolium* type. In the studied site, cereals include pollen from the *Avena/Triticum* and *Hordeum* groups, *Secale cereale* and *Panicum*.

4.3. Pedosedimentary analyses

Thin sections from undisturbed blocks, integrated with grain size and routine chemical-physical analyses on bulk samples, have been used to understand the depositional and post-depositional processes forming the stratigraphic sequence. Moreover, they helped in distinguishing between the environmental and anthropogenic factors for sedimentation and post-depositional changes (Courty, 2001; Goldberg and Macphail, 2006; Goldberg and Berna, 2010; Cremaschi et al., 2014). Bulk samples from the sequence were collected for textural and chemical-physical analyses. Applied methods are summarized as follows: i) Grain size was determined (diameter from 2000 to 63 μm) through wet sieving after removing organics by hydrogen peroxide (130 vol) treatment (Gale and Hoare, 1991). ii) Humified organic carbon was identified following the Walkley and Black (1934) method, using chromic acid to measure the oxidizable organic carbon (titration). iii) Calcium carbonate equivalents were chemically performed using a Dietrich–Frühling calcimeter (Gale and Hoare, 1991). Oriented and undisturbed sediment blocks from the stratigraphic units of the infilling of the moat were collected. Thin sections (5x9 cm) were manufactured after consolidation according to standard methods (Murphy, 1986). Micromorphological observation under plane-polarized light (PPL), cross-polarized light (XPL) and oblique incident light (OIL) of thin sections employed an optical petrographic microscope at various magnifications (20x, 40x, 100x, 200x, 400x). For the description and interpretation of thin sections, the reader should consider the terminology and concepts established by Bullock et al. (1985), Stoops (2003) and Stoops et al. (2010). Properties of each sample detected by thin section analysis are summarized in **Table 2**.

4.4. Dating of the sequence

The dating of the sequence relies on two types of evidence: i) three radiocarbon dates were obtained from bone, seeds and charcoal collected along the stratigraphic sequence of the moat of the VP; ii) the pottery found into the same sequence during the archaeological excavation has been attributed to different archaeological ages based on its typological characteristics (**Fig. 5**). Both radiocarbon dating and the pottery fragments retrieved along the sequence well fit with the following archaeological phases of the North Italian Bronze Age: Recent Bronze (BR=BR1+BR2) (1340–1170 cal yr BC), late Middle Bronze Age (BM3) (1450–1340 cal yr BC) and central phase of the Middle Bronze Age (BM2) (1550–1450 cal yr BC; Bernabò Brea and Cardarelli, 1997). The archaeological evidence allows correlating this sequence with the others studied and radiocarbon dated in the site (**Table 3**). In particular, the archaeological sequence of VP, whose chronology is supported by the chrono-typology of the archaeological finds and by several radiocarbon dates (Bernabò Brea and Cremaschi, 2004; Cremaschi, 2004), was correlated to the fill of the moat. This allowed us to refer its basal units (SU10119–SU10124) to the BM2 phase (1550–1450 cal yr BC); the stratigraphic correlation made possible to attribute an age to the stratigraphic units that lack of a direct radiocarbon dating.

5. Results

5.1. The stratigraphic sequence of the moat of VP-Villaggio Piccolo

The moat is c. 23 m large and reaches a maximum depth of 4 m from the extant ground level. It is cut within loamy to silty-sandy alluvial deposits (**Fig. 6**). The main pedosedimentary characteristics are listed in **Table 1**. Its infilling consists of two main units below the present day Ap (agricultural) horizon. The upper unit, thicker at the centre and pinched out along the banks, is composed of alluvial clay, which deposited after the abandonment of the Bronze Age site. Clay sedimentation mostly occurred in post-Roman age and during the early Medieval period, before the reclamation of the area for cultivation that took place since the 15th century, and during more recent flood events (Cremaschi, 2004). On the contrary, the lower unit consists of deposits dating back to the Bronze Age, formed during the lifetime of the village (approximately 1550–1170 cal years BC).

An upper set of units (SSUU 10058, 10066) clayey silt in texture, brown in colour, rich in organic matter, and bioturbated wraps the margins of VP, and grades into units located at the centre of the moat (SSUU 10044, 10338 and 10059). The units along the margins of the site are rich in archaeological finds dumped from the dwelling area into the moat. Discontinuous evidence of planar lamination appears in the unit (SU10059) at the centre of the moat; in the same unit several turtle shells were found.

Below these layers, six units (SSUU 10062, 10106, 10102, 10119, 10120, and 10024) fill the lower part, which is delimited by the artificial cut of the moat. The latter was articulated into two adjoining concavities (**Fig. 6a**), and was extensively exposed during the excavation of the site. The recognition of boundaries of the concavities was favoured by the lithological contrast between the substrate in which the moat was excavated (rich in sand and silt) and its infilling, consisting of silty clay. The moat was realized in a single phase, at the time of foundation of the VP. This is suggested by the stratigraphic correlations and by the occurrence in SU10024 of large fragments of the wood palisade that surrounded the village in its initial phase (Bernabò Brea and Cremaschi, 2004).

SU10106 lies on the bank of the moat as a lateral transition of US10062. They are silty clay in texture, display hydromorphic colours, have high content of calcium carbonate and low content of organics. Sets of thin planar laminae are observed in this part of the sequence alternating with wavy ones, both intercalated by this dusty carbonated layer. Few pottery fragments were found, whereas plant remains, including large charcoal fragments in SU10119, were abundant.

5.2. Thin sections' micromorphology

Micromorphological analysis of thin sections from the stratigraphic units of the moat is summarized in **Table 2**. The main features of each stratigraphic unit are reported below. Two main groups of units may be distinguished on the base of their micromorphological characteristics.

The upper-central group of units (SSUU 10066, 10038, and 10059) display properties typical of colluvial phenomena or sedimentation in very shallow water, and include a huge quantity of anthropogenic features (**Fig. 7**). SU10066 displays a dense and crystallittic groundmass, with few voids; it is silty-clayey and rich in sand grains and amorphous organics; submillimetric, rounded $CaCO_3$ nodules developed in the groundmass and land snails shell fragments are present. Organic and anthropogenic features are represented by small bone fragments, common microcharcoals, fragments of coprolites (rich in spherulites), bundles and isolated phytoliths, and phosphate nodules. SU10038 has a micromass almost consisting of clay, with common planar voids and some evidence of bioturbation; the latter consists mostly of passage features, which are related to roots or invertebrates acting after the emersion of the moat. Microcharcoals are frequent and sometimes they are related to sparite crystals, possibly derived from wood ash. SU10059 is still rich in clay, but some sandy grains are present in the groundmass and voids are rare. The slide includes fragments of shells, small angular charcoal fragments; moreover, discontinuous fine, graded laminations are present, displaying an upward fining up trend.

To the second group of units (SSUU 10106, 10062, 10102, and 10124) have characteristics mainly related to depositional features produced by sedimentation in standing water (evident laminations with fining-up graded bedding; **Fig. 7**) while few elements are related to human interference. SU 10106 has a later continuation to SU10102 deposits along the bank of the moat; it displays a strong evidence of hydromorphic features: Mn-rich coatings along bedding and on the surface of voids and in situ orthic Fe-oxides nodules. Mn and Fe-bearing nodules indicate the permanence of sediments in waterlogged environment. Rolled pedorelicts, angular charcoal fragments, and phytoliths (embedded in the groundmass) are also common. The occurrence of pedorelicts reveals movements of sediment along the slope of the moat and faint trace of lamination confirm that the unit was deposited in water. The section of SU10062 is silty to clayey and massive; charcoal fragments along with mollusc shell fragments are also present. In this case horizontal laminations are common and clearly visible. Two slides are available for SU10102; the unit consists of a fine sandy to silty sediment, with a well-defined pattern of horizontal laminae. The latter are less than 1 mm thick but present an upward fining sedimentary trend; toward the bottom of the slide, lamination become more wavy. Horizontal laminae are interlayered by planar to convolute lenses/ layers consisting of the remains of calcareous algae and vegetal filaments. Microcharcoals are also common. SU10124 displays the same lamination due to decantation observed in slide SU10102, but calcareous algae are not present; on the contrary, microcharcoals are frequent.

5.3. Chronology of the sequence

5.3.1 Archaeological context

Archaeological finds recovered from the stratigraphy of the moat mainly consist of sherds, faunal remains and charcoal. Pottery is highly concentrated along the bank of the ditch, in the upper units (SSUU 10058–10106), while is less represented in the central and in lower units (SU10059 and SU10124) of the moat. While the deposit is not related to living floors and originated by dumping from the overlying dwelling area of VP, the distribution of pottery with depth follows a clear and reliable chrono-typological stratigraphic trend, which is recognizable on the base of occurrence of diagnostic pottery elements (**Fig. 5**). The unit SU10058 may be attributed to the late Recent Bronze Age (BR2), and SU10066 to the full BR. Units SSUU 10038 to 10062 are mostly characterized by pottery dating to the late Middle Bronze Age (BM3), while sherds of full Middle Bronze Age (BM2) occurred in the lower part of the sequence, and especially in SU10119.

5.3.2 Radiocarbon dates

Three radiocarbon dates were obtained from the infilling of the moat, in particular from SU10066 and SU10062. The collagen fraction extracted from an animal bone found in SU10066 was dated to 1402 – 1262 cal yr BC (**Table 3**). Seeds of *Sambucus* from SU10062 were dated to 1497 – 1413 cal yr BC; small charcoal fragments from the same level were dated to 1695 – 1621 cal yr BP.

The dates obtained on collagen and seeds are in agreement with the archaeological context falling the first in the BR and the second in BM3 phases. The charcoal, while collected in the same unit, resulted 150 years older than the date of the seeds, therefore rendering an age inconsistent with the archaeological context. This is due to the 'old wood effect' that was found to affect the whole radiocarbon dataset of VP of Terramara Santa Rosa di Poviglio. This effect is plausibly due to the age of the charcoal, which was mostly derived from *Quercus* wood (Rottoli and Mottella 2004) and taken from very old trees. In fact, at early periods of the life of the Terramara many old trees were cut. The use of wood of centenary trees has probably added to the stratigraphic layers a significant amount of charcoal older than the depositional phases (Cremaschi, 2004).

On the basis of archaeological correlations, the radiocarbon dates of the BM2 phase, obtained on collagen of animal bones from archaeological layers of VP (Cremaschi, 2004), could be extended to the basal layers of the infilling of the moat (SSUU 10119 and 10124). The correlated units contain, in fact, the same type of diagnostic sherds. These radiocarbon dates are: SU7: 1619 – 1416 cal yr BC, and SU10/ 12: 1692 – 1436 cal yr BC. A further correlation based on the archaeological stratigraphy may be proposed also for the SU 10058 – at the top of the sequence –with the SU6750. The latter is the uppermost infilling of the well SU6751 of VG, which was obtained on the collagen of animal bone and dated to 1375 – 1128 cal yr BC.

5.4. The pollen sequence PVG VP/VG (Figs. 8,9)

Disturbance effects of compaction or chemically unfavourable sediment composition generally affect pollen from archaeological sites. However, in this sequence, only a few pollen grains were observed crumpled or folded due to post-depositional processes, and pollen has prevalently well preserved wall (exine).

Pollen concentration was about 81,000 pollen/ gram (p/ g) on average, showing good amount of organic supply to the sediments. Floristic richness consists of 202 different pollen taxa, ranging from 53 (P31) to 83 (P15) taxa per sample. The number of herbs prevails (44 taxa per sample, on average), almost twice than that of trees/ shrubs (24 taxa).

The percentage of woody plants is 46% on average, consisting of 34% of trees. They are mainly represented by the hygrophilous trees alder-*Alnus* (9%) and willow-*Salix* (5%), and by the broadleaved oak-*Quercus* (8%). This gives evidence for some hygrophilous wood and oak wood near the site. The hazel-*Corylus* (6%) is the most represented among shrubs: it may have a twofold significance of natural element of oak woods and plant selected for its edible fruits.

Poaceae-grasses (14%) and daisy family-Asteraceae (8%, including Cichorieae 3%) prevail among the herb pollen. Sedges-Cyperaceae (4%), buttercup family-Ranunculaceae (3%), chenopods-Chenopodiaceae and plantain family-Plantaginaceae (2% each) were common too.

Among cultivated plants, cereals were almost ubiquitous (1.6%). Grapevine-*Vitis* was well represented (3%, with maximum 18% in P19), and found in 87% of samples. Hemp-*Cannabis* (0.3%) pollen was common as it was found in 65% of the samples but its values do not seem high enough to suggest retting of textile plants (Mercuri et al., 2002). Anthropogenic pollen indicators-API (11%) and other synanthropic plants (4%) were important markers of human activities in all samples.

The reworked pollen was common (7%), and includes some saccatae pollen, triporate types and fern spores, and *Classopollis*. This is a Mesozoic pollen, produced by coniferous plants (Traverse, 1988), which has a worldwide distribution in Upper Triassic-Turonian strata (Srivastava, 2007); it is common in early Cretaceous deposits – Flysch formations of Northern Italy (Keller et al., 2011), occurring in the Northern Apennine range. Along with high presence of broken and whole *Pinus* pollen, reworked pollen is frequently found in pollen spectra from alluvial layers of the Po Plain, and in deposits from other terramare (Ravazzi et al., 2004; Mercuri et al., 2012). This issue supports the idea of an Apennine origin for the large river (a Po palaeochannel) bordering the site.

5.5. Non pollen palynomorphs

The NPPs observed were few, prevalently attributable to the algae living in the stagnant waters of the ditch. The most frequent algal remains belong to three types listed below (**Fig. 9**): i) Cysts of *Concentricystis* (or *Pseudoschizaea* 0.7**%**, on average) is usually considered to be a freshwater algae. It indicates erosion and variation (decreasing) of water level due to drier conditions. ii) Heterocysts of *Rivularia* type (0.6%), Cyanophyceae that grows on submerged stones, moist rocks and on damp soils near riversides. iii) *Botryococcus* (0.1**%**) is a colonial green algae that generally lives in freshwater fens, temporary pools, ponds and lakes where it forms a thick surface scum, but considerable abundances in variable salinity habitats are also known. To freshwater environments also belongs the Copepoda remain.

An interesting record, found in P22, is the egg of *Dicrocoelium* (Trematoda), a parasite of ruminants with resistant shell made of sclerotin (Florenzano et al., 2012). Among fungi, only rare spores of *Glomus* were observed: this arbuscular mycorrhizal fungus is known to form symbiotic relationships (mycorrhizas) with plant roots, and indicates soil erosion (van Geel, 2001).

5.6. Pollen zones

Four main pollen zones were recognized (**Figs. 8,9,10; Table 4**). The PCA distribution of samples shows a good correspondence with cluster analysis, and pollen zones from PVG 1 to PVG 4 approximately follow the anticlockwise sense in **Fig. 11.** This means a quite typical floristic assemblage in each zone. In particular, open grasslands and cereals fall in the first sector, while riparian communities fall in the third sector (F1 = increasing human impact from left to right).

Pollen zones are described below, from the bottom. If not differently reported, pollen percentages are approximate mean value of the zone, and interpretation relies on the mean average changes per zone to avoid the one-sample over-representation bias. The chronology of the limits separating the pollen zones was established by considering radiocarbon dates (**Table 3**) and the archaeostratigraphical ages.

5.6.1. PVG 1 (P31-P24, from c. 150 to 115 cm; SU10124, SU10119; BM2, c. 1550 – 1480 cal yr BC)

Pollen concentration has the lowest value (22,000 p/ g) while the reworked pollen percentage is the highest (16%): the two data are probably related to the supply of alluvial sediments that deposited a high amount of matter diluting pollen. Accordingly, there are the highest values of *Pinus* (4%), also found as fragments and broken, as they are fairly common in the alluvial plain. The cysts of *Concentricystis* (up to 2.2%) mark some soil erosion processes. Besides pine, *Abies* is well represented among conifers.

Forest cover (44%) mainly consists of broadleaved *Quercus* (10%) and oak wood components such as *Carpinus betulus*, *Acer campestre* type and *Fraxinus excelsior* type. *Corylus* is the most important shrubby plant, which is well represented together with *Prunus* among plants producing edible fruits.

Hygrophilous woods are mainly represented by *Alnus*, together with *Salix*: they are the main components of pollen from wet environments (18%) also including hydrophilous herbs (5%) and aquatics (1%).

Chenopodiaceae have significant values (4%), together with Poaceae and Cyperaceae, Apiaceae and *Urtica dioica* type. In general, API and other synanthropic plants sum up to 16%. Among them, cereals are well represented (1.9%).

5.6.2. PVG 2 (P23-P17, from c. 114 to 80 cm; SU10102, SU10062; BM3, 1480 – 1395 cal yr BC)

Pollen concentration becomes seven times higher (152,600 p/ g) while the reworked pollen seven times lower (2.2%) than in the previous zone. Organic matter was abundant in these layers, possibly by very close input of plant parts, or growing of plants near the water surface; undecomposed or partially decomposed, small fragments of plants were also observed in thin sections (**Table 2**).

However, forest cover largely increases in the area (**Fig. 8**). In fact, despite the high representation of two woody plants, *Salix* and *Vitis* probably marking some very local overrepresentation of riparian vegetation near the channel, the forest cover remains evident even if these woody plants and all hygrophilous plants are excluded from the pollen sum (**Fig. 10**).

Pinus and *Abies* decrease among conifers, together with broadleaved *Quercus* (7%). The curve of deciduous oaks, like that of some other woody plants, shows short zigzag-like oscillations (**Fig. 8, 10**) suggesting the repeated cutting of trees and subsequent resprouting suckers. *Tilia* disappeared toward the top of the zone. However, other woody trees like *Acer campestre* type and *Fraxinus excelsior* type, together with the shrub *Sambucus* cf. *nigra*, increase probably taking space within the oak wood. There is the only trace of *Olea* probably arriving from long distance transport. *Corylus* increases at the beginning of the zone, while *Vitis* has two peaks within a very high value (7.2% on average; max. 18% in P19). A continuous curve of *Cornus mas* starts. Among herb pollen, Scrophulariaceae indiff. and Brassicaceae are well represented while Asteroideae and Apiaceae decrease.

Pollen from wet environments increases to 26% thanks to *Salix* (10.5% on average; max. 33.4% in P17) prevailing on *Alnus* among hygrophilous trees; meanwhile, pollen from hydrophytes and aquatics decreases to 5%. However, pollen of *Lemna* is significant and continuous (0.8% on average, and up to 1.5%) in accordance to the standing water in thin sections (see above 5.3).

5.6.3. PVG 3 (P16-P6, from c. 79 to 25 cm; SU10059, SU10038; BM3, BR1, c. 1395 – 1340 cal yr BC

Despite the highest peak is registered in P15, the pollen concentration notably decreases (to 32,000 p/ g if the maximum is excluded). Reworked pollen is c. 5%. Forest cover is meanly similar to that of PVG1, with *Corylus* increases. Conifers are insignificant, *Sambucus* cf. *nigra* decreases, and *Betula* practically disappeared. Broadleaved *Quercus* remained quite steady to 7%, still showing the seesaw trend of the pollen curve. *Vitis* decreases but remains sensibly present. *Cornus mas* is well represented. Grasslands have again a good component of Apiaceae, herbaceous Rosaceae, and *Thalictrum*.

Pollen from wet environments decreases to 19%. The hygrophilous wood is still important but its composition changes, with decreasing presence of *Salix* and increase of *Populus*. Pollen from hydrophytes and aquatics remains quite steady to 5% except for *Lemna* that reaches a peak of 10% at the beginning of the zone thus marking shallow water habitats. Although the value of Chenopodiaceae is low on average (2%), their curves show an increasing trend towards the top (**Fig. 9**). This marks the spreading of grasslands in the area. Cereals, especially *Hordeum* group, are significant (2%), and *Secale* appears at the top of the zone (P6).

5.6.4. PVG 4 (P5-P1, from c. 24 to 0 cm; SU10066, SU10044; BR1-BR2, 1340 – 1170 cal yr BC

Pollen concentration increases (c. 38,200 p/ g) and reworked pollen is the lowest in the sequence (3%). Forest cover decreased dramatically to 20%, with broadleaved *Quercus* decreased to 5%. *Fagus*, that showed sparse records in previous zones, disappeared. *Vitis* disappeared toward the top of the zone. The most impressive datum is the strong decrease of *Corylus* and *Vitis* representing fruit producing plants whose reduction probably caused detriment of food (see below 6.2).

Pollen from wet environments decreases again to 12% where *Salix* reduced before *Alnus*; however, pollen from hydrophytes and aquatics increases to 7% especially because the limno-telmatophytes doubled. Chenopodiaceae (5%), along with *Centaurea nigra* type and *Plantago* species (c. 2% each), are well represented. These data, combined to the joint increase of the Cichorieae and Poaceae curves, suggest an expansion of pastureland in the area. Interestingly, the percentage of cereal pollen (2.5% on average) increases up to 6% at the beginning of the zone (P5). This is especially due to *Hordeum* group (4%) followed by *Avena/Triticum* group while the traces of *Panicum* and *Secale* pollen are index that crops probably became more diversified.

6. Discussion

6.1. Formation processes of the stratigraphic sequence

At the bottom of the sequence, SSUU 10124 to 10062 show lamination and hydromorphic colours that indicate conditions of permanent standing of water. The water level was deep enough to allow the slow decantation of finely laminated sediments (laminae) with an upward fining trend. Slow sedimentation has occurred during the BM2 and the beginning of BM3 phases. Moreover, in the SSUU 10119, 10102, and 10062, remains of calcareous algae are interlayered with the laminae, indicating a sort of well developed occasional (seasonal) flourishing of algae in the moat. Fresh water calcareous algae include organisms with calcareous skeletons such as Charophytes, which are characterized by chlorophyll pigmentation. They are submerged aquatic plants (Streptophyta) occurring throughout the world in all sort of non-marine watery habitats; sometimes they may be index of shallow water, also tolerating brackish habitats. During sexual reproduction they produce oospores, which calcify in some genera (Reichenbacher et al., 2004). Charophytes are not uniform in their responses to environmental conditions, nor follow defined patterns of growth only dictated by the season or age. Although different species can respond in different ways to environmental conditions, and some species may flourish several times in a year, they display reproductive plasticity in response to water level changes (Casanova, 1994). Their reproduction in response to decreased water levels may ensure that the drought-resistant oospores are produced before the habitat dries out completely. In conclusion, the laminae rich in calcareous algae may indicate the fluctuation of the water level, which is possibly related to seasonal variations of water availability.

The calcareous algae occur contemporarily to the NPP algal remains and aquatic plants (**Fig. 9**). This fits well with the general geoarchaeological and botanical reconstruction of the depositional context, which shows the local wet environments living locally and consisting of riparian vegetation with well-developed hygrophilous woods (including *Vitis*; **Fig. 11**). The sedimentary environment appears to be mainly a lacustrine habitat. The sediments have some similarities with the laminated deposits, dating back to the same period, observed in the artificially confined pool of Noceto. There, the occasional flourishing of algae was identified in thin sections and under the scanning microscope (Cremaschi et al., 2009). At Santa Rosa di Poviglio the algal remains consisted of calcareous laminae, whereas at Noceto they were exclusively diatoms.

The formation of this part of the infilling can be explained by considering the general setting of the site. The moat of VP was directly connected, at its northernmost reach, to a large palaeochannel of the Po river (Cremaschi, 2014; **Fig. 2**). For that reason in the northern part of the moat, its infilling mostly consists of river sediments; therein, previous archaeological excavations evidenced the occurrence of cross-laminated sand interlayered to silty deposits (Mele et al., 2014; Cremaschi, 2014). These sediments were deposited by running water as an effect of direct connection with a main water stream. On the contrary, the occurrence of a lacustrine sedimentary environment recorded in the southern part of the infilling (the one discussed here) suggests the occurrence of a threshold separating the two areas of VP. The part of the site located beyond the threshold (southward) acted as flood basin of the main stream flowing in the northern part of the moat.

From SU10059 upward, the sedimentological properties and associated biomarkers of deposits suggest that the water level inside the moat dropped consistently. Sediments deposited in shallow water in a more organic and highly bioturbated environment. Deposition occurred with a main contribution of colluviation along the margin of VP, which was promoted by the runoff from the banks when the moat was seasonally dried. Based on the available chronological framework, the drop in water availability has mostly to be related to the latest BM3 and the beginning of the BR phases, which on the basis of the regional archaeological stratigraphy is dated at c. 1330 cal yr BC.

This is consistent with the state and development of the ditches of VG, which are known to date mainly to the BR. They have never hosted standing water, and faced both desiccation and defunctionalisation at the end of the BR period (BR2, at c. 1170 cal yr BP; Cremaschi et al., 2006, Cremaschi and Pizzi, 2010, 2011).

6.2. Palaeoenvironmental and palaeoethnological inferences

The pollen spectra shown in this paper (**Figs. 8,9,10**) resulted from both human presence/ action and natural vegetation cover in the area. Some peculiar pollen assemblages were mainly linked to environmental/ climatic conditions, being the human influence a less conditioning factor for the development of such habitats. For example, the gently but rapid oscillations of the curve of deciduous oaks, sometimes visible also in other woody plants, is indicative of coppicing. This was already clear in the pollen diagram from the Terramara di Montale where the coppicing of woods was evident at c. 1450 cal yr BC (3400 cal. BP; pollen zone MTI4) showing peaks of *Carpinus betulus* alternating with those of deciduous *Quercus*, or *Corylus*, or *Fraxinus* and *Carpinus orientalis/Ostrya carpinifolia* (Mercuri et al., 2012, p. 365).

The extraordinary high-resolution of this sequence makes visible these anthropogenic-induced changes in forest cover that had occurred at the Middle and Recent Bronze Age in the Po Plain.

Archaeological chronology and correlations, in fact, demonstrate that the pollen sequence PVG VP/ VG has been accumulated over a time period of approximately 380 years (from c. 1550 cal yr BC, beginning of the BM2 to c. 1170 cal yr BC, termination of the BR). Although there were fluctuations in the deposition, and a linear sedimentation rate may be hypothesized only for the laminated units, the mean resolution may be estimated c. 12 years per sample (2.5 yr/ cm) in lower units.

6.2.1. Wet environments

The pollen from plants living in ecologically wet environments reflect the growing of this kind of plant communities in the moat as well as in the territory surrounding the Terramara. In general, wet environments are evident from the good biodiversity of aquatics and limno-telmatophytes, and from NPPs of algal remains (see also the calcareous algae visible in the stratigraphy; par. 6.1). The fluctuation of curves of wetland indicators, that are common in these pollen spectra, may be interpreted as a signal of variation in the environmental conditions due to climatic or hydrographic oscillations, and to the human management of ditches. Pollen diagram suggests that the riparian woody vegetation was firstly dominated by *Alnus* and *Populus* (PVG1), and then locally replaced by *Salix* (**Fig. 9**). This may have been due to different water levels derived from environmental or anthropogenic changes. Tolerance to the hydric stress from inundation and drought can vary notably between species. In the palaeochannel of the Allier River (France), Ejarque et al. (2015) observed that the decrease of *Alnus* pollen coeval with the rise of *Salix* and the increasing trend of *Populus* (as visible in PVG2/ PVG3, **Fig. 9**) reflected the partial replacement of the alder-dominated forest by a pioneering willow-poplar community. Francis et al. (2005) found that *Alnus incana* and *Populus nigra* are intolerant to inundation conditions differently from *Salix elaeagnos* that also tolerates slow water table decline. At Santa Rosa di Poviglio, the fast rate of water table decline, which is detrimental to all species, had most likely caused the synchronous decline of the three trees, together with that of elm, visible in PVG4 (**Figs. 8,9**).

6.2.2. The role of fruit trees

The pollen diagram is characterized by sparse oak wood besides the locally living hygrophilous wood. The role of trees and shrubs supplying fruits is of special interest. *Olea* and *Juglans*, which are part the OJC group of 'cultural trees' (Mercuri et al., 2013b), are present in traces. Only *Castanea* shows a somewhat continuous curve increasing at the top of the diagram (PVG 4). Interestingly, indeed, there is a significant presence of *Prunus* and other woody Rosaceae, *Cornus mas*, and especially *Corylus* and *Vitis* (**Figs. 8,9**). All the species of *Prunus* are known to be low-pollen producers, underrepresented in pollen spectra, and even a very low percentage of this pollen may be evidence of a large distribution of trees, and fruits, in the source area (Mercuri, 2015). All the fruit-bearing trees were an important food source, and may have been collected on the wild or cultivated.

The archaeobotanical record supports the palaeoethnobotanical evidence inferred from pollen. At Vasca di Noceto there were fruits belonging to many Rosaceae (*Prunus spinosa*, *Pyrus* sp., *Rubus fruticosus* aggr., *Fragaria vesca*, *Sorbus domestica*), and cornelian cherries were found. At Terramara di Montale, Rosaceae fruits belonged to *Prunus spinosa*, *Sorbus* spp. and *Malus sylvestris* while the endocarps of *Cornus mas* prevailed. In these two terramare sites, also hazelnuts and grapes were common in the macroremain record.

Also *Cornus mas* is a low-producer, entomophilous, shrub but it should have been so common in the landscape that its pollen is significantly present in traces in the Bronze Age samples of the Adriatic Sea core RF93-30, which collected sediments from the Po Valley (Mercuri et al., 2012). The recovery of endocarps of *C. mas* is common in Bronze Age sites of Italy and Europe (Mercuri et al., 2015a, and reference therein), connected to the consumption of fruits and possibly to the preparation of alcoholic beverages.

Indeed, high amounts of *Corylus* in pollen spectra are justified by the anemophilous nature of these shrubs that are high-producers by definition. Since the early Holocene, *Corylus* pollen followed the expansion of broadleaved woods in the Mediterranean area (Lowe et al., 1996; Finsinger et al., 2006; Magri et al., 2015). This occurred under increasing temperatures, and seasonality with drier and warmer summers, summer water shortages and natural wildfires (Peyron et al., 2011; Branch, 2013; Sadori et al., 2015). Human action was also partly responsible for the dissemination of hazelnut fruits collected for food. The consumption of nuts has been suggested since the Neolithic in Northern Italy (Nisbet and Rottoli, 1997). This probably contributed to the spreading of this plant. Although *Corylus* then decreased, it remained a common shrub in mid-Holocene woods. *Corylus* pollen is fairly ubiquitous in terramare sites such as Montale, Baggiovara, Casinalbo and Noceto as part of oak woods. The riparian vegetation favoured the growth of shrubs. The role of this plant as food supply for the Terramare people seems unquestionable, also considering that their macroremains are common besides pollen at Montale and Noceto. Moreover, at Vasca di Noceto, hazelnut shrubs were probably planted bordering the area around a votive pond, and their pollen fell abundantly in the water filling during the winter season (Aceti et al., 2009).

6.2.3 *Vitis*: wild or domesticated grapevine?

The high values of *Vitis* pollen in this sequence deserve attention. In pollen diagrams from archaeological sites, *Vitis* pollen grains are often few, and are considered as an indicator of the local presence of viticulture (Bottema and Woldring, 1990). The rarity of *Vitis* pollen is due to the pollination of cultivated varieties of the vine (*Vitis vinifera* subsp. *vinifera*) that is accomplished by self-pollination, with entomophilous and anemophilous cross-pollination (Turner and Brown, 2004). However, pollen spectra from Santa Rosa di Poviglio show high percentages of *Vitis* that reaches two peaks within a very high value in zone PVG 2, and especially in samples from SU 10062 (P18, 85 cm) and SU 10102 (P23, 110 cm) that are typical lacustrine-type units. Accordingly, the PCA diagram shows *Vitis* near *Salix* and *Sambucus nigra* in the sector III (**Fig. 11**). This evidence suggests that some grapevine grew as part of the riparian communities near the moat. Wild grapevine (*Vitis vinifera* subsp. *sylvestris*) is common in riparian deciduous woodland and willow communities of Euro-Siberian and Mediterranean regions (Rivas-Martínez et al., 2002; Biondi and Blasi, 2009).

Vitis pollen morphology does not allow distinguishing between the wild or cultivated grapevine. The absence of diagnostic macroremains in this deposit prevents the possibility of distinguishing among the subspecies. At the beginning of Middle Bronze Age, pips with intermediate characteristics between the two subspecies *sylvestris* and *vinifera* were reported by several authors (Castello di Annone - Asti, Piedmont: Castelletti and Motella De Carlo, 1998; San Lorenzo a Greve – Florence, Tuscany: Aranguren et al., 2007; Portella, Salina – Sicily: Fiorentino et al., 2010; Marvelli et al., 2013; Mercuri et al., 2015b).

Interestingly, previous pollen analyses carried out at Santa Rosa di Poviglio demonstrated that *Vitis* pollen was not spread. It was only found in traces in the Eastern ditch (sample P901b) while no pollen is visible in the diagram from the Northern ditch (Ravazzi et al., 2004). This seems to contradict the above-mentioned hypothesis of the spreading of grapevine as part of riparian vegetation because, in that case, the widespread growing of wild plants close to the ditches would have been expected. Waiting for further investigations, considering that the Bronze Age was a transitional cultural phase, it is plausible that some grapevine plants were cultivated, even not domesticated, in the site. Probably, plants were easily grown in wet habitats representing the most suitable environment for their life. If the presence of some cultivated grapevine is accepted, the high *Vitis* percentages found in some samples could actually reflect some human action such as an intentional accumulation of vine-lopping remnants thrown into the moat. For example, in the Middle Bronze Age sites of Strepparo and Cento Moggie sites (Capua, Caserta - Campania), a developed cultivation system was inferred by the recovery of grapevine branches (21 pieces with a diameter of 4-10 mm; Castiglioni and Rottoli, 2001).

6.2.4 Cichorieae and the spreading of pasturelands

The curve of Cichorieae has a double significance; it has a precious ecological (dry-resistant vegetation) and economical (pasture) values. In modern vegetation, these plants prevail in secondary pastures and some types of primary open habitats (Florenzano et al., 2015). In archaeological contexts their pollen is among the most important pastureland or grazing indicators (Florenzano et al., 2013; Mercuri et al., 2010). In off-site records, the trend of Cichorieae pollen commonly follows the trend of Poaceae pollen marking dry grassland spreading during increasing climate aridity and human impact in the last three millennia (Mercuri et al., 2012).

It is known that the terramare villages were located in open spaces on the Po Plain because settlements need space and a considerable deforestation supplied timber for houses. Pollen diagrams recorded low forest cover (c. 21–25% in Baggiovara and Casinalbo, c. 30% in Montale; c. 34% in Santa Rosa di Poviglio) during the lifetime of the villages. Moreover, the openness of the landscape dramatically increased towards the BR phases. At Montale (Mercuri et al., 2006a) this looks synchronous with the decrease of cereals in the diagram of trench P1 suggesting land overexploitation and depletion of soils locally (Mercuri et al., 2006b).

The comparison of curves of Cichorieae pollen obtained from Terramare villages shows that (**Fig. 12**): i) Cichorieae are very low in the VP/ VG sequence (studied in this paper) suggesting that pastures were irrelevant compared with other land-uses in proximity of this moat; ii) in the same moat, very low values correspond to the Middle Bronze Age, while a tendency toward increase is observed in the late Recent Bronze Age phases; iii) relatively higher values of Cichorieae were found in the North and East ditches suggesting that pasturelands were prevalently distributed in those sectors of the site, especially considering the more recent chronologies; iv) in general, Cichorieae pollen is lower in the Terramara Santa Rosa di Poviglio than in the Terramare of Montale and Baggiovara suggesting that the economy of Santa Rosa should have been less based on animal breeding than it was in the other terramare villages; v) an increase of the Cichorieae curve marks the last part of the Recent Bronze Age in the moats from Santa Rosa of Poviglio, in the top sample of Montale P1 while in the diagram of Baggiovara this phase is missed. This increase marks the spreading of dry pastures that may correspond to both a land-use change under dryer climate conditions and the abandonment of the fields. In Santa Rosa di Poviglio, cereal fields continued to be cultivated but a set of drought-tolerant crops such as barley, millet and rye seems to be preferred to oat and wheat.

7. Conclusions

The fill of the VP/ VG moat is the first continuous sedimentary sequence, which accumulated all over the time span of the Terramare civilisation (**Fig. 13**). Depositional conditions were suitable for good preservation of sediments and their palynological content. The archaeological context facilitated their dating, which is also supported by radiocarbon ages. Our results allow exploring with deeper detail an issue still open, concerning the land use promoted by the Terramare culture and its palaeoclimatic context. Both the geoarchaeological study of the deposits and pollen data elaboration, concordantly, show well developed evidence of anthropization in the palaeoenvironmental record of the moat of Santa Rosa di Poviglio. Pedosedimentary features and biological records (pollen of aquatics and algal remains) demonstrate that, at the beginning of the formation of this sedimentary sequence, shallow water was permanent, and its level dropped significantly in the moat during the last phase of life of the site. The occurrence of reworked pollen, in particular those derived from the Cretaceous flysch formations, in these units indicates water supply from a catchment area that presumably was located in the Apennine range, south of the site.

Palaeoenvironmental reconstruction shows fairly open vegetation, where riparian communities and oak woods were the main elements of the natural plant landscape. The latter showed continuous transformation in flora composition and communities. Complex and dynamic agricultural economy was based on wood management including coppicing, fruit collection on the wild, growing of woody plants and crop fields. These fields included a fairly diversified set of cereals especially increasing in variety during dryness or water crisis phases. Probably, grapevines were cultivated near the moat where wet habitat was also favourable to the growing of wild plants. The extraordinary high-resolution of this sequence makes visible the management of woods at the Middle and early Recent Bronze Age, while the economy of Santa Rosa di Poviglio should have been probably less based on animal breeding than it was in other Terramare villages.

At the top of the sequence VP/ VG (in the recent BR2 archaeological phase), in correspondence with the drying of the moat system, a dramatic decrease of woods, including oak and riparian woods, may have had a twofold, interdependent, causation: aridity and intensive land-use might have played a fairly synchronous action on vegetation. At Santa Rosa di Poviglio cereal cultivation seems to have continued during the late Recent Bronze phase, but the main traits of the landscape became pasturelands. This was possibly a result of a fall in soil fertility (Cremaschi, 2009). The pasturelands probably expanded in a fairly sudden way, partly on abandoned fields that were no longer grown in the site. This change of land-use appears to be contemporary, at the local scale, to the shortage of water resource, which at the edge of the history of the VG of Santa Rosa di Poviglio (at the acme of its expansion) caused the deep excavation of wells, into the dried bottom, to reach the water table, which had dropped to lower levels (Cremaschi et al., 2006).

In this perspective, our research confirmed a scenario of an impoverished natural landscape occurred at the end of the life of the Poviglio Santa Rosa village, and, more in general, in connection with the collapse of the Terramare culture (**Fig. 13**). Fields and woods were affected by a global, dry climatic episode that could be correlated to the evidence from Santa Rosa, and the Po Plain. This is also evident in regional and global climatic records. In Fig. 13, it is shown how the trajectory of the Terramare culture is well constrained between several episodes of climatic deterioration. These are highlighted, at a global scale, by variations in the residual $\Delta^{14}C$ (Stuiver et al., 1998; Blaauw et al., 2004). In particular, a pronounced dry peak is roughly coincident with the supposed age of the collapse of this civilization. At a continental scale, we confirm the consistent correlation between this phase and proxy data for environmental changes, as the glaciers' advance in the Alps and the lake level changes of lakes in West and Central Europe (Magny, 1993, 2004; Lockwood, 2001; Holzhauser et al., 2005; Magny et al., 2012). The dry episode identified at Santa Rosa di Poviglio can be put in relation to the drops of water levels of lake Ledro and lake Accesa (Magny et al., 2012, 2013), which are located at the northern and southern limits of the Po Plain, respectively. Finally, in Fig. 13 the phases of expansion of the Bronze Age villages (pile dwelling settlements) along the lakes of Central Europe (France and Switzerland; Magny, 2004) show key peculiarities. The main settlement interruption of the Early Bronze Age corresponded to a period of cooling. Few centuries later, the increase of temperature promoted the expansion of the Final Bronze Age settlements along the shores of Alpine lakes. The gap between these two phases was occupied by the trajectory of the Terramare culture. A connection between the Bronze age cultures of the transalpine region and those of the Po plain appears highly probable, connected to a relocation of populations as a response to the climate changes that occurred during the Bronze Age.

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Figure 1. (A) Digital terrain model of Northern Italy illustrating the area where Terramare settlements are distributed. (B) Detail of the area of distribution of the Terramare settlement in the central Po Plain; the localities cited in the text are reported. Key: 1) pre-Quaternary formations; 2) Alpine Pleistocene glacial deposits; 3) Pleistocene deposits at the foot of the Apennine; 4) Pre-Holocene terraces; 5) alluvial plain; 6) site belonging to the Terramare culture; 7) The site of Terramara Santa Rosa di Poviglio.

Figure 2. (A) Geomorphological settings of the area surrounding the site of Terramara Santa Rosa di Poviglio (indicated by the red star). Key: (1) Pre-Quaternary deposits; (2) Pre-Holocene terraces; (3) Holocene alluvial plain; (4) palaeo-channels; (5) poorly drained lowland.
(B) The Terramara Santa Rosa di Poviglio and surrounding waterways (modified from Mele et al., 2013); the position of the excavation discussed in this paper is indicated by the yellow rectangle. Key: 1) Small Village (VP); 2) fluvial deposits at the margin of the VP; 3) Large Village (VG); 4) moats and connected ditches; 5) bridge connecting VP and VG; 6) archaeological debris of Roman Age; 7) remains of Roman Age ditches; 8) deposits recently accumulated by present-day agrarian activities; 9) shallow ditches delimiting present-day fields; 10) steep margin; 11) gently dipping margin; 12) direction of the palaeo-channel of the river Po during the live time of the site; 13) flow directions inside the moat and the connected channels.

Figure 3. Map of the FDEM 15 kHz apparent electrical resistivity of the site Terramara Santa Rosa di Poviglio

illustrating the subsurface archaeological features. Non-surveyed areas correspond to inaccessible areas (private estates, areas of earth disposal and ploughed fields); warm colours indicate high resistivity, cool colours indicate low resistivity. The main archaeological features and the position of the excavation trench are indicated by labels.

Figure 4. Field pictures of the excavation. (A) General view of the trench opened in correspondence of the moat of VP; (B) detail of the stratigraphic section sampled for laboratory analyses.

Figure 5. A selection of pottery fragments from the stratigraphic units of the VP moat, representing the archaeological chronology of the infilling of the moat. BR2: 1 (SU10058), 3 (SU10066); BR1: 2 (SU10066); BR1/BM3: 6–8 (SU10044); BM3: 9–11 (SU10038); BM3/BM2: 12 (SU10062); BM2: 13-14 (SU10106), 15 (SU10102).

Figure 6. (A) Simplified stratigraphic section of the trench excavated in the moat between the VP and VG; a detail of the stratigraphic sequence discussed in this paper is in (B). The latter indicates the main stratigraphic units discussed in the text, the position of the sampling points for pollen analyses, the pollen zones, the archaeological dating of each stratigraphic unit, and the position of available radiocarbon dating. The same scale for vertical and horizontal axes is adopted.

Figure 7. Photomicrographs of the thin sections from the infilling of the moat; pictures A–C are from stratigraphic units related to colluvial processes, whereas pictures D–I are from stratigraphic units formed by sedimentation in water. (A) Groundmass of the slide of SU 10066, note the occurrence of bone (B) and shell fragments (S), and rolled pedorelicts (P). (B) A fragment of ovicaprine coprolite from SU 10066. (C) A fragment of weathered coprolite (with few residual spherulites) from SU 10038. (D) Weakly laminated sediment in SU 10062. (E) Thin, silty-clayey laminae in SU 10102. (F) A detail of the lamination in SU 10102, including laminar fragments of undecomposed plant remains and algal material (chains of calcite macrocrystals). (G) Wavy laminations in the lower part of SU 10102; in the upper right corner note the occurrence of convoluted algal laminae. (H) Laminations with an upward fining trend in SU 10124. (I) Detail of the lamination of SU 10124, showing the occurrence of organic material at the end of each cycle of sedimentation.

Figure 8. Percentage pollen diagram of PVG VP/VG (enhanced curves x10): selected curves and pollen zones (TGView; Grimm, 2004). Two asterisks mark the stratigraphical units from which samples are taken for radiocarbon dates. In the chronology column, the dates of zone PVG 1 (in brackets) are based on stratigraphical

correlations. Bronze Age: BM = Middle Bronze Age (phases 2 and 3), BR = Recent Bronze Age (phases 1 and 2).

Figure 9. Percentage pollen diagram of PVG VP/VG (enhanced curves x 10). Top: pollen from wet environments, pollen concentration, reworked pollen, fern spores, and NPPs. Bottom: selected curves of Anthropogenic Pollen Indicators (API) and grassland; main sums and number of taxa; pollen zones and cluster analysis (TGView; Grimm, 2004; see legend of Fig. 1 for chronology). Two asterisks mark the stratigraphical units from which samples are taken for radiocarbon dates.

Figure 10. Percentage pollen diagram of PVG VP/VG (enhanced curves x 10) of selected curves calculated on a pollen sum which excludes both *Salix* and *Vitis* (overrepresented in zone PVG 2) and other pollen from wet environment plants (hydrophilous trees and hygro-hydrophilous herbs); pollen zones and cluster analysis (TGView; Grimm, 2004). In the left column, the pedosedimentary facies are described by letters: A = dump, colluvial deposits; B = bioturbated fill; C = decantation in standing water / drying out ; D = decantation in standing water. Two asterisks mark the stratigraphical units from which samples are taken for radiocarbon dates (SU10066: 3282±70 cal yr BP; SU10062: 3405±42 cal yr BP). Main features useful for palaeoclimate inferences are summarised: changes in pollen curves are described from the bottom (PVG 1) to the top (PVG 4).

Figure 11. Principal component analysis (PCA; elaboration: XLStat) for the 31 pollen samples from the Terramara S. Rosa di Poviglio. The graphs shows the sample points from <dataset> projected on the max variance plane given by PCA. The first axis separates pollen spectra along an anthropic pressure gradient (from 'natural' to 'anthropic'). In the sectors I and III, different landscapes are proposed according to the taxa distribution. For each sector are featured the corresponding pollen zones.

Figure 12. Cichorieae pollen percentage curves from the terramare of Baggiovara, Montale and Santa Rosa di Poviglio. Cichorieae percentages are calculated on the pollen sum including all taxa from pollen profiles spanning from 'before Bronze Age' and Middle Bronze Age to the Recent and 'after Bronze Age'. At Baggiovara, pollen record does not include the Recent Bronze phase (this gap is marked by the grey line). The curves are correlated according to the chronological phases. The radiocarbon dates refer to the pollen sequences of Montale (Mercuri et al., 2006) and of the S. Rosa di Poviglio VP/VG Ditch.

Figure 13. The archaeological phases of the Terramare culture in Northern Italy, radiocarbon dating and pollen zones of the infilling of the moat, as described in the text, are compared with several regional and global climatic and cultural records: age of Early Bronze Age (EBA) and Final Bronze Age (FBA) pile-dwelling villages in the Alps (Magny et al., 2011[az1]); residual D14C curve (according to Blaauw et al., 2004); lake Ledro and lake

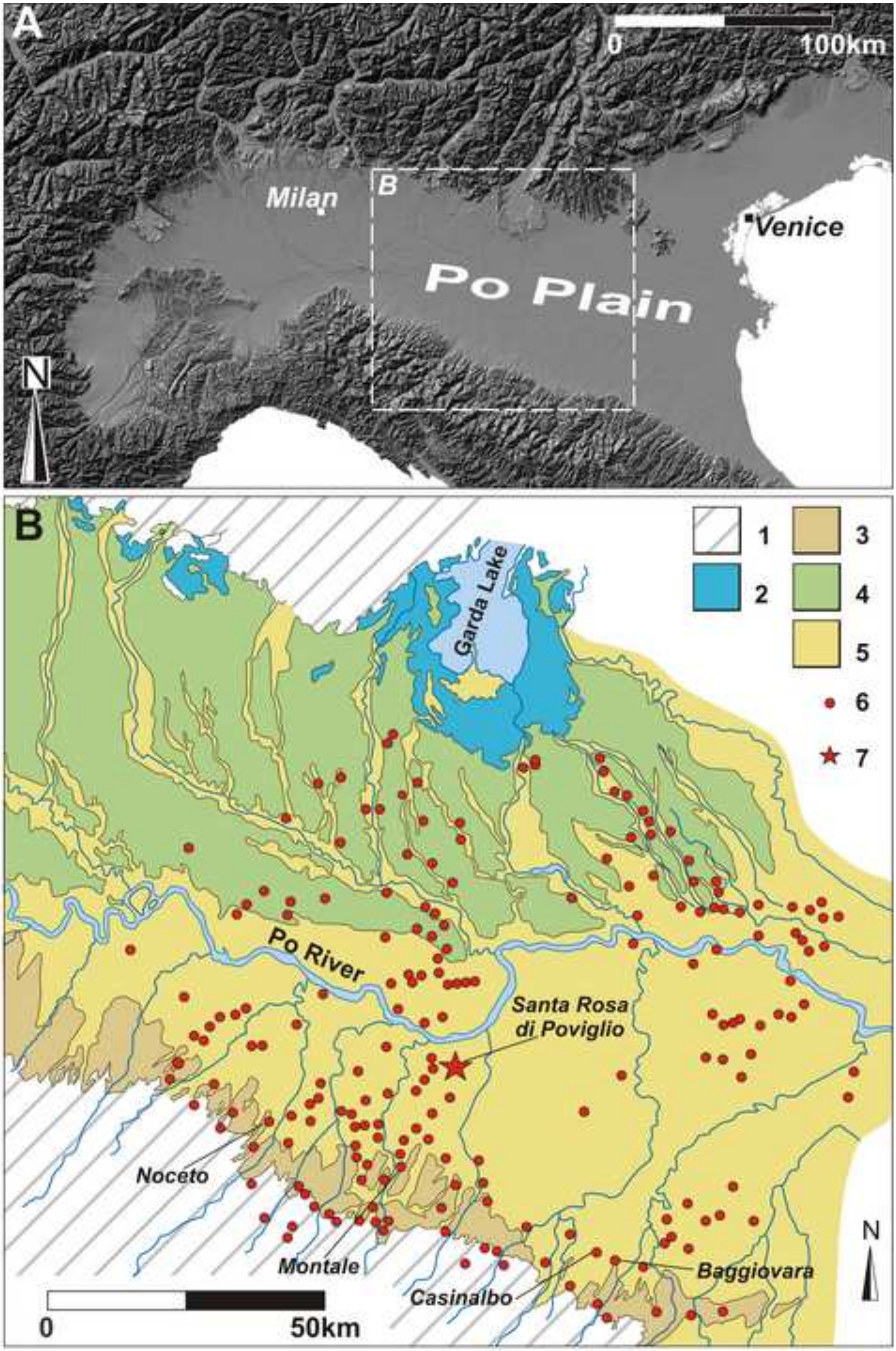
Accesa level changes (Magny et al., 2012); phases of higher lake level in West and Central Europe (Magny et al., 2012); phases of glaciers advances in the Alps (Lockwood, 2001). The grey bar indicates the chronological interval of the Terramare culture in Northern Italy.

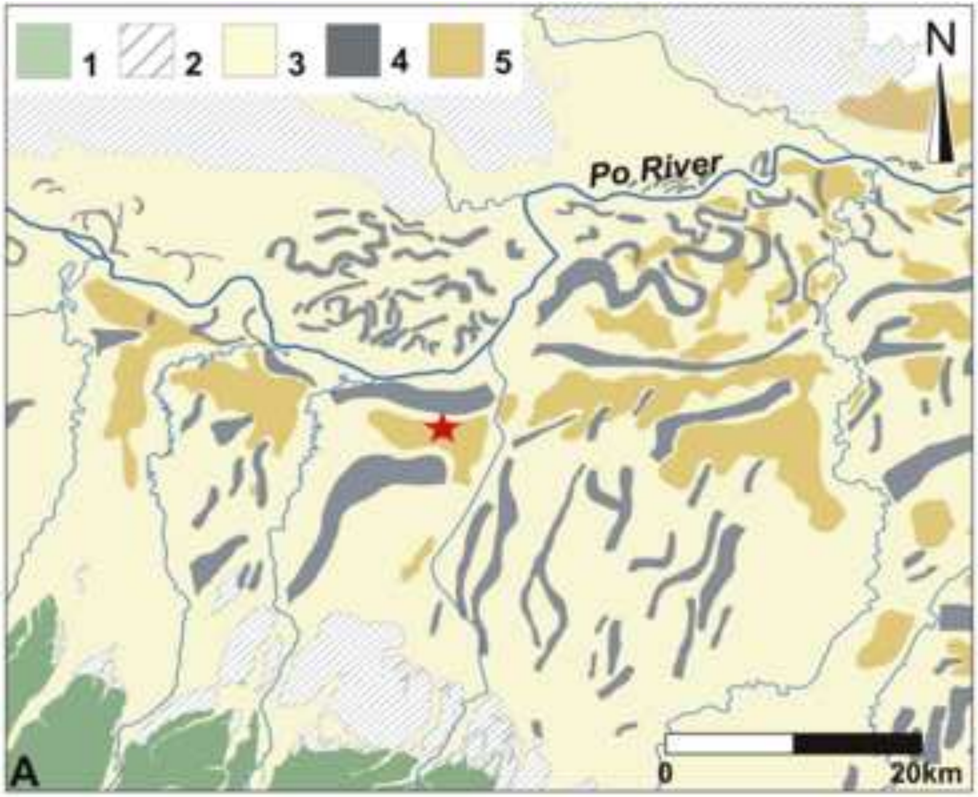
Unit	Colour	Field properties	Grain size (%) Sand	Silt	Clay	$CaCO_3$ (%)	Organic carbon	Dating
A_p	-	Agricultural horizon - top layer	-	-	-	-	-	recent
Vertisol 1	5Y 7/4 (pale yellow)	loamy-clay; coarse blocky structure; mottled; common $CaCO_3$ nodules; common slikensides; clear lower boundary	2	35	63	13	9.03	Medieval and later
Vertisol 2	2.5Y 5/2 (graysh brown)	loamy-clay; coarse blocky structure; common $CaCO_3$ nodules; scarce Roman red brick fragments and scarse fragments of Iron Age pottery at the bottom; clear lower boundary	6	39	55	4	8.41	Post-Roman
SU10066/SU1004	10YR 6/2 (light brownish gray)	loam; medium subangular blocky structure; common $CaCO_3$ nodules; few fragments of charcoal; few fragments of animal bones; fragments of Bronze Age pottery; clear lower boundary	8	41	51	15	9.13	BR1, BR2
SU10038	10YR 4/2 to 2.5Y 4/2 (dark graysh brown)	loamy-clay; medium to fine angular blocky structure; common $CaCO_3$ coating and noduless; common to abundant fragments of charcoal; fragments of Bronze Age pottery; clear lower boundary	3	50	47	25	4.96	BM3
SU10059(=10093	5Y 4/2 (olive gray) with common mottles 10YR 4/6 (dark yellowish brown)	loam; fine angular blocky structure (poorly developed); few $CaCO_3$ coatings; few fragments of charcoal; fragments of Bronze Age pottery; gradual lower boundary	1	53	46	24	3.64	BM3
SU10062	2.5Y 5/2 (graysh brown)with common mottles 2.5Y 5/6 (light olive brown)	loamy-clay; fine angular blocky structure (poorly developed); thin planar lamination and discontinuous lenses of algal carbonates; fragments of Bronze Age pottery; gradual lower boundary	1	50	49	27	5.51	BM3
SU10102	2.5Y 5/4 (light olive gray)	loamy-clay; thin planar to wavy lamination and continuous lenses of algal carbonates; laminae are interlayered of vegetal remains; few fragments of Bronze Age pottery; clear lower boundary	3	52	45	25	9.02	BM3/BM2
SU10119	2.5Y 6/2 (light brownish gray) with common mottles 2.5Y 5/6 (light olive brown)	loam; thin planar to convoluted lamination; few snails; some chunks of burned wood; clear lower boundary	2	60	38	24	4.15	BM2
SU100124	5Y 5/1 (gray) with common mottles 5Y 5/4 (olive)	loamy-clay; poorly laminated to massive; few $CaCO_3$ nodules; abrupt lower boundary to the moat cut (substrate)	4	59	37	23	4.56	BM2
Substrate	5Y 5/4 (olive)	Loamy-silt; massive; scarse to common $CaCO_3$ nodules	6	55	39	19	2.92	-

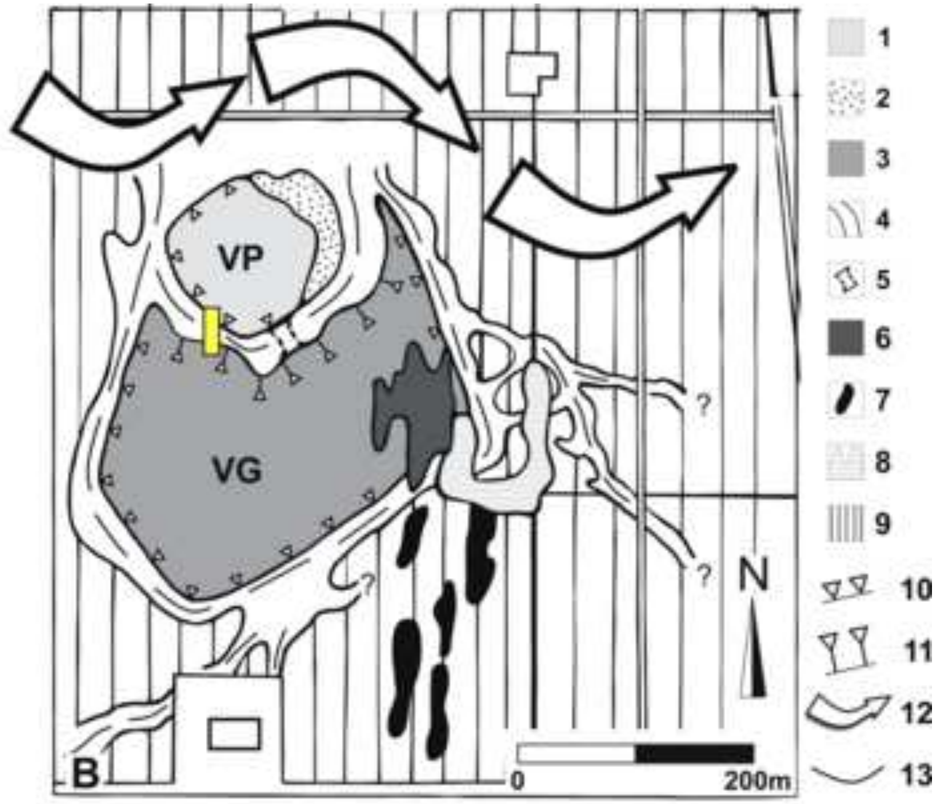
Unit	Mineral costituents and micromass	Organic and anthropogenic costituents	Voids	Aggregation	Microstructure and sedimentary features	b-fabric	:/f related distributior	pedofeatures
SU10066	Silty quartz grains; very few sandy quartz grains; opaque clay rich micromass	Common to frequent fragments of land snail shells; common microcharcols; scarce small bone fragments; scarce angular fragments of charcoal; fragments of coprolites (with spherulites); very few undecomposed vegetal remains; few phosphatic nodules; few bundles of phytoliths	Scarce vesicles; few planes; few chambers; few vughs	Angular blocky peds	Angular blocky microstructure	Crystallittic	Open to double spaced porphyric	Common $CaCO_3$ nodules and infillings; common Fe-rich impregnative pedofeatures; scarce rolled pedorelicts; few earthworm granules
SU10038	Scarce sandy and silty quartz grains; clay-rich micromass, locally birefringent	Frequent microcharcoals; scarce to common fragments of land snail shells; scarce fragments of bones; few fragments of undecomposed vegetal remains; few fragments of coprolites (with spherulites); few oncentrations of $CaCO_3$ crystals possibly related to wood ash	Common canals; common planes; scarce chambers; scarve vesicles; few vughs	-	Massive; common sand lenses	Crystallittic	Open porphyric	Common Fe-rich impregnative pedofeatures; few rolled pedorelicts; very few void infillings due to bioturbation
SU10059	Scarce sandy and silty quartz grains; opaque, clay-rich micromass	Common fragments of land snail shells; scarce fragments of angula charcoal; scarce microcarcoal; few oncentrations of CaCO3 crystals possibly related to wood ash	Common planes; common chambers; scarce canals; scarce	Subangula blocky	Massive to subangular blocky; few and weak horizontal laminations	Crystallittic	Open to double spaced porphyric	Common Fe-rich impregnative pedofeatures; few $CaCO_3$ sub-millimetric rounded nodules and coatings; very few rolled pedorelicts
SU10062	Scarce to common fine sandy and silty quartz grains; opaque, clay-rich micromass	Scarce fragments of land snail shells; scarse, small fragments of charcoal; scarce microcharcoal; very few, samll fragments of bones; very few undecomposed vegetal remains	Common plains; common chambers; common vesicles;	-	Massive with weak horizontal laminations	Crystallittic	Open porphyric	Scarce Fe-rich impregnative pedofeatures and hypocoatings; few $CaCO_3$ infillings and coatings
SU10106	Silty and sandy quartz grains; opaque clay rich micromass	Common microcharcoals; carse angular fragments of charcoal; few bundles of phytoliths; few, small bone fragments; few phosphatic nodules	Few chambers; few canals; few planes; few vesicles; few vughs	-	Massive microstructure; sommon sand lenses	Crystallittic	Open to close porphyric	Abundant Fe-rich impregnative pedofeatures; common $CaCO_3$ few CaCO3 sub-millimetric rounded nodules and infillings; scarce Mn-rich coatings; scarce rolled pedorelicts
SU10102	Scarce to common fine sandy and silty quartz grains; opaque, clay-rich micromass	Scarce to common laminar chains of calcite crystals (algal material); scarce laminar fragments of undecomposed plant remains; few fragments of land snail shells; few microcharcoal; very few small fragments of charcoal	Common plains; scarce, small chambers; few vesicles; few vughs	-	Massive; evident horizontal laminations; laminations are occasionally wavy to convoluted; in the lower part laminae present a upward fining trend	Crystallittic	Open to close porphyric	Scarce Fe-rich impregnative pedofeatures; few $CaCO_3$ infillings and coatings
SU10124	Scarce to common fine sandy and silty quartz grains; opaque, clay-rich micromass	Scarce laminar fragments of undecomposed plant remains; few microcharcoal; very few fragments of land snail shells	Common plains; few vesicles; few vughs	-	Massive; evident horizontal lamination; laminations have a upward fining trend	Crystallittic	Open to close porphyric	Scarce to common Fe-rich impregnative pedofeatures; few accumulation of amorphous organics; very few $CaCO_3$ coatings

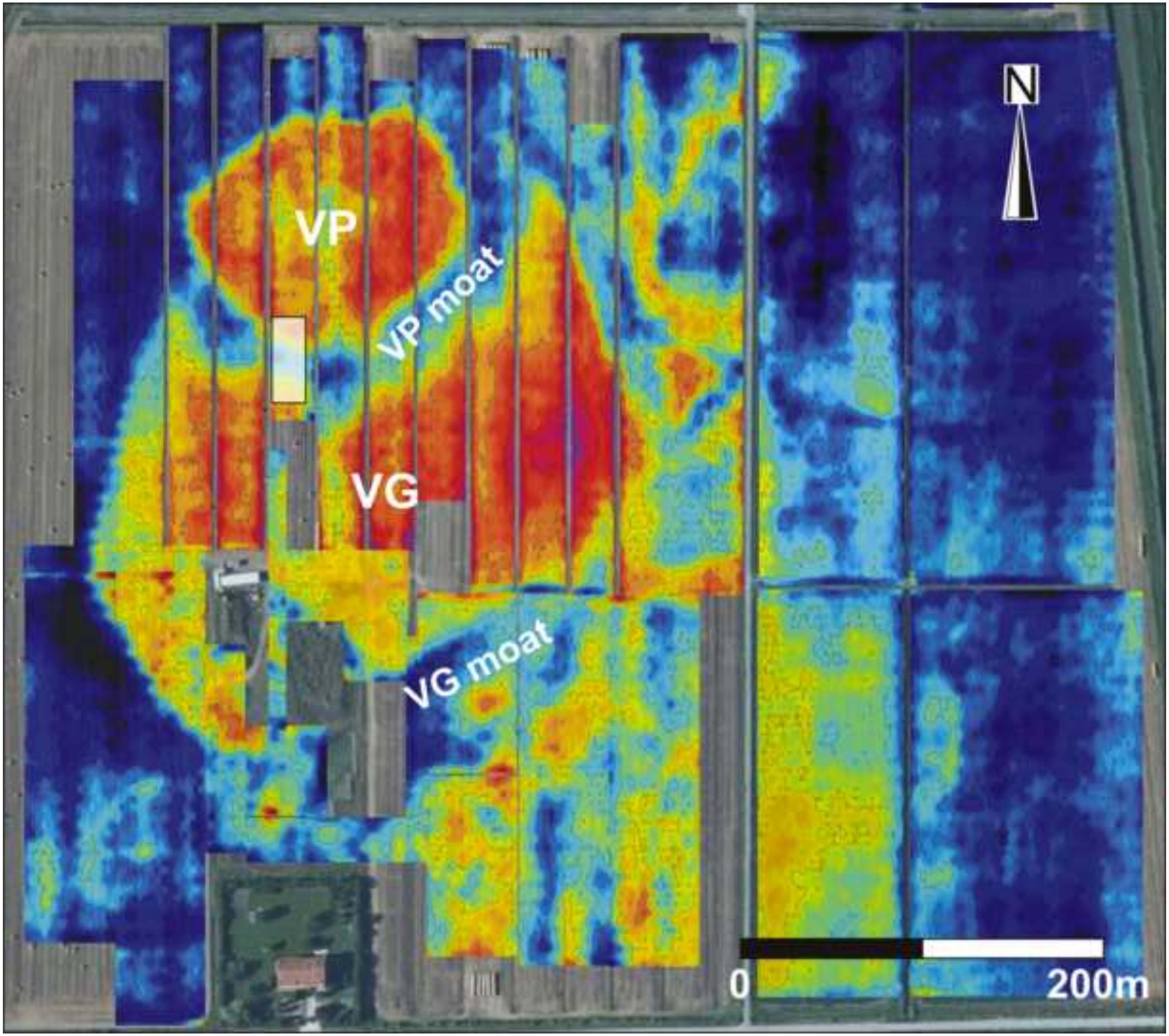
Position of the sample	**Stratigraphic unit**	**Archaeological dating**	**Dated material**	**Uncal ^{14}C age (years BP)**	**Cal ^{14}C age (years BC)**
VP, moat infillin	SU10066	BR	Collagen	3060±20	1402–1262
VP, moat infillin	SU10062	BM3	*Sambucus* seeds	3170±20	1497-1413
VP, moat infillin	SU10062	BM3	Charcoal	3370±20	1736–1621
VP dwelling are	SU10		Charcoal	3210±40	1562–1412
VP dwelling are	SU7	BM2	Collagen	3230±50	1619–1436
VP dwelling are	SU10/12	BM2	Collagen	3290±60	1730–1438
VG, well infilling	SU6750	BR	Collagen	3000±25	1375–1128

Label LPAZ	**Depth** ***(cm, excl. 2.5 m at the top)***	**Stratigraphical Unit**	**Number of samples**	**Sample label**	**Concentration (p/g)**	**AP**	**Oak wood**	**Wet environments**	**Cereals**	**API** ***(Mercuri et al. 2013)***	**Other API**	**Reworked**	**LPAZ description**
PVG 1	c. 150 - 115	10124, 10119 (BM2)	8	P31 - P24	c. 22,000	44.2%	21.9%	17.7%	1.9%	11.4%	4.8%	15.8%	Thin oak wood and denser hygrophilous woods near water courses; open environment with grasslands and cereal fields in the area; high input of alluvial sediments
PVG 2	c. 114 - 80	10102, 10062 (BM3)	7	P23 - P17	c. 152,600	62.6%	21.3%	26.4%	0.9%	6.7%	2.4%	2.2%	There are signs of local growing of shrubs and lianas (grapevine) very close to the channel; wood renewal (low or change of human activity) with some evidence of coppicing; freshwater habitats or low water flow; low input of alluvial sediments
PVG 3	c. 79 - 25	end of 10062, 10059, 10038 (BM3, BR1)	11	P16 - P6	c. 169,500 (35,500 if the maximum is excluded)	48.4%	24.2%	18.6%	1.6%	11.7%	2.9%	5.4%	Wet environments are spread, and oak woods supply subsistence resources including wood and fruits; agrarian economy is based on wood management and land-use with cereal fields
PVG 4	c. 24 - 0	beginning of 10038, 10066-10044 (BR1-BR2)	5	P5 - P1	c. 38,200	20.1%	9.6%	11.7%	2.6%	17.3%	6%	2.6%	Open vegetation predominates; hygrophilous wood and oak wood are reduced while dry grasslands/pastures (Cichorieae) widespread

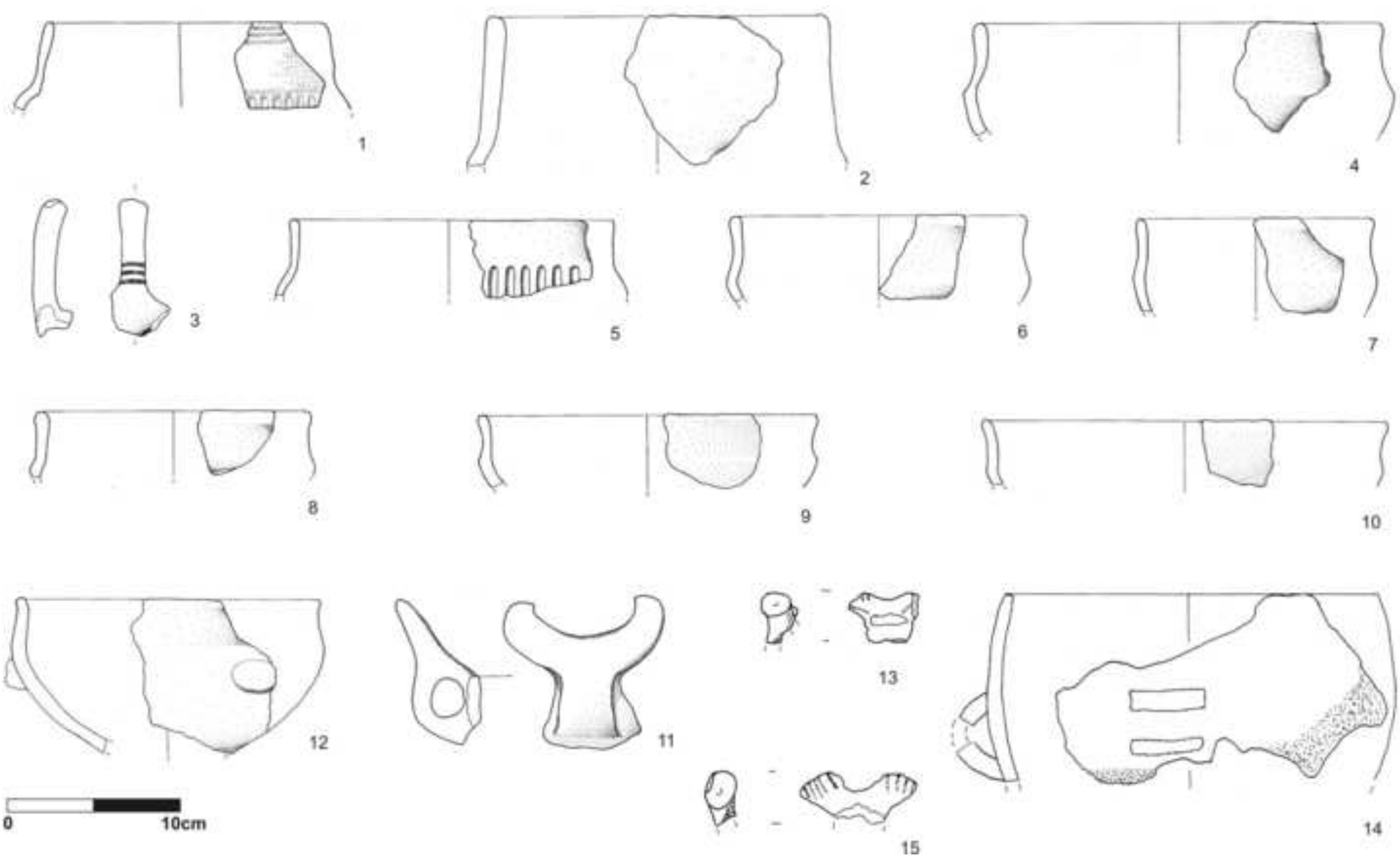

A
0
100km
Milan
B
Venice
Po Plain
N
B
1
2
3
4
5
6
7
Garda Lake
Po River
Santa Rosa
di Poviglio
Noceto
Montale
Casinalbo
Baggiovara
N
0
50km

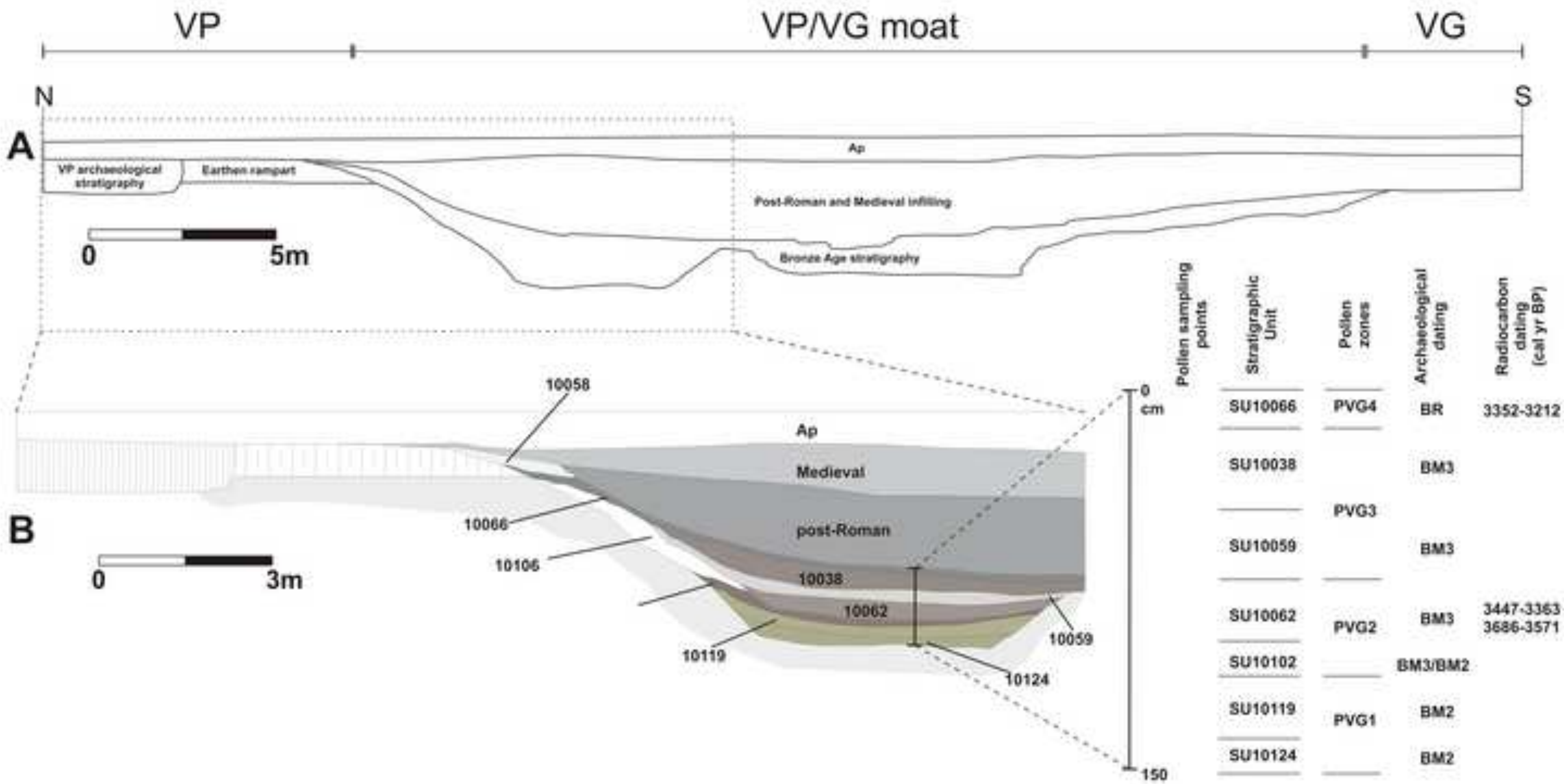

1
2
3
4
5
N
Po River
0
20km
A


VP
VG
?
?
?
N
0
200m
B
1
2
3
4
5
6
7
8
9
10
11
12
13

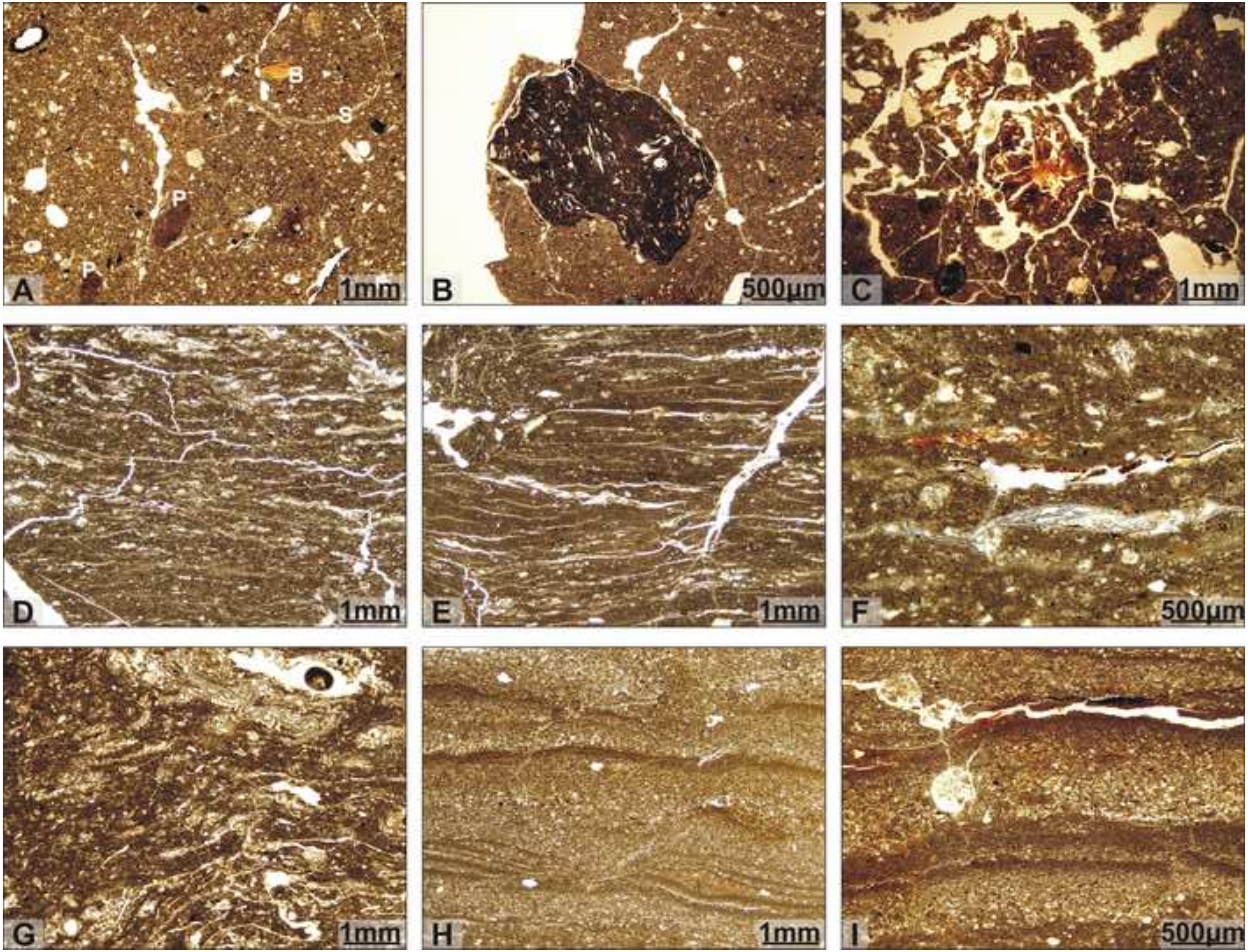

N
VP
VP moat
VG
VG moat
0
200m

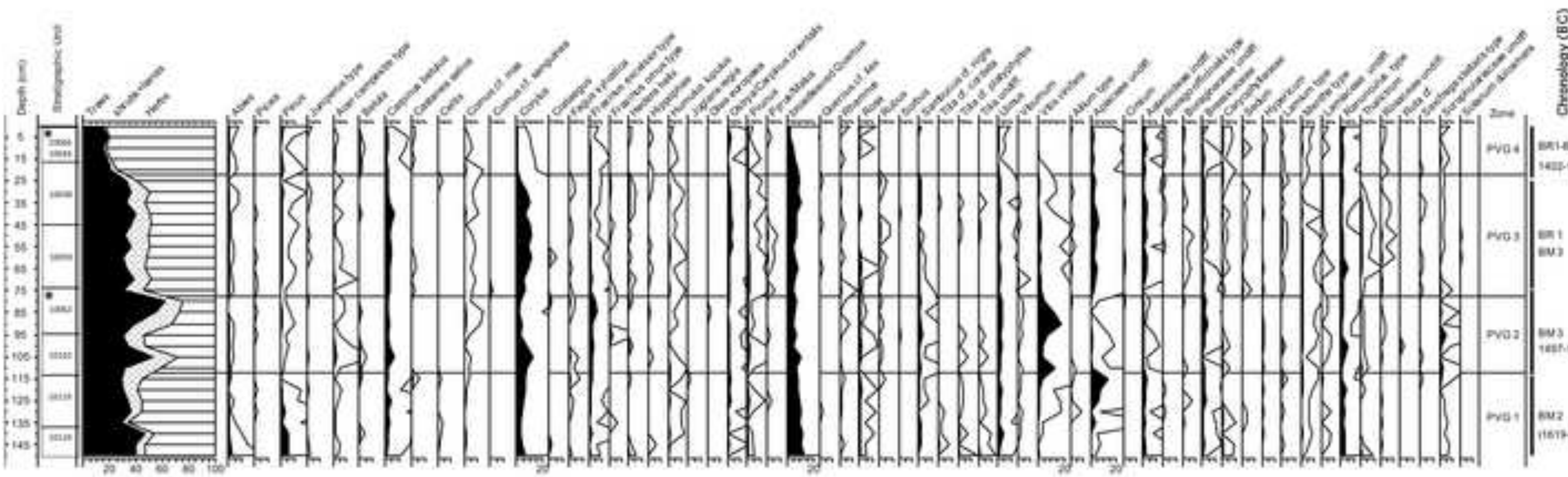

A
B

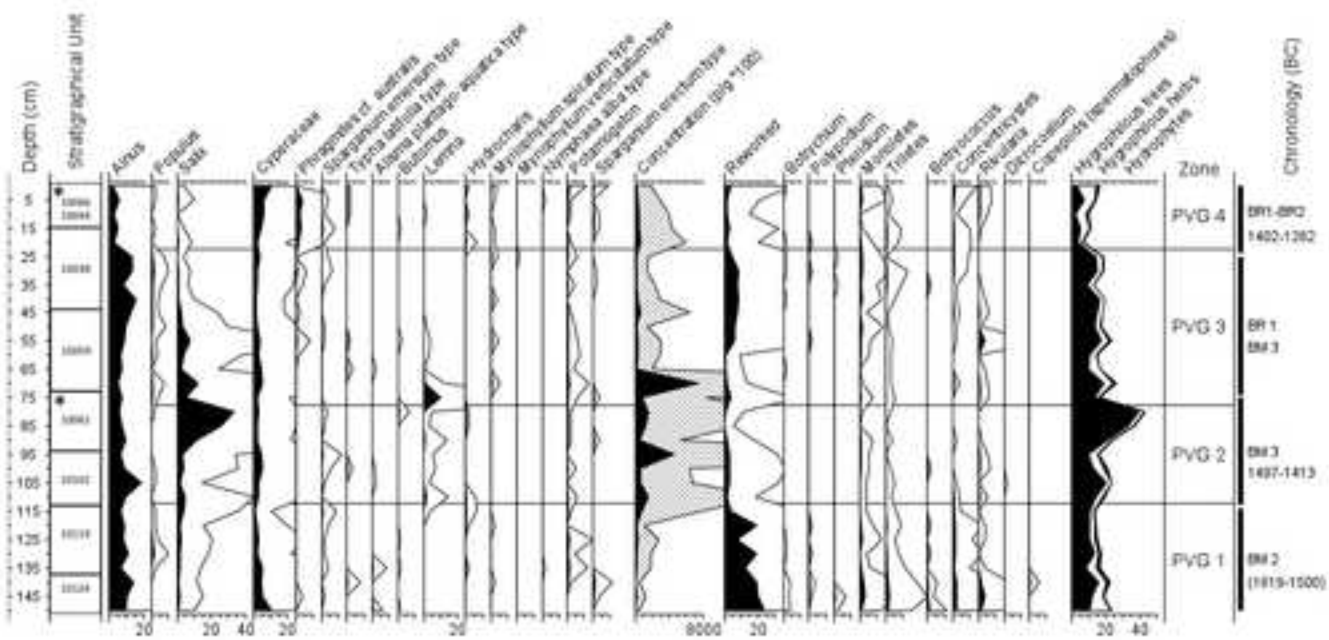

1
2
4
3
5
6
7
8
9
10
12
11
13
15
14
0
10cm

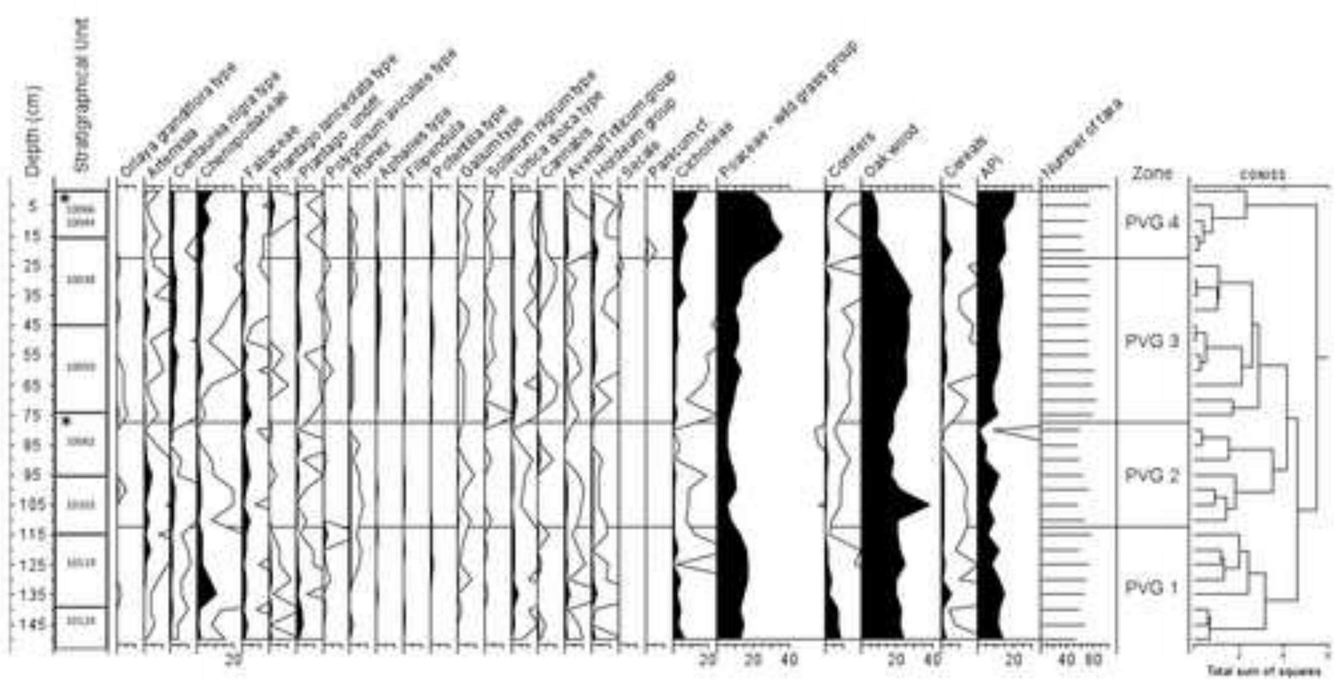


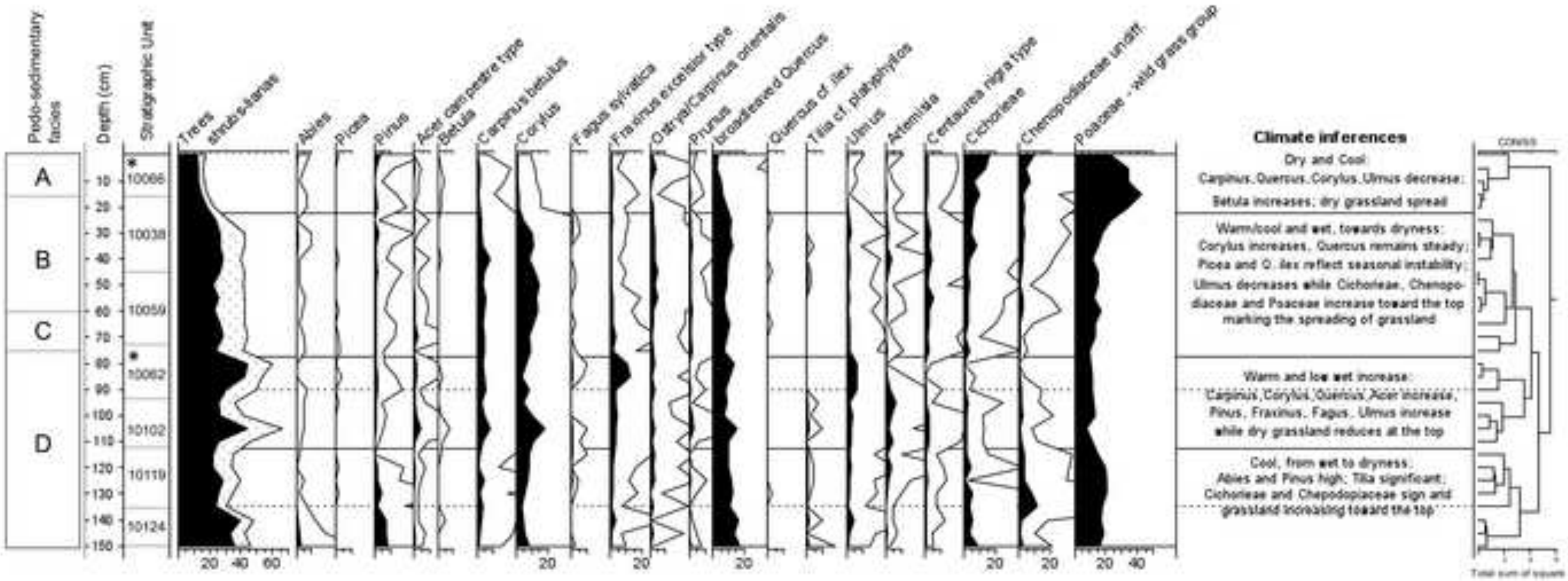
VP
VP/VG moat
VG
N
S
A
Ap
VP archaeological stratigraphy
Earthen rampart
Post-Roman and Medieval infilling
Bronze Age stratigraphy
0
5m
B
0
3m
10058
Ap
Medieval
post-Roman
10066
10106
10038
10062
10119
10059
10124
0 cm
150
Pollen sampling points
Stratigraphic Unit
Pollen zones
Archaeological dating
Radiocarbon dating (cal yr BP)
SU10066
PVG4
BR
3352-3212
SU10038
BM3
PVG3
SU10059
BM3
SU10062
PVG2
BM3
3447-3363
3686-3571
SU10102
BM3/BM2
SU10119
PVG1
BM2
SU10124
BM2

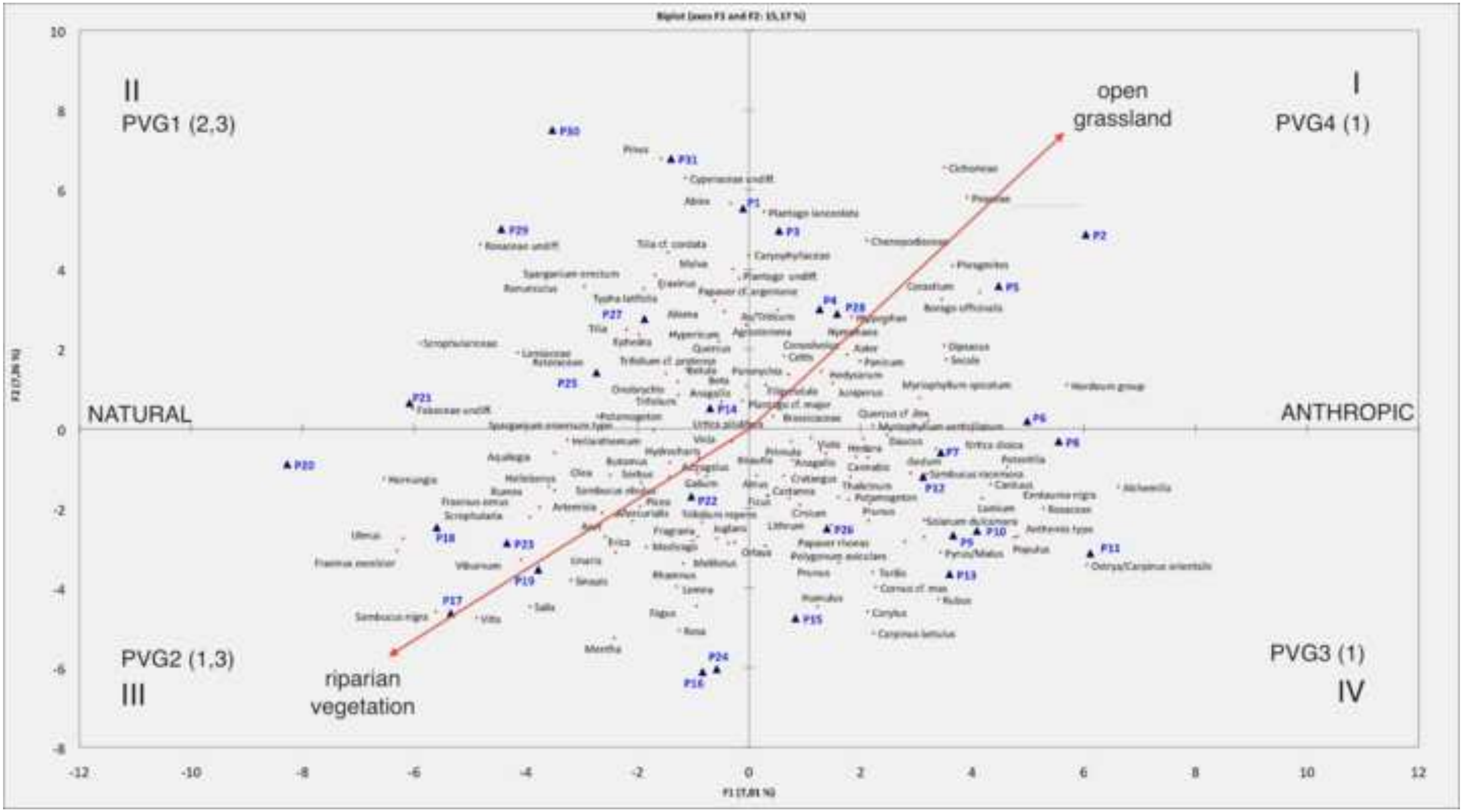

B
S
P
P
A
1mm
B
500µm
C
1mm
D
1mm
E
1mm
F
500µm
G
1mm
H
1mm
I
500µm


Depth (cm)
Stratigraphic Unit
Trees
Herbs
Abies
Picea
Pinus
Juniperus type
Betula
Carpinus betulus
Castanea sativa
Celtis
Corylus
Fagus sylvatica
Juglans regia
Olea europaea
Pistacia
Quercus cf. ilex
Rosa
Rubus
Sorbus
Ulmus
Viburnum
Vitis vinifera
Allium type
Apiaceae undiff.
Cirsium
Sedum
Hypericum
Lamium type
Ranunculus type
Thalictrum
Rosaceae undiff.
Zone
Chronology (BC)
PVG 4
PVG 3
PVG 2
PVG 1
BR1-BR2
1422-1262
BR 1
BM 3
BM 3
1497-1413
BM 2
(1619-1500)
5
15
25
35
45
55
65
75
85
95
105
115
125
135
145
20
40
60
80
100

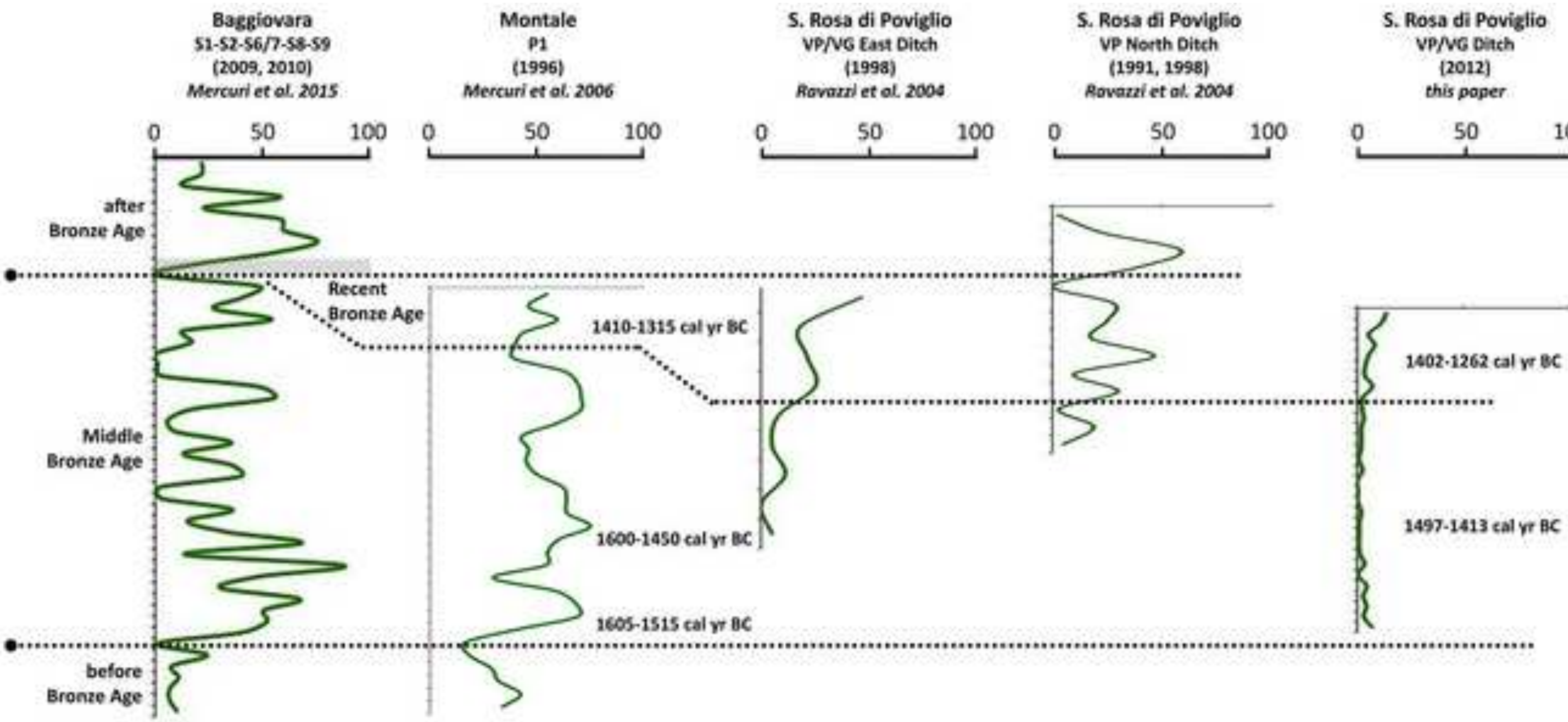

Depth (cm)
Stratigraphical Unit
Alnus
Populus
Salix
Cyperaceae
Phragmites cf. australis
Sparganium emersum type
Typha latifolia type
Alisma plantago-aquatica type
Butomus
Lemna
Hydrocharis
Myriophyllum spicatum type
Myriophyllum verticillatum type
Nymphaea alba type
Potamogeton
Sparganium erectum type
Reworked
Botrychium
Polypodium
Pteridium
Monoletes
Triletes
Botryococcus
Concentricystes
Rivularia
Hygrophilous trees
Hygrophilous herbs
Hydrophytes
Zone
PVG 4
PVG 3
PVG 2
PVG 1
Chronology (BC)
BR1-BR2
1402-1282
BR 1
BM 3
BM 3
1497-1413
BM 2
(1619-1500)

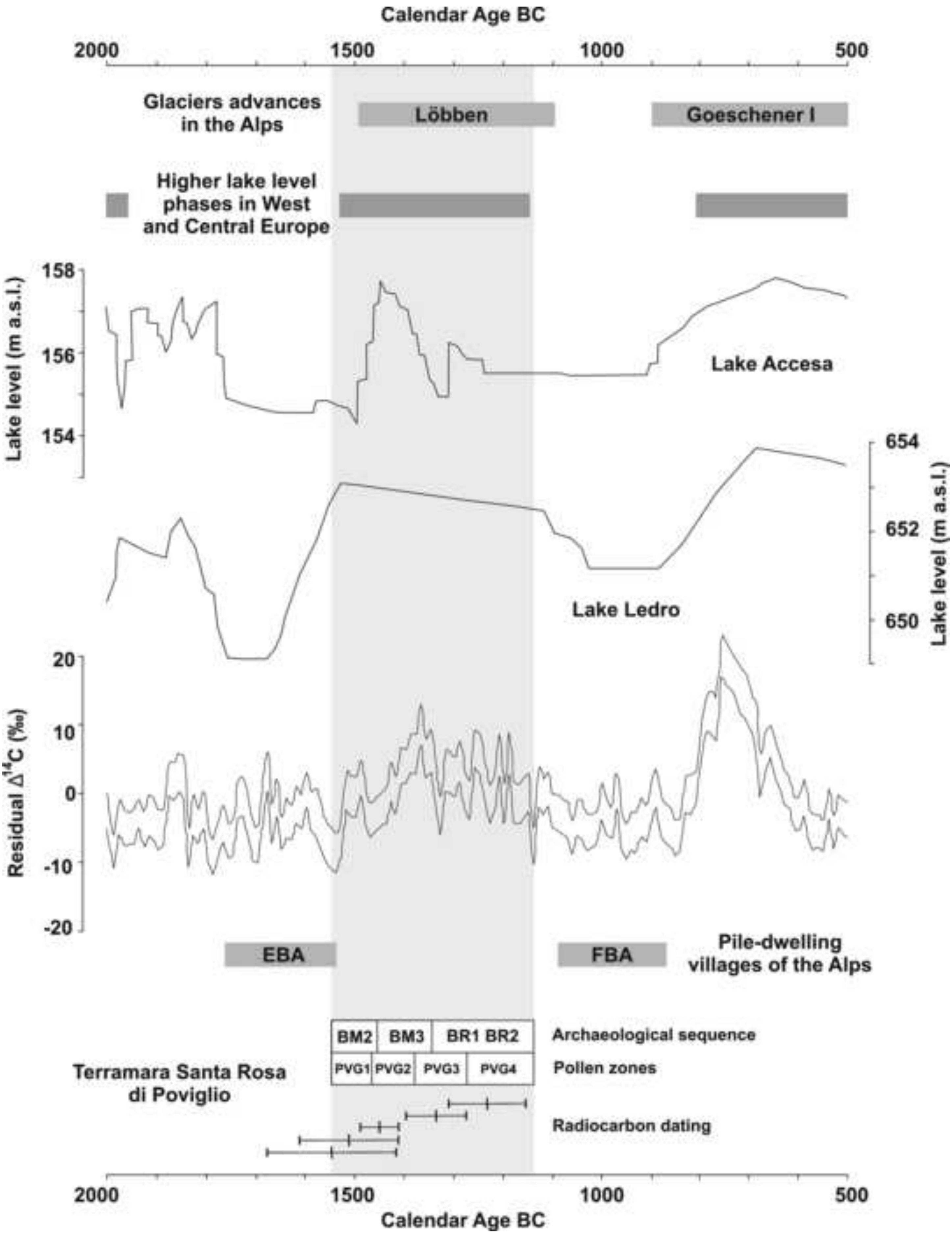

Depth (cm)
Stratigraphical Unit
Orlaya grandiflora type
Artemisia
Centaurea nigra type
Chenopodiaceae
Fabaceae
Plantago lanceolata type
Plantago undiff.
Polygonum aviculare type
Rumex
Aphanes type
Filipendula
Potentilla
Galium type
Solanum nigrum type
Urtica dioica type
Cannabis
Avena/Triticum group
Hordeum group
Secale
Panicum cf.
Cichorieae
Poaceae - wild grass group
Conifers
Oak wood
Cereals
API
Number of taxa
Zone
PVG 4
PVG 3
PVG 2
PVG 1
CONISS
Total sum of squares


Pedo-sedimentary facies
Depth (cm)
Stratigraphic Unit
Trees
shrubs-lianas
Abies
Picea
Pinus
Acer campestre type
Betula
Carpinus betulus
Corylus
Fagus sylvatica
Fraxinus excelsior type
Ostrya/Carpinus orientalis
Prunus
broadleaved Quercus
Quercus cf. ilex
Tilia cf. platyphyllos
Ulmus
Artemisia
Centaurea nigra type
Cichorieae
Chenopodiaceae undiff.
Poaceae - wild grass group
A
B
C
D
10066
10038
10059
10062
10102
10119
10124
Climate inferences
Dry and Cool:
Carpinus, Quercus, Corylus, Ulmus decrease;
Betula increases; dry grassland spread
Warm/cool and wet, towards dryness:
Corylus increases, Quercus remains steady;
Picea and Q. ilex reflect seasonal instability;
Ulmus decreases while Cichorieae, Chenopodiaceae and Poaceae increase toward the top marking the spreading of grassland
Warm and low wet increase:
Carpinus, Corylus, Quercus, Acer increase,
Pinus, Fraxinus, Fagus, Ulmus increase
while dry grassland reduces at the top
Cool, from wet to dryness:
Abies and Pinus high; Tilia significant;
Cichorieae and Chepodopiaceae sign and
grassland increasing toward the top
CONISS
Total sum of square



I
II
III
IV
PVG1 (2,3)
PVG2 (1,3)
PVG3 (1)
PVG4 (1)
open grassland
riparian vegetation
NATURAL
ANTHROPIC


Baggiovara
S1-S2-S6/7-S8-S9
(2009, 2010)
Mercuri et al. 2015
Montale
P1
(1996)
Mercuri et al. 2006
S. Rosa di Poviglio
VP/VG East Ditch
(1998)
Ravazzi et al. 2004
S. Rosa di Poviglio
VP North Ditch
(1991, 1998)
Ravazzi et al. 2004
S. Rosa di Poviglio
VP/VG Ditch
(2012)
this paper
0
50
100
after Bronze Age
Recent Bronze Age
Middle Bronze Age
before Bronze Age
1410-1315 cal yr BC
1600-1450 cal yr BC
1605-1515 cal yr BC
1402-1262 cal yr BC
1497-1413 cal yr BC



Calendar Age BC
2000
1500
1000
500
Glaciers advances in the Alps
Löbben
Goeschener I
Higher lake level phases in West and Central Europe
Lake level (m a.s.l.)
158
156
154
Lake Accesa
654
652
650
Lake level (m a.s.l.)
Lake Ledro
Residual Δ14C (‰)
20
10
0
-10
-20
EBA
FBA
Pile-dwelling villages of the Alps
BM2
BM3
BR1 BR2
Archaeological sequence
PVG1
PVG2
PVG3
PVG4
Pollen zones
Terramara Santa Rosa di Poviglio
Radiocarbon dating
2000
1500
1000
500
Calendar Age BC