Pliocene and Early Pleistocene carpological records of terrestrial plants from the southern border of the Po Plain (northern Italy).

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1   Pliocene and Early Pleistocene carpological records of terrestrial plants from the southern border

2   of the Po Plain (N-Italy)

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13

15   *ABSTRACT* - The analysis of fruit and seed assemblages in Pliocene and Early Pleistocene

16   successions of the southern border of the Po Plain showed that these deposits contain an

17   interesting record of the terrestrial palaeoflora which integrates the information provided by the

18   extensive pollen record available in this area. We could fix in the geological time scale, locally

19   with a precision of 100 ka, 14 carpoflora-bearing layers spanning from 5.1 to 0.9 Ma, thus

20   obtaining a framework which is not available in any other parts of Europe. This permitted us to

21   provide precise ages for the occurrence of fruits and seeds of a few plant groups with a proven late

22   Cenozoic differentiation (*Carex, Hypericum, Thymelaea*), as an important support to future

23   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

47   chronological framing is usually problematic (Bertoldi and Martinetto, 1996; Martinetto, 1999;

48   Cavallo and Martinetto, 2001; Martinetto et al., 2007).

49   Since the first analyses on the Pliocene fruit and seed assemblages in northern Italy (Gregor, 1986;

50   Martinetto, 1995) it was noticed that the species composition varied conspicuously from older to

51   younger strata, and was able to provide useful information on the floral change from 5 to 1 Ma.

52   Therefore, a long-lasting research for fruit-bearing layers in stratigraphically well-framed sections

53   has been carried out in northern and central Italy, discontinuously, for the last 20 years

54   (Martinetto, 1994, 1999 and 2001a; Martinetto et al., 2007). Recently, new interest for the

55   examination of the material from the studied sections was raised by studies on continental sections

56   of NW-Italy, where the concomitant occurrence of some carpological taxa seems to be crucial for

57   the chronologic framing of the deposits (Irace et al., 2012).

58   The first aim of this paper is to point out the presence of rather rich assemblages of carpological

59   remains of terrestrial plants in Pliocene and Early Pleistocene successions exposed along the

60   southern border of the Po Plain, thus improving the preliminary reports by Gregor (1986 and

61   1990). Additionally, we wanted to obtain an updated scheme reporting the occurrence of such

62   plant taxa in the Zanclean-Calabrian of northern Italy and we tried to recognize in this fossil

63   record the signal of changes in the terrestrial flora (and vegetation). We also wanted to discuss the

64   possible causes of the appearance and disappearance of the plant species in the fossil record, by

65   considering environmental changes, migrations as well as phylogeny of those plant taxa with a

66   proven diversification in the last 5 Ma (e.g., Thymelaeaceae: Galicia-Herbada, 2006; Cyperaceae:

67   Jiménez-Mejías and Martinetto, 2013).

68

69   2. Geological setting and material

70

71   2.1 Geological setting

72   During the Pliocene-Early Pleistocene interval the southern side of the Po Plain area was affected

73   by the compressional N-NE-verging Apennine tectonic activity, which was responsible for the

74   formation of coeval but distinct and structurally separated thrust-top and foredeep basins (e.g.,

75   Ricci Lucchi, 1986; Ghielmi et al., 2010).

76   At the western termination of the Po Plain, the Plio-Pleistocene Piedmont Basin evolved as a wide

77   wedge top basin, bounded to the north by the westernmost arc of the Padane thrust front (Fig. 2).

78   To the south-east, the Castell'Arquato Basin acted as a closed piggy-back basin on top of

79   Apennine thrust fronts. The Adriatic Foredeep developed in the south-eastern sector of the Po

80   Plain.

81   During the Piacenzian-Calabrian time span, transitional to continental successions were deposited

82   in the Piedmont Basin, while deep water to shelfal units filled the Castell'Arquato and the Adriatic

83   Foredeep basins (Fig. 3). In these basins paralic and continental facies appeared only in the

84   Calabrian.

85

86   2.2 Stratigraphic sections and carpological material

87   The fossil fruit and seed material studied in this work comprises both previously unpublished

88   material from freshly analysed sediment samples (East area samples in Fig. 4) and taxonomically

89   revised collection material (West area samples, Fig. 4). All these carpological samples were

90   prepared starting from bulk sediment samples collected in well constrained sections along the

91   southern side of the Po Plain (Fig. 2). Seven Pliocene-Lower Pleistocene successions of marine to

92   transitional environment were taken into consideration in the East area, and compared with the

93   existing records of 3 sections from the West area (Fig. 3). In both areas, several successions,

94   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).

118   The samples are located in stratigraphic logs (Fig. 3) that represent a portion of longer

119   stratigraphic successions. As a whole, 21 samples of fruit and seed-bearing deposits were

120   collected, 9 of which have been so-far analysed, as reported below:

121   1) **Chiavenna Rocchetta section** (Roveri and Taviani, 2003). This succession was deposited in a

122   shelf environment during the Piacenzian. The sample CVE2 comes from a silty sand layer, rich in

123   marine mollusc shells and with scattered terrestrial plant remains, cropping out on the left bank of

124   the Chiavenna Creek, below the first calcarenitic body. According to the magnetostratigraphic data

125   reported by Roveri and Taviani (2003) for a neighbouring drill-core, the CVE2 bed was attributed

126   to the subchron Kaena.

127   2) **Lugagnano Quarry section** (Barbieri, 1967). This stratigraphic interval is assigned to the

128   lower part of the Zanclean (MPL2 Zone) because of the occurrence of *Globorotalia margaritae*

129   (listed as *Globorotalia hirsuta* by the author) and the absence of *Globorotalia puncticulata.*

130   Benthic foraminiferal assemblages are highly diversified and include mainly *Bulimina aculeata*

131   *minima, Bulimina costata, Cibicides pseudoungerianus, Siphonina reticulata, Sphaeroidina*

132   *bulloides, Uvigerina peregrina, Uvigerina pigmea* and *Uvigerina rutila* (Barbieri, 1967). These

133   species are considered to reflect deposition within an outer shelf or upper slope environment (e.g.

134   Blanc-Vernet, 1969; Rasmussen, 2005; Schweizer, 2006). The presence of rare shallow marine

135   taxa, specifically *Ammonia beccarii, Cribroelphidium semistriatum, Elphidium macellum* and

136   *Elphidium complanatum*, suggests downslope transport during deposition. The sample LU1 was

137   collected in a sandy silt layer rich in plant remains, in the middle portion of Barbieri's (1967)

138   section 2. Gregor (1990) reported a list of carpological taxa gathered by hand-picking on the

139   outcrop of the Lugagnano Quarry section, which included the species *Visnea germanica.*

140

141   3) **Castell'Arquato composite section** (Monegatti et al., 1997 and 2002; Roveri and Taviani,

142   2003)**.** This composite section includes Zanclean to Calabrian marine sediments. Carpological

143   samples have been collected in subsections Monte Falcone and Arda.

144   3a) **Monte Falcone subsection** (Monegatti et al., 2002). This succession includes silt and sand

145   passing upward to dominant calcarenite, deposited within a shallow marine to coastal

146   environment. Magnetostratigraphic analyses reveal the occurrence of normal polarity interval

147   2An.1n (Gauss Chron) of late Piacenzian age (Monegatti et al., 1997; 2002). The sample CQ1 was

148   collected in the lower portion of the outcropping succession, within shallow marine silty sands rich

149   in mollusc shells and with scattered terrestrial plant remains, deposited at 30-60 m water depth

150   (Monegatti et al., 2002).

151   3b) **Arda subsection** (Dominici, 2001; Roveri and Taviani, 2003). The succession was deposited

152   in a shoreface to inner shelf environment (5-40 m water depth). This represents the youngest part

153   of the composite section, assigned to the Gelasian-Calabrian transition (Calabrese and Di Dio,

154   2009). The collection of samples from as much as four layers (AD3, AD6, AD7, AD9 in Fig. 3)

155   was stimulated by the detailed stratigraphic and palaeoenvironmental analyses of Dominici (2001);

156   however only the sample from the AD3 layer has been so-far analysed.

157   4) **Stirone section** (Papani and Pelosio, 1963)**.** The part of the historical Stirone River succession

158   (Cremaschi, 1982; Dominici, 2001; Gunderson et al., 2012) considered in this work includes

159   Gelasian and Calabrian sediments, showing shelf deposits passing upward to a cyclic alternation

160   of shallow marine to continental deposits (Fig. 3). In the Calabrian portion (Stirone-Laurano in

161   Martinetto, 1999), two samples were collected in layers rich of terrestrial plant remains (Fig. 3):

162   LA1 comes from freshwater dark grey massive muds, immediately preceding the base of the

163   Jaramillo subchron (Gunderson et al., 2012), which were rich in terrestrial plant remains

164   associated to tree stumps in growth position; LA3 was collected in shallow-marine sands referable

165   to the last 200 ka of the Matuyama chron (C1r.1r; Cremaschi, 1982; Gunderson et al., 2012).

166   These samples correspond, respectively, to beds S3 and S7-8 of Gregor (1986, 1990), from which

167   this author reported abundant carpological remains, not yet subjected to a dateiled taxonomic

168   treatment. Mai (1994) reported a cone of *Picea florschuetzii* Van der Hammen from

169   "Millepioppi", the locality where Gregor's bed S3 (our LA1) was in outcrop during the 1980s.

170

171   5) **Enza Creek section** (Iaccarino and Monegatti, 1996). The lower part of this succession consists

172   of shelf clays locally interbedded with calcarenites and sands. The upper part includes mainly

173   coastal sands passing upward to continental sediments (Iaccarino and Monegatti, 1996). An age

174   model for the section has been recently provided by Gunderson et al. (2014), combining

175   magnetobiostratigraphic data with cosmogenic radionuclide burial dating and cyclostratigraphy.

176   According to these authors, the section of Fig. 3 is almost entirely attributed to the Calabrian. The

177   boundary between Calabrian and "Ionian" has been traced within continental sediments. Seven

178   samples were collected (Fig. 3), however, only sample EZ38, providing a rich carpological

179   assemblage, has been analysed so-far. Magnetostratigraphic analyses reveal that this sample has

180   been collected in proximity of the upper boundary of Jaramillo subchron (Gunderson et al., 2014),

181   allowing an age attribution of about 1.0 Ma. The depositional environment of plant-bearing

182   samples has been investigated through analyses of foraminiferal assemblages in the whole section

183   (Appendix A), showing an overall regressive tendency from inner shelf (EZ20) to coastal (EZ30-

184   40) and continental environments (EZ50-51).

185   6) **Santerno River section** (Colalongo, 1969; Cremonini et al., 1969). The part of the Santerno

186   River succession considered in this work, includes open marine clays with interbedded sands

187   (Cremonini et al., 1969). The Gelasian-Calabrian boundary occurred in the lowermost portion of

188   the analyzed section (Fig. 3; Colalongo, 1969). The sample SNT1 comes from a sandy layer, rich

189   in phytoclasts (Gastaldo, 1994), which cropped out in the year 2001, close to the Gelasian-

190   Calabrian boundary (Fig. 3). Foraminiferal assemblages of a 2.6 m-thick succession including the

191   sampled layer, have been investigated (Appendix A), in order to improve the biostratigraphic and

192   palaeoenvironmental framework of plant-bearing sediments. Foraminiferal associations reveal an

193   outer shelf depositional environment attributed to the *G. cariacoensis* biozone, according to

194   comparable assemblages observed in the nearby Lamone section by Vaiani (2000).

195   7) **Marecchia River section** (Colalongo et al., 1982a; Rio et al., 1997). The part of the Marecchia

196   River succession considered in this work, consists of slope sediments, represented by clays and

197   sapropels, with subordinate sands. These deposits are ascribed to the late Piacenzian (Gauss

198   Chron, normal polarity interval 2An.1n) according to the stratigraphic scheme reported by Rio et

199   al. (1997). Three samples were collected in sandy beds below (MR1) and above (MR2, MR3) the

200   sapropel bearing intervals M1 and M2 of Rio et al. (1997), possibly corresponding to sapropel

201   cluster O of Roveri and Taviani (2003). Only the sample MR3 has been so-far analysed.

202   As a whole the analyzed sections are substantially well-calibrated within a detailed

203   chronostratigraphic frame. This allows us to propose a rather precise chronological framing

204   (locally with resolution of ca. 100 ka) of the plant-bearing layers (Tab. 1) and to place the East

205   area analyzed material into a definite chronological order (Fig. 4).

206

207   3. Methods

208   This research was not intended to complete the analyses in a short time, since several weeks of

209   analytic work are needed for each sample; rather, the aim was to sample and preserve for long

210   time the carpological record provided by a few layers, often exposed in ephemeral sections, which

211   had been calibrated, more or less precisely, from a chronostratigraphic point of view. In order to

212   improve our knowledge of the biochronologic range of some key-species found in the late

213   Cenozoic of northern Italy, we decided to analyse their occurrences in ten chronostratigraphically

214   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

240   (Letter-numer-Letter, e.g. A0B). The sediments (usually 4-30 dm^3) were treated according to the

241   method described by Basilici et al. (1997), and floating material was collected with final mesh size

242   of 0.3 mm. As for the sinking material, the removal of the clastic matrix left a very limited volume

243   of plant-bearing residue (maximum 20% of the original volume). When completely dry, this was

244   stored for long-term preservation, and analysed after variable times, up to 25 years after

245   preparation (Stirone section). For the picking of fruit and seeds the residue of each sample was

246   separated in 2 fractions: > 3 mm and < 3 mm: the coarser fraction was examined at naked eye, and

247   the finer one under a Wild M3B stereomicroscope. Only a few selected carpological species with

248   characteristic morphology (those listed in Fig. 4) were picked out, and we took care to proceed in a

249   uniform way for all the samples. The identification of these species has been carried out by

250   comparison to the CENOFITA collection of late Cenozoic carpological material (Martinetto and

251   Vassio, 2010), which had been the subject of several taxonomical studies (Basilici et al, 1997;

252   Cavallo and Martinetto, 2001; Martinetto, 2001a and 2001c; Mai and Martinetto, 2006; Jacques et

253   al., 2011; Vassio, 2012; Jiménez-Mejías and Martinetto, 2013; Martinetto and Festa, 2013). In a

254   few cases comparison to modern material has been necessary, and it was carried out in the

255   carpological collection of the Museum für Naturkunde of Berlin (label MFN, without number) and

256   in the Modern Carpological Collection of the Turin University (Martinetto et al., 2014), whose

257   samples are indicated by the label MCC and designated by a collection number (e.g. MCC0001).

258   Images of the fossil fruits and seeds (Plate I) were obtained obtained by using a Leica M205 C

259   optical microscope integrated with Leica Microsystems' Leica DFC290 HD digital camera and

260   Leica Application Suite software.

261   For the ecological and climatic characterisation of the fossil taxa we conducted a search for the

262   nearest living relatives (NLRs), and we consulted the data contained in the ClimGrim (Grimm and

263   Denk, 2012) and PALAEOFLORA databases (Utescher and Mosbrugger, 2013), as well as those

264   reported in the supplementary material of Denk et al. (2013). The reconstructed thermal

265   requirements of the species treated in this paper have been indicated by boundary values of Mean

266   Annual Temperature (MAT in °C), as explained in Fig. 4. Furthermore, we determined the

267   Köppen signature (of several species as explained by Denk et al. (2013). When the "potential

268   modern analogs" (our NLRs) where not reported by these authors, we analysed the modern

269   geographic distribution and we checked their Köppen climatic zone (see Supplementary material).

270   We consulted Boufford (1997) for *Boehmeria*, Galicia-Herbada (2006) for *Thymelaea*, Fang et al.

271   (2011) for Chinese plants, Hansen and Sunding (1993) for Macaronesian plants, Stevens (2014)

272   for *Phytolacca* and *Stemona*, and Thomson et al. (1999a, 1999b) for North American plants.

273

274

275   4. Taphonomy

276

277   As discussed above, 10 of the 14 studied fruit and seed assemblages were formed in a marine or

278   nearshore palaeoenvironment. Unfortunately there is no actuopalaeobotanical study dealing with

279   the taphonomy fruits and seeds of terrestrial plants deposited on marine bottoms, so we do not

280   know the degree of fidelity of such fossil record with respect to the contemporary flora and

281   vegetation of the terrestrial environment. Zavala et al. (2012) illustrated, with specific reference to

282   the Plio-Pliostocene sediments of the Eastern area, that the origin of the concentration of terrestrial

283   plant remains in marine successions can be explained by a massive transport of terrestrial

284   phytoclasts to the marine bottoms, carried out by the rivers. This allows us to interpret such marine

285   assemblages in the light of the present knowledge on the relationships between vegetation and

286   fruit and seed assemblages in fluvial deposits (Cappers, 1993; Gee, 2005; Vassio and Martinetto,

287   2012). These studies indicate that fruit and seed assemblages provide a record of the flora and

288   vegetation of a broad area of the river's catchment, although with several mismatches. For our

289   purposes, the above-mentioned studies also suggest that, given a fixed type of terrestrial flora, we

290   must assume that the list of plants obtained by analysing fruits and seeds in different samples of

291   marine sediment (with plant phytoclasts of terrestrial provenance) would be rather different from

292   one sample to the other, just due to taphonomical processes. For this reason a large number of

293   well-calibrated marine samples would be needed to reliably assess when a terrestrial plant species

294   appeared, disappeared or became more or less frequent in the surrounding terrestrial areas.

295   In addition, the geological context of the studied marine successions suggests that the possibility

296   of reworking of fossil plant remains has to be considered. In facts the progressive uplift of the

297   northern Apennine foothills determined the exposure and erosion of the Pliocene sediments, and

298   the recycling of their plant phytoclasts into the Pleistocene marine and continental basins is

299   theoretically possible. There are very few reports in the literature about fruits and seeds in modern

300   or fossil assemblages for which reworking from older sediments could be demonstrated (e.g.,

301   Thomasson, 1991). In light of the poor available evidence we suggest that reworked fossil fruits

302   and seeds seem to be extremely rare.

303

304   5. Palaeobotanical results

305

306   5.1 Sample analysis

307   The analysis of the 9 palaeocarpological samples from the East area sections showed that fruits

308   and seeds made up an extremely subordinate component of the phytoclasts (ca. 1 fruit/seed per

309   100-1000 wood fragments), and their taxonomic analysis indicated a prevalence of terrestrial

310   plants, although fruits of the seagrass *Cymodocea* cf. *nodosa* occurred in several samples (see

311   below). The palaeocarpological analysis of these samples did not permit so-far to obtain a

13

312   complete list of taxa, but the presence/absence of the species listed in Fig. 4 was carefully checked

313   into the residues of all samples.

314   The number of carpological species and specimens represented in different samples varies greatly.

315   Samples CQ1, CVE2, EZ38, LA1, LU1 yielded poor assemblages in terms of number of both

316   species (<20) and fruit/seed specimens (<50). Rich carpological assemblages, certainly with more

317   that 30 species and more than 50 (but often>200) carpological specimens, were obtained from

318   layers AD3, LA3, MR3 and SNT1.

319

320   5.2 Carpological data analysis

321   By analysing the whole CENOFITA dataset for N-Italy (Fig. 5) we could gather most species into

322   six groups on the basis of the similar biochronologic distribution: Group 1, only Zanclean records;

323   Group 2, records in the Zanclean and in the late Piacenzian (from 3.0 to 2.8 Ma); Group 3, records

324   in the Zanclean and in the middle-late Piacenzian (from 3.3 to 2.8 Ma); Group 4, definite records

325   in the (Zanclean-) Piacenzian, and clues for the persistence after the Piacenzian/Gelasian transition

326   given by occurrences in localities under investigation (Irace et al., 2012); Group 5, records from

327   (Zanclean-) Piacenzian to Calabrian, but not from the Middle Pleistocene onwards; Group 6,

328   records in the (Gelasian-) Calabrian, and partly also from the Middle Pleistocene onwards. In

329   general, the East area record (Fig. 4) fitted within the biochronologic distribution of each species

330   provided by the analysis of the N-Italian CENOFITA dataset (Fig. 5), and only two species

331   showed a broader distribution in the East area record (Fig. 4): *Eurya stigmosa* and *Sparganium*

332   *nanum*, occurring here newly in the Gelasian. As an alternative explanation to the longer survival

333   of these two species in the East area, we must consider the possible reworking of fruit and seed

334   specimens from older sediments, already discussed above. Additionally, the East area samples did

335   not contain any record of a few key-species which, according to the data of the N-Italian

336 CENOFITA database, would seem to be potentially useful for the biochronologic framing of the

337 West area fluvial-alluvial successions: *Actinidia faveolata, Boehmeria lithuanica, Carex*

338 *flagellata, Cryptomeria rhenana, Datisca gratioloides, Meliosma wetteraviensis, Styrax maximus,*

339 *Schoenoplectus isolepioides, Symplocos schereri*. All of these occur in the West area samples

340 reconsidered in this work (Fig. 4).

341 We also observe the lack in the East area samples of any record of Group 1 ("Zanclean") elements

342 (Fig. 4), even in the Zanclean assemblage of Lugagnano (LU1). However, Gregor (1990) reported

343 the occurrence in this locality of *Visnea germanica*, which suggests that we missed the Group 1

344 elements due to relatively small size of our sediment sample. The West area record shows that

345 Group 1 elements are well represented in the Zanclean sample of Pocapaglia (PO1, over 100 dm^3

346 of sediment analysed: Cavallo and Martinetto, 1996; Repetto, 1997), whereas only 4 out of 10

347 species occur in the less intensively sampled layer of Breolungi (BR3, 19 dm^3).

348 The climatic characterisation of the species treated in this paper is shown by the boundary values

349 of Mean Annual Temperature (MAT in °C) reported in Fig. 4, which permit to point out several

350 thermophile species (e.g. MAT>9°C or >15°C, etc.), as well as cool-tolerant species (e.g.

351 MAT>5°C or >3°C, etc.) and a few warm-intolenrant ones (e.g. MAT<14°C or <17°C).

352 Furthermore, the Köppen climate type for the Pliocene plant assemblages (BR3, PO1, RDB1,

353 RDB6, RT1, LU1, CVE2, MR3, CQ1) can be easily determined as Cfa, being this the single type

354 shared by all the occurring plant taxa (see Supplementary material). For the Early Pleistocene

355 assemblages (AD3, EZ38, LA1, LA3 and SNT1) the main Köppen signature is for the Cfa and Cfb

356 climate types. Thus, our elementary climatic analysis does not point out a definite change of the

357 Köppen climate types within the Pliocene and the Early Pleistocene assemblages studied.

358 However, the boundary values of MAT (Fig. 4) distinctly show that the Pliocene floras are rich in

359 thermophile species, that disappeared or became rare in the Early Pleistocene floras, which are

360 mainly made up by cool-tolerant and warm-intolenrant species. This situation suggests that a

361 decrease in temperatures is one of the causes of the palaeofloral differences observed between

362 Pliocene and Early Pleistocene assembleges.

363

364 6. Occurrences of selected plant taxa

365

366 The complete list of taxa which have been studied in the West and East area samples is reported in

367 Fig. 4, and in this section we provide additional information on selected species. The description

368 of each species displays its occurrence only in the studied sections, expressed by the label of the

369 plant-bearing layer, as reported in Tab. 1. Other known records of each species, even in the studied

370 region, are reported under "*General distribution and characteristics*".

371

372 Family Betulaceae

373 *Carpinus betulus* L.

374 1996 *Carpinus betulus* L. - Cavallo and Martinetto: pl. 5, fig. 2 (Pocapaglia, layer PO1).

375 *Occurrence:* West area: BR3, PO1 (Zanclean); RDB1, RDB6 (Piacenzian); East area: LU1

376 (Zanclean); CQ1, MR3 (Piacenzian); AD3 (Gelasian); SNT1 (early Calabrian), LA1, EZ38, LA3

377 (late Calabrian).

378 *General distribution and characteristics*: *C. betulus* has been selected for this analysis in order to

379 evaluate the pattern of the fossil record of this plant, whose habit, ecology, and diaspore

380 taphonomy are well known. This is a medium-sized deciduous tree, still living in the Po Plain

381 nowadays, and characterizing its few relics of semi-natural forest vegetation (Pignatti, 1982). It is

382 also a species frequently found in modern fruit and seed accumulations, where its wind-dispersed

383 fruits are overrepresented with respect to the frequency in the surrounding vegetation (Gee, 2005;

384 Vassio and Martinetto, 2012). Its fossil record in northern Italy covers all the intervals from latest

385 Miocene (Messinian: Cavallo et al., 1986), through Pliocene (Pavia, 1970; Martinetto, 1994;

386 Cavallo and Martinetto, 1996; 2001), Early Pleistocene (Martinetto and Sami, 2001; Ghiotto,

387 2010), Middle Pleistocene (Martinetto, 2009), to the Holocene (Vassio, 2012).

388 The lack of *C. betulus* in three Piacenzian samples (Fig. 4) can be explained by two possibilities: i)

389 it was absent or very rare in the time slices corresponding to the deposition of the layers where its

390 fruits are lacking; ii) it was present in the time slices corresponding to the deposition of the layers

391 where its fruits are lacking, but has not been recorded. We would propend for the second

392 hypothesis and conclude that our data contribute to the assessment of a long-lasting presence of

393 *Carpinus betulus* in the studied area during Pliocene and Early Pleistocene.

394

395 Family Cucurbitaceae

396 *Trichosanthes fragilis* E.M. Reid

397 Plate I, 1

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

399 *General distribution and characteristics*: this species had been reported in Italy only for the Front

400 site (Martinetto, 1995; Martinetto et al., 2007) and is figured here for the first time (Plate I, 1).

401 From the analysis of the distribution of its N-Italian occurrences it would seem an index fossil of

402 the Piacenzian age, but this is due to the rarity of this species in the fossil record, which does not

403 permit to use it in biochronological analyses.

404

405   Family Cymodoceaceae

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

407   Plate I, 2

408   *Occurrence:* West area: PO1 (Zanclean); East area: LU1 (Zanclean); CVE2, MR3, CQ1

409   (Piacenzian); AD3 (Gelasian); SNT1 (Calabrian).

410   *General distribution and characteristics*: The occurrence of fossil fruits of *Cymodocea* in other

411   Zanclean sites of the West area had been previously reported by Pavia (1976) and Basilici et al.

412   (1997). The fossil fruits from the studied samples seem to be identical to the modern ones

413   (reference material: MCC1662) of *Cymodocea nodosa* (Ucria) Ascherson, a common seagrass in

414   the Mediterranean; yet we prefer to adopt the open nomenclature (*Cymodocea* cf. *nodosa*) because

415   the fossils did not yet undergo a thorough morphological characterisation, and possible differences

416   between older (Zanclean) and younger (early Calabrian) remains (Fig. 5) must be verified.

417   The record of *Cymodocea* fruits in the studied samples shows very well how the occurrence data

418   coincide with the sediment facies. In fact, by examining Fig. 5 it appears that *Cymodocea* cf.

419   *nodosa* has a very constant occurrence in the Zanclean, Piacenzian and the oldest Calabrian, but it

420   is lacking in the late Calabrian assemblages. The "disappearance" of this seagrass can be attributed

421   to the unsuitable palaeoenvironment (coastal to continental) of the younger Calabrian deposits.

422

423   Family Cyperaceae

424   *Carex* cf. *elata* All.

425   Plate I, 3

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

427   *General distribution and characteristics*: The importance of the fossil record of *C. elata* and

428   related forms in the Plio-Pleistocene has been recently pointed out by Martinetto et al. (2012) and

429   Jiménez-Mejías and Martinetto (2013); therefore a careful search for the tiny fruits has been

430   carried out. However, the record in the studied sections turned out to be extremely scanty, possibly

431   due to the prevailing marine-coastal facies. In fact, *C.* cf. *elata* was only detected in the

432   palustrine-lacustrine assemblage LA1 (Fig. 4).

433   The modern *C. elata* is a rather tall herb forming tussocks in various non-saline waterlogged

434   environments of western Eurasia. Actuopalaeobotanical analyses (Vassio, 2012; Vassio and

435   Martinetto, 2012) showed that its tiny fruits are only abundant in the sediments that are directly

436   deposited in the places where the plant grows, whereas they are rare in the adjoining fluvial

437   sediments (Bertolotto et al., 2012). So, the absence of the fruits in marine-coastal sediments, in

438   which the abundance of plant material depends on the fluvial input (Zavala et al., 2012), does not

439   mean that the plant was absent in the continental palustrine environments.

440

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

442   Plate I, 4

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

444   *Taxonomical remarks*: Recent work on Cyperaceae showed the great taxonomic importance of

445   fruit morphology (e. g. Pignotti, 2003; Ercole et al., 2012; Jiménez-Mejías and Martinetto, 2013).

446   Some fruits found in the studied sections can easily be assigned to the genus *Schoenoplectus* for

447   the following characters: achenes with a narrowly obovate outline, acute base and largely obtuse

448   apex, flat on one side (Plate I, 4a) and convex on the other (Plate I, 4b); apex with a tubercle, but

449   style-remain lacking; epidermal cells small-sized and subrectangular. Only five modern European

450   species bear, as the fossil specimens, smooth fruits (Jiménez-Mejías et al., 2007): *S. pungens, S.*

451 *lacustris, S. litoralis, S. tabaernamontani* and *S. triqueter*. Another taxon, *S. carinatus* has been

452 found to be a hybrid (Ercole et al., 2012). The morphologically similar *S. corymbosum* has fruits

453 with small irregularly distributed wrinkles (Jiménez-Mejías et al., 2007).

454 The nutlets of *S. pungens* (MCC1515), *S. lacustris* (MCC1983)*, S. tabaernamontani* (MCC1995)

455 and *S. triqueter* (MCC2005) are always longer than 2.3 mm, so the smaller dimensions of the

456 fossils (LA3: 1.5-1.9; AD3: 1.5-1.8 mm), suggest assignment to *S. litoralis*, whose modern nutlets

457 are 1.6-1.9 [2.1] mm-long. However, Pignotti (2003) reported that also the hybrid *S. carinatus* has

458 comparably small fruits, and this is one of the reason for keeping the open nomenclature

459 *Schoenoplectus* cf. *litoralis*. Another reason is the total lack of the typical, feather-like perianth

460 bristles (not preserved).

461 *General distribution and characteristics*: We are not aware of previous fossil records of *S.*

462 *litoralis.* Today this is an herbaceous plant of rather limited distribution, found in coastal marshes.

463 The time of diversification of the five above-mentioned species of *Schoenoplectus* was not

464 discussed in the recent phylogenetic analyses (Muasya et al., 2009; Jung and Choi, 2011), however

465 some divergence times should note date back more than 5 Ma, in consideration of the patterns of

466 diversification pointed out in the Cyperaceae clades (Escudero et al., 2012; Escudero and Hipp,

467 2013).

468 Our Gelasian fossil record of *S*. cf. *litoralis,* as well as the "upper Pliocene" (but possibly

469 Gelasian) ones of *S. lacustris* (Mai and Walther, 1988) and *S. lacustroides* (Velichkevich and

470 Zastawniak, 2003) may become important for dating the phylogenetic tree, but need a more

471 detailed morphological characterisation. As *S. lacustris* is broadly distributed in lakes, marshes

472 and rivers, its time of diversification could be used for the biochronology of continental sediments.

473 The time of diversification of *S. litoralis,* which developed an adaptation to survive in salty soils,

474 could be useful for the biochronology of coastal successions.

475

476   Family Ehretiaceae

477   *Ehretia europaea* E.M. Reid

478   1996 *Ehretia* sp. - Cavallo and Martinetto: pl. 3, figs. 2, 3 (Pocapaglia, layer PO1).

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

480   *General distribution and characteristics*: The two endocarps figured by Cavallo and Martinetto
481   (1996) are 2.0 mm broad and 2.1-2.5 mm long. These dimensions are similar to those of the two
482   type specimens of *E. europaea* (1.8-1.25 x 1.6-2.75), described by Reid (1923) from the Late
483   Miocene locality of Pont-de-Gail in France. Also the diagnostic morphological characters
484   (Gottschling et al., 2002) show a good agreement between the Italian and the French specimens.

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

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

491

492   Family Eucommiaceae

493   *Eucommia europaea* Mädler

494   Plate I, 5

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

496   (late Calabrian).

497   *General distribution and characteristics*: this species had been reported in Italy only for the

498   Castelletto Cervo II site, possibly Gelasian (Cavallo and Martinetto, 2001). The occurrence of

499   fruits in the Gelasian of N Italy is remarkable because they have not been found in Pliocene

500   sediments, and there is only a preliminary report in the Calabrian (Gregor, 1986). This pattern of

501   fossil record would suggest either an immigration or an increase of *Eucommia europaea* in N

502   Italy, possibly in correspondence of the cooling at the Piacenzian/Gelasian transition (Bertini,

503   2010). Unfortunately, the scarce woodiness in addition to the large size of the fruits (Plate I, 5)

504   hampers their preservation in the fossil record (Vassio and Martinetto, 2012), and limits the use of

505   this species in biochronological analyses.

506

507   Family Hypericaceae

508   *Hypericum tertiaerum* P. Nikitin

509   Plate I, 6

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

511

512   *General distribution and characteristics:* An overview about the fossil record of this species has

513   been recently reported by Martinetto et al. (2012). We add here its occurence in the Piacenzian

514   sample of Monte Falcone (CQ1). The occurrence of *H. tertiaerum* in marine sediments appears to

515   be extremely scanty, and not suitable for the assessment of the presence/absence of this species in

516   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

541   records from "Pliocene" localities of Germany and Russia. Our fossil record of layer LA3 (ca 1.0

542   to 0.8 Ma) is the oldest for Italy, and is immediately followed by the early Middle Pleistocene one

543   of Pianico (Martinetto, 2009). So the present evidence would suggest a late immigration of *H.*

544   *perforatum* in Italy (around 1.0 Ma), much later than the diversification of the species.

545

546   Family Magnoliaceae

547   *Liriodendron geminata* Kirchheimer

548   Plate I, 8

549   1996 *Liriodendron geminata* Kirchheimer - Cavallo and Martinetto: pl. 1, fig. 4 (Pocapaglia, layer

550   PO1).

551   *Occurrence:* West area: PO1 (Zanclean); RDB1 (Piacenzian); East area: CVE2 (Piacenzian);

552   SNT1 (early Calabrian); EZ38 (late Calabrian).

553   *General distribution and characteristics: Liriodendron geminata* is a seed-morphospecies possibly

554   linked to the leaves described as *L. procaccinii* in the Messinian (Massalongo and Scarabelli,

555   1859). However the oldest records of seeds in Italy are available only from the Zanclean (Cavallo

556   and Martinetto, 1996). The CENOFITA database (Martinetto and Vassio, 2010) indicates that it is

557   abundant in a few coastal-continental sites attributed to the late Zanclean-late Piacenzian (Aulla,

558   Fossano, Sento II, Terzoglio III), but also occurs in many other sites with a few seeds. Its modern

559   relatives are tall deciduous trees that produce wind-dispersed fruits, which are poorly lignified, so

560   that only the hard seeds are often recorded as fossils.

561   By combining the reconstructed habit, dispersal syndrome and the rather dense fossil record of this

562   species (Fig. 5) we can conclude that *L. geminata* was most probably a deciduous tall tree, broadly

563   distributed in the Zanclean and Piacenzian of northern Italy, but possibly uncommon or only

564 locally common. In marine sediments its occurrence is sporadic, so that the absence in CQ1 and

565 MR3 is not surprising. The post-Piacenzian record was so-far poorly known, and the occurrence in

566 two marine carpological assemblages of the Calabrian (EZ38, SNT1 in Fig. 4) points to the late

567 survival of this plant in Italy. Its rarity in Calabrian sediments (absent from the LA1 and LA3

568 samples, as well as from Leffe, San Pietro di Ragogna, Steggio: Ravazzi and Rossignol-Strick,

569 1995; Ghiotto, 2010; Martinetto et al., 2012) could mean that, after the end of the Piacenzian, *L.*

570 *geminata* became a rare tree in northern Italy. Furthermore, the record of the long, but poorly

571 dated, section of the Cervo River in the western Po Plain (BU in Fig. 1) (Cavallo and Martinetto,

572 2001; Martinetto and Festa, 2013), where *L. geminata* occurs only in two out of ca. twenty fruit-

573 bearing layers of possible Gelasian and/or Calabrian age, could indicate that this plant has left a

574 detectable fossil record only in limited Early Pleistocene time slices, which could be better

575 pinpointed by future research. Unfortunately the pollen record of *Liriodendron* is scanty (Bertini

576 and Martinetto, 2011) and cannot help us to clear this situation.

577

578 *Magnolia allasoniae* Martinetto

579 Plate I, 9

580 1996 *Magnolia allasoniae* Martinetto - Cavallo and Martinetto: pl. 4, figs. 5, 6 (Pocapaglia, layer

581 PO1).

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

583 *General distribution and characteristics:* This is a seed-morphospecies firstly established in the

584 Pliocene of NW Italy (Martinetto, 1995), and it has been recorded in several sites of northern and

585 central Italy in the time span Messinian-Piacenzian. Curiously, it is common in several Italian

586 sites, but it has not yet been reported in the adjoining countries, which could suggest a plant with a

587 limited geographic distribution in the late Cenozoic (endemic?). The leaves, pollen and wood of

25

588 the ancient whole plant are unknown. The seeds of *M. allasoniae* have been so-far compared with

589 just a few species within the genus *Magnolia*, so that its modern relatives are not yet precisely

590 indicated, even if an affinity of the fossil seeds to those of the living species *M. tripetala* has been

591 pointed out. This last species is a deciduous tree which can grow in waterlogged environments.

592 *M. allasoniae* is broadly distributed and often frequent in the Zanclean of northern Italy, and the

593 single occurrence in the Piacenzian is reported here (MR3 in Fig. 4). The fossil record and the

594 ecology of the living *M. tripetala* would suggest that this plant was probably a common river-side

595 or wetland tree in the Zanclean, while it became very rare in the Piacenzian, possibly with a relic

596 distribution just in the southernmost areas (see MR3 in Fig. 2), as well as in central Italy

597 (Martinetto, 2001a). The importance of the *M. allasoniae*-plant in the Zanclean is confirmed even

598 by considering that *Magnolia* seeds have a fleshy tegument adaptive for animal dispersal, which

599 may cause an overrepresentation in the sedimentary deposists (Vassio and Martinetto, 2012).

600

601 *Magnolia cor* Ludwig

602 Plate I, 10

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

604 *General distribution and characteristics:* This seed-morphospecies has been recorded in the late

605 Cenozoic of several parts of Europe (Mai, 1975). In Italy it occurs, sometimes abundantly (Cavallo

606 and Martinetto, 2001), only from the Piacenzian to the Calabrian (Fig. 5). The smooth, heart-

607 shaped seeds of *M. cor* (Plate I, 10) are very variable and morphologically similar to those of

608 several modern East-Asian species (*M. kobus, M. stellata*, etc.). These modern plants are both

609 deciduous trees and shrubs, growing in mesic forests. For this reason the seeds of *M. cor* are

610 considered to represent an ancient deciduous tree or shrub with animal-dispersed seeds.

611

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.

628

Family Menispermaceae

Sinomenium cantalense (E.M. Reid) Dorofeev

Plate I, 12

632 1996 *Sinomenium cantalense* (E.M. Reid) Dorofeev - Cavallo and Martinetto: pl. 1, figs. 5, 6

633 (Pocapaglia, layer PO1).

634 *Occurrence:* West area: PO1, BR3 (Zanclean); RDB1 (Piacenzian); East area: LU1 (Zanclean);

635 CVE2, MR3, CQ1 (Piacenzian).

636 *General distribution and characteristics: S. cantalense* is reported, never abundant, in most of the

637 Zanclean-Piacenzian sites of northern Italy (Martinetto, 1999; Martinetto et al., 2007). Its single

638 modern relative, *S. acutum*, is an evergreen or semi-evergreen climber, which produces drupes

639 dispersed by animals (endozoochory). This feature can be hypothesized also for *S. cantalense*. So,

640 the habit of the single living relative, the dispersal syndrome and the rather dense fossil record of

641 this species (Fig. 5) suggest that the *S. cantalense* fossil endocarps were produced by an

642 evergreen-semievergreen climber, broadly distributed in the mesic and river-side forests of

643 northern Italy, during Zanclean and Piacenzian. In northern Italy there are no post-Piacenzian

644 records of this species, whereas in central Italy it has been abundantly recorded in the Ponte Naja

645 Formation of the Cava Toppetti II site, assigned to the Gelasian (Leone et al., 2000; Martinetto,

646 2001a).

647

648 Family Rutaceae

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

650 2001a *Toddalia naviculaeformis* (E.M. Reid) Gregor - Martinetto: pl. 1, figs. 14, 15 (Marecchia,

651 layer MR3).

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

653 *General distribution and characteristics:* two seeds of this species from the Piacenzian sediments

654 of the Marecchia section (MR3) had been figured in Martinetto (2001a), and other few records

655   were published for sites of Zanclean and/or Piacenzian age in northern Italy (Martinetto and Mai,

656   1996; Basilici et al., 1997; Ferrero et al., 2005). This species is less common than its relatives *T.*

657   *latisiliquata* and *T. rhenana*, which are more useful for biochronological analyses (Fig. 5). In

658   general, for the species of *Toddalia* there are no records younger than late Piacenzian in northern

659   Italy, whereas in central Italy *T. latisiliquata* is suspected to persist in the Gelasian (see Martinetto,

660   2001a).

661

662   *Zanthoxylum ailanthiforme* (Gregor) Gregor

663   1996 *Zanthoxylum ailanthiforme* (Gregor) Gregor - Cavallo and Martinetto: pl. 6, fig. 1

664   (Pocapaglia, layer PO1).

665   2001a *Zanthoxylum ailanthiforme* (Gregor) Gregor- Martinetto, pl. 1, fig. 21 (Marecchia, layer

666   MR3).

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

668   *General distribution and characteristics:* The taxonomic treatment and occurrences of this species

669   in central as well as in northern Italy have already been discussed by Martinetto (2001a), who also

670   figured one specimen from the Piacenzian sediments of the Marecchia section (MR3). This species

671   seems to be important for biochronological analyses because in northern Italy is well represented

672   only in the Messinian (Kovar-Eder et al., 2006) and Zanclean, with a single Piacenzian record in

673   the layer MR3 (Marecchia section). Also in central Italy *Z. ailanthiforme* never occurred in sites of

674   well-assessed Gelasian and/or Calabrian age (Martinetto, 2001a; Girotti et al., 2003).

675

676

677   Family Sparganiaceae

678   *Sparganium nanum* Dorofeev

679   Plate I, 13

680   1996 *Sparganium nanum* Dorofeev - Cavallo and Martinetto: pl. 3, fig. 7 (Pocapaglia, layer PO1).

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

682   AD3 (Gelasian).

683   *General distribution and characteristics*: The record of AD3 represents the last occurrence of this

684   species in Europe. The single fruitlet is small, globose, and very resistant (Plate I, 13), so that

685   reworking cannot be excluded and further findings in other layers of the same age would be

686   necessary to confirm the extension of the range of *S. nanum* to the early Gelasian.

687   The habit of *S. nanum* can be reconstructed as that of an herb living in freshwater wetlands,

688   possibly with submerged roots and floating leaves as the modern *S. angustifolium* (Pignatti, 1982).

689

690   Family Stemonaceae

691   *Stemona germanica* (Mai) Mai

692   Plate I, 14

693   1996 *Spirellea* aff. *bohemica* Knobloch et Mai - Cavallo and Martinetto: pl. 3, fig. 9 (Pocapaglia,

694   layer PO1).

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

696   (Piacenzian).

697 *General distribution and characteristics*: This carpological species was assigned to the modern

698 genus *Stemona* by Mai (2008), who reported occurrences from the Late Cretaceous to the Late

699 Miocene in Central Europe. In Italy, material of this species was often reported as "*Spirellea* aff.

700 *bohemica* Knobloch et Mai" (Cavallo and Martinetto, 1996; Basilici et al., 1997; Martinetto and

701 Ravazzi, 1997) or "*Spirellea* sp." (Martinetto, 2001a) and was assigned to *S. germanica* for the

702 first time in Martinetto and Vassio (2010).

703 A revision of the CENOFITA collection carried out for this paper confirmed that *S. germanica*

704 occurs, in northern Italy, in four sites reliably dated to the Zanclean (BG-Sento I, BR-Breolungi,

705 MZ-Morozzo and PO-Pocapaglia in Fig. 1), in four sites of supposed Zanclean age (BG-Sento II,

706 CV-Ca' Viettone, RB-Ronco Biellese, CGL-Cortiglione d'Asti), and in a single site of supposed

707 Piacenzian age (MO-Momello/Lanzo). So this species disappeared from Italy later than in central

708 Europe and seems to be useful for biochronological analyses (Fig. 5), since there are no records

709 younger than late Piacenzian in northern Italy. We revise here as *S. germanica* also the record of

710 "*Spirellea* sp.", reported by Martinetto (2001a) from the Dunarobba site (Piacenzian or Gelasian)

711 in central Italy, which consists in a single seed.

712

713 Family Symplocaceae

714 *Symplocos casparyi* Ludwig

715 1996 *Symplocos lignitarum* (Quenstedt) Kirchheimer - Cavallo and Martinetto, pl. 5, fig. 9

716 (Pocapaglia, layer PO1).

717 *Occurrence:* West area: BR3, PO1 (Zanclean); RT1 (Piacenzian); East area: LU1 (Zanclean);

718 CVE2, MR3, CQ1 (Piacenzian).

719   *General distribution and characteristics*: *S. casparyi*, as circumscribed by Mai and Martinetto

720   (2006), is a morphospecies with largely variable endocarps. In Italy it occurred in several coastal-

721   continental sites attributed to the late Zanclean (Ca' Viettone, Castellengo, Fossano, Sento II). As

722   its modern relatives, which are small evergreen trees or shrubs, produce drupes which favour

723   animal dispersal (endozoochory), this feature can be hypothesized also for *S. casparyi*. By

724   combining the reconstructed habit, dispersal syndrome and the rather dense fossil record of this

725   species (Fig. 5), we can conclude that the *S. casparyi* fruits were most probably produced by an

726   evergreen small tree or shrub, broadly distributed in the Zanclean and Piacenzian mesic forests of

727   northern Italy. This is in agreement with its occurrence in all the marine carpological assemblages

728   of the Zanclean and Piacenzian in the East area (Fig. 4).

729

730   Family Theaceae

731   *Eurya stigmosa* (Ludwig) Mai

732   Plate I, 15

733   1996 *Eurya stigmosa* (Ludwig) Mai - Cavallo and Martinetto: pl. 2, fig. 1 (Pocapaglia, layer PO1).

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

735   AD3 (Gelasian).

736   *General distribution and characteristics*: One of the commonest species in the Zanclean of

737   northern Italy and already reported in sites dated back to a possible Piacenzian age (Martinetto,

738   1995). The record of 3 seeds in the CQ1 layer, treated in this paper, is a further clue to the survival

739   of this plant till the late Piacenzian, not only in central Italy (Martinetto, 2001a), but also in the

740   northern part of this country. Finally, the interpretation of a single seed found in the Gelasian

741 sample of the AD3 layer is not easy: the good preservation (Plate 1, 15) does not provide any

742 evidence of reworking, anyway we suggest to take in consideration this possibility.

743

744 Family Thymelaeaceae

745 *Thymelaea* cf. *passerina* L.

746 Plate I, 16

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

748 *General distribution and characteristics*: The phylogeny of *Thymelaea*, whose present distribution

749 is limited to the peri-Mediterranean area, has been studied by Galicia-Herbada (2006). The genus

750 includes 31 species, most of which show a distribution restricted to the westernmost

751 Mediterranean (Iberia plus Northwest Africa) and, according to the phylogenetic analysis of

752 Galicia-Herbada (2006), have a recent origin (not older than 2 Ma) and should not be crucial for

753 the comparison with our fossils. In Italy (Pignatti, 1982) only 4 species of *Thymelaea* occur at

754 present: *T. dioica, T. hirsuta, T. passerina* and *T. tartonraira.* The narrow drop-shaped seeds of

755 samples AD3 and LA3, with a thick and shining wall, are respectively 2.0 and 1.7-mm long and

756 both have a length/width ratio of 1.8. The 1.6-2.2 mm-long (mean specimens' length around 1.9

757 mm) seeds of *T. passerina* from NW Italy (MCC1516), with a 1.8-2.2 length/width ratio, agree in

758 all the morphological characters with those of fossil samples. The seeds of *T. hirsuta* (MCC1767)

759 and *T. tartonraira* (MCC1768) are easily distinguishable for the larger dimensions, lower

760 length/width ratio, and coarser cell pattern.

761 The perfect morphological agreement of the fossil seeds with the modern ones of *T. passerina*

762 would suggest an assignment of the *T. passerina* clade (Galicia-Herbada, 2006). Furthermore, it

763 does not seem possible the occurrence of species other than *T. passerina* in northern Italy (also in

764 the past) because the differentiation of other species occurred because of geographic isolation in

765 the western (e.g. *T. salsa*) or eastern (e.g. *T. mesopotamica*) Mediterranean (Urbani, 1992).

766 However, due to strong phylogenetic link between *T. passerina* and *T. salsa,* pointed out by

767 Galicia-Herbada (2006: fig. 7), it would be desirable to study in more detail the seed morphology

768 of these two species in order to evaluate the presence of differential morphological characters

769 which could be checked in the Early Pleistocene fossils.

770 The record of AD3 most probably represents the oldest known for *T. passerina* in the fossil record.

771 Its occurrence in the Middle Pleistocene of central Europe was reported by Mai (2010). This

772 species was also reported from archaeological sites of the East area dating back from the 2nd

773 century BC to the 6th century AD (Rinaldi et al., 2013).

774

775 Family *incertae sedis*

776 *Carpolithes minimus* (Szafer) Mai

777 Plate I, 17

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

779

780 *General distribution and characteristics:* Despite the good morphological and anatomical

781 agreement (Martinetto, 2001c), assignment of *C. minimus* to *Thalictrum* (Ranunculaceae) has to be

782 rejected because the indehiscent achenes of *Thalictrum* do not correspond to the apparently

783 dehiscent condition of *C. minimus* (Plate I, 17). The new efforts in searching the same structure as

784 in *C. minimus* in fruits and seeds of modern plant taxa, just brought to the detection of superficial

785 resemblances (Lamiaceae: *Horminum*; Cannabaceae: *Humulus*). Therefore, this common and

786 characteristic fossil taxon is still to be considered *incertae sedis*, and we have no information

787   about the habit and ecology of the plant which produced these remains. It was certainly not linked

788   to coastal areas, since these fossils are also found in ancient freshwater intermontane basins

789   (Steggio: Ghiotto, 2010).

790

791   7. Discussion

792   Our analyses, aimed at the reconstruction of the distribution in time and space of plant species, are

793   based on the interpretation of the presence of carpological remains in well-dated layers, whereas

794   the absence of fossils is considered less important. In fact, the analyses of fruit and seed

795   assemblages in modern contexts showed that the fruit/seeds of one species may frequently be

796   absent in the sediments formed close to its growth place, due to several biological and

797   taphonomical factors. Absence of the fruits/seeds with hard parts in the fossil record can be used

798   as a clue to the absence of one plant in an ancient environment, but only after the analysis of

799   several samples and localities of the same age. Conversely, the presence of the fruits/seeds of one

800   species in a sedimentary deposit is a strong evidence for the presence of the mother plant in the

801   environment surrounding the place of deposition (at the catchment basin scale: Vassio and

802   Martinetto, 2012). An exception is represented by the reworking of fruits and seeds from older

803   sediments, which seems to be a rare event at the light of the evidence discussed above;

804   nevertheless, should be kept in consideration.

805   The fossil fruit and seed record of selected plant taxa in Zanclean, Piacenzian, Gelasian and

806   Calabrian layers showed that the distribution of several species was limited to one or a few

807   chronostratigraphic stages (Fig. 4). The climatic characterisation of these species indicates that the

808   major floristic changes are linked to the disappearence or retreat of thermophile elements in the

809   late Zanclean, late Piacenzian, and during the Calabrian. Additionally, most of the species which

810   appear in the Early Pleistocene fossil record are cool-tolerant.In the Zanclean we observe the

811   highest number of thermophile species, and some of them (Group 1 in Fig. 4) occur only in this

812   stage. Howewer, the independently dated (Barbieri, 1967) Lugagnano assemblage (Fig. 4) shows

813   that a poor Zanclean flora may lack Group 1 elements (excepted *Visnea germanica*, reported by

814   Gregor, 1990), and fit the criteria used to suggest a Piacenzian affinity (simultaneous occurrence

815   of several species of groups 2 and 3, without species of groups 1 and 5). Unfortunately, we have

816   no information on carpological assemblages of the earliest Piacenzian (3.6 to 3.3 Ma), and the

817   oldest known Piacenzian assemblages come from the West area sites re-examined in this work

818   (RDB1, RDB6, RT1), which have been interpreted by Martinetto et al. (2007) as falling within the

819   Mammoth reversed magnetic polarity event (ca. 3.3 to 3.2 Ma). The record of these Piacenzian

820   western sites (Fig. 4) appears consistently different from that of the eastern ones, mainly because

821   of the occurrence of Group 2 species in the last ones (Fig. 4). In our opinion this difference is

822   linked to the slightly younger age (3.0-2.8 Ma) of the eastern sites CQ1 and MR3 (Tab. 1), since

823   the thermophilous Group 2 elements (MAT often >8°C in Fig. 4) could have profited from the

824   climate warming reported around 3.0 Ma (Bertini, 2010). So, we can argue that the carpoflora of

825   Chiavenna (CVE2 in Fig. 4) lacks of Group 2 elements because it is dated to the reversed

826   magnetic polarity event Kaena (3.1 to 3.0 Ma), which predates the warming. This is also

827   confirmed, in the northern part of the western Po Plain, by the lack of Group 2 elements in the rich

828   palaeoflora of the Stura di Lanzo Fossil Forest, also dated to the Kaena (Martinetto et al., 2007).

829   On the other hand, the successive (ca. 3.0-2.8 Ma) Piacenzian records of Marecchia (MR3) and

830   Monte Falcone (CQ1) point out a thermophilous palaeoflora (MAT>8°C) in which even the

831   species characterizing the Zanclean palaeoflora (Group 2 in Fig. 4) are still abundant, therefore

832   they seem to correspond to the warming phase. Therefore, in the interpretation of the age of

833   Pliocene floras, we must consider that the thermophilous species of Group 2 did not disappear at

834   the Zanclean/Piacenzian transition (see Martinetto, 1999), but just experienced a temporary retreat

835   from 3.2 to 3.0 Ma, and assumed again greater importance into the late Piacenzian (ca. 3.0 to 2.8

836   Ma).

837   The newly obtained carpological assemblage dated to the early Gelasian (AD3), is particularly

838   important because in the whole N-Italy there was only another carpoflora, the Casnigo one (CG in

839   Fig. 1, already mentioned in Martinetto, 1999), which was reliably dated to the Gelasian, in

840   particular to the final part of this age (ca. 2.1 to 1.8 Ma). Another assemblage interpreted as

841   Gelasian has been described at San Pietro di Ragogna (SPR in Fig. 1, NE Italy), but mainly

842   represents an ancient freshwater plant community and provides a very poor record of the terrestrial

843   palaeoflora (Martinetto et al., 2012). Richer assemblages of possible Gelasian age have been

844   described from the Cervo River section (Fig. 1; Castelletto Cervo II and Buronzo floras: Cavallo

845   and Martinetto, 2001; Martinetto and Festa, 2013) for which a confirmation of the age with

846   methods independent from palaeobotany would be needed. Also the ongoing studies in the

847   southern Piedmont Basin, along the Bormida valley (Fig. 2; Irace et al., 2012) are promising for

848   the gathering of data on Gelasian carpofloras. Nevertheless, the Gelasian is still largely "*terra*

849   *incognita*" as for the distribution of carpological taxa, and this is particularly critical for the better

850   definition of the last appearance in northern Italy of a large number of Zanclean-Piacenzian

851   species, never detected in the Gelasian/Calabrian. The last known occurrences of such "old" taxa

852   (Groups 2-3 in Fig. 5) mostly fall within the late Piacenzian, but in 2 cases (*Eurya stigmosa,*

853   *Sparganium nanum*) Gelasian occurrences were detected in this work (Fig. 4). However, in

854   consideration of the possibility of reworking (see above), we suggest much caution before placing

855   into the Gelasian the local extinction of these taxa.

856   The Calabrian carpological record of the East area sections starts with the Santerno-SNT1

857   assemblage, dated at the very base of the Calabrian (ca. 1.8-1.7 Ma), which is followed by a

858   definitely younger Calabrian assemblages (LA1, ca. 1.1 Ma after Gunderson et al., 2012). Due to

859   gap of ca. 600 ka between the SNT1 and LA1 assemblages, at present it is not possible to point out

860   eventual changes of the carpofloras within the lower Calabrian. About the EZ38 and LA3

861   assemblages, new magnetostratigraphic data (Gunderson et al., 2012, 2014) point to a late

862   Calabrian age, just after the Jaramillo normal subchron. This is also supported by the occurrence

863   of *Tsuga,* that is unknown in the Middle Pleistocene, even in pollen records (Ravazzi et al., 2005;

864   Martinetto, 2009; Bertini, 2010). The four Calabrian fruit and seed assemblages studied are

865   typically formed by an admixture of species inherited from the Pliocene floras (*Carpolithes*

866   *minimus, Juglans bergomensis, Liriodendron geminata, Magnolia cor*, *Selaginella* gr. *pliocenica*)

867   and species which appear in the North Italian record only in the Gelasian (*Ajuga* cf. *iva, Picea*

868   *florschuetzii, Taxus baccata, Thymelaea* cf. *passerina, Tsuga* cf. *chiarugii*) or Calabrian

869   (*Hypericum perforatum*). None of these new occurrences is interpretable as an evolutionary

870   appearance. Rather, the effect of the environmental factors seems having prevailed, favouring the

871   immigration of these species from adjoining areas; for the Gymnosperms, this could simply

872   consist in descending from the mountains (where no fossil record was preserved).

873   The record of those plant taxa with a proven diversification in the last 5 Ma (e.g., Thymeleaceae:

874   Galicia-Herbada, 2006; Cyperaceae: Jiménez-Mejías and Martinetto, 2013) is much scattered in

875   the sections studied, but offers intriguing opportunities for a future detection of the time of

876   evolutionary appearance of a few species. As for the Cyperaceae the 2.5-2.4 Ma record of

877   *Schoenoplectus* cf. *litoralis* (AD3) falls within an interesting time range to calibrate the phylogeny

878   of the group. As for *Thymelaea,* the 2.5-2.4 Ma record of AD3 is the oldest known for the *T.*

879   *passerina* clade (Galicia-Herbada, 2006), and could predate the diversification of *T. salsa*. The

880   supposed Late Miocene origin of the clade would suggests that plants producing seeds of the *T.*

881   *passerina*-type were present since that time somewhere in the Mediterranean. So, the appearance

882   of such seeds in the fossil record of N-Italy, as late as the Gelasian, could be explained by the

883   expansion of the plant's habitat at that time, due to slightly drier climatic conditions, which were

884   possibly absent in the Pliocene (more persistent humidity). In fact the plants of the *T. passerina*

885   group are small herbs linked to open areas with temporarily dry soil (Pignatti, 1982).

886

887   7. Conclusions

888   Our analysis of carpological assemblages in Pliocene and Early Pleistocene successions cropping

889   out along the southern margin of the Po Plain showed that these deposits contain an interesting

890   record of the terrestrial palaeoflora, which integrates the information provided by the extensive

891   pollen record available in this area. We could fix in the geological time scale, often with a

892   precision of 100 ka (Tab. 1), 14 carpoflora-bearing layers spanning from 5.1 to 0.9 Ma, thus

893   obtaining a framework which is not available in other parts of Europe. This enabled us to provide

894   precise ages for the occurrence of fruits and seeds of a few plant groups with a proven late

895   Cenozoic differentiation, as a possible contribution to future phylogenetic analyses. For the other

896   species, with a phylogenetic origin dating back to the Miocene, Palaeogene or Cretaceous, we

897   obtained an updated synthesis of the distribution in time of the fossil record in the studied area.

898   Our dataset was revealed useful for biochronological analyses, since the fossil record of several

899   species showed an interesting distribution, often limited to one to three chronostratigraphic stages

900   (Zanclean-Piacenzian-Gelasian-Calabrian). Nevertheless, several relevant differences could be

901   pointed out by comparing the record of the West and the East area. In particular, several species

902   occurring only in the Zanclean of the West area were detected in the late Piacenzian of the East

903   area (Fig. 4), thus suggesting that both datasets, separately, were not reliable for the reconstruction

904   of the distribution in time of each plant species.

905   Our elementary palaeoclimatic characterisation of the individual species, and of the plant

906   assemblages in which they occur (Fig. 4), suggests that temperature decrease is one of the causes

907   of the disappearance from the fossil record of several species, in particular at the

908   Piacenzian/Gelasian transition. Also the disappearance (or retreat) of some species at the

909   Zanclean/Piacenzian transition would seem to be due to climate deterioration, since it affects the

910   thermophilous Group 1 (NLRs' MAT boundaries often >15°C and mostly >9°C).

911 As for the appearance of new species in the studied fossil record, the analysis of the habit,

912 ecological-climatic requirements and phylogeny of the recent relatives indicates that it is mostly

913 due to the establishment of favourable local environmental conditions, rather than to evolutionary

914 events.

915 The input of the new data obtained into the CENOFITA database led to an apparent improvement

916 of the distribution chart of carpological taxa in the Pliocene and Early Pleistocene. This new chart

917 shows the carpological species clustered in groups with a similar biochronologic distribution

918 (Groups 1-6 in Fig. 5) and we suggest that the analysis of the representation of such groups in

919 undated or poorly dated carpological assemblages would be useful for their biochronological

920 interpretation. In this sense, the possibility to characterise the Zanclean floras against the

921 Piacenzian ones is provided by the occurrence of Group 1 species in the first ones. In addition, the

922 simultaneous occurrence of several species of groups 2 and 3 (Fig. 5), without species of groups 1

923 and 5, could be used to suggest a Piacenzian affinity for undated assemblages.

924 The characterisation of Gelasian floras is a major problem, because of the lack of record in the

925 crucial time span between 2.8 and 2.5 Ma, so that we cannot really say whether the Gelasian

926 carpological floras can be distinguished from the latest Piacenzian ones. Fruit and seed

927 assemblages with several species of groups 5 and 6, without species of groups 1-3 (Fig. 5), have

928 not been detected in any Zanclean or Piacenzian carpoflora, and would suggest a Gelasian or

929 Calabrian affinity.

930 In conclusion, the new data presented here determined several changes in the biochronological

931 distributions published in preceeding works and, despite the good chronostratigraphic framing

932 available in the studied sections, we suggest that the biochronologic chart presented in this paper

933 (Fig. 5) still requires an integration of data from a broader geographic area, before being

934 considered as definitely stable. The implementation of the N-Italian Plio-Pleistocene carpological

935 dataset, especially with data from other calibrated continental sections, would be the right

936   direction for completing our knowledge of the chronologic distribution of single carpological

937   species as well as species-groups.

938

954

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1290   Figures and tables captions:

1291   Fig. 1. Schematic map of northern-central Italy showing the location of the Zanclean-Calabrian

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1293   Sento I and II; BL: Candelo; BO: Boca; BR: Breolungi; BU: Buronzo; GA: Castelletto Cervo I

1294   and II; CGL: Cortiglione d'Asti; CM: Crava di Morozzo; CO: Cossato; CVE: Chiavenna; CG:

1295   Casnigo; CQ: Castell'Arquato-Monte Falcone - Rio Crevalese; CV: Ca' Viettone; EZ: Enza; FR:

1296   Front; LA: Stirone-Laurano; LF: Leffe; LU: Lugagnano; MO: Momello-Lanzo; MR: Val

1297   Marecchia; MZ: Morozzo; PO: Pocapaglia; RBS: Ranica Borgo Sale; RDB: RDB Quarry,

1298   Villafranca d'Asti; RDL: Rio della Lupa; RT: Roatto; SG: Steggio; SNT: Santerno; SPR: San

1299   Pietro di Ragogna; STU: Stura di Lanzo Fossil Forest; TC: Castellengo; TZ: Terzoglio; VF: Valle

1300   della Fornace. Towns: Tu, Turin; Ve, Venice.

1301

1302   Fig. 2. Schematic map of the southern margin of the Po Plain with the location of the studied

1303   sections. Red lines indicate the frontal thrust arcs. The star indicates the Villafranca d'Asti type

1304   area; Br: Breolungi; Po: Pocapaglia; 1: Chiavenna Rocchetta; 2: Lugagnano; 3: Monte Falcone and

1305   Arda (Castell'Arquato section); 4: Stirone; 5: Enza; 6: Santerno; 7: Marecchia.

1306   Fig. 3. Simplified logs of the studies sections with data useful for the chronostratigraphic

1307   calibration. Chronostratigraphy after Gradstein et al. (2004), Cita et al. (2006), Gibbard and Head

1308 (2010). Magnetostratigraphy after Cande and Kent (1995). Planktonic foraminifer biostratigraphy

1309 after Cita (1975), Iaccarino (1985), and Sprovieri (1992). Stratigraphy of analyzed sections are

1310 modified after 1) Roveri and Taviani (2003); 2) Barbieri (1967); 3a) Monegatti et al. (2002); 3b)

1311 Dominici (2001), Roveri and Taviani (2003); 4) Papani and Pelosio (1963), Gunderson et al.

1312 (2012); 5) Iaccarino and Monegatti (1996), Gunderson et al. (2014); 6) Cremonini et al. (1969),

1313 Colalongo (1969); 7) Colalongo et al. (1982a and 1982b), Rio et al. (1997).

1314

1315 Fig. 4. List of selected carpological taxa from the West and East area sections (see Tab. 1). Black

1316 boxes indicate occurrence in our samples, grey boxes are referred to the report of *Eucommia*

1317 *europaea*, *Juglans bergomensis*, *Tsuga* cf. *chiarugii* and *Visnea germanica* by Gregor (1990), and

1318 *Picea florschuetzii* by Mai (1994). Z = Zanclean; G = Gelasian. Palaeoenvirnoment: C = coastal;

1319 M = marine; P = palustrine. The listed taxa have been gathered in 6 main groups, as explained in

1320 the text.

1321 A simple characterisation of the growth forms of the listed taxa is reported in the two columns

1322 named respectively "Deciduous/Evergreen" and "Habit", where "c", "h", "s" and "t" stand for

1323 climber, herb, shrub and tree. The thermal climatic requirements of each species have been

1324 synthetically expressed by the boundary values of Mean Annual Temperature (NLR Clim.

1325 boundaries), e.g.: >13 = distribution of Nearest Living Relatives (NLRs) mainly in areas where the

1326 MAT is higher than 13°C; <14 = distribution of NLRs mainly in areas where the MAT is lower

1327 than 14°C; u = uncertain, b = broad climatic distribution (literature sources: ^Denk and Grimm,

1328 2012; *Utescher and Mosbrugger, 2013; #other sources, reported in Supplementary materials).

1329 The column "exotic/native" (ex/n) is referred to the NLRs, and "X" means no-NLR (extinct genus

1330 or morphogenus).

1331

1332   Fig. 5. Scheme summarizing the biochronological distribution of the carpological records of

1333   selected plant taxa in N-Italy. The order of the species and the groups are the same as in Fig. 4.

1334   Mes = Messinian; MP = Middle Pleistocene.

1335   The records from all the localities indicated in Fig. 1, deduced from the whole N-Italian

1336   CENOFITA database (Martinetto and Vassio, 2010), are reported. The age range for each species

1337   is indicated by black bars, for the records originating from reliably dated localities: Lugagnano

1338   (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

1339   (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

1340   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

1341   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

1342   Ma), Oriolo (1.0-0.8 Ma), Stirone-LA3 (1.0-0.8 Ma). Hatched bars indicate records from the

1343   following poorly dated localities (see Martinetto, 1999): Ca' Viettone (late Zanclean, 3.8 to 3.6

1344   Ma); Fossano (late Zanclean, 4.0 to 3.6 Ma); Sento II (late Zanclean, 3.8 to 3.6 Ma); Front

1345   (Piacenzian, 3.3 to 3.0 Ma); Momello-Lanzo (Piacenzian, 3.6 to 3.0 Ma); Castelletto Cervo I (late

1346   Piacenzian, 2.8 to 2.6 Ma); Castelletto Cervo II (Gelasian, 2.6 to 2.0 Ma); San Pietro di Ragogna

1347   (Gelasian, 2.6 to 1.8 Ma); Buronzo (Gelasian, 2.2 to 1.8 Ma); Steggio (Calabrian, 1.8 to 0.9 Ma).

1348   The dashed lines indicate the presence of records in central Italy, considered a refuge area in the

1349   Piacenzian-Calabrian (Martinetto, 2001a).

1350

1351   Tab. 1. Lithologic and stratigraphic data for the studied palaeocarpological samples.

1352

1353   **Plate I** - Examples of fossil fruits from the studied sections. Figs. 1-5 and 8-17 scale bars = 1mm;

1354   Figs. 6-7 scale bars = 0.5 mm. The 3-characters codes (e.g. B3E) assign the fossil specimen to a

1355 precise sediment sample recorded in the CENOFITA database; the label MGPT-PU+number is

1356 referred to the collections' catalogue of the Earth Sciences Department of the Turin University.

1357 1) *Trichosanthes fragilis* E.M. Reid: a) outer surface, b) inner surface of the seed, Marecchia

1358 section, sample MR3 B3E, Piacenzian; MGPT-PU105884;

1359 2) *Cymodocea* cf. *nodosa* (Ucria) Ascherson: a, b) lateral views of the endocarp, Marecchia

1360 section, sample MR3 B3E, Piacenzian, MGPT-PU105885;

1361 3) *Carex* cf. *elata* All.: achene, Stirone section, sample LA1 A5B, Calabrian, MGPT-PU105886;

1362 4) *Schoenoplectus* cf. *litoralis* (Schrad.) Palla: a) ventral view and b) dorsal view of the achene,

1363 Stirone section, sample LA3 A5C, Calabrian, MGPT-PU105887;

1364 5) *Eucommia europaea* Mädler: fruit, Arda section, sample AD3 B7E, Gelasian, MGPT-

1365 PU105888;

1366 6) *Hypericum tertiaerum* Nikitin: seed, Monte Falcone subsection, sample CQ1 B6D, Piacenzian,

1367 MGPT-PU105889;

1368 7) *Hypericum perforatum* L.: seed, Stirone section, sample LA3 A5C, Calabrian, MGPT-

1369 PU105890;

1370 8) *Liriodendron geminata* Kirchheimer: seed, Santerno section, sample SNT1 B6L, Calabrian,

1371 MGPT-PU105891;

1372 9) *Magnolia allasoniae* Martinetto: seed, Marecchia section, sample MR3 B3E, Piacenzian,

1373 MGPT-PU105892;

1374 10) *Magnolia cor* Ludwig: seed fragment, Arda section, sample AD3 B7E, Gelasian, MGPT-

1375 PU105893;

1376   11) *Magnolia ludwigii* Ettingshausen: seed, Marecchia section, sample MR3 B3E, Piacenzian,

1377   MGPT-PU105894;

1378   12) *Sinomenium cantalense* (E.M. Reid) Dorofeev: endocarp, Monte Falcone subsection, sample

1379   CQ1 B6D, Piacenzian, MGPT-PU105895;

1380   13) *Sparganium nanum* Dorofeev: endocarp, Monte Falcone subsection, CQ1 B6D, Piacenzian,

1381   MGPT-PU105896;

1382   14) *Stemona germanica* (Mai) Mai: a) apical view, b) basal view of one seed, Monte Falcone

1383   subsection, sample CQ1 B6D, Piacenzian, MGPT-PU105897;

1384   15) *Eurya stigmosa* (Ludwig) Mai: seed, Arda section, sample AD3 B7E, Gelasian, MGPT-

1385   PU105898;

1386   16) *Thymelaea* cf. *passerina* L.: seed, Arda section, sample AD3 B7E, Gelasian, MGPT-

1387   PU105899;

1388   17) *Carpolithes minimus* (Szafer) Mai: a) outer surface, b) inner surface of the seed, Stirone

1389   section, sample LA3 A5C, Calabrian, MGPT-PU105900.

1390