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# Pliocene and Early Pleistocene carpological records of terrestrial plants from the southern border of the Po Plain (N-Italy)

Edoardo Martinetto [a*], Giovanni Monegato [b], Andrea Irace [b], Stefano Claudio Vaiani [c], Elena Vassio [a]

[a] Dipartimento di Scienze della Terra, Università degli Studi di Torino. Via Valperga Caluso 35, I-10125 Torino, Italy; edoardo.martinetto@unito.it

[b] CNR - IGG Institute of Geosciences and Earth Resources. Via Valperga Caluso 35, I-10125 Torino, Italy

[c] Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università degli Studi di Bologna. Via Zamboni 67, I-40126 Bologna, Italy, stefano.vaiani@unibo.it

*KEY WORDS* - Fruits and seeds, biochronology, Italy, Pliocene and Early Pleistocene.

*ABSTRACT* - The analysis of fruit and seed assemblages in Pliocene and Early Pleistocene successions of the southern border of the Po Plain showed that these deposits contain an interesting record of the terrestrial palaeoflora which integrates the information provided by the extensive pollen record available in this area. We could fix in the geological time scale, locally with a precision of 100 ka, 14 carpoflora-bearing layers spanning from 5.1 to 0.9 Ma, thus obtaining a framework which is not available in any other parts of Europe. This permitted us to provide precise ages for the occurrence of fruits and seeds of a few plant groups with a proven late Cenozoic differentiation (*Carex, Hypericum, Thymelaea*), as an important support to future phylogenetic analyses. However, our main aim is to evaluate the usefulness of our dataset for biochronological analyses. At first glance, the fossil record of several species showed an interesting distribution, often limited to one to three chronostratigraphic stages among the Zanclean, Piacenzian, Gelasian and Calabrian. An elementary palaeoclimatic characterisation of the individual species, but also of the plant assemblages, suggests that a temperature decrease is one of the causes of the observed palaeofloral differences. The input of the new data into the CENOFITA database led to an improvement of the chart of the distribution of carpological taxa in the Pliocene and Early Pleistocene of northern Italy. Within this new chart, the carpological species were clustered in groups with a similar chronologic distribution, which are useful for the biochronological interpretation of undated carpological assemblages.

## 1. Introduction

The Pliocene and Early Pleistocene (Zanclean-Calabrian) continental palaeoflora of northern Italy, as well as its ecological and climatic interpretation, has been documented by several papers dealing with rather long pollen sequences (Lona and Bertoldi, 1973; Ravazzi and Rossignol Strick, 1995; Bertini, 2001 and 2010) and by macrofloral records referred to more limited chronostratigraphic intervals (Gregor, 1990; Mai, 1995; Basilici et al., 1997; Martinetto, 1995, 1999, 2001b and 2003; Martinetto and Sami, 2001; Martinetto et al., 2007 and 2012; Ghiotto, 2010).

Due to the possibility to precisely identify several carpological taxa at species level much detailed macrofloral data are presently provided by fruits and seeds (carpological remains), whose Zanclean-Calabrian records from northern Italy (34 localities in Fig. 1) have been listed into the CENOFITA database (Martinetto and Vassio, 2010). The richest carpological assemblages are reported mainly from shallow marine and continental sections of NW Italy (Fig. 1), whose precise chronological framing is usually problematic (Bertoldi and Martinetto, 1996; Martinetto, 1999; Cavallo and Martinetto, 2001; Martinetto et al., 2007).

Since the first analyses on the Pliocene fruit and seed assemblages in northern Italy (Gregor, 1986; Martinetto, 1995) it was noticed that the species composition varied conspicuously from older to younger strata, and was able to provide useful information on the floral change from 5 to 1 Ma. Therefore, a long-lasting research for fruit-bearing layers in stratigraphically well-framed sections has been carried out in northern and central Italy, discontinuously, for the last 20 years (Martinetto, 1994, 1999 and 2001a; Martinetto et al., 2007). Recently, new interest for the examination of the material from the studied sections was raised by studies on continental sections of NW-Italy, where the concomitant occurrence of some carpological taxa seems to be crucial for the chronologic framing of the deposits (Irace et al., 2012).

The first aim of this paper is to point out the presence of rather rich assemblages of carpological remains of terrestrial plants in Pliocene and Early Pleistocene successions exposed along the southern border of the Po Plain, thus improving the preliminary reports by Gregor (1986 and 1990). Additionally, we wanted to obtain an updated scheme reporting the occurrence of such plant taxa in the Zanclean-Calabrian of northern Italy and we tried to recognize in this fossil record the signal of changes in the terrestrial flora (and vegetation). We also wanted to discuss the possible causes of the appearance and disappearance of the plant species in the fossil record, by considering environmental changes, migrations as well as phylogeny of those plant taxa with a proven diversification in the last 5 Ma (e.g., Thymelaeaceae: Galicia-Herbada, 2006; Cyperaceae: Jiménez-Mejías and Martinetto, 2013).

## 2. Geological setting and material

## 2.1 Geological setting

During the Pliocene-Early Pleistocene interval the southern side of the Po Plain area was affected by the compressional N-NE-verging Apennine tectonic activity, which was responsible for the formation of coeval but distinct and structurally separated thrust-top and foredeep basins (e.g., Ricci Lucchi, 1986; Ghielmi et al., 2010).

At the western termination of the Po Plain, the Plio-Pleistocene Piedmont Basin evolved as a wide wedge top basin, bounded to the north by the westernmost arc of the Padane thrust front (Fig. 2). To the south-east, the Castell’Arquato Basin acted as a closed piggy-back basin on top of Apennine thrust fronts. The Adriatic Foredeep developed in the south-eastern sector of the Po Plain.

During the Piacenzian-Calabrian time span, transitional to continental successions were deposited in the Piedmont Basin, while deep water to shelfal units filled the Castell’Arquato and the Adriatic Foredeep basins (Fig. 3). In these basins paralic and continental facies appeared only in the Calabrian.

## 2.2 Stratigraphic sections and carpological material

The fossil fruit and seed material studied in this work comprises both previously unpublished material from freshly analysed sediment samples (East area samples in Fig. 4) and taxonomically revised collection material (West area samples, Fig. 4). All these carpological samples were prepared starting from bulk sediment samples collected in well constrained sections along the southern side of the Po Plain (Fig. 2). Seven Pliocene-Lower Pleistocene successions of marine to transitional environment were taken into consideration in the East area, and compared with the existing records of 3 sections from the West area (Fig. 3). In both areas, several successions, straddling the Pliocene-Early Pleistocene time interval (Barbieri, 1967; Colalongo, 1969;

Cremonini et al., 1969; Iaccarino and Monegatti, 1996; Rio et al., 1997; Monegatti et al., 2002; Roveri and Taviani, 2003; Calabrese and Di Dio, 2009), are particularly suitable for palaeobotanical studies due to the frequent occurrence of layers with terrestrial plant remains. Recent magnetostratigraphic analyses (Gunderson et al., 2012, 2014) fixed to the end of the Early Pleistocene some layers with rich palaeofloras in the Stirone (Gregor, 1990) and Enza (Iaccarino and Monegatti, 1996) sections; the same age has been proposed by Muttoni et al. (2011) for the leaf-bearing Oriolo section (Martinetto and Sami, 2001), which is not reconsidered here because of the scarcity of carpological remains.

The palaeocarpological analyses of samples collected in the West area (Fig. 3) concerned the record of two beds from the Argille Azzurre Fm. (BR3, PO1), already described by Martinetto (1995) and Cavallo and Martinetto (1996). Micropalaeontological (Casnedi, 1971; Pavia et al., 1989; Violanti, 2012) and stratigraphic (Vigna et al., 2010) studies assigned the marine sediments of this formation, in the studied area, to the Zanclean, and precisely to biozones MPL2 and MPL3 (5.1-3.8 Ma). Three other layers (RDB1, RDB6, RT1), sampled in the Villafranchian type area (Fig. 2), represent the continental deposits of the “Villafranchian lower complex” (*sensu* Carraro, 1996), which were ascribed to the middle Piacenzian (Boano et al., 1999; Napoleone et al., 2003; Martinetto et al., 2007). In this basin dated sites with Gelasian or Calabrian carpological assemblages are lacking.

In the East area, seven sections (1-7 in Fig. 3) were sampled for carpological analysis. Among these, sections 1-4 belong to the Castell’Arquato Basin (Roveri and Taviani, 2003), which includes the historical Piacenzian stratotype (e.g., Mayer-Eymar, 1858; Pareto, 1865; Barbieri, 1967; Raffi et al., 1989). Sections 5-7 belong to the Adriatic Foredeep (Colalongo et al., 1982a and 1982b; Ricci Lucchi, 1986; Iaccarino and Monegatti, 1996).

The samples are located in stratigraphic logs (Fig. 3) that represent a portion of longer stratigraphic successions. As a whole, 21 samples of fruit and seed-bearing deposits were collected, 9 of which have been so-far analysed, as reported below:

1) **Chiavenna Rocchetta section** (Roveri and Taviani, 2003). This succession was deposited in a shelf environment during the Piacenzian. The sample CVE2 comes from a silty sand layer, rich in marine mollusc shells and with scattered terrestrial plant remains, cropping out on the left bank of the Chiavenna Creek, below the first calcarenitic body. According to the magnetostratigraphic data reported by Roveri and Taviani (2003) for a neighbouring drill-core, the CVE2 bed was attributed to the subchron Kaena.

2) **Lugagnano Quarry section** (Barbieri, 1967). This stratigraphic interval is assigned to the lower part of the Zanclean (MPL2 Zone) because of the occurrence of *Globorotalia margaritae* (listed as *Globorotalia hirsuta* by the author) and the absence of *Globorotalia puncticulata.* Benthic foraminiferal assemblages are highly diversified and include mainly *Bulimina aculeata minima, Bulimina costata, Cibicides pseudoungerianus, Siphonina reticulata, Sphaeroidina bulloides, Uvigerina peregrina, Uvigerina pigmea* and *Uvigerina rutila* (Barbieri, 1967). These species are considered to reflect deposition within an outer shelf or upper slope environment (e.g. Blanc-Vernet, 1969; Rasmussen, 2005; Schweizer, 2006). The presence of rare shallow marine taxa, specifically *Ammonia beccarii, Cribroelphidium semistriatum, Elphidium macellum* and *Elphidium complanatum*, suggests downslope transport during deposition. The sample LU1 was collected in a sandy silt layer rich in plant remains, in the middle portion of Barbieri's (1967) section 2. Gregor (1990) reported a list of carpological taxa gathered by hand-picking on the outcrop of the Lugagnano Quarry section, which included the species *Visnea germanica*.

3) **Castell'Arquato composite section (**Monegatti et al., 1997 and 2002; Roveri and Taviani, 2003**).** This composite section includes Zanclean to Calabrian marine sediments. Carpological samples have been collected in subsections Monte Falcone and Arda.

3a) **Monte Falcone subsection** (Monegatti et al., 2002). This succession includes silt and sand passing upward to dominant calcarenite, deposited within a shallow marine to coastal environment. Magnetostratigraphic analyses reveal the occurrence of normal polarity interval 2An.1n (Gauss Chron) of late Piacenzian age (Monegatti et al., 1997; 2002). The sample CQ1 was collected in the lower portion of the outcropping succession, within shallow marine silty sands rich in mollusc shells and with scattered terrestrial plant remains, deposited at 30-60 m water depth (Monegatti et al., 2002).

3b) **Arda subsection** (Dominici, 2001; Roveri and Taviani, 2003). The succession was deposited in a shoreface to inner shelf environment (5-40 m water depth). This represents the youngest part of the composite section, assigned to the Gelasian-Calabrian transition (Calabrese and Di Dio, 2009). The collection of samples from as much as four layers (AD3, AD6, AD7, AD9 in Fig. 3) was stimulated by the detailed stratigraphic and palaeoenvironmental analyses of Dominici (2001); however only the sample from the AD3 layer has been so-far analysed.

4) **Stirone section** (Papani and Pelosio, 1963)**.** The part of the historical Stirone River succession (Cremaschi, 1982; Dominici, 2001; Gunderson et al., 2012) considered in this work includes Gelasian and Calabrian sediments, showing shelf deposits passing upward to a cyclic alternation of shallow marine to continental deposits (Fig. 3). In the Calabrian portion (Stirone-Laurano in Martinetto, 1999), two samples were collected in layers rich of terrestrial plant remains (Fig. 3): LA1 comes from freshwater dark grey massive muds, immediately preceding the base of the Jaramillo subchron (Gunderson et al., 2012), which were rich in terrestrial plant remains associated to tree stumps in growth position; LA3 was collected in shallow-marine sands referable to the last 200 ka of the Matuyama chron (C1r.1r; Cremaschi, 1982; Gunderson et al., 2012).

These samples correspond, respectively, to beds S3 and S7-8 of Gregor (1986, 1990), from which this author reported abundant carpological remains, not yet subjected to a dateiled taxonomic treatment. Mai (1994) reported a cone of *Picea florschuetzii* Van der Hammen from "Millepioppi", the locality where Gregor's bed S3 (our LA1) was in outcrop during the 1980s.

5) **Enza Creek section** (Iaccarino and Monegatti, 1996). The lower part of this succession consists of shelf clays locally interbedded with calcarenites and sands. The upper part includes mainly coastal sands passing upward to continental sediments (Iaccarino and Monegatti, 1996). An age model for the section has been recently provided by Gunderson et al. (2014), combining magnetobiostratigraphic data with cosmogenic radionuclide burial dating and cyclostratigraphy. According to these authors, the section of Fig. 3 is almost entirely attributed to the Calabrian. The boundary between Calabrian and "Ionian" has been traced within continental sediments. Seven samples were collected (Fig. 3), however, only sample EZ38, providing a rich carpological assemblage, has been analysed so-far. Magnetostratigraphic analyses reveal that this sample has been collected in proximity of the upper boundary of Jaramillo subchron (Gunderson et al., 2014), allowing an age attribution of about 1.0 Ma. The depositional environment of plant-bearing samples has been investigated through analyses of foraminiferal assemblages in the whole section (Appendix A), showing an overall regressive tendency from inner shelf (EZ20) to coastal (EZ30-40) and continental environments (EZ50-51).

6) **Santerno River section** (Colalongo, 1969; Cremonini et al., 1969). The part of the Santerno River succession considered in this work, includes open marine clays with interbedded sands (Cremonini et al., 1969). The Gelasian-Calabrian boundary occurred in the lowermost portion of the analyzed section (Fig. 3; Colalongo, 1969). The sample SNT1 comes from a sandy layer, rich in phytoclasts (Gastaldo, 1994), which cropped out in the year 2001, close to the Gelasian-Calabrian boundary (Fig. 3). Foraminiferal assemblages of a 2.6 m-thick succession including the

sampled layer, have been investigated (Appendix A), in order to improve the biostratigraphic and palaeoenvironmental framework of plant-bearing sediments. Foraminiferal associations reveal an outer shelf depositional environment attributed to the *G. cariacoensis* biozone, according to comparable assemblages observed in the nearby Lamone section by Vaiani (2000).

7) **Marecchia River section** (Colalongo et al., 1982a; Rio et al., 1997). The part of the Marecchia River succession considered in this work, consists of slope sediments, represented by clays and sapropels, with subordinate sands. These deposits are ascribed to the late Piacenzian (Gauss Chron, normal polarity interval 2An.1n) according to the stratigraphic scheme reported by Rio et al. (1997). Three samples were collected in sandy beds below (MR1) and above (MR2, MR3) the sapropel bearing intervals M1 and M2 of Rio et al. (1997), possibly corresponding to sapropel cluster O of Roveri and Taviani (2003). Only the sample MR3 has been so-far analysed.

As a whole the analyzed sections are substantially well-calibrated within a detailed chronostratigraphic frame. This allows us to propose a rather precise chronological framing (locally with resolution of ca. 100 ka) of the plant-bearing layers (Tab. 1) and to place the East area analyzed material into a definite chronological order (Fig. 4).

## 3. Methods

This research was not intended to complete the analyses in a short time, since several weeks of analytic work are needed for each sample; rather, the aim was to sample and preserve for long time the carpological record provided by a few layers, often exposed in ephemeral sections, which had been calibrated, more or less precisely, from a chronostratigraphic point of view. In order to improve our knowledge of the biochronologic range of some key-species found in the late Cenozoic of northern Italy, we decided to analyse their occurrences in ten chronostratigraphically framed sections, cropping out along the southern border of the Po Plain (Fig. 2), where we distinguished a West area (Piedmont Basin in Fig. 3) from an East area (Castell'Arquato Basin and Adriatic Foredeep in Fig. 3). The stratigraphic position of the sampled layers is indicated in synthetic logs (Fig. 3), with the aim to favour the connection between palaeobotanical data and the results of other, already rich, stratigraphic records (mainly magnetostratigraphy, foraminifer and nannoplankton biostratigraphy).

Methodological approaches to the late Cenozoic biochronology of terrestrial plant fossils are discussed by Martinetto and Ravazzi (1997), Martinetto (1999), and Martinetto et al. (2007), who evidenced the scattered occurrence of plant macrofossils in the stratigraphic record. The biochronological analysis carried out in this paper procceded with the input of newly obtained occurrence data into the CENOFITA database (Martinetto and Vassio, 2010), in which the proved or inferred age of each fossil site is reported. Those species whose chronostratigraphic distribution in N-Italy appeared to be restricted to one or a few stages (Zanclean, Piacenzian, Gelasian, Calabrian) were singled out in order to evaluate their biochronologic potential, depending on biological and ecological features (habitat, growth form, dispersal mechanism, etc.), which are discussed below.

The collection of carpological samples was carried out outside the frame of specific projects, but profited from the results of stratigraphic studies carried out by other authors (Barbieri, 1967; Cremonini et al., 1969; Colalongo, 1969; Iaccarino and Monegatti, 1996; Rio et al., 1997; Dominici, 2001; Monegatti et al., 2002; Roveri and Taviani, 2003), which often permitted a correct lithostratigraphic positioning of the plant-bearing layers. Furthermore, in two of the studied sections a new sampling for foraminifer assemblages has been carried out in the attempt to improve the biostratigraphic framing of the plant-bearing beds (see Appendix A).

The labels used for the sampled layers are indicated in Table 1, and they are also used for indicating carpological samples, with the addition of a conventional code of 3 characters which designates all the carpological records of each individual sample in the CENOFITA database

(Letter-numer-Letter, e.g. A0B). The sediments (usually 4-30 $dm^3$) were treated according to the method described by Basilici et al. (1997), and floating material was collected with final mesh size of 0.3 mm. As for the sinking material, the removal of the clastic matrix left a very limited volume of plant-bearing residue (maximum 20% of the original volume). When completely dry, this was stored for long-term preservation, and analysed after variable times, up to 25 years after preparation (Stirone section). For the picking of fruit and seeds the residue of each sample was separated in 2 fractions: > 3 mm and < 3 mm: the coarser fraction was examined at naked eye, and the finer one under a Wild M3B stereomicroscope. Only a few selected carpological species with characteristic morphology (those listed in Fig. 4) were picked out, and we took care to proceed in a uniform way for all the samples. The identification of these species has been carried out by comparison to the CENOFITA collection of late Cenozoic carpological material (Martinetto and Vassio, 2010), which had been the subject of several taxonomical studies (Basilici et al, 1997; Cavallo and Martinetto, 2001; Martinetto, 2001a and 2001c; Mai and Martinetto, 2006; Jacques et al., 2011; Vassio, 2012; Jiménez-Mejías and Martinetto, 2013; Martinetto and Festa, 2013). In a few cases comparison to modern material has been necessary, and it was carried out in the carpological collection of the Museum für Naturkunde of Berlin (label MFN, without number) and in the Modern Carpological Collection of the Turin University (Martinetto et al., 2014), whose samples are indicated by the label MCC and designated by a collection number (e.g. MCC0001). Images of the fossil fruits and seeds (Plate I) were obtained obtained by using a Leica M205 C optical microscope integrated with Leica Microsystems' Leica DFC290 HD digital camera and Leica Application Suite software.

For the ecological and climatic characterisation of the fossil taxa we conducted a search for the nearest living relatives (NLRs), and we consulted the data contained in the ClimGrim (Grimm and Denk, 2012) and PALAEOFLORA databases (Utescher and Mosbrugger, 2013), as well as those reported in the supplementary material of Denk et al. (2013). The reconstructed thermal requirements of the species treated in this paper have been indicated by boundary values of Mean Annual Temperature (MAT in °C), as explained in Fig. 4. Furthermore, we determined the Köppen signature (of several species as explained by Denk et al. (2013). When the "potential modern analogs" (our NLRs) where not reported by these authors, we analysed the modern geographic distribution and we checked their Köppen climatic zone (see Supplementary material). We consulted Boufford (1997) for *Boehmeria*, Galicia-Herbada (2006) for *Thymelaea*, Fang et al. (2011) for Chinese plants, Hansen and Sunding (1993) for Macaronesian plants, Stevens (2014) for *Phytolacca* and *Stemona*, and Thomson et al. (1999a, 1999b) for North American plants.

## 4. Taphonomy

As discussed above, 10 of the 14 studied fruit and seed assemblages were formed in a marine or nearshore palaeoenvironment. Unfortunately there is no actuopalaeobotanical study dealing with the taphonomy fruits and seeds of terrestrial plants deposited on marine bottoms, so we do not know the degree of fidelity of such fossil record with respect to the contemporary flora and vegetation of the terrestrial environment. Zavala et al. (2012) illustrated, with specific reference to the Plio-Pliostocene sediments of the Eastern area, that the origin of the concentration of terrestrial plant remains in marine successions can be explained by a massive transport of terrestrial phytoclasts to the marine bottoms, carried out by the rivers. This allows us to interpret such marine assemblages in the light of the present knowledge on the relationships between vegetation and fruit and seed assemblages in fluvial deposits (Cappers, 1993; Gee, 2005; Vassio and Martinetto, 2012). These studies indicate that fruit and seed assemblages provide a record of the flora and vegetation of a broad area of the river's catchment, although with several mismatches. For our purposes, the above-mentioned studies also suggest that, given a fixed type of terrestrial flora, we must assume that the list of plants obtained by analysing fruits and seeds in different samples of marine sediment (with plant phytoclasts of terrestrial provenance) would be rather different from one sample to the other, just due to taphonomical processes. For this reason a large number of well-calibrated marine samples would be needed to reliably assess when a terrestrial plant species appeared, disappeared or became more or less frequent in the surrounding terrestrial areas.

In addition, the geological context of the studied marine successions suggests that the possibility of reworking of fossil plant remains has to be considered. In facts the progressive uplift of the northern Apennine foothills determined the exposure and erosion of the Pliocene sediments, and the recycling of their plant phytoclasts into the Pleistocene marine and continental basins is theoretically possible. There are very few reports in the literature about fruits and seeds in modern or fossil assemblages for which reworking from older sediments could be demonstrated (e.g., Thomasson, 1991). In light of the poor available evidence we suggest that reworked fossil fruits and seeds seem to be extremely rare.

## 5. Palaeobotanical results

### 5.1 Sample analysis

The analysis of the 9 palaeocarpological samples from the East area sections showed that fruits and seeds made up an extremely subordinate component of the phytoclasts (ca. 1 fruit/seed per 100-1000 wood fragments), and their taxonomic analysis indicated a prevalence of terrestrial plants, although fruits of the seagrass *Cymodocea* cf. *nodosa* occurred in several samples (see below). The palaeocarpological analysis of these samples did not permit so-far to obtain a complete list of taxa, but the presence/absence of the species listed in Fig. 4 was carefully checked into the residues of all samples.

The number of carpological species and specimens represented in different samples varies greatly. Samples CQ1, CVE2, EZ38, LA1, LU1 yielded poor assemblages in terms of number of both species (<20) and fruit/seed specimens (<50). Rich carpological assemblages, certainly with more that 30 species and more than 50 (but often>200) carpological specimens, were obtained from layers AD3, LA3, MR3 and SNT1.

## 5.2 Carpological data analysis

By analysing the whole CENOFITA dataset for N-Italy (Fig. 5) we could gather most species into six groups on the basis of the similar biochronologic distribution: Group 1, only Zanclean records; Group 2, records in the Zanclean and in the late Piacenzian (from 3.0 to 2.8 Ma); Group 3, records in the Zanclean and in the middle-late Piacenzian (from 3.3 to 2.8 Ma); Group 4, definite records in the (Zanclean-) Piacenzian, and clues for the persistence after the Piacenzian/Gelasian transition given by occurrences in localities under investigation (Irace et al., 2012); Group 5, records from (Zanclean-) Piacenzian to Calabrian, but not from the Middle Pleistocene onwards; Group 6, records in the (Gelasian-) Calabrian, and partly also from the Middle Pleistocene onwards. In general, the East area record (Fig. 4) fitted within the biochronologic distribution of each species provided by the analysis of the N-Italian CENOFITA dataset (Fig. 5), and only two species showed a broader distribution in the East area record (Fig. 4): *Eurya stigmosa* and *Sparganium nanum*, occurring here newly in the Gelasian. As an alternative explanation to the longer survival of these two species in the East area, we must consider the possible reworking of fruit and seed specimens from older sediments, already discussed above. Additionally, the East area samples did not contain any record of a few key-species which, according to the data of the N-Italian

CENOFITA database, would seem to be potentially useful for the biochronologic framing of the West area fluvial-alluvial successions: *Actinidia faveolata, Boehmeria lithuanica, Carex flagellata, Cryptomeria rhenana, Datisca gratioloides, Meliosma wetteraviensis, Styrax maximus, Schoenoplectus isolepioides, Symplocos schereri.* All of these occur in the West area samples reconsidered in this work (Fig. 4).

We also observe the lack in the East area samples of any record of Group 1 ("Zanclean") elements (Fig. 4), even in the Zanclean assemblage of Lugagnano (LU1). However, Gregor (1990) reported the occurrence in this locality of *Visnea germanica*, which suggests that we missed the Group 1 elements due to relatively small size of our sediment sample. The West area record shows that Group 1 elements are well represented in the Zanclean sample of Pocapaglia (PO1, over 100 $dm^3$ of sediment analysed: Cavallo and Martinetto, 1996; Repetto, 1997), whereas only 4 out of 10 species occur in the less intensively sampled layer of Breolungi (BR3, 19 $dm^3$).

The climatic characterisation of the species treated in this paper is shown by the boundary values of Mean Annual Temperature (MAT in °C) reported in Fig. 4, which permit to point out several thermophile species (e.g. MAT>9°C or >15°C, etc.), as well as cool-tolerant species (e.g. MAT>5°C or >3°C, etc.) and a few warm-intolenrant ones (e.g. MAT<14°C or <17°C). Furthermore, the Köppen climate type for the Pliocene plant assemblages (BR3, PO1, RDB1, RDB6, RT1, LU1, CVE2, MR3, CQ1) can be easily determined as Cfa, being this the single type shared by all the occurring plant taxa (see Supplementary material). For the Early Pleistocene assemblages (AD3, EZ38, LA1, LA3 and SNT1) the main Köppen signature is for the Cfa and Cfb climate types. Thus, our elementary climatic analysis does not point out a definite change of the Köppen climate types within the Pliocene and the Early Pleistocene assemblages studied. However, the boundary values of MAT (Fig. 4) distinctly show that the Pliocene floras are rich in thermophile species, that disappeared or became rare in the Early Pleistocene floras, which are mainly made up by cool-tolerant and warm-intolenrant species. This situation suggests that a decrease in temperatures is one of the causes of the palaeofloral differences observed between Pliocene and Early Pleistocene assembleges.

## 6. Occurrences of selected plant taxa

The complete list of taxa which have been studied in the West and East area samples is reported in Fig. 4, and in this section we provide additional information on selected species. The description of each species displays its occurrence only in the studied sections, expressed by the label of the plant-bearing layer, as reported in Tab. 1. Other known records of each species, even in the studied region, are reported under "*General distribution and characteristics*".

### Family Betulaceae

*Carpinus betulus* L.

1996 *Carpinus betulus* L. - Cavallo and Martinetto: pl. 5, fig. 2 (Pocapaglia, layer PO1).

*Occurrence:* West area: BR3, PO1 (Zanclean); RDB1, RDB6 (Piacenzian); East area: LU1 (Zanclean); CQ1, MR3 (Piacenzian); AD3 (Gelasian); SNT1 (early Calabrian), LA1, EZ38, LA3 (late Calabrian).

*General distribution and characteristics*: *C. betulus* has been selected for this analysis in order to evaluate the pattern of the fossil record of this plant, whose habit, ecology, and diaspore taphonomy are well known. This is a medium-sized deciduous tree, still living in the Po Plain nowadays, and characterizing its few relics of semi-natural forest vegetation (Pignatti, 1982). It is also a species frequently found in modern fruit and seed accumulations, where its wind-dispersed fruits are overrepresented with respect to the frequency in the surrounding vegetation (Gee, 2005; Vassio and Martinetto, 2012). Its fossil record in northern Italy covers all the intervals from latest Miocene (Messinian: Cavallo et al., 1986), through Pliocene (Pavia, 1970; Martinetto, 1994; Cavallo and Martinetto, 1996; 2001), Early Pleistocene (Martinetto and Sami, 2001; Ghiotto, 2010), Middle Pleistocene (Martinetto, 2009), to the Holocene (Vassio, 2012).

The lack of *C. betulus* in three Piacenzian samples (Fig. 4) can be explained by two possibilities: i) it was absent or very rare in the time slices corresponding to the deposition of the layers where its fruits are lacking; ii) it was present in the time slices corresponding to the deposition of the layers where its fruits are lacking, but has not been recorded. We would propend for the second hypothesis and conclude that our data contribute to the assessment of a long-lasting presence of *Carpinus betulus* in the studied area during Pliocene and Early Pleistocene.

Family Cucurbitaceae

*Trichosanthes fragilis* E.M. Reid

Plate I, 1

*Occurrence:* East area: MR3 (Piacenzian).

*General distribution and characteristics*: this species had been reported in Italy only for the Front site (Martinetto, 1995; Martinetto et al., 2007) and is figured here for the first time (Plate I, 1). From the analysis of the distribution of its N-Italian occurrences it would seem an index fossil of the Piacenzian age, but this is due to the rarity of this species in the fossil record, which does not permit to use it in biochronological analyses.

Family Cymodoceaceae

*Cymodocea* cf. *nodosa* (Ucria) Ascherson

Plate I, 2

*Occurrence:* West area: PO1 (Zanclean); East area: LU1 (Zanclean); CVE2, MR3, CQ1 (Piacenzian); AD3 (Gelasian); SNT1 (Calabrian).

*General distribution and characteristics*: The occurrence of fossil fruits of *Cymodocea* in other Zanclean sites of the West area had been previously reported by Pavia (1976) and Basilici et al. (1997). The fossil fruits from the studied samples seem to be identical to the modern ones (reference material: MCC1662) of *Cymodocea nodosa* (Ucria) Ascherson, a common seagrass in the Mediterranean; yet we prefer to adopt the open nomenclature (*Cymodocea* cf. *nodosa*) because the fossils did not yet undergo a thorough morphological characterisation, and possible differences between older (Zanclean) and younger (early Calabrian) remains (Fig. 5) must be verified.

The record of *Cymodocea* fruits in the studied samples shows very well how the occurrence data coincide with the sediment facies. In fact, by examining Fig. 5 it appears that *Cymodocea* cf. *nodosa* has a very constant occurrence in the Zanclean, Piacenzian and the oldest Calabrian, but it is lacking in the late Calabrian assemblages. The "disappearance" of this seagrass can be attributed to the unsuitable palaeoenvironment (coastal to continental) of the younger Calabrian deposits.

Family Cyperaceae

*Carex* cf. *elata* All.

Plate I, 3

*Occurrence:* East area: LA1 (Calabrian).

*General distribution and characteristics*: The importance of the fossil record of *C. elata* and related forms in the Plio-Pleistocene has been recently pointed out by Martinetto et al. (2012) and Jiménez-Mejías and Martinetto (2013); therefore a careful search for the tiny fruits has been carried out. However, the record in the studied sections turned out to be extremely scanty, possibly due to the prevailing marine-coastal facies. In fact, *C.* cf. *elata* was only detected in the palustrine-lacustrine assemblage LA1 (Fig. 4).

The modern *C. elata* is a rather tall herb forming tussocks in various non-saline waterlogged environments of western Eurasia. Actuopalaeobotanical analyses (Vassio, 2012; Vassio and Martinetto, 2012) showed that its tiny fruits are only abundant in the sediments that are directly deposited in the places where the plant grows, whereas they are rare in the adjoining fluvial sediments (Bertolotto et al., 2012). So, the absence of the fruits in marine-coastal sediments, in which the abundance of plant material depends on the fluvial input (Zavala et al., 2012), does not mean that the plant was absent in the continental palustrine environments.

*Schoenoplectus* cf. *litoralis* (Schrad.) Palla

Plate I, 4

*Occurrence:* East area: AD3 (Gelasian), LA3 (Calabrian).

*Taxonomical remarks*: Recent work on Cyperaceae showed the great taxonomic importance of fruit morphology (e. g. Pignotti, 2003; Ercole et al., 2012; Jiménez-Mejías and Martinetto, 2013). Some fruits found in the studied sections can easily be assigned to the genus *Schoenoplectus* for the following characters: achenes with a narrowly obovate outline, acute base and largely obtuse apex, flat on one side (Plate I, 4a) and convex on the other (Plate I, 4b); apex with a tubercle, but style-remain lacking; epidermal cells small-sized and subrectangular. Only five modern European species bear, as the fossil specimens, smooth fruits (Jiménez-Mejías et al., 2007): *S. pungens, S.*

*lacustris, S. litoralis, S. tabaernamontani* and *S. triqueter*. Another taxon, *S. carinatus* has been found to be a hybrid (Ercole et al., 2012). The morphologically similar *S. corymbosum* has fruits with small irregularly distributed wrinkles (Jiménez-Mejías et al., 2007).

The nutlets of *S. pungens* (MCC1515), *S. lacustris* (MCC1983), *S. tabaernamontani* (MCC1995) and *S. triqueter* (MCC2005) are always longer than 2.3 mm, so the smaller dimensions of the fossils (LA3: 1.5-1.9; AD3: 1.5-1.8 mm), suggest assignment to *S. litoralis*, whose modern nutlets are 1.6-1.9 [2.1] mm-long. However, Pignotti (2003) reported that also the hybrid *S. carinatus* has comparably small fruits, and this is one of the reason for keeping the open nomenclature *Schoenoplectus* cf. *litoralis*. Another reason is the total lack of the typical, feather-like perianth bristles (not preserved).

*General distribution and characteristics*: We are not aware of previous fossil records of *S. litoralis*. Today this is an herbaceous plant of rather limited distribution, found in coastal marshes. The time of diversification of the five above-mentioned species of *Schoenoplectus* was not discussed in the recent phylogenetic analyses (Muasya et al., 2009; Jung and Choi, 2011), however some divergence times should note date back more than 5 Ma, in consideration of the patterns of diversification pointed out in the Cyperaceae clades (Escudero et al., 2012; Escudero and Hipp, 2013).

Our Gelasian fossil record of *S.* cf. *litoralis,* as well as the “upper Pliocene” (but possibly Gelasian) ones of *S. lacustris* (Mai and Walther, 1988) and *S. lacustroides* (Velichkevich and Zastawniak, 2003) may become important for dating the phylogenetic tree, but need a more detailed morphological characterisation. As *S. lacustris* is broadly distributed in lakes, marshes and rivers, its time of diversification could be used for the biochronology of continental sediments. The time of diversification of *S. litoralis,* which developed an adaptation to survive in salty soils, could be useful for the biochronology of coastal successions.

Family Ehretiaceae

*Ehretia europaea* E.M. Reid

1996 *Ehretia* sp. - Cavallo and Martinetto: pl. 3, figs. 2, 3 (Pocapaglia, layer PO1).

*Occurrence:* West area: PO1 (Zanclean).

*General distribution and characteristics*: The two endocarps figured by Cavallo and Martinetto (1996) are 2.0 mm broad and 2.1-2.5 mm long. These dimensions are similar to those of the two type specimens of *E. europaea* (1.8-1.25 x 1.6-2.75), described by Reid (1923) from the Late Miocene locality of Pont-de-Gail in France. Also the diagnostic morphological characters (Gottschling et al., 2002) show a good agreement between the Italian and the French specimens.

Gottschling et al. (2002) place *E. europaea* in the clade *Ehretia* II, but do not indicate a precise Nearest Living Relative.

A revision of the CENOFITA collection carried out for this paper showed that *E. europaea* occurs, in northern Italy, only in two sites reliably dated to the Zanclean (BG-Sento I, PO-Pocapaglia in Fig. 1) and in three sites of supposed Zanclean age (BG-Sento II, CV-Ca’ Viettone, RB-Ronco Biellese in Fig. 1).

Family Eucommiaceae

*Eucommia europaea* Mädler

Plate I, 5

*Occurrence:* East area: AD3 (Gelasian); reported by Gregor (1986) in laters corresponding to LA3 (late Calabrian).

*General distribution and characteristics*: this species had been reported in Italy only for the Castelletto Cervo II site, possibly Gelasian (Cavallo and Martinetto, 2001). The occurrence of fruits in the Gelasian of N Italy is remarkable because they have not been found in Pliocene sediments, and there is only a preliminary report in the Calabrian (Gregor, 1986). This pattern of fossil record would suggest either an immigration or an increase of *Eucommia europaea* in N Italy, possibly in correspondence of the cooling at the Piacenzian/Gelasian transition (Bertini, 2010). Unfortunately, the scarce woodiness in addition to the large size of the fruits (Plate I, 5) hampers their preservation in the fossil record (Vassio and Martinetto, 2012), and limits the use of this species in biochronological analyses.

Family Hypericaceae

*Hypericum tertiaerum* P. Nikitin

Plate I, 6

*Occurrence:* West area: RDB1, RDB6, RT1 (Piacenzian); East area: CQ1 (Piacenzian).

*General distribution and characteristics:* An overview about the fossil record of this species has been recently reported by Martinetto et al. (2012). We add here its occurence in the Piacenzian sample of Monte Falcone (CQ1). The occurrence of *H. tertiaerum* in marine sediments appears to be extremely scanty, and not suitable for the assessment of the presence/absence of this species in the contemporary continental environments. For this reason the hypothetic extinction of this species from northern Italy in correspondence to the Gelasian/Calabrian transition (Martinetto et al., 2012) needs to be confirmed by further data from continental sections.

The phylogeny of *Hypericum* has recently been investigated by Meseguer et al. (2013) and Nürk et al. (2013). The modern relatives of *H. tertiaerum*, at species level, are not yet well assessed because *Hypericum* is a large genus of ca. 500 species of shrubs, trees and herbs distributed mainly in temperate regions of the northern Hemisphere, but also in high-altitude tropical and subtropical areas (Meseguer et al., 2013). Despite some recent work dealing with seed characters (Meseguer and Sanmartin, 2012), these are still unknown for most of the modern species. According to Velichkevich and Zastawniak (2003), *H. japonicum* Thunberg in Murray, *H. tubulosum* Walt. and *H. virginicum* are the three extant species of *Hypericum* whose seeds most closely resemble those of *H. tertiaerum*. This would suggest a tentative placement of the fossil species into the clade (Meseguer et al., 2013) comprising the 3 modern species ("New World clade B"), whose divergence is estimated in the Oligocene (ca. 30 Ma) on a molecular basis. The members of this clade are a few species of wetland herbs with present disjunct distribution in East Asia and North America.

*Hypericum perforatum* L.

Plate I, 7

*Occurrence:* East area: LA3 (Calabrian).

*General distribution and characteristics*: This species has been reported in numerous interglacial and interstadial floras of eastern Europe (Velichkevich and Zastawniak, 2008). The seed morphology is very characteristic (checked in MCC1183) and allows an accurate identification of the species (Meseguer and Sanmartin, 2012). Molecular data (Meseguer et al., 2013) suggest a late Miocene divergence of *H. perforatum*, and Mai and Walther (1988) reported the oldest fossil records from “Pliocene” localities of Germany and Russia. Our fossil record of layer LA3 (ca 1.0 to 0.8 Ma) is the oldest for Italy, and is immediately followed by the early Middle Pleistocene one of Pianico (Martinetto, 2009). So the present evidence would suggest a late immigration of *H. perforatum* in Italy (around 1.0 Ma), much later than the diversification of the species.

Family Magnoliaceae

*Liriodendron geminata* Kirchheimer

Plate I, 8

1996 *Liriodendron geminata* Kirchheimer - Cavallo and Martinetto: pl. 1, fig. 4 (Pocapaglia, layer PO1).

*Occurrence:* West area: PO1 (Zanclean); RDB1 (Piacenzian); East area: CVE2 (Piacenzian); SNT1 (early Calabrian); EZ38 (late Calabrian).

*General distribution and characteristics: Liriodendron geminata* is a seed-morphospecies possibly linked to the leaves described as *L. procaccinii* in the Messinian (Massalongo and Scarabelli, 1859). However the oldest records of seeds in Italy are available only from the Zanclean (Cavallo and Martinetto, 1996). The CENOFITA database (Martinetto and Vassio, 2010) indicates that it is abundant in a few coastal-continental sites attributed to the late Zanclean-late Piacenzian (Aulla, Fossano, Sento II, Terzoglio III), but also occurs in many other sites with a few seeds. Its modern relatives are tall deciduous trees that produce wind-dispersed fruits, which are poorly lignified, so that only the hard seeds are often recorded as fossils.

By combining the reconstructed habit, dispersal syndrome and the rather dense fossil record of this species (Fig. 5) we can conclude that *L. geminata* was most probably a deciduous tall tree, broadly distributed in the Zanclean and Piacenzian of northern Italy, but possibly uncommon or only locally common. In marine sediments its occurrence is sporadic, so that the absence in CQ1 and MR3 is not surprising. The post-Piacenzian record was so-far poorly known, and the occurrence in two marine carpological assemblages of the Calabrian (EZ38, SNT1 in Fig. 4) points to the late survival of this plant in Italy. Its rarity in Calabrian sediments (absent from the LA1 and LA3 samples, as well as from Leffe, San Pietro di Ragogna, Steggio: Ravazzi and Rossignol-Strick, 1995; Ghiotto, 2010; Martinetto et al., 2012) could mean that, after the end of the Piacenzian, *L. geminata* became a rare tree in northern Italy. Furthermore, the record of the long, but poorly dated, section of the Cervo River in the western Po Plain (BU in Fig. 1) (Cavallo and Martinetto, 2001; Martinetto and Festa, 2013), where *L. geminata* occurs only in two out of ca. twenty fruit-bearing layers of possible Gelasian and/or Calabrian age, could indicate that this plant has left a detectable fossil record only in limited Early Pleistocene time slices, which could be better pinpointed by future research. Unfortunately the pollen record of *Liriodendron* is scanty (Bertini and Martinetto, 2011) and cannot help us to clear this situation.

*Magnolia allasoniae* Martinetto

Plate I, 9

1996 *Magnolia allasoniae* Martinetto - Cavallo and Martinetto: pl. 4, figs. 5, 6 (Pocapaglia, layer PO1).

*Occurrence:* West area: PO1, BR3 (Zanclean); East area: LU1 (Zanclean), MR3 (Piacenzian).

*General distribution and characteristics:* This is a seed-morphospecies firstly established in the Pliocene of NW Italy (Martinetto, 1995), and it has been recorded in several sites of northern and central Italy in the time span Messinian-Piacenzian. Curiously, it is common in several Italian sites, but it has not yet been reported in the adjoining countries, which could suggest a plant with a limited geographic distribution in the late Cenozoic (endemic?). The leaves, pollen and wood of the ancient whole plant are unknown. The seeds of *M. allasoniae* have been so-far compared with just a few species within the genus *Magnolia*, so that its modern relatives are not yet precisely indicated, even if an affinity of the fossil seeds to those of the living species *M. tripetala* has been pointed out. This last species is a deciduous tree which can grow in waterlogged environments.

*M. allasoniae* is broadly distributed and often frequent in the Zanclean of northern Italy, and the single occurrence in the Piacenzian is reported here (MR3 in Fig. 4). The fossil record and the ecology of the living *M. tripetala* would suggest that this plant was probably a common river-side or wetland tree in the Zanclean, while it became very rare in the Piacenzian, possibly with a relic distribution just in the southernmost areas (see MR3 in Fig. 2), as well as in central Italy (Martinetto, 2001a). The importance of the *M. allasoniae*-plant in the Zanclean is confirmed even by considering that *Magnolia* seeds have a fleshy tegument adaptive for animal dispersal, which may cause an overrepresentation in the sedimentary deposists (Vassio and Martinetto, 2012).

*Magnolia cor* Ludwig

Plate I, 10

*Occurrence:* West area: RDB1 (Piacenzian); East area: AD3 (Gelasian).

*General distribution and characteristics:* This seed-morphospecies has been recorded in the late Cenozoic of several parts of Europe (Mai, 1975). In Italy it occurs, sometimes abundantly (Cavallo and Martinetto, 2001), only from the Piacenzian to the Calabrian (Fig. 5). The smooth, heart-shaped seeds of *M. cor* (Plate I, 10) are very variable and morphologically similar to those of several modern East-Asian species (*M. kobus, M. stellata*, etc.). These modern plants are both deciduous trees and shrubs, growing in mesic forests. For this reason the seeds of *M. cor* are considered to represent an ancient deciduous tree or shrub with animal-dispersed seeds.

*Magnolia ludwigii* Ettingshausen

Plate I, 11

*Occurrence:* East area: MR3, CQ1 (Piacenzian).

*General distribution and characteristics:* The characteristic morphology of this seed morphospecies, often reported in the literature under the invalid synonym *M. lignita*, has been described by Mai (1975), who suggested an affinity with the living *M. ashei*. The habit and climatic requirements (see Utescher and Mosbrugger, 2013) of this modern species (actually considered a subspecies or variety of *M. macrophylla* by Azuma et al., 1999) were used to interpret *M. ludwigii* as an evergreen tree which required a very warm climate, so that its occurrence in fossil assemblages is often determinant for their climatic characterisation by means of the coexistence approach (Mosbrugger and Utescher, 1997). For the thermal characterisation of *Magnolia ludwigii* (MAT > 9°C in Fig. 4) we used *M. macrophylla* as a NLR and data from the GrimClim database (Grimm and Denk, 2012).

*M. ludwigii* is always rare in the Zanclean of northern Italy, and the only two occurrences in the Piacenzian are those reported here (CQ1, MR3). So this plant was probably uncommon in the Pliocene vegetation of northern Italy.

Family Menispermaceae

*Sinomenium cantalense* (E.M. Reid) Dorofeev

Plate I, 12

1996 *Sinomenium cantalense* (E.M. Reid) Dorofeev - Cavallo and Martinetto: pl. 1, figs. 5, 6 (Pocapaglia, layer PO1).

*Occurrence:* West area: PO1, BR3 (Zanclean); RDB1 (Piacenzian); East area: LU1 (Zanclean); CVE2, MR3, CQ1 (Piacenzian).

*General distribution and characteristics: S. cantalense* is reported, never abundant, in most of the Zanclean-Piacenzian sites of northern Italy (Martinetto, 1999; Martinetto et al., 2007). Its single modern relative, *S. acutum*, is an evergreen or semi-evergreen climber, which produces drupes dispersed by animals (endozoochory). This feature can be hypothesized also for *S. cantalense*. So, the habit of the single living relative, the dispersal syndrome and the rather dense fossil record of this species (Fig. 5) suggest that the *S. cantalense* fossil endocarps were produced by an evergreen-semievergreen climber, broadly distributed in the mesic and river-side forests of northern Italy, during Zanclean and Piacenzian. In northern Italy there are no post-Piacenzian records of this species, whereas in central Italy it has been abundantly recorded in the Ponte Naja Formation of the Cava Toppetti II site, assigned to the Gelasian (Leone et al., 2000; Martinetto, 2001a).

Family Rutaceae

*Toddalia naviculaeformis* (E.M. Reid) Gregor

2001a *Toddalia naviculaeformis* (E.M. Reid) Gregor - Martinetto: pl. 1, figs. 14, 15 (Marecchia, layer MR3).

*Occurrence:* West area: RDB1 (Piacenzian); East area: MR3 (Piacenzian).

*General distribution and characteristics:* two seeds of this species from the Piacenzian sediments of the Marecchia section (MR3) had been figured in Martinetto (2001a), and other few records were published for sites of Zanclean and/or Piacenzian age in northern Italy (Martinetto and Mai, 1996; Basilici et al., 1997; Ferrero et al., 2005). This species is less common than its relatives *T. latisiliquata* and *T. rhenana*, which are more useful for biochronological analyses (Fig. 5). In general, for the species of *Toddalia* there are no records younger than late Piacenzian in northern Italy, whereas in central Italy *T. latisiliquata* is suspected to persist in the Gelasian (see Martinetto, 2001a).

*Zanthoxylum ailanthiforme* (Gregor) Gregor

1996 *Zanthoxylum ailanthiforme* (Gregor) Gregor - Cavallo and Martinetto: pl. 6, fig. 1 (Pocapaglia, layer PO1).

2001a *Zanthoxylum ailanthiforme* (Gregor) Gregor- Martinetto, pl. 1, fig. 21 (Marecchia, layer MR3).

*Occurrence:* West area: PO1 (Zanclean); East area: MR3 (Piacenzian).

*General distribution and characteristics:* The taxonomic treatment and occurrences of this species in central as well as in northern Italy have already been discussed by Martinetto (2001a), who also figured one specimen from the Piacenzian sediments of the Marecchia section (MR3). This species seems to be important for biochronological analyses because in northern Italy is well represented only in the Messinian (Kovar-Eder et al., 2006) and Zanclean, with a single Piacenzian record in the layer MR3 (Marecchia section). Also in central Italy *Z. ailanthiforme* never occurred in sites of well-assessed Gelasian and/or Calabrian age (Martinetto, 2001a; Girotti et al., 2003).

Family Sparganiaceae

*Sparganium nanum* Dorofeev

Plate I, 13

1996 *Sparganium nanum* Dorofeev - Cavallo and Martinetto: pl. 3, fig. 7 (Pocapaglia, layer PO1).

*Occurrence:* West area: PO1, BR3 (Zanclean); RDB1 (Piacenzian); East area: CQ1 (Piacenzian); AD3 (Gelasian).

*General distribution and characteristics*: The record of AD3 represents the last occurrence of this species in Europe. The single fruitlet is small, globose, and very resistant (Plate I, 13), so that reworking cannot be excluded and further findings in other layers of the same age would be necessary to confirm the extension of the range of *S. nanum* to the early Gelasian.

The habit of *S. nanum* can be reconstructed as that of an herb living in freshwater wetlands, possibly with submerged roots and floating leaves as the modern *S. angustifolium* (Pignatti, 1982).

Family Stemonaceae

*Stemona germanica* (Mai) Mai

Plate I, 14

1996 *Spirellea* aff. *bohemica* Knobloch et Mai - Cavallo and Martinetto: pl. 3, fig. 9 (Pocapaglia, layer PO1).

*Occurrence:* West area: BR5 (layer ca. 5 m above BR3), PO1 (Zanclean); East area: CQ1 (Piacenzian).

*General distribution and characteristics*: This carpological species was assigned to the modern genus *Stemona* by Mai (2008), who reported occurrences from the Late Cretaceous to the Late Miocene in Central Europe. In Italy, material of this species was often reported as "*Spirellea* aff. *bohemica* Knobloch et Mai" (Cavallo and Martinetto, 1996; Basilici et al., 1997; Martinetto and Ravazzi, 1997) or "*Spirellea* sp." (Martinetto, 2001a) and was assigned to *S. germanica* for the first time in Martinetto and Vassio (2010).

A revision of the CENOFITA collection carried out for this paper confirmed that *S. germanica* occurs, in northern Italy, in four sites reliably dated to the Zanclean (BG-Sento I, BR-Breolungi, MZ-Morozzo and PO-Pocapaglia in Fig. 1), in four sites of supposed Zanclean age (BG-Sento II, CV-Ca' Viettone, RB-Ronco Biellese, CGL-Cortiglione d'Asti), and in a single site of supposed Piacenzian age (MO-Momello/Lanzo). So this species disappeared from Italy later than in central Europe and seems to be useful for biochronological analyses (Fig. 5), since there are no records younger than late Piacenzian in northern Italy. We revise here as *S. germanica* also the record of "*Spirellea* sp.", reported by Martinetto (2001a) from the Dunarobba site (Piacenzian or Gelasian) in central Italy, which consists in a single seed.

Family Symplocaceae

*Symplocos casparyi* Ludwig

1996 *Symplocos lignitarum* (Quenstedt) Kirchheimer - Cavallo and Martinetto, pl. 5, fig. 9 (Pocapaglia, layer PO1).

*Occurrence:* West area: BR3, PO1 (Zanclean); RT1 (Piacenzian); East area: LU1 (Zanclean); CVE2, MR3, CQ1 (Piacenzian).

*General distribution and characteristics*: *S. casparyi*, as circumscribed by Mai and Martinetto (2006), is a morphospecies with largely variable endocarps. In Italy it occurred in several coastal-continental sites attributed to the late Zanclean (Ca' Viettone, Castellengo, Fossano, Sento II). As its modern relatives, which are small evergreen trees or shrubs, produce drupes which favour animal dispersal (endozoochory), this feature can be hypothesized also for *S. casparyi*. By combining the reconstructed habit, dispersal syndrome and the rather dense fossil record of this species (Fig. 5), we can conclude that the *S. casparyi* fruits were most probably produced by an evergreen small tree or shrub, broadly distributed in the Zanclean and Piacenzian mesic forests of northern Italy. This is in agreement with its occurrence in all the marine carpological assemblages of the Zanclean and Piacenzian in the East area (Fig. 4).

Family Theaceae

*Eurya stigmosa* (Ludwig) Mai

Plate I, 15

1996 *Eurya stigmosa* (Ludwig) Mai - Cavallo and Martinetto: pl. 2, fig. 1 (Pocapaglia, layer PO1).

*Occurrence:* West area: PO1, BR3 (Zanclean); East area: LU1 (Zanclean); CQ1 (Piacenzian); AD3 (Gelasian).

*General distribution and characteristics*: One of the commonest species in the Zanclean of northern Italy and already reported in sites dated back to a possible Piacenzian age (Martinetto, 1995). The record of 3 seeds in the CQ1 layer, treated in this paper, is a further clue to the survival of this plant till the late Piacenzian, not only in central Italy (Martinetto, 2001a), but also in the northern part of this country. Finally, the interpretation of a single seed found in the Gelasian sample of the AD3 layer is not easy: the good preservation (Plate 1, 15) does not provide any evidence of reworking, anyway we suggest to take in consideration this possibility.

Family Thymelaeaceae

*Thymelaea* cf. *passerina* L.

Plate I, 16

*Occurrence:* East area: AD3 (Gelasian); LA3 (Calabrian).

*General distribution and characteristics*: The phylogeny of *Thymelaea*, whose present distribution is limited to the peri-Mediterranean area, has been studied by Galicia-Herbada (2006). The genus includes 31 species, most of which show a distribution restricted to the westernmost Mediterranean (Iberia plus Northwest Africa) and, according to the phylogenetic analysis of Galicia-Herbada (2006), have a recent origin (not older than 2 Ma) and should not be crucial for the comparison with our fossils. In Italy (Pignatti, 1982) only 4 species of *Thymelaea* occur at present: *T. dioica, T. hirsuta, T. passerina* and *T. tartonraira.* The narrow drop-shaped seeds of samples AD3 and LA3, with a thick and shining wall, are respectively 2.0 and 1.7-mm long and both have a length/width ratio of 1.8. The 1.6-2.2 mm-long (mean specimens' length around 1.9 mm) seeds of *T. passerina* from NW Italy (MCC1516), with a 1.8-2.2 length/width ratio, agree in all the morphological characters with those of fossil samples. The seeds of *T. hirsuta* (MCC1767) and *T. tartonraira* (MCC1768) are easily distinguishable for the larger dimensions, lower length/width ratio, and coarser cell pattern.

The perfect morphological agreement of the fossil seeds with the modern ones of *T. passerina* would suggest an assignment of the *T. passerina* clade (Galicia-Herbada, 2006). Furthermore, it does not seem possible the occurrence of species other than *T. passerina* in northern Italy (also in the past) because the differentiation of other species occurred because of geographic isolation in the western (e.g. *T. salsa*) or eastern (e.g. *T. mesopotamica*) Mediterranean (Urbani, 1992). However, due to strong phylogenetic link between *T. passerina* and *T. salsa,* pointed out by Galicia-Herbada (2006: fig. 7), it would be desirable to study in more detail the seed morphology of these two species in order to evaluate the presence of differential morphological characters which could be checked in the Early Pleistocene fossils.

The record of AD3 most probably represents the oldest known for *T. passerina* in the fossil record. Its occurrence in the Middle Pleistocene of central Europe was reported by Mai (2010). This species was also reported from archaeological sites of the East area dating back from the 2nd century BC to the 6th century AD (Rinaldi et al., 2013).

Family *incertae sedis*

*Carpolithes minimus* (Szafer) Mai

Plate I, 17

*Occurrence:* East area: LA1, LA3 (Calabrian); EZ38 (Calabrian).

*General distribution and characteristics:* Despite the good morphological and anatomical agreement (Martinetto, 2001c), assignment of *C. minimus* to *Thalictrum* (Ranunculaceae) has to be rejected because the indehiscent achenes of *Thalictrum* do not correspond to the apparently dehiscent condition of *C. minimus* (Plate I, 17). The new efforts in searching the same structure as in *C. minimus* in fruits and seeds of modern plant taxa, just brought to the detection of superficial resemblances (Lamiaceae: *Horminum*; Cannabaceae: *Humulus*). Therefore, this common and characteristic fossil taxon is still to be considered *incertae sedis*, and we have no information about the habit and ecology of the plant which produced these remains. It was certainly not linked to coastal areas, since these fossils are also found in ancient freshwater intermontane basins (Steggio: Ghiotto, 2010).

## 7. Discussion

Our analyses, aimed at the reconstruction of the distribution in time and space of plant species, are based on the interpretation of the presence of carpological remains in well-dated layers, whereas the absence of fossils is considered less important. In fact, the analyses of fruit and seed assemblages in modern contexts showed that the fruit/seeds of one species may frequently be absent in the sediments formed close to its growth place, due to several biological and taphonomical factors. Absence of the fruits/seeds with hard parts in the fossil record can be used as a clue to the absence of one plant in an ancient environment, but only after the analysis of several samples and localities of the same age. Conversely, the presence of the fruits/seeds of one species in a sedimentary deposit is a strong evidence for the presence of the mother plant in the environment surrounding the place of deposition (at the catchment basin scale: Vassio and Martinetto, 2012). An exception is represented by the reworking of fruits and seeds from older sediments, which seems to be a rare event at the light of the evidence discussed above; nevertheless, should be kept in consideration.

The fossil fruit and seed record of selected plant taxa in Zanclean, Piacenzian, Gelasian and Calabrian layers showed that the distribution of several species was limited to one or a few chronostratigraphic stages (Fig. 4). The climatic characterisation of these species indicates that the major floristic changes are linked to the disappearence or retreat of thermophile elements in the late Zanclean, late Piacenzian, and during the Calabrian. Additionally, most of the species which appear in the Early Pleistocene fossil record are cool-tolerant.In the Zanclean we observe the highest number of thermophile species, and some of them (Group 1 in Fig. 4) occur only in this stage. However, the independently dated (Barbieri, 1967) Lugagnano assemblage (Fig. 4) shows that a poor Zanclean flora may lack Group 1 elements (excepted *Visnea germanica*, reported by Gregor, 1990), and fit the criteria used to suggest a Piacenzian affinity (simultaneous occurrence of several species of groups 2 and 3, without species of groups 1 and 5). Unfortunately, we have no information on carpological assemblages of the earliest Piacenzian (3.6 to 3.3 Ma), and the oldest known Piacenzian assemblages come from the West area sites re-examined in this work (RDB1, RDB6, RT1), which have been interpreted by Martinetto et al. (2007) as falling within the Mammoth reversed magnetic polarity event (ca. 3.3 to 3.2 Ma). The record of these Piacenzian western sites (Fig. 4) appears consistently different from that of the eastern ones, mainly because of the occurrence of Group 2 species in the last ones (Fig. 4). In our opinion this difference is linked to the slightly younger age (3.0-2.8 Ma) of the eastern sites CQ1 and MR3 (Tab. 1), since the thermophilous Group 2 elements (MAT often >8°C in Fig. 4) could have profited from the climate warming reported around 3.0 Ma (Bertini, 2010). So, we can argue that the carpoflora of Chiavenna (CVE2 in Fig. 4) lacks of Group 2 elements because it is dated to the reversed magnetic polarity event Kaena (3.1 to 3.0 Ma), which predates the warming. This is also confirmed, in the northern part of the western Po Plain, by the lack of Group 2 elements in the rich palaeoflora of the Stura di Lanzo Fossil Forest, also dated to the Kaena (Martinetto et al., 2007). On the other hand, the successive (ca. 3.0-2.8 Ma) Piacenzian records of Marecchia (MR3) and Monte Falcone (CQ1) point out a thermophilous palaeoflora (MAT>8°C) in which even the species characterizing the Zanclean palaeoflora (Group 2 in Fig. 4) are still abundant, therefore they seem to correspond to the warming phase. Therefore, in the interpretation of the age of Pliocene floras, we must consider that the thermophilous species of Group 2 did not disappear at the Zanclean/Piacenzian transition (see Martinetto, 1999), but just experienced a temporary retreat from 3.2 to 3.0 Ma, and assumed again greater importance into the late Piacenzian (ca. 3.0 to 2.8 Ma).

The newly obtained carpological assemblage dated to the early Gelasian (AD3), is particularly important because in the whole N-Italy there was only another carpoflora, the Casnigo one (CG in Fig. 1, already mentioned in Martinetto, 1999), which was reliably dated to the Gelasian, in particular to the final part of this age (ca. 2.1 to 1.8 Ma). Another assemblage interpreted as Gelasian has been described at San Pietro di Ragogna (SPR in Fig. 1, NE Italy), but mainly represents an ancient freshwater plant community and provides a very poor record of the terrestrial palaeoflora (Martinetto et al., 2012). Richer assemblages of possible Gelasian age have been described from the Cervo River section (Fig. 1; Castelletto Cervo II and Buronzo floras: Cavallo and Martinetto, 2001; Martinetto and Festa, 2013) for which a confirmation of the age with methods independent from palaeobotany would be needed. Also the ongoing studies in the southern Piedmont Basin, along the Bormida valley (Fig. 2; Irace et al., 2012) are promising for the gathering of data on Gelasian carpofloras. Nevertheless, the Gelasian is still largely "*terra incognita*" as for the distribution of carpological taxa, and this is particularly critical for the better definition of the last appearance in northern Italy of a large number of Zanclean-Piacenzian species, never detected in the Gelasian/Calabrian. The last known occurrences of such “old” taxa (Groups 2-3 in Fig. 5) mostly fall within the late Piacenzian, but in 2 cases (*Eurya stigmosa, Sparganium nanum*) Gelasian occurrences were detected in this work (Fig. 4). However, in consideration of the possibility of reworking (see above), we suggest much caution before placing into the Gelasian the local extinction of these taxa.

The Calabrian carpological record of the East area sections starts with the Santerno-SNT1 assemblage, dated at the very base of the Calabrian (ca. 1.8-1.7 Ma), which is followed by a definitely younger Calabrian assemblages (LA1, ca. 1.1 Ma after Gunderson et al., 2012). Due to gap of ca. 600 ka between the SNT1 and LA1 assemblages, at present it is not possible to point out eventual changes of the carpofloras within the lower Calabrian. About the EZ38 and LA3 assemblages, new magnetostratigraphic data (Gunderson et al., 2012, 2014) point to a late

Calabrian age, just after the Jaramillo normal subchron. This is also supported by the occurrence of *Tsuga,* that is unknown in the Middle Pleistocene, even in pollen records (Ravazzi et al., 2005; Martinetto, 2009; Bertini, 2010). The four Calabrian fruit and seed assemblages studied are typically formed by an admixture of species inherited from the Pliocene floras (*Carpolithes minimus, Juglans bergomensis, Liriodendron geminata, Magnolia cor*, *Selaginella* gr. *pliocenica*) and species which appear in the North Italian record only in the Gelasian (*Ajuga* cf. *iva*, *Picea florschuetzii, Taxus baccata, Thymelaea* cf. *passerina, Tsuga* cf. *chiarugii*) or Calabrian (*Hypericum perforatum*). None of these new occurrences is interpretable as an evolutionary appearance. Rather, the effect of the environmental factors seems having prevailed, favouring the immigration of these species from adjoining areas; for the Gymnosperms, this could simply consist in descending from the mountains (where no fossil record was preserved).

The record of those plant taxa with a proven diversification in the last 5 Ma (e.g., Thymeleaceae: Galicia-Herbada, 2006; Cyperaceae: Jiménez-Mejías and Martinetto, 2013) is much scattered in the sections studied, but offers intriguing opportunities for a future detection of the time of evolutionary appearance of a few species. As for the Cyperaceae the 2.5-2.4 Ma record of *Schoenoplectus* cf. *litoralis* (AD3) falls within an interesting time range to calibrate the phylogeny of the group. As for *Thymelaea*, the 2.5-2.4 Ma record of AD3 is the oldest known for the *T. passerina* clade (Galicia-Herbada, 2006), and could predate the diversification of *T. salsa*. The supposed Late Miocene origin of the clade would suggests that plants producing seeds of the *T. passerina*-type were present since that time somewhere in the Mediterranean. So, the appearance of such seeds in the fossil record of N-Italy, as late as the Gelasian, could be explained by the expansion of the plant's habitat at that time, due to slightly drier climatic conditions, which were possibly absent in the Pliocene (more persistent humidity). In fact the plants of the *T. passerina* group are small herbs linked to open areas with temporarily dry soil (Pignatti, 1982).

## 7. Conclusions

Our analysis of carpological assemblages in Pliocene and Early Pleistocene successions cropping out along the southern margin of the Po Plain showed that these deposits contain an interesting record of the terrestrial palaeoflora, which integrates the information provided by the extensive pollen record available in this area. We could fix in the geological time scale, often with a precision of 100 ka (Tab. 1), 14 carpoflora-bearing layers spanning from 5.1 to 0.9 Ma, thus obtaining a framework which is not available in other parts of Europe. This enabled us to provide precise ages for the occurrence of fruits and seeds of a few plant groups with a proven late Cenozoic differentiation, as a possible contribution to future phylogenetic analyses. For the other species, with a phylogenetic origin dating back to the Miocene, Palaeogene or Cretaceous, we obtained an updated synthesis of the distribution in time of the fossil record in the studied area.

Our dataset was revealed useful for biochronological analyses, since the fossil record of several species showed an interesting distribution, often limited to one to three chronostratigraphic stages (Zanclean-Piacenzian-Gelasian-Calabrian). Nevertheless, several relevant differences could be pointed out by comparing the record of the West and the East area. In particular, several species occurring only in the Zanclean of the West area were detected in the late Piacenzian of the East area (Fig. 4), thus suggesting that both datasets, separately, were not reliable for the reconstruction of the distribution in time of each plant species.

Our elementary palaeoclimatic characterisation of the individual species, and of the plant assemblages in which they occur (Fig. 4), suggests that temperature decrease is one of the causes of the disappearance from the fossil record of several species, in particular at the Piacenzian/Gelasian transition. Also the disappearance (or retreat) of some species at the Zanclean/Piacenzian transition would seem to be due to climate deterioration, since it affects the thermophilous Group 1 (NLRs' MAT boundaries often >15°C and mostly >9°C).

As for the appearance of new species in the studied fossil record, the analysis of the habit, ecological-climatic requirements and phylogeny of the recent relatives indicates that it is mostly due to the establishment of favourable local environmental conditions, rather than to evolutionary events.

The input of the new data obtained into the CENOFITA database led to an apparent improvement of the distribution chart of carpological taxa in the Pliocene and Early Pleistocene. This new chart shows the carpological species clustered in groups with a similar biochronologic distribution (Groups 1-6 in Fig. 5) and we suggest that the analysis of the representation of such groups in undated or poorly dated carpological assemblages would be useful for their biochronological interpretation. In this sense, the possibility to characterise the Zanclean floras against the Piacenzian ones is provided by the occurrence of Group 1 species in the first ones. In addition, the simultaneous occurrence of several species of groups 2 and 3 (Fig. 5), without species of groups 1 and 5, could be used to suggest a Piacenzian affinity for undated assemblages.

The characterisation of Gelasian floras is a major problem, because of the lack of record in the crucial time span between 2.8 and 2.5 Ma, so that we cannot really say whether the Gelasian carpological floras can be distinguished from the latest Piacenzian ones. Fruit and seed assemblages with several species of groups 5 and 6, without species of groups 1-3 (Fig. 5), have not been detected in any Zanclean or Piacenzian carpoflora, and would suggest a Gelasian or Calabrian affinity.

In conclusion, the new data presented here determined several changes in the biochronological distributions published in preceeding works and, despite the good chronostratigraphic framing available in the studied sections, we suggest that the biochronologic chart presented in this paper (Fig. 5) still requires an integration of data from a broader geographic area, before being considered as definitely stable. The implementation of the N-Italian Plio-Pleistocene carpological dataset, especially with data from other calibrated continental sections, would be the right direction for completing our knowledge of the chronologic distribution of single carpological species as well as species-groups.

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Figures and tables captions:

Fig. 1. Schematic map of northern-central Italy showing the location of the Zanclean-Calabrian localities with published carpological assemblages. AD: Castell'Arquato-Arda; BE Benasso; BG: Sento I and II; BL: Candelo; BO: Boca; BR: Breolungi; BU: Buronzo; GA: Castelletto Cervo I and II; CGL: Cortiglione d'Asti; CM: Crava di Morozzo; CO: Cossato; CVE: Chiavenna; CG: Casnigo; CQ: Castell'Arquato-Monte Falcone - Rio Crevalese; CV: Ca' Viettone; EZ: Enza; FR: Front; LA: Stirone-Laurano; LF: Leffe; LU: Lugagnano; MO: Momello-Lanzo; MR: Val Marecchia; MZ: Morozzo; PO: Pocapaglia; RBS: Ranica Borgo Sale; RDB: RDB Quarry, Villafranca d'Asti; RDL: Rio della Lupa; RT: Roatto; SG: Steggio; SNT: Santerno; SPR: San Pietro di Ragogna; STU: Stura di Lanzo Fossil Forest; TC: Castellengo; TZ: Terzoglio; VF: Valle della Fornace. Towns: Tu, Turin; Ve, Venice.

Fig. 2. Schematic map of the southern margin of the Po Plain with the location of the studied sections. Red lines indicate the frontal thrust arcs. The star indicates the Villafranca d'Asti type area; Br: Breolungi; Po: Pocapaglia; 1: Chiavenna Rocchetta; 2: Lugagnano; 3: Monte Falcone and Arda (Castell'Arquato section); 4: Stirone; 5: Enza; 6: Santerno; 7: Marecchia.

Fig. 3. Simplified logs of the studies sections with data useful for the chronostratigraphic calibration. Chronostratigraphy after Gradstein et al. (2004), Cita et al. (2006), Gibbard and Head

(2010). Magnetostratigraphy after Cande and Kent (1995). Planktonic foraminifer biostratigraphy after Cita (1975), Iaccarino (1985), and Sprovieri (1992). Stratigraphy of analyzed sections are modified after 1) Roveri and Taviani (2003); 2) Barbieri (1967); 3a) Monegatti et al. (2002); 3b) Dominici (2001), Roveri and Taviani (2003); 4) Papani and Pelosio (1963), Gunderson et al. (2012); 5) Iaccarino and Monegatti (1996), Gunderson et al. (2014); 6) Cremonini et al. (1969), Colalongo (1969); 7) Colalongo et al. (1982a and 1982b), Rio et al. (1997).

Fig. 4. List of selected carpological taxa from the West and East area sections (see Tab. 1). Black boxes indicate occurrence in our samples, grey boxes are referred to the report of *Eucommia europaea*, *Juglans bergomensis*, *Tsuga* cf. *chiarugii* and *Visnea germanica* by Gregor (1990), and *Picea florschuetzii* by Mai (1994). Z = Zanclean; G = Gelasian. Palaeoenvirnoment: C = coastal; M = marine; P = palustrine. The listed taxa have been gathered in 6 main groups, as explained in the text.

A simple characterisation of the growth forms of the listed taxa is reported in the two columns named respectively “Deciduous/Evergreen” and “Habit”, where “c”, “h”, “s” and “t” stand for climber, herb, shrub and tree. The thermal climatic requirements of each species have been synthetically expressed by the boundary values of Mean Annual Temperature (NLR Clim. boundaries), e.g.: >13 = distribution of Nearest Living Relatives (NLRs) mainly in areas where the MAT is higher than 13°C; <14 = distribution of NLRs mainly in areas where the MAT is lower than 14°C; u = uncertain, b = broad climatic distribution (literature sources: ^Denk and Grimm, 2012; *Utescher and Mosbrugger, 2013; #other sources, reported in Supplementary materials). The column "exotic/native" (ex/n) is referred to the NLRs, and “X” means no-NLR (extinct genus or morphogenus).

Fig. 5. Scheme summarizing the biochronological distribution of the carpological records of selected plant taxa in N-Italy. The order of the species and the groups are the same as in Fig. 4. Mes = Messinian; MP = Middle Pleistocene.

The records from all the localities indicated in Fig. 1, deduced from the whole N-Italian CENOFITA database (Martinetto and Vassio, 2010), are reported. 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), Sento I (3.8-3.6 Ma), Candelo (4.5-3.6 Ma), Roatto (3.3-3.2 Ma), RDB Quarry of Villafranca d'Asti (3.3 to 3.0 Ma), Stura di Lanzo Fossil Forest (3.1-3.0 Ma), Casnigo (2.1-1.9 Ma), Santerno (1.8-1.7 Ma), Leffe (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): Ca' Viettone (late Zanclean, 3.8 to 3.6 Ma); Fossano (late Zanclean, 4.0 to 3.6 Ma); Sento II (late Zanclean, 3.8 to 3.6 Ma); Front (Piacenzian, 3.3 to 3.0 Ma); Momello-Lanzo (Piacenzian, 3.6 to 3.0 Ma); Castelletto Cervo I (late Piacenzian, 2.8 to 2.6 Ma); Castelletto Cervo II (Gelasian, 2.6 to 2.0 Ma); San Pietro di Ragogna (Gelasian, 2.6 to 1.8 Ma); Buronzo (Gelasian, 2.2 to 1.8 Ma); Steggio (Calabrian, 1.8 to 0.9 Ma). The dashed lines indicate the presence of records in central Italy, considered a refuge area in the Piacenzian-Calabrian (Martinetto, 2001a).

Tab. 1. Lithologic and stratigraphic data for the studied palaeocarpological samples.

**Plate I** - Examples of fossil fruits from the studied sections. Figs. 1-5 and 8-17 scale bars = 1mm; Figs. 6-7 scale bars = 0.5 mm. The 3-characters codes (e.g. B3E) assign the fossil specimen to a precise sediment sample recorded in the CENOFITA database; the label MGPT-PU+number is referred to the collections' catalogue of the Earth Sciences Department of the Turin University.

1) *Trichosanthes fragilis* E.M. Reid: a) outer surface, b) inner surface of the seed, Marecchia section, sample MR3 B3E, Piacenzian; MGPT-PU105884;

2) *Cymodocea* cf. *nodosa* (Ucria) Ascherson: a, b) lateral views of the endocarp, Marecchia section, sample MR3 B3E, Piacenzian, MGPT-PU105885;

3) *Carex* cf. *elata* All.: achene, Stirone section, sample LA1 A5B, Calabrian, MGPT-PU105886;

4) *Schoenoplectus* cf. *litoralis* (Schrad.) Palla: a) ventral view and b) dorsal view of the achene, Stirone section, sample LA3 A5C, Calabrian, MGPT-PU105887;

5) *Eucommia europaea* Mädler: fruit, Arda section, sample AD3 B7E, Gelasian, MGPT-PU105888;

6) *Hypericum tertiaerum* Nikitin: seed, Monte Falcone subsection, sample CQ1 B6D, Piacenzian, MGPT-PU105889;

7) *Hypericum perforatum* L.: seed, Stirone section, sample LA3 A5C, Calabrian, MGPT-PU105890;

8) *Liriodendron geminata* Kirchheimer: seed, Santerno section, sample SNT1 B6L, Calabrian, MGPT-PU105891;

9) *Magnolia allasoniae* Martinetto: seed, Marecchia section, sample MR3 B3E, Piacenzian, MGPT-PU105892;

10) *Magnolia cor* Ludwig: seed fragment, Arda section, sample AD3 B7E, Gelasian, MGPT-PU105893;

11) *Magnolia ludwigii* Ettingshausen: seed, Marecchia section, sample MR3 B3E, Piacenzian, MGPT-PU105894;

12) *Sinomenium cantalense* (E.M. Reid) Dorofeev: endocarp, Monte Falcone subsection, sample CQ1 B6D, Piacenzian, MGPT-PU105895;

13) *Sparganium nanum* Dorofeev: endocarp, Monte Falcone subsection, CQ1 B6D, Piacenzian, MGPT-PU105896;

14) *Stemona germanica* (Mai) Mai: a) apical view, b) basal view of one seed, Monte Falcone subsection, sample CQ1 B6D, Piacenzian, MGPT-PU105897;

15) *Eurya stigmosa* (Ludwig) Mai: seed, Arda section, sample AD3 B7E, Gelasian, MGPT-PU105898;

16) *Thymelaea* cf. *passerina* L.: seed, Arda section, sample AD3 B7E, Gelasian, MGPT-PU105899;

17) *Carpolithes minimus* (Szafer) Mai: a) outer surface, b) inner surface of the seed, Stirone section, sample LA3 A5C, Calabrian, MGPT-PU105900.