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# Pennsylvanian floras from Italy: an overview of the main sites and historical collections

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## ABSTRACT

The paper provides an overview of the main Pennsylvanian sites in Italy yielding associations rich in plants and/or palynomorphs. So far in Italy, the principal outcrops are located in the Southern Alps, Tuscany and Sardinia. In the Western Southern Alps and bordering Switzerland, Westphalian outcrops are small and scattered. Nevertheless, one of them yielded an abundant fossil flora, stored at the Museo Civico di Storia Naturale of Milan, (Venzo and Maglia Collection). In the Carnic Alps, (Eastern Southern Alps), continental deposits of Moscovian to Gzhelian age also occur near the border with Austria. They have produced a high number of preserved plant fossils, presently stored in the Museo Friulano di Storia Naturale of Udine. In Tuscany, the two main sections yielding Westphalian to Autunian floras are those of the Iano and Pisani Mountains. A rich collection of plant fossils from those sites is hosted at the Museo di Storia Naturale of Florence University and at the Museum of Natural History of Pisa University. In Sardinia, plant fossil sites are located in the south west and central east parts of the island. The San Giorgio Basin (Iglesiente subregion) and the Tuppa Niedda section (Arburese subregion) are late Westphalian – early Stephanian in age. In the Barbagia at Seui-Seulo and the Gerrei subregions, other continental basins yielded transitional "Stephanian-Autunian" fossil plant associations. The slabs are stored as part of the Lovisato Collection at the Lovisato Museum of the Chemical and Geoscience Department of Cagliari University. Smaller historical outcrops of Carboniferous age are also known from other Italian regions, such as Liguria.

**Keywords:** Pennsylvanian, Southern Alps, Tuscany, Sardinia, plant fossils, palynomorphs, fossil plant collections

## 1. INTRODUCTION

The Pennsylvanian was one of the most important times for coal formation in Earth history. The lowland areas of Euramerica and China were covered by extensive wetland forests dominated by arborescent lycopsids and tree ferns (OPLUŠTIL & CLEAL, 2007). Extensive floras are known from Upper Silesia, the Intra Sudetic Basin, Central and Western Bohemia, South Wales and from the Pennines (for more details see OPLUŠTIL & CLEAL, 2007).

In Italy (Southern Alps, Tuscany, Sardinia, Liguria), several outcrops of terrestrial sediments have also yielded Pennsylvanian floras. Although the Carboniferous sections are mostly scattered and of limited extent, these Pennsylvanian occurrences are fundamental for regional correlations and palaeogeographic reconstructions.

Therefore the goal of this paper is to provide an updated review on the main sections which have yielded rich Pennsylvanian plant megafossils and palynofloras, hoping that a future taxonomic revision of them can provide a better picture of the Pennsylvanian floras of Italy.

## 2. THE MAJOR PENNSYLVANIAN FLORAS IN ITALY

From Northern to Southern Italy, the most important outcrops are mainly concentrated in four different regions (Fig.

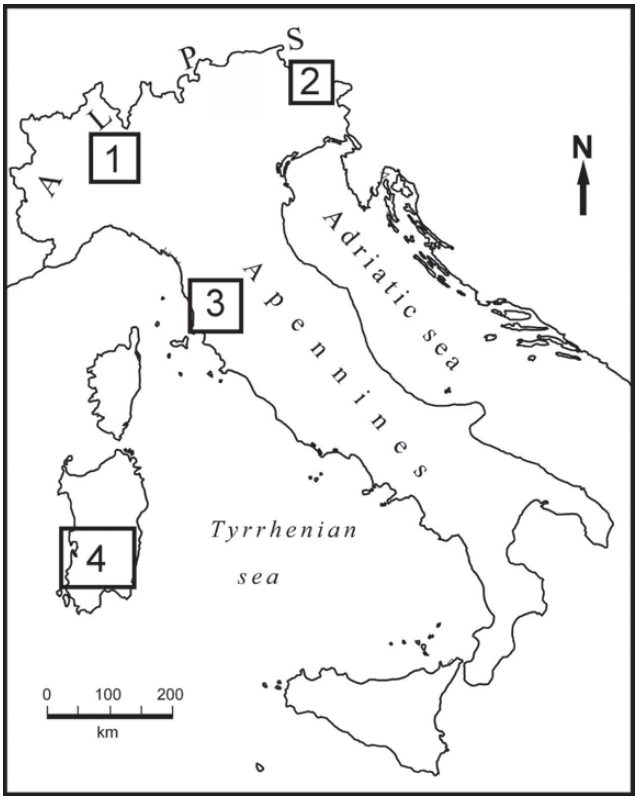


**Figure 1:** Location of the main Pennsylvanian sites in Italy. 1 – Western Lombardy region and Canton Ticino (Switzerland); 2 – Carnic Alps (Alto Adige and Tyrol, Austria); 3 – Tuscany (Pisani Mountains and Iano); 4 – South western, central and South eastern Sardinia.

1), excluding small and debated outcrops in Western Liguria. They are briefly described in paragraph 5 and synthesized here below.

## 2.1. Southern Alps

### 2.1.1. Western Southern Alps/Canton Ticino (Switzerland)

Sparse continental Pennsylvanian successions crop out in the western Southern Alps, especially in the so-called Varesotto-Lugano area, to the West of Lake Como (Fig. 2). The main localities are Alpe Logone, Val Rezzo, Mesenzana, Grantola, Bèdero, Bosco Valtravaglia-Fabiasco, Val Tresa on the Italian side of the border and Manno (and other small sections in Val Colla, Cadro, Denti della Vecchia, etc.) in the Canton Ticino area (Switzerland).

The successions, called by many authors the "Basal Conglomerate", are alternations of conglomerates, sandstones and siltstones composed of metamorphic and vein-type quartz clastics. These units were also name "non-porphyric" conglomerates (e.g., BAGGIO & DE MARCO, 1960), in order to distinguish them from younger deposits where volcano-clastic deposits occur. The bedding of these generally coarse-grained sediments is often irregular and some crude channelling is observed. Deposits occur generally pinched along major tectonic lines or in stratigraphic non-conformities above the metamorphic basement, and represent the "Southern Alps sedimentary front". These sediments are the product of the erosion of the Variscan mountain chain, and the contact with the crystalline

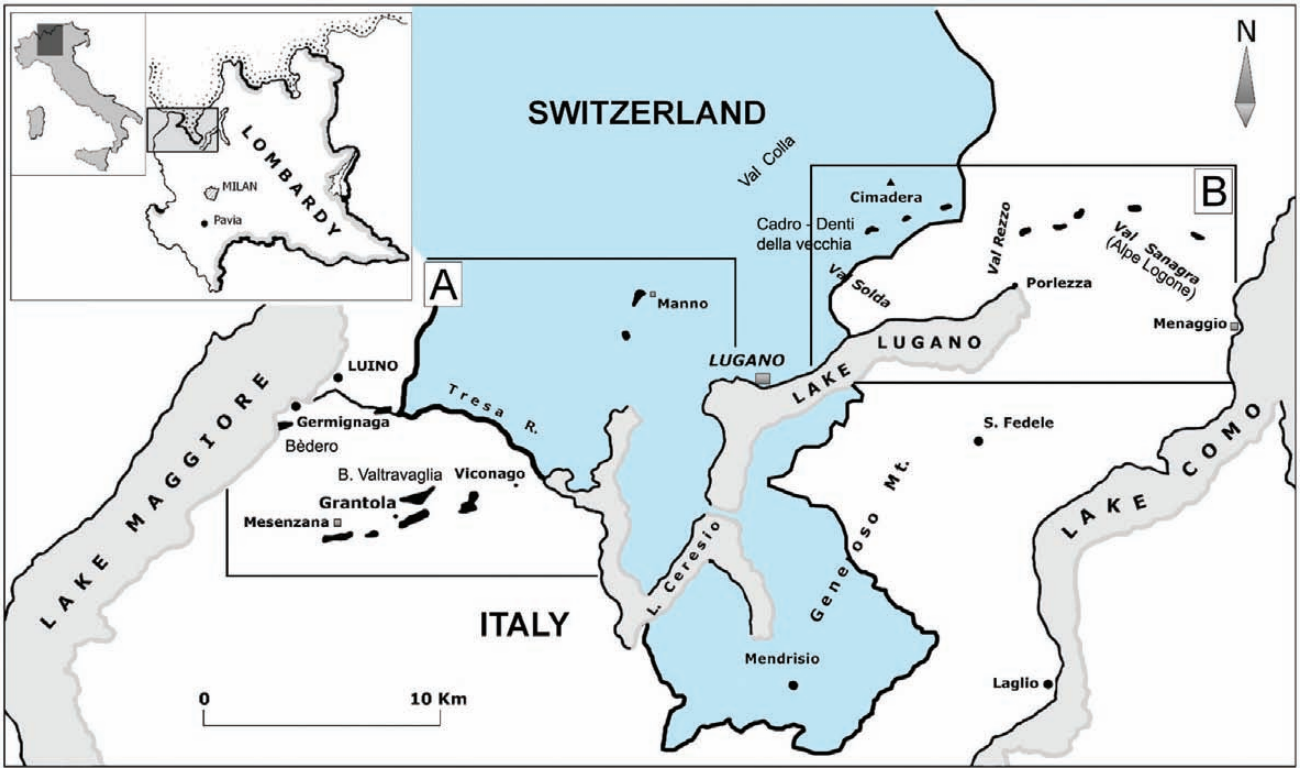


**Figure 2:** Location of the main outcrops of Pennsylvanian sections in the Western Southern Alps and Canton Ticino (from PITTAU et al., 2008a, mod.) A – Italian/Swiss sector between Lake Maggiore and Lake Lugano; B – Italian/Swiss sector between Lake Lugano and Lake Como. Bold line is the Italian-Swiss border.

basement is marked by a gap of unknown time (BERTOTTI, 1991). The thickness varies from 0–15 m in the Val Sanagra (VENZO & MAGLIA, 1947), to 20–30 m in the Val Rezzo (Fig. 3) and in the upper Val Colla, and to about 100 m beneath the Denti della Vecchia (LEHNER, 1952).

The finer grey-to-reddish clastic sediments structurally developed in a basin situated south of the Marzio Lineament, (or Brusimpiano-Cabiaglio Lineament). They generically follow the initial deposition of volcanic-rich conglomerate, and are called the Mesenzana Formation (CASATI, 1978; see Fig. 5).

The age of all the Upper Palaeozoic, strongly tectonically stressed, sedimentary successions, scattered over a wide area between Lake Como, Lake Maggiore and Ticino, has long been debated as being between the Westphalian and Stephanian (e.g. LEHNER, 1952; VENZO & MAGLIA, 1947; STADLER et al., 1976; CASATI, 1978; GAETANI et al., 1986).

The whole region, where all these so-called "Basal Conglomerats" crop out, can be subdivided into two sectors (Fig. 2) which, from E to W, are described below.

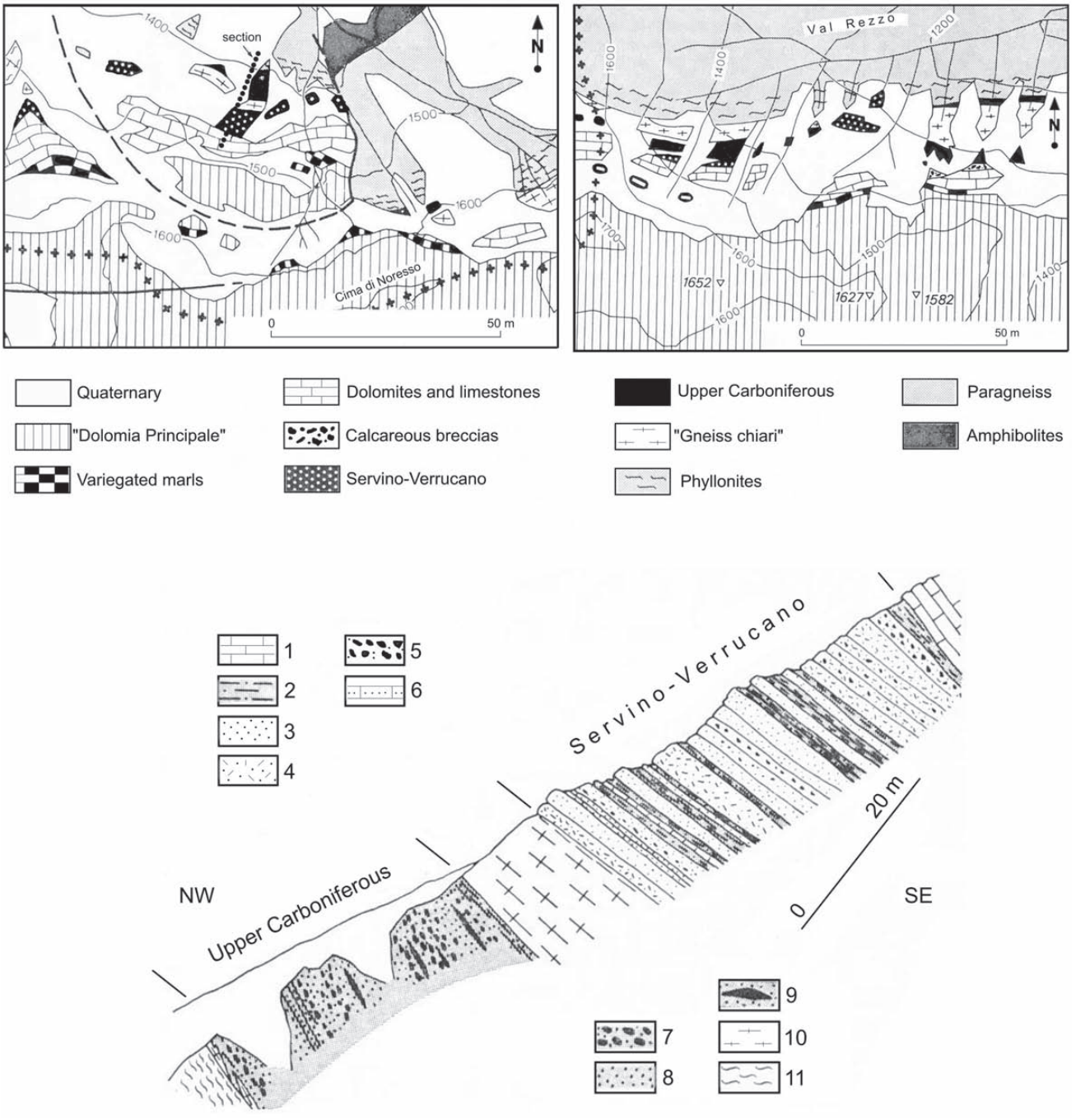


**Figure 3:** Lithological and stratigraphic section South-East of Cimadera-Val Rezzo (from LEHNER, 1952, mod.). The Upper Carboniferous (i.e. Pennsylvanian) conglomerates and the overlying "Verrucano-Servino Series" are tectonically separated by a thinband and of "Gneiss chiari". 1– dolostones, 2– micaceous, clayey sandstones, 3 – mainly quartzose sandstones, 4 – arkosic sandstones, 5 – conglomerate breccia, 6 – sandy dolostones and dolomitic sandstones, 7 – conglomerates, 8 – sandstones, 9 – coal bearing-sandstone, 10 – "Gneiss chiari", 11 – phyllonites.

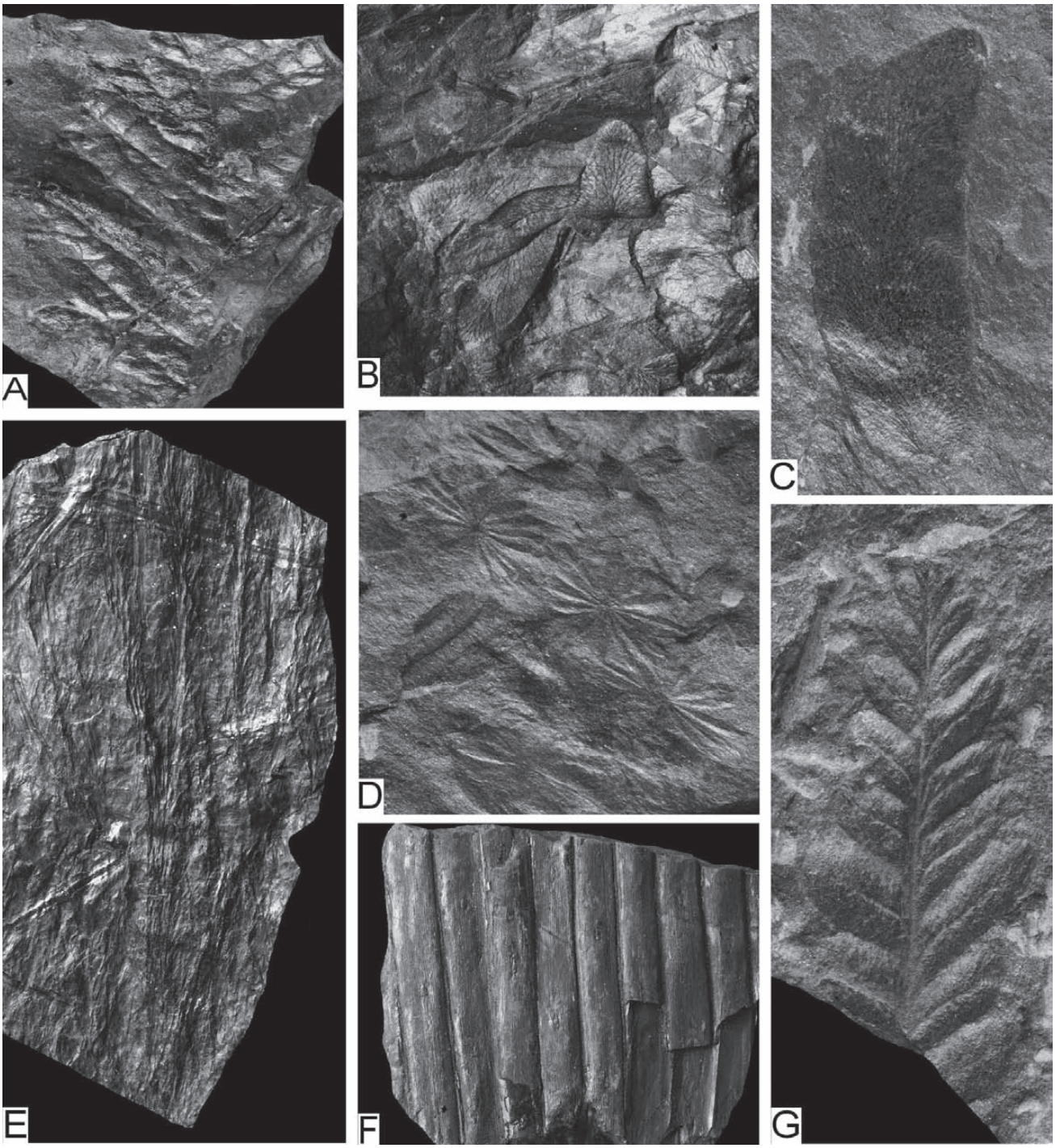


**Figure 4:** Some examples of Plant fossils from the Pennsylvanian of the Alpe Logone/Val Sanagra (W Lombardy), from Venzo Collection hosted in Milano Museum (determinations by S. Opluštil and J. Pšenička). A. *Pecopteris* (*Lobatopteris*) cf. *simoni* (sample B1519); B. *Linopteris obliqua* (sample B1605); C. *Paripteris linguaefolia* (sample B1895); D. *Annularia radiata* (sample B1888); E. *Bothrodendron* sp. (sample B1686); F. *Sigillaria rugosa* (sample B1722); G. *Alepthopteris* cf. *grandinioides* var. *grandinioides* (sample B1902b).

## SECTOR B

To the East, between the Lugano and Como lakes, some small outcrops with fine to coarse grained clastic deposits occur (Fig. 2B), including Alpe Logone, which has yielded a rich macrofloral association. The first report on Carboniferous macrofloras from this locality is from MAGNANI (1946), who discovered impressions and casts of *Calamites*, *Sigillaria* and *Lepidodendron*. In the mid 20$^{th}$ century, Silvio Venzo and Luigi Maglia (VENZO & MAGLIA, 1947; VENZO, 1951) collected more than 2000 leaf compressions and impressions from the anthraciferous and silicified beds at Alpe Logone, (in the Val Sanagra and, particularly, in Val Gariasca). They described about 22 genera and 75 species belonging to the Sphenophyllaceae (*Sphenophyllum*), Equisetales (e.g., *Calamites*, *Asterophyllites*, *Annularia*), Lycopodiales (e.g., *Lepidodendron*, *Knorria*, *Lepidophyllum*; Sigillariaceae, *Sigillaria*, *Stigmaria*; Ulodendraceae), Cycadaceae, Cordaitales, Filicales and Pteridospermales (e.g., *Pecopteris*,

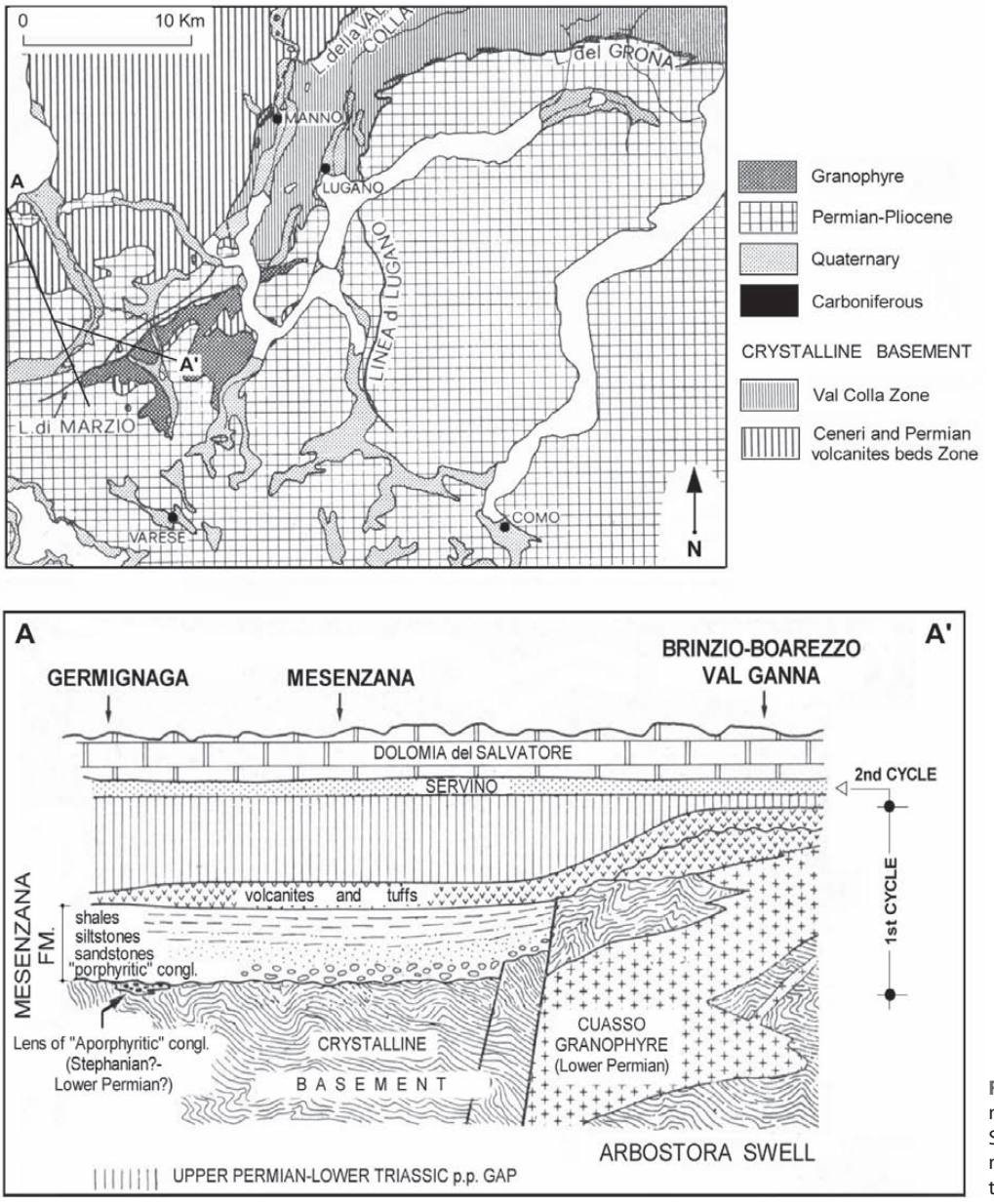


**Figure 5:** A simplified geological map and section of the Western Southern Alps (from CASATI, 1978, mod). This area relates generally to Sector A shown in Fig. 2.

*Mariopteris*, *Neuropteris*, *Linopteris*). Poorly preserved banded fragments of *Sigillaria* were also reported from the arenaceous layers. The rich collection, housed in the Museo Civico di Storia Naturale of Milan, is currently under revision (Fig. 4).

The flora was ascribed to the late Westphalian (Westphalian C) by VENZO & MAGLIA (1947) and VENZO (1951). These authors consider the flora of the Alpe Logone to be slightly older than the flora from the Manno Conglomerate in Ticino (see below), even if both show close affinities. According to PITTAU et al. (2008a), the very rich Logone and Manno's macrofloristic assemblages allow assignment to the Bolsovian (Westphalian C) or to the Duckmantian-Bolsovian (Westphalian B–C) transition.

## SECTOR A

To the West, between the Maggiore and Lugano lakes (Fig. 2A), several small outcrops of the Manno conglomerate are known. The type section crops out in the homonymous village in Ticino (Switzerland). The fossiliferous successions are characterized by alternations of fine layered sandstones and conglomerates of light-grey colour. Locally they bear anthracite-type rock layers with poorly preserved plant remains. As in Manno, these deposits occur in very scattered outcrops, generally pinched along tectonic lines. They represent the oldest sedimentary units in the Western Southern Alps. The Manno conglomerates likely filled a fault-bounded intracontinental basin characterized by fluviolacustrine and fluviopalustrine environments. These deposits represent the base of an initial tectono-sedimentary cycle developed mainly during the Early to Middle Permian throughout the Southern Alpine domain (e.g., GAETANI et al., 1986; CASSINIS & PEROTTI, 2007).

From the Manno type-locality, HEER (1876) listed *Calamites cisti*, *Sigillaria elongata* and *S. elegans*. ESCHER (1911), confirmed *Calamites cisti*, and *Sigillaria elonga* , but

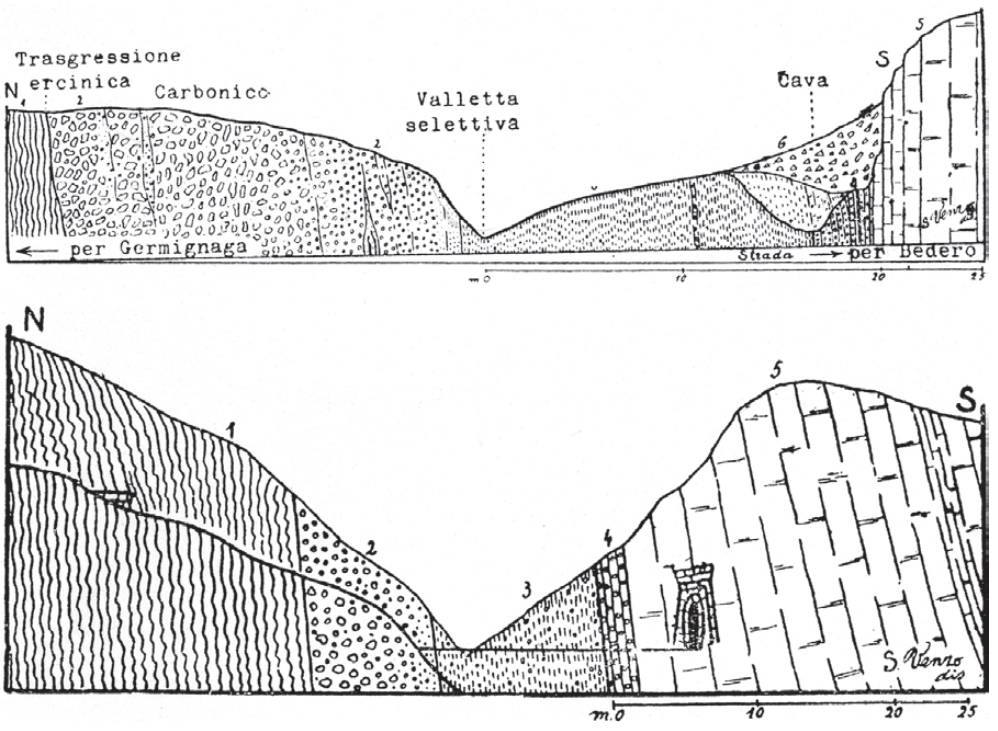


**Figure 6:** Geological sketch sections of the Pennsylvanian to Ladinian succession on the Germignaga-Bèdero road and railroad, near Luino, Lake Maggiore (from VENZO, 1950, mod). Above: on the road to Bèdero; below: on the lakeside road and between the railway tunnels "Lunghi" and "Lavello". 1. Basement mica-schists; 2. Pennsylvanian transgressive conglomerates and sandstones (Stephanian); 3. Reddish clayey sandstones (Permian?-Scythian), 4. Reddish porphyritic conglomerates (late Scythian); 5. Dolostones (Anisian-Ladinian); 6. Talus.

attributed the last species to *S. tessellata*. SORDELLI (1896), recognized 13 species; ten are common with the flora from the Alpe Logone, including five species of *Sigillaria*, and another five species among the genera *Calamites*, *Lepidodendron* and *Cordaites*. He attributed the Manno flora to the early Stephanian, but with many Westphalian elements (SORDELLI, 1896). VENZO (1951) attributed the flora from Manno to the transition between the Westphalian B and Westphalian C, suggesting it to be slightly older than the flora from Alpe Logone (see above). JONGMANS (1950), related the floras of various Swiss localities (including Manno), first to the Westphalian B–C due to the presence of some elements such as *Linopteris neuropteroides*, cf. *Pecopteridium*, *Sigillariaephyllum*, *Cordaites* cf. *borassifolius*, but later considered it to be slightly younger, most likely Westphalian ("Mittleres Westphalen", JONGMANS, 1960, p. 95).

Along the Germignaga-Bèdero road on the eastern side of Lake Maggiore, some light grey coloured layers of sandstones and conglomerates also occur. Locally, they bear anthracite with badly preserved plant remains including *Sigillaria*, which is putatively attributed to the Stephanian (VENZO & MAGLIA, 1947). Clasts of this succession show an origin from the metamorphic basement alone, but at the top of the Bèdero section, and in the very nearby outcrop, (i.e. along the Luino-Laveno railway-line), volcanic-rich conglomerates are also reported by these authors and thus suggesting a younger (Permian?) age for these latter sediments (Fig. 6).

More recently, the Bèdero section (Lake Maggiore, Fig. 2A and Fig. 7) yielded a rich palynoflora, which allowed assignment of these sediments to the late Westphalian-early Stephanian (PITTAU et al., 2008a). In the sporomorphs, 42 genera and 76 species with one new genus (*Cassinisporites*) and ten new species have been distinguished. The Bèdero assemblages are suggested as being younger than the successions studied from North-Eastern Italy, and to be more or less of the same age as the flora of San Giorgio (South-Western Sardinia). The dominance of trilete spores, with a pronounced taxonomic diversity, and *Florinites* pollen (over 70%), is indicative of a well-developed flora dominated by ferns, pteridosperms and Cordaitales, typical of a lowland flora (PITTAU et al., 2008a).

### 2.1.2. Eastern Southern Alps and border with Austria (Carnian Alps)

The Carboniferous successions of the Eastern Southern Alps crop out in several localities of the Carnian Alps, near the border with Austria and in Carinthia (Fig. 8). They represent the lower part of the more than 200 metre-thick terrestrial-transitional-marine Permo-Carboniferous sequence (Fig. 9).

From the 1970's onwards, Pennsylvanian plant megafossils have been studied from several localities, mostly on the Austrian side, (e.g., VAN AMEROM et al., 1976; VAN AMEROM & SCHOENLAUB, 1992., FRITZ, 1980, 1983; FRITZ & BOERSMA, 1983; FRITZ & KRAINER, 1993, 1994, 1995, 1997, 2006; VAN AMEROM & KABON, 2000). Nowadays, three different Permo-Carboniferous basins are distinguished in the Carnian Alps, respectively around Forni Avoltri, Pramollo and Tarvisio (SELLI, 1963; VENTURINI, 1983, 1990a, b, 1991; VENTURINI et al., 1991). The Pramollo Basin is the most important and extensive with several localities (e.g., Passo Pramollo, Cason di Lanza, Monte Corona) yielding rich floras (Fig. 10). This basin has been studied in detail with respect to its sedimentology, stratigraphy, petrography and palaeomagnetics (e.g., VENTURINI, 1990a and ref. therein). The rich fossil content (brachiopods, crinoids, *Zoophycos*, fusulinids, plants; FRITZ et al., 1990) has been used to constrain the age of the different formations and to

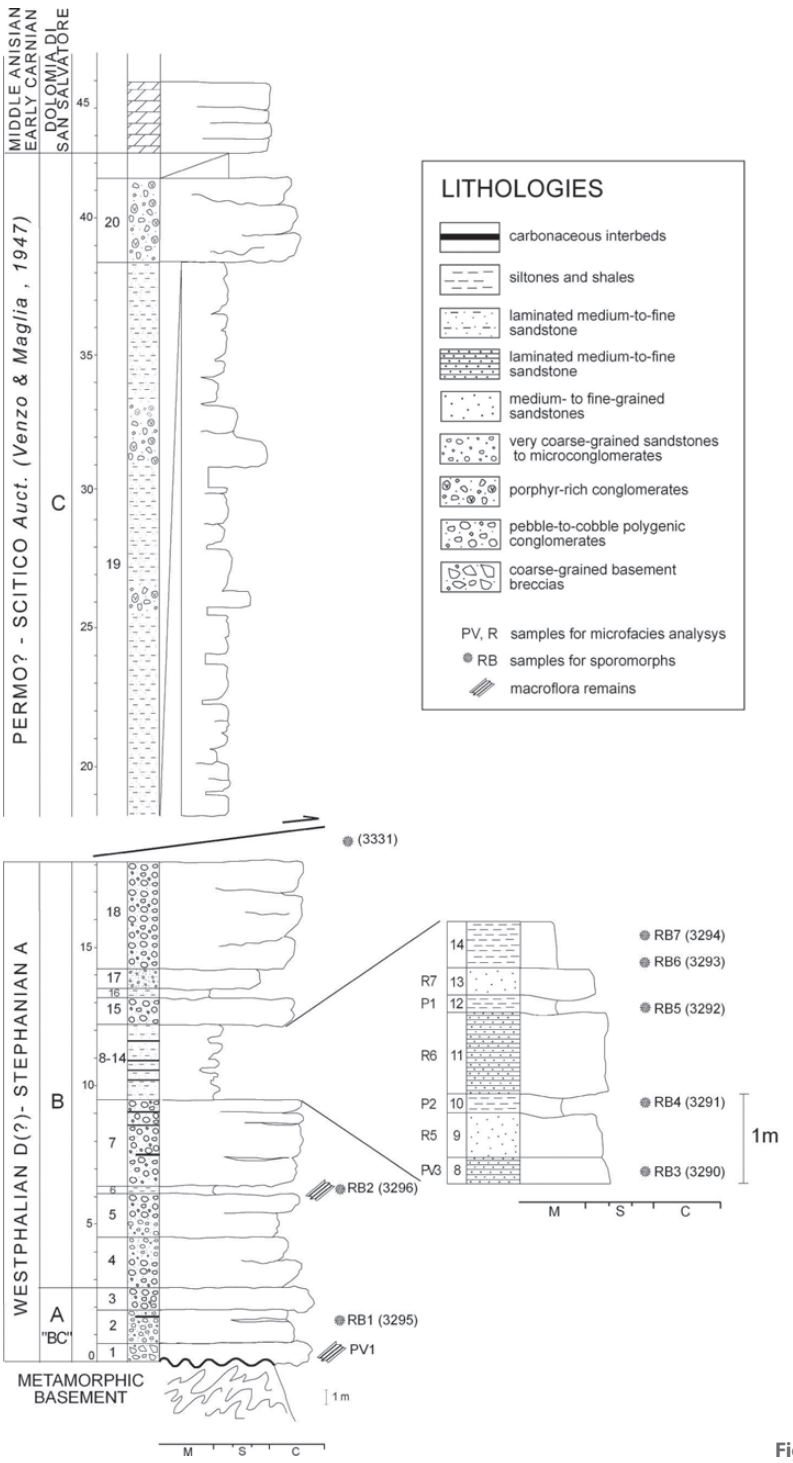


**Figure 7:** The Bèdero Section (from PITTAU et al., 2008a, mod).

reconstruct the evolution of the basin. The ichnoassemblages reflecting changes from terrestrial to lagoonal facies are also important (BAUCON & CARVALHO, 2008).

From base to top, the Pramollo Group (VENTURINI, 2002a, b), formerly the Auernig Group *sensu* SELLI (1963; see Fig. 9), is composed of the Meledis, Pizzul, Corona, Auernig and Carnizza Formations. The Pramollo Group consists of cyclic, shallow-marine, clastic and carbonate deposits up to 1200 m thickness. Shore-face and offshore environments are quite common. Moreover, the regressive–transgressive cycles ("Auernig cyclothems"), in the upper part of this group have been related to eustatic sea-level changes due to the Permo-Carboniferous glaciation, where the carbonatic levels would correspond to interglacial phases with a sea-level rise covering this area (VENTURINI, 1990a, b; 1991; MASSARI et al., 1991). The most abundant flora comes from the Corona Formation ($A_3$ formation *sensu* VENTURINI, 1990a, b), a terrigenous succession of uppermost Gzhelian age, (Massari et al. in VENTURINI et al., 2002b). Plant fossils are, however, widely distributed in most of the fine sandstones and pelites of the Bombaso Formation and basal Pramollo Group, (Meledis, Pizzul, basal Auernig and Carnizza Forma-

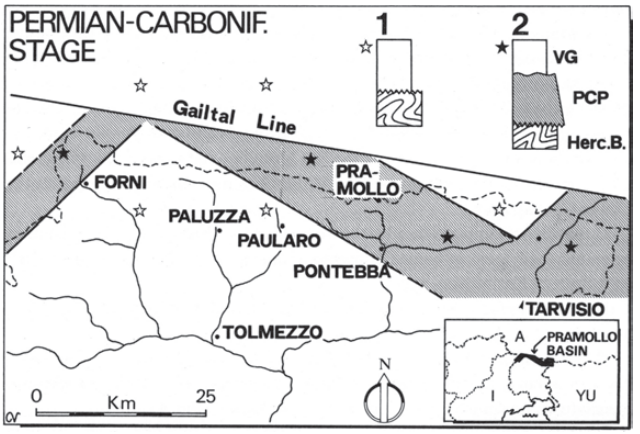


**Figure 8:** Location of the Permian-Carboniferous Carnic Basins of the Carnic Alps (from VENTURINI, 1990b). PCP: Permo-Carboniferous sequence; VG: Val Gardena Sandstone. 1 and 2 are idealized and very schematic sections respectively, outside and inside the Permo-Carboniferous basin areas.

tions, respectively $A_1$, $A_2$, $A_4$ and $A_5$ of VENTURINI 1990a, b, see Fig. 9).

The Corona Formation is characterized by its almost complete lack of carbonatic levels (so far only one has been identified, see Krainer in VENTURINI, 1990b). It consists mainly of alternations of fine quartzose conglomerates, sandstones and siltstones corresponding to subaerial or paralic environments (VENTURINI, 1990a, b). There also exist, two transgressional acmes with fine siltstone, hummocky structures and a high abundance of marine fauna (brachiopods, crinoids, marine ichnofossils). Plant megafossils occur in the fine sandstones and pelitic levels (Fig. 10), and several sphenophyte trunks have been found in situ (with a diameter of up to 20 cm). Coal-rich levels of up to 30 cm have also been recorded from these horizons (SELLI, 1963).

More than 2000 slabs with rich and well preserved plant remains from Casera Auernig, Casera Cordin Grande, Cason di Lanza, Creta di Lanza, Forca di Pizzul, Fontanone, La Scaletta, Mt. Auernig, Mt. Carnizza, Mt. Cocco, Mt. Corona, Mt. Pic Chiadin, Mt. Pizzul, Passo Pramollo, Passo Volaia, Pian di Lanza, Pontebba, Rio Bombaso, Rio Bruca, Rio dai Amplis, Rio degli Uccelli (Vogelbach) and Sella Barizze (Fig. 11), are currently stored at the Museo Friulano di Storia Naturale of Udine (Fig. 12; courtesy of Udine Museum), at the University of Innsbruck (Austria) and at the Landesmuseum Klagenfurt (Germany).

The floras of the Austrian side of the border have been mostly studied since the 1980's. Grouping the floras stratigraphically (Fig. 13), the following information can be given (for more details see FRITZ & KRAINER, 2006, 2007). The Bombaso Formation crops out near Passo Pramollo (FRITZ & KRAINER, 1995, 2006), Tomritsch (layers 1, 2, 5, 6) and Rudniggraben (KRAINER in VENTURINI, 1990b; FRITZ & KRAINER, 2006). According to the authors, typical elements of the floras include *Linopteris neuropteroides*, *Neuropteris cordata*, *N. scheuchzeri* and *N. ovata*. Tomritsch 6 has been attributed to the *Odontopteris cantabrica*-Zone, due to the presence of *Sphenophyllum oblongifolium* and *Neuropteris scheuchzeri* (moved to *Macroneuropteris)* following the megaflora-zonation of WAGNER (1984). This translates to a Cantabrian age (late Pennsylvanian; FRITZ & KRAINER, 1995). The fossiliferous horizons of Malga (Alm) Straniger, Waidegger Alm, Zollner See, Passo del Cason di Lanza and Tomritsch 3 belong to the Meledis Formation. Tomritsch 3 has been attributed, due to the presence of *Sphenophyllum angus-*

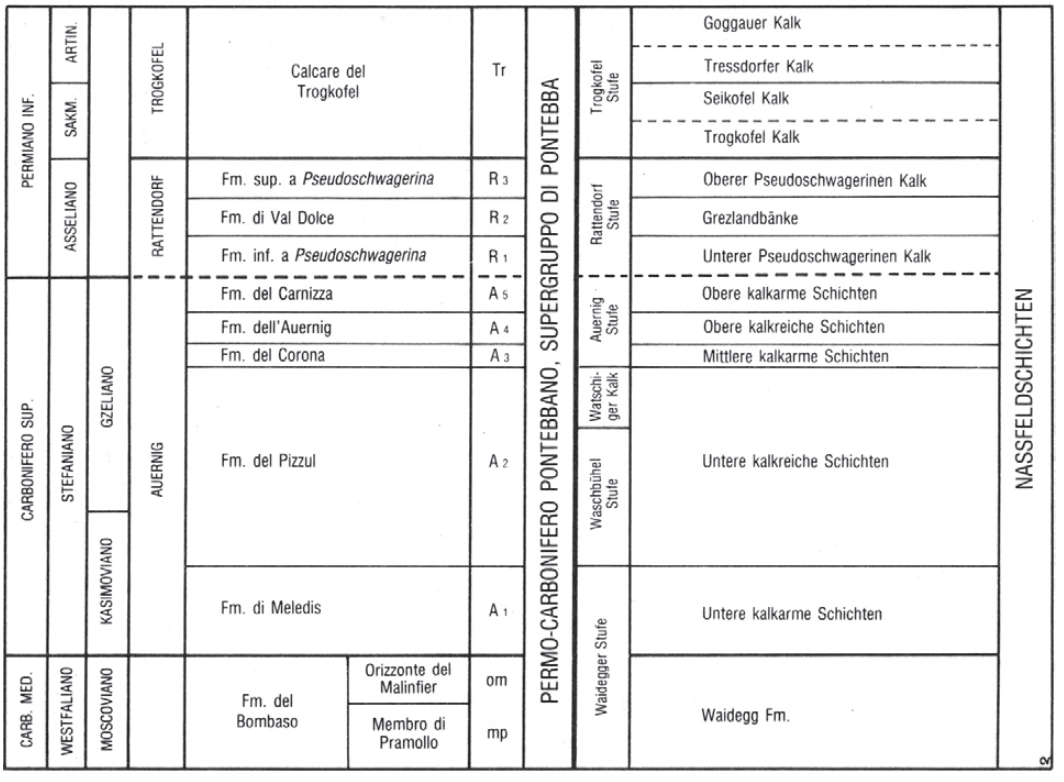


**Figure 9:** A general stratigraphic scheme of the Carboniferous-Permian units in the Carnic Alps (from VENTURINI, 1990 b). The Auernig Group is now called the Pramollo Group.

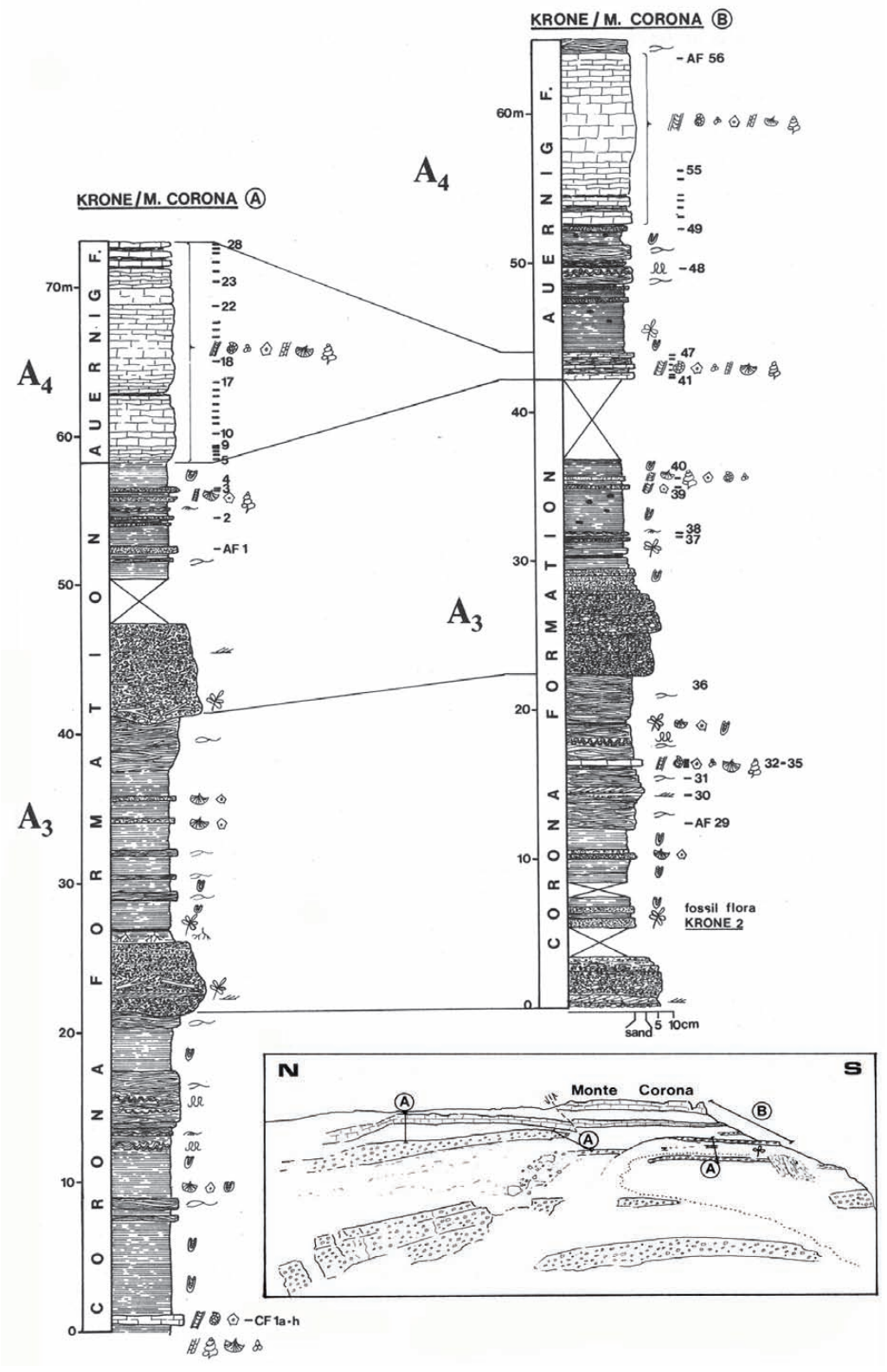


**Figure 10:** Stratigraphic sections from the upper part of the Corona Formation (A3) and the basal Auernig Formation (A4). Section A is from the western side and section B from the southern side of the Monte Corona (from KRAINER in VENTURINI, 1990b, mod.).

*tifolium* and *Pseudomariopteris busquetii*, to the *Sphenophyllum angustifolium*- Zone, which according to WAGNER (1984), corresponds to a lower to middle Stephanian C age. One of the most prominent elements of this flora is *Linopteris neuropteroides* var. *major,* as well as a high abundance in fragments of the *Neuropteris cordata* and *N. ovata* (FRITZ, 1990; FRITZ & KRAINER, 2006). VAI et al. (1980) attributed the formation to the Cantabrian (late Moscovian to early Kasimovian, early Stephanian) (see also PITTAU et al., 2008a).

The floras of the Pizzul Formation, (Rio Tratte/Garnitzenberg (malga Auernig), Watschinger Alm, Rudniggsattel, Ringmauer; Austria, FRITZ & KRAINER, 2006), are characterized by the occurrence of *Sigillaria brardii*, *Sphenophyllum angustifolium, Sph. oblonguifolium*, *Pecopteris*

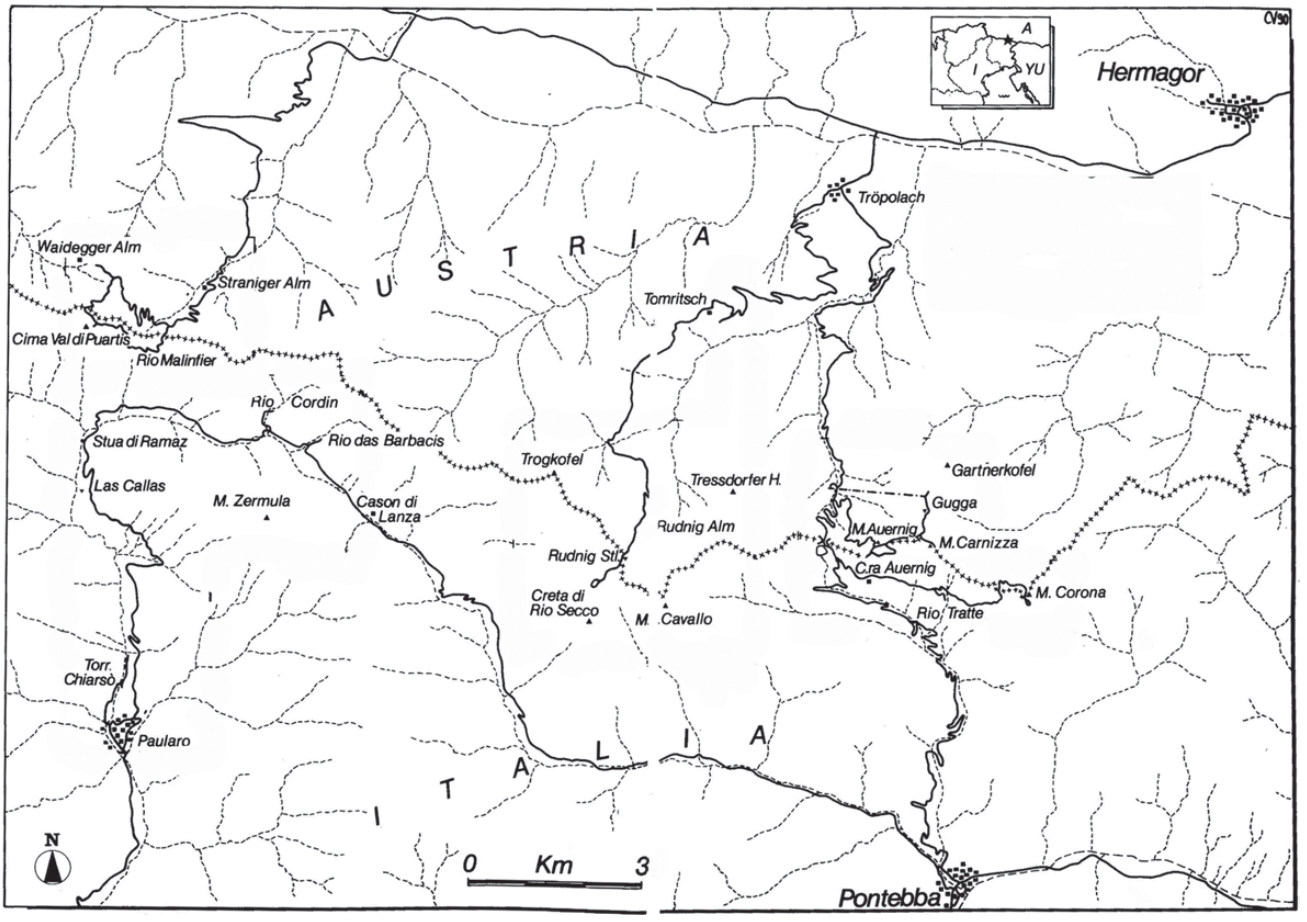


**Figure 11:** Detailed location of the main fossil flora sites in the Italian and Austrian sides of the Carnic Alps (from VENTURINI, 1990b, mod.).

*feminaeformis*, *Callipteris gigas*, *Pseudomariopteris busquetii* and *Poa-Cordaites linearis* which attributes the flora to the *Sphenophyllum angustifolium*-Zone (lower to middle Stephanian C; FRITZ & KRAINER, 1994).

The most important and fossiliferous formation of the Pramollo Group is the Corona Formation (Ofenalm, Kronalpe/Monte Corona, Garnitzenalm/Malga Carnizza, Garnitzensattel, Gugga, Madritschenkopf, Schlanitzer Almweg, Treßdorfer Alm, Naßfelder Sattel/Passo Pramollo; FRITZ & KRAINER, 2007). The most famous locality is Monte Corona (e.g., STACHE, 1874; FRECH, 1894; GEYER, 1897; FRITZ, 1980, 1990; FRITZ, et al. 1990; KRAINER, 1992; FRITZ & KRAINER, 1993). The presence of *Pseudomariopteris busquetii* attributes these floras to the *Sphenophyllum angustifolium*-Zone, (lower to middle Stephanian C; FRITZ & KRAINER, 1993). *Linopteris neuropteroides* and *Neuropteris cordata* seem to disappear in the upper part of the formation. The appearance of the genus *Lebachia,* an important conifer genus during the Permian, is of particular interest, and not described from any of the other Carboniferous floras of the Carnian Alps (FRITZ & KRAINER, 1993, 2006). The last formations yielding Carboniferous floras in the Carnian Alps are the Auernig Formation, (Gugga, Garnitzenberg/Monte Carnizza, Schulter and Rattendorfer Alm) and the Carnizza Formation (KRAINER in VENTURINI 1990 b, pag. 96–98). The *Cordaites* are missing in the Auernig Formation, while the Autunian marker *Callipteris conferta* (*i.e* now *Autunia conferta)* appears (FRITZ & BOERSMA, 1983; FRITZ & KRAINER, 2007).

So far, there has been only one study of the palynoflora of this area (FRANCAVILLA, 1966). According to the author, the microflora is characterized by the spores *Densosporites*, *Dictyotriletes*, *Lycospora* and *Verrucosisporites*.

Very interesting regional correlations and comparison between the Italian/Austrian Carboniferous and Permian floras could be also done in the future with neighboring countries such as Slovenia (KOLAR-JURKOVŠEK & JURKOVŠEK, 2012).

## 3. TUSCANY

### Pisani Mountains

The Pisani Mountains are located along the so-called Middle-Tuscan Ridge, a regional morpho-structural high extending from the Apuan Alps to the Leoni Mountain (Fig. 14).

The stratigraphic sections of the Pisani Mountains, near San Lorenzo of Vaccoli in North-Western Tuscany (Valle del Guappero), can be subdivided into two main sedimentary cycles (RAU & TONGIORGI, 1974). The first is represented by the alluvial to lacustrine San Lorenzo Schists (Fig. 15), very rich in megafloras of Pennsylvanian to Cisuralian age. The overlying fluvial Asciano red breccias and conglomerates, are attributed to the Early Permian for regional correlations.

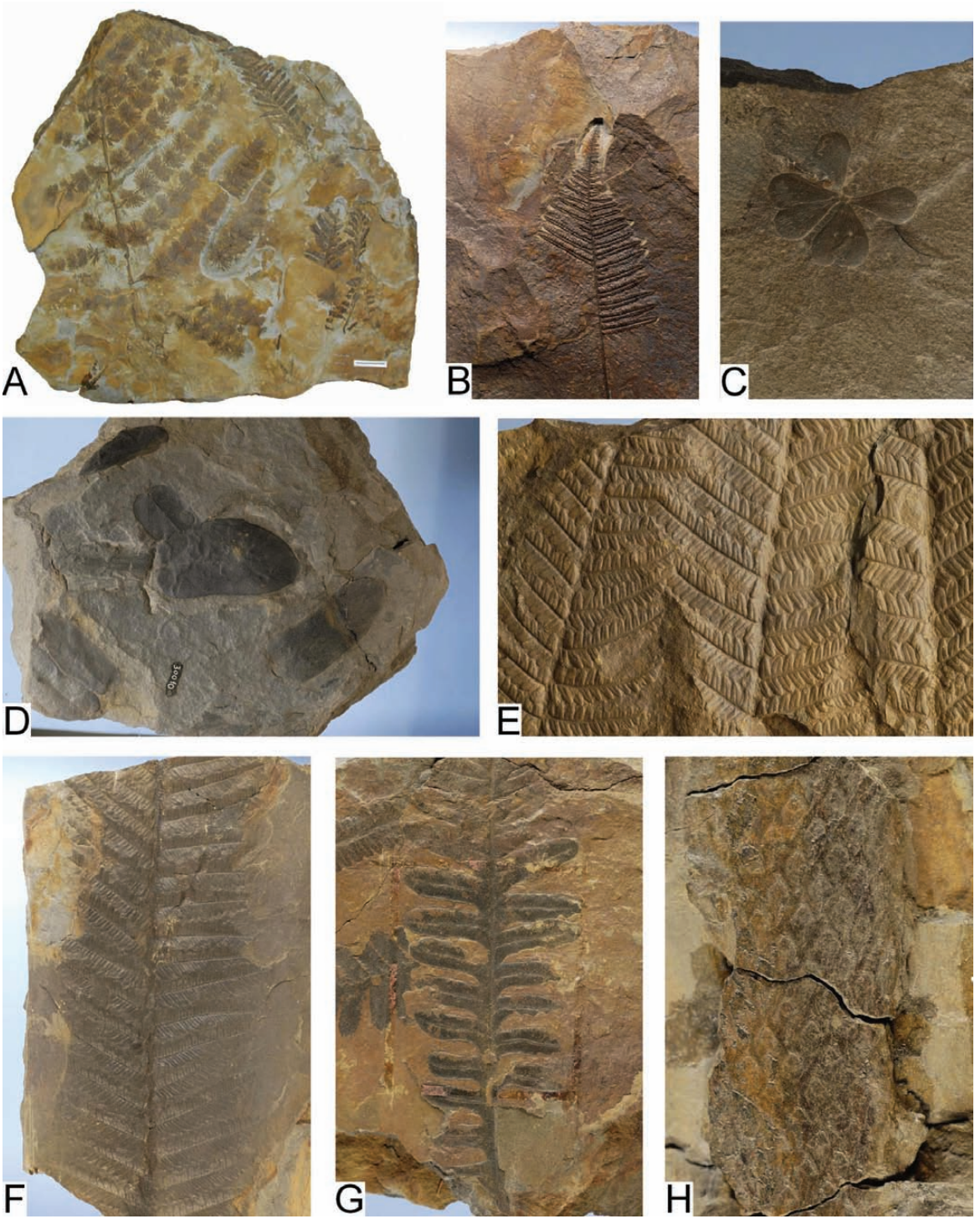


**Figure 12:** Some examples of the Pennsylvanian megaflora of the Carnic Alps (with kind permission of Udine Museum). A. *Annularia carinata*; B. *Pecopteris* sp.; C. *Lilpopia raciborskii*; D. *Paripteris* cf. *linguaefolia*; E., F. *Acitheca polymorpha*, G. *Alethopteris* sp.; H. *Lepidodendron* cf. *subdichotum* (determinations S. Opluštil). Specimens A, B, E, F and H from Mt. Corona (Pontebba, Udine); C from Casera Cordin Grande (Paularo, Udine); D and G from Casera Auernig (near the old landslide, Pontebba; Udine).

Large collections from the graphite-rich metapelites and metasandstones of the San Lorenzo Schists were put together by SIGISMONDO DE BOSNIAKI (1837–1921) and CARLO DE STEFANI (1851–1924), at the end of 19th century (DE BOSNIAKI, 1894; DE STEFANI, 1901). The collection of plant fossils of DE STEFANI (~ 1.000 specimens), is stored at the Natural History Museum of Florence, and at the Museum of Natural History of Pisa University (see CIOPPI in MONECHI & ROOK, 2010 for details; Fig. 16); the palaeontological collection (7000 specimens of plants and animals) of DE BOSNIAKI (1894) is stored at the Museum of Natural History of Pisa University. Additional discoveries in the same area (Valentona, Monte Togi, Monte Vignale, Sasso Campanaro) enriched the collection of those two museums.

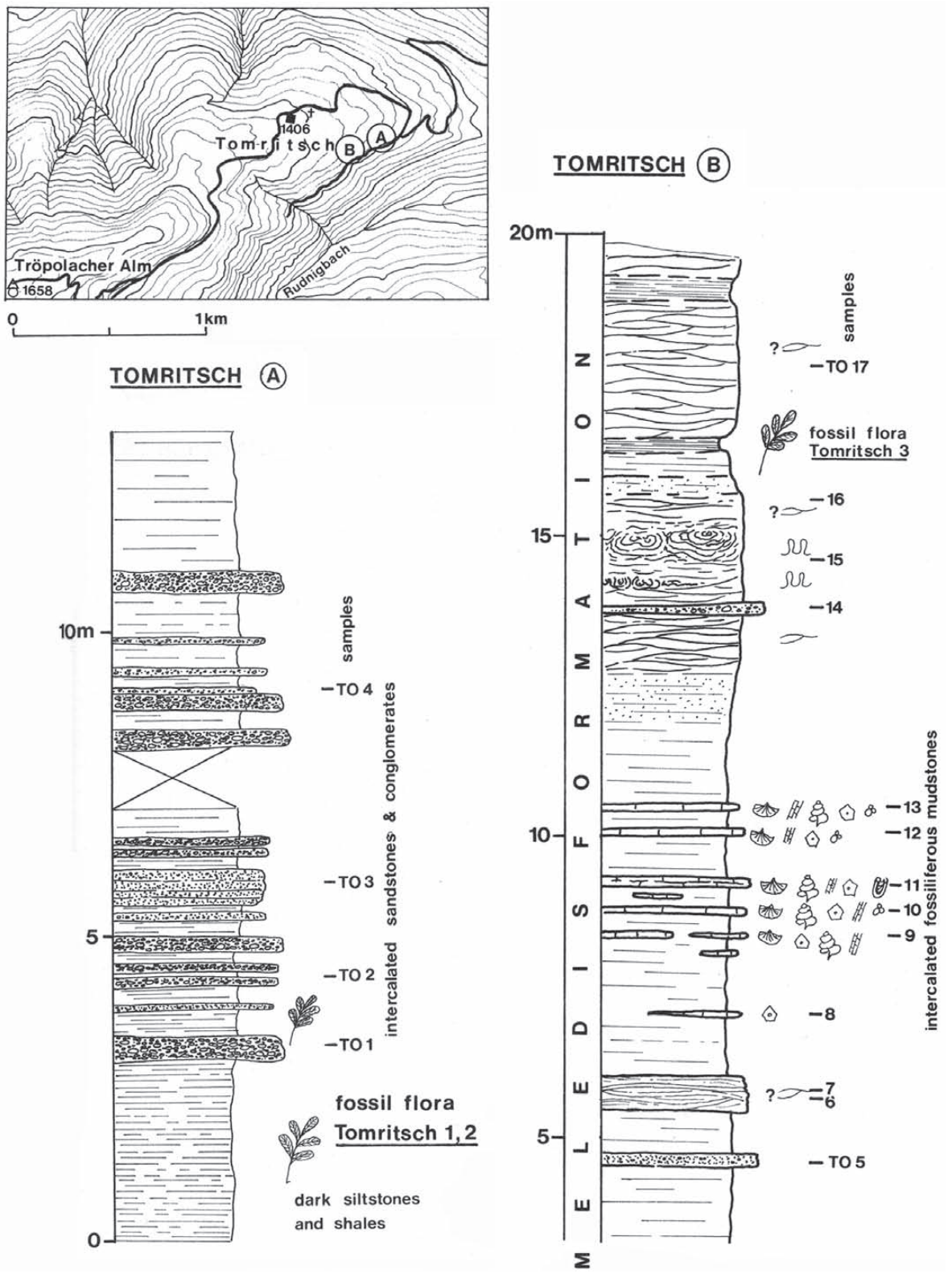


**Figure 13:** Stratigraphic sections from the Bombaso Formation (Pramollo Mb.: Tomritsch A) and basal Pramollo Group (Auernig Group auct) units (Meledis Formation or A1 Formation: Tomrisch B). In the inset, a location map of the two sections Tomritsch A and B.) (from KRAINER in VENTURINI, 1990b, mod.).

A recent reorganisation of DE STEFANI'S collection shows a flora composed of lycopsids (*Sigillaria, Lepidodendron*), horsetails (*Calamites*, *Asterophyllites*, *Annularia*, *Sphenophyllum*), ferns (*Acitheca*, *Cyathocarpus*, *Diplazites*, *Sphenopteris*), seed ferns (*Alethopteris*, *Callipteris*), "cycads", *Cordaites* and conifers (*Walchia*; LANDI DEGLI INNOCENTI et al., 2008; CIOPPI in MONECHI & ROOK, 2010). No further information exists on the collection of DE BOSNIAKI. DE BOSNIAKI (1894) attributed the floras to the Permian, while DE STEFANI (1984) attributed them to

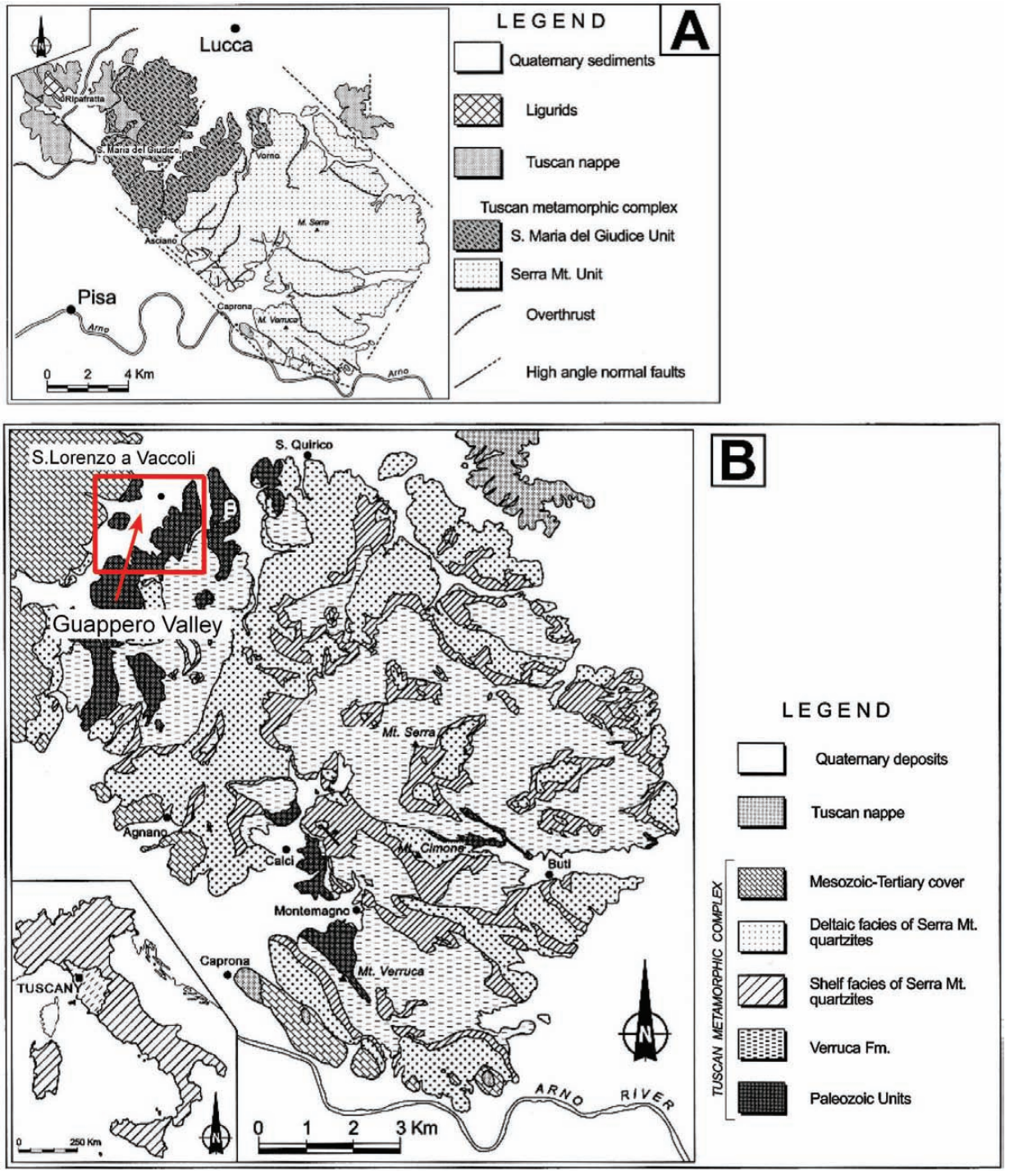


**Figure 14:** A structural sketch of the Pisani Mountains A. Tectonic map; B. Geological map (From RAU & TONGIORGI, 1974; TONGIORGI et al., 1977).

the Carboniferous. Fig. 17 shows a biostratigraphic and lithostratigraphic subdivision of the Pennsylvanian-Autunian succession, on the basis of different fossil floras found at various localities in the Valle del Guappero (from TREVISAN, 1955 and RAU & TONGIORGI, 1974 in LANDI DEGLI INNOCENTI et al., 2008; mod.).

It is suggested that these floras are similar to the Sardinian flora of the San Giorgio basin described by COCOZZA (1967). The genera *Annularia*, *Asterophyllites*, *Calamites*, *Callipteridium*, *Cordaites*, *Pecopteris*, and *Walchia*, occur in both floras (LANDI DEGLI INNOCENTI et al., 2008; CIOPPI in MONECHI & ROOK, 2010; see Fig. 18). TONGIORGI unsuccessfully attempted to collect micro-palaeontological data in the area of the Pisani Mountains (LANDI DEGLI INNOCENTI et al., 2008). Marine fossils of inferred Pennsylvanian age, were recently discovered in the lower part of the San Lorenzo Schists at Montuolo (PANDELI et al., 2008). These discoveries indicate strong palaeoenvironmental analogies between this part of the San Lorenzo Schists and the coeval, coastal-neritic Iano Schists and sandstones

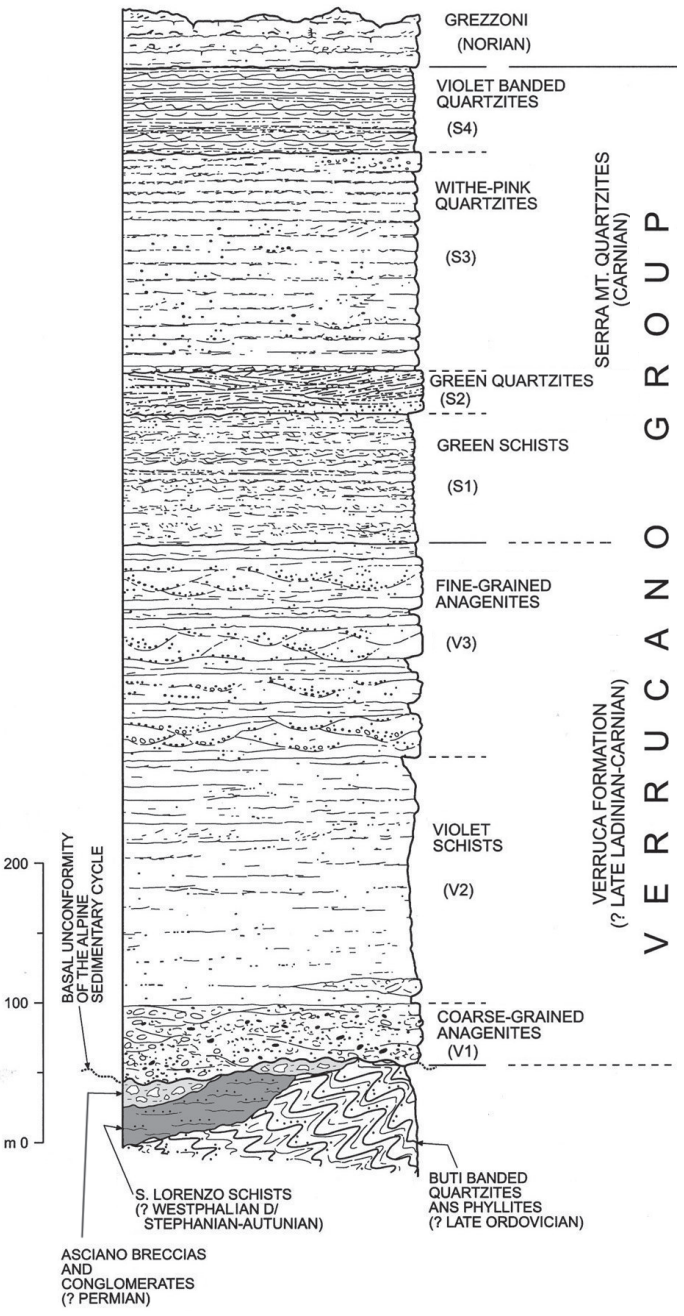


**Figure 15:** Lithotratigraphic column of the Palaeozoic–Carnian succession of the Pisani Mountains, (after RAU & TONGIORGI, 1974).

cropping out near Volterra (COSTANTINI et al., 1998) and the Rio Marina Formation on Elba Island (PANDELI et al., 2008).

### Iano

Eastward, south of the Arno River, in the neighbourhood of the village of Iano (near Volterra) (Fig. 19), the basal sedimentary succession of the Iano Schists (Fig. 20) yielded, plant fossils, crinoids, bivalves and putative brachiopods of Stephanian age from some of the more pelitic beds (VAI & FRANCAVILLA, 1974; PANDELI, 1998).

The plants belong to the lycopsids (*Stigmaria*), horsetails (*Calamites*, *Annularia*,) and ferns (*Acitheca*, *Aspidiopsis*, *Cyathocarpus*, *Diplazites*; CIOPPI in MONECHI & ROOK, 2010)

## 4. SARDINIA

Trans-tensional tectonics, which deeply affected the dismantling of the Variscan orogen, led to the opening of a number of intramontane basins, filled with lacustrine to alluvial sediments (RONCHI et al., 2008 and ref. therein; see Fig. 21).

### South-western Sardinia

Clear evidence of the first post-orogenic clastic deposition on the island is represented by the reduced San Giorgio Basin sequence, which crops out in the Iglesiente subregion (Figs. 21 and 22), and has been studied in detail (COCOZZA, 1967; BARCA & COSTAMAGNA, 2003; see Fig. 23). The San Giorgio flora comprises for example *Pecopteris arborescens*, *Callipteridium pteridium*, *Neuropteris planchardi* and *Diksonites plueckenetii* f. *sterzeli*. This flora is stored in the Carbonia Museum and in the Museo di Geologia e Paleontlogia "D. Lovisato" of the Dipartimento di Scienze Chimiche e Geologiche of Cagliari. COCOZZA (1967) proposed a late Stephanian age for it, based on the composition of the megafossils. The finer sediments of this basin yielding a rich microflora have been attributed a late Westphalian and early Stephanian (A and B) age (DEL RIO & PITTAU in CASSINIS et al., 2000; PITTAU & DEL RIO, 2002b). The flora shows several endemic species, suggesting onset of a regional characterized Sardinian flora resulting from the isolation of Sardinia from southern Europe during the Pennsylvanian, (for more details see PITTAU et al., 2008b).

### Central-eastern Sardinia

In central-eastern Sardinia (Fig. 21), there are two basins with transitional "Stephano-Autunian" macrofloras: the Lake Mulargia (Sarcidano subregion), and the Seui-Seulo/Montarbu (Barbagia di Seulo subregion; RONCHI et al. 2008; CASSINIS et al., 2003). The flora of Lake Mulargia, with taxa such as *Callipteris conferta (*now *Autunia conferta)*, *C. naumanni*, *Lebachia* cf. *hypnoides* was originally dubiously ascribed to the late Autunian (FRANCAVILLA et al., 1977). In the Seui Basin and the adjacent Seulo Basin, outcrops with plant megafossils occur in the fine-grained sediments (CASSINIS et al., 2003). About 50 different species were described by LAMARMORA (1857), MENEGHINI (1857), PAMPALONI (1900) and ARCANGELI (1901) for more details see COMASCHI CARIA (1959). The flora has been attributed to the Pennsylvanian-Cisuralian period. Also a recently collected flora with *Annularia sphenophylloides*, cf. *Pecopteris arborcens*, (?*P. cyathea*, *Pecopteris* sp., *Pecopteris* sp. aff. *hemitelioides*, *P. unita*, *Cordaites* sp., *Sigillaria brardi*, and *Artisia* sp. has been ascribed to an interval spanning the latest Carboniferous to basal Early Permian (Autunian; BROUTIN et al., 2000; CASSINIS et al., 2003).


**Figure 16:** A. *Acitheca isomorpha* (sample IGF 13164); B. *Crossotheca pinnatifida* (sample IGF 332P); C. *Sphenophyllum oblongifolium* (sample IGF 160P); D. *Asterophyllites equiseformis* (sample IGF 13142); E. *Crossotheca pinnatifida* (sample IGF 424P). With the kind permission of Elisabetta Cioppi (Museo di Storia Naturale dell'Università degli Studi di Firenze, Sezione di Geologia e Paleontologia).

A succession with a clear "early Autunian" age (i.e., basal Asselian) macro- and microflora, is that of Guardia Pisano (Sulcis subregion, PITTAU et al., 2002a), whereas succession with "late Atunian" macro- and microfloristic associations include those of Escalaplano, Perdasdefogu (Gerrei and Ogliastra subregions) and Lu Caparoni (Nurra subregion). For more information on such basins see also RONCHI et al. (1998) and CASSINIS et al. (2000). A comparative and chronostratigraphic correlation chart of the different Pennsylvanian, Permo-Carboniferous and Permian basins of Sardinia was produced by RONCHI et al. (2008; see Fig. 25).

Slightly different age-attributions for the latest Carboniferous-Autunian basins are suggested by PITTAU et al. (2008b; Fig. 26) based on the microfloristic data. Given the microfloral composition, these authors distinguish four different palynological phases: Pteridophytic pre- Striatiti pollen Phase (Westphalian C-Stephanian A); *Florinites* Phase (Stephanian/Autunian) with relatively dominant *Cordaites* pollen grains; *Potonieisporites* Phase (Asselian) with dominant monosaccate pollen (*Potonieisporites*); *Vittatina*-Striatiti pollen Phase (Asselian-(?)Sakmarian age). The flora of central-eastern Sardinia is stored at the Lovisato Museum at the Dipartimento di Scienze Chimiche e Geologiche of Cagliari and at the Natural History Museum of Florence (PAMPALONI collection).

| L. TREVISAN (1955)<br>Biostratigraphy | A. RAU & M. TONGIORGI (1974)<br>Lithostratigraphy |
|---|---|
| Via Pari and Sasso Campanaro:<br>*Walchia piniformis, Callipteris conferta*<br>AUTUNIAN (LOWER PERMIAN) | Sasso Campanaro:<br>AUTUNIAN (LOWER PERMIAN) |
| M. Vignale:<br>*Taeniopteris multinervis*<br>STEPHANIAN A and B | M. Vignale:<br>AUTUNIAN (probable) |
| M. Togi:<br>*Sphenophyllum oblungifolium, Pecopteris arborescens, Acitheca isomorpha*<br>STEPHANIAN A | Traina:<br>?STEPHANIAN B and STEPHANIAN C |
| Villa Massagli:<br>Lepidodendris flora<br>WESTPHALIAN D | Villa Massagli:<br>STEPHANIAN A and B |

**Figure 17:** Chronological ordering of the main fossil sites of the San Lorenzo Schists formation according to TREVISAN (1955) and RAU & TONGIORGI (1974). TREVISAN (1955) indicated the index fossils for each fossil locality (from LANDI DEGLI INNOCENTI et al., 2008, mod.).

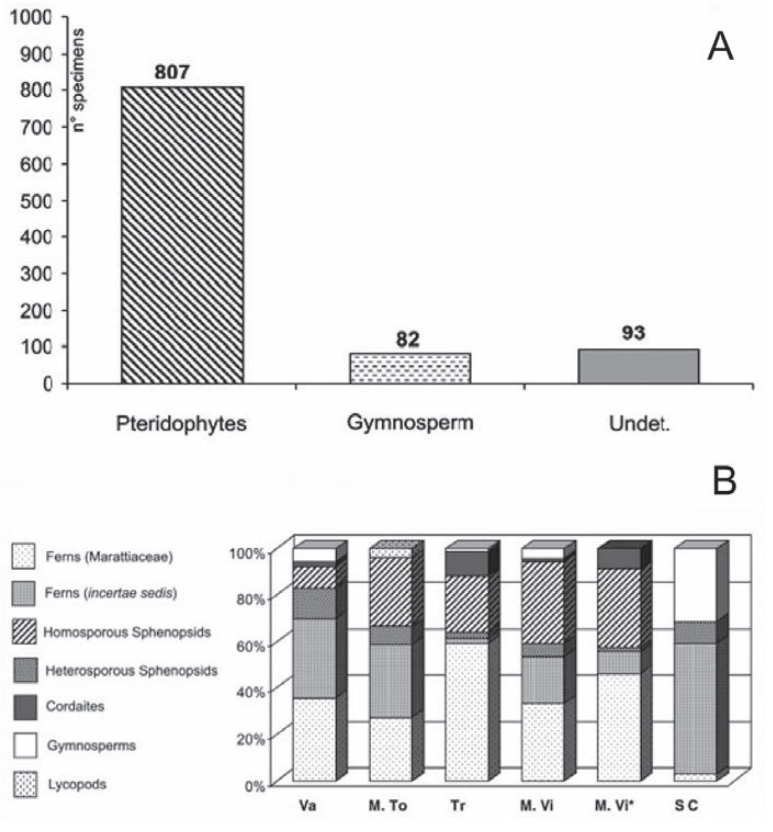


**Figure 18:** Fossil floras from the Pisani Mountains. A. Main taxonomic groups of the De Stefani collection B. Percentages of the taxonomical groups of the fossil sites identified in the De Stefani collection. Va: Valentona; M. To: Monte Togi; Tr: Traina; M. Vi: Monte Vignale; M. Vi*: Monte Vignale (collected by Fucini); SC: Sasso Campanaro (after LANDI DEGLI INNOCENTI et al., 2008, mod.).

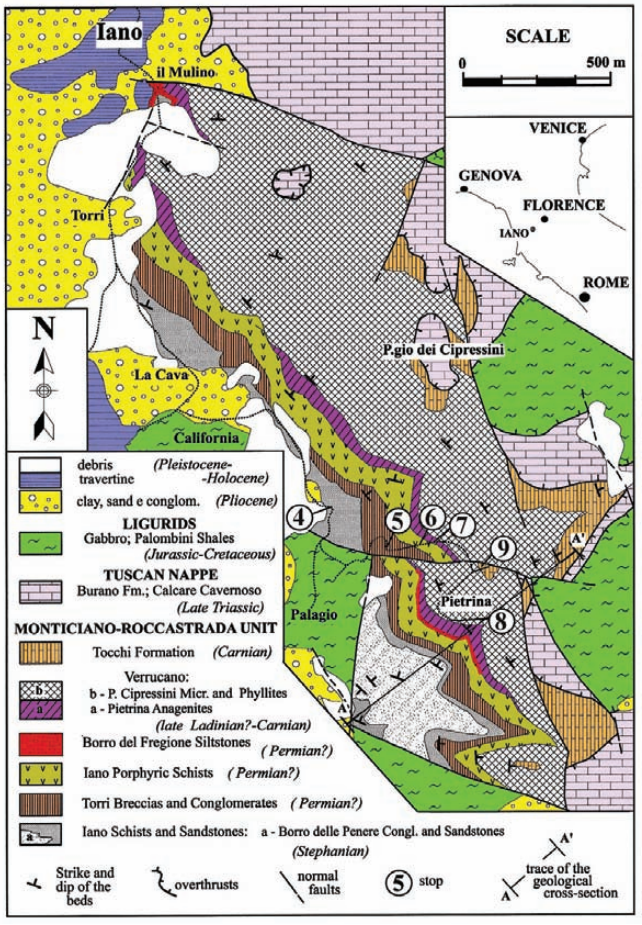


**Figure 19:** Generalized geological map of Iano (after COSTANTINI et al., 1998 and PANDELI, 1998).

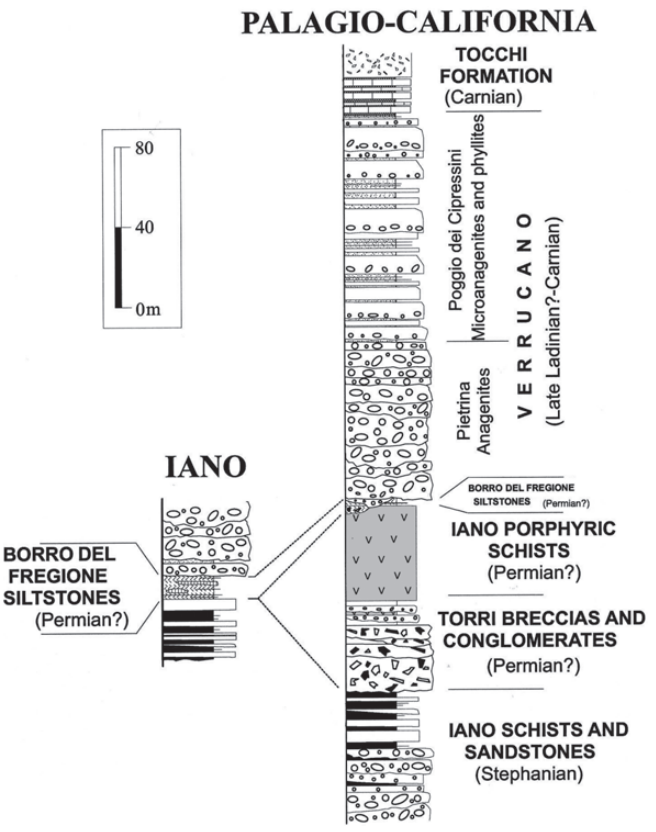


**Figure 20:** Lithotratigraphic column of the Carboniferous-Carnian succession of the Iano inlier (after COSTANTINI et al., 1998).

According to BROUTIN (in RONCHI et al., 2008), the Montarbu flora (Barbagia di Seulo subregion), firstly signalled by SPANO (1976), is a hygrophyllous Stephanian-like assemblage, with the very fragmentary cf. *Rhachiphyllum* sp. looking as an "Autunian" callipterid. Thus, the age of the Montarbu flora is still not well constrained.

From a palynological point of view, the Montarbu microflora is framed in the *Potonieisporites* Phase (PITTAU et al., 2008b), being represented by high numbers of *Potonieisporites* and *Florinites* and with a minor component represented by *Plicatipollenites, Costapollenites* and *Vittatina* pollen types. Thus, Voltziales, Cordaitales and, to a lesser extent, Peltaspermales appear to characterize the flora growing on dry or drained areas and slopes, in the surroundings of the lacustrine basin of Montarbu, at Seui and Seulo, whereas a hygrophillous flora of licophytes, sphenophytes and pterophytes, covered shorelake, banks, ponds and the alluvial plain.

## 5. LIGURIA

In Western Liguria (Briançonnais units) the Late Palaeozoic volcano-sedimentary sequence begins with fine to coarse-grained arkosic and quartzitic meta-sediments of continental origin, formed by reworking of the underlying orthogneissic Namurian(?) basement, some hundred metres thick (Lisio Formation). This is followed by widespread calc-alkaline rhyolitic–rhyodacitic ignimbrites (Case Lisetto Metarhyolites) (VANOSSI et al., 1986; CORTESOGNO et al., 1988b), in turn covered by fluvial-lacustrine meta-conglomerates (Ollano Formation).

This sequence of sedimentary units was generally ascribed to the Late Westphalian–Stephanian interval on the basis of old records of plant remains, among which were *Senftenbergia (Pecopteris) elegans*, *Pecopteris nodosa*, *Annularia longifolia* (Pian del Fo, Viozene; PORTIS, 1887) and *Odontopteris obtusa* (Pietratagliata; SQUINABOL, 1887). In the second half of the 20th century, BLOCH (1966) distinguished the following forms in the Ollano Formation: *Pecopteris plumosa dentata*, *Sphenopteris schatzlarensis*, *Imparipteris* (*Neuropteris*) *oblique* and *Lepidophyllum* sp., together with traces of *Neuropteris* and *Calamites*, and attributed the pertaining deposits to the late Westphalian (-Stephanian).

According to the authors (e.g. VANOSSI et al., 1986), during the Pennsylvanian (Stephanian–?Autunian), lacustrine shales and siltstones (Murialdo Formation) or continental arenites (Viola and Gorra Schists) were deposited

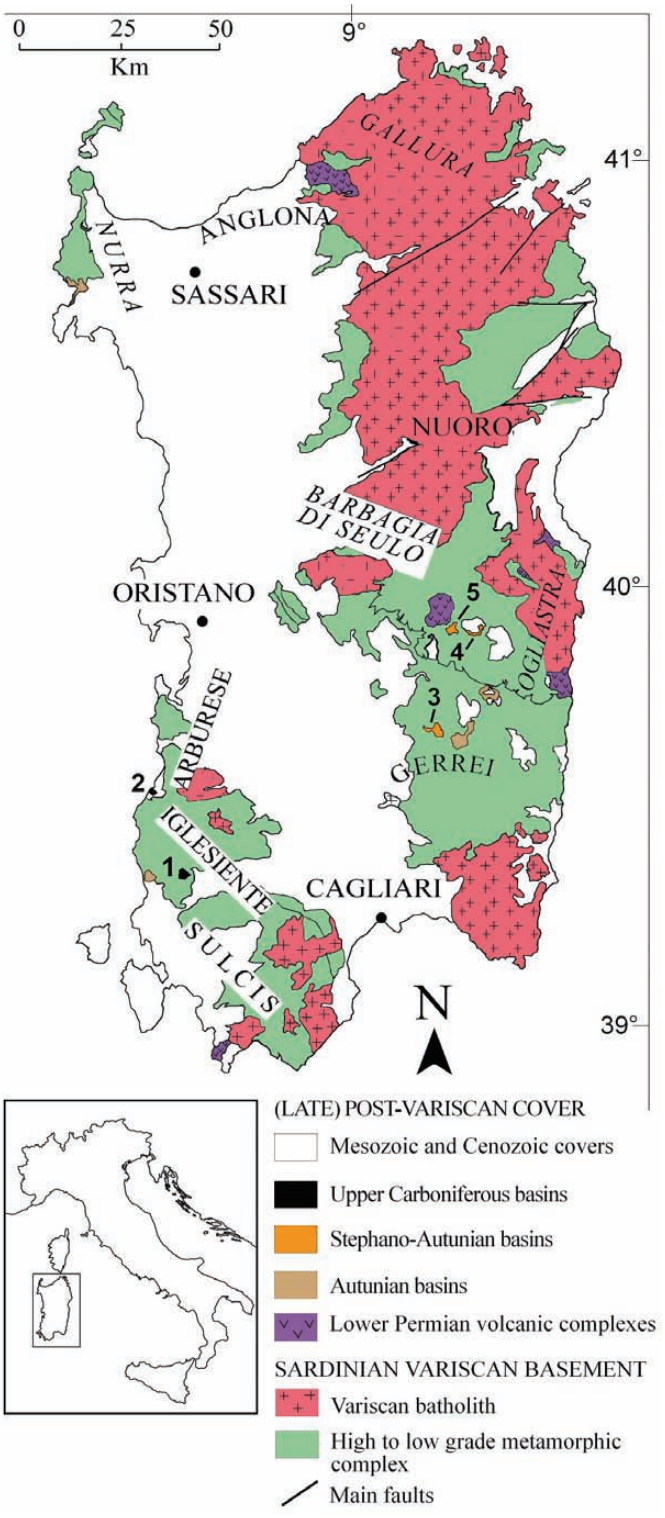


**Figure 21:** Location of the main Pennsylvanian and Permo-Carboniferous basins in Sardinia: 1) San Giorgio (Iglesiente subregion); 2) Tuppa Niedda (Arburese subregion); 3) Lake Mulargia (Sarcidano subregion); 4) Seui-Seulo (Barbagia di Seulo subregion); 5) Montarbu (Barbagia di Seulo) (from RONCHI et al., 2008, mod.).

either on the Ollano Formation, or directly on the basement. This sedimentation is associated with the emplacement of andesite, and rare dacite lavas, and volcanic breccias, mainly in lacustrine basins. Tuffs and epiclastites of intermediate composition are widespread, also within continental arenites (Eze Formation).

Elsewhere in the Penninic domain, Pennsylvanian magmatism is poorly represented, whereas the continental deposits, associated with strike-slip tectonics, are well developed, such as within the coeval sediments of the 'Zone Houiller Briançonnais' (e.g. FABRE, 1961; BROUSMICHE-DELCAMBRE et al., 1995 and ref. therein).

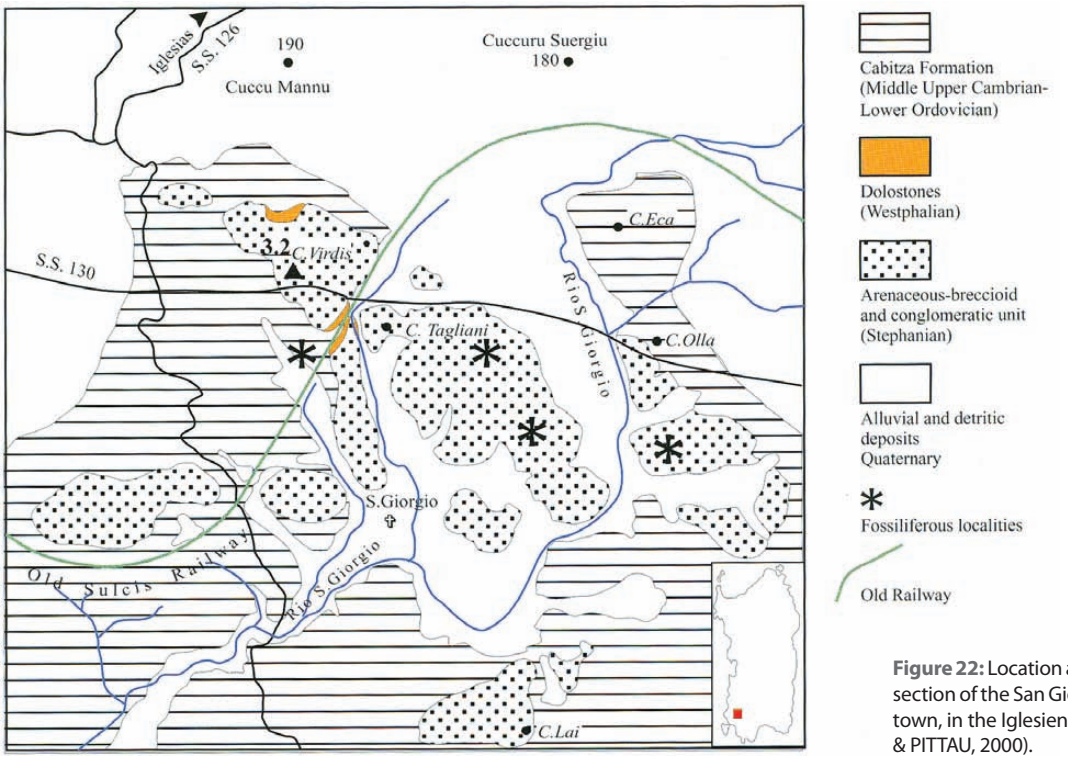


**Figure 22:** Location and schematic stratigraphic section of the San Giorgio basin, close to Iglesias town, in the Iglesiente subregion (from DEL RIO & PITTAU, 2000).

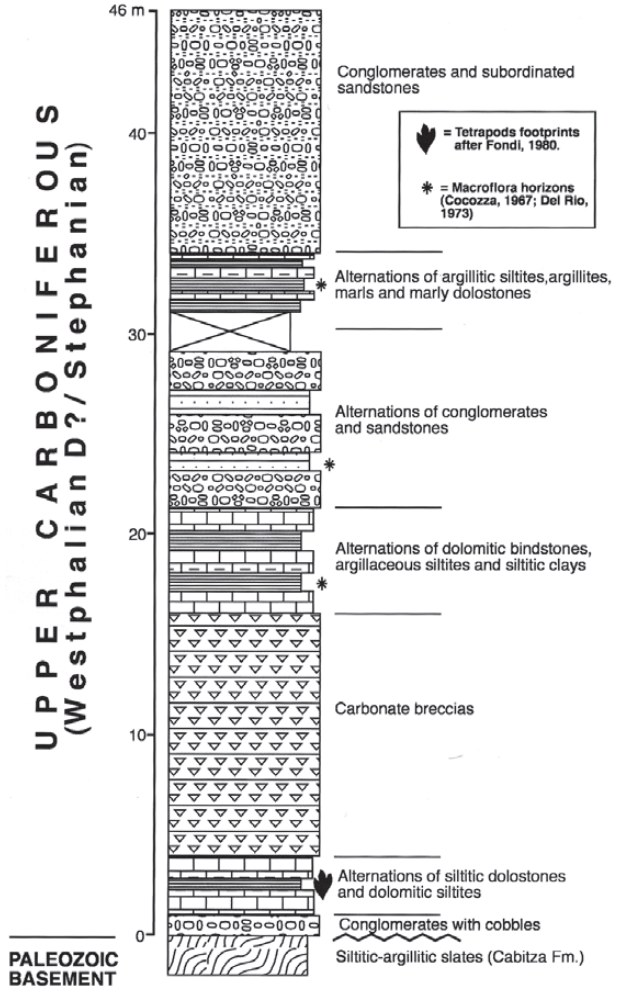


**Figure 23:** Stratigraphic section of the Pennsylvanian San Giorgio Basin (from BARCA & COSTAMAGNA, 2003).

In contrast with such accepted age-determinations, and with all the former stratigraphic interpretations (see e.g., VANOSSI et al., 1986), the Pennsylvanian volcanic and sedimentary clastic deposits, which unconformably overlie a Namurian crystalline basement, have recently been related to Permian ages (DALLAGIOVANNA et al., 2009). New radioisotopic dates on the Case Lisetto rhyolites (285.6 ±2.6 Ma concordant age), ascribed these volcanic rocks to the late Sakmarian–?Artinskian time-span. Therefore the Ollano Formation should be placed in the Early Permian, in firm conflict with its palaeontological content, as reported in earlier literature.

Shiny graphite-like features, found whitin Carboniferous schists by DE STEFANI (1887a) on his excursions to Pietratagliata (Genoa), are stored in the Natural History Museum of Florence (CIOPPI in MONECHI & ROOK, 2010).

## 6. CONCLUSIONS

The Italian Pennsylvanian continental successions are scattered across the country in the following places:

1) In the western Southern Alps (Lombardy/Switzerland) sparse sections occur pitched in tectonic slices at the front of the metamorphic basement. The rich macroflora from the Alpe Logone has been dated to the Bolsovian (Westphalian C), or Duckmantian-Bolsovian (Westphalian B–C transition). Between the Maggiore and Lugano lakes, the outcrops are less rich in plant remains, and perhaps slightly older than these of Logone.

2) In the eastern Southern Alps (Carnic Alps) the Carboniferous successions crop out in several localities near the border with Austria, such as Passo Pramollo, Cason di Lanza,

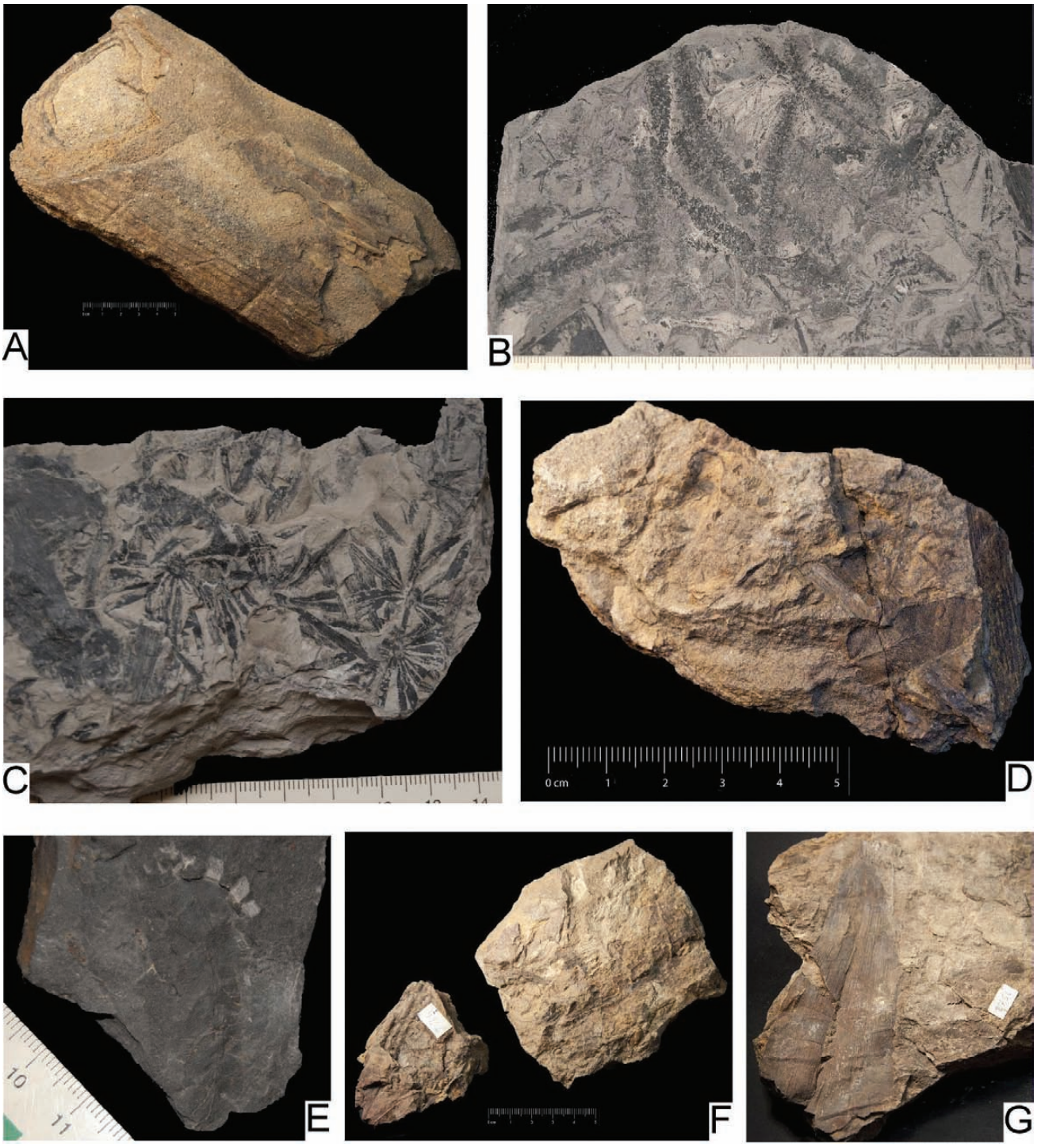


**Figure 24:** Plant fossils from the Pennsylvanian San Giorgio Basin (SW Sardinia). A. *Calamites* sp.; B. *Sphenophyite strobili* (cf. *Calamostachys*); C. *Annularia* sp.; D. *Neuropteris planchardii*; E. *Odontopteris* sp., F. *Dicksonites plueckenetii*; G. *Cordaites* cf. *lingulatus*.

Rio dai Amplis, Fontanone, Cima Val di Puartis, Monte Pizzul and Monte Corona. Although the flora has been studied partly on the Austrian side, the Italian outcrops are poorly studied. Plant fossils occur there in several formations of the Pramollo Group, but are especially abundant in the Corona Formation. The floras seem to have ages varying from Cantabrian up to lower to middle Stephanian.

3) In Tuscany, the floras mostly come from the Pisani Mountains and the surroundings of Iano. The San Lorenzo Schists, from which the specimens of the historic collections were collected, have been attributed to a Pennsylvanian to Cisuralian age.

4) Several small basins in Sardinia yield megafossils and/or palynomorphs respectively of Westphalian-Stepha-

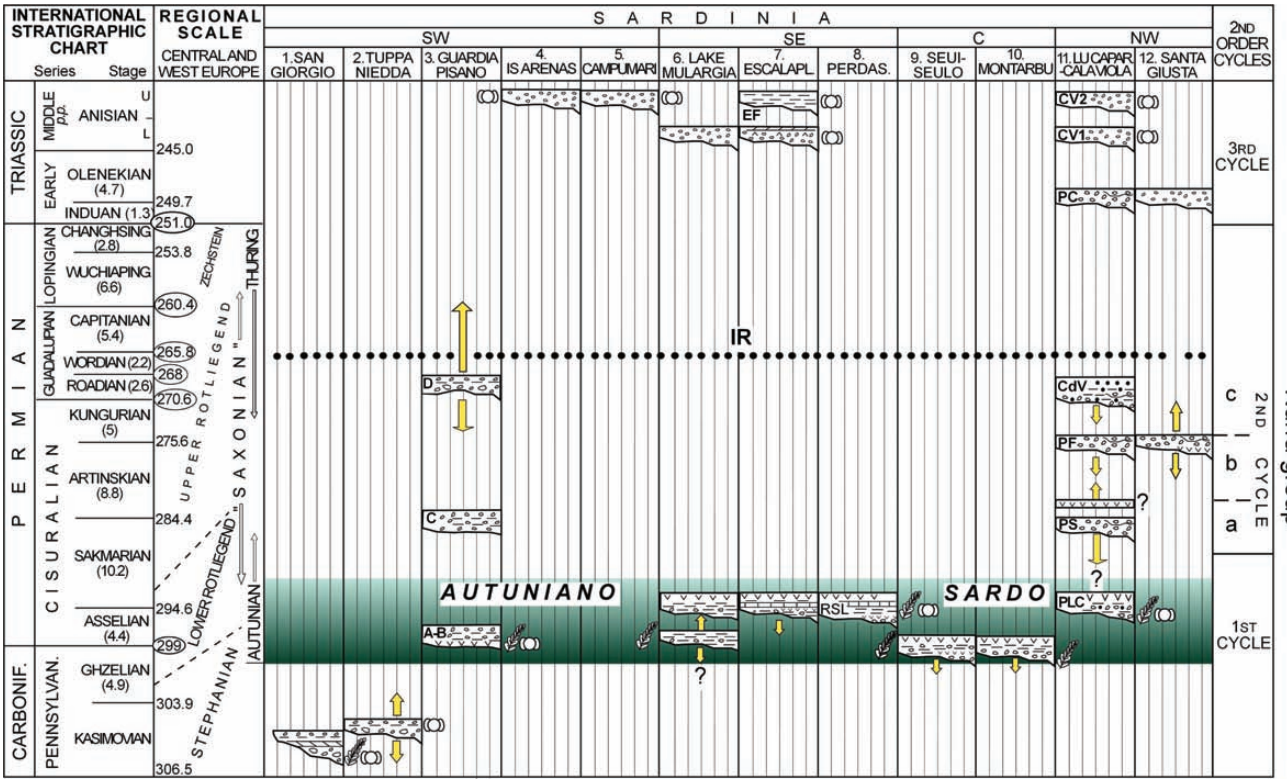


**Figure 25:** Correlation chart of the main Pennsylvanian and Permo-Carboniferous basin of Sardinia (from RONCHI et al., 2008, mod.). The numbers below stage names represent the duration of the stages.

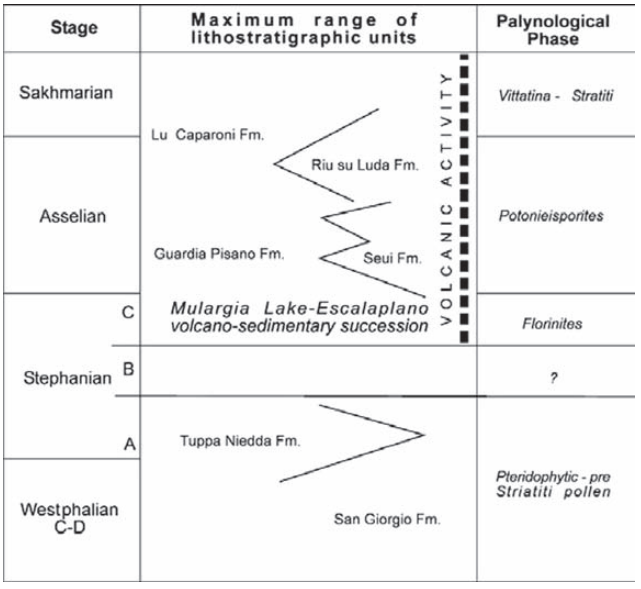


**Figure 26:** Correlation hypothesis for lithostratigraphic units and Palynological phases proposed for the continental succession of the Upper Carboniferous and Lower Permian of Sardinia (from PITTAU et al., 2008b).

nian, Stephano-Autunian or Autunian age, suggesting the differentiated onset of basins in Late Palaeozoic times in relation to the Hercynian and moreover post-Hercynian tectonic events.

5) The floras of Liguria mostly come from Pietratagliata (Genoa). This flora has a Late Westphalian–Stephanian age.

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