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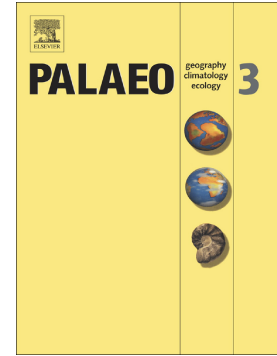
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**High-diversity European palaeoflora favoured by early Pliocene warmth:  
New chronological constraints from the Ca' Viettone section, NW Italy**

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**Abstract**

We present new chronological constraints for a reference European palaeoflora based on integrated stratigraphic, palaeobotanical, palaeomagnetic and micropalaeontological analysis carried out on the Pliocene section of Ca' Viettone, northwestern Italy. This site is characterized by rich fossil plant records of high taxonomic diversity, good preservation, and varied taphonomic mode. Palaeofloral analysis shows that the Ca' Viettone assemblage reflects a chronologically delimited and distinguishable stage of vegetation development in northern Italy (called Ca' Viettone Florenkomplex). Palaeomagnetic analyses show a dominant normal polarity that, however, seems to be the result of a remagnetization process due to secondary oxidation. Layers with no evidence of oxidation have registered a reverse polarity, which likely represents the original magnetization of the sediments. These results, in

combination with biochronological indications, suggest that deposition of the succession preceded the Gilbert-Gauss reversal and took place during the final part of the Gilbert chron. This confirms a late Zanclean age for the rich Ca' Viettone palaeoflora and allows us to propose this locality both as reference for a regional Florenkomplex and as a representative example of terrestrial vegetation in Europe during the early Pliocene warm interval.

Keywords: Palaeobotany; Magnetostratigraphy; Foraminifers; Cenozoic; Florenkomplex; Piemonte.

## 1. Introduction

In recent decades, great attention has been focused on the study on the Earth's climate evolution during the Pliocene, which is characterized by global warmth (Salzmann et al., 2011; Fedorov et al., 2013; De Schepper et al., 2013, 2014; Dowsett et al., 2016). This warm interval, preceding the Pleistocene glaciations, is particularly interesting because it provides evidence for past and future climate model simulations (Salzmann et al., 2011; Haywood et al., 2013, 2016; Prescott et al., 2014, 2018). Great attention has been paid to the relatively short-lived mid-Pliocene Warm Period (mPWP) of the Piacenzian Stage (3.6 – 2.6 Ma; De Schepper et al., 2013, 2014; Prescott et al., 2014, 2018 and reference therein); however, fewer studies have focussed on the longer-lived early Pliocene warmth of the Zanclean Stage (5.3 to 3.6 Ma). Fedorov et al. (2013) stated that this time interval was, in some aspects, very different from the world of today: surface temperatures in polar regions were so much higher that continental glaciers were absent from the Northern Hemisphere, and sea level was approximately 25 m higher. Several aspects remain incompletely understood and none of the currently proposed mechanisms can reproduce all of the key Pliocene climate features (Fedorov et al., 2013).

The Pliocene climate model simulations must be evaluated against available proxy data (Haywood et al., 2013, 2016). The fossil record of terrestrial vegetation is a particularly important proxy for assessing Pliocene climate oscillations (Salzmann et al., 2011; Dowsett et al., 2016; Prtesscott et al., 2018). For European successions, early Pliocene terrestrial vegetation dynamics are mainly based on pollen diagrams (Zagwijn, 1992; Popescu et al., 2006; Barrón et al., 2010; Bertini, 2010; Jiménez-Moreno et al., 2010). Detailed morphological analyses of pollen grains have contributed to define the palaeofloral spectrum during this period (Van der Burgh and Zetter, 1998; Vieira et al., 2011). Plant macrofossil assemblages (in particular carpofloras) can, also, significantly increase the taxonomic resolution of the palaeofloral documentation (Bertoldi and Martinetto, 1995; Van der Burgh and Zetter, 1998; Bertini and Martinetto, 2011).

A few plant macrofossil localities, reliably dated to the early Pliocene on the basis of non-palaeobotanical methods, have been reported in Germany (Wetterau's localities: Mai and Walther, 1988; Lower Rhine Basin: Van der Burgh and Zetter, 1998; Schäfer et al., 2005; Schäfer and Utescher, 2014) and in Hungary (Gerce and Pula: Erdei et al., 2007), whereas the age of two Romanian localities is less well-assessed (Baraolt, Borsec: Mai and Walther, 1988; Țicleanu, 1995). However, most of the Pliocene macrofloras of Europe come from sections that still lack precise dating constraints (Brunssum, The Netherlands: Reid and Reid, 1915; Zagwijn, 1990; Kroscienko, Poland: Szafer, 1954; Gerstungen, Germany: Mai and Walther, 1988; Nochten-Ost 4803, Germany and Ruszów, Poland: Mai and Wähnert, 2000; Sessenheim, France: Teodoridis et al., 2009; Vildstejin, Czech Republic: Teodoridis et al., 2017). All of these sections are short and poorly exposed.

In northwestern Italy, the Messinian and post-Messinian tectonic setting led to the formation of a broad marine palaeogulf surrounded by the western Alps (Damarco, 2009; Ghielmi et al., 2010), which favoured the preservation of a very rich terrestrial plant record in

thick Pliocene marine to continental successions. Well-dated layers with early Pliocene palaeofloras occur in marine successions (Cavallo and Martinetto, 1996; Martinetto et al., 2015). Similar palaeofloras are also found in several non-marine sections (Fig. 1) of unresolved Pliocene to early Pleistocene age, providing the richest records as for taxonomic diversity and abundance of diagnostic plant remains (Bertoldi and Martinetto, 1995; Martinetto, 1995, 2015). However, such valuable information is difficult to get organized in a precise chronological frame. Even if good results have already been obtained for the dating of a few key-sections in the Piacenzian-Gelasian interval (Martinetto et al., 2007; Irace et al., 2017), several other rich local floras still pertain to stratigraphic sections with very poor dating elements (Basilici et al., 1997; Cavallo and Martinetto, 1996, 2001; Martinetto, 1995, 2001, 2015).

Many of these local floras are characterized by very similar plant taxa composition; for this reason, in some previous studies the definition of collective units, comprising both dated and undated floras, was considered as a reliable approach for giving an overview (Martinetto, 1995; 1999; Martinetto et al., 2007). Such units were described with the German plural term "Florenkomplexe", whose singular form is "Florenkomplex". The Florenkomplex can be considered as an ecostratigraphic unit (Retallack, 1978), which also subtends biochronological information: "a group of local fossil floras reflecting a chronologically delimited and distinguishable stage of vegetation development" (Mai and Walther, 1978). Each Florenkomplex is named from a specific locality bearing a representative local palaeoflora (e.g. Florenkomplex Wiesa, see Mai, 1995 and 2000). Here, we adopt the Florenkomplex concept (despite the doubts casted by Kvaček (2010) on its appropriateness) to order plant macrofossil assemblages in a time sequence based on ecostratigraphic events. We strongly suggest to avoid the English translation "floristic complex" that may be ambiguous as it is used in a different context for modern floras (e.g., Tzonev et al., 2011).

In the Italian Cenozoic only two Florenkomplexe, mainly differentiated by the taxonomic frequency of so-called “subtropical elements”, have been distinguished and determined so far: "Ca' Viettone" and "Stura" (Martinetto, 1995, 1999). Martinetto (1995) used the shared high percentage (25-55%) of genera of “woody subtropical taxa” to assign the assemblages of several localities to the "Ca' Viettone" Florenkomplex, which includes as typical representatives: *Cyclea*, *Ficus*, *Cinnamomum*, *Litsea*, *Mallotus*, *Meliosma canavesana*, several Rutaceae, *Symplocos* spp., three species of Pentaphylaceae and *Trigonobalanopsis*. The reconstructed palaeovegetation of "Ca' Viettone" Florenkomplex was compared (Martinetto, 1995; Kovar Eder et al., 2006) on a floral basis to the cooler types of forests in the modern “subtropical vegetation zone” of East Asia (Hou, 1983), and the recent Asian analogue allowed to reconstruct a humid climate (alternatively classified as warm temperate or subtropical: Peel et al., 2007 versus Baker et al., 2010) with Mean Annual Temperature of 15-17°C and Mean Annual Precipitation above 1000 mm per year.

The name "Ca' Viettone" (meaning Viettone House) originates from a hamlet close to the village of Levone (Piemonte, northern Italy) (Fig. 1). Along a brook, named Rio di Ca' Viettone (Fig. 2), a continental succession crops out, whose deposits were assigned to a fluvial-alluvial palaeoenvironment (Allason et al., 1981). These sediments yielded very rich plant macrofossil assemblages, in particular carpofloras (Martinetto and Gregor, 1989; Bertoldi and Martinetto, 1995; Martinetto, 1995; Martinetto and Vassio, 2010), which provide valuable palaeoenvironmental information and deserve a precise chronological framing. The earliest attempts to date these continental deposits were based on pollen analyses, carried out in short portions of the succession by Allason et al. (1981) and Bertoldi and Martinetto (1995). The first study suggested an attribution to the Gelasian/Calabrian transition, whereas the second one suggested a late Zanclean age based on the Bertoldi et al.'s (1994) scheme. However, the reliability of this last scheme has been questioned by Bertini

(2010), who pointed out the difficulty to establish a clear pollen biozonation for the Italian Plio-Pleistocene. Continental vertebrate/invertebrate biochronology could provide further dating constraints (Gliozzi et al., 1997) but unfortunately no animal skeletal remains have been found in the well exposed continental sediments of Ca' Viettone. It was the highly thermophilous character of the Ca' Viettone macroflora (Martinetto, 1995) to suggested, for the first time, that it could be connected to the early Pliocene global warmth, but the hypothesis was not supported by firm chronological evidence so far.

An integrated approach, combining sedimentology, magnetostratigraphy and palaeobotanical analyses, has been successfully applied in a nearby sector to date a complex fluvial succession straddling the Pliocene-Pleistocene transition (Irace et al., 2017). Following a similar approach, in this paper we present the results of a detailed stratigraphic, palaeobotanical and palaeomagnetic study of the Ca' Viettone continental succession, providing an improved chronological interpretation of the whole succession. As a further chronological constraint, foraminiferal assemblages of marine deposits underlying the continental strata (Martinetto et al., 1997) were also studied.

## **2. Geological setting**

The Ca' Viettone site is situated in the northwestern sector of the Piemonte region (Fig. 1A), at the western margin of the Western Po Basin (WPB), one of the major Plio-Quaternary sedimentary basins in northwestern Italy, together with the Savigliano Basin (SB) and Alessandria Basin (AB). The WPB, SB and AB constitute syn-orogenic basins, as they are effective part of the Alps-Apennines orogenic system (Piana et al., 2017). The WPB is located between the western Alps, to the North, and the Torino Hill and Monferrato relieves, made up of uplifted Eocene-Miocene successions, to the South (Fig. 1).



The Pliocene succession of the WPB has been the subject of numerous geological studies starting from the work of Sacco (1890), until the biomagnetostratigraphic study of Martinetto et al. (2007). Recently, a few geological maps have been also published (Forno and Ferrando, 2008; Balestro et al., 2009; Forno et al., 2009). Along the northwestern border of the WPB (Fig. 1B), the Pliocene succession unconformably rests on the Alpine basement. The Pliocene deposits are overlain by a widespread blanket of Pleistocene-Holocene continental units that constitute the westernmost part of the Po Plain. This Quaternary cover hides the geometrical and stratigraphic relationships of the Pliocene sediments, which are only exposed in minor outcrops scattered at the foothills or along main river beds.

The Pliocene succession is represented by a transgressive-regressive cycle made up of outer shelf to nearshore deposits (Aimone and Ferrero Mortara, 1983; d'Atri and Piazza, 1988; Bertoldi and Martinetto, 1995), referable to the latest Zanclean (Basilici et al., 1997) and continental deposits, up to date generically ascribed to the “Villafranchiano” informal unit (Martinetto et al., 2007). This term is still in use in the Piemonte region solely for historical reasons and designates the non-marine deposits, which conformably overlie the Pliocene marine successions. However, these continental deposits seem to have significantly different ages in the different parts of the WPB (Piana et al., 2017); they span from Zanclean, in the northern part, to Piacenzian towards the south (Martinetto et al., 2007), testifying to the SE-ward basin scale regression. In this perspective, complex stratigraphic relationships and time transgressive boundaries also exist between the continental and marine deposits. In fact, in the drilled succession of the Intenza well (IW in Fig. 2; Martinetto et al., 1997), the local Pliocene succession shows the interfingering of a marine interval between two non-marine sedimentary bodies.

### **3. Materials and methods**

In this study, integrated stratigraphic, palaeobotanical and magnetic analyses were performed on a fluvial sedimentary succession, cropping out on the banks of the Ca' Viettone brook (Fig. 2). Micropalaeontological analyses were performed on cuttings obtained during the drilling of the Intenza well drillcore (Latitude 45°19'4"N; Longitude 7°37'0"E; Martinetto et al., 1997).

### *3.1 Stratigraphic analysis*

The stratigraphy and facies of the Ca' Viettone (CV) continental succession was studied in six outcrops scattered along the about 1 km long ravine. We applied the lithofacies classification of Miall (1996) and Vincent (2001) and we grouped the dominant lithofacies into five sets of distinct, commonly occurring facies associations (F1-F5), described in Table 1 and illustrated in Figures 3 and 4. Detailed stratigraphic logs (Fig. 3) were measured and facies analyses were carried out in two of the better-exposed sections along the brook: CV20 and CV21 (Martinetto, 1995). The CV21 section (Latitude 45°19'18"N; Longitude 7°37'9"E), 17 m thick, was logged on the right bank of the brook and nearly corresponds to the "section 1" of Allason et al. (1981). The CV20 section (Latitude 45°19'21"N; Longitude 7°37'8"E), 1.8 m thick, was logged ~100 m westward on the left bank of the brook. Thanks to the presence of easily correlated layers and surfaces, the logs of the CV20 and CV21 sections were integrated as to constitute the CV20-21 composite log (Fig. 3). Moreover, a third very short section CV5 (Latitude 45°19'23"N; Longitude 7°36'44"E), situated about 500 m to the west and lying a few meters stratigraphically below the base of the composite log, was also measured (Fig. 2 and 4B). The stratigraphy of all these outcrops was finally integrated by subsurface data, coming from the Intenza well drillcore (Martinetto et al., 1997), located about 500 m south of the CV20-21 composite log (Fig. 2B). The Pliocene drilled succession, as interpreted by Martinetto et al. (1997), consists from base to top of 6 m of freshwater

deposits (mainly yellowish sand, from -108 to -102 m) resting on the crystalline substratum overlain by 14 m of marine deposits (from -102 to -88 m) and 79 m of a coarsening upward fluvial unit (from -88 to -9 m); a 9 m thick cover of Quaternary fluvial deposits caps the succession.

### 3.2 *Palaeobotanical analyses*

New palaeobotanical analyses were carried out in order to compare the assemblages of the CV20-21 section (Table 2) with the already well-known comprehensive palaeoflora of the Ca' Viettone site (Table 3). As previously shown (Martinetto, 1995; Bertoldi and Martinetto, 1995; Martinetto and Vassio, 2010), fruit and seed (carpological) assemblages provide the most complete record of the composition and diversity of the Ca' Viettone palaeoflora; for this reason, our analysis focused on this palaeobotanical record. Sampling for carpological analyses was concentrated in the few productive layers. A total of five large samples were collected and processed, coming from the bottom and the top of the composite CV20-CV21 section (Fig. 3). Palaeocarpological assemblages were gathered by processing dry sediment samples with 5% hydrogen peroxide. After complete reaction, the floating fraction was sieved (final mesh size: 0.3 mm) separately from the sunken material (final mesh size: 1.5 mm). Finally, fruits, seeds and related organs were picked up from the residue of both fractions. For a more detailed description of the method and for the taxonomic identification procedures see Martinetto (2015). For each fossil assemblage we used the standard labels of the CENOFITA database (Martinetto and Vassio, 2010; Martinetto, 2015), compiled a floral list (Table 2) and used it to analyse the significant biochronological groups specified by Martinetto et al. (2015). The same analysis was carried out on the comprehensive palaeoflora of the Ca' Viettone site (Table 3).

Although palaeoclimate quantifications are beyond the scope of this paper, we discuss previous palaeoclimatic interpretations according to the definitions of the Köppen–Trewartha climate classification (Baker et al., 2010; Belda et al., 2014). For the analysis of the climatic requirements of the fossil plant taxa we did not use the traditional analysis based on the percentage of “woody subtropical taxa” (Mai, 1995; Martinetto, 1995). The recent availability of more precise data on climatic distribution of the East Asian flora (Martinetto et al., 2017) showed the difficulty to characterize, from the climatic point of view, several genera traditionally considered as “subtropical” in Europe (e.g., *Alangium*, *Eurya*, *Meliosma*). In fact, some modern species of these genera also occur in cool temperate climate. Therefore, we preferred to use three categories introduced by Martinetto et al. (2015):

- (1) HUTEA (“HUMid Thermophilous extinct European taxa of East Asian affinity”): plant taxa which have well-documented fossil records in the late Cenozoic of Europe, which do not grow spontaneously in this continent and West Asia at present (unless as aliens), which do not tolerate a MAT below 8 °C and a Mean Annual Precipitation (MAP) below ca. 800–1000 mm/year, and which belong to genera or infrageneric taxa that presently grow in East Asia.
- (2) CTEA (“Cool-Tolerant extinct (=extirpated) European taxa of East Asian affinity”): the modern representatives have the same pattern of fossil records and geographic distribution as HUTEA, but do tolerate a MAT below 8 °C.
- (3) TEWA (“Thermophilous European, West Asian and/or African elements”): the modern representatives do not tolerate a MAT below 8 °C and grow in southern Europe, North Africa (incl. Macaronesia) and/or West Asia.

### 3.3 Palaeomagnetic analyses

Samples for palaeomagnetic analysis were collected from both CV20 and CV21 sections as their composite log provides the thickest sedimentary succession (Fig. 3). Additionally, a few samples from CV5 section were collected for a further control of the palaeomagnetic signal recorded in layers that were laterally affected by oxidation (Fig. 4B). In all cases, sampling was performed using non-magnetic plastic cylinders (diameter = 2.4 cm; height = 2.2 cm) that were pushed into the poorly consolidated sediment and oriented *in situ* with a magnetic compass and clinometer. Direct drilling was also attempted in the CV21 section, but it was possible only in the lower part, whereas for the upper part drilling was not feasible due to technical problems (soft material and difficult access). Sampling was performed approximately every 10 cm and in some cases twin samples (samples corresponding to the same stratigraphic level) were collected to allow both magnetic mineralogy and magnetic polarity studies at the same material.

A total of 55 samples were collected; 15 from CV20 section, 34 from CV21 section and 6 from CV5 section. All magnetic analyses were performed at the ALP Palaeomagnetic laboratory (Peveragno, Italy). The Natural Remanent Magnetization (NRM) was measured with a JR-6 spinner magnetometer (AGICO). The magnetic mineralogy of representative samples was investigated through Isothermal Remanent Magnetization (IRM) curves, back field plots and thermal demagnetization of a composite three axes IRM (Lowrie, 1990). IRM was initially stepwise imparted along the z axes of the samples up to 1T with a ASC pulse magnetizer. Then an IRM of 0.5 T was imparted along the y axes and finally an IRM of 0.1 T was imparted along the x axes of the samples. Thermal demagnetization of the composite three axes IRM was performed with a Schostendt TSD-1 furnace. After each thermal demagnetization step, the bulk magnetic susceptibility at room temperature was measured with a KLY-3 Kappabridge (AGICO). Such thermal experiments were performed for a few samples after extracting the material from the plastic boxes. The polarity of the Characteristic

Remanent Magnetization (ChRM) was determined through stepwise Alternating Field (AF) demagnetization and the results were plotted and interpreted using the Remasoft software (Chadima and Hrouda, 2006).

### *3.4 Micropalaeontological analyses*

Micropalaeontological analyses were carried out on 8 sediment cuttings from the -108 m to -88 m portion below ground level (Fig. 2) of the Intenza well drillcore (Marinetto et al., 1997). The sediments were processed with the flotation method usually employed for palaeocarpological samples (Marinetto, 2015). For each sample the floating fraction was sieved on a  $>63 \mu\text{m}$  mesh, the sunken sediment was washed and sieved into grain fractions greater than  $250 \mu\text{m}$ ,  $125\text{--}250 \mu\text{m}$  and  $63\text{--}125 \mu\text{m}$ , dried and weighed. Taxonomic determination of foraminiferal species followed Kennett and Srinivasan (1983) for planktonic taxa, AGIP (1982) and Loeblich and Tappan (1988) for benthic species. Semiquantitative analyses were carried out on about 300 specimens of the total  $>125 \mu\text{m}$  residues. Finally, the percentages of planktonic specimens versus the total (planktonic + benthic) foraminiferal assemblage, i.e. the  $P/(P+B)$  ratios, were estimated to give an approximate evaluation of the palaeobathymetry (Wright, 1978).

## **4. Results**

### *4.1 Stratigraphy*

The strata of the Ca' Viettone succession are sub-horizontal to gently dipping south-eastward and are exposed for a total thickness of about 20 m along the brook bed. The succession is systematically characterized by three different degrees of sediment oxidation: a) light-grey, yellow to brown highly oxidised sediments, b) grey, partially oxidised sediments and c) blue-grey non-oxidised sediments. Sand and gravel are mostly oxidized, whereas silt

and clay are locally oxidation-free, thus preserving mummified plant fossils. The oxidation front is usually parallel to internal bedding and/or lamination surfaces, and it also follows the erosional base of gravel and sand sedimentary bodies. However, it may also be very irregular and oblique in respect to these primary surfaces.

The outcrop-scale facies analysis and the detailed study of logged sections reveal that the succession is dominated by laterally and vertically stacked, lenticular bodies consisting of cross-bedded gravelly sands of the F3 facies association (Table 1; Figs. 3 and 4), with subordinate lenses of the F1 and F2 gravel-sand deposits. It also comprises scattered lenses of the F4 fines. As a whole, the F1 to F4 sedimentary stack constitutes 5 to 10 m thick, large scale lenticular bodies, interlayered with F5 fines. The last ones form laterally persistent 1 to 3 m thick bodies (Fig. 2) whose uppermost parts (10-20 cm thick) are often characterized by palaeosols, indicated by the concentration of root-traces or haloes.

The overall architecture points to a deposition in a low-gradient floodplain (F5) crossed by multi-storey sandy-gravelly shallow braided systems, dominated by downstream migration of gravelly sand dunes and sand waves (F3) with very occasional development of transverse (F2) and longitudinal gravel bars (F1), filling low-sinuosity channels, and deposition from suspension in abandoned channels (F4).

The bottom of the fluvial succession analysed in the CV20-21 composite log can be correlated with the uppermost part of the Pliocene succession of the Intenza well (Martinetto et al., 1997) (Fig. 2).

#### *4.2 Palaeoflora*

The new palaeobotanical analyses, performed on selected layers of the composite CV20-CV21 section (Table 2), confirmed that these plant assemblages match with the comprehensive palaeoflora of the Ca' Viettone site (Table 3). Nearly all of the species

detected in the CV20-21 section were already identified in other sections of the Ca' Viettone site. The most frequent taxa are *Cryptomeria rhenana*, *Eurya stigmosa*, *Magnolia allasoniae*, and *Trigonobalanopsis exacantha* (Martinetto and Vassio, 2010), which occur frequently in other sections too. Therefore, we discuss here the main features of the comprehensive palaeoflora of the Ca' Viettone site, rather than the individual composition of the assemblages from the CV20-21 section.

In general, the plant macrofossil assemblages from the Ca' Viettone site show high taxonomic diversity (total 133 taxa) and contain a large number of fruits and seeds of woody plants. Hydrophytes are almost absent and wetland herbs are never dominant. Such assemblages are mostly composed by plants grown in well-drained conditions ("mesic"), so that plant remains may have been picked up from ancient litter by ephemeral streams during palaeofloods. All the assemblages are characterised by a considerable proportion of exotic elements (20% to 60% of the taxa), which mostly belong to genera now living in East Asia and/or North America. The high percentage of taxa belonging to the categories "Cool-Tolerant extinct (= extirpated) European taxa of East Asian affinity" ("CTEA": 15.8 %) and "humid thermophilous plant taxa of East Asian affinity" ("HUTEA": 17.3 %), introduced by Martinetto et al. (2017), confirm the East Asian subtropical affinities (sensu Baker et al., 2010) of the Ca' Viettone palaeoflora (Martinetto, 1998). About 25% of the taxa are either classifiable as HUTEA or as "Thermophilous European, West Asian and/or African elements" ("TEWA": 6,8 %), thus indicating that the Ca' Viettone mesic plant communities had a strongly thermophilous character (Bertini and Martinetto, 2011). This feature distinguishes the Ca' Viettone palaeofloral assemblages from those of the Piacenzian of northern Italy (Martinetto et al., 2007), where the thermophilous elements are not so abundant, even if the taxa originating from mesic plant communities are also recorded.



The analysis of the significant biochronological groups recognized by Martinetto et al. (2015) (Table 3) reveals a massive occurrence of Group 1 elements (14 taxa) in the Ca' Viettone palaeoflora. Groups 2 and 3 are also well represented (10 and 11 taxa, respectively), whereas Groups 4 and 5 are scarce (7 taxa as a whole).

#### 4.3 Palaeomagnetism

The NRM of the studied samples varies from  $2.5 \times 10^{-5}$  A/m to  $2.6 \times 10^{-3}$  A/m, with lower values for the blue-grey samples (at the range of  $10^{-5}$  A/m) and higher values for the grey-brown samples (at the range of  $10^{-3}$  to  $10^{-4}$  A/m). IRM and back field curves are similar for all studied samples and indicate that saturation is reached at fields around 0.3-0.4 T, suggesting the presence of a low coercivity mineral (Fig. 5). The thermal demagnetization of a composite IRM (Lowrie, 1990) also confirms the dominance of the low coercivity component (Fig. 6). In most of the samples, a decrease of magnetization of the soft and medium coercivity components can be noticed at temperature around 200 °C, probably indicating the presence of some iron sulphides; after this temperature the magnetization slowly decreases up to 580 °C, suggesting the presence of magnetite as the main magnetic carrier. In all cases, the high coercivity component is negligible. A significant increase of the magnetic susceptibility was observed around 380 °C, indicating possible mineralogical transformations induced by thermal alteration.

AF demagnetization results, interpreted through Zijderveld diagrams, intensity decay curves and equal area plots, identify two main magnetic behaviours. The blue-grey sediments from the lower part of the CV20 section (samples CV20-2 to CV20-5) and the upper part of the CV21 section (samples CV21-21 and CV21-22) are weakly magnetized, show disturbed Zijderveld diagrams and are characterized by an inverse polarity (Fig. 7A, B), even if not always well defined. A viscous component is cancelled at 5-10 mT and then a ChRM is

generally isolated at the 10-50 mT range. Differently, in the case of grey to brown samples (samples CV20-6 to CV20-8, CV21-7 to CV21-20 and CV21-23 to CV21-27) a very stable magnetization can be observed, with linear and almost single component Zijderveld diagrams that clearly indicate a normal polarity isolated at 10-100 mT (Fig. 7 C, D). Samples CV21-1 to CV21-6 show a chaotic magnetic behaviour, probably caused by bioturbation that was also macroscopically identified in the field.

The very stable and intense magnetization of the samples characterized by a normal polarity, the absence of a viscous component in most of these samples and the systematic coincidence of the different magnetic polarity records with evident change in sediment oxidation (inverse polarity for the blue-grey sediments and normal for the grey-brown ones) raise doubts related to the primary origin of the normal polarity registered by the grey-brown and evidently oxidized sediments. The mean direction of the Characteristic Remanent Magnetization (ChRM) of the samples with normal polarity is  $D= 0^\circ$ , and  $I= 59.7^\circ$  (with  $\alpha_{95}= 5.2^\circ$ ), consistent with the expected value for a geocentric axial dipole field at the sampling locality ( $D= 0^\circ$ ,  $I= 63.4^\circ$ ) and to the present's day field at the geographic coordinates of Ca' Viettone ( $D= 1.9^\circ$ ,  $I= 61.1^\circ$ ). This result further sustains the possibility that the part of the succession with evidence of oxidation has been remagnetized during the Brunhes period of normal polarity while the original magnetization of the section is maintained only in the non-oxidized blue-grey sediments that show a reverse magnetic polarity.

In order to test this hypothesis, we studied six more samples coming from the fine-grained strata (F4 facies association) of the neighbouring CV5 section (Fig. 2 and 4B). This section presents the advantage that individual layers show a lateral transition between non-oxidized blue-grey sediments and grey-brown ones with some evidence of oxidation (Fig. 8). Thanks to the presence of a lateral oxidation front, we were able to collect and study three samples from the blue-grey clay (CV5-1a, CV5-2a and CV5-3a) and three from the grey-

brown part (CV5-1b, CV5-2b and CV5-3b), with a and b named samples corresponding to the same stratigraphic level (Fig. 8A). In the case that sediments still carry their original magnetization (or if all of them have been remagnetized at the same time), we would expect to find the same magnetic polarity registered by all the samples corresponding to the same stratigraphic level. On the contrary, in the case that a remagnetization has occurred only at the oxidized part, replacing the original magnetization of the sediments acquired during their deposition, blue-grey and grey-brown samples would be expected to show different magnetic behaviour. In fact, the AF demagnetization results confirm such different magnetic behaviour for the blue-grey and grey-brown sediments. Samples CV5-1a, CV5-2a and CV5-3a generally showed a weak magnetization ( $10^{-5}$  A/m), with a not well defined but however inverse polarity (Fig. 8B). On the other hand, samples CV5-1b, CV5-2b and CV5-3b showed a much stronger ( $10^{-3}$  A/m) and stable magnetization of clearly normal polarity (Fig. 8C). These results indicate that the normal polarity is probably the result of a remagnetization process under today's normal field, whereas the original magnetization of the studied succession was acquired in the presence of an ambient field of inverse polarity.

#### 4.4 Foraminifera

Foraminifera were absent in the yellowish sand samples from the interval -108 m and -102 m below the ground level of the Intenza well drillcore (Fig. 2). In the interval between -102 m and -88 m Foraminifera were frequent to scarce and well preserved, plant frustules were abundant, fragments of mollusc shells and echinoid tests were common, ostracod valves were scarce. Planktonic Foraminifera were common only in the sample -102/98 m (P/ (P+B) ratio about 15%), mainly represented by *Globigerinoides extremus*, *G. obliquus* and by scarcer *G. trilobus*, *Globigerina bulloides*, *Globigerinella obesa*, *Globoturborotalita apertura*, *Gb. woody*, *Neogloboquadrina acostaensis* and *Orbulina universa*. In the interval

between -98 m and -88 m the same planktonic species occurred with lower percentages (P/(P+B) ratio less than 10%). Benthic taxa of the studied interval were low in diversity, dominated by shallow water calcareous forms (*Florilus boueanum*, *Elphidium* spp. [*E. aculeatum*, *E. advenum*, *E. crispum*, *E. macellum*, etc.]) and by *Cibicides lobatulus*, followed by *Ammonia* spp. [*A. beccarii*, *A. tepida*, *A. parkinsoniana*], *Neoconorbina planorbis*, *Glabratella* spp., *Globulina gibba*, *G. tuberculata*, *Rosalina globularis*, *Buccella granulata* and *Reussella spinulosa*). Agglutinants (*Bannerella gibbosa*, *Bigenerina nodosaria*, *Textularia* spp.) were scarce, as well as miliolids (*Quinqueloculina seminulum*, *Triloculina trigonula*). Taxa typical of shelf pelitic bottoms, such as *Bolivina variabilis*, *Brizalina spathulata*, *Bulimina lappa*, *B. minima*, *B. subulata*, *Cibicidoides ungerianus*, *Valvulineria brayana*, seldom occurred. Only in sample -102 m *B. subulata*, typical of shallow pelitic bottoms, was common and specimens of *Amphicoryna proxima*, *B. minima*, *Cancris auriculus*, *Cassidulina carinata*, *Globobulimina affinis*, *Heterolepa bellincionii* and *Orthomorphina tenuicostata*, typical of outer neritic or deeper deposits, were collected.

From the biostratigraphical point of view, the occurrence of *B. granulata* suggests an age referable to the MP14a biozone or younger (Basilici et al., 1997), whereas the absence of cold benthic taxa such as *Bulimina marginata* implies an age older than 2.63 My BP (*B. marginata* FCO, Patacca and Scandone, 2004). The absence of planktonic biostratigraphic markers (*i.e.* *Globorotalia* spp.) does not allow a better resolution.

From the palaeoecological point of view, foraminiferal assemblages are dominated by infaunal species of silty bottoms (*F. boueanum*) and by epiphytic forms (*Elphidium* spp., *C. lobatulus* and *N. planorbis*, in abundance order) (Murray, 2006). *Ammonia* spp. and *G. gibba*, infaunal taxa typical of sandy sediments, are common in the studied interval, whereas the outer neritic genera (*Heterolepa*, *Cibicidoides*, *Textularia*, etc.) are scarce. The assemblage thus documents a shallow depositional palaeoenvironment, on the inner shelf, at the boundary

between the inner and the outer neritic zones, with or nearby to seagrass meadows in which *Elphidium* spp. and *Globulina* spp. were reported as frequent (Moissette et al., 2007). A rather muddy and only slightly deeper palaeoenvironment is suggested for the layer at -102 m by the frequency of *B. subulata* and by a more diversified outer neritic assemblage (*A. proxima*, *B. minima*, *C. carinata*, *G. affinis*, *H. bellincionii*, etc.).

## 5. Discussion

### 5.1 Chronological constraints of the Ca' Viettone section

The foraminiferal assemblages detected in the marine deposits of the Intenza well (Fig. 2), stratigraphically beneath the Ca' Viettone continental deposits, suggest their assignment to the MPI4 foraminiferal biozone. The overlying continental succession bearing the rich Ca' Viettone palaeoflora assemblage, cannot be older than the base of this biozone. Consequently, these results can be used as an important *post quem datum* for the dating of the studied continental succession.

The analysis of the significant biochronological groups singled out by Martinetto et al. (2015) offers additional palaeoflora-based chronological constraints. Based on several dated records contained in the CENOFITA database, the massive occurrence of Group 1 elements in the Ca' Viettone palaeoflora (Fig. 10) would constrain its age between 4.5 and 3.6 Ma. Nevertheless, due to the existence of an earliest Zanclean gap and an early Piacenzian gap in the independently dated palaeofloral record (Fig. 10), an extension of the Group 1 elements distribution (and therefore the existence of the Ca' Viettone type of flora) from 5.3 to 3.3 Ma cannot be excluded based on our present knowledge of the global climatic trend (De Schepper et al., 2013, 2014).

In the time span 3.3-3.0 Ma a consistent palaeofloral documentation is available, which demonstrates the lack of the Group 1 and Group 2 elements, so typical for the

assemblages of the Ca' Viettone type (Fig. 10). In fact, the distinct plant assemblages of this time interval were assigned to another Florenkomplex, named "Stura" (Martinetto, 1995, 1999). The Group 3 elements, very common from 5.3 to 3.3 Ma, seem to be lacking from 3.3-3.0 Ma but reappear in the time span 3.0-2.8 Ma. In this last time span the plant assemblages (e.g., Marecchia and Monte Falcone: Martinetto et al., 2015) have a composition very similar to the Ca' Viettone type, but the Group 1 elements are missing in northern Italy, and are scarce in central Italy.

The increasing bulk of Pliocene macrofloral data in Italy (Martinetto, 1995, 1999, 2015) could indeed provide more accurate information on the floral and vegetation features of shorter intervals of the Pliocene climatic cycles. However, the assessment of the correct chronological position of individual macrofloras, and their correspondence with definite phases of the climatic cycles, still needs much more multidisciplinary and comparative work. Palaeomagnetic data have already importantly contributed to the improvement of the chronological framework of Plio-Pleistocene macrofloras (Boano et al., 1999; Martinetto et al., 2007; Muttoni et al., 2007; Gundersson et al., 2013; Monesi et al., 2016; Irace et al., 2017) and, despite several difficulties, also in this case offer further chronological constraints for the dating of the Ca' Viettone succession. In fact, the inverse magnetization observed in the oxidation-free layers of the CV20-21 section (and hypothesized also as primary magnetization for the rest of the succession), combined to the foraminifer and plant biochronological indications (Fig. 10) suggest that the succession was deposited in the final part of the Gilbert chron, confirming an age older than 3.59 Ma.

### *5.2 Detection and delimitation of the Ca' Viettone Florenkomplex*

The main issues of plant macrofossil biochronology in terrestrial settings have been effectively explained by Retallack (1978), Martinetto and Ravazzi (1997), Martinetto (1999),

Kvaček (2000) and Lucas (2013). Environmental variations have a stronger impact on plant assemblages than evolution, especially in the late Cenozoic, so that the delimitation of ecostratigraphic units, such as the Florenkomplexe, does not exploit evolutionary events (as in the case of the florachrons of Lucas, 2013), but floral differences between older and younger fossil floras, most likely controlled by climate changes. Biochronological schemes based on Florenkomplexe have been mainly used in Europe (e.g., Mai and Walther, 1978, 1988; Mai, 1995, 2000; Martinetto, 1995, 1999; Kunzmann et al., 2016). The assignment of several local palaeofloras to the same Florenkomplex depends on the detection of a characteristic association of plant fossil taxa that are only found in a limited time span and in a restricted geographic area (Kunzmann et al., 2016).

Although Mai and Walther (1988) and Mai (1995) proposed to correlate each Florenkomplex over a broad area in Europe, this procedure seems to be highly risky and most probably not completely correct (see also Kvaček, 2010), due to the several environmental factors controlling the geographic distribution of terrestrial plant taxa and vegetation types. Restricting the recognition of a Florenkomplex to a regional scale is definitely more appropriate, since it may delimit an area in which the floristic composition of the zonal vegetation was relatively homogeneous during the reference time period.

Based on the outstanding diversity plus richness of the comprehensive plant fossil record (Table 3) and the accessibility plus long-lasting exposure of several outcrops, Ca' Viettone may be confirmed as a suitable reference locality for a Florenkomplex. The various outcrops of the Ca' Viettone succession (Martinetto, 1995; Bertoldi and Martinetto, 1995; Martinetto and Vassio, 2010), scattered along a W-E transect of 1.5 km, provide an uncommon documentation of an ancient palaeoflora. Allason et al. (1981) estimated that the whole succession was not thicker than 30 m, and the small differences detected among the plant assemblages of different deposits (Martinetto, 1995; Vassio and Martinetto, 2010) can

be easily explained by local ecological conditions or taphonomical processes, and not by floristic change through time. The taxonomic composition of the flora was first investigated by Martinetto and Gregor (1989), Martinetto (1995) and Bertoldi and Martinetto (1995), and later slowly proceeded in the frame of a general long term project on the taxonomy of the Italian Pliocene and Pleistocene floras (Martinetto, 2015). Nevertheless, several taxa are still imprecisely identified and would need further detailed studies.

By analyzing the plant assemblages from the Pliocene localities near to Ca' Viettone (Figs 1 and 9), it is apparent that the Sento I and Sento II palaeofloras, pertaining to the partly dated Val Chiusella succession (Basilici et al., 1997: foraminiferal biozone MPI4a, c. 3.9-3.6 Ma), have a taxonomic composition very similar to the Ca' Viettone's one. The facies associations of Ca' Viettone and the transgressive-regressive trend of the succession, detected in the Intenza well (Fig. 2), were also found in the Val Chiusella outcrops (Basilici et al., 1997). There, the marine deposits at the bottom were dated to the uppermost Zanclean on the basis of the concomitant occurrence of the benthic foraminifer *Buccella granulata* and of the gastropod *Bufonaria marginata*, which disappeared in correspondence with the Last Appearance Datum of *Globorotalia puncticulata*, marking the upper boundary of the MPI4a Zone. On the contrary, the plant assemblages of three nearby localities, Front, La Cassa and Stura (Martinetto et al., 2007; Vassio et al., 2008), show clear differences (lack of Group 1 and Group 3 elements) and cannot be ascribed to the same type of palaeoflora detected at Ca' Viettone. These successions have been dated by means of magnetobiochronological analyses at ca. 3.3-3.1 Ma (Martinetto et al., 2007).

A few assemblages similar to that of Ca' Viettone were found in marine sediments dated to the early Pliocene (5.3 to 3.6 Ma ago) based on biostratigraphic analysis of marine biota (Martinetto, 1999; Kovar-Eder et al., 2006; Martinetto et al., 2015). These are found in the following localities (Fig. 1A): Breolungi (foraminiferal biozone MPI2), Crava di Morozzo



(MPI2), Pocapaglia (MPI3) and Sento I (MPI4a). Also, the continental sediments which yielded the palaeofloras Fossano I, Fossano II and Fossano III were correlated to the foraminiferal biozones MPI3-MPI4a on the basis of sequence stratigraphy (Macaluso et al., 2018). Floras very similar to the one detected at Ca' Viettone have also been found in successions constrained within the Zanclean - earliest Piacenzian interval (5.3 to 3.3 Ma ago): Baldichieri-Fornace, Candelo, Castellengo, Cortiglione d'Asti, Cossato (Martinetto, 2015). Finally, rich assemblages of the Ca' Viettone type were also found in several other sites that, however, lack reliable and independent dating constraints (e.g. Benasso, Boca, Ronco Biellese).

Since the fossil floras detected at Ca' Viettone seem to reflect "a chronologically delimited and distinguishable stage of vegetational development" (Mai and Walther, 1978), we propose to conserve the concept of a Ca' Viettone Florenkomplex. However, its lower and upper boundaries are still poorly defined:

- The lower boundary is indefinite due to a chronological gap in macrofloral documentation from the Breolungi assemblage (MPI2 zone: Martinetto et al., 2015) down to the latest Messinian Corneliano and Scipione Ponte assemblages (Kovar-Eder et al., 2006);
- The upper boundary is marked by a floral change at the transition to the younger Stura Florenkomplex, which cannot be precisely dated at the current state of the art; it might be related to the "Brunssumian-Reuverian floral transition", detected in several mid-latitude regions at c. 3.3 Ma ago (Suc, 1984; Popescu et al., 2006, 2010) and corresponding to a cooling event detected in the marine stable isotope record (De Schepper et al., 2013, 2014), which had a strong impact also on marine molluscs with tropical affinities (Monegatti and Raffi, 2007).

Since the detection of the Ca' Viettone Florenkomplex is based on the floral composition, which varies depending on ecological and climatic factors (e.g., Retallack,

1978), we recommend to limit its application to northern Italy, because there are clues for consistent differences in both climate and vegetation of the adjoining regions during Pliocene (Popescu et al., 2006, 2010; Barrón et al., 2010; Jiménez-Moreno et al., 2010; Salzmann, 2011; Teodoridis et al., 2009, 2017; Velitzelos et al., 2014). From the point of view of ancient vegetation, Martinetto and Vassio (2010) and Bertini and Martinetto (2008, 2011) reconstructed a "subtropical humid forest" type with many evergreen trees for the assemblages of the Ca' Viettone Florenkomplex, whereas in other European regions evergreen trees were less abundant (Kovar-Eder et al., 2008). The characterisation of the "subtropical humid forest" vegetation type in terms of quantitative climatic parameters was already discussed by Bertini and Martinetto (2008), and can be emended here according to the Köppen-Trewartha classification for the Cfa climate (Baker et al., 2010; Belda et al., 2014): temperature of warmest month greater than or equal to 10 °C; temperature of coldest month between -3 °C and 18 °C; significant precipitation in all seasons; warmest month average temperature above 22 °C.

### *5.3 The importance of the Ca' Viettone site and its Florenkomplex in the European panorama.*

In Europe, early Pliocene macrofloral assemblages which are both taxonomically diverse and reasonably well dated, occur mostly in the classic succession of the Lower Rhine Basin (Reid and Reid, 1915; Zagwijn, 1960, 1992; Van der Burgh and Zetter, 1998; Schäfer et al., 2005; Kuhlmann et al., 2006; Westerhoff et al., 2008; Schäfer and Utescher, 2014). A few other central European sedimentary successions that provide a rich record of plant macrofossil taxa are still poorly chronologically constrained (Kroszienko: Szafer, 1954; Gerstungen: Mai and Walther, 1988; Fortuna-Garsdorf: Van der Burgh and Zetter, 1998; Nochten-Ost 4803 and Ruszów: Mai and Wähnert, 2000; Sessenheim: Teodoridis et al.,

2009). The better dated palaeofloras of the German Wetterau's localities (Mai and Walther, 1988) and Hungary (Gerce and Pula: Erdei et al., 2007) do not contain more than 20 taxa each, a small number when compared to the 133 taxa of the Ca' Viettone palaeoflora. The remaining European records concern localities that are both poorly dated and with a low diversity palaeoflora (e.g., Vildstejin: Teodoridis et al., 2017).

Due to the scarcity of early Pliocene macrofloral records, the more abundant pollen data could contribute to the reconstruction of the characteristics of the terrestrial plant cover in Europe during the early Pliocene warmth. However, by combining pollen and carpological records (Bertoldi and Martinetto, 1995; Martinetto and Ravazzi, 1997; Van der Burgh and Zetter, 1998; Bertini and Martinetto, 2011), it was noticed that pollen assemblages document very well the anemophilous plants, but do not accurately represent the assemblages of "subtropical humid forest" type, which are rich in entomophilous plants, often recorded solely by carpological fossils (Bertini and Martinetto, 2011; Martinetto et al., 2017). Actually, the ancient plant species diversity is definitely underestimated in the sites without carpological data, and a good reconstruction of the terrestrial flora during the early Pliocene warmth can only be provided by those sites where both pollen and fruits/seeds occur (with the possible addition of leaf and wood remains). In this respect, the taxonomic diversity of the microflora (Bertoldi and Martinetto, 1995) and macroflora (Table 3), the variety of fossil plant assemblages, and the good exposure and chronological framing of the Ca' Viettone succession, provide to this locality a relevant role at the broader European scale. Such relevance is even enhanced by the occurrence of several similar floras in northern Italy, forming the Ca' Viettone Florenkomplex. This is characterized by abundant thermophilous plant taxa that are completely lacking in the other European sites (e.g., *Cyclea*, *Ficus*, *Cinnamomum*, *Litsea*, *Ocotea*, *Mallotus*, *Meliosma canavesana*, *Tetrastigma*, etc.). Important floral similarities (e. g., occurrence of *Symplocos* spp., *Toddalia*, *Turpinia ettingshausenii*,

*Trigonobalanopsis exacantha*) can be pointed out only with the less diverse "Brunssumian" macrofloras of the Lower Rhine Basin (Zagwijn, 1990; Van der Burgh and Zetter, 1998), which seem to be chronologically equivalent to the Ca' Viettone section (Popescu et al., 2010). The scarcity of "humid" thermophilous elements in the remaining early Pliocene floras can be attributed to the cooler conditions at the central and eastern European areas, and to the drier conditions at the Mediterranean area (Popescu et al., 2006, 2010; Barrón et al., 2010; Bertini, 2010; Jiménez-Moreno et al., 2010; Salzmann, 2011; Velitzelos et al., 2014). In fact, northern-central Italy was probably one of the few areas where the humidity-requiring and thermophilous woody plants of the European Miocene flora (Mai, 1995, 2010) could still prosperously grow during the early Pliocene, and even partly survive until the Gelasian (Martinetto et al., 2017).

## 6. Conclusions

The micropalaeontological, palaeobotanical and magnetostratigraphic results presented in this study importantly contribute to better constrain the age of the Ca' Viettone continental section, highlighting its importance in a European context. Foraminiferal analysis on the underlying marine deposits indicate that the continental succession of Ca' Viettone cannot be older than the base of the MPI4 foraminiferal biozone. Magnetic polarity investigation of the 18 m thick composite section shows an original inverse magnetization (often re-magnetized) that, in combination with the biochronological constraints provided by foraminifers and plant macrofossils, suggest the deposition of the Ca' Viettone succession during the late Gilbert chron (i.e. late Zanclean). The plant macrofossil assemblages yielded by the Ca' Viettone continental succession show high taxonomic diversity (in total 133 taxa) and abundance of woody plants extirpated from Europe, in particular those of the carpological Groups 1 and 3. An hypothetical assignment of the Ca' Viettone section to one

of the two inversely magnetized intervals of the Gauss epoch (Piacenzian) can be excluded because these intervals are documented in two neighbouring successions (Stura di Lanzo and Villafranca d'Asti) characterized by a well distinct palaeoflora (lacking Group 1 and Group 3 elements). The Ca' Viettone type of palaeoflora was also detected in all of the NW Italian localities assigned to the time span between the beginning of the foraminiferal biozone MPI2 and the end of the biozone MPI4a (4.5 to 3.6 Ma). The Ca' Viettone locality could be therefore considered as reference site for a late Zanclean regional Florenkomplex, and its palaeoflora overcomes the scarce and poorly dated macrofloral information provided by other European areas, and allows us to better assess the characteristics of the terrestrial plant cover during the early Pliocene warmth. The palaeofloras of the Ca' Viettone Florenkomplex accurately represent a vegetation of "subtropical humid forest" type, showing that numerous humidity-requiring and thermophilous woody plants, already disappeared from central and eastern Europe, could still enjoy the early Pliocene warmth in northern Italy.

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**References**

AGIP, 1982. Foraminiferi padani (Terziario e Quaternario). Atlante iconografico e distribuzioni stratigrafiche, Second Edition, 52 pls., AGIP Mineraria, S. Donato Milanese, Italy.

Aimone, S., Ferrero Mortara, E., 1983. Malacofaune plioceniche di Cossato e candelo (Biellese, Italia NW). *Boll. Mus. Reg. Sci. Nat. (Torino)* 1(2), 276-328.

Allason, B., Carraro, F., Ghibaudo, G., Paganelli, A., Ricci, B., 1981. Prove palinologiche dell'età pleistocenica inferiore di depositi "villafranchiani" in Piemonte. *Geogr. Fis. Din. Quat.* 4, 39-47.

Balestro, G., Cadoppi, P., Piccardo, G.B., Polino, R., Spagnolo, G., Tallone, S., Fioraso, G., Lucchesi, S., Forno, M.G., 2009. Geological map of Italy at the scale 1:50:000, sheet 155 Torino Ovest. ISPRA, Istituto Superiore per la Protezione e la Ricerca ambientale, Roma.

Barrón, E., Rivas-Carballo, R., Postigo-Mijarra, J. M., Alcalde-Olivares, C., Vieira, M., Castro, L., Pais, J., Valle-Hernández, M., 2010. The Cenozoic vegetation of the Iberian Peninsula: a synthesis. *Rev. Palaeobot. Palynol.* 162(3), 382-402.

Basilici, G., Martinetto, E., Pavia, G., Violanti, D., 1997. Paleoenvironmental evolution in the Pliocene marine-coastal succession of Val Chiusella (Ivrea, NW Italy). *Boll. Soc. Paleont. Ital.* 36 (1-2), 23-52.

Baker, B., Diaz, H., Hargrove, W., Hoffman, F., 2010. Use of the Köppen-Trewartha climate classification to evaluate climatic refugia in statistically derived ecoregions for the People's Republic of China. *Clim. Change* 98, 113–131.

Belda, M., Holtanová, E., Halenka, T., Kalvová, J., 2014. Climate classification revisited: from Köppen to Trewartha. *Clim. Res.* 59(1), 1-13.

Bertini, A., 2010. Pliocene to Pleistocene palynoflora and vegetation in Italy: state of the art. *Quat. Int.* 225, 5-24.

Bertoldi, R., Martinetto, E., 1995. Ricerche paleobotaniche (palinologiche e paleocarpologiche) sulla successione villafranchiana del rio Ca' Viettone. *Il Quat.* 8 (2), 403-422.

Bertoldi R., Binotti A., Castello F., 1994. *Reevesia* and *Itea* in the pollen flora of the upper Neogene continental deposit at Sarzana (lower Magra Valley, northern Italy). *Rev. Paleobot. Palynol.* 80, 159-172.

Boano, P., Bormioli, D., Carraro, F., Lanza, R., 1999. Magnetic stratigraphy of the Villafranchian type-section (Villafranca d'Asti, Italy). *Ann. Geofisica* 42, 9-19.

Carraro, F., 1996. Revisione del Villafranchiano nell'area-tipo di Villafranca d'Asti. *Il Quat.* 9, 1-119.

Cavallo, O., Martinetto, E., 1996. Flore plioceniche del bacino del Tanaro. *Alba Pompeia* 17 (1), 5-31.

Cavallo, O., Martinetto, E., 2001. Flore carpologiche del Pliocene di Castelletto Cervo (Biella). *Boll. Mus. Reg. Sci. Nat. Torino* 18 (2), 277-343.

Chadima, M., Hrouda, F. 2006. Remasoft 3.0 a user-friendly paleomagnetic data browser and analyzer. *Travaux Géophys.* 27, 20-21.

Cita, M.B., 1975. Studi sul Pliocene e sugli strati di passaggio dal Miocene al Pliocene. VIII. Planktonic foraminiferal biozonation of the Mediterranean Pliocene deep sea record. A revision. *Riv. Ital. Paleont. Strat.* 81, 527-544.

Damarco, P., 2009. La formazione di un territorio – Storia geo-paleontologica dell’Astigiano. *Quad. Sci. Ente Parchi Astigiani* 7, pp. 312.

d’Atri, A., Piazza, M., 1988. Facies a Corallinacee del Pliocene di Masserano (Biellese). *Atti IV° Simposio Ecologia e Paleoecologia delle Comunità Bentoniche. Sorrento 1-5 Novembre 1988. Boll. Mus. Reg. Sci. Nat. (Torino)*, 387-395.

De Schepper, S., Gibbard, P.L., Salzmann, U., Ehlers, J., 2014. A global synthesis of the marine and terrestrial evidence for glaciation during the Pliocene Epoch. *Earth Sci. Rev.* 135, 83-102.

De Schepper, S., Groeneveld, J., Naafs, B.D.A., Van Renterghem, C., Hennissen, J., Head, M.J., Louwye, S., Fabian, K., 2013. Northern Hemisphere Glaciation during the Globally



Warm Early Late Pliocene. Plos One 8 (12), e81508.

<http://dx.doi.org/10.1371/journal.pone.0081508>.

Dowsett, H., Dolan, A., Rowley, D., Moucha, R., Forte, A.M., Mitrovica, J.X., Pound, M., Salzmann, U., Robinson, M., Chandler, M., Foley, K., and Haywood, A., 2016. The PRISM4 (mid-Piacenzian) paleoenvironmental reconstruction. *Clim. Past* 12, (7), 1519-1538.

Erdei, B., Hably, L., Kázmér, M., Utescher, T., Bruch, A.A., 2007. Neogene flora and vegetation development of the Pannonian domain in relation to palaeoclimate and palaeogeography. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 253, 115–140.

Fedorov, A.V., Brierley, C.M., Lawrence, K.T., Liu, Z.P., Dekens, S., Ravelo, A.C., 2013. Patterns and mechanisms of early Pliocene warmth. *Nature* 496 (7443), 43–49.

Forno, M.G., Ferrando, S., 2008. Plio-Quaternary continental deposits of the Castellamonte area, between Orco and Dora Baltea Basins (Torino Province, Italy). *Quat. Int.* 190, 103-111.

Forno, M.G., Gregorio, L., Vatteroni, R., 2009. The Geology of La Mandria Natural Park. I *Quad. La Mandria* 4, 1-48.

Ghielmi, M., Minervini, M., Nini, C., Rogledi, S., Rossi, M., Vignolo, A., 2010. Sedimentary and Tectonic Evolution in the Eastern Po-Plain and Northern Adriatic Sea Area from Messinian to Middle Pleistocene (Italy). In: Sassi F.P. (ed.): *Nature and Geodynamics of the Lithosphere in Northern Adriatic*. *Rend. Fis. Acc. Lincei* 21 (Suppl. 1), 131-166.

Gliozzi, E., Abbazzi, L., Argenti, P., Azzaroli, A., Caloi, L., Capasso Barbato, L., di Stefano, G., Esu, D., Ficarelli, G., Girotti, O., Kotsakis, T., Masini, F., Mazza, P., Mezzabotta, C., Palombo, M.R., Petronio, C., Rook, L., Sala, B., Sardella, R., Zanalda, E., Torre, D., 1997. Biochronology of selected Mammals, Molluscs and Ostracods from the Middle Pliocene to the Late Pleistocene in Italy. The state of the art. *Riv. Ital. Paleont. Strat.* 103, 369-388.

Gunderson, K. L., Kodama, K. P., Anastasio, D. J., Pazzaglia, F. J., 2013. Rock-magnetic cyclostratigraphy for the Late Pliocene–Early Pleistocene Stirone section, Northern Apennine mountain front, Italy. *Geol. Soc. London Spec. Publ.* 373(1), 309-323.

Haywood, A.M., Dolan, A.M., Pickering, S.J., Dowsett, H.J., McClymont, E.L., Prescott, C.L., Salzmann, U., Hill, D.J., Hunter, S.J., Lunt, D.J., Pope, J.O., Valdes, P.J., 2013. On the identification of a Pliocene time slice for data–model comparison. *Phil. Trans. R. Soc. A* 371: 20120515. <http://dx.doi.org/10.1098/rsta.2012.0515>.

Haywood, A.M., Dowsett, H.J., Dolan, A.M., Rowley, D., Abe-Ouchi, A., Otto-Bliesner, B., Chandler, M.A., Hunter, S.J., Lunt, D.J., Pound, M., Salzmann, U., 2016. The Pliocene Model Intercomparison Project (PliMIP) Phase 2: scientific objectives and experimental design. *Clim. Past* 12 (3), 663-675.

Hou, H.-Y., 1983. Vegetation of China with reference to its geographical distribution. *Ann. Missouri Bot. Garden* 70: 509-548.

Irace, A., Monegato, G., Tema, E., Martinetto, E., Gianolla, D., Vassio, E., Bellino, L., Violanti, D., 2017. Unconformity-bounded stratigraphy in the Plio-Pleistocene continental record: New insights from the Alessandria Basin (NW Italy). *Geol. J.* 52, 177-206.

Kennett, J.P., Srinivasan, M.S., 1983. Neogene Planktonic Foraminifera - A phylogenetic atlas, 265 pp, Hutchinson Ross Publishing Company, Stroudsburg, Pennsylvania, U.S.A.

Kovar-Eder, J., Kvaček, Z., Martinetto, E., Roiron, P., 2006. Late Miocene to Early Pliocene vegetation of southern Europe (7–4 Ma) as reflected in the megafossil plant record. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 238, 321–339.

Kovar-Eder, J., Jechorek, H., Kvaček, Z., Parashiv, V., 2008. The integrated plant record: an essential tool for reconstructing Neogene zonal vegetation in Europe. *Palaios* 23, 97–111.

Kuhlmann, G., Langereis, C. G., Munsterman, D., Van Leeuwen, R. J., Verreussel, R., Meulenkamp, J. E., Wong, T. E., 2006. Integrated chronostratigraphy of the Pliocene-Pleistocene interval and its relation to the regional stratigraphical stages in the southern North Sea region. *Netherl. J. Geosci.* 85(1), 19-35.

Kunzmann, L., Kvaček, Z., Teodoridis, V., Müller, C., Moraweck, K., 2016. Vegetation dynamics of riparian forest in central Europe during the late Eocene. *Palaeontogr. Abt. B.* 295, 1-26.

Kvaček, Z., 2000. Climatic oscillations versus environmental changes in the interpretation of Tertiary plant assemblages. In: Hart M.B. (ed.) *Climates: Past and Present*. Geol. Soc. London Spec. Publ. 181, 89–94.

Kvaček, Z., 2010. Forest flora and vegetation of the European early Palaeogene – a review. *Bull. Geosci.* 85 (1), 63–76.

Jiménez-Moreno, G., Fauquette, S., Suc, J. P., 2010. Miocene to Pliocene vegetation reconstruction and climate estimates in the Iberian Peninsula from pollen data. *Rev. Paleobot. Palynol.* 162(3), 403-415.

Loeblich, A.R., Tappan, H., 1988. Foraminiferal genera and their classification. pp. 1-970, pls. 1-847, Van Nostrand Reinhold, New York, U.S.A.

Lowrie, W., 1990. Identification of ferromagnetic minerals in a rock by coercivity and unblocking temperature properties. *Geophys. Res. Lett.* 17, 159-162.

Lucas, S.G., 2013. Plant megafossil biostratigraphy and biochronology, upper Triassic Chinle Group, western USA. In Tanner, L.H., Spielmann, J.A. and Lucas, S.G., eds., *The Triassic System*. New Mexico Mus. Nat. Hist. Sci. Bull. 61, 354-365.

Macaluso, L., Martinetto, E., Vigna, B., Bertini, A., Cilia, A., Teodoridis, V., Kvaček, Z., 2018. Palaeofloral and stratigraphic context of a new fossil forest from the Pliocene of NW Italy. *Rev. Paleobot. Palynol.* 248, 15–33

- Mai, D.H., 1995. Tertiäre Vegetationsgeschichte Europas. 691 pp., Gustav Fischer, Jena.
- Mai, D.H. 2000. Die untermiozänen Floren aus der Sprenberger Folge und dem 2. Flözhorizont in der Lausitz. Teil IV: Fundstellen und Paläobiologie. *Palaeontographica* Abt. B. 254(4–6), 65–176.
- Mai, D.H., Wähnert, V., 2000. On the problems of the Pliocene floras in Lusatia and Lower Silesia. *Acta Palaeobot.* 40, 165–205.
- Mai, D.H., Walther, H., 1978. Die Floren der Haselbacher Serie im Weisselster-Becken (Bezirk Leipzig, DDR). *Abh. Staatl. Mus. Min. Geol. Dresden* 28, 1-200.
- Mai, D.H., Walther, H., 1988. Die pliozänen Floren von Thüringen Deutsche Demokratische Republik. *Quartärpaläont.* 7, 55-297.
- Martinetto, E., 1995. Significato cronologico e paleoambientale dei macrofossili vegetali nell'inquadramento stratigrafico del "Villafranchiano" in alcuni settori del Piemonte. PhD Thesis, Univ. of Torino, 149 pp.
- Martinetto, E., 1999. Chronological framing of Pliocene to Early Pleistocene plant macrofossil assemblages from northern Italy. *Acta Palaeobot. Suppl.* 2, 503-511.
- Martinetto, E., 2001. The role of central Italy as a centre of refuge for thermophilous plants in the late Cenozoic. *Acta Palaeobot.* 41 (2), 299-319.

Martinetto, E., 2015. Monographing the Pliocene and Early Pleistocene carpo-floras of Italy: methodological challenges and current progress. *Palaeontographica Abt. B.* 293, 57-99.

Martinetto, E., Gregor, H.-J., 1989. The first occurrence of *Sinomenium cantalense* (Reid) Dorofeev in the Italian Neogene with special remarks on the Villafranchian stage - *Doc. Naturae*, 49, 1-11.

Martinetto, E., Ravazzi, C., 1997. Plant biochronology of the Valle della Fornace succession (Varese) based on the Plio-Pleistocene record in northern Italy. *Geol. Insub.* 2(2), 81-98.

Martinetto, E., Vassio, E., 2010. Reconstructing "Plant Community Scenarios" by means of palaeocarpological data from the CENOFITA database, with an example from the Ca' Viettone site (Pliocene, Northern Italy). *Quat. Int.* 225, 25-36.

Martinetto, E., Pavia, G., Bertoldi, R., 1997. Fruit and seed floras rich in exotic and subtropical elements from two Lower Pliocene successions of Italy. *Meded. Nederl. Inst. Toeg. Geowet. TNO* 58, 237-244.

Martinetto, E., Scardia, G., Varrone D., 2007. Magnetobiostratigraphy of the Stura di Lanzo fossil forest succession. *Riv. It. Paleont. Strat.* 113 (1), 109-125.

Martinetto, E., Momohara, A., Bizzarri, R., Baldanza, A., Delfino, M., Esu, D., Sardella, R., 2017. Late persistence and deterministic extinction of humid thermophilous plant taxa of East Asian affinity (HUTEA) in southern Europe. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 467, 211-231.

Miall, A.D., 1996. *The Geology of Fluvial Deposits*. Springer-Verlag: Berlin Heidelberg, 582 pp.

Moissette, P., Koskeridou, E., Corneè, J.J., Guillocheau, F., Le'Cuyer, C., 2007. Spectacular Preservation of seagrasses and seagrass-associated communities from the Pliocene of Rhodes, Greece. *Palaios* 22, 200–211.

Monegatti, P., Raffi, S., 2007. Mediterranean - Middle Eastern Atlantic Façade: molluscan biogeography and ecobiostratigraphy throughout the Late Neogene. In: Avila, S.P., de Frias Martins, A.M., *Proceedings of the first Atlantic Islands Neogene International Congress. AÇOREANA Suppl. 5*, 132-154.

Monesi, E., Muttoni, G., Scardia, G., Felletti, F., Bona, F., Sala, B., Tremolada, F., Francou, C., Raineri, G., 2016. Magnetostratigraphy of the Pleistocene marine-continental transition in the Arda River section (northern Italy): insights on the opening of the Galerian mammal migration pathway during the Late Matuyama climate revolution. *Quat. Res.* 86, 220-231.

Murray, J.W., 2006. *Ecology and Applications of Benthic Foraminifera*. Cambridge University Press, Cambridge, 426 pp.

Muttoni, G., Ravazzi, C., Breda, M., Laj, C., Kissel, C., Mazaud, A., Pini, R., Garzanti, E., 2007. Magnetostratigraphy of the Lefte lacustrine succession (Southern Alps, Italy): evidence for an intensification of glacial activity in the Alps at Marine Isotope Stage 22 (0.87 Ma). *Quat. Res.* 67(1), 161-173.

Patacca, E., Scandone, P., 2004. The Plio-Pleistocene thrust belt - foredeep system in the Southern Apennines and Sicily (Italy). *Spec. Vol. Ital. Geol. Soc. IGC Florence 2004*, 93-129.

Peel, M. C., Finlayson, B. L., & McMahon, T. A., 2007. Updated world map of the Köppen-Geiger climate classification. *Hydr. Earth Sys. Sci. Dic.* 4(2), 439-473.

Piana, F., Fioraso, G., Irace, A., Mosca, P., d'Atri, A., Barale, L., Falletti, P., Monegato, G., Morelli, M., Tallone, S., Vigna, G.B., 2017. Geology of Piemonte region (NW Italy, Alps-Apennines interference zone). *Journal of Maps*, 13 (2), 395-405.

Popescu, S.M., Krijgsman, W., Suc, J.P., Clauzon, G., Mărunțeanu, M., Nica, T., 2006. Pollen record and integrated high-resolution chronology of the early Pliocene Dacic Basin (southwestern Romania). *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 238, 78-90.

Popescu, S. M., Biltekin, D., Winter, H., Suc, J. P., Melinte-Dobrinescu, M. C., Klotz, S., Rabineau, M., Combourieu-Nebout, N., Clauzon, G., Deaconu, F., 2010. Pliocene and Lower Pleistocene vegetation and climate changes at the European scale: Long pollen records and climatostratigraphy. *Quat. Int.* 219(1), 152-167.

Prescott, C.L., Haywood, A.M., Dolan, A.M., Hunter, S.J., Pope, J.O., Pickering, S.J., 2014. Assessing orbitally-forced interglacial climate variability during the mid-Pliocene Warm Period. *Earth Planet. Sci. Lett.* 400, 261-271.



Prescott, C.L., Dolan, A.M., Haywood, A.M., Hunter, S.J., Tindall, J.C., 2018. Regional climate and vegetation response to orbital forcing within the mid-Pliocene Warm Period: A study using HadCM3. *Glob. Planet. Change* 161, 231–243.

Reid, C., Reid, E.M., 1915. The Pliocene floras of the Dutch-Prussian border. *Meded. Rijks Geol. Dienst* 6, 1-178.

Retallack, G.J., 1978. Floral ecostratigraphy in practice. *Lethaia* 11, 81-83.

Sacco, F., 1890. Il bacino terziario e quaternario del Piemonte. R. Univ. Torino, Tip. Bernardoni. Milano, 643 pp.

Salzmann, U., Williams, M., Haywood, A.M., Johnson, A.L.A., Kender, S., Zalasiewicz, J., 2011. Climate and environment of a Pliocene warm world. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 309, 1-8. <http://dx.doi.org/10.1016/j.palaeo.2011.05.044>.

Schäfer, A., Utescher, T., 2014. Origin, sediment fill, and sequence stratigraphy of the Cenozoic Lower Rhine Basin (Germany) interpreted from well logs. *Z. Deutsc. Gesell. Geowiss.* 165(2), 287-314.

Schäfer, A., Utescher, T., Valdivia-Manchego, M., Klett, M., Eichhorst, F. and von der Hocht, F., 2005. The Cenozoic Lower Rhine Basin - rifting, sediment input, and cyclic stratigraphy. *Geol. Rundschau* 94, 621-639.

Suc, J. P., 1984. Origin and evolution of the Mediterranean vegetation and climate in Europe. *Nature* 307(5950), 429-432.

Szafer, W., 1954. Pliocene Flora from the vicinity of Czorsztyn (West Carpathians) and its relationship to the Pleistocene. *Prace Geol. Inst. Warszawa* 11, 1-238.

Teodoridis, V., Kvaček, Z., Uhl, D., 2009. Pliocene palaeoenvironment and correlation of the Sessenheim-Auenheim floristic complex (Alsace, France). *Palaeodiv.* 2, 1-17.

Teodoridis V., Bruch A.A., Vassio E., Martinetto E., Kvaček Z., Stuchlik L., 2017. Plio-Pleistocene floras of the Vildštejn Formation in the Cheb Basin, Czech Republic – a floristic and palaeoenvironmental review. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 467, 166-190. doi: 10.1016/j.palaeo.2015.09.038

Țicleanu, N., 1995. Macrofloré et végétation Daciennes du Bassin Dacique. *Chronostratigraphie und Neostatotypen, Neogen der Zentrale Paratethys, Bd. IX, Pliozan, PL1, Dazien*, pp. 473-497, Ed. Academiei Române, București.

Tzonev, R., Hinkov, G., Karakiev, T., 2011. Ecological characteristics of the floristic complex of the chestnut (*Castanea sativa* Mill.) forests in Belasitsa Mountain. *Silva Balcan.* 12(1), 47-61.

Van der Burgh, J., Zetter, R., 1998. Plant mega- and microfossil assemblages from the Brunsumian of “Hambach” near Düren, B.R.D. *Rev. Palaeobot. Palynol.* 101, 209-256.

Vassio, E., Martinetto, E., Dolezych, M., Van Der Burgh, J., 2008. Wood anatomy of the *Glyptostrobus europaeus* “whole-plant” from a Pliocene fossil forest of Italy. *Rev. Palaeobot. Palynol.* 151, 81–89.

Velitzelos, D., Bouchal, J. M., Denk, T., 2014. Review of the Cenozoic floras and vegetation of Greece. *Rev. Paleobot. Palynol.* 204, 56-117.

Vieira, M., Poças, E., Pais, J., Pereira, D.I., 2011. Pliocene flora from S. Pedro da Torre deposits (Minho, NW Portugal). *Geodiv.* 33 (1), 71–85.

Vincent, S.J., 2001. The Sis palaeovalley: a record of proximal fluvial sedimentation and drainage basin development in response to Pyrenean mountain building. *Sedimentol.* 48, 1235-1276.

Violanti, D., 2012. Pliocene Mediterranean foraminiferal biostratigraphy: a synthesis and application to the paleoenvironmental evolution of Northwestern Italy. In: Elitok, Ö. (Ed.), *Stratigraphic Analysis of Layered Deposits*. INTECH Open Access Publisher, 123-160.

Westerhoff, W.E., Kemna, H A., Boenigk, W., 2008. The confluence area of Rhine, Meuse, and Belgian rivers: Late Pliocene and Early Pleistocene fluvial history of the northern Lower Rhine Embayment. *Netherl. J. Geosci./ Geol. Mijnbouw* 87 (1), 107-126.

Wright, R., 1978. Neogene paleobathymetry of the Mediterranean based on benthic foraminifers from DSDP Leg 42A. In: R. B. Kidd & P. J. Worstell (Eds.), *Initial Reports of the Deep Sea Drilling Program*, 42, 837-846, U.S. Gov. Print. Off., Washington, U.S.A.

Zagwijn, W.H., 1960. Aspects of the Pliocene and Early Pleistocene vegetation of The Netherlands. Meded. Geol. Sticht. ser. C-III-1 5: 1-78.

Zagwijn, W.H., 1990. Subtropical relicts in the Pliocene flora of Brunssum (The Netherlands). Geol. Mijnbouw 69, 219-225.

Zagwijn, W.H., 1992. The beginning of the Ice Age in Europe and its major subdivisions. Quat. Sci. Rev. 11 583–591.

**Figure captions**

Fig. 1. A, Summary geological map of the Piemonte region showing the location of the syn-orogenic basins, characterizing the Alps/northern Apennines system (after Piana et al., 2017). B, Simplified geological map of the western Po Plain (modified from Martinetto et al., 2007 and Piana et al., 2017). The geographic position of the localities with Pliocene carpological assemblages (after Martinetto, 2015) are shown as follows: WPB: Western Po Basin; SB: Savigliano Basin; AB: Alessandria Basin; THM: Torino Hill and Monferrato domains. BA: Baldichieri-Fornace; BE: Benasso (Castellamonte); BG: Sento I, II and Pian Torinetto; BL-RB: Candelo-Ronco Biellese; BO: Boca; CGL: Cortiglione d'Asti; CO-TC: Cossato-Castellengo; CV: Ca' Viettone; FO: Fossano; FR: Front; MZ-BR: Crava di Morozzo-Breolungi; LC: La Cassa; PO: Pocapaglia; RDB: Villafranca d'Asti-RDB Quarry; STU: Stura di Lanzo Fossil Forest.

Fig. 2. A, Simplified geological map of the Ca' Viettone site (after Martinetto, 1995). B, Reconstructed cross-section of the Pliocene succession showing Intenza well (IW; Latitude 45°19'4"N; Longitude 7°37'0"E) and other sites (CV5; Latitude 45°19'23"N; Longitude 7°36'44"E; CV20-21; Latitude 45°19'18"N; Longitude 7°37'9"E) (after Martinetto et al., 1997).

Fig. 3. Summary log correlation of the CV20 and CV21 sections, indicating the lithofacies, facies associations (defined in Table 1) and the degree of sediment alteration. The stratigraphic position of the analysed samples and the correlation with the layers and/or layer groups defined by Allason et al. (1981) are reported (All1 etc.).

Fig. 4. Outcrop photographs. A, Aspect of the outcrop of CV21 section; B, General view of the outcrop including the CV5 section. The main lithofacies and facies associations are classified according to Table 1.

Fig. 5. Magnetostratigraphy. A, Normalized IRM acquisition curves up to 1.2 T; B, IRM back-field curves for samples from the composite CV20-21 section.

Fig. 6. Stepwise thermal demagnetization of three IRM components following Lowrie (1990) for representative samples. Symbols: circle= Soft- (0.1 T); diamond= Medium- (0.3 or 0.5 T); square= Hard- (1.2 T) coercivity component.

Fig. 7. Stepwise alternating field demagnetization results illustrated in Zijderveld diagrams and intensity decay plots. Representative samples of (A-B) inverse and (C-D) normal polarity. Symbols: closed circles = declination; open circles = apparent inclination.

Fig. 8. A, Photograph of the CV5 section where the lateral penetration of the oxidation has permitted the collection of samples from both the blue-grey (group a samples) and grey-brown (group b samples) sediments, corresponding to the same stratigraphic level. B, C, Zijderveld diagrams indicating an inverse polarity for the group a samples and a normal polarity for the group b samples. Symbols: closed circles = declination; open circles = apparent inclination.

Fig. 9. Chronostratigraphic frame for the Ca' Viettone succession as derived by comparison with other northern Italian sections on the basis of magnetostratigraphic and biochronological constraints (after Martinetto et al., 2007).

Fig. 10. Scheme summarizing the biochronological distribution of selected carpological records of plant taxa occurring at the Ca' Viettone site. The Groups 1-5 are defined in Martinetto et al. (2015). Mes = Messinian; MP = Middle Pleistocene.

The biochronological distribution of each taxon is deduced from the whole N-Italian CENOFITA database (Martinetto and Vassio, 2010; Martinetto, 2015; Martinetto et al., 2015). The age range for each species is indicated by black bars, for the records originating from reliably dated localities: Lugagnano (5.1–4.5 Ma), Pocapaglia (4.5–3.8 Ma), Breolungi (5.1–3.8 Ma), Morozzo (5.1–3.8 Ma), Fossano I-III (4.5–3.9 Ma); Candelo (4.5–3.6 Ma), Sento I (3.8–3.6 Ma), Roatto (3.3–3.2 Ma), Villafranca d'Asti-RDB Quarry (3.3–3.0 Ma), Fossil Forest of the Stura di Lanzo River (3.1–3.0 Ma), Casnigo (2.1–1.9 Ma), Santerno (1.8–1.7 Ma), Lefte (1.7–1.5 Ma), Stirone-LA1 (1.1–1.0 Ma), Enza-EZ38 (1.1–1.0 Ma), Ranica (1.1–1.0 Ma), Oriolo (1.0–0.8 Ma), Stirone-LA3 (1.0–0.8 Ma). Hatched bars indicate records from the following poorly dated localities (see Martinetto, 1999): Sento II (late Zanclean, 3.8–3.6 Ma); Front (Piacenzian, 3.3–3.0 Ma); Momello-Lanzo (Piacenzian, 3.6–3.0 Ma); Castelletto Cervo I (late Piacenzian, 2.8–2.6 Ma); Castelletto Cervo II (Gelasian, 2.6–2.0 Ma); San Pietro di Ragogna (Gelasian, 2.6–1.8 Ma); Buronzo (Gelasian, 2.2–1.8 Ma); Steglio (Calabrian, 1.8–0.9 Ma). The dashed lines indicate the presence of records in central Italy, considered a refuge area in the Piacenzian-Calabrian (Martinetto, 2001; Martinetto et al., 2016).

**Table captions**

Table 1. Description of each facies association. Dominant lithology, geometry and relationship with other facies associations are indicated. The lithofacies codes follow Miall (1996) and Vincent (2001).

Table 2. Quantitative results of the taxonomical analyses of the plant remains. Data from sediment samples originating from the bottom of the CV20 section and from a layer at 13.2 m in section CV21. A few categories of biogeographic-climatic relevance, defined by Martinetto et al. (2017) are singled out: HUTEA, "HUMid Thermophilous extinct European taxa of East Asian affinity"; CTEA, "Cool-Tolerant extinct European taxa of East Asian affinity"; TEWA, "Thermophilous European, West Asian and/or African elements".

Table 3. Comprehensive floral list of the Ca' Viettone macrofossil plant remains. Several sections and layers of the Ca' Viettone site sampled so far are estimated to pertain to no more than 20 metres of thickness of the Ca' Viettone succession (Fig. 2) and to represent a short geological time span. e/n: exotic/native; LEAF-TYPE CATEGORY: EC, evergreen conifer; E, broadleaved evergreen (BLE in Kovar-Eder et al., 2008); D, broadleaved deciduous (BLD in Kovar-Eder et al., 2008); HABITUS: t, tree; s, shrub; c, climber; h, herb. ECOLOGY: m, mesic; hy, hygrophilous; a, aquatic; r, riparian. See Table 2 for explanation of "CTEA", "HUTEA" and "TEWA".



Table 1

FACIES ASSOCIATIONS	LITHOFACIES	DESCRIPTION	ENVIRONMENTAL INTERPRETATION
<i>F1</i> (longitudinal barform)	Gh, Gm, Sm	Clast to sand matrix-supported, moderately sorted to sorted, pebbly gravels with sub-rounded to rounded poligenic clasts. Sub-horizontal fabric (Gh) to massive (Gm). Abundant dm- to m-sized rounded mud-clasts. Beds of massive sands are intercalated (Sm). Lenticular bedsets, 0.1-0.5 m up to 1 m thick, several metres wide, are floored by sharp concave-upward erosional surfaces. Interbedded within F4 association	Downstream migration of longitudinal (Gh) gravel-sand bars, grading to debris-flows (Gm, Sm), deposited within low-sinuosity fluvial channels
<i>F2</i> (side and transverse barform)	Gp, Sp	Sand matrix-supported, moderately to well sorted angle-of-repose planar cross-bedded sandy gravels (Gp) grading to cross-laminated sands (Sp). Arranged in isolated lenticular bodies with erosive basal scours, several metres wide and several decimetres deep, interbedded within F4 association.	Scour filling by downstream migration of: 1) gravel side bars or 2) transverse barforms, deposited within low-sinuosity fluvial channels
<i>F3</i> (dune and sandwave)	Gt, St, Sp	Sorted to well sorted, trough cross-bedded coarse-medium gravelly sands (Gt, St) and planar-laminated sand (Sp). Mainly occurring in some dm to 2.5 m thick tabular intervals of highly amalgamated sheet-like to lenticular bedsets, filling shallow concave-up erosional surfaces. F3 association may cap both F4 and F5 facies associations. Basal erosive boundary is locally marked by gravel lag.	Channel accretion by migration of sandy-gravel dunes and sandwaves during falling flood stage
<i>F4</i> (abandoned channel)	Fsm, Fl, Fm, Sm, Sh, (Sr)	Massive to thinly laminated clays and silts (Fsm, Fl, Fm), commonly forming scattered plane-concave lenses some tens of m wide and up to 2 m thick, or thin tabular bedsets; interbedded with gravels and sands of F1, 2, 3 associations. Rare lamina sets or thin beds of planar to massive, or ripple cross-laminated sands are intercalated (Sm, Sh, Sr). Convolute bedding to chaotic texture may be present. Clusters of plant remains. Bioturbation: very limited to absent.	Deposition from suspension in medium to large-scale abandoned channel (Fsm, Fm, Fl), occasionally affected by gravity flows (Sm) and traction currents (Sh, Sr)

*F5*  
(flood plain)

Fsm, Fm, Fl,  
Sm, Sh

Poorly-bedded massive to thinly laminated silty clays, forming laterally persistent 1-3 m thick tabular bodies, encasing the vertically stacked F1, F2, F3, F4 associations. A characteristic structure may be convolute bedding. Varying degree of pedogenic alteration and density of root-traces. Bioturbation: widespread to absent.

Deposition from suspension in a muddy fluvial flood plain and or in a lacustrine/palustrine setting, occasionally affected by gravity flows (Sm) and traction currents (Sh, Sr)

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ACCEPTED MANUSCRIPT

Table 2

Taxon	Author	Family	Part (type of remain)	CV2 0 A0H	CV2 0 B8F	CV2 0 C0A	CV20 -2 A5O	CV2 1 A1Z	Frequenc y other CV sections	HUTEA, CTEA TEWA	Clim.- biochro n. Groups
<i>Abies</i> sp.		PINACEAE	leaf					3	rare		
<i>Alangium deutschmanii</i>	F. Geissert et H.-J. Gregor (A. Braun)	ALANGIACEAE	endocarp		3	1			absent	CTEA	1
<i>Ampelopsis ludwigii</i>	D.H. Mai	VITACEAE	seed	3	1				rare	CTEA	4
<i>Arctostaphylos</i> sp.		ERICACEAE	fruit	1					common		
Betulaceae indet.		BETULACEAE	fruit					1	absent		
<i>Boehmeria lithuanica</i>	Dorofeev	URTICACEAE	fruit					3	rare	CTEA	4
<i>Carex</i> sp. A		CYPERACEAE	fruit					2	rare		
<i>Carpolites plicocurbitinus</i>	Martinetto Gossmann ex	INCERTAE SEDIS	fruit/seed					1	rare		
<i>Cathaya vanderburghii</i>	Winterschei d et Gossmann	PINACEAE	cone	1		1			common	CTEA- added	
<i>Chamaecyparis</i> sp.	(D.H. Mai)	CUPRESSACEAE	seed/shoot			1sh		1se	rare	CTEA	
<i>Cinnamomum costatum</i>	Pingen, Ferguson et Collinson	LAURACEAE	fruit	3	16	5	1		common	HUTEA	3
Cornaceae? indet.		CORNACEAE??	fruit	1					rare		
<i>Cryptomeria rhenana</i>	Kilpper (Martinetto)	CUPRESSACEAE		8	8			2	common	CTEA	4
<i>Datisca gratiolooides</i>	D.H. Mai	DATISCACEAE	seed					1	rare	TEWA	3
<i>Ehretia europaea</i>	E.M.Reid (Brongniart)	EHRETIACEAE	endocarp		1				rare	HUTEA	1
<i>Engelhardia macroptera</i>	Jaenichen et al.	JUGLANDACEAE	fruit	3		1			rare	HUTEA	

<i>Erica aff. carnea</i>	L.	ERICACEAE	seed				1	rare		
<i>Eurya stigmosa</i>	(Ludwig) D.H. Mai	PENTAPHYLACEAE	seed	19	4	8	4	abundant	HUTEA	3
<i>Fagaropsis?</i>		RUTACEAE	seed			1		rare		
Hamamelidoideae indet.		HAMAMELIDACEAE		1		1		rare		
<i>"Hartia" quinqueangularis</i>	(Menzel) D.H. Mai	THEACEAE?	fruit	1	2	3		rare	HUTEA	
<i>Ilex saxonica</i>	D.H. Mai	AQUIFOLIACEAE	seed		1			rare		1
Lamiaceae gen. et sp. indet. B		LAMIACEAE	fruit				4	rare		
<i>Leucothoe sp. A</i>		ERICACEAE	fruit	1	3	1		rare	CTEA	
<i>Liquidambar europaea</i>	Al. Braun	ALTINGIACEAE	infrutescence	1	15		1	common	TEWA	
<i>Liriodendron geminata</i>	Kirchheimer	MAGNOLIACEAE	seed	1			1	rare	CTEA	5
<i>Litsea sonntagii</i>	H.-J. Gregor	LAURACEAE	endocarp		16	4		common	CTEA	2
<i>Magnolia allasoniae</i>	Martinetto	MAGNOLIACEAE	seed	1	18	13	24	abundant	CTEA	2
<i>Magnolia ludwigii</i>	Ettingshausen	MAGNOLIACEAE	seed		13	6	2	common	CTEA	2
<i>Magnolia sp.</i>		MAGNOLIACEAE	fruit		1	1		rare	CTEA	
<i>Mahonia staphyleaeformis</i>	D.H. Mai et Walther	BERBERIDACEAE	seed			1		rare	CTEA	
<i>Mallotus maii</i>	Martinetto	EUPHORBIACEAE	seed		1	1		rare	HUTEA	2
<i>Meliosma canavesana</i>	Martinetto	SABIACEAE	endocarp	1	5	2		common	CTEA	1
<i>Meliosma wetteraviensis</i>	(Ludwig) Mai	SABIACEAE	endocarp			1		rare	HUTEA	
<i>Nyssa disseminata</i>	(Ludwig) Kirchheimer	NYSSACEAE	endocarp	1	1		4	common	CTEA	
<i>Ocotea sp. A</i>		LAURACEAE	fruit			2		common	TEWA	1
<i>Phellodendron cf. elegans</i>	(C. Reid et E.M. Reid) C. Reid et E.M. Reid	RUTACEAE	seed	1	1			rare	CTEA	
<i>Phytolacca salsoloides</i>	Martinetto	PHYTOLACCACEAE	seed		1		1	rare	CTEA	1
Pinaceae indet.		PINACEAE	leaf	11				common		

<i>Pinus cf. spinosa</i>	Herbst emend. D.H. Mai	PINACEAE	cone		hand picking			rare			
<i>Pinus hampeana</i>	(Unger) Heer	PINACEAE	cone		1	1		common			
<i>Pinus peuce</i>	Grisebach	PINACEAE	cone	1				common			
<i>Pterocarya limburgensis</i>	C. Reid et E.M. Reid	JUGLANDACEAE	fruit	1				common			
<i>Quercus</i> sp.		FAGACEAE	cupule		3	9	5	1	common		
<i>Rehderodendron ehrenbergii</i>	(Kirchheimer ) D.H. Mai	STYRACACEAE	fruit	1	10	6		common	HUTEA	2	
<i>Rosaceae</i> indet.		ROSACEAE		1				rare			
<i>Rubus</i>		ROSACEAE	endocarp	1			2	common			
<i>Sapindoidea margaritifera</i>	(Ludwig) Kirchheimer	SAPOTACEAE?	?	2	11	2	1	common	TEWA	1	
<i>Saurauiasp.</i>		ACTINIDIACEAE	seed		2			rare	HUTEA	1	
<i>Schoenoplectus</i> sp.		CYPERACEAE	fruit				10	rare			
<i>Sinomenium cantalense</i>	(E. Reid) Dorofeev (Knobloch et D.H. Mai)	MENISPERMACE AE	endocarp		2			common	HUTEA	3	
<i>Stemona germanica</i>	D.H. Mai D.H. Mai	STEMONMACEAE	seed		3	3		rare	HUTEA	3	
<i>Styrax</i> sp.		STYRACACEAE	endocarp			1		rare	TEWA		
<i>Symplocos casparyi</i>	Ludwig	SYMPLOCACEAE	fruit	3	23	7	1	1	common	HUTEA	3
<i>"Sorbus" herzogenthensis</i>	(Menzel) H.- J. Gregor	SYMPLOCACEAE	endocarp		1	1			rare	HUTEA	3
<i>Symplocos minutula</i>	(Sternberg) Kirchheimer	SYMPLOCACEAE	endocarp		1				rare	HUTEA	1
<i>Symplocos schereri</i>	Kirchheimer	SYMPLOCACEAE	fruit	5	12	2			common	HUTEA	2
<i>Tetraclinis salicornioides</i>	(Unger) Z. Kvaček	CUPRESSACEAE	shoot/cone	1		1			rare	TEWA	1
<i>Tetrastigma chandlerae</i>	Kirchheimer	VITACEAE	seed		5	2			rare	HUTEA	1
<i>Toddalia latisiliquata</i>	(Ludwig) H.- J. Gregor	RUTACEAE	seed		8	7		1	common	HUTEA	2
<i>Toddalia rhenana</i>	H.-J. Gregor	RUTACEAE	seed	1	22	6	2		common	HUTEA	3
<i>Trigonobalanopsis</i>	(D.H. Mai) Z.	FAGACEAE	cupule	23	20	8	19		common		1

<i>exacantha</i>	Kvaček et Walther									
<i>Turpinia ettingshausenii</i>	(Engelhardt) D.H. Mai	STAPHYLEACEAE	endocarp	1	1			rare	HUTEA	1
cf. <i>Viburnum</i>		VERBENACEAE	endocarp		1			absent		
<i>Viola</i> sp.		VIOLACEAE	seed		1			rare		
<i>Viola</i> sp. B		VIOLACEAE	seed				1	absent		
<i>Visnea germanica</i>	Menzel	PENTAPHYLACE AE	fruit	2	?			rare	TEWA	1
<i>Vitis</i> sp.		VITACEAE	seed	1				common		
<i>Vitis teutonica</i>	Al. Braun	VITACEAE	seed	1	15	7		rare		1
<i>Zanthoxylum ailanthiforme</i>	(H.-J. Gregor) H.- J. Gregor	RUTACEAE	seed	2	8	2	3	common		2
<i>Zanthoxylum mueller-stollii</i>	H.-J. Gregor	RUTACEAE	seed	1	1			rare		2

Table 3

Taxon	Author	Family	e / n	LEAF - TYPE	Habitu s	Ecolog y	Part (type of remain)	Species as named in Bertoldi and Martinetto, 1995	HUTE A CTEA TEWA	Clim.-biochron. groups
<i>Abies</i> sp.		PINACEAE	n	EC	t	m	leaf			
<i>Acer</i> (sect. <i>Platanoidea</i> ) sp.		SAPINDACEAE	n	D	t	m	fruit			
<i>Actinidia faveolata</i>	C. Reid et E.M. Reid	ACTINIDIACEAE	e	D	c	m	seed		CTEA	4
<i>Ajuga antiqua</i>	C. Reid et E.M. Reid	LAMIACEAE	n	/	h	m	fruit			
<i>Alangium deutschmanii</i>	H.-J. Gregor	ALANGIACEAE	e	E/D	t	m	endocarp		CTEA	1
<i>Alisma</i> sp.		ALISMACEAE	n	/	h	hy	seed			
<i>Alnus</i> sp.		BETULACEAE	n	D	s/t	hy	various			
<i>Ampelopsis ludwigii</i>	(A. Braun) D.H. Mai	VITACEAE	e	D	c	m/r	seed	<i>Ampelopsis malvaeformis</i>	CTEA	4
<i>Aralia</i> sp.		ARALIACEAE	e	D	s	m	seed		CTEA	
<i>Arctostaphylos</i> sp.		ERICACEAE	n	E	s	m	fruit	<i>Arctostaphyloides cf. menzeldii</i>		
<i>Boehmeria lithuanica</i>	Dorofeev	URTICACEAE	e	/	h	hy	fruit		CTEA	4
Cappaceae gen. et sp. indet.		CAPPARACEAE	e	E/D	h/s	m	seed	Menispermaceae gen. et sp. indet.		
<i>Carex</i> sp.		CYPERACEAE	n	/	h	hy	fruit			
<i>Carex panormitana</i> -type		CYPERACEAE	n	/	h	hy	fruit			
<i>Carex loliacea</i> -type		CYPERACEAE	n	/	h	hy	fruit			
<i>Carex</i> cf. <i>plicata</i>	Lancucka-Srodoniowa	CYPERACEAE	n	/	h	hy	fruit			
<i>Carex</i> sp. A		CYPERACEAE	n	/	h	hy	fruit	<i>Carex paucifloroides</i>		
<i>Carex pseudocyperus</i>	L.	CYPERACEAE	n	/	h	hy	fruit			
<i>Carex</i> sp. B		CYPERACEAE	n	/	h	hy	fruit			
<i>Carpinus betulus</i>	L.	BETULACEAE	n	D	t	m	fruit			
<i>Carpinus</i> cf. <i>europaea</i>	Negru	BETULACEAE	n	D	t	m	fruit			

<i>Carpolites pliocucurbitinus</i>	Martinetto Gossmann ex	INCERTAE SEDIS	/	/	/	/	fruit/seed	<i>Carpolithes cucurbitinus</i>		
<i>Cathaya vanderburghii</i>	Winterschei d et Gossmann	PINACEAE	e	EC	t	m	cone		CTEA-added	
<i>Chamaecyparis</i> sp.	(D.H. Mai) Pingen, Ferguson et Collinson	CUPRESSACEAE	e	EC	t	m	various		CTEA	
<i>Cinnamomum costatum</i>		LAURACEAE	e	E	t	m	fruit		HUTE A	3
Cornaceae? indet.		CORNACEAE?	/	E/D	s/t	m	fruit	<i>Myrica</i> cf. <i>altenburgensis</i>		
<i>Cornus discimontana</i>	D.H. Mai	CORNACEAE	n	D	s/t	m	fruit			
<i>Cornus maii</i>	Martinetto (Unger) Z. Kvaček, Buzek et Manchester	CORNACEAE	n	D	s/t	m	fruit	<i>Swida gorbunovii</i>		
<i>Craigia bronni</i>		TILIACEAE	e	D	t	m	fruit	<i>Pteleaecarpum bronnii</i>	HUTE A	
<i>Cryptomeria rhenana</i>	Kilpper	CUPRESSACEAE	e	EC	t	m	various		CTEA	4
<i>Cyclea palatinati-bavariae</i>	H.-J. Gregor (Martinetto)	MENISPERMACEAE	e	E	c	m	endocarp		HUTE A	2
<i>Datisca gratioloides</i>	D.H. Mai	INCERTAE SEDIS	e	/	h	m	seed	<i>Carpolithes gratioloides</i>	TEWA	3
<i>Dulichium arundinaceum</i>	(L.) Britton	CYPERACEAE	e	/	h	hy	fruit			
<i>Ehretia europaea</i>	E.M. Reid (Brongniart) Jaenichen et al.	EHRETIACEAE	e	D	t	m	fruit	<i>Ehretia</i> sp.	HUTE A	1
<i>Engelhardia macroptera</i>		JUGLANDACEAE	e	E/D	t	m	fruit	<i>Paleocarya macroptera</i>	HUTE A	
<i>Erica</i> aff. <i>carnea</i>	L. (Ludwig)	ERICACEAE	n	E	h/s	m	seed			
<i>Eurya stigmosa</i>	D.H. Mai	PENTAPHYLACEAE	e	E	s	m	seed		HUTE A	3
cf. <i>Fagaropsis</i>		RUTACEAE	/	/	/	/	seed			
<i>Fagus</i> cf. <i>deucalionis</i>	Kovats	FAGACEAE	n	D	t	m	cupule or fruit	<i>Fagus</i> sp.		



<i>Ficus potentilloides</i>	D.H. Mai	MORACEAE	n	E	s/t	m	endocarp		TEWA	3
Hamamelidoideae indet.		HAMAMELIDACEAE	/	E/D	s/t	m	various	Hamamelidoideae gen. et sp. indet.		
" <i>Hartia</i> " <i>quinqueangularis</i>	(Menzel) D.H. Mai	THEACEAE?	e	E	s	m	fruit	<i>Hartia quinqueangularis</i>		
<i>Hypericum</i> sp. C		GUTTIFERAE	n	E/D	h/s	m	seed			
<i>Hypericum</i> sp. D		GUTTIFERAE	n	E/D	h/s	m	seed			
<i>Hypericum tertiaerum</i>	P. Nikitin	GUTTIFERAE	n	E/D	h/s	m	seed			4
<i>Ilex</i> cf. <i>cantalensis</i>	E. M. Reid	AQUIFOLIACEAE	n	E/D	s	m	seed			
<i>Ilex saxonica</i>	D.H. Mai	AQUIFOLIACEAE	n	E/D	s	m	seed			1
<i>Ilex</i> sp.	L.	AQUIFOLIACEAE	n	E/D	s	m	seed			
<i>Ilex thuringiaca</i>	D.H. Mai	AQUIFOLIACEAE	n	E/D	s	m	seed			
<i>Juglans bergomensis</i>	(Balsamo-Crivelli) Massalongo	JUGLANDACEAE	e	D	t	m	endocarp		CTEA	5
Lamiaceae gen. et sp. indet. B		LAMIACEAE	/	/	h	m	fruit			
Lamiaceae gen. et sp. indet. C		LAMIACEAE	/	/	h	m	fruit			
<i>Leucothoe</i> aff. <i>narbonnensis</i>	(Saporta) D.H. Mai	ERICACEAE	e	E/D	s	m	fruit		CTEA	
<i>Leucothoe</i> sp. A		ERICACEAE	e	E/D	s	m	fruit		CTEA	
cf. <i>Lindera</i>		LAURACEAE	/	/	/	/	endocarp			
<i>Liquidambar europaea</i>	Al. Braun	ALTINGIACEAE	e	D	t	m/r	infrutescence	<i>Liquidambar magniloculata</i>	TEWA	
<i>Liriodendron geminata</i>	Kirchheimer	MAGNOLIACEAE	e	D	t	m	seed		CTEA	5
<i>Litsea sonntagii</i>	H.-J. Gregor	LAURACEAE	e	E/D	s/t	m	endocarp	<i>Gironniera?</i> cf. <i>carinata</i>	CTEA	2
	Muhl. ex W.P.C.	LAMIACEAE	n	/	h	hy	fruit			
<i>Lycopus</i> aff. <i>americanus</i>	Barton	LAMIACEAE	n	/	h	hy	fruit			
<i>Magnolia allasoniae</i>	Martinetto	MAGNOLIACEAE	e	E/D	s/t	m	seed		CTEA	2
<i>Magnolia ludwigii</i>	Ettingshausen	MAGNOLIACEAE	e	E/D	s/t	m	seed	<i>Magnolia lignita</i>	CTEA	2
<i>Magnolia</i> sp.		MAGNOLIACEAE	e	E/D	s/t	m	fruit		CTEA	

<i>Mahonia staphyleaeformis</i>	D.H. Mai et Walther	BERBERIDACEAE	e	E	s	m	seed		CTEA	
<i>Mallotus maii</i>	Martinetto	EUPHORBIACEAE	e	D	t	m	seed	<i>Mallotus</i> sp. A	HUTE A	2
<i>Meliosma canavesana</i>	Martinetto (Ludwig)	SABIACEAE	e	E	s/t	m	endocarp	<i>Meliosma</i> aff. <i>reticulata</i>	CTEA	1
<i>Meliosma wetteraviensis</i>	D.H. Mai	SABIACEAE	e	D	s/t	m	endocarp		HUTE A	3
<i>Melissa</i> sp.		LAMIACEAE	n	/	h	m	fruit			
<i>Mentha</i> sp.	L.	LAMIACEAE	n	/	h	r/m	fruit			
<i>Nuphar canaliculatum</i>	C. Reid et E.M. Reid (Ludwig)	NYMPHAEACEAE	n	/	h	a	seed			
<i>Nyssa disseminata</i>	Kirchheimer	NYSSACEAE	e	D	t	m	endocarp	<i>Nyssa sibirica</i>	CTEA	
<i>Ocotea</i> sp. A		LAURACEAE	e	E	t	m	fruit		TEWA	1
<i>Oenanthe</i> sp.		APIACEAE	n	/	h	hy	fruit			
<i>Olea</i> cf. <i>moldavica</i>	Negru	OLEACEAE	n	E	s/t	m	endocarp		TEWA	
cf. <i>Ostrya</i>		INCERTAE SEDIS	/	/	/	/	fruit			
<i>Paulownia cantalensis</i>	(E.M. Reid) D.H. Mai in Martinetto (C. Reid et E.M. Reid) C. Reid et E.M. Reid	PAULOWNIACEAE	e	D	t	m	seed		HUTE A	
<i>Phellodendron</i> cf. <i>elegans</i>		RUTACEAE	e	D	t	m	seed		CTEA	
cf. <i>Phoebe</i> sp.		LAURACEAE	/	/	t	m	calyx	<i>Phoebe</i> sp.		
<i>Phytolacca salsoloides</i>	Martinetto Herbst emend. D.H. Mai (Unger)	PHYTOLACCACEAE	e	/	h	m	seed		CTEA	1
<i>Pinus</i> cf. <i>spinosa</i>	Heer	PINACEAE	n	EC	t	m	cone	<i>Pinus</i> cf. <i>massalongi</i>		
<i>Pinus hampeana</i>	Grisebach	PINACEAE	n	EC	t	m	cone			
<i>Pinus peuce</i>		PINACEAE	n	EC	t	m	cone			
<i>Pinus</i> sp.		PINACEAE	n	EC	t	m	cone			
<i>Polygonum</i> sp.		POLYGONACEAE	n	/	h	m	fruit			
<i>Potamogeton</i> sp.		POTAMOGETONACE AE	n	/	h	hy	endocarp			

<i>Proserpinaca reticulata</i> cf. <i>Pseudotsuga</i>	C. Reid et E.M. Reid	HALORAGACEAE	e /	h	hy	fruit			
		PINACEAE	/ EC	t	m	cone	not mentioned		
<i>Pterocarya limburgensis</i> <i>Quercus</i> sp.	C. Reid et E.M. Reid	JUGLANDACEAE	n D	t	m	fruit			
<i>Ranunculus</i> cf. <i>tanaiticus</i>	Dorofeev (Kirchheimer ) D.H. Mai	FAGACEAE	n E/D	t	m/hy	various			
<i>Rehderodendron ehrenbergii</i>		RANUNCULACEAE	n /	h	m/hy	fruit			
<i>Rhododendron</i> sp.		STYRACACEAE	e D	s/t	m	fruit		HUTE A	2
<i>Rosaceae</i> indet.		ERICACEAE	n D	s/t	m	fruit			
		ROSACEAE	n D	s	m	various			
<i>Rubus microspermus</i>	C. Reid et E.M. Reid	ROSACEAE	n D	s	m	endocarp			
<i>Rubus semirobundatus</i>	Lancucka- Srodoniowa	ROSACEAE	n D	s	m/hy	endocarp			
<i>Sambucus pulchella</i>	C. Reid et E.M. Reid	ADOXACEAE	n D	s	m	endocarp			
<i>Sapindoidea margaritifera</i>	(Ludwig) Kirchheimer	SAPOTACEAE?	/ /	/	m	?		TEWA HUTE A	1 1
<i>Saurauia</i> sp.		ACTINIDIACEAE	e E/D	t	m	seed	<i>Erica</i> aff. <i>carnea</i> L.		
<i>Schoenoplectus</i> sp.		CYPERACEAE	n /	h	hy	fruit	<i>Scirpus</i> sp.		
<i>Selaginella kunovicensis</i>	Knobloch	SELAGINELLACEAE	n /	h	m	megaspore			
<i>Selaginella moravica</i>	Knobloch	SELAGINELLACEAE	n /	h	m	megaspore			
<i>Sequoia abietina</i>	(Brongniart) Knobloch	CUPRESSACEAE	e EC	t	m	seed			
<i>Sinomenium cantalense</i>	(E. Reid) Dorofeev	MENISPERMACEAE	e E	c	m/r	endocarp		HUTE A	3
<i>Solanum</i> cf. <i>dulcamara</i>	L.	SOLANACEAE	n /	h	m/hy	seed			
<i>Sparganium nanum</i>	Dorofeev in Kolakovskij	SPARGANIACEAE	n /	h	hy	fruit			3
<i>Spiraea</i> sp.		ROSACEAE	n D	s	m	fruit			
<i>Stemona germanica</i>	(Knobloch et D.H. Mai) D.H. Mai	STEMONACEAE	e E	c	m	seed	<i>Spirellea</i> aff. <i>bohemica</i>	HUTE A	3
<i>Styrax</i> sp.		STYRACACEAE	n D	s/t	m	endocarp		TEWA	
<i>Symplocos casparyi</i>	Ludwig	SYMPLOCACEAE	e E	s/t	m	fruit	<i>Symplocos</i>	HUTE	3

									<i>durensis</i> , <i>S.</i> <i>lignitarum</i> , <i>S.</i> <i>salzhausenensi</i> <i>s</i>	A	
<i>"Sorbus" herzogenthensis</i>	(Menzel) H.- J. Gregor	SYMPLOCACEAE	e	E	s/t	m	endocarp			HUTE A	3
<i>Symplocos minutula</i>	(Sternberg) Kirchheimer	SYMPLOCACEAE	e	E	s/t	m	endocarp			HUTE A	1
<i>Symplocos schereri</i>	Kirchheimer	SYMPLOCACEAE	e	E	s/t	m	fruit			HUTE A	2
<i>Taiwania</i> cf. <i>paracryptomerioides</i>	Kilpper (Chandler)	CUPRESSACEAE	e	EC	t	m	cone	<i>Taiwania</i> sp.		HUTE A	
<i>Ternstroemia reniformis</i>	D.H. Mai (Unger) Z.	PENTAPHYLACEAE	e	E	t	m	seed			HUTE A	
<i>Tetraclinis salicornioides</i>	Z. Kvaček	CUPRESSACEAE	e	EC	s	m	cone				1
<i>Tetrastigma chandlerae</i>	Kirchheimer (Ludwig) H.- J. Gregor	VITACEAE	e	E	c	m	seed			TEWA HUTE A	1
<i>Toddalia latisiliquata</i>		RUTACEAE	e	E	c	m	seed			HUTE A	2
<i>Toddalia rhenana</i>	H.-J. Gregor (D.H. Mai) Z. Kvaček et Walther	RUTACEAE	e	E	c	m	seed			HUTE A	3
<i>Trigonobalanopsis exacantha</i>		FAGACEAE	/	E	t	m	cupule?				1
Betulaceae indet.		BETULACEAE	/	D	t	m	fruit	<i>Tubela</i> sp.			
<i>Turpinia</i> cf. <i>ettingshausenii</i>	(Engelhardt) D.H. Mai	STAPHYLEAECEAE	e	E	t	m	fruit			HUTE A	1
cf. <i>Viburnum</i>		VERBENACEAE	/	/	s	/	endocarp				
<i>Viola</i> sp.		VIOLACEAE	n	/	h	m	seed				
<i>Viola</i> cf. <i>neogenica</i>	D.H. Mai et Walther	VIOLACEAE	n	/	h	m	seed	<i>Viola</i> sp.			
<i>Viola</i> sp. <i>B</i>		VIOLACEAE	n	/	h	m	seed				
<i>Visnea germanica</i>	Menzel	PENTAPHYLACEAE	e	E	s	m	fruit			TEWA	1
<i>Visnea?</i>		PENTAPHYLACEAE?	/	/	/	/	?				
<i>Vitis</i>		VITACEAE	n	D	c	m/r	seed				
<i>Vitis sylvestris</i> -type		VITACEAE	n	D	c	m/r	seed	<i>Vitis</i> <i>parasylyvestris</i>			

<i>Vitis teutonica</i>	A. Braun (H.-J. Gregor) H.- J. Gregor	VITACEAE	n	D	c	m/r	seed	<i>Vitis teutonica</i>	1
<i>Zanthoxylum ailanthiforme</i>	H.-J. Gregor	RUTACEAE	e	E/D	s/t	m	seed		2
<i>Zanthoxylum cf. tiffneyi</i>	H.-J. Gregor	RUTACEAE	e	E/D	s/t	m	seed		
<i>Zanthoxylum mueller-stollii</i>	H.-J. Gregor	RUTACEAE	e	E/D	s/t	m	seed		2
<i>Zanthoxylum</i> sp.		RUTACEAE	e	E/D	s/t	m	seed	<i>Zanthoxylum</i> sp.	

### Highlights

- New palaeofloral, magnetostratigraphic and foraminiferal data from Italy
- Rich palaeoflora in continental sediments deposited during the late Gilbert chron
- Biogeographic-climatically relevant taxa indicate a “subtropical humid forest”
- Ca' Viettone locality as reference site for a late Zanclean regional Florenkomplex
- One of the best European vegetation records during early Pliocene warmth

ACCEPTED MANUSCRIPT

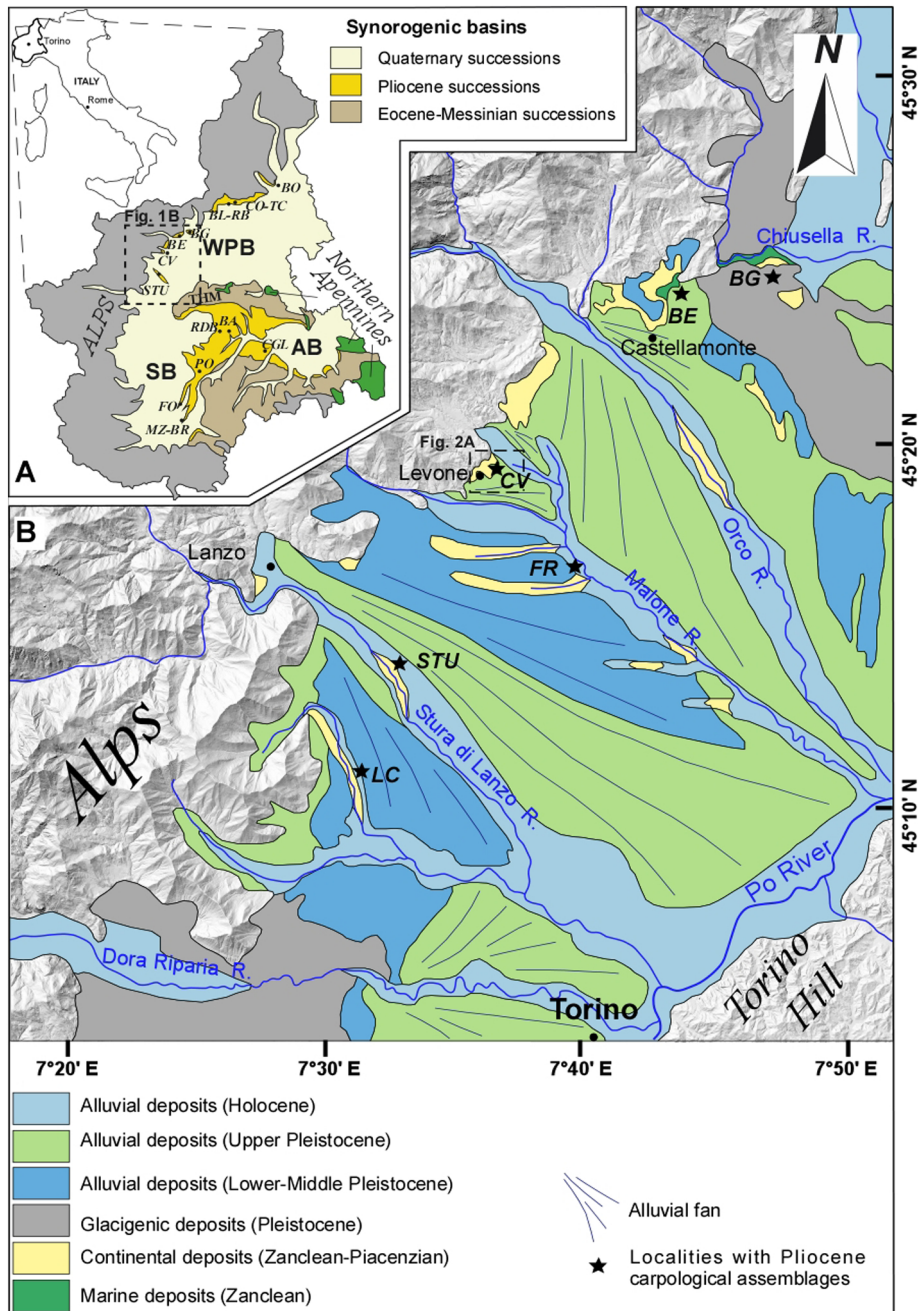


Figure 1

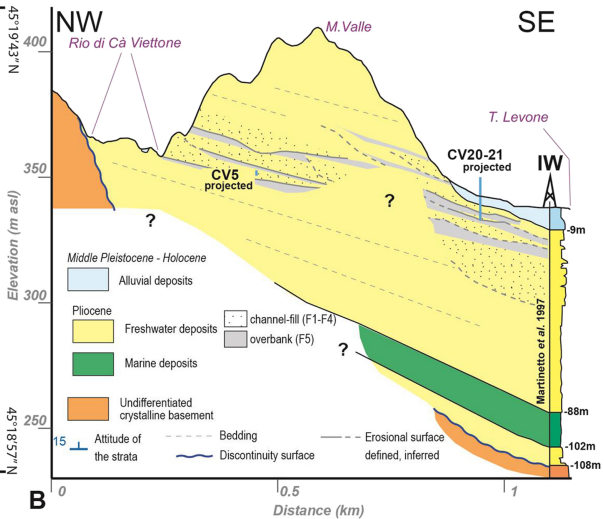
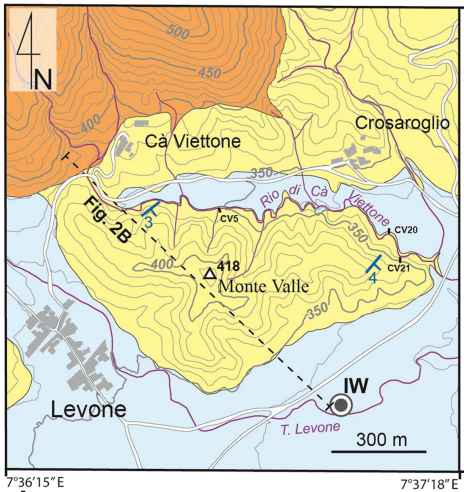
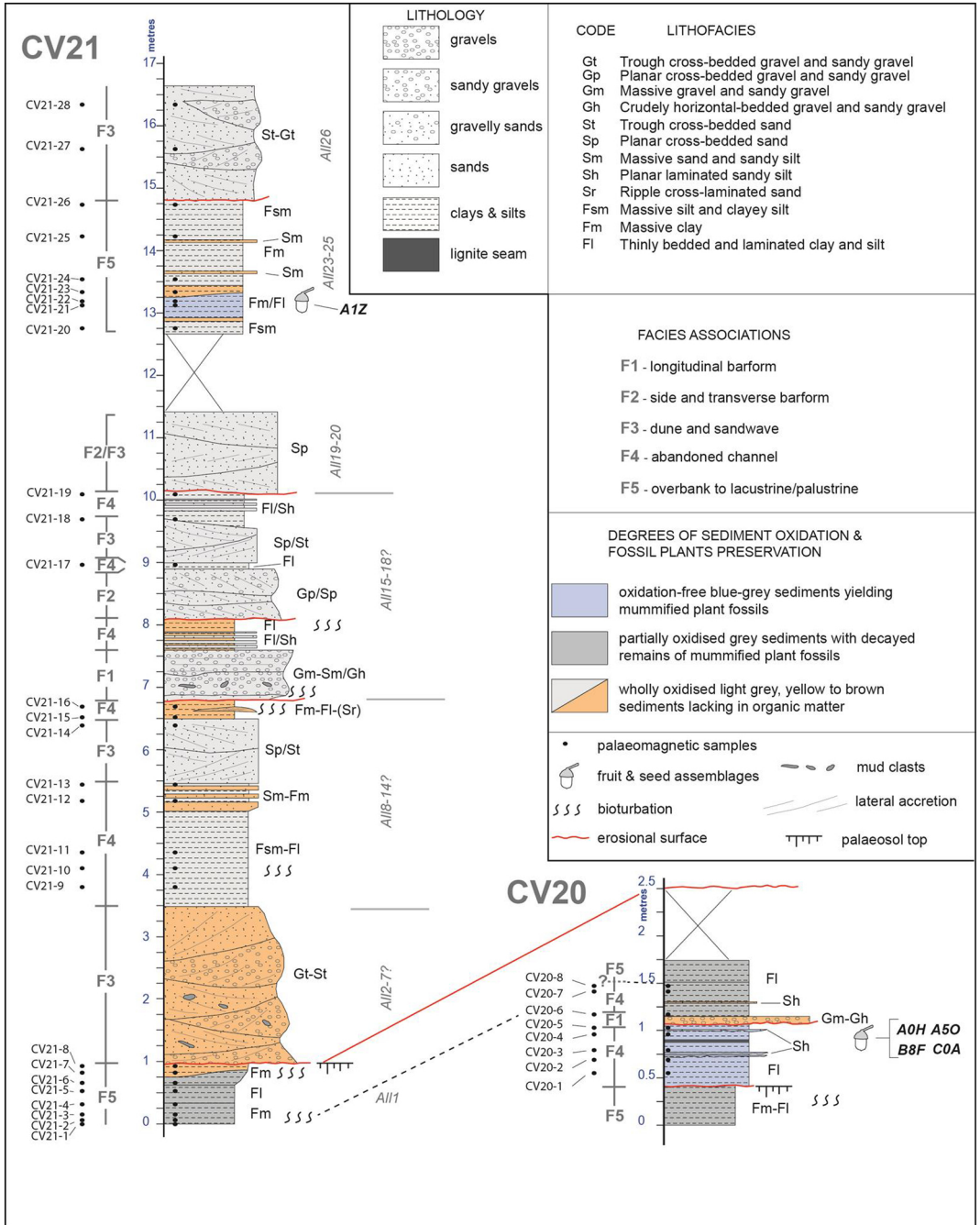


Figure 2





## CV20

**CV20 Stratigraphy:**

- CV20-8: F5
- CV20-7: F4
- CV20-6: F4
- CV20-5: F1
- CV20-4: F4
- CV20-3: F4
- CV20-2: F4
- CV20-1: F5

Figure 3

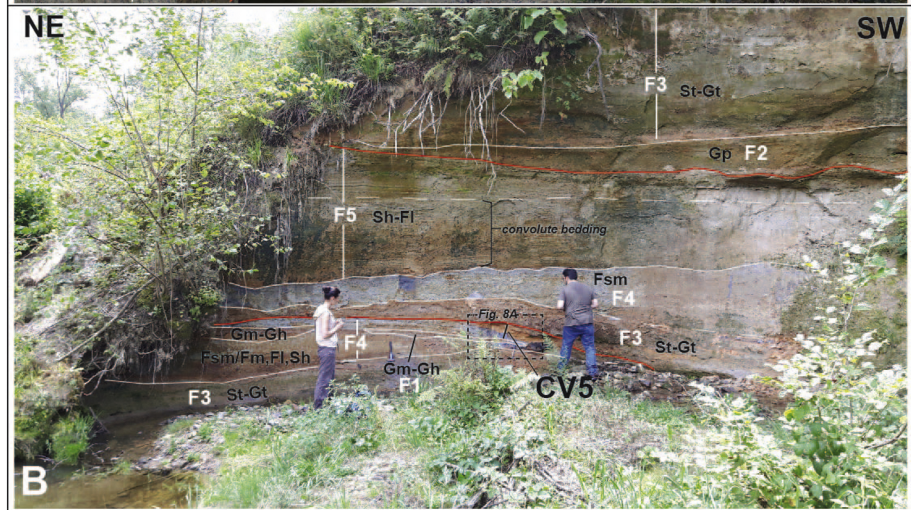
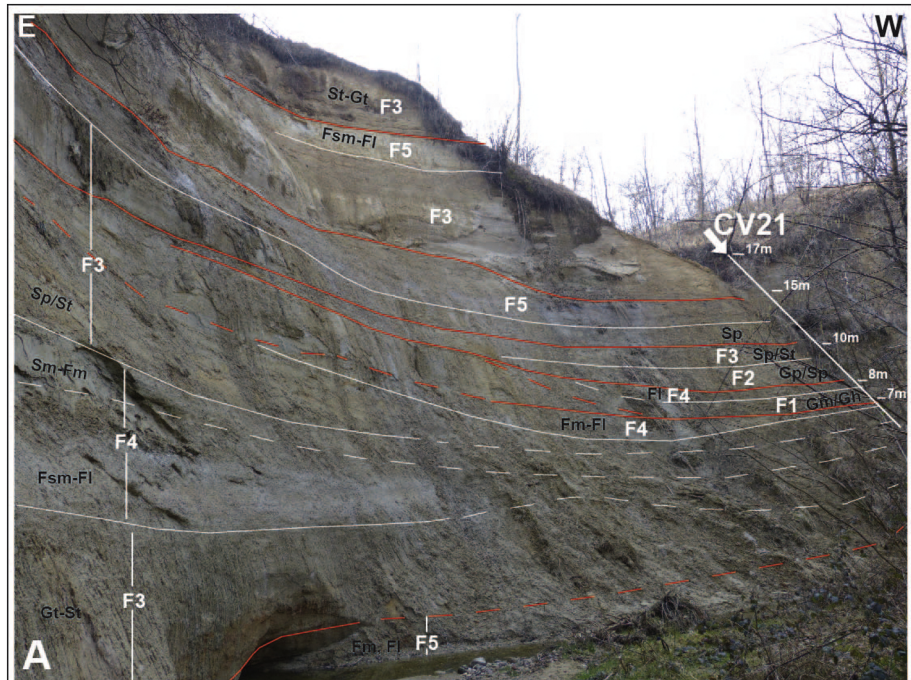


Figure 4

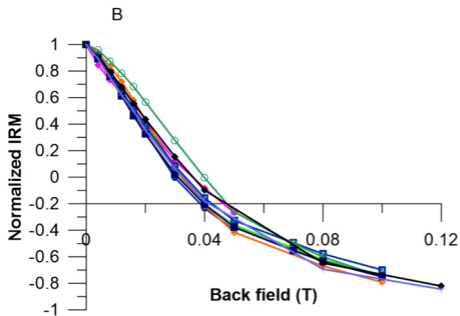
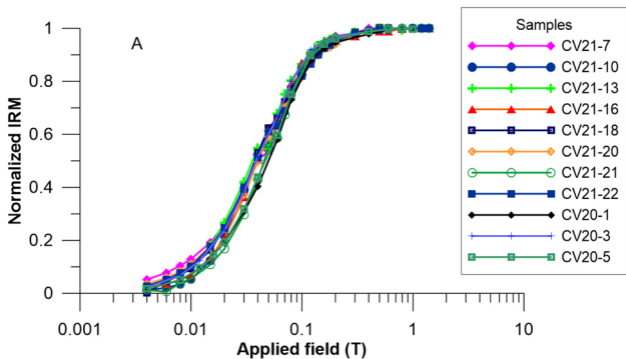


Figure 5

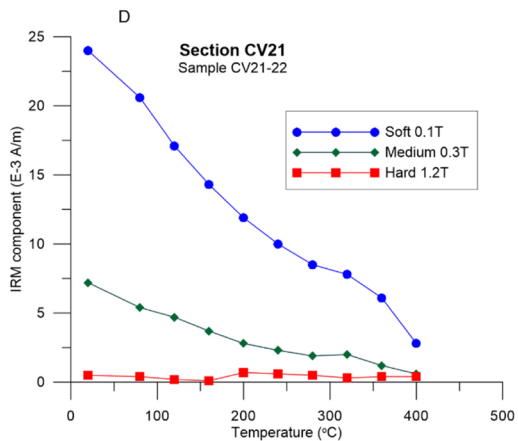
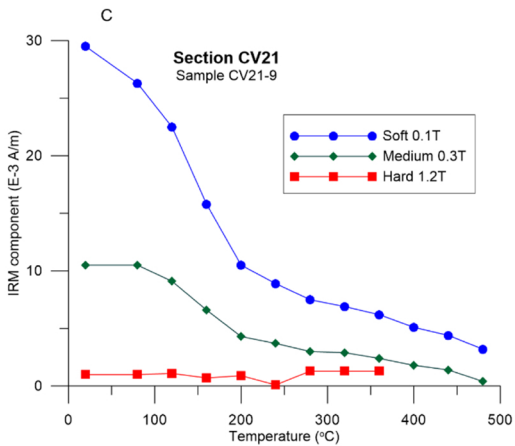
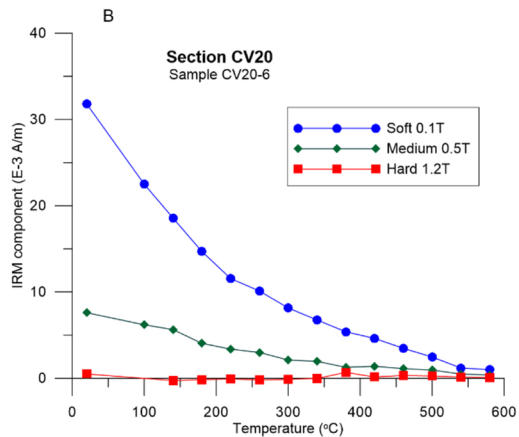
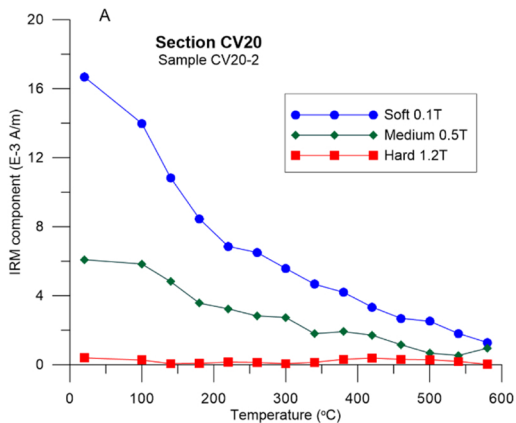


Figure 6

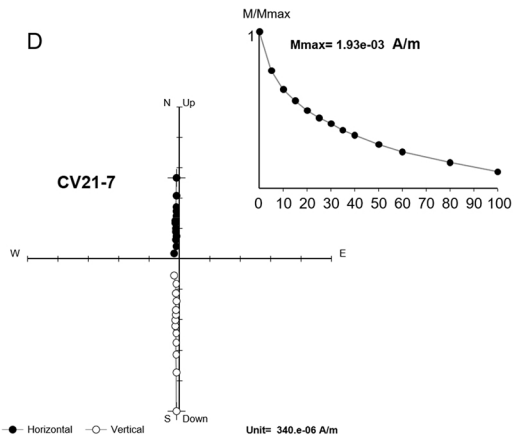
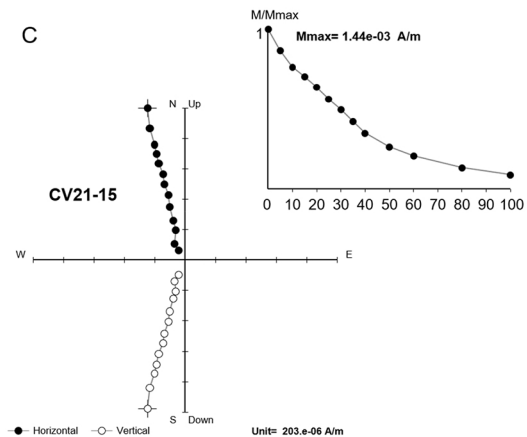
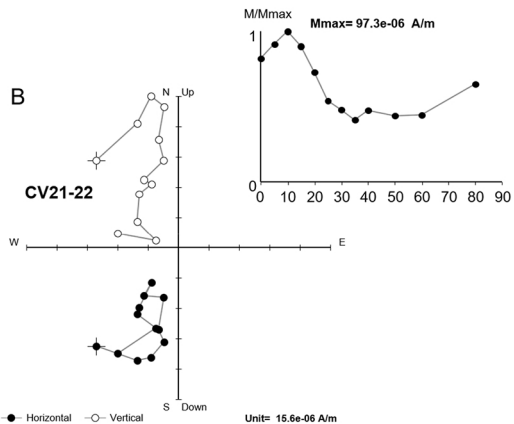
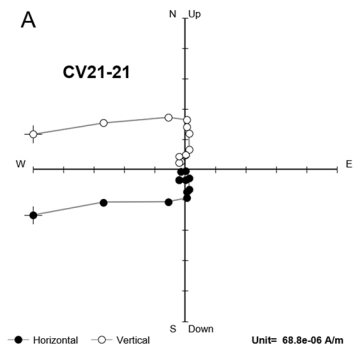


Figure 7

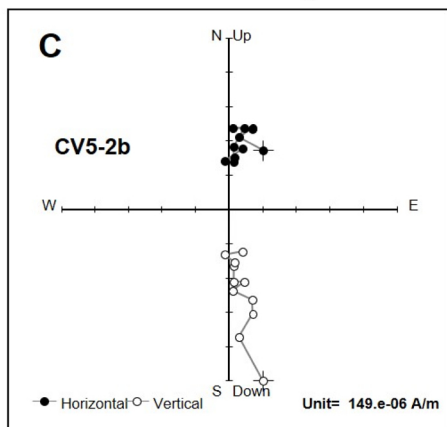
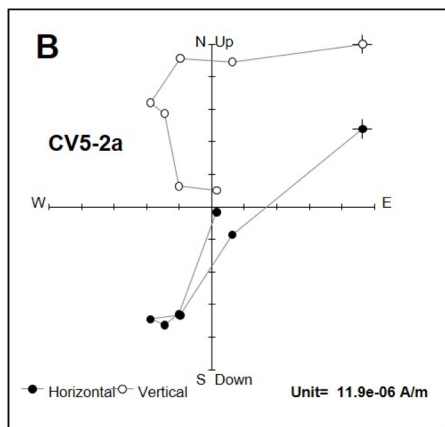
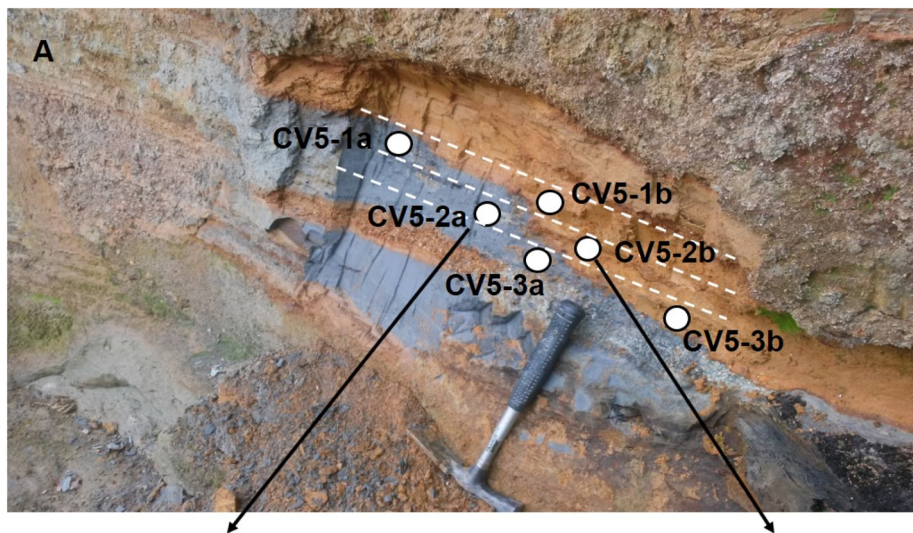


Figure 8

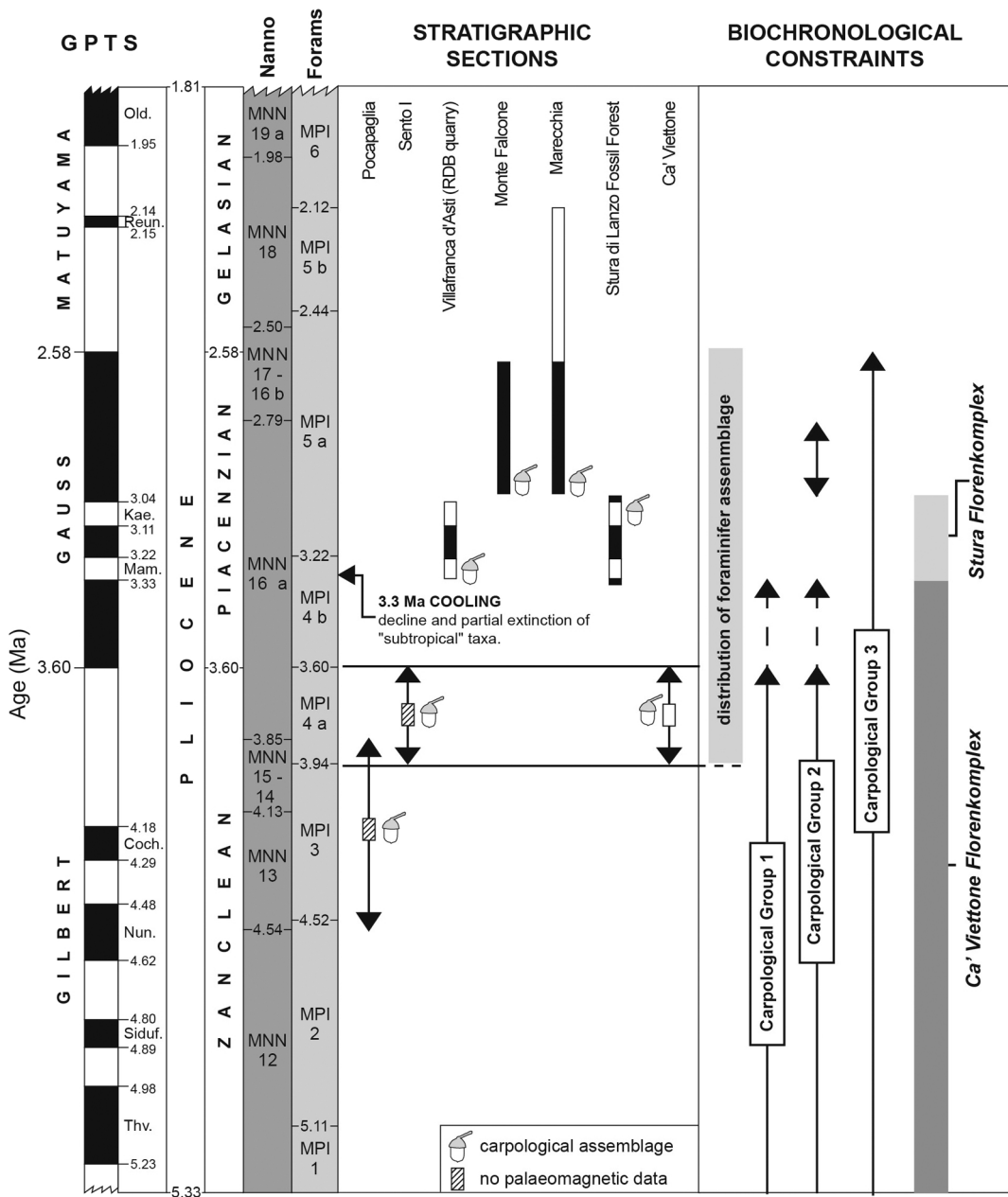


Figure 9

Series and Stage	MIO	PLIOCENE					PLEISTOCENE			Ca' Viettone	Breolungi	Pocapaglia	Sento I	Sento II	Fossano I FO2-FO3	Chiavenna CVE1-2	Villafranca RDB	Front FR1-2	Stura FF	HUTEA/CTEA/TEWA	Groups with biochronological relevance
	Mes	Zanclean	Piacenzian		Gelasian	Calabrian	MP														
Age (Ma)	7.0-5.3	5.3	4.5	4.0	3.6	3.3	3.1	2.6 to 1.8	1.8 to 0.8	0.0-0.0											
Marine biozones		MPL2	MPL3	MPL4			MPL5														
Magnetic polarity		[Magnetic polarity bar chart showing alternating black and white segments]																			
Intervals covered by dated carpofloras		[Shaded bars indicating dated carpofloras across the timeline]																			
Main Köppen climate type		Cfa					Cfa		Cfa/Cfb			Cfa/b	D	Cfa/b							
<i>Alangium deutschmannii</i> Geissert et Gregor														X							C
<i>Ehretia europaea</i> E. M. Reid	?													X	X	X	X				H
<i>Symplocos minutula</i> (Stemberg) Kirchheimer														X	X	X					H
<i>Tetrastigma chandlerae</i> Kirchheimer														X	X						H
<i>Vitis teutonica</i> A. Braun														X	X	X	X				
<i>Sapindoidea margaritifera</i> (Ludwig) Kirchheimer														X	X	X					T
<i>Ilex saxonica</i> Mai	?													X	X	X					
<i>Meliosma canavesana</i> Martinetto														X	X	X					C
<i>Phytolacca salsoloides</i> Martinetto														X	X	X					C
<i>Ocotea</i> sp. A														X	?	X	X	X			T
<i>Saurauia</i> sp.														X	X	X	X				H
<i>Tetraclinis salicomioides</i> (Unger) Kvaček														X	X	X	X				T
<i>Trigonobalanopsis exacantha</i> (Mai) Kvaček & Walther														X	X	X	X				
<i>Turpinia ettingshauseni</i> (Engelhardt) Mai														X	X	X	X				H
<i>Visnea germanica</i> Menzel														X	X	X	X	X			T
<i>Zanthoxylum ailanthiforme</i> (Gregor) Gregor														X	X	X					C
<i>Zanthoxylum mueller-stollii</i> Gregor														X	X	X					C
<i>Cyclea palatinati-bavariae</i> Gregor														X	X		X				H
<i>Litsea Sonntagii</i> Gregor														X	X	X	X				C
<i>Magnolia ludwigii</i> Ettingshausen														X	X	X	X				C
<i>Mallothus maii</i> Martinetto														X	X	X	X				H
<i>Rehderodendron ehrenbergii</i> (Kirchheimer) Mai														X	X	X	X				H
<i>Symplocos schereri</i> Kirchheimer														X	X	X					H
<i>Toddalia latissiquata</i> (Ludwig) Gregor														X	X	X	X				H
<i>Magnolia allasoniae</i> Martinetto														X	X	X	X	X		?	C
<i>Ficus potentilloides</i> Mai														X	X	X	X	X			T
<i>Meliosma wetteraviensis</i> (Ludwig) Mai														X		X	X		X		H
<i>Cinnamomum costatum</i> (Mai) Pingen et al.														X	X	X	X				X
<i>Datisca gratioides</i> (Martinetto) Mai														X	X	X				X	T
<i>Eurya stigmosa</i> (Ludwig) Mai														X	X	X	X				C
<i>Sparganium nanum</i> Dorofeev														X	X	X	X		X	X	X
<i>Stemona germanica</i> (Mai) Mai														X	X	X	X				H
<i>Toddalia naviculaeformis</i> (E.M. Reid) Gregor														X	X	X					H
<i>Viola bergaensis</i> Mai et Walther														?			X	X	X	X	
<i>Sinomenium cantalense</i> (E.M. Reid) Dorofeev														X	X	X	X	X	X		H
<i>Toddalia rhenana</i> Gregor														X	X	X	X	X	X	X	H
<i>Symplocos casparyi</i> Ludwig														X	X	X	X	X			H
<i>Actinidia faveolata</i> C. & E.M. Reid														X		X	X		X		C
<i>Ampelopsis ludwigii</i> (Al. Braun) Kirchheimer														X	X	X	X				X
<i>Boehmeria lithuanica</i> Dorofeev														X	X	X		X	X	X	C
<i>Cryptomeria rhenana</i> Kilpper														X	X	X	X				C
<i>Hypericum tertiaerum</i> Nikitin														X			X	X	X		C
<i>Styrax maximus</i> (Weber) Kichheimer														?			X	X	X		T
<i>Juglans bergomensis</i> (Balsamo-Crivelli) Massalongo														X		X					C
<i>Liriodendron geminata</i> Kirchheimer														X	X	X	X				C
<i>Phellodendron elegans</i> (C. et E.M. Reid) C. et E.M. Reid														?	?	X		X	X		C
<i>Viola neogenica</i> Mai et Walther														?			X	X	X		

Figure 10