



MESSINIAN AGE OF AN “OLIGOCENE” FOSSIL FLORA FROM ITALY

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Abstract: An enigmatic deposit at Pavone d’Alessandria provided, at the end of the 19th century, about one hundred plant macrofossils, considered to be Oligocene in age. That material is no longer available, but a few animal (an insect and a fish) and plant remains have recently been recovered from this locality. A single remnant of *Aphanius crassicaudus* is considered relevant, in combination with a recent assessment of the geology in the studied area, to propose a Messinian age for the deposit. The taxonomic composition of the 19th century plant assemblage, only documented by sketchy drawings, is difficult to re-interpret, but its possible relationship with Messinian plant assemblages studied in the last 30 years is discussed in the light of recent observations. A few plant taxa that can be recognized on the basis of elementary morphological traits, e.g., *Fagus gussonii*, support a Messinian rather than Oligocene age.

Key words: *Aphanius*, fault, fossil leaves, geology, Neogene, Pavone d’Alessandria, Vena del Gesso

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Introduction

In NW Italy, the Piemonte (Piedmont) region is rich in remains of Neogene flora (Bertini and Martinetto 2008, Martinetto et al. 2023), whereas Oligocene flora is exclusively documented at its southern border with the Liguria region (Peola 1900b, Charrier et al. 1964, Martinetto 2011). Therefore, the possibility to locate and study new Oligocene floras in more northern positions, e.g., in the Monferrato area (Text-fig. 1), could provide interesting information. A single Oligocene flora was reported by Peola (1900a) from eastern Monferrato. It has long been overlooked because of the very poor condition of the outcrop, with a consequent lack of geological and palaeontological information. Prof. Paolo Peola (1869–1947) lived, during the first part of his life, in Montecastello d’Alessandria (Peola 1899) and possibly paid much attention to the fossil plant remains reported around his home village. He occasionally found, and repeatedly sampled till exhaustion, a plant fossil assemblage from an ephemeral, very small outcrop in the bed of the Tanaro river at Pavone d’Alessandria (from here onwards, Pavone; Text-figs 1b, 2), in the neighbourhood of Montecastello d’Alessandria (Text-fig. 3). The same sedimentary body also yielded fish fossils that Peola (1900a: 58–59) sent to Prof F. Bassani, who interpreted them as “ciprindonti” [Cyprinodontidae?], related to the genus “*Lebias* CUVIER” (= *Aphanius* NARDO,

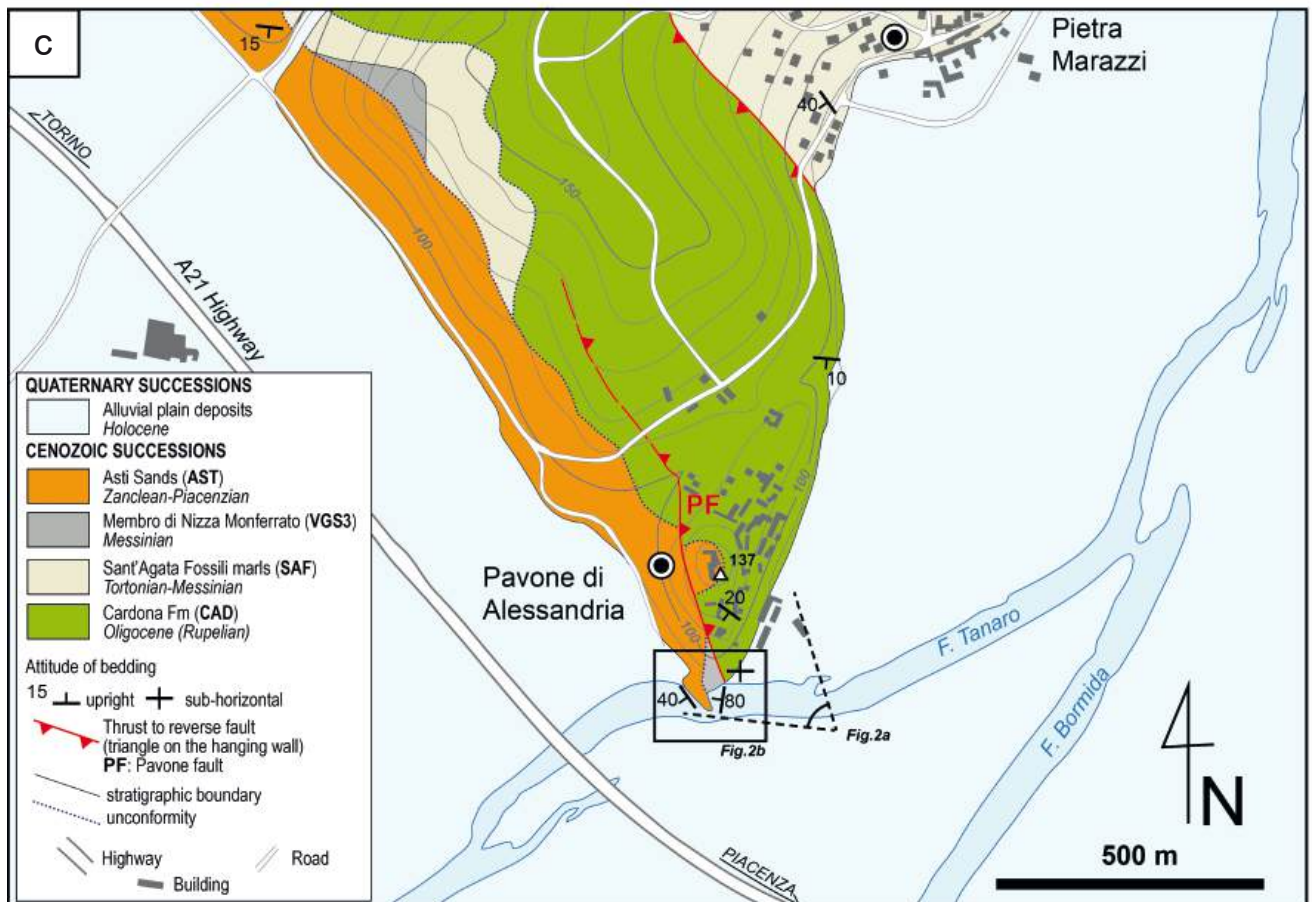
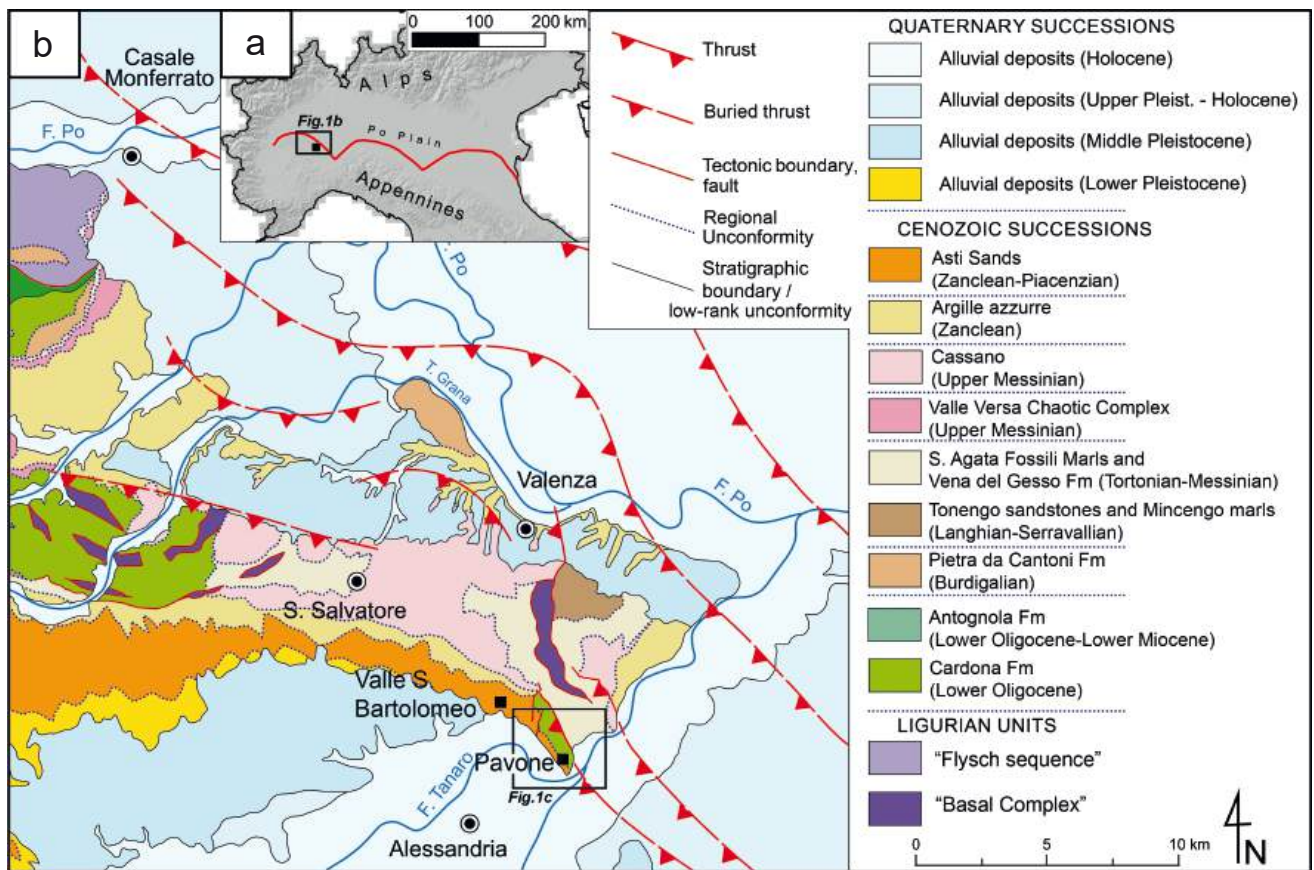
1827). Peola (1900a) wrote to keep the plant fossil material with him, and not in public collections, and presently it is unknown whether the collection still exists or not.

The first author of the present paper checked on the possibility of resampling the locality in the 1990s, but no outcrop was available at that time. In March 2022, an exceptionally long period of drought caused an extreme lowering of the Tanaro river water level, exposing sediments that are usually submerged. In the frame of a renewed interest in the cartographic representation of the area’s geology (Pellegrino et al. 2020a, b, Irace et al. 2022), new field investigations along the left bank of the river showed some useful elements to better constrain the stratigraphic position of the fossil-bearing deposits described by Peola (1900a).

In summary, the aims of this work were to locate the historical plant-bearing deposit of Pavone, to obtain new samples, to revise the geological age of the deposit using new geological and palaeontological evidence and, finally, to attempt a taxonomical revision of the drawings by Peola (unpublished).

Geological setting

Pavone is situated in the eastern sector of the Piemonte region, in the eastern Monferrato reliefs (Text-fig. 1a, b),



Text-fig. 1. Location maps of the study area. a: Regional setting of Pavone di Alessandria site; trace of major buried thrust fronts of N Apennines also shown (modified after Frigerio et al. 2017). b: Geological sketch map of eastern Monferrato and adjoining Alessandria and Po alluvial plains (after Piana et al. 2017a). c: Simplified geological map of Pavone d'Alessandria site.

where the Cretaceous to Eocene External Ligurian Units are unconformably overlain by the Oligocene to Messinian sedimentary succession of the Tertiary Piemonte Basin (TPB), in turn unconformably followed by the Plio-Quaternary successions of the Alessandria and Padane Basins (Sacco 1890, Boni and Casnedi 1970, Dela Pierre et al. 2003a, b, Irace et al. 2010a, Piana et al. 2017a, b).

The Ligurian substratum is poorly exposed and crops out mainly within tectonic slices (Text-fig. 1b). The overlying TPB succession starts with unconformable fan-delta deposits (Cardona Formation, Rupelian) and prodelta slope sediments (Antognola Formation, Rupelian-Aquitainian). They are unconformably followed by carbonate ramp deposits (Pietra da Cantoni Formation, Burdigalian). Above another significant unconformity, inner shelf deposits (Tonengo sandstones, Langhian) mark the onset of a fining- and deepening-upward trend (Casnedi 1975), evidenced by the overlying outer shelf (Mincengo Marls, Serravallian) to slope sediments (Sant'Agata Fossili Marls, Tortonian-Messinian), which record progressive restriction of the basin before the onset of the Messinian Salinity Crisis (hereafter, MSC). The Sant'Agata Fossili Marls consist of cyclically bedded hemipelagites (marls and silty clays) and are also characterised by diatomaceous deposits (Sturani and Sampò 1973, Pavia 1989, Gaudant et al. 2010, Pellegrino et al. 2020 a, b). New field investigations (see Frigerio et al. 2017), more recently related to the Geological Map of Italy at 1:50,000 scale (CARG Project, e.g., Irace et al. 2022), have highlighted the upward transition of the Sant'Agata Fossili Marls to a "euxinic" clayey succession consisting of thinly laminated shales and marls, and laterally discontinuous carbonate-rich layers. Subordinate primary gypsum laminae, some millimetres thick and made up of tiny acicular crystals, randomly oriented on the surface of the laminae, occasionally occur. Although the timing of these deposits is currently difficult to constrain, because of the lack of detailed bio-magnetostratigraphic investigations, their stratigraphic position and facies characters are very similar to those of the deeper water equivalents of the in-situ primary evaporites deposited during the first MSC phase (CIESM 2008, Dela Pierre et al. 2011, 2012). From a lithostratigraphic point of view, the clayey succession can be separated from the "normal" marine deposits of the Sant'Agata Fossili Marls and informally ascribed to the Nizza Monferrato Member of the Vena del Gesso Formation, previously recognized SW of the studied sector (Irace et al. 2010b, d'Atri et al. 2016). To the West, this syn-evaporitic succession is missing, as it is erosionally replaced by post-evaporitic chaotic gypsum deposits (Valle Versa chaotic Complex, sensu Dela Pierre et al. 2003a, b), of the second phase of the MSC (CIESM 2008). Conversely, in eastern Monferrato, it is unconformably topped by the post-evaporitic fan-delta to lacustrine deposits (Cassano-Spinola Conglomerates), recording the third MSC phase (CIESM 2008). The lower, erosional boundary of the Cassano-Spinola Conglomerates includes the tectonic-enhanced intra-Messinian unconformity, encompassing the deposition of the chaotic deposits recorded in western Monferrato.

The Pliocene succession comprises outer shelf to slope deposits (Argille Azzurre, Zanclean) and peculiar shallow marine sediments, referred to as the Asti Sands. These were

bio-chronologically constrained to the Zanclean-Piacenzian transition by Vannucci et al. (1994) through the integrated palaeontological study of some outcrops, located along the southwestern foothills of Monferrato, between Valle San Bartolomeo and Pavone (Text-fig. 1b). At the base of the Asti Sands, a definite intra-Zanclean erosional surface occurs, locally associated with an angular unconformity. The Pliocene succession is unconformably followed by Lower Pleistocene alluvial deposits which are, in turn, unconformably overlain by the Middle Pleistocene to Holocene terraced alluvial units.

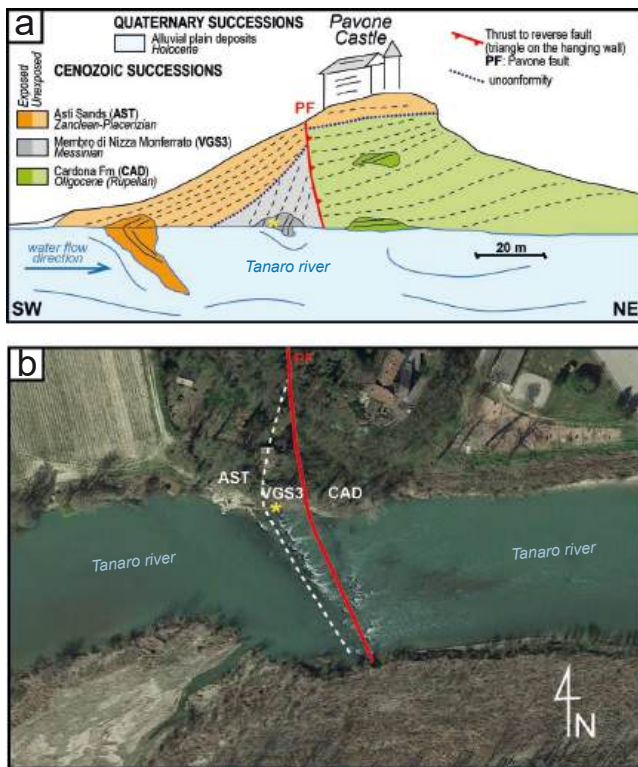
The structural setting of the eastern Monferrato is mainly characterised by NE-verging thrust fronts, with an arcuate shape (Text-fig. 1a, b), and NW-SE trending, hm- to km-scale open to tight folds, affecting the whole Mesozoic-Pliocene succession (see Frigerio et al. 2017). Since the Early Miocene, the eastern Monferrato acted as a structural high between the Alessandria thrust-top Basin to the SW, and the Padane Basin to the NE. The evolution of this area was significantly controlled by the activity of the most external thrusts present in the Po Plain subsurface, as well as that of the internal ones, which are partly exposed in the present-day hills (Text-fig. 1b). During the Pliocene and Pleistocene, this tectonic activity induced the further uplift of the Monferrato Oligocene-Miocene successions and their NE-ward overthrusting onto the thicker Pliocene-Quaternary sedimentary pile of the Padane Basin.

Material and methods

Fieldwork, which included novel geological and palaeontological prospection and analysis, was carried out to reassess the poorly-known plant-bearing deposits sampled in the late 19th century by Peola. The left bank of the Tanaro river showed a large outcrop of strongly inclined Pliocene calcarenites (Text-figs 2a, 4a), followed eastwards by about 10 m without outcrops, but with sparse boulders of a fine sandstone, bearing a few leaf impressions (Text-fig. 5a). The next small outcrop showed rather chaotic, cemented, dominantly fine-grained sediments (Text-fig. 4b), bearing some animal and plant fossils. A few fossil specimens were recovered in the field and stored in the collections of the Museo di Geologia e Paleontologia at the Università degli Studi di Torino (MGPT).

For the few newly collected fossil remains, a Wild M3 dissecting microscope was used to observe finer details, and photos were taken using a Nikon Coolpix camera. The plant remains are fossilised as adpressions, with very scanty to null remains of organic matter, which do not seem to include cuticles when analysed under a stereomicroscope. Therefore, identification of leaves was based solely on macromorphological details. An arthropod remnant was compared to similar ones occurring in other Cenozoic sites of the Piemonte region, described by Cavallo and Galletti (1987). The traits of a fish remnant (Text-fig. 6) were interpreted using literature: Gaudant 1979, Parenti 1981, Carnevale et al. 2006, 2019, Caputo et al. 2009, Vasilyan et al. 2009, Bedosti et al. 2015, Carnevale and Schwarzshans 2022.

The most diverse fossil assemblage described from this site, consisting of plant fossils, is not available for revision



Text-fig. 2. a: Reconstructed field-line drawing showing intra-Zanclean angular unconformity between Oligocene-Miocene successions and Pliocene deposits, and NE-dipping backthrust (i.e., Pavone reverse fault (PF)) affecting entire succession (looking NW; see Text-fig. 1a for location). **b:** Line drawing of Google Earth aerial view showing Cardona Formation (Oligocene; CAD) tectonically juxtaposed to Nizza Monferrato Member (Messinian; VGS3), and Asti Sands (Pliocene; AST); asterisk indicates studied outcrop (see Text-fig. 1a for location).

(probably lost), but several sketchy drawings by Peola (unpublished) and his description of the site and its fossils (Peola 1900a) at the end of the 19th century have been considered useful materials that deserved to be re-analysed.



Text-fig. 3. Panoramic view of low hill of Pavone d'Alessandria with Tanaro river, from Montecastello d'Alessandria (NE to SW). Arrow indicates position of studied outcrop.

The reliability of the drawing by Peola has been checked for the first time against a few original fossil leaf specimens, not from Pavone, but from the Pliocene site of Bra (still very well preserved at the Craveri Museum of Bra; Text-fig. 7). Concerning the missing Pavone plant fossils, residual traits of leaf architecture visible in the drawings were checked against the macromorphological descriptions of Dilcher (1974) and Ellis et al. (2009). The outline and venation pattern of the leaf drawings have been analysed in an attempt to identify characteristic morphological traits that could throw some light on the taxonomic affinity of at least part of the plant remains. In any case, several leaves drawn by Peola were probably fragmented before sedimentation, so that the difficulties for their determination are increased by the original lack of information on the appearance of the whole leaf lamina.

Some tentative revised determinations (Tab. 1) could be proposed only by constraining the analysis to the types reported in the recent north Italian palaeobotanical literature on leaf assemblages from the Neogene (Bertini and Martinetto 2008, Brambilla and Gallo 2002, Denk 2004, Macaluso et al. 2018, Martinetto 2003, Martinetto et al. 2000, 2007, 2022, 2023, Teodoridis et al. 2015, 2017). Also relevant was a comparison to leaf morphotypes shown in a few other works from the Mediterranean area, dealing with almost contemporary leaf remains (Denk et al. 2017, Güner et al. 2017, Kvaček et al. 2002, Velitzelos 2002, Zidianakis et al. 2020). A few problematic specimens, which showed rather characteristic morphological traits in Peola's drawings, were compared to the type specimens of the taxa indicated by Peola (1900a), but also with other similar taxa of the European Cenozoic (Text-fig. 8). Finally, we indicated if Peola's determinations could be accepted or not (Tab. 1).

Results

Tectono-stratigraphic framework of the Pavone site

The Pavone di Alessandria area is characterised by a roughly SW-dipping Oligocene to Pliocene monocline (Text-fig. 1). Here the Asti Sands unconformably overlay the different terms of the monocline (from top to base: Argille Azzurre; Cassano-Spinola Formation; Nizza Monferrato Member of the Vena del Gesso Formation; Sant'Agata Fossili Marls; Cardona Formation). Two main fault systems (NW-SE and N-S to NNW-SSE directed) dissect the monocline (Text-fig. 1b). The former mainly corresponds to NE-vergent thrusts, which are parallel to the main thrust fronts, and here superpose the Cardona Formation onto the Sant'Agata Fossili Marls. The N- to NNW-striking system consists of high angle, transpressive to reverse faults, which probably worked as transfer fault.

The Pavone di Alessandria site (Text-fig. 1c) develops above one of the SW-ward verging backthrusts (i.e., a reverse fault with opposite vergence respect to the NE-vergent main thrust surfaces). This structure, hereafter named the Pavone Fault (PF), juxtaposes the Oligocene succession to the Messinian euxinic deposits and Pliocene bioclastic sediments.

More in detail (Text-fig. 2), in the hanging wall of the PF, the lower Oligocene Cardona Formation strata are sub-horizontal to gently (up to 20°) dipping toward SW. This

Table 1. List of fossil plant taxa cited by Peola (unpublished) for the Pavone d’Alessandria site and tentative taxonomic revision proposed here based on drawings of Text-figs 9–11.

Original determination and species number by Peola (1900a)	Revised determination	Peola (unpubl.), pl./fig.	This paper, Text-fig.
2. <i>Taxites eumenidium</i> A.MASSAL.	Coniferales indet.	4/6	Text-fig. 9q
3. <i>Podocarpus oceanica</i> UNGER	cf. <i>Pseudotsuga</i>	4/8	Text-fig. 9f
4. <i>Podocarpus gypsorum</i> SAPORTA	Coniferales indet.	4/10	Text-fig. 9g
5. <i>Podocarpus peyriacensis</i> SAPORTA	Coniferales indet.	4/11	Text-fig. 9l
6. <i>Podocarpus taxiformis</i> SAPORTA	Coniferales indet.	4/12	Text-fig. 9p
7. <i>Sequoia couttsiae</i> HEER	cf. <i>Taiwania</i>	5/1	Text-fig. 9c
7. <i>Sequoia couttsiae</i> HEER	cf. <i>Cryptomeria</i> vel <i>Sequoia</i>	5/1	Text-fig. 9d–e
8. <i>Sequoia langsdoftii</i> (BRONGN.) HEER	cf. <i>Cryptomeria</i> vel <i>Sequoia</i>	5/2	Text-fig. 9b
9. <i>Sequoia sternbergii</i> (GÖPP.) HEER	cf. <i>Cryptomeria</i> vel <i>Sequoia</i>	5/5	Text-fig. 9a
10. <i>Sequoia tourmalii</i> (BRONGN.) SAPORTA.	cf. <i>Taxodium dubium</i> (STERNB.) A.BRAUN (less probable <i>Sequoia</i>)	5/9	Text-fig. 9i
11. <i>Widdringtonia helvetica</i> HEER	Most probably foliage of <i>Glyptostrobus europaeus</i> (BRONGN.) UNGER; the name <i>W. helvetica</i> HEER was introduced by Heer (1853) for a putative new species of conifer represented by a small shoot and a putative cone, later recognized respectively as a shoot of <i>Glyptostrobus</i> and as a fossil fruit of <i>Cercidiphyllum</i> (Jähnichen et al. 1980).	5/10	Text-fig. 9j
12. <i>Libocedrus salicornioides</i> (UNGER) HEER	indeterminable	5/13	Text-fig. 9o
13. <i>Chamaecyparites massiliensis</i> (SAPORTA) SCHIMP.	cf. <i>Glyptostrobus europaeus</i> (BRONGN.) UNGER	5/16	Text-fig. 9k
14. <i>Pinites cryptomeriodes</i> A.MASSAL.	Coniferales indet.	5/17	Text-fig. 9n
15. – 21. <i>Pinus</i> spp.	<i>Pinus</i> spp. The fascicle with three needles and the fascicle with two long needles (Text-fig. 9u, w) can be assigned to <i>Pinus</i> cf. <i>rigios</i> (UNGER) ETTINGSH. (Text-fig. 9y), as discussed by Teodoridis et al. (2015). Other fascicles with two shorter or broken needles could belong to one or more separate species (e.g., <i>P. hepios</i> (UNGER) HEER).	6/1, 3, 4, 6, 9, 10; 7/6	Text-fig. 9r–y
22., 24. <i>Pinus pseudotaeda</i> SAPORTA and <i>P. palaeostrobus</i> (ETTINGSH.) HEER	<i>Pinus</i> cf. <i>palaeostrobus</i> (ETTINGSH.) HEER; fascicles of five thin needles (Text-fig. 9z, zb) suggest the occurrence of this species, as already discussed by Teodoridis et al. (2015).	8/5, 9	Text-fig. 9z, zb
23. <i>Pinus quadrifoliata</i> PEOLA	<i>Pinus</i> sp. The fascicle of four needles (Text-fig. 9za) can be interpreted either as an original morphology or as an incomplete five-needled fascicle that lost one needle. In the second case, regardless of the longer needles in comparison to the other two above-cited fascicles, it could be assigned to <i>P. cf. palaeostrobus</i> (ETTINGSH.) HEER. Although Peola (1900a) based a new species on this fossil, the description of the specimen (presently unavailable) does not seem to indicate morphological details that can justify the erection of a new taxon.	7/10	Text-fig. 9za
25. <i>Abies piccottii</i> PEOLA	Coniferales indet. (much unlikely to be <i>Abies</i> , due to the description of a very small petiole in Peola 1900a)	9/2	Text-fig. 9m
26. <i>Abies?</i> sp. ind.	Coniferales indet.	9/3	Text-fig. 9h
27. <i>Panicum miocenicum</i> ETTINGSH.	Monocotyledones indet.	9/9	Text-fig. 11ze
28. <i>Bambusa alexandrina</i> PEOLA	“ <i>Bambusa</i> ” sp.; the leaf fragment corresponds morphologically to entire leaves assigned to <i>Bambusa</i> sp. by Teodoridis et al. (2015: pl. 4, figs 4, 5); the fragmentary specimen was inadequate to create a new species	10/7	Text-fig. 10a
29. <i>Carpinus grandis</i> UNGER	<i>Carpinus</i> cf. <i>betulus</i> L.; the bract shows two lobes whose venation is characteristic for this living species, reported with several fossils at least since the Messinian (e.g., Bertini and Martinetto 2008, Martinetto 2015); <i>Carpinus grandis</i> UNGER is a name based on fossil leaves (fossil-species), which do not show relevant differences in comparison to those of the foregoing living species	13/4	Text-fig. 11f
29. <i>Carpinus grandis</i> UNGER	cf. <i>Carpinus</i> ; the leaf fragment does not seem to show definite characters, apart the double serrulation, therefore the evidence is insufficient for sound assignment to the genus <i>Carpinus</i>	13/3	Text-fig. 11e
30. <i>Fagus ambigua</i> A.MASSAL.	<i>Fagus gussonii</i> A.MASSAL.	15/1	Text-fig. 10o
31. <i>Fagus deucalionis</i> UNGER	<i>Fagus gussonii</i> A.MASSAL.	16/2	Text-fig. 10g

Table 1. continued

Original determination and species number by Peola (1900a)	Revised determination	Peola (unpubl.), pl./fig.	This paper, Text-fig.
32. <i>Quercus cornaliae</i> A.MASSAL.	<i>Quercus</i> gr. <i>pseudocastanea</i> GÖPP./ <i>Q. roburoides</i> C.T.GAUDIN	20/6	Text-fig. 10n
33. <i>Quercus scilliana</i> C.T.GAUDIN	cf. <i>Quercus pseudocastanea</i> GÖPP.	25/4	Text-fig. 11d
34. <i>Myrica salicina</i> UNGER	Indeterminable, but compatible with both <i>Laurophyllum</i> and <i>Trigonobalanopsis</i> .	30/6	Text-fig. 11c
35. <i>Salix angusta</i> A.BRAUN	cf. <i>Salix</i>	32/1	Text-fig. 11b
36. <i>Salix media</i> HEER	<i>Salix</i> sp. 1	32/8	Text-fig. 11m
37. <i>Salix tenera</i> A.BRAUN	indeterminable	32/12	Text-fig. 10d
38. <i>Salix varians</i> GÖPP.	<i>Salix</i> sp. 2	32/14	Text-fig. 11p
39. <i>Populus latior</i> A.BRAUN	<i>Populus latior</i> A.BRAUN.	34/1	Text-fig. 10u
40. <i>Planera ungeri</i> ETTINGSH.	cf. <i>Zelkova zelkovifolia</i> (UNGER) BŮŽEK et KOTL. (the name <i>Planera ungeri</i> is considered a synonym)	33/4	Text-fig. 11y
41. <i>Ficus arcinervis</i> HEER	cf. Leguminosae gen. et sp. indet. 1 of Teodoridis et al. (2015); this is the most probable identification, but it is also possible to indicate this morphotype as “ <i>Ficus</i> ” <i>arcinervis</i> (ROSSM.) HEER (because of the unknown taxonomic position, it is customary to assign “ <i>Ficus</i> ” as the genus). Less similar, for the arches of secondary veins closer to the margin, are Lauraceae and <i>Dicotylophyllum maii</i> BŮŽEK, HOLÝ et KVAČEK [never recorded in Italy]. Among extant plants, a strong resemblance to <i>Sabia</i> as for secondary venation can also be seen.	35/13	Text-fig. 10r
42. <i>Ficus tiliaefolia</i> HEER	cf. <i>Fagus gussonii</i> A.MASSAL.	37/2	Text-fig. 10p
43. <i>Persea braunii</i> HEER	cf. <i>Trigonobalanopsis rhamnoides</i> (ROSSM.) KVAČEK et H.WALTHER, a hypothesis supported by the analysis of the available Pliocene leaves from Bra (Martinetto et al. 2023); less probably <i>Laurophyllum</i> sp.	40/1	Text-fig. 10k
44. <i>Persea speciosa</i> HEER	cf. <i>Trigonobalanopsis rhamnoides</i> (ROSSM.) KVAČEK et H.WALTHER, see above	40/4	Text-fig. 10j
44. <i>Persea speciosa</i> HEER	Indeterminable, remotely similar to <i>Laurophyllum</i> and <i>Magnolia</i> , too broad for <i>Trigonobalanopsis</i> .	40/3	Text-fig. 10b
45. <i>Benzoin paucinerve</i> HEER	Indeterminable, remotely similar to <i>Laurophyllum</i> sp. and <i>Trigonobalanopsis</i> .	41/6	Text-fig. 11v
46. <i>Cinnamomum emarginatum</i> SAPORTA	cf. <i>Ocotea heeri</i> (C.T.GAUDIN) W.R.MÜLL.	41/11	Text-fig. 11k
47. <i>Cinnamomum lanceolatum</i> SAPORTA	cf. <i>Ocotea heeri</i> (C.T.GAUDIN) W.R.MÜLL.	42/2	Text-fig. 10c
48. <i>Cinnamomum polymorphum</i> HEER	cf. <i>Daphnogene polymorpha</i> (A.BRAUN) ETTINGSH.	42/8	Text-fig. 11i
49. <i>Cinnamomum rosmaessleri</i> HEER	<i>Daphnogene polymorpha</i> (A.BRAUN) ETTINGSH.	42/14	Text-fig. 11h
50. <i>Cinnamomum scheuczeri</i> HEER	cf. <i>Ocotea heeri</i> (C.T.GAUDIN) W.R.MÜLL., alternatively <i>Laurophyllum pseudoprinceps</i> WEYL. et KILPPER, but not <i>Daphnogene polymorpha</i> (A.BRAUN) ETTINGSH.	42/16	Text-fig. 11j
51. <i>Apeibopsis gaudinii</i> HEER	cf. <i>Carya</i> fruit	45/7	Text-fig. 11q
52. <i>Sterculia tenuinervis</i> HEER	cf. <i>Acer integerrimum</i> VIV. in C.KEFERST.; the visible characters correspond to those of trilobate leaves assigned to the above-cited species, e.g., in Martinetto (2003: pl. 1 figs 11, 12) and Martinetto et al. (2023: fig. 18F); alternatively, it could be <i>Acer palaeosaccharinum</i> STUR or <i>Dombeyopsis lobata</i> UNGER, whereas <i>Sterculia</i> has not been confirmed by recent research in the Neogene of Piemonte.	46/2	Text-fig. 10t
53. <i>Ptelea acuminata</i> HEER	Indeterminable, but possibly similar to the leaf shown at Text-fig. 10h.	46/6	Text-fig. 10l
54. <i>Rhus pyrrhae</i> UNGER	Indeterminable, similar to <i>Rhus heufleuri</i> HEER, reported by Martinetto et al. (2000) for the Messinian of Alba, but in need of revision.	46/11	Text-fig. 11z
55. <i>Acer primaevum</i> SAPORTA	<i>Acer</i> sp.; many species represented by fruits are known from the Neogene of Europe, and specific research would be needed to assess the priority and validity of several names, e.g., <i>Acer primaevum</i> SAPORTA	47/6	Text-fig. 11r
56. <i>Berchemia multinervis</i> (A.BRAUN) HEER	“ <i>Juglans</i> ” <i>acuminata</i> A.BRAUN ex UNGER – The narrow base and definite asymmetry are not typical characters for <i>Berchemia multinervis</i> (A.BRAUN) HEER, a species that occurs in Piemonte (Niccolini et al. 2022); in addition, Peola (1900a and unpubl.) never describes the typical tertiary venation. The lamina shape, dimensions and course of secondary veins agree much better with those of a lamina assigned to <i>Annona lortetii</i> SAPORTA by Brambilla and Gallo (2002); according to Denk (pers. comm.) this specimen from a neighbouring Messinian locality could be referred to “ <i>Juglans</i> ” <i>acuminata</i> A.BRAUN ex UNGER, a species indicated for the Messinian of northern Italy by Teodoridis et al. (2017).	52/8	Text-fig. 10h
57. <i>Rhamnus rectinervis</i> HEER	cf. “ <i>Juglans</i> ” <i>acuminata</i> A.BRAUN ex UNGER – see above	53/13	Text-fig. 10i

Table 1. continued

Original determination and species number by Peola (1900a)	Revised determination	Peola (unpubl.), pl./fig.	This paper, Text-fig.
58. <i>Weinmannia tetrastepala</i> PEOLA	Indeterminable, it can be indicated as a specimen that was inadequate to create a new species.	54/6	Text-fig. 11za
59. <i>Liquidambar europaea</i> A.BRAUN	<i>Liquidambar europaea</i> A.BRAUN	54/7	Text-fig. 10m
60. <i>Platanus depertita</i> SORDELLI.	<i>Platanus leucophylla</i> (UNGER) ERW.KNOBLOCH (the name <i>P. depertita</i> is considered as a synonym)	55/1	Text-fig. 10v
61. <i>Terminalia elegans</i> HEER	cf. Leguminosae gen. et sp. indet. 2 of Teodoridis et al. (2015); Peola (1900a) mentions poorly visible secondary veins, as is the case of the leaf shown by Teodoridis et al. (2015: pl. 5, fig. 9)	58/2	Text-fig. 10f
62. <i>Terminalia radabojensis</i> UNGER	cf. <i>Laurophyllum</i> ; the outline, dimension and course of secondary venation are identical to those of specimens of <i>Laurophyllum pseudoprinceps</i> WEYL. et KILPPER from Fossano (Macaluso et al. 2018); however, without any information about the cuticle, the similarity of the Pavone fossil to that fossil-species remains very speculative	59/1	Text-fig. 10s
63. <i>Eucalyptus oceanica</i> UNGER	Indeterminable, but surely not <i>Eucalyptus</i> . Without secondary venation this narrow leaf is similar to several taxa, even if <i>Salix</i> could be the most parsimonious hypothesis.	59/5	Text-fig. 11a
64. <i>Banksia laharpaii</i> HEER	cf. Rosaceae, e.g., <i>Rosa</i> (see Teodoridis et al. 2015: pl. 6, fig. 3) or <i>Sorbus</i> (see Kvaček et al. 2020)	54/18	Text-fig. 11t
65. <i>Robinia regelii</i> HEER	cf. Leguminosae	60/10	Text-fig. 11zc
66. <i>Dalbergia cuneifolia</i> HEER	Indeterminable, among several possibilities, the best match seems to be <i>Trigonobalanopsis rhamnoides</i> (ROSSM.) KVAČEK et H.WALTHER.	60/15	Text-fig. 11zg
67. <i>Dalbergia jaccardii</i> HEER	indeterminable	60/16	Text-fig. 11zf
68. <i>Cassia berenices</i> UNGER	Indeterminable, among several possibilities it could be <i>Laurophyllum</i> , Leguminosae or <i>Trigonobalanopsis</i> .	61/10	Text-fig. 11zb
69. <i>Cassia lignitum</i> UNGER	Indeterminable, among several possibilities, it could be <i>Laurophyllum</i> , Leguminosae or <i>Trigonobalanopsis</i> .	61/15	Text-fig. 11zd
70. <i>Cassia zephyri</i> ETTINGSH.	Indeterminable, among several possibilities, it could be <i>Laurophyllum</i> , Leguminosae or <i>Trigonobalanopsis</i> .	61/22	Text-fig. 11n
71. <i>Luciothoe protogaea</i> SCH.	Indeterminable, among common Messinian taxa, it could be <i>Trigonobalanopsis</i> , <i>Laurophyllum</i> , Leguminosae or even <i>Salix</i> .	62/3	Text-fig. 11u
72. <i>Luciothoe vacciniifolia</i> UNGER	Indeterminable	62/7	Text-fig. 11g
73. <i>Sapotacites eximius</i> SAPORTA	cf. Leguminosae gen. et sp. indet. 2 of Teodoridis et al. (2015); the fine secondary and tertiary veins, only drawn at the bottom of the right side, agree with those of the leaf shown by Teodoridis et al. (2015: pl. 5, fig. 9); the acute versus rounded apex does not mean that this leaf must belong to a different species than the one of Text-fig. 10f	62/14	Text-fig. 10e
74. <i>Diospyros varians</i> SAPORTA	Indeterminable, among common Messinian taxa it could be, e.g., <i>Trigonobalanopsis rhamnoides</i> (ROSSM.) KVAČEK et H.WALTHER.	62/20	Text-fig. 11s
75. <i>Styrax stylosus</i> HEER	indeterminable	62/21	Text-fig. 11w
76. <i>Olea proxima</i> SAPORTA	indeterminable	63/7	Text-fig. 11o
77. <i>Fraxinus ulmifolia</i> SAPORTA	cf. <i>Pterocarya paradisiaca</i> (UNGER) ILJINSK., whereas <i>Fraxinus</i> seems to be unlikely because of the densely packed, regular, small teeth; it is remotely similar to <i>Alnus gaudinii</i> (HEER) ERW.KNOBLOCH et KVAČEK as to leaf shape and secondary venation, but the teeth are too dense	63/8	Text-fig. 11l
78. <i>Apocinophyllum helveticum</i> HEER	cf. Leguminosae gen. et sp. indet. 1 of Teodoridis et al. (2015). The identification is only tentative because the leaf was not described by Peola (1900a). The course of secondary veins as drawn by Peola (unpubl.) is not similar to that of the leaves of <i>Apocinophyllum helveticum</i> HEER. The discussion about specimen 35/13 can also be applied here, because the two leaves share the same basic traits.	64/1	Text-fig. 10q

unit consists of shallow marine coarse-grained sediments made up of conglomerates and partly burrowed yellowish to greenish sandstones in decimeter- to meter-thick beds. Clasts are mainly composed of ophiolitic bed-rocks and covers (serpentinites, gabbros, red-cherts, micritic limestones). During our field work we saw only bivalve fragments in sandy layers, poorly preserved.

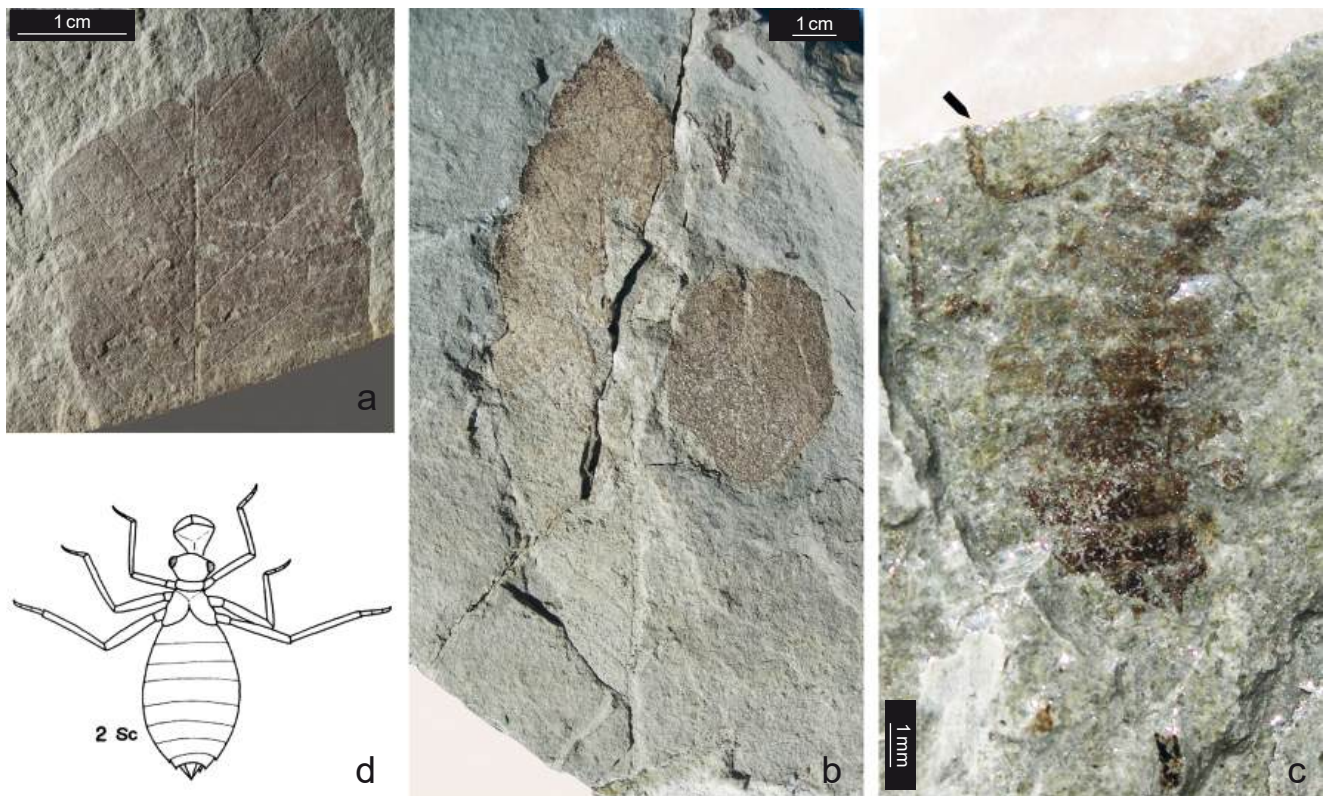
In the footwall of the PF, the Nizza Monferrato Member of the Vena del Gesso Formation is discontinuously exposed. Its bedding is mainly steeply inclined toward W and is sub-vertical close to the fault. This unit consists of a rhythmic alternation of thinly bedded and laminated dark grey-coloured shaley and fine sandy deposits, which here are intensively cemented. The most remarkable features of the



Text-fig. 4. Aspect of small outcrop of Pavone d’Alessandria on left bank of Tanaro river. a: Seen from bed of river (SW to NE); white arrow: Arenitic boulder with *Fagus* leaves (AST? Pliocene?); black arrow: Fossil-bearing outcrop of Messinian sediments (VGS3). b: Detail of stratified, fossil-bearing Messinian marls (VGS3). c: Seen from left bank of river (NE to SW) (see Text-fig. 2b for explanation).

succession are the well-developed thin stratification (beds are rarely thicker than 10 cm), the extremely thin lamination that mostly reflects changes in grain-size between laminae, and the complete absence of bioturbation. Some intervals of the laminated shales form strongly cemented dm-thick carbonate-rich layers, in which millimetre to centimetre-sized voids or calcite pseudomorphs after gypsum crystal are

locally recognizable. Fossil content mainly consists of leaf adpressions. The original stratigraphic thickness of this unit cannot be estimated, because it is truncated by the tectonic boundary. The Nizza Monferrato Member is unconformably followed SW-ward (i.e., top of the section) by the Asti Sands, here comprising carbonate ramp biocalcirudites and biocalcarenites in dm- to cm-thick beds. The fossil content



Text-fig. 5. Fossils recently recovered from Pavone outcrop. **a:** *Fagus*, fragmentary leaf adpression on fine sandstone, retrieved from boulder in covered area, just below outcropping Pliocene succession, MGPT-PU141128. Occurrence of marine bivalves in these sediments suggests Pliocene succession origin (see Text-fig. 2a, AST?). **b:** Sediment sample from Messinian marls of Pavone outcrop (year 2022) with two badly preserved leaf adpressions, MGPT-PU141127; largest one likely *Quercus drymeja*, smaller one to right could be Leguminosae. **c:** Odonata, *Oryctodiplax*?; poorly preserved arthropod remnant (MGPT-PU141126) showing some similarities to pre-imaginal stages of fossil dragonfly *Oryctodiplax gypсорum* (Cavallo and Galletti 1987): Abdomen with 8 segments, two incomplete legs (arrow), last abdominal segment with anal appendages, and two darker spots in anterior part that could represent displaced eyes. **d:** Drawing of pre-imaginal fossil specimen of *Oryctodiplax gypсорum* from Cavallo and Galletti (1987), for comparison.

consists of calcareous red algae, bivalves, gastropods, brachiopods and foraminifera. The basal stratigraphic contact with the Vena del Gesso is associated with an about 40° inferred angular unconformity (Text-fig. 2a), which corresponds to an important hiatus encompassing the late Messinian and almost the whole Zanclean. Scattered boulders of arenites, not in place, containing *Fagus* leaves (Text-fig. 5a), were found near this unconformity at the river water level. The occurrence of marine bivalves in these sediments suggests an origin from the Pliocene succession.

Tentative taxonomic interpretation of Peola's plant drawings

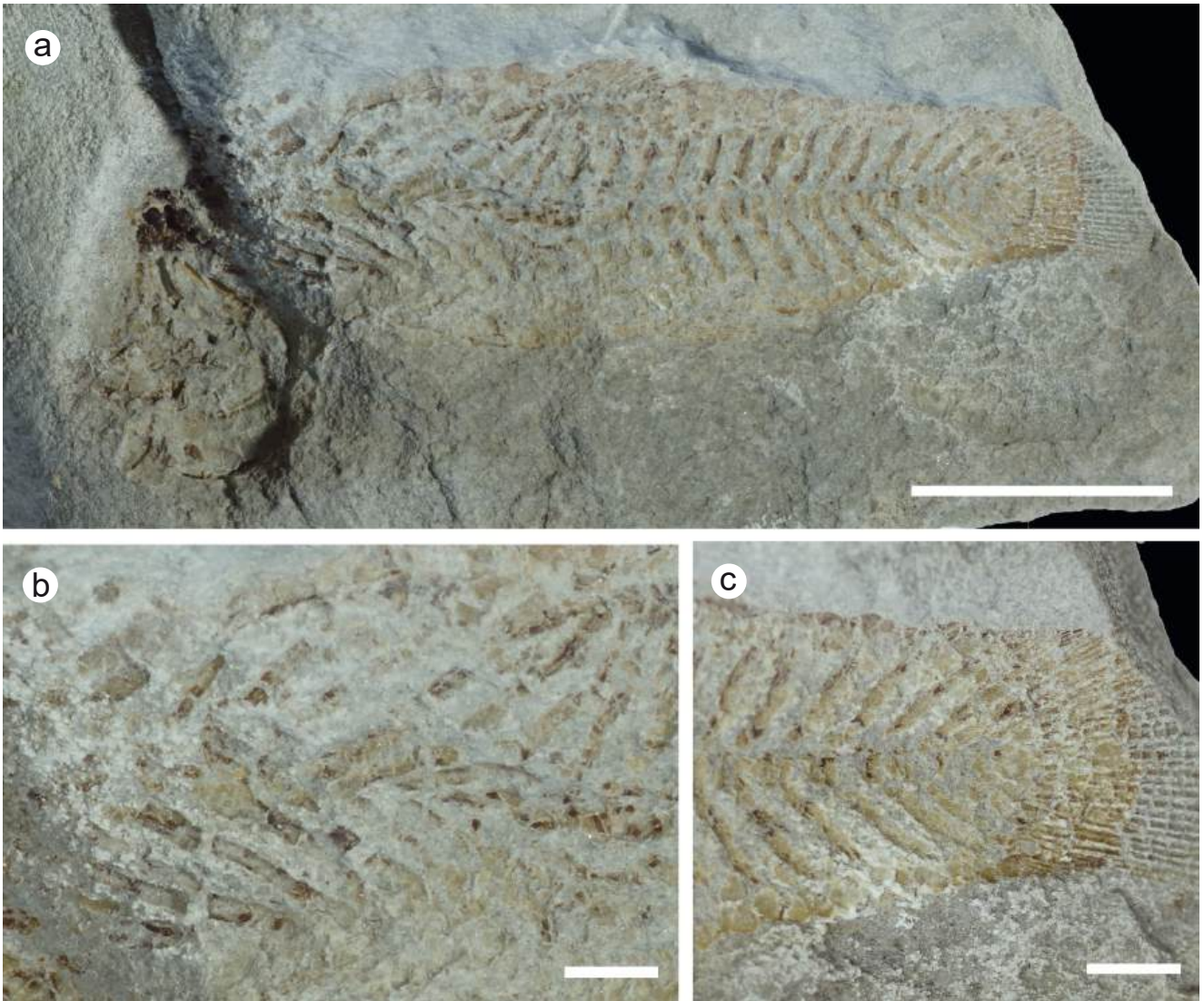
In Peola (unpublished) we found 81 drawings of specimens originating from Pavone, mostly of leaves or leaf fragments, and only three carpological remains. The drawings provide at least one sketchy image of each of the 77 "species" of terrestrial plants (Tab. 1) listed in Peola's (1900a) monograph of the fossil flora of Pavone. Several of these names have been indicated, after Peola's paper (1900a), as synonyms of previous valid names (Tab. 1), e.g., in the case of *Widdringtonia helvetica* HEER, a name introduced by Heer (1853) for a small conifer shoot, later recognized as a shoot of *Glyptostrobus europaeus* (BRONGN.) UNGER (Jähnichen et al. 1980; actually, these authors considered

the name as valid for a co-occurring putative cone, revised as a fossil fruit of *Cercidiphyllum*, consequently named *C. helveticum* (HEER) JÄHNICHEN, MAI et H. WALTHER).

The reliability of the drawing by Peola has been checked, for the first time in this work, against a few original Pliocene leaf specimens still very well preserved at the Craveri Museum of Bra. The specimens appear as in a mirror (Text-fig. 7), so that the drawings of Pavone's specimens were reflected horizontally in Text-figs. 9–11. The real leaf specimens from Bra show characters which were not reported in Peola's drawings (e.g., tertiary venation), and, generally, secondary venation and outline are reproduced with low precision. However, the secondary venation pattern, as drawn by Peola, is suitable to characterise the original one, as it is the outline. Teeth are reproduced in a very unreliable way in the leaf of Text-fig. 7a. Highly diagnostic characters were misinterpreted, such as the complete emarginate apex with attenuate midvein of the leaf, shown in Text-fig. 7d, drawn as a broken apex with an incomplete midvein. This analysis implies that only the dimensions, the secondary venation pattern and the outline could be used for a very tentative revised determination of Peola's Pavone drawings. Only a small proportion of the taxa reported in the Italian Neogene was suitable for an identification through these few characters.

Table 2. Revised determination of 52 specimens (missing material) drawn by Peola (unpublished) and shown in Text-figs 9–11, with reference to similar specimens illustrated in recent literature on Cenozoic leaf floras of Northern Italy.

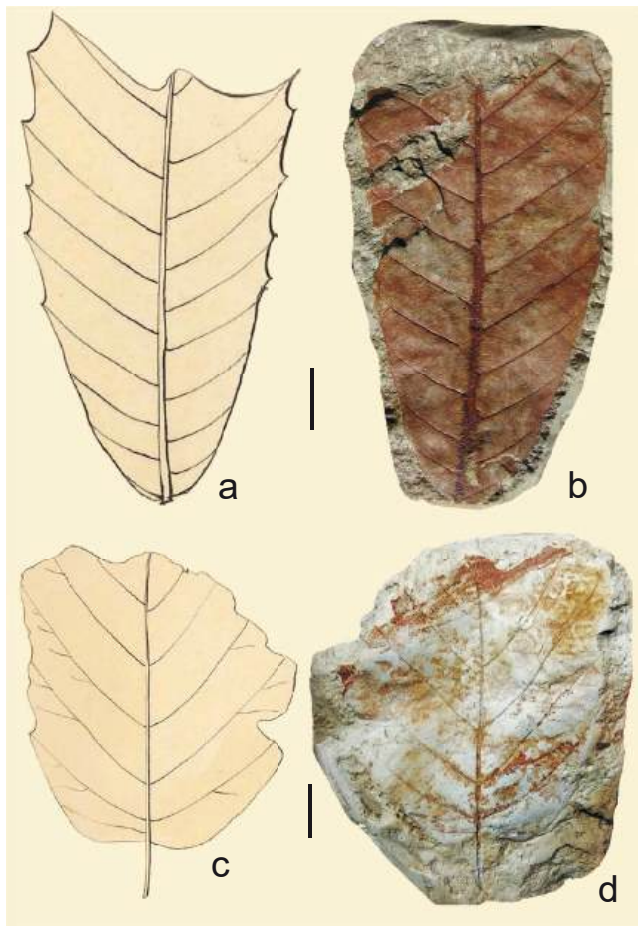
This paper, Text-fig.	Revised determination	Peola's drawings (unpublished), original determination	Reference for comparison
Text-fig. 9a	cf. <i>Cryptomeria</i> vel <i>Sequoia</i>	<i>Sequoia sternbergii</i>	Teodoridis et al. 2015: pl. 1, fig. 7; Martinetto et al. 2022: pl. 1, fig. 3a
Text-fig. 9b	cf. <i>Cryptomeria</i> vel <i>Sequoia</i>	<i>Sequoia langsdorfii</i>	Martinetto et al. 2022: pl. 1, fig. 5
Text-fig. 9c	cf. <i>Taiwania</i>	<i>Sequoia couttsiae</i>	Martinetto et al. 2022: pl. 1, fig. 1
Text-fig. 9d–e	cf. <i>Cryptomeria</i> vel <i>Sequoia</i>	<i>Sequoia couttsiae</i>	Martinetto et al. 2022: pl. 1, figs 2, 4, 5
Text-fig. 9f	cf. <i>Pseudotsuga</i>	<i>Podocarpus oceanica</i>	Martinetto et al. 2023: fig. 13A
Text-fig. 9i	cf. <i>Taxodium dubium</i> (less probable <i>Sequoia</i>)	<i>Sequoia tourmalii</i>	Teodoridis et al. 2015: pl. 1, figs 9, 13
Text-fig. 9j	cf. <i>Glyptostrobus europaeus</i>	<i>Widdringtonia helvetica</i>	Teodoridis et al. 2015: pl. 1, fig. 11
Text-fig. 9k	cf. <i>Glyptostrobus europaeus</i>	<i>Chamaecyparites massiliensis</i>	Teodoridis et al. 2015: pl. 1, fig. 11
Text-fig. 9r–v, za	<i>Pinus</i> indet.	<i>Pinus</i> div. sp.	Teodoridis et al. 2017: figs 2/3–2/6
Text-fig. 9w, y	<i>Pinus</i> cf. <i>rigios</i>	<i>Pinus</i> div. sp.	Teodoridis et al. 2015: pl. 1, fig. 2
Text-fig. 9z, zb	<i>Pinus</i> cf. <i>palaeostrobus</i>	<i>Pinus</i> div. sp.	Teodoridis et al. 2015: pl. 1, fig. 4
Text-fig. 10a	“ <i>Bambusa</i> ” sp.	<i>Bambusa alexandrina</i>	Teodoridis et al. 2015: pl. 4, fig. 4
Text-fig. 10c	cf. <i>Ocotea heeri</i>	<i>Cinnamomum lanceolatum</i>	Teodoridis et al. 2015: pl. 2, fig. 9
Text-fig. 10e	cf. Leguminosae gen. et sp. indet.	<i>Sapotacites eximius</i>	Teodoridis et al. 2015: pl. 5, figs 6, 7
Text-fig. 10f	cf. Leguminosae gen. et sp. indet.	<i>Terminalia elegans</i>	Teodoridis et al. 2015: pl. 2, fig. 9
Text-fig. 10g	<i>Fagus gussonii</i>	<i>Fagus deucalionis</i>	Denk 2004: fig. 12K, M
Text-fig. 10h	“ <i>Juglans</i> ” <i>acuminata</i>	<i>Berchemia multinervis</i>	Teodoridis et al. 2017: fig. 9/4
Text-fig. 10i	cf. “ <i>Juglans</i> ” <i>acuminata</i>	<i>Rhamnus rectinervis</i>	Teodoridis et al. 2017: fig. 9/3
Text-fig. 10j	cf. <i>Trigonobalanopsis rhamnoides</i>	<i>Persea speciosa</i>	Teodoridis et al. 2015: pl. 2, fig. 4
Text-fig. 10k	cf. <i>Trigonobalanopsis rhamnoides</i>	<i>Persea braunii</i>	Martinetto et al. 2007: figs 4–37
Text-fig. 10m	<i>Liquidambar europaea</i>	<i>Liquidambar europaea</i>	Martinetto et al. 2007: figs 4–34
Text-fig. 10n	<i>Quercus</i> gr. <i>pseudocastanealroburoides</i>	<i>Quercus cornaliae</i>	Teodoridis et al. 2015: pl. 7, fig. 12
Text-fig. 10o	<i>Fagus gussonii</i>	<i>Fagus ambigua</i>	Teodoridis et al. 2015: pl. 2, fig. 10
Text-fig. 10p	<i>Fagus gussonii</i>	<i>Ficus tiliaefolia</i>	Teodoridis et al. 2015: pl. 8, fig. 11 (base of the leaf very similar)
Text-fig. 10q	cf. Leguminosae gen. et sp. indet.	<i>Apocynophyllum helveticum</i>	Teodoridis et al. 2015: pl. 5, fig. 12
Text-fig. 10r	cf. Leguminosae gen. et sp. indet.	<i>Ficus arcinervis</i>	Teodoridis et al. 2015: pl. 5, fig. 4
Text-fig. 10s	cf. <i>Laurophyllum</i>	<i>Terminalia radabojensis</i>	Martinetto 2003: pl. 5, fig. 6
Text-fig. 10t	cf. <i>Acer integerrimum</i>	<i>Sterculia tenuinervis</i>	Martinetto et al. 2023: fig. 18F
Text-fig. 10u	<i>Populus latior</i>	<i>Populus latior</i>	Martinetto 2003: pl. 7, fig. 5
Text-fig. 10v	<i>Platanus leucophylla</i>	<i>Platanus depertita</i>	Martinetto et al. 2007: figs 4–34
Text-fig. 11d	cf. <i>Quercus pseudocastanea</i>	<i>Quercus scilliana</i>	Martinetto 2003: pl. 4, fig. 7
Text-fig. 11e	cf. <i>Carpinus</i>	<i>Carpinus grandis</i>	Martinetto 2003: pl. 3, fig. 7
Text-fig. 11f	<i>Carpinus</i> cf. <i>betulus</i>	<i>Carpinus grandis</i>	Teodoridis et al. 2015: pl. 10, fig. 2
Text-fig. 11h	<i>Daphnogene polymorpha</i>	<i>Cinnamomum rossmassleri</i>	Martinetto et al. 2023: figs 11F, 16G
Text-fig. 11i	cf. <i>Daphnogene polymorpha</i>	<i>Cinnamomum polymorphum</i>	Teodoridis et al. 2015: pl. 3, fig. 2
Text-fig. 11j	cf. <i>Ocotea heeri</i>	<i>Cinnamomum scheuczeri</i>	Teodoridis et al. 2015: pl. 2, fig. 11
Text-fig. 11k	cf. <i>Ocotea heeri</i>	<i>Cinnamomum emarginatum</i>	Teodoridis et al. 2015: pl. 2, fig. 13
Text-fig. 11l	cf. <i>Pterocarya paradisiaca</i>	<i>Fraxinus ulmifolia</i>	Teodoridis et al. 2015: pl. 9, fig. 7; Güner et al. 2017: pl. 7, fig. 4
Text-fig. 11m	<i>Salix</i> sp. 1	<i>Salix media</i>	Teodoridis et al. 2015: pl. 9, fig. 4
Text-fig. 11p	<i>Salix</i> sp. 2	<i>Salix varians</i>	Teodoridis et al. 2015: pl. 10, fig. 6
Text-fig. 11r	<i>Acer</i> sp.	<i>Acer primaevum</i>	Teodoridis et al. 2015: pl. 10, fig. 12
Text-fig. 11t	cf. Rosaceae	<i>Banksia laharpii</i>	Teodoridis et al. 2015: pl. 6, figs 4, 5
Text-fig. 11y	cf. <i>Zelkova zelkovifolia</i>	<i>Planera ungeri</i>	Teodoridis et al. 2015: pl. 7, fig. 1
Text-fig. 11zc	cf. Leguminosae	<i>Robinia regelii</i>	Teodoridis et al. 2015: pl. 5, figs 6, 7



Text-fig. 6. Fossil fish *Aphanius crassicaudus* AGASSIZ, 1848 recovered in Pavone outcrop, MGPT-PU 135802. **a:** Entire specimen. **b:** Close up of abdominal region showing tick epipleurals. **c:** Close up of caudal region. Scale bar 10 mm (a), 2 mm (b, c).

Comparison of Peola's Pavone drawings with Cenozoic fossil plant taxa described in north Italian literature (Bertini and Martinetto 2008, Bonci et al. 2011, Brambilla and Gallo 2002, Denk 2004, Hably 2010, Macaluso et al. 2018, Martinetto 2003, Martinetto et al. 2000, 2007, 2022, 2023, Teodoridis et al. 2015, 2017) led us to suggest the revised systematic placement of 52 specimens on the basis of definite morphological traits (Tab. 2). A few of them show traits that are useful for a less questionable determination, so that, in contrast with the 77 taxa identified by Peola (1900a), we confidently detected the occurrence of only 15 taxa (Tab. 1): *Pinus* cf. *rigios* (UNGER) ETTINGSH. (Text-fig. 9w, y), *Pinus* cf. *palaeostrobis* (ETTINGSH.) HEER (Text-fig. 9z, zb), *Acer* sp. (Text-fig. 11r, winged fruit), bambusoid grasses (Text-fig. 10a), *Carpinus* cf. *betulus* L. (Text-fig. 11f, fruit-bract), *Daphnogene polymorpha* (A.BRAUN) ETTINGSH. (Text-fig. 11h), *Fagus gussonii* A.MASSAL. (Text-fig. 10g, o), *Liquidambar europaea* A.BRAUN. (Text-fig. 10m), *Ocotea* cf. *heeri* (C.T.GAUDIN) W.R.MÜLL. (Text-fig. 10c), *Populus latior* A.BRAUN (Text-fig. 10u), *Platanus leucophylla* (UNGER) ERW.KNOBLOCH, (Text-fig. 10v), *Quercus* gr. *pseudocastanea* GÖPP./*Q. roburoides* C.T.GAUDIN (Text-fig. 10n) and *Salix* (Text-fig. 11p).

The last confidently identified taxon is represented by a 7 cm long lamina (Text-fig. 8a) with characteristic secondary venation, which was subjected to particularly detailed comparisons. It was assigned by Peola (1900a) to *Berchemia multinervis* (A.BRAUN) HEER, but the leaves of such species are generally shorter than 5 cm, with less arched secondary veins, not running along the margin towards the leaf tip (Text-fig. 8b). The Pavone specimen shows more analogies with a fossil leaf from the Pliocene of Lombardy (Text-fig. 8c – 10 cm long without petiole), assigned by Sordelli (1896) to *Annona lortetii* SAPORTA, and another from the Messinian of Nizza Monferrato (Text-fig. 8g), also assigned to *Annona lortetii* by Brambilla and Gallo (2002). However, the observation of both the detailed drawing by Saporta et al. (1872: 272, pl. 32, fig. 5) and the original specimen of *Annona lortetii* at the MNHN of Paris evidenced a quite different pattern of tertiary veins (Text-fig. 8d, e). The three Italian fossil leaves (Text-fig. 8a, c, g) may well belong to a single taxon, but it is not *Annona lortetii*. A major similarity in overall leaf characters, and tertiary venation pattern in particular, was detected with specimens (Text-fig. 8h) assigned to "*Juglans*" *acuminata*



Text-fig. 7. Comparison of two drawings of Peola (unpubl.) with real fossil specimens from Pliocene site of Bra (Martinetto et al. 2023). **a:** Drawing of basal part of leaf fragment assigned by Peola (1896) to “*Castanea tornabonii* A.MASSAL.”. **b:** Fossil specimen corresponding to drawing in (a), assigned to *Quercus gigas* Göpp. by Martinetto et al. (2023). **c:** Drawing of fossil leaf assigned by Peola (1896) to *Quercus cyclophylla* UNGER. **d:** Fossil specimen corresponding to drawing in (c), assigned to *Alnus ducalis* (C.T.GAUDIN) ERW.KNOBL. by Martinetto et al. (2023). Scale bar 1 cm.

A.BRAUN ex UNGER (Heer 1859: pls. 128, 129, Ludwig 1860: pl. 56, figs 2, 4, 6, pl. 57, fig. 6 [as “*Juglans costata* C.PRESL ex UNGER”], Teodoridis et al. 2017: fig. 9/4). This name is associated with a very variable type of leaflets of problematic systematic placement (Kvaček and Hurník 2000, Kvaček et al. 2011). In recent works, it has been considered as non-related to the Juglandaceae, and Kvaček et al. (2020) indicated an assignment to Meliaceae (e.g., *Cedrela*: Text-fig. 8f). Although the leaflets of “*Juglans*” *acuminata* are generally narrower and have an acuminate tip, the known range of variability (Heer 1859: pls 128, 129) also includes larger leaflets with a more obtuse tip, as in Sordelli’s specimen (Text-fig. 8c). Therefore, we concluded that the most consistent assignment of the Pavone specimen (Text-fig. 8a) and the two similar ones (Text-fig. 8c, g) is to “*Juglans*” *acuminata* (Meliaceae).

Concerning the 13 other Pavone specimens, we just mention a possible similarity with genera or fossil-species reported in the Neogene of northern Italy (names preceded by “cf.”), most of whose diagnostic traits cannot be detected

with certainty in Peola’s drawings: cf. *Carya* (Text-fig. 11q – possible endocarp), cf. *Cryptomeria* vel *Sequoia* (Text-fig. 9a, b, d, e), cf. *Glyptostrobus europaeus* (BRONGN.) UNGER (Text-fig. 9j, k), cf. *Taiwania* (Text-fig. 9c), cf. *Taxodium dubium* (STERNB.) A.BRAUN (Text-fig. 9i), cf. *Acer integerrimum* Viv. (Text-fig. 10t), cf. *Carpinus* (Text-fig. 11e), cf. *Laurophyllum* (Text-fig. 11s), cf. Leguminosae (Text-figs 10q, 11zc), cf. “*Juglans*” *acuminata* (Text-fig. 10i), cf. *Pterocarya paradisiaca* (UNGER) ILJINSK. (Text-fig. 11m), cf. Rosaceae (Text-fig. 11t), cf. *Trigonobalanopsis rhamnoides* (ROSSM.) KVAČEK et H.WALTHER (Text-fig. 10j, k) and cf. *Zelkova zelkovifolia* (UNGER) BŮŽEK et KOTL. (Text-fig. 11y). Systematic interpretation of the smaller leaves is mostly impossible (Text-fig. 11), because their drawings do not show diagnostic characters: We can single out (Tab. 1) only individual specimens of cf. *Daphnogene polymorpha*, cf. *Ocotea heeri* (C.T.GAUDIN) W.R.MÜLL. and cf. *Salix* (taxa already reported above).

Newly recovered fossils

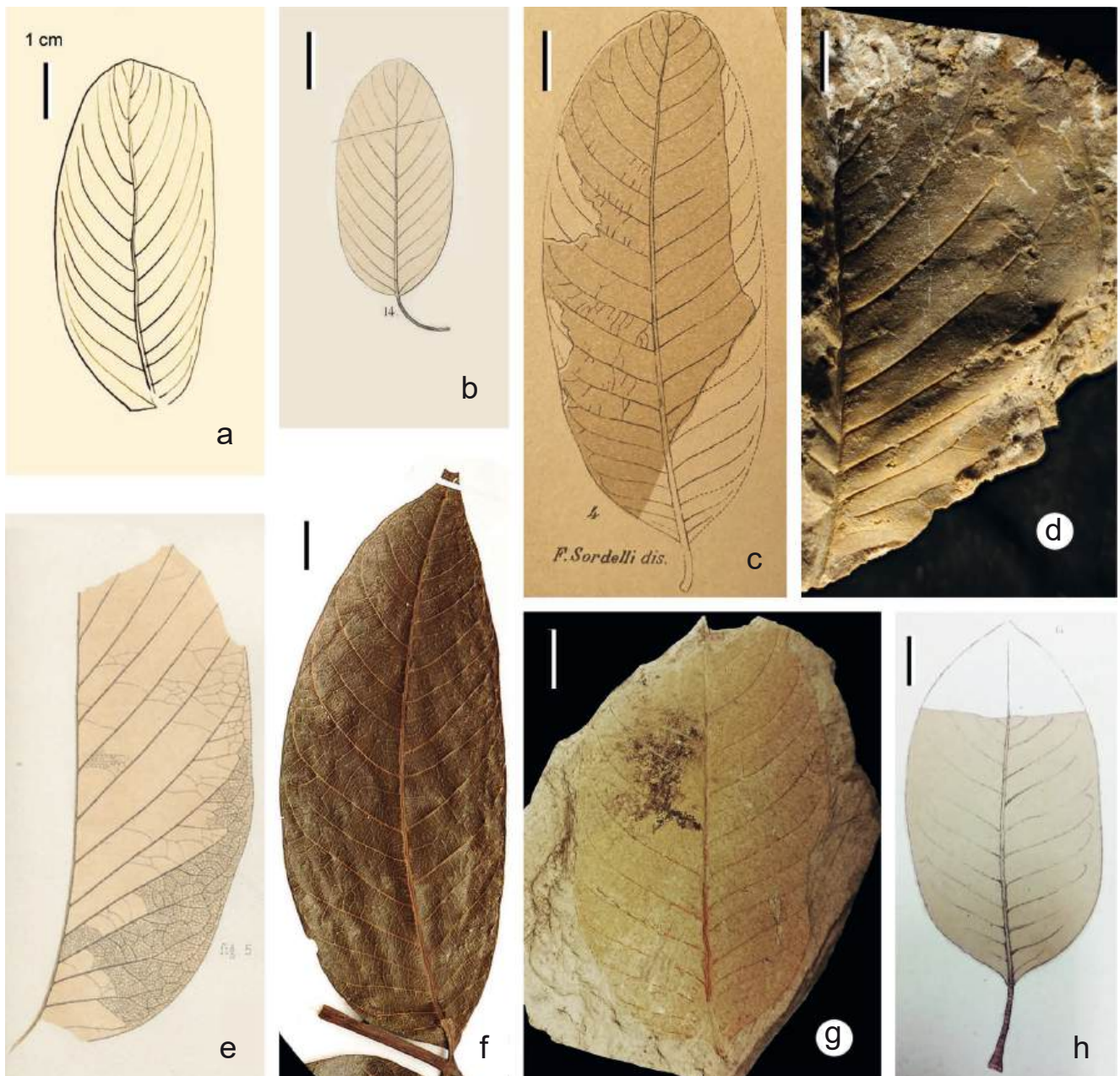
At the Pavone outcrop (Text-fig. 2), leaf-bearing sediments have been detected in thinly, flat-layered pelites, dipping at steep angles (Nizza Monferrato Member, VGS3 in Text-figs 2, 4). A portion of these sediments yielded adpressions of a few conifer and dicotyledonous-type leaves (Text-fig. 5b), an arthropod remnant (Text-fig. 5c) and a small portion of a fish tail. 2 m northwards, an almost complete external cast of a fish body was recovered (Text-fig. 6) from a stratigraphic position roughly corresponding to that of the plant- and arthropod-bearing layer.

Plant fossils

The best-preserved plant remains retrieved from the Nizza Monferrato Member of the Pavone outcrop (Text-fig. 2) were two laminae (Text-fig. 5b) on a single sediment sample (MGPT-PU141127). The largest leaf has a characteristic outline, secondary venation and teeth type, which suggest *Quercus drymeja* UNGER (see Denk et al. 2017: pl. 4, fig. 1), a fossil-species which occurs in the Neogene of northern Italy, where only a few specimens have been found. Its rarity supports a random occurrence, and may explain why it is not present in Peola’s drawings (1900a). The second, smaller lamina does not correspond to any of Peola’s drawings (1900a), but its sub-rounded shape and fine secondary venation suggest that it could be a leaflet from a member of Leguminosae (Denk et al. 2017: pl. 3, fig. 9), not particularly similar to the types recognized on the basis of drawings (Text-figs 10e, f, q, r, 11za). An admissible alternative would be a small, entire margined leaf of *Quercus mediterranea* UNGER (see Velitzelos 2002: pl. 16, fig. 9).

Arthropod fossil

The arthropod remnant (MGPT-PU141126) is poorly visible on the sedimentary matrix because a minor portion of the exoskeleton was preserved (Text-fig. 5c), but the detectable morphology shares significant characters with the pre-imaginal stages of *Oryctodiplax gypsorum* CAVALLO et GALLETTI (Text-fig. 5d), as described by Cavallo and Galletti (1987): dimension, breadth and oval outline of the



Text-fig. 8. Comparison of drawing of fossil leaf from Pavone (a), assigned by Peola (1900a) to *Berchemia multinervis* (A.BRAUN) HEER, with other fossil and extant specimens. b: *Berchemia multinervis* (A.BRAUN) HEER (Heer 1859: pl. 123, fig. 14). c: specimen from Pliocene of Lombardy assigned to *Annona lortetii* SAPORTA by Sordelli (1896). d: original specimen of *Annona lortetii*, courtesy of MNHN of Paris (Saporta et al. 1872). e: drawing based on foregoing specimen in Saporta et al. (1872: 272, pl. 32, fig. 5). f: leaflet of extant *Cedrela montana* J.MORITZ ex TURCZ. (from Peru), courtesy of Missouri Botanical Garden Herbarium. g: specimen from Messinian of Nizza Monferrato assigned to *Annona lortetii* SAPORTA by Brambilla and Gallo (2002). h: specimen from Miocene of Germany, treated as “*Juglans costata* C.PRESL ex UNGER” by Ludwig (1860).

abdomen with 8 segments, length and thickness of the legs, length of last abdominal segment and dimensions of the anal appendages. The head is not visible, but two darker spots could represent the displaced eyes, which would agree with those of Cavallo and Galletti's (1987) fossils in dimension and distance among them. This arthropod remnant can be assigned to the order Odonata and possibly to the genus *Oryctodiplax*.

Fish fossil

Subdivision Teleostei MÜLLER 1845 sensu Patterson and Rosen (1977)

Order Cyprinodontiformes BERG, 1940 sensu Parenti (1981)

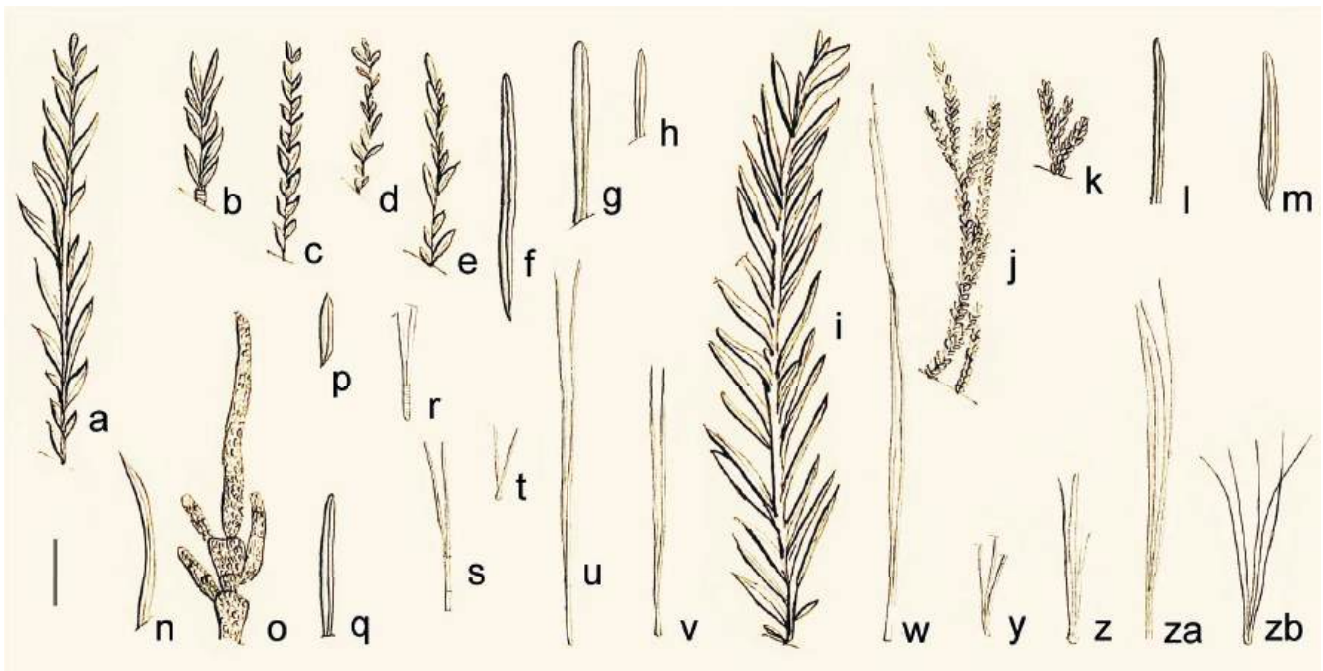
Family Cyprinodontidae AGASSIZ, 1834

Genus *Aphanius* NARDO, 1827

Aphanius crassicaudus AGASSIZ, 1839

Text-fig. 6

Material. Specimen (MGPT-PU135802) is a small, articulated and partially incomplete skeleton, lacking the head and the distalmost margin of the caudal fin (Text-fig. 6). The preserved skeleton is 39.8 mm in length, with a maximum body depth at dorsal-fin origin of 10.3 mm.



Text-fig. 9. Drawings of Messinian plant fossils from Pavone (Peola unpublished). a: cf. *Cryptomeria* vel *Sequoia*, as *Sequoia sternbergii* in Peola (unpubl.). b: cf. *Cryptomeria* vel *Sequoia*, as *Sequoia langsdorfii* in Peola (unpubl.). c: cf. *Taiwania*, as *Sequoia couttsiae* in Peola (unpubl.). d, e: cf. *Cryptomeria* vel *Sequoia*, as *Sequoia couttsiae* in Peola (unpubl.). f: cf. *Pseudotsuga*, as *Podocarpus oceanica* in Peola (unpubl.). g: Coniferales indet., as *Podocarpus gypsorum* in Peola (unpubl.). h: Coniferales indet., as *Abies?* sp. ind. in Peola (unpubl.). i: cf. *Taxodium dubium* (less probable *Sequoia*), as *Sequoia tournaillii* in Peola (unpubl.). j: cf. *Glyptostrobus europaeus*, as *Widdringtonia helvetica* in Peola (unpubl.). k: cf. *Glyptostrobus europaeus*, as *Chamaecyparites massiliensis* in Peola (unpubl.). l: Coniferales indet., as *Podocarpus peyriacensis* in Peola (unpubl.). m: Coniferales indet., as *Abies piccottii* in Peola (unpubl.). n: Coniferales indet., as *Pinites cryptomeriodes* in Peola (unpubl.). o: Indeterminable, as *Libocedrus salicornioides* in Peola (unpubl.). p: Coniferales indet., as *Podocarpus taxiformis* in Peola (unpubl.). q: Coniferales indet., as *Taxites eumenidium* in Peola (unpubl.). r–v: *Pinus* indet., as *Pinus* div. sp. in Peola (unpubl.). w–y: *Pinus* cf. *rigios*, as *Pinus* div. sp. in Peola (unpubl.). z–zb: *Pinus* cf. *palaeostrobis*, as *Pinus* div. sp. in Peola (unpubl.). Scale bar 1 cm.

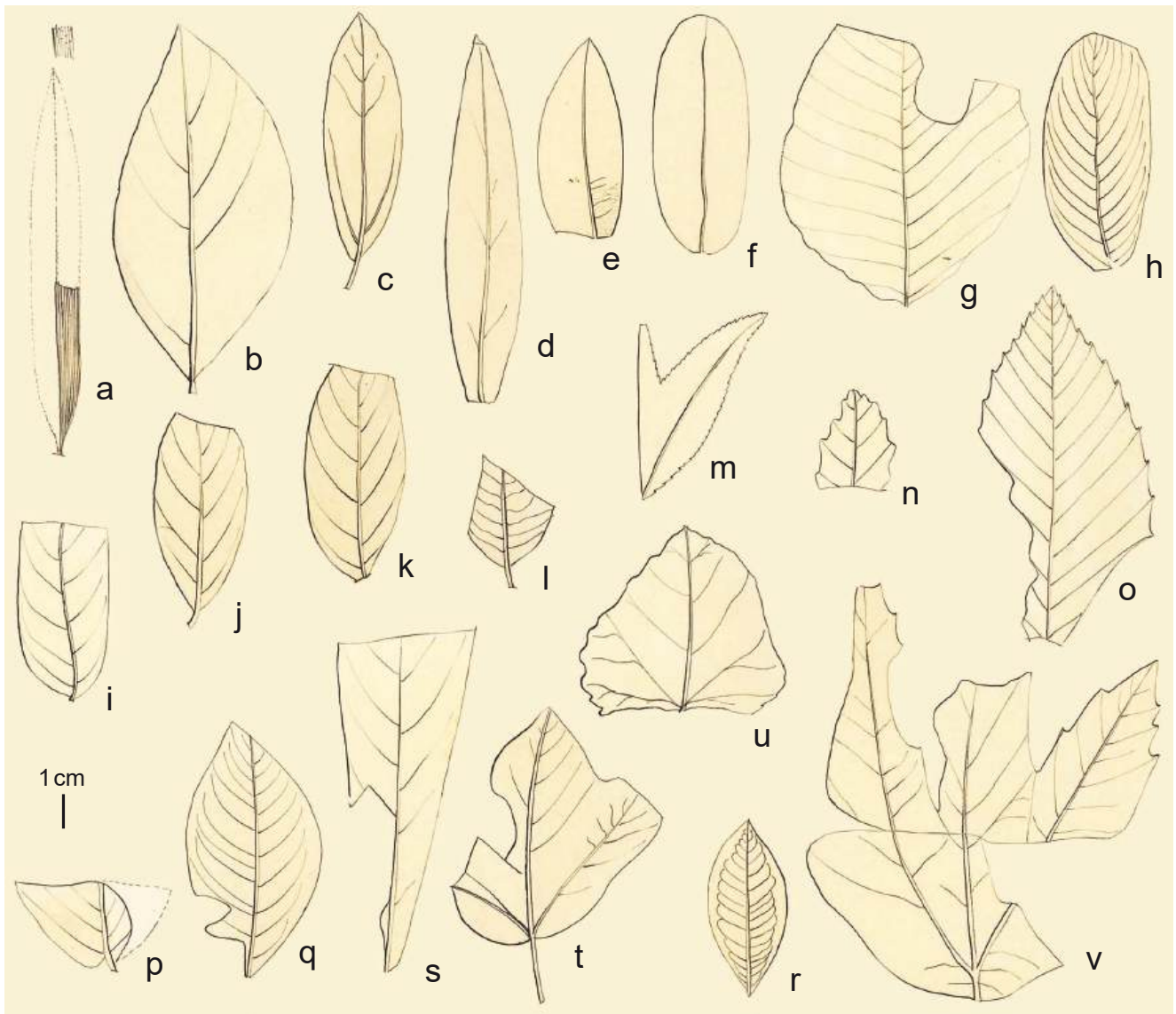
Description. The body of the fossil specimen is laterally compressed, moderately elongate and shallow, with nearly straight dorsal and abdominal profiles (Text-fig. 6a). The caudal peduncle is short and stocky, with its height about two-thirds of its length. There are 24 vertebrae preserved, but it is likely that their original number was higher, being the anteriormost portion of the vertebral column not preserved. Of these, 16 vertebrae are caudal. The centra are subrectangular, longer than high and characterised by a high degree of hyperostosis of their neural and haemal arches and spines, these latter being posteriorly oriented with an angle measuring about 45°. At least seven epipleurals can be recognized on the posteriormost abdominal vertebrae (Text-fig. 6b): they are short, remarkably thick, nearly fusiform and not bifid, with their distal margin postero-dorsally directed. Dorsal and anal fins are short based. The dorsal fin is located at about mid-length, with its origin being clearly anterior to the anal fin, this latter originating below the perpendicular to posterior end of the dorsal fin. There are 10 or 11 dorsal-fin rays and 9 or 10 anal-fin rays, both supported by an equal number of pterygiophores. The pelvic fins are small and placed anteriorly to the dorsal-fin origin, with about six rays. The caudal-fin skeleton has all hypural plates fused into a single hypural fan (Text-fig. 6c). The caudal fin is incomplete in its distalmost margin, but at least 28 caudal-fin rays (15 principals + 13 procurent) can be counted in its proximal part. Body scales are mostly not

preserved, but large and thick scattered cycloid scales cover part of the dorsal and ventral margins of the body.

Despite its incompleteness, the fossil preserves many features that support its inclusion in the cyprinodontid genus *Aphanius*, including the general body physiognomy and its small size, hypural plates fused into a hypural fan, presence of an undivided dorsal fin positioned slightly in front of the anal fin, epipleurals not bifid, and meristic count ranges consistent with that of the genus (Parenti 1981, Vasilyan et al. 2009). Moreover, the specimen exhibits a combination of features that support its alignment with the species *A. crassicaudus* AGASSIZ, 1848, an euryhaline estuarine species widespread in the Mediterranean basin throughout the Messinian (e.g., Carnevale et al. 2006, 2019, Caputo et al. 2009, Reichenbacher and Kowalke 2009, Carnevale and Schwarzthans 2022). These traits include the number of caudal vertebrae (16), dorsal- and anal-fin rays (10–11 and 9–10, respectively), caudal-fin rays (28+), and hyperostosis that often characterises the bones *A. crassicaudus* as evident enlargement of the bone structures (Gaudant 1979, Parenti 1981, Vasilyan et al. 2009, Bedosti et al. 2015).

Discussion and conclusions

Even if there is not a single specimen of Peola's plant fossils from Pavone which is still available, we argue, on the basis of the occurrence of fish fossils related to *Aphanius*

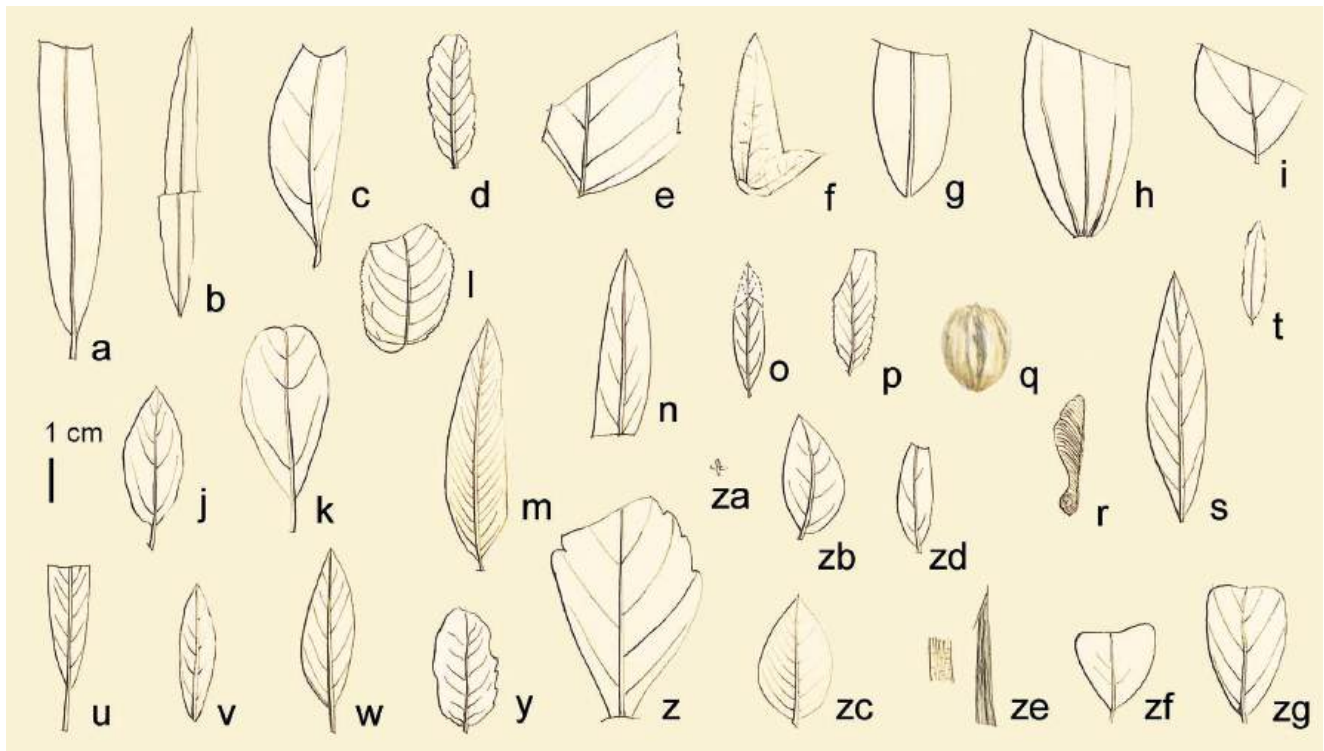


Text-fig. 10. Drawings of Messinian plant fossils from Pavone (Peola unpublished). a: “*Bambusa*” sp., as *Bambusa alexandrina* in Peola (unpubl.). b: Indeterminable, as *Persea speciosa* in Peola (unpubl.). c: cf. *Ocotea heeri*, as *Cinnamomum lanceolatum* in Peola (unpubl.). d: Indeterminable, as *Salix tenera* in Peola (unpubl.). e: cf. Leguminosae gen. et sp. indet., as *Sapotacites eximius* in Peola (unpubl.). f: cf. Leguminosae gen. et sp. indet., as *Terminalia elegans* in Peola (unpubl.). g: *Fagus gussonii*, as *Fagus deucalionis* in Peola (unpubl.). h: “*Juglans*” *acuminata*, as *Berchemia multinervis* in Peola (unpubl.). i: cf. “*Juglans*” *acuminata*, as *Rhamnus rectinervis* in Peola (unpubl.). j: cf. *Trigonobalanopsis rhamnoides*, as *Persea speciosa* in Peola (unpubl.). k: cf. *Trigonobalanopsis rhamnoides*, as *Persea braunii* in Peola (unpubl.). l: Indeterminable, as *Ptelea acuminata* in Peola (unpubl.). m: *Liquidambar europaea*, as *Liquidambar europaea* in Peola (unpubl.). n: *Quercus* gr. *pseudocastanea* / *Q. roburoides*, as *Quercus cornaliae* in Peola (unpubl.). o: *Fagus gussonii*, as *Fagus ambigua* in Peola (unpubl.). p: cf. *Fagus gussonii*, as *Ficus tiliaefolia* in Peola (unpubl.). q: cf. Leguminosae gen. et sp. indet., as *Apocinophyllum helveticum* in Peola (unpubl.). r: cf. Leguminosae gen. et sp. indet., as *Ficus arcinervis* in Peola (unpubl.). s: cf. *Laurophyllum*, as *Terminalia radabojensis* in Peola (unpubl.). t: cf. *Acer integerrimum*, as *Sterculia tenuinervis* in Peola (unpubl.). u: *Populus latior*, as *Populus latior* in Peola (unpubl.). v: *Platanus leucophylla*, as *Platanus deperita* in Peola (unpubl.). Scale bar 1 cm.

and of the descriptions of plant fossils he published (Peola 1900a), that his material could have come from sediments similar to the leaf-bearing ones we observed in the field during the year 2022 (Nizza Monferrato Member). Considering the local lithostratigraphy and palaeontological assemblages, the occurrence of a dragonfly larva and a cast of *Aphanius crassicaudus* suggests that these sediments could belong to the first MSC phase (Dela Pierre et al. 2016). At least one plant fossil-species, recognized on the basis of Peola’s (1900a) drawings, supports a Messinian rather than Oligocene age: *Fagus gussonii* A.MASSAL. has

never been reported from the Oligocene anywhere in the entire Mediterranean area (Denk 2004). The plant-bearing sediment of Pavone is more likely Messinian rather than “Tongrian” (i.e., Oligocene), as was suggested by Peola (1900a). A Messinian locality with similar lithologies and fossils is known only 16 km to the SE in the bed of the Scrivia river (Brambilla et al. 1982).

Even if the occurrence of fossil leaves originating from Pliocene sediments was observed by us in the Pavone outcrop (Text-fig. 5a), Peola (1900a: 37) firmly stated that the plant fossils described by him were collected from a single



Text-fig. 11. Drawings of Messinian plant fossils from Pavone (Peola unpublished). a: Indeterminable, as *Eucalyptus oceanica* in Peola (unpubl.). b: cf. *Salix*, as *Salix angusta* in Peola (unpubl.). c: Indeterminable, as *Myrica salicina* in Peola (unpubl.). d: cf. *Quercus pseudocastanea*, as *Quercus scilliana* in Peola (unpubl.). e: cf. *Carpinus*, as *Carpinus grandis* in Peola (unpubl.). f: *Carpinus* cf. *betulus*, as *Carpinus grandis* in Peola (unpubl.). g: Indeterminable, as *Lucothoe vacciniifolia* in Peola (unpubl.). h: *Daphnogene polymorpha*, as *Cinnamomum rosmaessleri* in Peola (unpubl.). i: cf. *Daphnogene polymorpha*, as *Cinnamomum polymorphum* in Peola (unpubl.). j: cf. *Ocotea heeri*, as *Cinnamomum scheuczeri* in Peola (unpubl.). k: cf. *Ocotea heeri*, as *Cinnamomum emarginatum* in Peola (unpubl.). l: cf. *Pterocarya paradisiaca*, as *Fraxinus ulmifolia* in Peola (unpubl.). m: *Salix* sp. 1, as *Salix media* in Peola (unpubl.). n: Indeterminable, as *Cassia zephyri* in Peola (unpubl.). o: Indeterminable, as *Olea proxima* in Peola (unpubl.). p: *Salix* sp. 2, as *Salix varians* in Peola (unpubl.). q: cf. *Carya* fruit, as *Apeibopsis gaudinii* in Peola (unpubl.). r: *Acer* sp., as *Acer primaevum* in Peola (unpubl.). u: Indeterminable, as *Lucothoe protogaea* in Peola (unpubl.). v: Indeterminable, as *Benzoin paucinerve* in Peola (unpubl.). w: Indeterminable, as *Styrax stylosus* in Peola (unpubl.). y: cf. *Zelkova zelkovifolia*, as *Planera ungeri* in Peola (unpubl.). z: Indeterminable, as *Rhus pyrrhae* in Peola (unpubl.). za: Indeterminable, as *Weinmannia tetrasepala* in Peola (unpubl.). zb: Indeterminable, as *Cassia berenices* in Peola (unpubl.). zc: cf. Leguminosae, as *Robinia regelii* in Peola (unpubl.). zd: Indeterminable, as *Cassia lignitum* in Peola (unpubl.). ze: Monocotyledones indet., as *Panicum miocenicum* in Peola (unpubl.). zf: Indeterminable, as *Dalbergia jaccardii* in Peola (unpubl.). zg: Indeterminable, as *Dalbergia cuneifolia* in Peola (unpubl.). Scale bar 1 cm.

marly-arenaceous body (“in uno di questi banchi marnoso-arenacei”), which also yielded some fish (*Aphanius?*). Both the lithology and the occurrence of *Aphanius?* indicate that the sedimentary body he sampled was most likely part of the Nizza Monferrato Member.

Therefore, Peola’s descriptions (1900a) and drawings (unpublished) can be referred to a Messinian plant assemblage that showed a considerable diversity of conifers (Text-fig. 9), among which are at least two types of *Pinus* foliage and some cupressoid, cryptomerioid and taxodioid shoots. The drawn Angiosperm leaves are mostly fragmentary. A smaller part shows almost complete laminae, even of large leaves (Text-fig. 10). Despite the uncertain systematic placement, they clearly show a diversity of morphotypes, suggesting that each plant taxon of the source vegetation produced one or a few specimens, buried together after considerable transport. Remarkably, one of the two recently recovered leaves is from a previously unrecorded taxon (*Quercus drymeja*). This kind of assemblage containing *Daphnogene polymorpha*, *Fagus gussonii*, *Liquidambar europaea*, *Ocotea heeri*, *Platanus*

leucophylla, *Populus latior*, etc., is similar from both the taphonomic and taxonomic point of view to most of the assemblages referred to the first MSC phase in northern Italy (Bertini and Martinetto 2008, Brambilla and Gallo 2002, Martinetto et al. 2000, 2007, 2023, Teodoridis et al. 2015, 2017).

Peola’s (1900a) Pavone work has just been cited in a few non-Italian palaeobotanical papers (Worobiec and Worobiec 2005, Wang et al. 2013, 2014, Srivastava et al. 2019). However, we deem it useful to underline the wrongly suggested age of the palaeoflora of Pavone in order to prevent a misuse of these published records. Actually, this already happened for the oldest record of bamboos in Europe, indicated by Srivastava et al. (2019) as being “from the Oligocene of Italy”, with special reference to Peola (1900a) and therefore to fossils from Pavone.

In reading Peola’s (1900a) conclusions, it would appear that the fossil flora of Pavone may have considerable significance, due to its purported diversity (77 species; Tab. 1). However, we see this author as having a tendency to

separate different species on the basis of minor differences that are actually merely variations within a species (see Martinetto et al. 2023, for the Pliocene flora of Bra), and we presume that, even if the Pavone plant remains had been better preserved and still available, they would still not sum up to more than a few tens of species. Furthermore, from Peola's descriptions (no photos, only drawings), it would seem that the state of preservation of his specimens was not good. This same poor preservation is also observed in the newly collected samples (Text-fig. 5c). Therefore, considering the richness of the Messinian floras in the Piemonte region (Martinetto et al. 2007, 2022, 2023) and the poor quality of preservation of the Pavone specimens, further recovery of fossils from this outcrop should not be considered a priority.

Finally, this study is a representative example of how detailed field mapping studies can produce tectono-stratigraphic reconstructions that can be helpful for the chronostratigraphic framing of palaeofloras, above all in those areas with poor rock exposures.

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