

CARBONIFEROUS PLANT FOSSILS FROM THE SAN LORENZO SCHISTS (PISANI MOUNTAINS, TUSCANY, ITALY): A PRELIMINARY STUDY OF THE PALAEOBOTANICAL COLLECTION OF THE MUSEO NATURALISTICO ARCHEOLOGICO DELL'APPENNINO PISTOIESE

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Abstract. The Museo Naturalistico Archeologico dell'Appennino Pistoiese (MUNAP) at Gavinana (PT) hosts one of the most abundant and diverse collections of Late Palaeozoic plant fossils from the San Lorenzo Schists of the Pisani Mountains. More than 1200 rock slabs yielding plant fossils were collected from six different outcrops in Guappero Valley in the San Lorenzo a Vaccoli area (NE of the Pisani Mountains, near Lucca), the type-locality of the formation. The present study concerns two outcrops at Via Pari that are characterized by a wide range of plant fossils (20 taxa) belonging to the lycopsids (*Stigmaria*), sphenopsids (*Calamites*, *Asterophyllites*, *Calamostachys*, *Sphenophyllum*, *Bowmanites*), ferns (*Acitbeca*, *Diplazites*, *Cyathocarpus*), seed ferns (*Alethopteris*, ?*Autunia*, gen. indet.), cordaites (*Cordaites*) and seeds (*Carpolithes*). This first description of the plant fossil collection and the revision of its stratigraphical context with respect to the surrounding famous fossiliferous sections of the Guappero Valley refine the stratigraphic and palaeoenvironmental framework of the Late Palaeozoic successions of the Pisani Mts. and more generally of the Apennine chain. The qualitative and quantitative analyses show significant environmental variations between neighbouring outcrops in the Via Pari area – i.e., more humid conditions in 'Via Pari Buca' than in 'Via Pari Smottamento' – and suggest a latest Carboniferous (Gzhelian) instead of an early Permian age as proposed by previous authors. Moreover, the differences in composition between the plant assemblages of the Via Pari sections with the historical assemblage of the nearby Monte Vignale outcrop (containing typical Permian and more xerophytic elements) in the De Stefani Collection of the Florence Natural History Museum is explained by a younger age (early Permian) of the latter.

INTRODUCTION

The Pennsylvanian was one of the most important coal-forming periods in Earth history. The lowland and coastal areas of equatorial to subtropical Pangea were covered by extensive wetland forests and swamps, dominated by arborescent lycopsids and tree ferns (e.g., Cleal & Thomas 2005; Opluštil & Cleal 2007; Cleal et al. 2012). The most important European coal deposits of this time interval are today located in Upper Silesia, the Intra-Sudetic Basin, Central and Western Bohemia, South Wales and in the Pennines (for more details see Opluštil & Cleal 2007). Five major areas yielding Pennsylvanian plant fossils can be distinguished in Italy: the Carnic Alps, the Western Southern Alps, the Ligurian Alps, Tuscany and Sardinia (e.g., Ronchi et al. 2012; Pšenička et al. 2012, 2017; Kustatscher et al. 2014; Cleal et al. 2016; Kustatscher et al. 2019; Opluštil et al. 2021). The famous Permo-Carboniferous macroflora of Tuscany comes from the Pisani Mts. (Pisa and Lucca provinces) and Iano (Florence Province) areas that represent the pinning point outcrops for the stratigraphy of the Late Palaeozoic on the Italian Peninsula as a whole. The geological history of the Pisani Mts. (=Monti Pisani) was for many decades a hot topic of discussion among local geologists, particularly regarding the age and significance of the so-called “Verrucano” that was described by Savi (1832) as a stratified clastic stratigraphic unit that rests below the Mesozoic carbonate rocks and took its name from ‘Verruca’, a mountain peak of the Pisani Mts. Long debates about the “Verrucano” (“Problematica Verrucana” = Verrucano problem in Fucini 1936) and intense field studies between the 19th and 20th centuries are testified by a variety of scientific papers, geological maps and fossil collections from this area (see Cioppi in Monechi & Rook 2010). Different chronological attributions were proposed over time for the “Verrucano” including all the metasiliciclastic units used also today (e.g., the San Lorenzo Schists): post-Carboniferous (Savi 1843), Permian (Lotti 1883), and Triassic (Savi 1847; Capellini 1864; De Stefani 1876). At the end of the 19th century, rich fossiliferous associations were discovered in the “Verrucano” of the Guappero Valley and dated as late Carboniferous–early Permian (De Stefani 1894, 1901; Canevari 1891, 1892; De Bosniaski 1890, 1894). Later Fucini (1925) distinguished for the first time two formations inside

the “Verrucano”: the mainly phyllitic Late Palaeozoic “Antracolitico” and the overlying predominantly coarse-grained “Verrucano tipico” (wrongly attributed by this author to the Cretaceous). This subdivision was confirmed by Trevisan (1955) who gave the Late Palaeozoic “Antracolitico” formation the name “San Lorenzo Schists” and distinguished at its base the new formation of the “Banded Quartzites”. Rau & Tongiorgi (1966b, 1968a, 1968b, 1972, 1974, 1976) and Elter (1966) refined the stratigraphic architecture by inserting the Asciano Breccias and Conglomerates in between the San Lorenzo Schists and the Verrucano Group (consisting of the Verruca Formation and the overlying Mt. Serra Quartzites Formation). Consequently, today the old “Verrucano” is divided into four units (Rau & Tongiorgi 1974; Pandeli 2002; Cassinis et al. 2018); the ?Early Palaeozoic Buti Banded Quartzites and Phyllites, the late Carboniferous–early Permian San Lorenzo Schists, the likely early–middle Permian Asciano Breccia and Conglomerate and the overlying ?late Ladinian–Carnian Verrucano Group (Fig. 1). The most important fossiliferous outcrops in the Pisani Mts. area are located in the San Lorenzo Schists: Traina, Monte Togi, Monte Vignale, Valentona, Via Pari, Sasso Campanaro and Villa Massagli near San Lorenzo a Vaccoli (Lucca Province). Large collections of plant fossils were assembled by two competing naturalists during the 19th century, Sigismondo De Bosniaski (1837–1921; ~7.000 specimens of plant and animal remains) and Carlo De Stefani (1851–1924; ~1.000 specimens of plant fossils) (e.g., Canavari 1891; De Bosniaski 1881, 1890, 1894; De Stefani 1890, 1891a, 1891b, 1891c, 1894). These plant collections include a wide variety of vegetative and reproductive organs of lycopsids, sphenopsids, ferns, seed ferns (or pteridosperms), taeniopterids, cordaites and conifers (e.g., Landi Degl’Innocenti 2006; Landi Degl’Innocenti et al. 2008; Cioppi in Monechi & Rook 2010; Mariotti in Monechi & Rook 2010). De Stefani (1901) established 21 new species and one new genus (*Aspasia*) based on Tuscany specimens.

The sedimentary succession of the Iano Schists near Iano yielded plant fossils (lycopsids, sphenopsids, ferns) together with crinoids, bivalves and putative brachiopods of Pennsylvanian age (Vai & Francavilla 1974; Pandeli 1998; Cioppi in Monechi & Rook 2010). Since the end of the 19th century no stratigraphical sampling of the Pisani Mts. out-

crops has been carried out up to the end of the 20th century when the Naturalistic Group of the Museo Naturalistico Archeologico dell'Appennino Pistoiese (MUNAP) started to collect plants, animals and fossils from Tuscany, including plant fossils from different outcrops of the San Lorenzo Schists (=SLs) outcropping in the Guappero Valley (NE of the Pisani Mts.) close to San Lorenzo a Vaccoli (Figs. 2, 3, and 4). The aim of this paper is to present a first detailed description of a part of the recently collected samples and in particular the fossil assemblages of two new fossiliferous outcrops located in the Via Pari area. These new data improve the stratigraphic and palaeoenvironmental framework of the Pennsylvanian–Cisuralian in Tuscany and permit a more detailed correlation with other coeval Italian successions (e.g., Sardinia, Southern Alps, Ligurian Alps, Carnic Alps).

GEOLOGICAL SETTING OF THE PISANI MOUNTAINS

The Northern Apennines represent an Adriatic-vergent segment of the Alpine-Himalayan orogenic belt (Vai & Martini 2001 and references therein). This orogenic segment originated in late Oligocene–middle Miocene times, through the collision of the Corsica-Sardinia block (i.e., the European continent) with the Tuscan part of the Adria plate, following the previous Late Cretaceous to Eocene subduction of the interposed Ligurian-Piedmontese oceanic area (Principi et al. 2001; Bortolotti et al. 2001). During the Oligocene–Miocene syn-collisional stages, the units of the oceanic accretionary prism (i.e., Ligurids) thrust over the Tuscan successions, which were shortened and doubled (e.g., overthrust of the non-metamorphic Tuscan Nappe) on those successions that would become the Tuscan Metamorphic Units (=TMU). The Tuscan Metamorphic Units of the Pisani Mts. suffered an polyphase, low-grade tectono-metamorphism, essentially in the greenschist facies, with peak conditions of $T = 400^{\circ}\text{C}$ and $P = 0.8\text{--}0.9$ GPa during the Apenninic tectogenesis (Franceschelli et al. 2004; Carosi et al. 1993, 1995), which occurred in an interval of 27 to 14–12 Ma (radiometric ages from the Apuan Alps Core: Kligfield et al. 1986) and belong to two tectonically superimposed tectonic subunits, namely the Serra Mountain subunit and the overlying San Maria del Giudice subunit (Fig. 3).

The Pisani Mts., together with the Apuan Alps and the Montagnola Senese-Monti Leoni Ridge, represent the most extensive outcrops of the TMU rocks in the Northern Apennines (Pandeli et al. 1994, 2004). All these outcrops are inliers relative to the wide tectonic window of the TMU that are buried below the non-metamorphic Tuscan Nappe and the overlying Ligurian and Sub-Ligurian Unit (Rau & Tongiorgi 1974; Pandeli et al. 2004). The Pisani Mts. inlier is bounded laterally by high-angle normal fault systems characterized by NW–SE and NE–SW strikes, referred to post-orogenic extensional events of Neogene to Quaternary age (Rau & Tongiorgi 1974; Pandeli et al. 2004; Landi Degl'Innocenti et al. 2008) (Fig. 3).

Similarly to other Tuscan metamorphic inliers (e.g., Apuan Alps, Monticiano-Roccastrada Ridge), the Pisani Mts. succession consists of a Palaeozoic 'basement' and the stratigraphically overlying Triassic to Oligocene formations of the Alpine sedimentary cycle that began with the syn-rift, siliciclastic fluvial-deltaic to neritic sediments of the ?late Ladinian–Carnian Verrucano Group (Rau & Tongiorgi 1974, 1976; Pandeli et al. 2004).

The Palaeozoic succession of the Pisani Mts. is composed from the base to the top as follows (Fig. 1):

Buti Banded Quartzites and Phyllites (Bbqp; pre-Variscan, ?Ordovician): these non-fossiliferous rocks were affected by processes due to the Variscan Orogeny and consist of grey, medium- to fine-grained metasandstones, interbedded with grey-violet and greenish-grey phyllites and metasiltstones. The latter contain hematite in millimetric bands and schistosity relics of the Variscan Orogenic event (Pandeli et al. 1994, 2004).

San Lorenzo Schists (SLs; ?late Moscovian/Kasimovian–Gzhelian to early Permian, i.e. Sakmarian): the metasiltstones and phyllites of grey–black colour are rich in organic matter and contain intercalations of well-stratified quartzite metasandstones and metaconglomerate beds in the uppermost part. These fossiliferous rocks were deposited in a continental fluvial–lacustrine, locally marine, depositional environment characterized by equatorial–subtropical, wet–humid climate conditions (Rau & Tongiorgi 1974, 1976; Landi Degl'Innocenti et al. 2008; Pandeli et al. 2008).

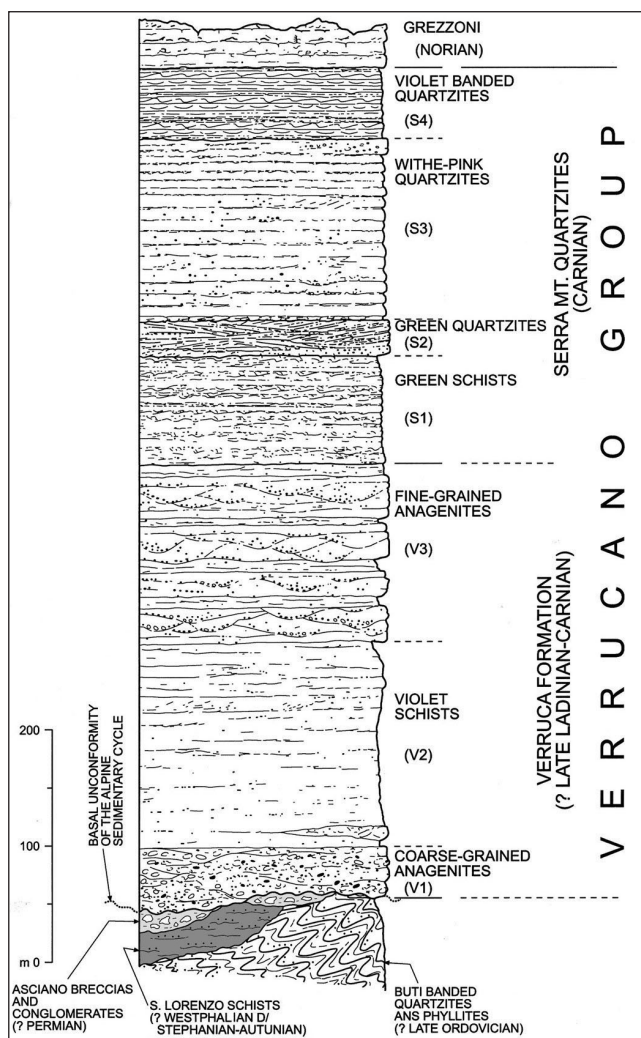


Fig. 1 - Stratigraphic column of the Paleozoic–Carnian succession of the Pisani Mountains (modified from Rau & Tongiorgi 1974; after Landi Degl'Innocenti et al. 2008).

Asciano Breccias and Conglomerates (Abc; ?latest early Permian–?middle Permian, i.e. Sakmarian/Artinskian to ?Roadian): These unfossiliferous, poorly bedded and massive metarudites are characterized by a low textural and compositional maturity and angular–subrounded clasts. The clasts are composed of phyllites, quartzites or metasandstones (including BBQP and SLs). They were deposited in a subtropical dry climate (Rau & Tongiorgi 1974; Landi Degl'Innocenti et al. 2008) or under well-drained monsoon-like conditions (Marini et al. 2020). These rocks did not yield any fossils so far but are attributed for their stratigraphic position in the more complete Iano succession (Pandeli 1998) to the latest early–middle Permian when the Saalian event of the Variscan Orogeny occurred and caused a strong rejuvenation of the Late Palaeozoic land-

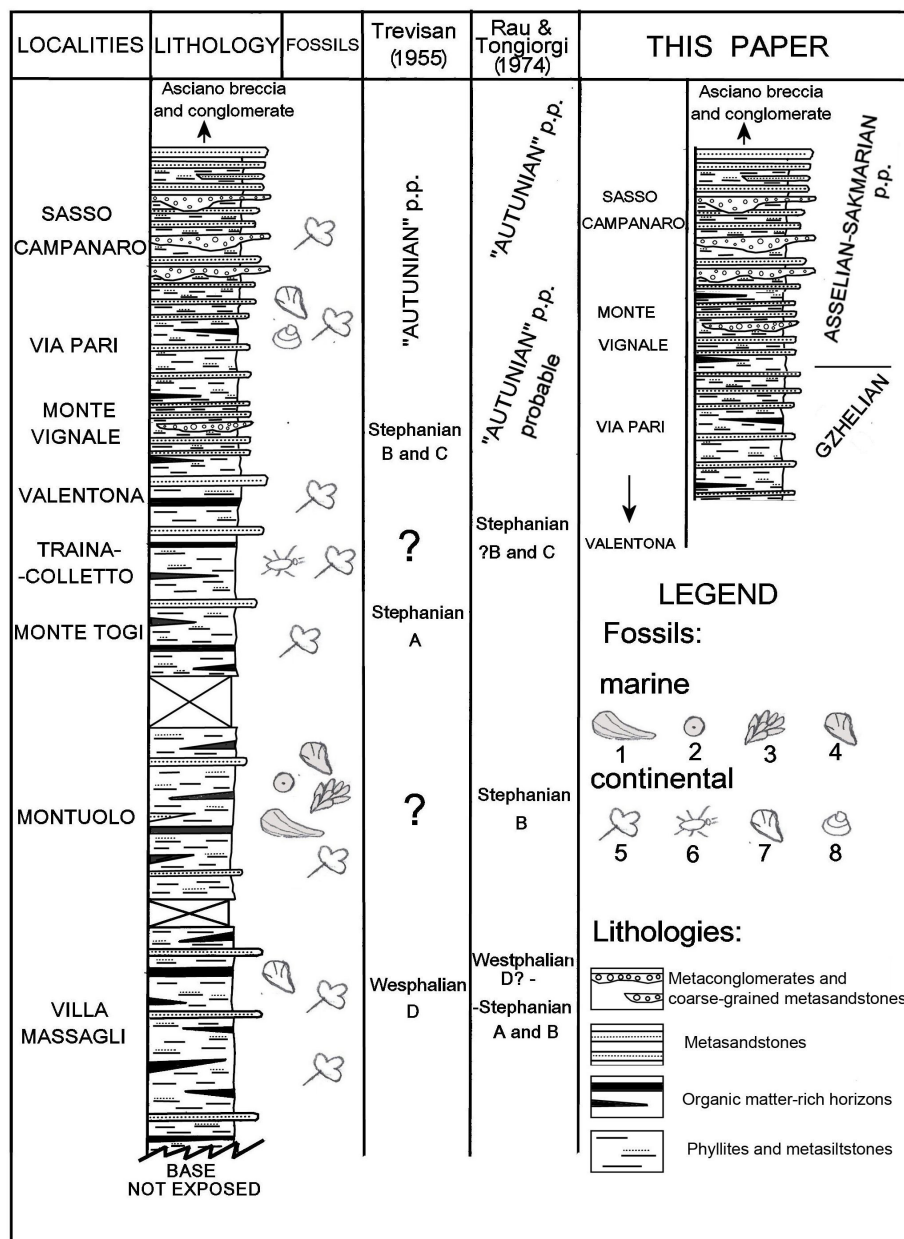
scape (Bagnoli et al. 1979; Pandeli et al. 1994; Pandeli 2002; Cassinis et al. 2018).

These three formations are separated from each other and from the overlying Verrucano Group by unconformity surfaces (Fig. 1). The Santa Maria del Giudice Subunit is characterized by the presence of relatively wide outcrops of San Lorenzo Schists and Asciano Breccias and Conglomerates, whereas their outcrops are reduced or missing above the pre-Carboniferous Buti Banded Quartzites and Phyllites in the Serra Mountain Subunit (Rau & Tongiorgi 1974; Pandeli et al. 2004).

In the stratigraphic framework of the San Lorenzo Schists (Rau & Tongiorgi 1974; Landi Degl'Innocenti et al. 2008) (Fig. 4), the Villa Massagli section represents the lowermost exposed part of the formation, and the Montuolo section, in which Pandeli et al. (2008) found marine fossils, i.e., brachiopods (Orthotetoidea) or rostroconchs (Conocardicea), crinoids and bryozoans, covers the middle-lower part. According to Rau & Tongiorgi (1974), the middle and middle–upper portion is represented by the Valentona, Monte Togi, Traina, Colletto and Monte Vignale sections, whereas the Via Pari, and the overlying Sasso Campanaro sections correspond to the upper part of the formation (see Fig. 2). The lower–middle part of SLs is dominated by black to grey phyllites with local horizons rich in organic matter. The Via Pari section is represented by a rhythmic alternation of phyllites and silty phyllites with local graphitic layers and fine- to middle-grained quartzitic metasandstone and metasiltstone intercalations. The Monte Vignale and Sasso Campanaro sections are characterized by a conspicuous increase in siliciclastic input (quartzitic metasandstones and metaconglomerates) as a result of the middle Permian tectonic uplift and/or due to a climate change (Rau & Tongiorgi 1974; Landi Degl'Innocenti et al. 2008).

The lower portion of the formation (Villa Massagli section) is assigned a Westphalian D (?late Moscovian) age based on the composition of the '*Lepidodendron* flora' (Trevisan 1955) or a ?Westphalian D/Stephanian A and B (?Late Moscovian/Kasimovian/early Gzhelian) age according to lithostratigraphic data (Rau & Tongiorgi 1974) (see Fig. 2). The middle to middle–upper portion was referred to the Stephanian A to C (Kasimovian–late Gzhelian; M. Togi and M. Vignale sections) by Trevisan (1955) or to the Stephanian B and C

Fig. 2 - Stratigraphic column (not in scale) of the San Lorenzo Schist in the Guappero valley area. Comparison between the age of the various fossiliferous localities as proposed by the different authors and in this paper. Fossils: marine (1- brachiopods or rostroconchs, 2- crinoids, 3- bryozoa, 4- limnic bivalves), continental (5- plant macrofossils, 6- insects, 7- bivalves, 8- crustaceans).



(Traina) to probably early Permian (M. Vignale section) by Rau & Tongiorgi (1974). The upper part of the formation (Via Pari and Sasso Campanaro sections) was dated early Permian (Asselian–Sakmarian) by both authors according to lithological and biostratigraphic evidence such as the finding of *Callipteris conferta* and *Walchia piniformis* (for more information see tab. 1 in Landi Degl’Innocenti et al. 2008).

From a depositional point of view, the lower–middle portions of SLs suggest a complex alluvial system close to a coastal plain characterized by small channels, with local swampy and lacustrine areas marked by occasional intercalations of coarse-grained deposits coming from the neighbouring

fluvial channels. In the uppermost part of SLs, the frequent intercalations of metasandstones and metaconglomerates testify to the evolution of the continental environment to an alluvial plain with channels, flooding plains and minor water pools (Rau & Tongiorgi 1974; Landi Degl’Innocenti et al. 2008; Marini et al. 2020).

MATERIALS AND METHODS

The San Lorenzo a Vaccoli area (Guappero Valley, NE of the Pisani Mts., near Lucca; Figs. 3, 4), type area of the San Lorenzo Schists and landmark for any study on the late Carboniferous–early Permian stratigraphy and palaeoecology of Tuscany, is famous because it yielded the plant fossil collection of the renowned natural-



Fig. 3 - Geographic position (image from <https://visibleearth.nasa.gov/images/65788/italy>), and structural sketch of the Pisani Mountains area, and location of Guappero Valley (modified from Rau & Tongiorgi 1974 and Landi Degl'Innocenti et al. 2008).

ist and geologist Carlo De Stefani (1851–1924). De Stefani (1890) discovered the first fossiliferous site 'La Traina'. New fossiliferous outcrops were identified by Canavari (1891) near Villa Massagli and Monte Vignale and by De Bosniaski (1890) near Colletto. Additionally, Canavari (1891, 1892) discovered limnic bivalves (*Anthracosia*) and insects (Blattinariae) in the continental graphite-rich lithotypes of the San Lorenzo Schists, whereas Rau & Tongiorgi (1974) found also crustaceans (*Estheriae*).

The Naturalistic Group of the Museo Naturalistico Archeologico dell'Appennino Pistoiese collected fossils from several outcrops in the Guappero Valley in the second half of 20th century.

More than 1200 rock slabs yielding plant fossils were collected from six different outcrops in the San Lorenzo a Vaccoli area including Via Pari, Villa Massagli, Traina, Colletto, Monte Togi/Colletto and Montuolo (Fig. 4). The most fossiliferous site is Via Pari with more than 600 rock slabs from two outcrops here named 'Via Pari Buca' (408 rock slabs) and 'Via Pari Smottamento' (250 rock slabs) (Fig. 4). Some rock slabs yielded more than one plant fossil. The lithotypes of samples from 'Via Pari Buca' are mostly silty phyllites and fine-grained metasandstone and metasiltstones, whereas phyllites

and rare silty phyllites are dominant in 'Via Pari Smottamento'. These two localities are situated close to De Stefani's site Monte Vignale. The Via Pari succession is represented by a rhythmic alternation of phyllites and silty phyllites with local graphitic layers and fine- to middle-grained quartzitic metasandstone and metasiltstone intercalations. The Monte Vignale section is characterized by an increase in coarse-grained siliciclastic input (i.e., quartzitic metasandstones and metaconglomerates intercalations). The fossils are preserved as impressions and permineralized impressions (limonite, hematite).

A first preliminary study has been carried out on this collection. Each rock slab has been inventoried in an Excel worksheet and photographed with the high-resolution camera of a Huawei P10 Lite smartphone in front of a black bristol cardboard background and illuminated with a grazing light to enhance details and to improve the contrast and depths. The photos have been treated with Photoshop in post-production. The inventory numbers of the specimens are composed of an acronym indicating the outcrop (e.g., VPB, VPS) followed by subsequent numbers. The suffixes A/B/C are used to indicate parts and counterparts (e.g., VP136A/B). Specimens with the acronym 'VP' come from the site 'Via Pari Buca' (VPB) except for

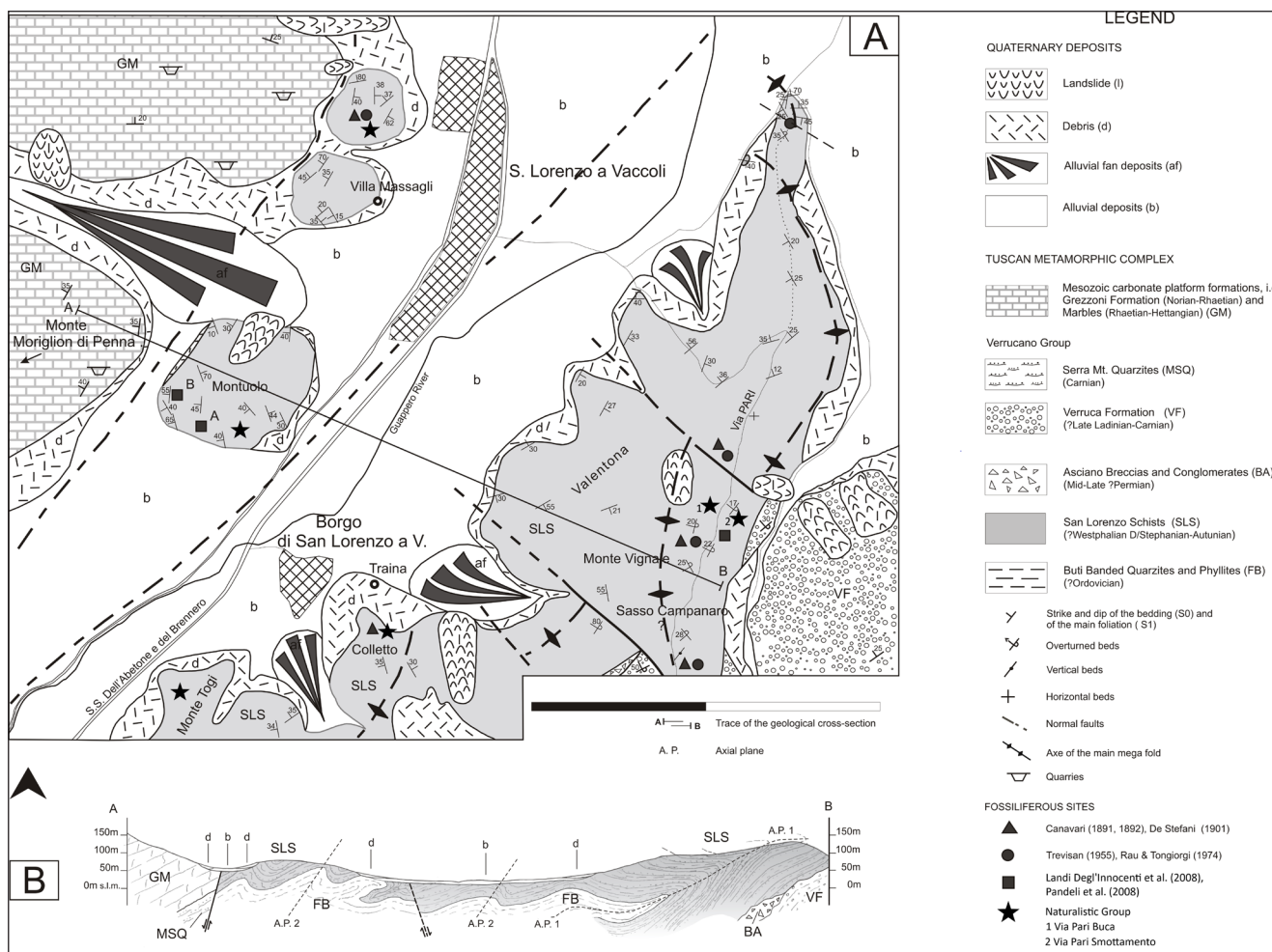


Fig. 4 - Geological map of the San Lorenzo a Vaccoli area (A), geological cross section (B) with the most important fossiliferous outcrops in the Guappero Valley (modified from Landi Degl'Innocenti et al. 2008).

the numbers VP306–VP389, which were collected from the outcrop called ‘Via Pari Smottamento’ (VPS), and the specimens VP57–VP66 from minor sites nearby. VPL refers to the biggest rock slabs from ‘Via Pari Buca’ (VPB). A limited number of the most important and beautiful specimens already had a pre-existing inventory number of the MUNAP (e.g., 242601). For identifications, the historical paper of De Stefani (1901) entitled ‘Flore carbonifere e permiane della Toscana’ has been considered in combination with recent taxonomical papers. Quantitative analyses at genus level have been carried out on the assemblages coming from the two main sampling sites (‘Via Pari Buca’, ‘Via Pari Smottamento’), including poorly preserved and fragmented specimens. Parts and counterparts have been counted only once. The genera *Cyathocarpus* and *Diplazites* were clustered, since they were difficult to distinguish in the case of small and/or badly preserved pinnae fragments.

The specimens are stored at the Museo Naturalistico Archeologico dell'Appennino Pistoiese (=MUNAP) at Gavinana (Province of Pistoia). The museum is part of the natural itinerary of the Ecomuseo della Montagna Pistoiese, a widespread museum structure that illustrates the historical and natural peculiarity of the territory. For the age references we use the bio-chronostratigraphic charts proposed by Menning et al. (2003), Opluštil et al. (2016) and Schneider et al. (2020); all historical information has been translated to these terminologies.

SYSTEMATIC PALAEOLOGY

Class **LYCOPSIDA** Scott, 1909

Order **Lepidodendrales** Haeckel, 1868

Genus *Stigmaria* Brongniart, 1822

Type species: *Stigmaria ficoides* (Sternberg) Brongniart, 1822

Stigmaria sp.

Fig. 5a–b

Material: 242538, VP26 (Fig. 5a), VP221, VP226, VP282 (Fig. 5b), VPB21.

Description. The root fragments are preserved as casts, up to 280 mm long and 120 mm wide. They are characterized by delicate rhomboidal impressions (Fig. 5a) of up to 25 mm length and 7 mm width with a central circular thickening (with a diameter of 2–3 mm) of the attachment

scars of the stigmarian appendages (Fig. 5b). The rhomboidal scars and the abscission scars of the stigmarian appendices are arranged helically.

Remarks. *Stigmaria* is a morphogenus for Carboniferous lycopsid rooting organs that were found attached to different genera of stems. They are common in the fossil record and are often found *in situ* in the clay layers immediately below Carboniferous coal deposits (Taylor et al. 2009). Since only casts of the root systems were found so far, we cannot identify which genus and/or species of Lepidodendrales was present during the Carboniferous in Tuscany. *Stigmaria ficoides* (Sternberg) is represented by a rooting system with repeated equivalent dichotomies and helicoidally arranged circular scars and attached rootlets. Our specimens are too small to show the dichotomies, and although the root scars are helicoidally arranged, they do not preserve any rootlets. Moreover, our specimens show some rhomboedral scar traces, not present in the type species. They resemble in the size of the rootlet scars *Stigmaria evenii* Lesquereux, 1866, but they lack the regularly disposed, undulating ridges of the latter, while that species does not have any indications of rhomboidal impressions. The delicate rhomboedral scars suggest a *Lepidodendron*-like plant, which would support the presence of swampy conditions, at least for a certain time interval.

Several lycopsid taxa belonging to the genera *Lepidodendron*, *Lepidophyllum*, *Lepidostrobus*, *Sigillaria*, *Sigillariophyllum*, *Stigmaria* and *Syringodendron* were historically described from the Pisani Mts. and Iano (Supplementary Tab. 1, 2). More recently, Landi Degl'Innocenti et al. (2008) listed *Sigillaria* sp. from Monte Togi and *Lepidodendron* sp. from Villa Massagli. Arcangeli (1895) was so far the only one to mention species of *Stigmaria* from the Pisani Mts., i.e., *Stigmaria ficoides* (Sternberg) Brongniart, 1822 and *Stigmaria* cf. *evenii* Lesquereux, 1866.

Class **SPHENOPSIDA** Goebel, 1887

Order **Equisetales** Dumortier, 1829

Family Calamostachyaceae Meyen, 1978

Genus *Calamites* Brongniart, 1828 nom. cons.

Type species: *Calamites suckowii* Brongniart, 1828

***Calamites suckowii* Brongniart, 1828**

Fig. 5c

- 1828 *Calamites suckowii* Brongniart, p.124, pl. 14, fig. 6, pl. 15, figs. 1–6, pl. 16.
 1853 *Calamites suckowii* Brng. – Menghini, p. 5.
 1894 *Calamites suckowii* Brongn. – De Bosniaski, p. 168.
 1895 *Calamites suckowii* Brongniart – Arcangeli, p. 242.
 1901 *Calamites suckowii* Brongniart – De Stefani, p. 63–66, 115, pl. 10, figs. 3–4.
 1904 *Calamites suckowii* Brongniart – Barsanti, p. 23–24.
 1974 *Calamites* cf. *suckowii* Brongniart – Vai & Francavilla, 77.
 2008 *Calamites suckowii* Brongniart – Landi Degl'Innocenti, p. 553, 556, tab. 2.

Material: VP160, VP169, VP184, VP250, VP251 (Fig. 5c).

Description. The stem fragments are preserved as permineralized casts of the external surface and the vascular bundles. The stem fragments are up to 330 mm long and 30–90 mm wide. The internodes are up to 75 mm long, sometimes very short (5 mm), in general getting more reduced towards the base of the stem. In at least one specimen the stem appears slightly curved (VP184), suggesting it to be a basal stem fragment. The nodal areas show distinct leaf scars of circular-elliptical shape, 1.5–2.5 mm wide and 2–5 mm long (Fig. 5c). The straight carinal canals are up to 1 mm thick and 1.5–3.5 mm apart.

Remarks. The absence of branch scars in the stem fragments are characteristic for this species. *Calamites suckowii* is very common and widespread in the Euramerican coalfields, where it occurs throughout most of the Pennsylvanian. Our specimens differ from *Calamites carinatus* Sternberg, 1825, *Calamites cruciatus* (Sternberg) Brongniart, 1828 and *Calamites multiramis* Weiss, 1884 because of the missing branch scars. They can be distinguished from *Calamites carinatus* and *Calamites undulatus* Sternberg, 1825 because of the distinctively undulating carinal canals in those species. In *Calamites cistii* Brongniart, 1828 the carinal canals are up to 1 mm broad and occur at up to 2 mm distance.

The species is well known from the Carboniferous of the Pisani Mts. and Iano (Supplementary Tab. 1, 2; De Bosniaski 1894; Arcangeli 1895; De Stefani 1901; Barsanti 1904; Vai & Francavilla 1974). Landi Degl'Innocenti et al. (2008) mention *Calamites suckowii* only from the locality Traina in the Carboniferous of Tuscany.

***Calamites cistii* Brongniart, 1828**

Fig. 5d–f

- 1828 *Calamites cisti* Brongniart, p. 129, pl. 20.
 1853 *Calamites cisti* Brng. – Menghini, p. 5.

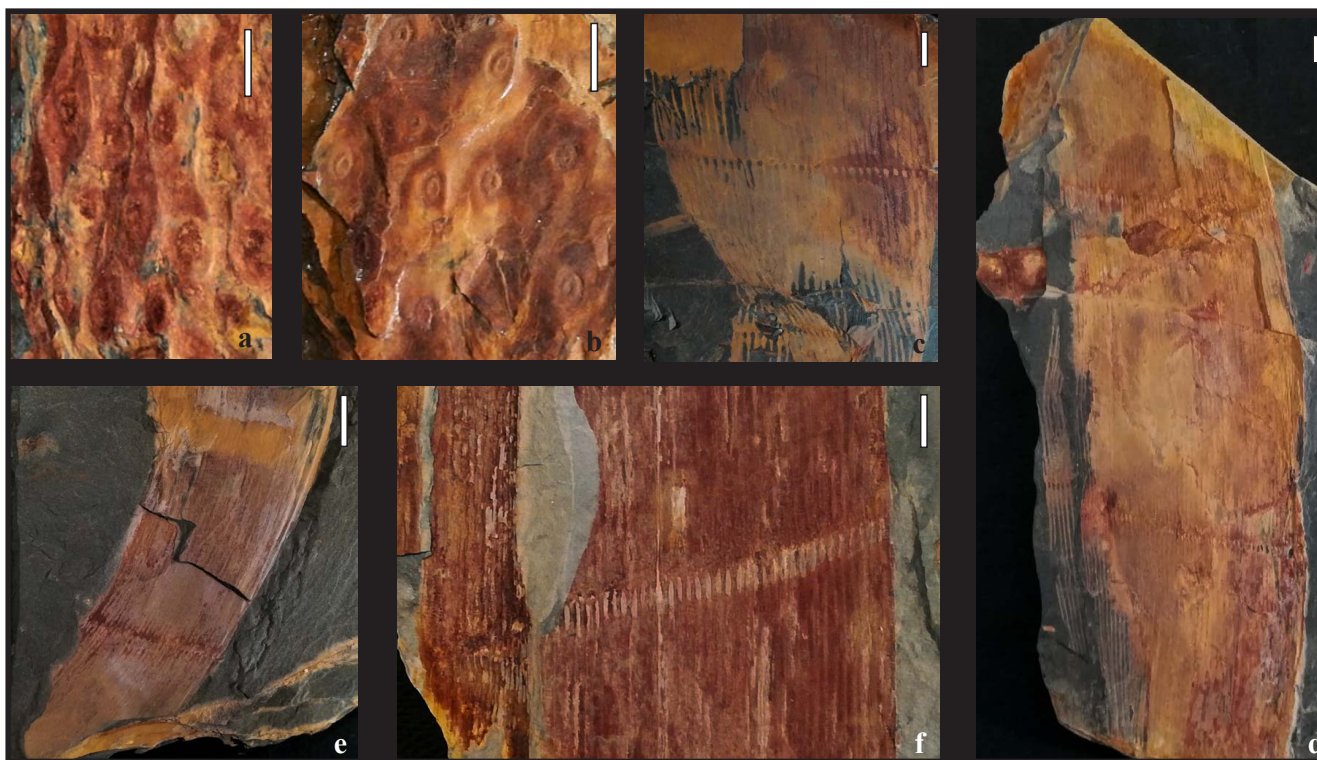


Fig. 5 - a) Root fragment of *Stigmaria* sp. with rhomboidal impressions of the attachment scars of the stigmarian appendages (VP26); b) Root fragment of *Stigmaria* sp. with central circular thickenings of the attachment scars of the stigmarian appendages (VP282); c) Stem fragment of *Calamites suckowii* Brongniart with node showing roundish to elliptical leaf scars (VP251); d) Stem fragment of *Calamites cistii* Brongniart (VPB13); e) Stem fragment of *Calamites cistii* Brongniart curved in the basal part (VP30); f) Nodal areas with elongated leaf scars of *Calamites cistii* Brongniart (VP132B). All scale bars = 1 cm.

- 1890 *Calamites cisti* Ad. Br. – De Bosniaski, p. 187, 190.
 1894 *Calamites cisti* Brongniart – De Stefani, p. 181.
 1894 *Calamites leioderma* Gutb. – De Stefani, p. 182.
 1895 *Calamites cisti* Brongniart – Arcangeli, p. 242.
 1895 *Calamites leioderma* Gutb. – Arcangeli, p. 242.
 1901 *Calamites leioderma* von Gutbier – De Stefani, p. 66–69, 115, pl. 9, fig. 9, pl. 10, fig. 1.
 1901 *Calamites heeri* De Stefani, p. 70–71, 115, pl. 3, fig. 10, pl. 10, fig. 2.
 1904 *Calamites cisti* Brongniart – Barsanti, p. 16, 24–26, 35.
 1974 *Calamites cisti* Brongniart – Vai & Francavilla, 77.
 2008 *Calamites cistii* Brongniart – Landi Degl’Innocenti, p. 553, tab. 2.
 2008 *Calamites leioderma* von Gutbier – Landi Degl’Innocenti, p. 553, tab. 2.

Material: 242539, 242597, VP30 (Fig. 5e), VP132A/B (Fig. 5f), VP165, VP180, VPB13 (Fig. 5d), VPL1.

Description. The stem fragments are preserved as permineralized impressions. They are up to 420 mm long, 35–125 mm wide and divided into nodes and internodes (Fig. 5d). The internodes are 40–150 mm long, narrowing towards the base of the stem. In at least one specimen (Fig. 5e) the stem curves slightly, suggesting it to be a basal stem fragment. The nodes are slightly restricted or undefined. The carinal canals are straight and narrow,

less than 1 mm thick and closely inserted (1–2 mm). Most nodal areas do not show distinct leaf scars; when present (Fig. 5f) they are elongated in shape, 1 mm wide and 3–5 mm long.

Remarks. Sphenophyte stems with straight and densely spaced carinal canals are assigned to this long-ranging species. Thus, it can easily be distinguished from all species with undulating carinal canals like *Calamites carinatus* and *Calamites undulatus*. The missing branch scars distinguish it from species like *Calamites carinatus*, *Calamites cruciatus* and *Calamites multiramis* Weiss, 1884.

This species is present in most of the Euramerican coalfields, where it occurs throughout most of the Pennsylvanian. Landi Degl’Innocenti et al. (2008) mention *Calamites cistii* only from the locality Traina in the Carboniferous of Tuscany. This species is actually well represented in the plant assemblages of Tuscany (Supplementary Tab. 1, 2), but has been mentioned either as *Calamites cistii* (De Bosniaski 1890; Arcangeli 1895; De Stefani 1901; Barsanti 1904; Vai & Francavilla 1974) or as *Calamites leioderma* von Gutbier, 1849 (De Stefani 1894;

Arcangeli 1895; De Stefani 1901). The latter has been mentioned also from Valentona, Monte Togi, Traina and Monte Vignale (Landi Degl'Innocenti et al. 2008). *Calamites leioderma* is a junior synonym of *Calamites cistii* Brongniart, 1828 (Sterzel 1886; Jongmans 1915). Moreover, Jongmans (1915) considered the specimens of De Stefani (1901, pl. 9, fig. 9; pl. 10, fig. 1) as not determinable.

Genus *Calamostachys* Schimper, 1880
Type species: *Calamostachys typica* Schimper, 1880

***Calamostachys* sp.**

Fig. 6a

Material: VP42 (Fig. 6a).

Description. The cone fragment with an articulated axis is 50 mm long and 5 mm wide. Nodes are present at a distance of about 3 mm. Lanceolate, arch-like bracts of unknown number are attached perpendicularly to the axis. Each sporophyll is 4 mm long and 1–2 mm wide (Fig. 6a).

Remarks. The specimen is too badly preserved for any species determination. De Bosniaski (1894) mentioned *Calamostachys typica* from the Pisani Mts., whereas Vai & Francavilla (1974) mention *Calamostachys* sp. from the Iano area (Supplementary Tabs. 1, 2).

Genus *Asterophyllites* Brongniart, 1828 nom. cons.
Type species: *Asterophyllites equisetiformis* (Schlotheim ex Sternberg) Brongniart, 1828

***Asterophyllites equisetiformis* (Schlotheim ex Sternberg) Brongniart, 1828**

Fig. 6b

- 1820 *Casuarinites equisetiformis* Schlotheim, p. 397.
1828 *Asterophyllites equisetiformis* (Schlotheim) – Brongniart, p. 159.
1894 *Asterophyllites equisetiformis* Schlot. – De Stefani, p. 181–182.
1895 *Asterophyllites equisetiformis* Schb. – Arcangeli, p. 242.
1901 *Asterophyllites equisetiformis* (Schlotheim) – De Stefani, p. 82–84, 115, pl. 7, figs. 2–3.
1904 *Asterophyllites equisetiformis* Schlot. – Barsanti, p. 8, 27–28, 35.
2008 *Asterophyllites equisetiformis* (Schlotheim) De Stefani – Landi Degl'Innocenti, p. 553, tab. 2, Pl. 1c.

Material: VP27A/B, VP74 (Fig. 6b).

Description: The leafy shoot fragments are up to 100 mm long and 2–3 mm wide. The internodes are 5–10 mm long. The leaf sheets are inserted at nodal level and composed of 12–14 leaves.

The leaves are linear to elongated lanceolate with a pointed apex and bend towards the apex. They are 10–25 mm long and less than 1 mm wide within a single whorl; the maximum width is reached around the middle of the leaf length (Fig. 6b).

Remarks. The linear to elongated lanceolate shape with a pointed apex bent upwards of the leaves is typical for this species. It differs from *Annularia stellata* (Schlotheim) Wood, 1860 because of the shorter internodes and the variable length of the leaves reaching its maximum width around the middle of the leaf length. It differs from *Asterophyllites spicatus* Weiss, 1870 because of the delicate structure of the latter and the lower number of leaves in each whorl. In *Asterophyllites charaeformis* (Sternberg) Göppert, 1844 the leaves are acicular, just slightly longer than the internodes, and curved sharply upwards to terminate in a position parallel to the internode. In *Asterophyllites grandis* (Sternberg) Geinitz, 1855 the stem is longitudinally distinctly striate, and the leaves are smaller, sickle-shaped and overlap slightly with the successive whorl. *Asterophyllites lindleyanus* Göppert, 1848 has smaller, more narrow and almost linear leaves, which bend upwards in the middle part of the leaf.

This stratigraphically long-ranging and geographically widespread taxon is known from most Pennsylvanian Euramerican coalfields. In Tuscany, it has been described both from the Pisani Mts. (Supplementary Tab. 1; De Stefani 1894; Arcangeli 1895; De Stefani 1901) and from Iano (Supplementary Tab. 2; De Stefani 1894; De Stefani 1901; Barsanti 1904). Landi Degl'Innocenti et al. (2008) list *Asterophyllites equisetiformis* from Valentona, Monte Togi, Traina and Monte Vignale in the Pisani Mts.

Genus *Sphenophyllum* Brongniart, 1822

Type species: *Sphenophyllum emarginatus* Brongniart, 1828

***Sphenophyllum oblongifolium* (Germar et Kaulfuss) Unger, 1850**

Fig. 6c–e

- 1831 *Rotularia oblongifolia* Germar et Kaulfuss, p. 225, pl. 65, fig. 3.
1850 *Sphenophyllum oblongifolia* Germar et Kaulfuss – Unger, p. 70.
1890 *Trizygia pteroides*. – De Bosniaski, p. 187, 190, fig. 3.
1890 *Trizygia speciosa*. – De Bosniaski, p. 187, 190, figs. 1–2.
1891 *Trizygia meneghiniana* De Stefani, p. 28.
1891 *Trizygia speciosa* R. – Canavari, p. 218.
1894 *Sphenophyllum oblongifolium* Germar et Kaulf. – De Stefani, p. 181–182.
1894 *Trizygia arcangeliana* De Bosniaski, p. 168.
1894 *Trizygia (Sphenophyllum) arcangeliana* De Bosniaski, p. 170.

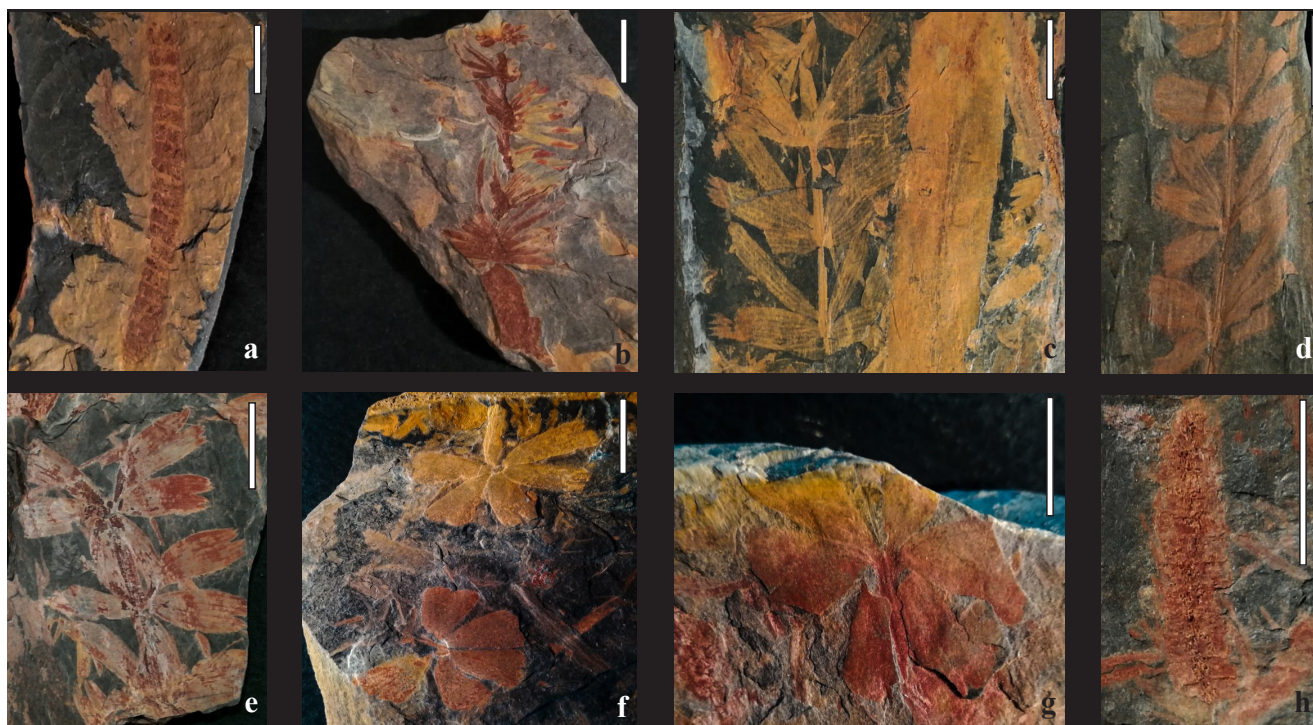


Fig. 6 - a) Strobilus fragment of *Calamostachys* sp. (VP42); b) Leafy axis fragment of *Asterophyllites equisetiformis* (Schlotheim ex Sternberg) Brongniart (VP74); c) Leafy axis fragments of *Sphenophyllum oblongifolium* (Germar et Kaulfuss) Unger (242536A); d) Leaf sheets with six leaves each whorl of *Sphenophyllum oblongifolium* (Germar et Kaulfuss) Unger (VPS6A); e) Leafy axis with leaves of *Sphenophyllum oblongifolium* (Germar et Kaulfuss) Unger characterized by terminal teeth and 4–6 veins each leaf (VP139); f) Leaf whorls of *Sphenophyllum verticillatum* (Schlotheim) Zeiller (VP69A); g) Detail of whorl of *Sphenophyllum verticillatum* (Schlotheim) Zeiller (VPB20) h) Strobilus fragment of *Bowmanites* sp. (VPB12). All scale bars = 1 cm.

- 1895 *Trizygia arcangeliana* Bosn. – Arcangeli, p. 242.
 1895 *Trizygia pteroides* Bosn. – Arcangeli, p. 242.
 1895 *Trizygia speciosa* Royle – Arcangeli, p. 242.
 1895 *Trizygia tenuifolia* White et Font. – Arcangeli, p. 242.
 1901 *Sphenophyllum oblongifolium* (Germar et Kaulfuss) – De Stefani, p. 84–87, 115, pl. 1, figs. 10, 15–16, pl. 12, figs. 4–7.
 2008 *Sphenophyllum oblongifolium* (Germar et Kaulfuss) De Stefani – Landi Degl Innocenti, p. 553, tab. 1–2, pl. 1, fig. e.

Material: 242536A/B (Fig. 6c), VP44, VP54, VP72A/B, VP139 (Fig. 6e), VP242, VP373A/B, VP374, VPS6A/B (Fig. 6d).

Description. The fragments of leafy axes (up to 45 mm long and 1 mm or less wide) bear up to five whorls of leaf sheets. The axis is up to 0.7 mm wide and divided into 10–12 mm long internodes (Fig. 6c). Each whorl is composed of up to six leaves (Fig. 6d). Two opposite pairs of leaves arise at an angle of 90°, whereas the third pair is arranged roughly parallel to the axis. Leaves are anisophyllous, trizygoid and terminate in small, pointed teeth at the leaf margin. The leaves are 6–22 mm long and 1–5 mm wide, with an incised apex. Four to six veins cross each leaf (Fig. 6e).

Remarks. Trizygoid architecture and anisophyllous leaves in whorls are typical features of *Sphenophyllum oblongifolium*. *Sphenophyllum oblongifolium*

differs from *Sphenophyllum verticillatum* in the pairing of the two opposite leaves and the presence of a third pair arranged parallel to the axis, as well as the pointed teeth at the leaf margin, which is incised. *Sphenophyllum cuneifolium* (Sternberg) Zeiller, 1880 has more deeply incised to lacerated bifid leaves. *Sphenophyllum priveticense* Libertin et al., 2014 has a wide heterophylly of leaves including leaves of the quadrifidum-type. The leaves are divided into two to four lobes, incised up to two-thirds of the length. In *Sphenophyllum myriophyllum* Crépin, 1966 the leaves are much more narrow and cuneiform, divided into four narrow lobes.

Sphenophyllum oblongifolium is common in late Pennsylvanian Euramerican coalfields and has its FAD (First Appearance Datum) at the base of the Kasimovian (Wagner 1984; Wagner & Álvarez-Vázquez 2010a). This species was already mentioned by De Stefani (1894, 1901) from the Pisani Mts. (Supplementary Tab. 1). To this species belong also various specimens previously assigned to *Trizygia pteroides* (De Bosniaski 1890; Arcangeli 1895), *Trizygia speciosa* (De Bosniaski 1890; Canavari 1891; Arcangeli 1895) and *Trizygia arcangeliana* (De Bos-

niaski 1894; Arcangeli 1895). Landi Degl'Innocenti et al. (2008) list *Sphenophyllum oblongifolium* from Valentona, Monte Togi, Traina, Monte Vignale and Sasso Campanaro.

Sphenophyllum verticillatum (Schlotheim)
Zeiller, 1885

Fig. 6f–g

1894 *Sphenophyllum verticillatum* (Schlot.) – De Stefani, p. 181.

Material: VP69A/B (Fig. 6f), VPB20 (Fig. 6g).

Description. The leaf whorls are nearly round with six leaves. The leaves are wedge-shaped and broaden distinctively from a narrow base. They are widest at the apex. The leaves are 10–12 mm long, up to 3 mm wide at the base and 4–9 mm wide at the apex. The distal margin is arcuate, with rounded teeth or slight undulations (Fig. 6f). The preservation is not good enough to distinguish veins clearly, but at least five veins on each leaf can be identified. The axes are badly preserved but are up to 2 mm wide.

Remarks. *Sphenophyllum verticillatum* differs from all heterophyllous taxa like *Sphenophyllum cuneifolium*, *Sphenophyllum oblongifolium*, *Sphenophyllum privetiscense* because of its isophyllous leaves and the slightly undulated margin that is, however, not deeply incised or lobated. It differs also from *Sphenophyllum emarginatum* Brongniart, 1822 because the latter has inverse ovoidal leaves with the margin being almost completely smooth or just slightly denticulated.

This species is a rare but widely distributed taxon of the Carboniferous. Remy & Remy (1959) suggested this species to be an index fossil for the Gzhelian in Western Europe. Wagner & Alvarez-Vázquez (2010a) documented it from the early Gzhelian of Spain. This species was described previously only by De Stefani (1894) from the Pisani Mts. (Supplementary Tab. 1).

Genus *Bowmanites* Binney, 1871

Type species: *Bowmanites cambrensis* Binney, 1871

***Bowmanites* sp.**

Fig. 6h

Material: VPB12 (Fig. 6h).

Description. The strobilus fragment is 15 mm long and 5 mm wide, with an axis of 1 mm

width. The axis is divided into nodes and internodes. At nodal level, modified leaves (sporophylls) arise almost perpendicularly from the axis (Fig. 6h).

Remarks. The poor preservation does not permit to distinguish details of the arrangement and number of the sporangia. Strobili of *Sphenophyllum*, similar to the ones described here, are historically referred to the genus *Sphenophyllostachys* Seward, 1896. However, Hoskins & Cross (1943) argued that *Bowmanites* Binney, 1871 has priority and should be used instead. In the Pisani Mts., De Stefani (1901) mentioned this taxon under the name *Sphenophyllum-stachys* (Supplementary Tab. 1).

Class **MARATTIOPSIDA** Doweld, 2001

Order **Marattiales** Link, 1833

Family Psaroniaceae Unger in Endlicher, 1842

Genus *Acitbeca* Schimper, 1879

Type species: *Acitbeca polymorpha* (Brongniart) Schimper, 1879

Acitbeca polymorpha (Brongniart) Schimper,
1879

Fig. 7a–e

- 1828 *Pecopteris polymorpha* Brongniart, p. 331, pl 113, figs. 1–4, 6.
1879 *Scolecopteris polymorpha* Schimper, p. 91, 119, figs. 1–3.
1891b *Scolecopteris polimorpha* Brongn. – De Stefani, p. 33.
1891c *Scolecopteris polimorpha* Brongn. – De Stefani, p. 27.
1894 *Acitbeca polymorpha* Brongn. – De Stefani, p. 182.
1895 *Pecopteris polymorpha* Brongn. – Arcangeli, p. 239.
1901 *Acitbeca polymorpha* (Brongniart) – De Stefani, p. 21–24, 115, pl. 5, fig. 2.
1901 *Acitbeca isomorpha* De Stefani, p. 24–28, 115, pl. 2, fig. 1, pl. 4, fig. 1–2, pl. 6, figs. 1–6.
1904 *Pecopteris polymorpha* Brongniart – Barsanti, p. 8, 11, 18–19, 35.
1974 *Pecopteris polymorpha* Brongniart – Vai & Francavilla, 77–78.
2008 *Pecopteris polymorpha* Brongniart – Landi Degl'Innocenti, p. 553, tab. 2.

Material: 242532A/B (Figs. 7c, e), 242533A/B (Figs. 7a–b), 242599A/B, 242603A/B, 242604A/B, VP2, VP31, VP106, VP133, VP240A/B, VP241, VP243, VP247, VP290, VPB11, VPB42A/B, VPB47, VPB49, VPB56, VPB60, VPL2 (Fig. 7d), VPL3A/B, VPL4, VPS29, VPS64.

Description. The species is characterized by large frond fragments with heterogeneous pinnule forms. The frond fragments are up to 500 mm long and 230 mm wide (Fig. 7a–b). From the penultimate rachis of 6–12 mm width arise, with an angle of 40–80°, lanceolate ultimate pinnae. They are more than 40 mm long and 10 mm wide, inserted alternately on the rachis with a distance of 20–25 mm at the base between the two ultimate rachises (Fig. 7a).

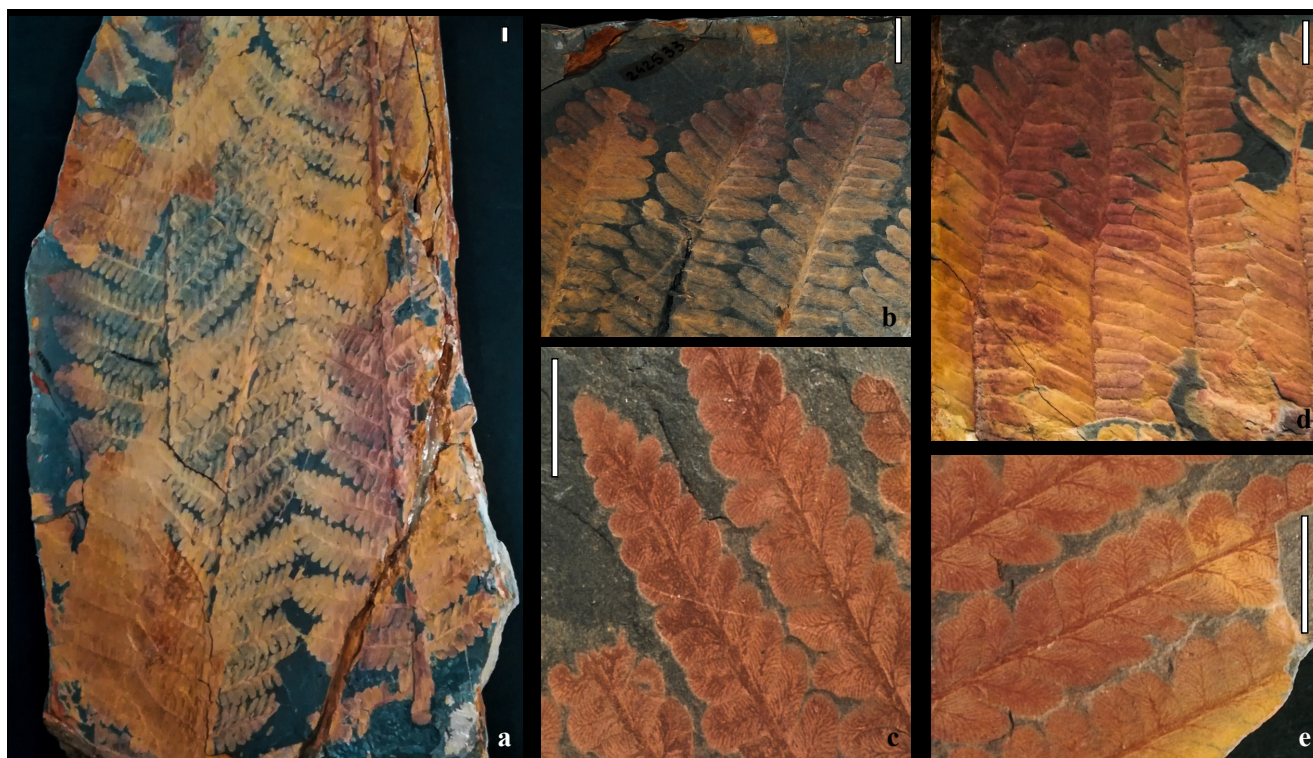


Fig. 7 - a) Frond fragment of *Acitbeca polymorpha* (Brongniart) Schimper (242533A); b) Detail of Fig. 6a, showing lanceolate ultimate pinnules of *Acitbeca polymorpha* (Brongniart) Schimper (242533A); c) Tongue-shaped apical pinnules of *Acitbeca polymorpha* (Brongniart) Schimper (242532A); d) Big and elongated basal pinnules of *Acitbeca polymorpha* (Brongniart) Schimper (VPL2); e) Pinnae fragment showing midvein and bifurcate lateral veins of the pinnules of *Acitbeca polymorpha* (Brongniart) Schimper (242532A). All scale bars = 1 cm.

Pinnules are attached alternately and closely spaced on the ultimate rachis (wide 1–2 mm), with the basiscopic pinnules being more elongate and more oblique than the acroscopic pinnules. The pinnules are tongue-shaped, with a rounded, obtuse subtriangular apex, 3–20 mm long and 2–8 mm wide. Apically, the pinnae and pinnules are attached with a smaller angle (40–60°), and the pinnules are of smaller size (3–7 mm long and 2–4 mm wide; e.g., Figs. 7c–e). Basal pinnules are bigger in size and more elongated (10–18 mm long and 4–8 wide mm; Fig. 7d). The midvein is straight to slightly curved and distinct (e.g., Figs. 7c, e). Lateral veins arise at an angle of 40–50° and bifurcate close to the midvein and sometimes a second time in the apical part, just before reaching the margin, giving origin to a polymorphopterid vein pattern (Figs. 7c, e).

Remarks. *Acitbeca polymorpha* is by far the species of *Acitbeca* with the highest intraspecific variability of the fronds. In *Acitbeca alii* Zodrow et al., 2006 the pinnules have a more obtuse and broader apex, and also the spores are different, although this could not be observed in our specimens. *Acitbeca ambigua* (Sternberg) Němejc, 1934 is distinguished

from *A. polymorpha* because the pinnules are distinctively larger, with a more broad apex and a lower vein density at the margin.

Acitbeca polymorpha is also the most widely reported species of the genus (Zodrow et al. 2006) and is widespread across the western palaeotropics. It extends in Europe from the Moscovian to the Gzhelian, with slight regional variations in its stratigraphic range. In central and southern France (one of the geographically closest areas), for example, it extends from the lowermost Kasimovian to the upper Gzhelian (Zodrow et al. 2006). This species has been described from Tuscany as *Scolecopteris polymorpha* (Brongniart) Stur, 1985 (De Stefani 1891a, 1891b) and *Pecopteris polymorpha* Brongniart, 1828 (Arcangeli 1895; Barsanti 1904; Vai & Francavilla 1974). This species includes also the remains described as *Acitbeca isomorpha* De Stefani, 1901 (De Stefani 1901) (Supplementary Tab. 1). Landi Degl'Innocenti et al. (2008) list this species from Traina and Monte Vignale.

Genus *Diplazites* Goepfert, 1836

Type species: *Diplazites emarginatus* Goepfert, 1836

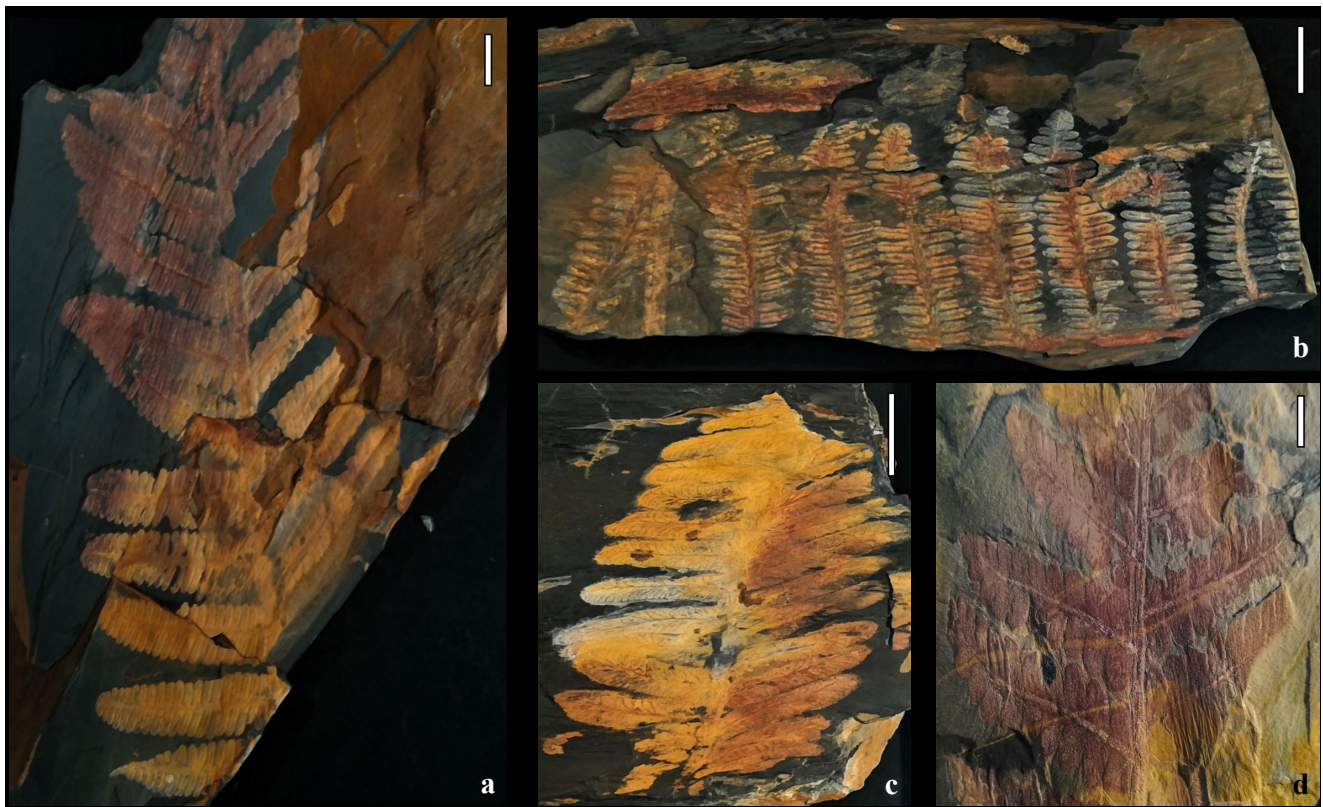


Fig. 8 - a) Frond fragment of *Diplazites unitus* (Brongniart) Cleal (VPS12X); b) Lanceolate ultimate pinnae with a slightly tapering lamina and a terminal pinnule of *Diplazites unitus* (Brongniart) Cleal (VPS2A); c) Basal tongue-shaped pinnules with an entire margin, midvein and bifurcate secondary veins of *Diplazites unitus* (Brongniart) Cleal (VPS6A); d) Pinnae of an apical frond fragment of *Diplazites unitus* (Brongniart) Cleal (242602B). All scale bars = 1 cm.

Diplazites unitus (Brongniart) Cleal, 2015

Fig. 8a–d

- 1835 *Pecopteris unita* Brongniart, p. 342, pl. 16, figs. 1–5.
 1853 *Aplophlebis arborescens* Menghini, p. 4.
 1890 *Pecopteris unita* Brngt. – De Bosniaski, p. 186, 189–190.
 1891b *Diplazites unitus* Brongn. – De Stefani, p. 33.
 1894 *Diplazites unitus* (Brongn.) – De Stefani, p. 181–182.
 1895 *Pecopteris unita* Brongn. – Arcangeli, p. 239.
 1901 *Diplazites unitus* (Brongniart) – De Stefani, p. 32–35, 115, 145–47, 165–167, pl. 3, figs. 1–6, pl. 6, fig. 10.
 1904 *Ptychocarpus unitus* (Brongn.) Weiss – Barsanti, p. 13–18, 21–23, 27, 35.
 1904 *Pecopteris unita* Brongn. – Barsanti, p. 8, 24, 39, 43, 54.
 2008 *Diplazites unitus* (Brongniart) De Stefani – Landi Degl'Innocenti, p. 553, tab. 2.

Material: 242601A/B, 242602A/B (Fig. 8d), VP62, VP298/BIS VP314A/B, VP336A/B, VP361, VP377A/B, VPB41A/B, VPS1A/B, VPS2A/B (Fig. 8b), VPS6A/C (Fig. 8c), VPS12A/B, VPS12X (Fig. 8a), VPS12Y, VPS14, VPS28, VPS38A/B, VPS40A/B, VPS56A/B, VPS57A/B, VPS59A/B, VPS68.

Description. The incomplete penultimate pinna fragments are up to 200 mm long and 70 mm wide, with a 1–6 mm wide penultimate rachis. Ultimate pinnae are lanceolate and of different dimensions (15–90 mm long and 5–35 mm wide), with a

slightly tapering lamina and a terminal pinnule (Figs. 8a–b). The ultimate rachis is up to 1 mm wide and arises with an angle of c. 40–60° or almost perpendicularly from the penultimate rachis. Pinnules are tongue-shaped, with an entire margin, 2–22 mm long and 1–5 mm wide. They arise at an angle of 45–55° (Fig. 8c). Adjacent pinnules are sometimes fused in their lowermost part. The distal part of the pinnules is always free. Pinnules are of different dimensions depending on their position on the leaves. The midvein is straight to slightly bent, secondary veins are slightly curved towards the midvein and bifurcate. Basal pinnules are much longer (up to 22 mm), with a slightly undulated margin, and the lateral veins bifurcate at least once or are fasciculate (Fig. 8c). In apical fragments (Fig. 8d) the pinnules are only 5–8 mm long and 3–4 mm wide, the veins are simple, and both ultimate pinnae and pinnules are attached with a smaller angle (respectively 30–40° and 25–35°).

Remarks. *Diplazites unitus* differs from *Diplazites emarginatus* Göppert, 1836 because of the fused pinnules of the last order, from *Diplazi-*

tes longifolium Göppert, 1836 because of the bigger and more elongated pinnules. The bigger basal pinnules are interpreted as a result of the fusion of the single pinnules. The fused forms of *Diplazites* become progressively more common in the latest Pennsylvanian and Permian floras. The genus ranges stratigraphically from the middle Moscovian to the Gzhelian (Cleal 2015). The species is well represented in the Carboniferous flora of the Pisani Mts. (Supplementary Tab. 1; e.g., De Stefani 1891, 1894, 1901), in some cases having been reported with its basionym *Pecopteris unita* Brongniart, 1836 (De Bosniaski 1890; Arcangeli 1895). De Stefani (1894, 1901) and Barsanti (1904, as *Pecopteris unita*) mention it also from Iano. Landi Degl'Innocenti et al. (2008) list this species from the fossiliferous localities Valentona, Monte Togi, Traina and Monte Vignale in the Pisani Mts. area.

Genus *Cyathocarpus* Weiss, 1869

Type species: *Cyathocarpus arboreus* (Sternberg) Weiss, 1869

Cyathocarpus arboreus (Sternberg) Weiss, 1869

Fig. 9a–d

- 1826 *Pecopteris arborea* – Sternberg, p. 18, pl. 1.
 1853 *Aplophlebis arborescens* Menghini, p. 4.
 1890 *Pecopteris arborescens* – De Bosniaski, p. 186, 189–190.
 1895 *Pecopteris arborescens* Sternb. – Arcangeli, p. 238.
 1894 *Cyathocarpus arborescens* (Schlot.) – De Stefani, p. 181.
 1901 *Cyathocarpus arborescens* (Schlotheim) – De Stefani, p. 13–17, 115, pl. 5, fig. 4.
 1904 *Asterotheca arborescens* (Schlot) Presl – Barsanti, p. 17, 21–22, 25–28, 30, 34.
 1974 *Pecopteris arborescens* (Schlotheim) – Vai & Francavilla, 77.
 2008 *Pecopteris arborescens* – Landi Degl'Innocenti, p. 550, tab. 1.

Material: VP331, VP347A/B, VP359A/B, VP372 (Fig. 9d), VPS4A/B (Figs. 9b, c), VPS37A/B (Fig. 9a).

Description. The penultimate pinnae fragments are more than 60 mm long and 80 mm wide. The penultimate rachis is 4–7 mm wide and has an irregular surface. Ultimate pinnae are inserted suboppositely to alternately with a distance between the attachment areas of adjacent pinnules of 7–8 mm. They are lanceolate, 25–65 mm long and 3–8 mm wide, basally parallel-sided, gradually tapering towards the apex. They are inserted on the penultimate rachis with an angle of almost 90° (Fig. 9a). The ultimate rachis is up to 1 mm wide, with an irregular surface. Pinnules are closely and subalternately inserted with basal margins touching (Figs. 9b, c). They are elongated rectangular to tongue-

shaped, c. 1.5–4 mm long and 1.5–4 mm wide, and have a rounded tip. The pinnules are attached with the entire base at an angle of 70–90°. The midvein is prominent, thick, extending almost up to the tip of the pinnules. Lateral veins are poorly preserved but appear to be simple or bifurcating once (Figs. 9b, c). Apical pinnules are smaller, more elongate and attached with a smaller angle (30–40°) to the rachis (Fig. 9d).

Remarks. The lectotype species of *Cyathocarpus* is often referred to as *Pecopteris arborescens* Schlotheim (1804). However, since it was described prior to the date accepted as the starting point for valid publications of plant fossil names (ICN, Art. 13.1), the earliest valid name is *Pecopteris arborea* Sternberg, 1825 (Mosbrugger 1983; Cleal 2015).

The specimens differ from most other species such as *Cyathocarpus cyatheus* (Brongniart) Mosbrugger, 1983, *Cyathocarpus lepidorachis* (Brongniart) Mosbrugger, 1983 and *Cyathocarpus candolleanus* (Brongniart) Weiss, 1869 due to the simple pinnule venation, the generally smaller pinnule size and the long pinnae with a pointed terminal pinnule. It differs from *Cyathocarpus daubreei* (Zeiller) De Stefani, 1901 due to the smaller pinnules and pinnae and the imbricating pinnules in the latter species. *Cyathocarpus hemitelioides* (Brongniart) Mosbrugger, 1983 also has a simple pinnule venation but its pinnules are distinctively bigger (with a length/width ratio of 2.5–3). *Cyathocarpus reptangulus* De Stefani, 1901 is characterized by a more rectangular shape of the pinnules and the much longer and more apically inclined pinnae of this species.

De Bosniaski (1890) and Arcangeli (1895) described this species under the name *Pecopteris arborescens* from the Pisani Mts. (Supplementary Tab. 1). De Stefani (1894, 1901) described *Cyathocarpus arborescens* from the area of Iano, as well as Barsanti (1904) and Vai & Francavilla (1974), who mentioned it as *Pecopteris arborescens* (Supplementary Tab. 2).

Cyathocarpus daubreei (Zeiller) De Stefani, 1901

Fig. 9e–f

- 1894 *Cyathocarpus daubreei* Zeiller – De Stefani, p. 181–182.
 1901 *Cyathocarpus daubreei* (Zeiller) – De Stefani, p. 20–21, 115, pl. 8, figs. 7–8, pl. 1, fig. 5.
 2008 *Cyathocarpus daubreei* (Zeiller) De Stefani – Landi Degl'Innocenti, p. 553, tab. 2, pl. 1, fig. b.

Material: VP36, VP136A/B, VP343A/B (Fig. 9e), VP378 (Fig. 9f).

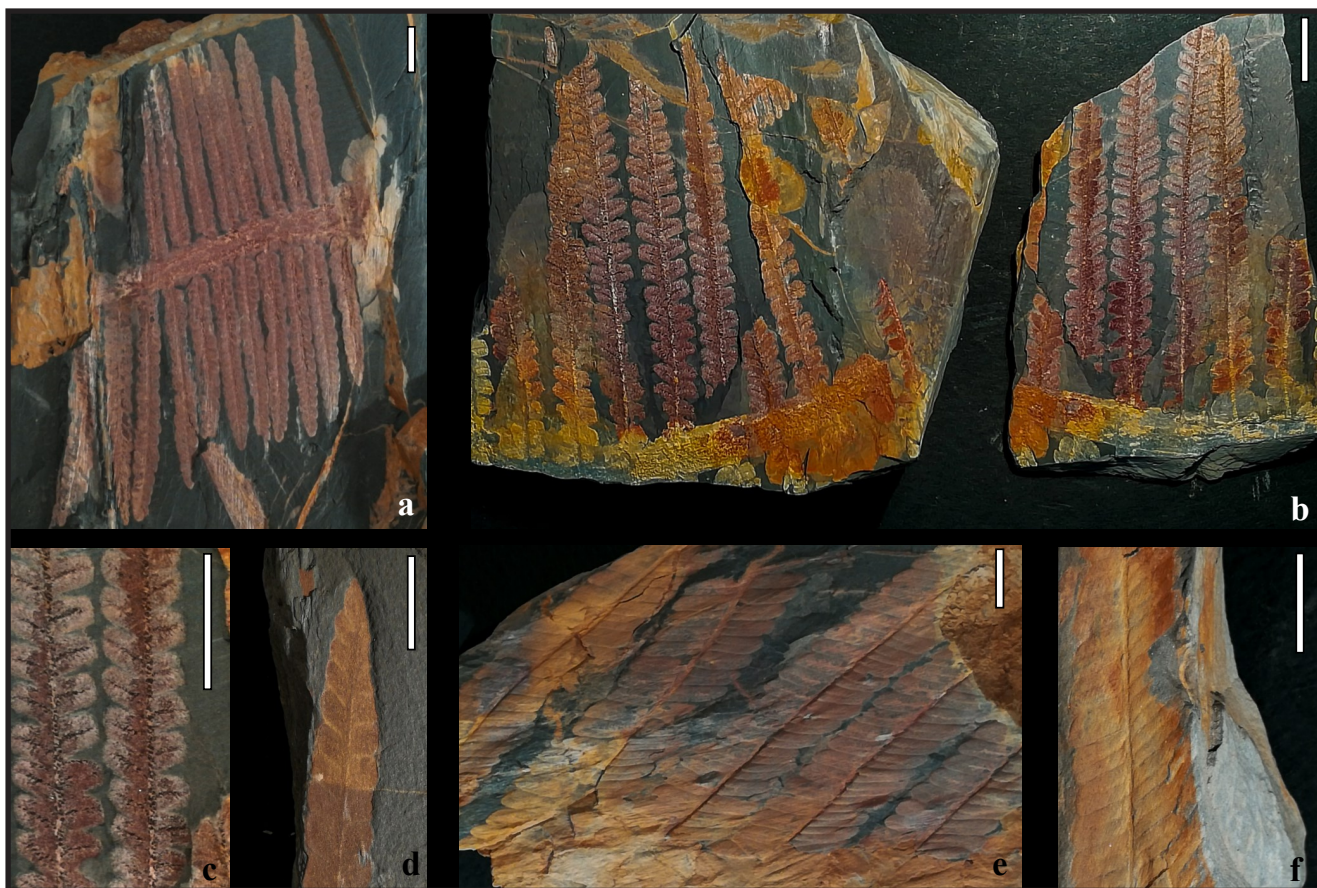


Fig. 9 - a) Frond fragment of *Cyathocarpus arboreus* (Sternberg) Weiss with ultimate pinnae attached sub-oppositely to the rachis (VPS37A); b) Ultimate pinnae of *Cyathocarpus arboreus* (Sternberg) Weiss with elongated rectangular to tongue-shaped pinnules (VPS4A/B); c) Pinnae fragments of *Cyathocarpus arboreus* (Sternberg) Weiss showing the prominent, thick midvein (VPS4A/B); d) Small apical pinnules of *Cyathocarpus arboreus* (Sternberg) Weiss (VP372); e) Linear ultimate pinna fragments of *Cyathocarpus daubreii* (Zeiller) De Stefani (VP343A); f) Linear pinnule fragment with parallel margins and prominent midvein of *Cyathocarpus daubreii* (Zeiller) De Stefani (VP378). All scale bars = 1 cm.

Description. The pinnae fragments are up to 100 mm long and 105 mm wide. The main rachis is up to 10 mm wide. Ultimate pinnae are linear, up to 90 mm long and 28 mm wide. They are inserted alternately with a distance between the attachment areas of adjacent pinnules of 15–22 mm. The ultimate rachis is 1 mm wide. Pinnules are linear, with parallel margins and a truncate to rounded apex (Fig. 9e). They are 5–14 mm long, 2.5–6 mm wide, and attached with the entire base alternately at an angle of 80–90°. The midvein is prominent, extending almost up to the tip of the pinnules. Lateral veins are poorly preserved but appear to be simple or bifurcating once (Fig. 9f).

Remarks. These specimens differ from other species of this flora due to its more elongated and imbricate pinnules. They differ from *Cyathocarpus arboreus* and *Cyathocarpus hemitelioides* because the veins in these two species are simple and from *Cyathocarpus candolleanus* because in the latter the veins can be twice

forked. *Cyathocarpus cyatheus* and *Cyathocarpus lepidorachis* have once forked veins like our specimens, but their pinnules are much longer (reaching a length/width ratio of more than 3) and the pinnules' bases are constricted. In *Cyathocarpus lepidorachis* the pinnules are about the same length but much less wide.

Cyathocarpus is a long-ranging genus that extended in Euramerica from the middle Moscovian to the Kungurian (Sun et al. 2019). De Stefani (1894, 1901) described this species from Valentona, Monte Togi, Traina and Monte Vignale (Landi Degl'Innocenti et al. 2008).

Cyathocarpus reptangulus De Stefani, 1901

Fig. 10a–b

1901 *Cyathocarpus reptangulus* De Stefani, p. 17–18, 115, pl. 1, figs. 1–4.

Material: VP357A/B (Figs. 10b), VPS5A/B/C (Fig. 10a), VPS27.

Description. The pinnae fragments are up to 180 mm long and 100 mm wide with a 4–10 mm wide rachis. Ultimate pinnae are linear, 50–120 mm long and 8–18 mm wide. They are inserted alternately with a distance between the attachment areas of adjacent pinnules of 10–18 mm. The ultimate rachis is 1 mm wide. Pinnules are linear, with parallel margins and a rounded apex (Fig. 10a). They are 4–8 mm long, 1–4 mm wide, and attached with the entire base alternately at an angle of almost 90°. The midvein is prominent, extending almost up to the tip of the pinnules. Lateral veins are poorly preserved, but appear to be simple or bifurcating once (Fig. 10b).

Remarks. These specimens differ from other species of this flora due to their linear pinnules with a parallel margin and rounded apex giving them a rectangular shape, and the relatively longer, linear ultimate pinnae. The pinnules are bigger than those of *Cyathocarpus arboreus* and *Cyathocarpus daubreei*. The length/width ratio is around 2 in our species, and distinguishes the specimens from those of species that bifurcate once but have a length/width ratio of more than 3 like *Cyathocarpus lepidorachis*, *Cyathocarpus cyathens* and *Cyathocarpus candolleanus*.

This species is so far only known from the Carboniferous of the Pisani Mts. (Supplementary Tab. 1; De Stefani 1901). Landi Degl'Innocenti et al. (2008) list this species from Valentona, Traina and Monte Vignale. Jongmans & Dijkstra (1963) suggest that the species should rather be assigned to the genus *Pecopteris*, without formally transferring it.

Class **PTERIDOSPERMOPSIDA**

Order **Medullosales** Corsin, 1960

Family Alethopteridaceae (Corsin) emend. Cleal et Shute, 2003

Genus *Alethopteris* Sternberg, 1825

Type species: *Alethopteris lonchitidis* Sternberg, 1825

Alethopteris sp. 1

Fig. 10c–e

Material: VP297, VP307A/B, VP311, VP312, VP315, VP318, VP371, VPS3, VPS25A/B (Fig. 10d), VPS34, VPS42, VPS48A/B (Fig. 10e), VPS62A/B (Fig. 10c).

Description. The frond fragments are up to 60 mm long and 90 mm wide (Figs. 10c–d), with a 2–8 mm wide rachis. The pinnae arise subalternately to alternately with an angle of 40–50° or almost per-

pendicularly and at a distance of 6–15 mm between the attachment areas of individual pinnae. The pinnae are lanceolate, slightly tapering towards the apex, up to 70 mm long and 15 mm wide. The rachis is 1 mm wide (Fig. 10e). The pinnules are subtriangular to lanceolate (2–12 x 2–9 mm), with a slightly rounded apex (Fig. 10e). They are attached with an angle of 30–45° and sub-alternately, with a decurrent base to the rachis. The midvein is delicate, extending for at least 2/3 of the lamina. The secondary veins arise at an acute angle and bifurcate sometimes halfway to the margin.

Remarks. The preservation is not well enough for any assignment at species level. *Alethopteris* sp. 1 differs from *Alethopteris* sp. 2 and *Alethopteris* sp. 3 because of the bigger, tongue-shaped to lanceolate pinnae of the latter, the distinct midvein that extends almost to the apex and the secondary veins arising almost perpendicularly. *Alethopteris bohemia* Franke, 1912 differs due to the bigger pinnules and the distinct, wide midrib, as well as the high number of secondary veins that bifurcate once or twice. Slender but linguiform pinnules distinguish *Alethopteris leonensis* Wagner, 1959 from our specimens, although the midvein is distinct and straight in both species. *Alethopteris zeilleri* (Ragot) Wagner, 1964 has bigger pinnae and bigger, linguiform pinnules with a more rounded apex.

De Stefani (1901) described two *Alethopteris* species from the Carboniferous of Tuscany; *Alethopteris florentina* De Stefani, 1901 from Iano and *Althopteris grandini* (Brogniart) Zeiller, 1888 from Monte Vignale. It is unclear whether the former is actually an *Alethopteris* species since it misses the typical decurrent or flared base on the lower side. The specimens are too poorly preserved to be confidently assigned to the latter species. Our specimens have in common with *Alethopteris serlii* (Brongniart) Göppert, 1836 the delicate midrib, but they are much smaller and do not show the typical biconvex lateral margin of the latter species. Moreover, the lateral veins arise at an acute angle from our specimens but are attached perpendicularly in *Alethopteris serlii*.

Alethopteris sp. 2

Fig. 11a–b

Material: VP54, VPB6, VPB55A/B (Figs. 11a–b), VPL7.

Description. The leaf fragments are up to 220 mm long and 180 mm wide. The rachis is 3–10

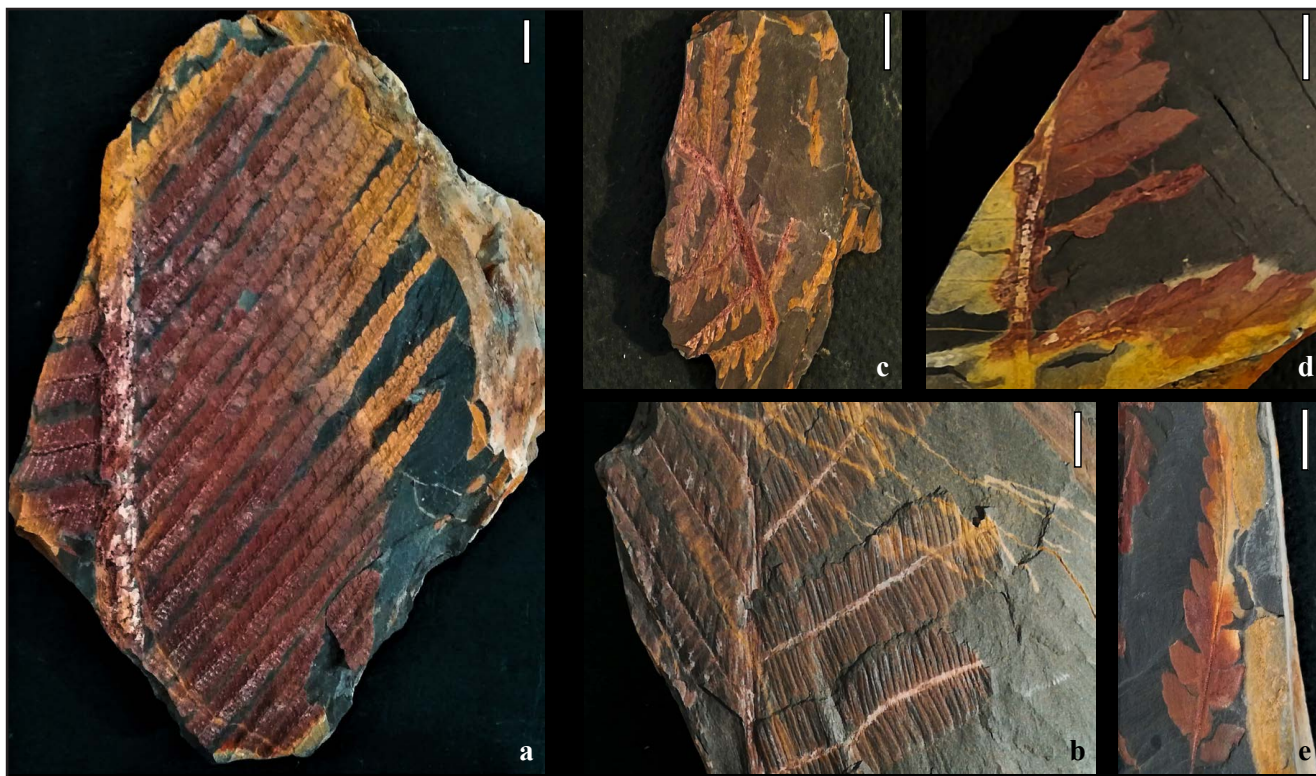


Fig. 10 - a) Frond fragment with linear ultimate pinnae of *Cyatbocarpus reptangulus* (De Stefani) (VPS5A); b) Ultimate asymmetrical pinnae of *Cyatbocarpus reptangulus* (De Stefani) with linear pinnules with parallel margins (VP357A); c) Apical frond fragment of *Alethopteris* sp. 1 (VPS62A); d) Apical frond fragment with subalternate to alternate ultimate pinnae of *Alethopteris* sp. 1 (VPS25B); e) Lanceolate ultimate pinnae and subtriangular to lanceolate pinnules of *Alethopteris* sp. 1 (VPS48A). All scale bars = 1 cm.

mm wide (Figs. 11a–b). The pinnae are linear to lanceolate, up to 100 mm long and 28 mm wide. They arise from the main rachis with an angle of 50–65° or almost perpendicularly and at a distance of 11–25 mm between the attachment areas. The pinnules are tongue-shaped to lanceolate, with a slightly rounded apex (6–17 long and 3–7 mm wide). They are inserted slightly apically inclined and subalternately, with a decurrent basis (Fig. 11b). The midvein is distinct, extending almost to the apex; the secondary veins arise almost perpendicularly and bifurcate sometimes halfway to the margin (Fig. 11b).

Remarks. The preservation is not well enough for any assignment at species level. *Alethopteris* sp. 2 differs from *Alethopteris* sp. 1 and *Alethopteris* sp. 3 because of the smaller, subtriangular to lanceolate pinnae, the delicate midvein and the secondary veins arising at an acute angle in the latter species. In *Alethopteris bohémica* the midrib is more distinct and wide, and the secondary veins bifurcate at least once but sometimes twice. *Alethopteris zeilleri* has distinctively bigger pinnae and pinnules, linguiform in shape and basally fused. The epidermal structure, which is often used to compare the

various species (e.g., Barthel 1983; Kerp & Barthel 1983), cannot be used in our case since our specimens do not preserve any cuticles. The midrib is also distinct in *Alethopteris lonchitica* Sternberg, 1825 but the pinnules are more narrow and the lateral veins are tripartite or forked twice. The dimension of the pinnules resembles slightly *Alethopteris pseudograndinioides* Zadow et Cleal, 1998 but does not show the biconvex lateral to parallel margins and the broadly arching lateral veins.

De Stefani (1901) described two *Alethopteris* species from the Carboniferous of Tuscany; *Alethopteris florentina* and *Althopteris grandini*. Neither resembles the specimens described here, although the latter are too poorly preserved to be assigned to any species.

Alethopteris sp. 3

Fig. 11c–e

Material: VP140 (Figs. 11c–e).

Description. The apical leaf fragment (180 x 70 mm) is linear to slightly spatulate with a rapid-

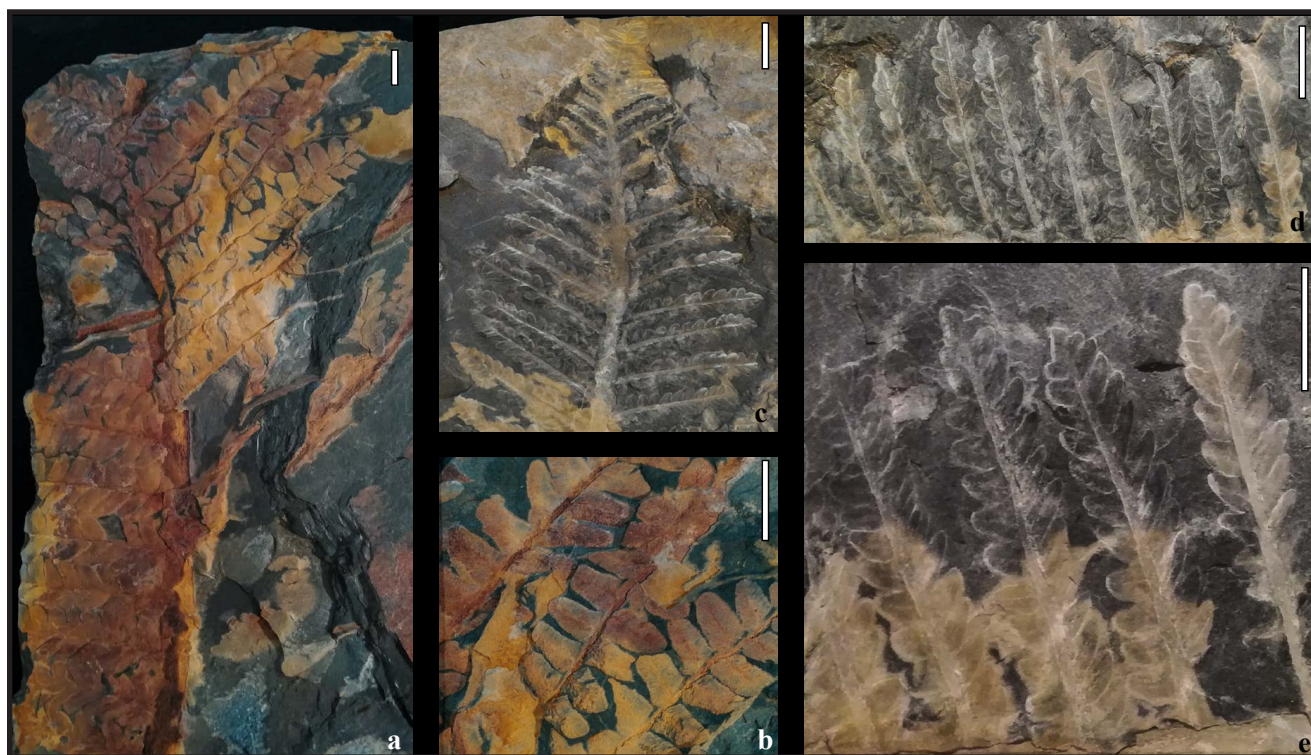


Fig. 11 - a) Frond fragment of *Alethopteris* sp. 2 with linear to lanceolate ultimate pinnae (VPB55A); b) Tongue-shaped to lanceolate pinnules of *Alethopteris* sp. 2 with a slightly rounded apex and prominent midvein (VPB55A); c) Apical frond fragment of *Alethopteris* sp. 3 (VP140); d) Detail of Fig. 10c with linear ultimate pinnae (VP140); e) Detail of Fig. 10c with triangular pinnules with a rounded apex (VP140). All scale bars = 1 cm.

ly reducing apex. The rachis is stout, slightly curved, 1–8 mm wide. The pinnae are inserted suboppositely, with an angle of 70–80° and at a distance of 6–10 mm between the attachment areas. The pinnae are linear in shape, 25–38 mm long and 5–8 mm wide, with a terminal pinna and a 1 mm thick rachis (Figs. 11c–e). The pinnules are inserted oppositely to suboppositely with an angle of 45–50°. They are triangular in shape, with a rounded apex. The midvein is visible in some parts of the specimen. Secondary veins cannot be distinguished due to preservation (Figs. 11c–e).

Remarks. Although the preservation does not permit to distinguish details that would be necessary in order to classify the specimen at species level, it differs well enough from the other two *Alethopteris* species to assign it to a different taxon. It resembles slightly *Alethopteris florentina* De Stefani, 1901 (De Stefani 1901; pl. 4, figs. 9, 11) but the pinnules are much smaller in the latter form. The pinnae are much shorter than in *Alethopteris* sp. 1 and *Alethopteris* sp. 2. The pinnules are subtriangular to lanceolate with a delicate midvein and secondary veins arising at an acute angle in *Alethop-*

teris sp. 1 and tongue-shaped to lanceolate with a distinct midvein extending almost to the apex and secondary veins arising almost perpendicularly in *Alethopteris* sp. 2. In *Alethopteris* sp. 3 the midrib is visible only in some of the specimens and the secondary veins are not visible at all. The missing pattern of the secondary veins makes it difficult to compare this species with most known species.

Order **Peltaspermales** Taylor, 1981

Family Peltaspermaceae Pilger et Melchior in
Melchior et Werdermann, 1954

Genus *Autunia* Krasser, 1919 emend. Kerp, 1988

Type species: *Autunia milleryensis* (B. Renault) F. Krasser, 1919

?*Autunia* sp. 1

Fig. 12a–b

Material: VP342A/B (Figs. 12a–b).

Description. The leaf fragments are up to 60 mm long and 185 mm wide. The primary rachis is robust, 8 mm wide. The pinnae are up to



Fig. 12 - a) Frond fragment with robust primary rachis of *?Autunia* sp. 1 (VP342A); b) Detail of Fig. 11a showing tongue-shaped to triangular pinnules with a thick lamina (VP342A); c) Frond fragment with primary rachis of Gen indet sp. indet. (VPB33); d) Tongue-shaped to linear pinnae inserted with a very acute angle on the rachis of Gen indet sp. indet. (VPB25A); e) Overlapping pinnae of Gen indet sp. indet. (VPB36). All scale bars = 1 cm.

145 mm long and 18 mm wide, with a thick rachis (Figs. 12a–b). They are attached oppositely to suboppositely to the primary rachis. The pinnules are tongue-shaped to triangular, with a thick lamina. They arise at 90° or with a slightly more acute angle (Figs. 12a–b). The midvein is distinct, lateral veins are not distinguishable. Between the single pinnae arise small intercalary pinnules from the main rachis, 8–11 mm in length and 5–10 mm in width.

Remarks. The polymorphic genus *Autunia* is one of the most characteristic uppermost Carboniferous to lower Permian elements, but has a complex taxonomic history (for more details see Kerp 1988; Kerp & Haubold 1988a, 1988b and references therein). Thus, its unequivocal presence and a determination at species level would be important for the age assignment of the plant assemblage. However, the specimen is small and the intercalary pinnules are barely visible. Thus, the assignment to this taxon remains questionable for the moment.

Gen indet sp. indet.

Fig. 12c–e

Material: VP170, VPB24A/B, VPB25A/B (Fig. 12d), VPB26, VPB27, VPB28, VPB29A/B, VPB30, VPB31, VPB32, VPB33 (Fig. 12c), VPB35, VPB36 (Fig. 12e), VPB37, VPB38, VPB39.

Description. The leaf fragments are up to 120 mm long and 85 mm wide. The primary rachis is only rarely preserved, up to 5–10 mm wide (Fig. 12c). The pinnae fragments are up to 85 mm long and 20 mm wide, with a 1 mm wide rachis. They are inserted at an angle of 40° or almost perpendicularly on the main rachis, with a distance of 9–20 mm between the single pinnae. The pinnules are inserted with a very acute angle (30–40°) on the rachis of the pinnae, touching (Fig. 12d) or overlapping each other (Fig. 12e). They are 8–20 mm long and 3–5 mm wide, tongue-shaped to linear, with a rounded apex. Neither the midvein nor the secondary veins are visible.



Fig. 13 - a) Leaf fragment of *Cordaites* sp. (242537B); b) Leaf fragment of *Cordaites* sp. (VPB3B); c) Restricted leaf basis of *Cordaites* sp. (VPB3A); d) Leaf fragment of *Cordaites* sp. showing parallel veins (VP260); e) Seed of roundish to elliptical shape assigned to *Carpolithes* sp. (VP157); f) Seed of roundish to elliptical shape assigned to *Carpolithes* sp. (VP97). All scale bars = 1 cm.

Remarks. Kerp (1988, pl. 17, figs. 1–5) showed small fronds of *Autunia conferta* Krasser, 1918 emend. Kerp, 1988 with similarly overlapping pinnules and pinnae. This would suggest that the specimens could represent some young seed fern leaves. However, the immaturity of the leaves does not permit to identify the taxon they belong to.

Class **PINOPSIDA** Burnett, 1835

Order **Cordaitanthales** Meyen, 1984

Family Cordaitanthaceae Meyen, 1984

Genus *Cordaites* Unger, 1850

Type species: *Cordaites borassifolius* (Sternberg) Unger, 1850

Cordaites sp.

Fig. 13a–d

Material: 242537A/B (Fig. 13a), VP173, VP239, VP260 (Fig. 13d), VP297, VPB3A/B (Fig. 13b, c), VPB4.

Description. The leaf fragments are up to 400 mm long (Figs. 13a–b). The basis is restricted (Fig. 13c), 12 mm wide. The leaves can reach a maximum width of 90 mm; the most common range is

20–40 mm. Veins are parallel and venation density is up to more than 20 veins per centimetre (Fig. 13d).

Remarks. The specimens are undeterminable at species level because they are missing apices and cuticles.

GYMNOSPERMAE indet.

Genus *Carpolithes* Brongniart, 1822

Type species: *Carpolithes thalictroides* Brongniart, 1828

Carpolithes sp.

Fig. 13e–f

Material: VP97 (Fig. 13f), VP157 (Fig. 13e).

Description. The compressed seeds are roundish to elliptical in shape with a structured surface. They are 28–40 mm long and 25–30 mm wide (Figs. 13e–f).

Remarks. The organic tissue was originally thick and probably coriaceous to woody. The preservation does not permit to identify any structures that would enable to assign the seeds to any known species, and thus to identify its botanical affinity.

DISCUSSION

The plant fossil assemblage from the Via Pari section of the Pisani Mountains in Tuscany

This first study of the collection of the Museo Naturalistico Archeologico dell'Appennino Pistoiese uncovered a wide range of plant fossils (20 taxa) belonging to the lycopsids (1 taxon), sphenopsids (7 taxa), ferns (5 taxa), seed ferns (5 taxa), cordaites (1 taxon) and undefined seeds (1 taxon). The lycopsids are represented only by root fragments (*Stigmaria* sp.), whereas sphenopsids are represented by vegetative (*Calamites suckowii*, *Calamites cistii*, *Asterophyllites equisetiformis*) and reproductive organs (*Calamostachys* sp.) of arboreal forms, as well as vegetative (*Sphenophyllum oblongifolium*, *Sphenophyllum verticillatum*) and reproductive organs (*Bowmanites* sp.) of herbaceous taxa. The ferns are represented by sterile frond fragments of Marattiales (*Acitbeca polymorpha*, *Diplazites unitus*, *Cyatocarpus arboreus*, *Cyatocarpus daubreei*, *Cyatocarpus reptangulus*). The seed ferns include Medullosales (*Alethopteris* sp. 1, *Alethopteris* sp. 2, *Alethopteris* sp. 3) and Peltaspermales (?*Autunia* sp. 1, gen. indet. sp. indet.). The Cordaitales, which are represented by leaf fragments and seeds, are not assignable to any species.

Landi Degl'Innocenti et al. (2008) listed a wide range of taxa (more than 50 taxa) coming from the Pisani Mts, based on the taxa mentioned by De Stefani (1901), partially revised with modern literature. The authors listed a wide range of lycopsids (2 taxa), sphenopsids (12 taxa), marattiaceous ferns (16 taxa), *incertae sedis* (12 taxa) including taeniopterids and several seed ferns, cordaites (3 taxa), cycads (1 taxon) and conifers (4 taxa). If we consider all publications on the plant fossils of the Pisani Mts., the diversity is even higher (Supplementary Tab. 1), with more than 130 taxa, even after a first taxonomic revision of some of the species. The much higher diversity (50 or 130 compared to 20 taxa) can be related to the fact that this count is based on the taxon lists of several different fossiliferous outcrops. Thus, not only a higher number of specimens is considered, but also a wide range of different environments and/or fossiliferous levels with a slightly different age may be included, increasing the number of taxa.

A taxonomic difference exists also between the two lists. As discussed above, *Calamites leioderma* von Gutbier, 1849 is a junior synonym of *Calamites cistii* Brongniart, 1828. *Acitbeca isomorpha* De Ste-

fani, 1901 is a junior synonym of *Acitbeca polymorpha* (Brongniart) Schimper, 1879, a species with a high morphological and geographical diversity (Kidston 1925; Zodrow et al. 2006), and the genus *Sphenophyllostachys* Seward, 1896 is a junior synonym of *Bowmanites* Binney, 1871 (see also Hoskins & Cross 1943). Moreover, the papers of De Stefani (1891a, 1891b, 1894, 1901), Canavari (1891), De Bosniaki (1881, 1890, 1894) and Arcangeli (1895) cite a wide range of rather obscure taxa that have to be reinvestigated and verified, as well as several new species that were created by De Stefani (1901) and later not described from anywhere outside Tuscany.

A taxonomical and nomenclatorial revision of the taxa from the Pisani Mts. and Iano (Tabs. 1, 2), as well as a restudy of the plant fossil collections of De Stefani and De Bosniaki with modern criteria would help to understand how diverse the Carboniferous flora of Tuscany was. The fact that the plant remains are not preserved as compressions, but rather as permineralized casts and impressions, decreases the possibility to recover *in situ* spores or cuticles, which is necessary for a species assignment in several taxa (e.g., cordaites). This limits the number of identifiable taxa at species level.

Difference in composition between the different outcrops

The plant fossil assemblages of the two new sampling sites of the Via Pari area ('Via Pari Buca' and 'Via Pari Smottamento') show some quantitative and qualitative differences, but both differ even more from that of the neighbouring Monte Vignale area. In total, 39 taxa have been identified in the Monte Vignale-Via Pari area (Supplementary Tab. 3). Most of these (29 taxa) are registered only from one of the three outcrops. Nine taxa are present in both plant assemblages of Via Pari sites, whereas seven are in common between 'Via Pari Buca' and Monte Vignale and six between 'Via Pari Smottamento' and Monte Vignale. The same six elements are also the only ones present in all three plant assemblages. Several of the taxa present only in the Monte Vignale collection (red colour in Supplementary Tab. 3) are typical Permian elements (e.g., *Autunia conferta*, *Walchia piniformis*) and/or more xerophytic elements (e.g., *Walchia eutassaefolia*, *Lesleya cocchii*), suggesting that the plant assemblage is slightly younger in age than those from the Via Pari area and/or reflects a drier environment.

If we consider the relative diversity, the number of taxa present in each of the collections is 18 from 'Via Pari Buca', 11 from 'Via Pari Smottamento' and 26 in the historical collection of Monte Vignale. The sphenophytes (7 taxa) are the most diverse group in the 'Via Pari Buca' plant assemblage, followed by ferns and pteridosperms (4 taxa each). Lycopods, Cordaitales, and the *incertae sedis* group are represented by one taxon each (Supplementary Tab. 3). The ferns (5 taxa) are the most diverse of the 'Via Pari Smottamento' plant assemblage, followed by the sphenophytes (3 taxa). Seed ferns are represented by two taxa and the Cordaitales by one taxon (Supplementary Tab. 3). By contrast, in the historical plant assemblage of Monte Vignale, the sphenophytes, ferns and pteridosperms are represented by seven taxa each (Supplementary Tab. 3). Conifers and the *incertae sedis* group are present with two taxa each, the Cordaitales with one taxon. This would suggest that the difference between the Via Pari and the Monte Vignale plant assemblages is rather related to a different age (younger for the latter) than to more arid conditions. Otherwise, the hygrophytic sphenophyte and fern groups would not be as well represented and the diversity so evenly distributed among the various major plant groups.

It is also worthy of note that a difference in the relative abundances of the various plant remains can be observed between the two Via Pari plant assemblages. The plant fossil assemblage of 'Via Pari Buca' (Supplementary Tab. 4; Fig. 14) is dominated by ferns (47.4 %) followed by sphenophytes (24.9 %), while seed ferns are abundant (13.7 %), and other gymnosperms and lycopods are rare (both 2.4 %). About 9 % of the plant remains could not be assigned to any genus. *Acitheca* is the most abundant taxon at genus level (42.7 %), followed by *Calamites* (20.2%) and *Alethopteris* (10.4%). The plant fossil assemblage of 'Via Pari Smottamento' differs only slightly. The ferns are even more abundant (71.2 %) in this outcrop, with the seed ferns being the second most abundant group (10.5 %). The sphenophytes are common (6.2 %), the cordaites rare (0.4 %). The percentage of plant remains that could not be identified is slightly higher (11.2 %). A peculiarity of this outcrop is the dominance of the two genera *Cyatbocarpus* and *Diplazites* (70.0 %), followed by the seed fern *Alethopteris* (10.5 %). All other genera are represented by less than 6% (Supplementary Tab. 4).

It cannot be completely ruled out that the difference between the two outcrops of Via Pari is based on a difference in sampling, since at 'Via Pari Buca' a more detailed sampling with some minor digging has been carried out, whereas the specimens from 'Via Pari Smottamento' were all collected from the surface of the outcrop. However, since both collections comprise a wide variety of specimens including also badly preserved material, this difference in sampling did probably not cause a sampling bias. Moreover, the numbers are statistically relevant with almost 260 plant remains from 'Via Pari Smottamento' and more than 560 from 'Via Pari Buca'. The difference is therefore interpreted as being related to the local environment of the two sites.

Palaeoenvironmental considerations of the Via Pari samples

The lithological and sedimentological features of the lower–middle part of the San Lorenzo Schists permits to reconstruct for the Pisani Mts. a complex environment made up of an alluvial system close to a coastal plain, characterized by channels, small local swamps and lacustrine areas. Neighbouring fluvial channels delivered occasional intercalations of coarse-grained deposits. Frequent intercalations of metasandstones and metaconglomerates in the uppermost part of the formation (e.g., the Sasso Campanaro section) evidence a change towards more continental environments characterized by an alluvial plain with channels, flood plains, and minor water pools (Rau & Tongiorgi 1974, 1976; Landi Degl'Innocenti et al. 2008; Marini et al. 2020). The presence of a wide range of plants and their preservation as fossils was facilitated by the high stability of the climate and environmental conditions, as well as the constant influx of water and siliciclastics (Rau & Tongiorgi 1974, 1976; Landi Degl'Innocenti et al. 2008). The palaeogeographic position of the area, which was close to the equator (about 10° South; Irving 1964; Stampfli & Borel 2002; Scotese 2010), supports the reconstruction of a wet equatorial to subtropical climate that permitted the establishment of a lush rainforest and/or swamp vegetation.

The plant fossil assemblage and the lithology of the Via Pari outcrops document a continental sedimentary environment characterized by flood plains with local marsh depressions and

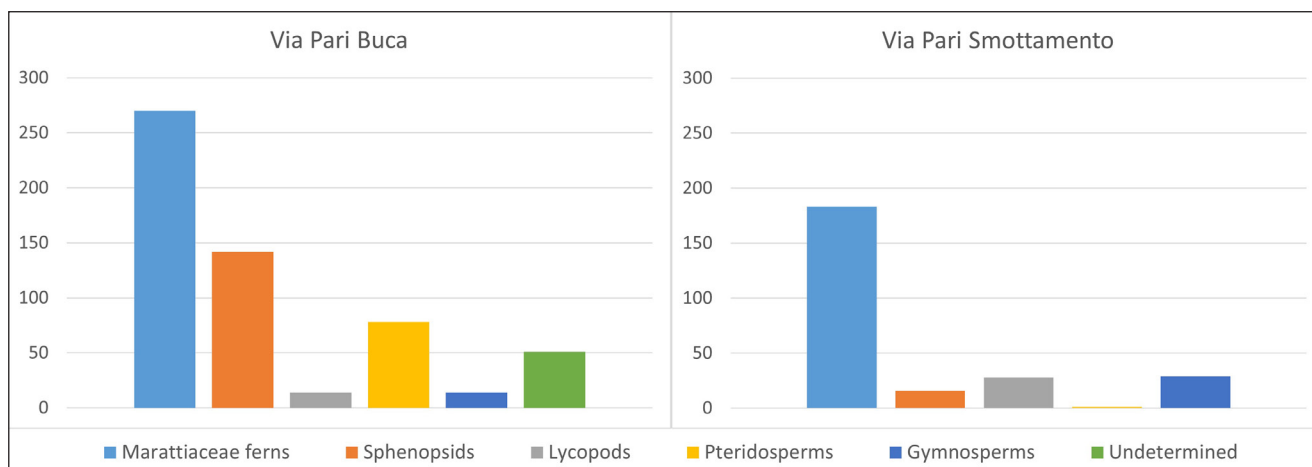


Fig. 14 - Quantitative composition of the plant assemblage of 'Via Pari Buca' (left) and 'Via Pari Smottamento' (right).

small fluvial channels (Rau & Tongiorgi 1974; Pandeli et al. 1994; Landi Degl'Innocenti et al. 2008). The swamps were small, considering the reduced amount of typical swampy elements. The marshy depressions were colonized by arboreal lycopods, as testified by the presence of their root fragments (*Stigmaria*). The arboreal sphenopsids (*Calamites*) grew in the marshy depressions or occupied the margins of the alluvial systems or wet areas of the fluvial system being relatively disturbance-tolerant regarding short-term (seasonal) precipitation flux (Calder et al. 2006). Arboreal marattialean ferns (*Acithea*, *Diplazites*, *Cyathocarpus*) formed the canopy of the surrounding wet lowland area. *Acithea* was an arborescent marattialean fern of about 3.5 m height with large, tripinnate or quadripinnate fronds that occupied a wide range of habitats including lowlands and intramontane basins (Zodrow et al. 2006).

The understory of the wet lowland would have been partly occupied by herbaceous sphenopsids (*Sphenophyllum*). The fact that the plant assemblages are dominated by ferns, pteridosperms and sphenophytes, suggests that the area was covered predominately by nutrient-rich, wetland clastic substrates, such as flood basins and channel levees (Gastaldo et al. 1995; Dimichele et al. 2001; Falcon-Lang 2003). Cordaitaleans were important Pennsylvanian gymnosperms that occurred both as large trees 20–40 m tall (Stewart & Rothwell 1993; Falcon-Lang & Bashforth 2004) and as shrubs (Rothwell & Warner 1984). They were adapted to a range of habitats (Cridland 1964; Falcon-Lang 2003), such as the margin of the wetlands (marshes or fluvial systems), peat-substrates (Costanza 1985) and clastic-substrates (Falcon-Lang & Bashforth

2004), or could even be part of dryer, more fire-prone communities, together with seed ferns (Falcon-Lang 2003).

Seed ferns such as the medullosalean *Alethopteris* could form medium-sized trees with large fronds (Laveine 1986) or smaller understory plants of the riparian systems in which the cordaites and marattialean ferns formed the tree-sized plants (e.g., Lacey 2000; Dilcher et al. 2005). They often favoured habitats adjacent to sites of sedimentary deposition or flowing water (Cleal 2007; Cleal et al. 2009). The quantitative difference (Fig. 14) shows that the two plant assemblages of Via Pari came from slightly different environments. This is supported by the fact that sphenophytes are much more abundant and diverse and include also the herbaceous form *Sphenophyllum* in 'Via Pari Buca'. Both assemblages were rich in *Alethopteris*, a medullosalean seed fern that had a wide distribution in wetland areas (e.g., Cleal et al. 2009, 2012; Bashforth & Nelson 2015). The marattialean ferns show an interesting change in composition between the two assemblages. While in 'Via Pari Buca' the genus *Acithea* is the most abundant one, the 'Via Pari Smottamento' plant fossil assemblage is completely dominated by species of *Cyathocarpus* and *Diplazites*. This suggests that the species of *Acithea* are more closely linked to wet environments than those of *Cyathocarpus* and *Diplazites*.

The conclusion would be that the plants preserved in the 'Via Pari Buca' assemblage grew in a more humid environment than those of the 'Via Pari Smottamento'. The former could correspond to an environment with relict swamp areas, whereas the latter would correspond more to fluvial chan-

nels in the floodplain where humidity was still high, but the water table was much lower with drained clastic soils. However, in ‘Via Pari Smottamento’ the environment would never have completely dried out since typical elements of drained soils are poorly represented (?*Autunia*) or completely absent (e.g., the conifers).

Biostratigraphic considerations

The plant fossil assemblage of Via Pari can be assigned to the Pennsylvanian due to the scarcity of arboreous lycopsids and other typical wetland elements. Trevisan (1955) discussed an assignment of the outcrops of Via Pari to the early Permian due to the findings of ‘*Callipteris conferta* (= *Autunia conferta* Krasser, 1918 emend. Kerp, 1988) and *Walchia piniformis* (Schlotheim) Sternberg, 1825 (Fig. 2). Currently, we cannot confirm nor deny an early Permian age for the Via Pari section since the typical taxa are missing in our assemblages with the exception of a leaf fragment that belongs putatively to *Autunia*. However, most of the taxa identified in the plant assemblage of Via Pari are long-ranging taxa (e.g., *Diplazites unitus*, *Acitheca polymorpha*) that extend from the Moscovian to the Gzhelian (see above) and support rather a latest Carboniferous age.

The plant fossil assemblage from the Monte Vignale has been assigned a late Carboniferous age by Trevisan (1955) based on the presence of *Taeniopteris multinervis* Weiss, 1869, whereas Rau & Tongiorgi (1974) dated it to a probable “Autunian” based on lithostratigraphic evidence (Fig. 2). At this point there has to be underlined that “Autunian” is not a chronostratigraphic term but rather refers to a defined composition of the flora that spans from the Gzhelian to the early Sakmarian (e.g., Broutin et al. 1999; Ronchi et al. 2008). Anyway, the comparison of the data collected in Via Pari with those reported in the literature for Monte Vignale (see in Landi Degl’Innocenti et al. 2008) suggests an earlier age for the latter section because of the presence of more xerophytes and typical Permian elements. However, without a revision of the historical collections, no age assignment can be made in this study. A Permian age seems also possible for the Sasso Campanaro section (Fig. 2), which is characterized by abundant conifers (31% of the assemblage) and pteridosperms like ‘*Callipteris conferta* (= *Autunia conferta*), whereas spore-pro-

ducing plants (ferns and sphenopsids) are poorly represented (Trevisan 1955; Rau & Tongiorgi 1974; Landi Degl’Innocenti et al. 2008).

CONCLUSIONS

The Museo Naturalistico Archeologico dell’Appennino Pistoiese (=MUNAP) hosts one of the most abundant and diverse collections (more than 1200 specimens) of late Carboniferous age from Tuscany, with at least 20 different taxa from the Via Pari area belonging to the lycopsids (1 taxon), sphenopsids (7 taxa), ferns (5 taxa), seed ferns (5 taxa), cordaites (1 taxon) and undefined seeds (1 taxon). The two plant fossil assemblages are stratigraphically and geographically well-located, permitting thus to define different taphofloras, which is unfortunately impossible for the historical collections of De Stefani and De Bosniaski collected in the 19th century.

The sedimentary structures and plant assemblages permit to reconstruct a complex alluvial system close to a coastal plain, characterized by channels, local marshy depressions and lacustrine areas for the Via Pari area. The plant remains reflect this variety of microenvironments with a wide range of plants adapted to different environmental conditions, from arboreous lycopsids that occupied the most humid environments to the seed ferns and cordaites that grew in disturbed and (?seasonally) dry environments. The two taphofloras of the Via Pari sites are noticeably different as well: the outcrop of ‘Via Pari Buca’ yielded a flora adapted to a wetter environment compared to that of ‘Via Pari Smottamento’, which shows less sphenophytes and a less diverse plant assemblage. This is reflected both by the quantitative and qualitative differences between the two plant assemblages.

This study does not confirm the presence of an “Autunian” flora for the Via Pari outcrop suggested by Trevisan (1955) and by Rau & Tongiorgi (1974) but would rather support an uppermost Pennsylvanian age due to the missing Permian marker. The age assignment of the assemblages is still poorly constrained since several taxa are long-ranging forms, but a Moscovian to Gzhelian age can be postulated. A comparison between the two Via Pari assemblages and the Monte Vignale assemblage from the De Stefani collection evidenced that there

are several differences between the floristic associations (more xerophytes and typical Permian elements in the latter), even though the two localities are close to each other. The difference between the assemblages of the Via Pari sites with the Monte Vignale assemblage seems to be related to a difference in age rather than just in environment. A detailed palynological study of the two sites could improve our understanding of the stratigraphic framework and of the palaeoenvironmental and palaeoclimatic conditions of the San Lorenzo Schists metasedimentary succession.

This first, preliminary study of the plant fossils of the Via Pari area underlines the high potential of the Carboniferous plant assemblages of Tuscany, but evidences also a substantial need for a taxonomical revision of the historical collections (Landi Degl'Innocenti et al. 2008) and for a reconstruction of the stratigraphic position of the original outcrops. A future revision of the plant assemblages from the different outcrops will not only permit to reconstruct in detail the different environments but also to evidence the change in floral composition from the Pennsylvanian to the Cisuralian in Tuscany.

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