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# Influence of terrestrial sedimentation in Pennsylvanian rocks of Croatia

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## ABSTRACT

Sedimentary rocks of Pennsylvanian age outcrop at several regions in Croatia. Most of these rocks were deposited in a marine environment, in different tectonic units: Karst (External) Dinarides, Internal Dinarides and Tisia. Pennsylvanian deposits contain a significant amount of terrestrial debris, related to the uplift of the Hercynian mountain belt and its intense erosion. Remnants of land flora are not common, but are present at almost all localities. The most diverse and the best preserved Pennsylvanian land flora in Croatia was discovered on the Velebit Mt. and in the Lika Region. It was dominated by ferns, pteridosperms and cordaitales. The fossil flora from Banovina is less diverse, with pteridosperms, scarce ferns, horsetails and lycopods. The sporadic occurrence of lycopods and horsetails was reported from the mountains of NW Croatia. In the Gorski Kotar Region only plant detritus was observed. Ferns and pteridosperms from Papuk Mt. were discovered in older, Mississippian deposits.
Palaeobotanical data reopen the discussion about the palaeogeographic position of the research areas.

**Keywords:** Pennsylvanian, terrestrial sedimentation, megaflora, Croatia

## 1. INTRODUCTION

Carboniferous rocks are present at the surface in several scattered areas in Croatia (RAMOVŠ et al., 1990; SREMAC, 2005) (Fig. 1). In all these areas Pennsylvanian deposition was influenced by the input of terrestrial debris, and by the occurrence of land flora.

The most interesting Pennsylvanian outcrops are described from the External (Karst) Dinarides (Figs. 1, 3). A rather continuous Carboniferous-Permian succession of sedimentary rocks is exposed as the core of the Velebit anticline (Locality 1). Late Palaeozoic rocks are present as scattered outcrops with tectonic boundaries in the Gorski Kotar region (Locality 2). Mountains of NW Croatia (Medvednica, Samoborska Gora and Marijagorička Brda) (Locality 3), are situated in the Zagorje-Mid-Transdanubian zone, a dislocated section of the Internal Dinarides with mixed clastic-carbonate deposition during the Palaeozoic era. The Banovina region (Locality 4), with deposits ranging in age from the Devonian to the end-Permian, belongs to the Internal Dinarides, representing the platform edge (e.g., PAMIĆ & JURKOVIĆ, 2002) (Figs. 1, 3).

The Slavonian Mts. (Papuk Mt.) and Moslavačka gora Mt. (locality 5) with a metamorphic Palaeozoic complex, belong to the Tisia Unit (Figs. 1, 3) (PAMIĆ & JURKOVIĆ, 2002; VOZAROVA et al., 2009).

Late Palaeozoic rocks were first studied in Croatia for the purpose of geological mapping during the Austro-Hungarian monarchy in the 19$^{th}$ century. The first collections of Carboniferous land flora in Croatia were discovered during ore exploitation in the area of Trgovska Gora Mt. (GEINITZ, 1868; STUR, 1868) and the Lika Region (NEMĚJC, 1939).

Salopek and his team performed detailed geological studies of the Late Palaeozoic deposits, producing precise maps of Velebit Mt. and the Lika and Gorski Kotar Regions (SALOPEK, 1942, 1948, 1949, 1960), while collecting numerous samples for further palaeontological studies. Carboniferous marine fossils were determined by KOCHANSKY-DEVIDÉ (1955, 1970), KOSTIĆ-PODGORSKA (1956), KOCHANSKY & HERAK (1960), ĐURĐANOVIĆ (1968, 1973), RUKAVINA (1973), BALAŽ (1981) and MILANOVIĆ (1982). During the field work in Northern Croatia, JENKO (1944) and HERAK (1956) reported spo-

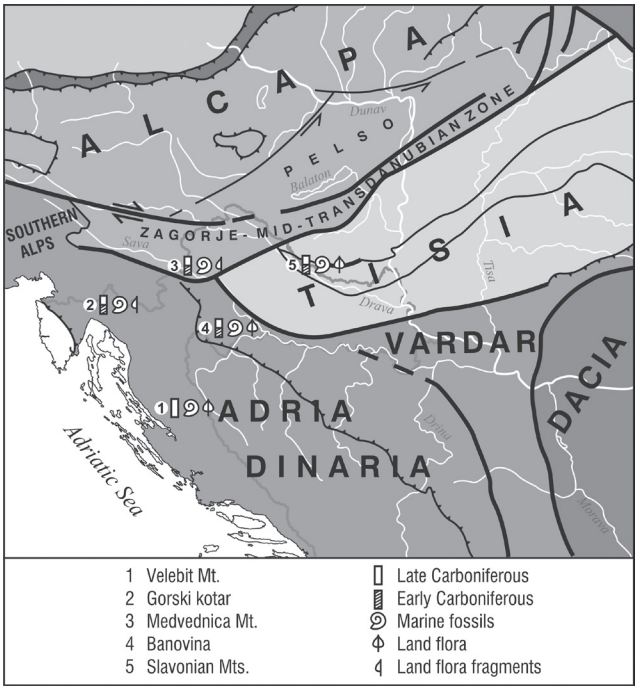


**Figure 1:** Tectonostratigraphic units of the Circum Pannonian Region with the position of Carboniferous outcrops in Croatia (modified after VOZAROVA et al., 2009).

radic occurrences of terrestrial megaflora in the Marijagorička Brda Hills and Samoborska Gora Mt.

A new cycle of mapping for the Basic Geological Map of Yugoslavia 1:100 000 yielded new information. Carboniferous areas in Croatia were presented as sheets and in explanatory booklets Crikvenica L33-102 (GRIMANI et al., 1970, 1973), Daruvar L33-95 (JAMIČIĆ, 1989; JAMIČIĆ et al., 1989), Delnice L33-90 (SAVIĆ & DOZET, 1985 a,b), Gospić L33-127 (SOKAČ et al., 1974, 1976a), Ivanić-Grad L33-81 (BASCH 1981, 1983), Obrovac L33-140 (IVANOVIĆ et al. 1973, 1976), Orahovica L33-96, JAMIČIĆ & BRKIĆ, 1988; JAMIČIĆ et al., 1987), Udbina L33-128 (ŠUŠNJAR et al., 1973; SOKAČ et al., 1976b) and Zagreb L34-98 (ŠIKIĆ et al., 1978, 1979). During this period, BRKIĆ et al. (1974) described Mississippian plant fossils from the Slavonian Mts.

The last mapping cycle in Croatia resulted in the new Geological map of Croatia 1:300 000 and Explanatory text with description of stratigraphic units (VELIĆ & VLAHOVIĆ, eds., 2009).

## 2. CARBONIFEROUS OUTCROPS IN CROATIA

### 2.1. Velebit Mt. and the Lika Region

The most complete succession of clastic and carbonate deposits from the Pennsylvanian (Moscovian) to the end of the Permian and the beginning of the Triassic (RAMOVŠ et al., 1990; SREMAC, 2005), can be derived from an elongate ca. 50 km long Palaeozoic belt, striking NW-SE, exposed as the core of the Velebit anticline in the External Dinarides (Figs. 1, 3). Carboniferous outcrops are presented on the Basic Geologic Map of Yugoslavia, sheets Gospić L33-127 (SOKAČ et al., 1974, 1976), Obrovac L33-140 (IVANOVIĆ et al., 1973, 1976) and Udbina L33-128 (ŠUŠNJAR et al., 1973; SOKAČ et al., 1976).

Pennsylvanian deposits in Velebit Mt. and the Lika Region are represented by shallow marine clastic-carbonate rocks of Moscovian to Gzhelian age (Fig. 2).

#### 2.1.1. Fossiliferous clastic-carbonate rocks: (Moscovian – Kasimovian)

The lowermost Carboniferous horizon outcrops in the area of Štikada and Sv. Rok (VELIĆ et al., 2009). Dark-grey finely bedded shale contains quartz greywacke and crinoid limestone/dolomite intercalations (SALOPEK, 1942, 1948). Numerous brachiopods and bryozoans are present in the yellowish-weathered shale. A Moscovian age was first determined on the basis of fusulinids and calcareous algae (KOCHANSKY-DEVIDÉ, 1955, 1970). It can be considered as the equivalent of the Fusulinella-Protriticites zone (MERINO-TOMÉ et al., 2009). Lower Kasimovian sediments contain the first fusulinid taxa with keriothecal wall-structure, such as *Protriticites* (KOCHANSKY-DEVIDÉ, 1955, 1970). Phylloid algae (*Eugonophyllum, Anchicodium*) and *Shamovella* (*Tubiphytes*) are common in limestone intercalations.

Contact with younger deposits is partially tectonic, and partly exhibits a continuous transition (VELIĆ et al., 2009).

#### 2.1.2. Fusulinid ("Triticites") sandstone: (Kasimovian)

Shale, sandstone and conglomerate rhythmically alternate within this horizon. Fine-grained well sorted greywacke dominates in the lower portion and shale is more common in the upper layers. The input of terrestrial debris is significant. Elongate fusulinids are often dissolved and washed out, with a dark brown film covering empty casts, due to the fresh-water influence and activity of iron synthesising bacteria. Conglomerate appears in the form of lenses or intercalations within the shale, sometimes with gradational or oblique bedding. Quartz pebbles predominate, but radiolarian chert, pyroclastic and siltite materials are also present. Fossiliferous limestone lenses are scarce, also containing terrigenous quartz grains (VELIĆ et al., 2009). Late-diagenetic dolomitization is common. On the basis of fusilinids: *Eoparafusulina pusilla* (SCHELLWIEN)*, E. pseudosimplex* (CHEN) *and „Triticites" brevispira* KOCHANSKY-DEVIDÉ (KOCHANSKY-DEVIDÉ, 1955), this horizon can be considered as an equivalent of the Montiparus zone (MERINO-TOMÉ et al., 2009).

#### 2.1.3. Shale and sandstone with land flora: (Late Kasimovian – Gzhelian)

Late Kasimovian deposits are highly fossiliferous and comparable to the Auernig beds of the Carnic Alps (FRITZ & KRAINER, 2006) and partly to some localities in the Karavanke Alps in Slovenia (KOCHANSKY-DEVIDÉ & RAMOVŠ, 1966; KOLAR-JURKOVŠEK & JURKOVŠEK, 2002; JURKOVŠEK, 2012). They can be considered as equivalent of the Rauserites zone (MERINO-TOMÉ et al., 2009).

These rocks are lithologically similar to the previous units, but with evidence of increased terrestrial influence.

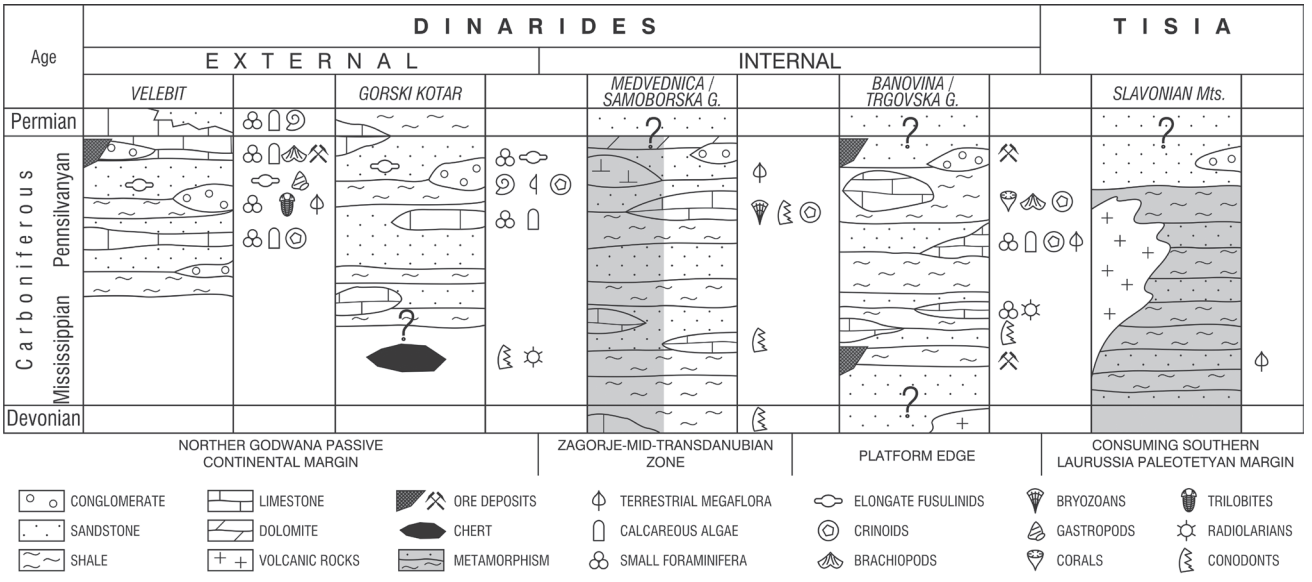


**Figure 2:** Schematic stratigraphic columns at different Carboniferous regions in Croatia. Deposit thickness not to scale (partly after RAMOVŠ et al., 1990; PAMIĆ & JURKOVIĆ, 2002; VOZAROVA et al., 2009, revised).

Shale, slate and sandstone with scarce intercalations of limestone and quartz conglomerate contain numerous fossils. Limestone intercalations are the most fossiliferous. They contain dasyclad *Anthracoporella spectabilis* PIA (KOCHANSKY-DEVIDÉ & HERAK, 1960; KOCHANSKY-DEVIDÉ, 1970), crinoids, brachiopods, bivalves, corals and foraminifera (SIMIĆ, 1935; SALOPEK, 1942, 1948; RUKAVINA, 1973; BALAŽ, 1981).

Diverse plant fossils (Table 1) occur within shale and greywacke. Well preserved lycopods (*Lepidodendron*), sphenophytes (*Sphenophyllum*), ferns (*Asterotheca, Pecopteris, Remia*), pteridosperms (*Callipteridium, Laveineopteris, Linopteris, Nemejcopteris, Taeniopteris, Sphenopteris*) and conifers (*Pseudomariopteris, Cordaites*) were collected by a coal-mining company in the early 20$^{th}$ century and described by NĚMEJC (1936). SALOPEK and his team discovered some new plant fossils during mapping in the area (SALOPEK, 1942, 1948) and the Croatian Museum of Natural History recently discovered one new locality with a terrestrial megaflora (ĐEREK, 2011, unpublished).

Zagreb plant collections were exhibited to participants of the IGCP 575 Zagreb meeting (2011) and examined in detail by Y. TENCHOV and C. CLEAL (plants), as well as E. JARZEMBOWSKI (insect traces). Plant taxa from the literature are presented at the Table 1, and new data are prepared and will be published separately.

### 2.1.4. Lower Rattendorf limestone (Gzhelian)

In the eastern part of the Velebit Palaeozoic belt, the terrestrial influence is prolonged into the Permian, resulting in carbonate-siliciclastic deposition. Western localities are characterized by dominantly carbonate rocks (equivalent of Rattendorf group), with large spherical preudoschwagerinids, small benthic foraminifera and calcareous algae (SALOPEK; 1942, 1948; KOCHANSKY-DEVIDÉ, 1959) (Fig. 2).

### 2.2. Gorski Kotar Region

Late Palaeozoic rocks in the Gorski Kotar Region (Fig. 1) outcrop as tectonically isolated blocks. Salopek and his team prepared the first detailed maps and lithofacies descriptions (SALOPEK, 1949, 1960). The area is represented on the Basic Geologic Map of Yugoslavia, sheets Crikvenica L33-102 (GRIMANI et al., 1970, 1973) and Delnice L33-90 (SAVIĆ & DOZET, 1985 a, b). Pennsylvanian rocks are interpreted as marine turbidite deposits (ŠPARICA, 2009).

The oldest autochthonous rock at the surface is the **Fusulinid sandstone**, with *Fusulinella* sp. div., some peculiar "*Triticites*" species and small schubertellids and endothyroids. A greywacke type of sandstone contains a significant amount of terrestrial debris and probably belongs to the Moscovian and/or Kasimovian periods (MILANOVIĆ, 1982; ŠPARICA, 2009).

Dark-grey, solid sandstone at first glance seems similar to the Fusulinid sandstone of Velebit Mt. (KOCHANSKY-DEVIDÉ, 1955). It is brown at the weathering surface, with numerous small cavities appearing after the dissolution of fusulinids. Parallel orientation of fusulinids or their moulds is typical for these rocks, indicating postmortem transport (MILANOVIĆ, 1982). Small, unrecognizable fragments of land flora can be found sporadically, probably transported down the slope by turbidite currents.

Carboniferous fossils also appear in clasts and pebbles of younger clastic deposits (SREMAC & ALJINOVIĆ, 1997; ALJINOVIĆ & KOZUR, 2003; ALJINOVIĆ et al., 2006).

### 2.3. Medvednica, Samoborska Gora and the Marijagorička Brda Mts.

Northwestern Croatia with Medvednica, Samoborska Gora and the Marijagorička Brda Mts. belongs to the Zagorje-Mid-Transdanubian Zone (Fig. 1). This tectono-stratigraphic

**Table 1:** List of Carboniferous megaflora from different localities in Croatia. External Dinarides: V - Velebit (NĚMEJC, 1936); Internal Dinarides: SG - Samoborska Gora Mt. (HERAK, 1956); MB - Marijagorička Brda Hills (JENKO, 1944); TG - Trgovska Gora Mt. (STUR, 1868); Tisia: P - Papuk (BRKIĆ et al., 1974). Modern assignment after LAVEINE (2005), ZODROW et al. (2006) and BASHFORTH et al. (2010).

| CARBONIFEROUS TERRESTRIAL FLORA IN CROATIA | Modern assignment | V | SG | MB | TG | P |
|---|---|---|---|---|---|---|
| LYCOPODIOPHYTA | | | | | | |
| *Lepidodendron* sp. | | X | | | | |
| *Lepidostrobus geinitzi* ZEILLER | | X | | | | |
| *Lomatophloios crassilepis* ZEILLER | | X | | | | |
| *Stigmaria ficoides* BRONGNIART | | | | | X | |
| *Sigillaria* sp. | | | X | | | |
| EQUISETOPHYTA | | | | | | |
| *Calamites suckowi* BRONGNIART | | | | | X | |
| *Calamites* cf. *carinatus* STERNBERG | | | | X | | |
| *Sphenophyllum angustifolium* GERMAR | | X | | | | |
| *Asterophyllites equisetiformis* (SCHLOTH.) BRONGNIART | | | | | | X |
| *Annularia stellata* SCHLOTHEIM | | X | | | | |
| *Annularia sphenophylloides* (ZENKER) GUTBIER | | X | | | | |
| *Calamospora* sp. | | | | | | X |
| POLYPODIOPHYTA | | | | | | |
| *Acitheca polymorpha* (BRONGNIART) NĚMEJC | | | | | X | |
| *Asterotheca arborescens* SCHLOTHEIM | | X | | | | |
| *Asterotheca candoleana* BRONGNIART | | X | | | | |
| *Asterotheca* cf. *paleacea* ZEILLER | *Pecopteris* | X | | | | |
| *Pecopteris* sp. | | | | | | X |
| *Dactylotheca plumosa* ARTIS | *Pecopteris,Seftenbergia* | X | | | | |
| *Crossotheca* cf. *pinnatifida* (GUTBIER) | *Remia* | X | | | | |
| *Ptychocarpus unitus* BRONGNIART | | X | | | | |
| PTERIDOSPERMALES | | | | | | |
| *Alethopteris aquilina* SCHLOTHEIM | | | | | X | |
| *Alethopteris bohemica* (FRANKE) | *Laveineopteris* | X | | | | |
| *Imparipteris (Neuropteris) attenuata* LINDLEY & HUTTON | *Laveineopteris* | | | | | X |
| *Imparipteris (Neuropteris)* cf. *tenuifolia* SCHLOTHEIM | *Laveineopteris* | | | | | X |
| *Callipteridium pteridium* (SCHLOTHEIM) ZEILLER | | X | | | | |
| *Linopteris duplex* NĚMEJC | | X | | | | |
| *Pecopteris feminaeformis* (SCHLOTHEIM) | *Nemejcopteris* | X | | | | |
| *Neuropteris auriculata* (BRONGNIART) | *Neurodontopteris* | | | | X | |
| *Odontopteris subcrenulata* (ROST) ZEILLER | | X | | | | |
| *Sphenopteris carnoti* ZEILLER | *Taeniopteris* | X | | | | |
| *Sphenopteris* cf. *haidingeri* (ETTINGSHAUSEN) | *Taeniopteris* | | | | X | |
| *Sphenopteris* cf. *weissi* (POTONIÉ) | | X | | | | |
| *Cyclopteris* sp. | | X | | | | |
| CORDAITALES | | | | | | |
| *Cordaites palmaeformis* GOEPPERT | | X | | | | |
| *Cordaites principalis* GERMAR | | | | | | X |
| *Cordaicarpus ovoides* (GOEPPERT & BERGER) SEWARD | | X | | | | |
| *Diplotmema busqueti* ZEILLER | *Pseudomariopteris* | X | | | | |
| *Diplotmema ribeyroni* ZEILLER | *Pseudomariopteris* | X | | | | |
| *Carpolites* sp. | | X | | | | |

unit, striking SW-NE, was interpreted as a dislocated part of the Internal Dinarides (PAMIĆ & TOMLJENOVIĆ, 1998; TOMLJENOVIĆ et al., 2003). The area is mapped on the Basic Geologic Map, sheets Ivanić-Grad L33-81 (BASCH 1981, 1983) and Zagreb L34-98 (ŠIKIĆ et al., 1978, 1979). Contacts with the surrounding Mesozoic rocks are tectonic.

Parametamorphic, previously clastic and carbonate rocks of Late Palaeozoic age surround the orthometamorphic core of Medvednica Mt. Some of these rocks are ore-bearing, originating from chert, tuffitic shale and sandstone. A black, low-metamorphic complex of dominantly phyllite appears in different areas (BELAK, 2009), and ranges from Early Silurian to Pennsylvanian age, based upon conodonts and graptolites (ĐURĐANOVIĆ, 1973; SREMAC & MIHAJLOVIĆ-PAVLOVIĆ, 1981). Recrystallized carbonate rocks outcrop in scattered areas. They contain conodonts in their lower portions (Devonian, Mississippian) and shallow marine stromatoporids and bryozoans in their upper parts (Pennsylvanian) (ĐURĐANOVIĆ, 1973; KOCHANSKY-DEVIDÉ, 1981). The whole complex is highly tectonized and it is difficult to reconstruct a stratigraphic column (Fig. 2) of this area (ŠIKIĆ et al., 1978; BASCH, 1981; ŠIKIĆ, 1995). Metamorphism is linked with the alpine tectonic cycle (BELAK, 2009).

West of Medvednica Mt., in the Marijagorička Brda Hills, clastic deposits contains remnants of the Carboniferous horsetail *Calamites (Diplocalamites)* cf. *carinatus* STERNBERG (JENKO, 1944). This horsetail occurs in Namurian and Westphalian deposits of Europe. Coarse-grained greywacke, sandstone and black shale indicate a significant terrestrial influence and resemble the protolite rocks in the parametamorphic Medvednica complex. Pennsylvanian rocks outcrop in deep gorges and creeks. Palynomorph analysis performed in 2011 did not provide new results (BRAJKOVIĆ, pers. comm.).

Farther westwards, discovery of the lycopod *Sigillaria* was reported from Samoborska Gora Mt. by HERAK (1956). The dominant sedimentary rocks are lithoclastic and quartz greywackes. Quartz conglomerate appears sporadically, sometimes with lenses of shale and siltite. Limestone and dolomite are developed laterally (ŠPARICA, 2009). Detrital quartz in carbonate rocks indicates the continuous terrestrial input. Palynological investigations performed in the late eighties were sterile (KOCH, pers. comm.). Carboniferous marine fossils were not found in this area, but the uppermost limestone intercalations contain Late Permian marine calcareous algae (HERAK & ŠKALEC, 1967).

Shallow marine dolomites and limestones are ore-bearing, with meso-epithermal Fe-Cu-Ba SEDEX type deposits (PALINKAŠ et al., 2010).

### 2.4. The Banovina-Kordun Region

Clastic Middle-Late Palaeozoic deposits with intercalations of fossiliferous carbonate rocks occur at Trgovska Gora Mt. in the Banovina-Kordun Region (Fig.1). This region is represented on the Basic Geologic Map, sheet Orahovica L33-96 (JAMIČIĆ et al., 1987; JAMIČIĆ & BRKIĆ, 1988). Detailed Palaeozoic stratigraphy of this region was not studied, but fossils belong to the Devonian and Carboniferous periods.

Shale, siltstone and sandstone dominate, containing scarce conglomerate lenses in upper horizons. Rhythmic alteration and gradation indicate the turbidite origin of these deposits (ŠIKIĆ, 2009). Organic matter and chert lenses are common in the lower parts of the succession, and terrigenous input is more significant in the upper portion. Conodonts, radiolarians and scarce ostracods from pelagic dark-grey argillaceous limestone range from the Devonian to Early Carboniferous (Viséan) in age (ĐURĐANOVIĆ, 1968, 1973). Ba-F mesothermal mineralization and Fe replacement are reported from these deposits (BOROJEVIĆ-ŠOŠTARIĆ et al., 2009).

Pennsylvanian uplift processes changed the mode of deposition. MILANOVIĆ (1982) studied dark-grey, mosaic-textured dolomite from this horizon and determined small foraminifera and calcareous algae (*Tuberitina bulbacea* GALLOWAY & HARLTON, *Dvinella (Trinodella) variolonga* KULIK and *Solenopora* sp.), crinoids and echinoids. He presumed shallow marine deposition during the Moscovian. Kasimovian-Gzhelian carbonate rocks contain a coral fauna, described by KOSTIĆ-PODGORSKA (1955), and are comparable to that of the Carnic Alps. Ba epithermal and Fe SEDEX ore deposits from these rocks represent the prolongation of the ore-bearing horizon from the Sana-Una Unit and are connected with opening of the Tethys Ocean (PALINKAŠ et al., 2008).

A terrestrial land flora ranging from the Pennsylvanian to Early Permian in age was discovered in 19$^{th}$ century, as a result of ore exploitation in Trgovska gora (GEINITZ, 1868; STUR, 1868). The Pennsylvanian flora is represented by horsetails *Calamites suckowi* BRONGNIART, lycopsid roots *Stigmaria ficoides* BRONGNIART and pteridosperms: *Sphenopteris* cf. *haidingeri* ETTINGSHAUSEN, *Neurodontopteris auriculata* (BRONGNIART) and *Alethopteris aquilina* (SCHLOTHEIM) (Table 1) and shows similarity with the Euroamerican palaeoprovince. Early Permian taxa include *Odontopteris obtusiloba* NAUMANN and *Calamites gigas* BRONGNIART (STUR, 1868).

### 2.5. Slavonian Mts. – Moslavačka Gora Mt.

The mountains of Eastern Croatia (Papuk Mt., Moslavačka gora Mt.) represent the only Carboniferous area in Croatia out of the Dinarides, forming part of the Europaean Tisia Unit (Figs. 1, 3). This area is represented on the Basic Geologic Map, sheets Daruvar L33-95 (JAMIČIĆ, 1989; JAMIČIĆ et al., 1989) and Orahovica L33-96 (JAMIČIĆ & BRKIĆ, 1988; JAMIČIĆ et al., 1987), and is described by JAMIČIĆ & CRNKO (2009).

Crystalline to low-grade parametamorphic rocks from the Slavonian Mountains range from Early Palaeozoic to the Triassic. Within the strongly tectonized low-metamorphic "Radlovac" unit, interpreted as intertidal deposits (RAMOVŠ at al., 1990), a Pennsylvanian (Westphalian) land flora was found in metagreywackes and metasandstones (Fig. 2). The

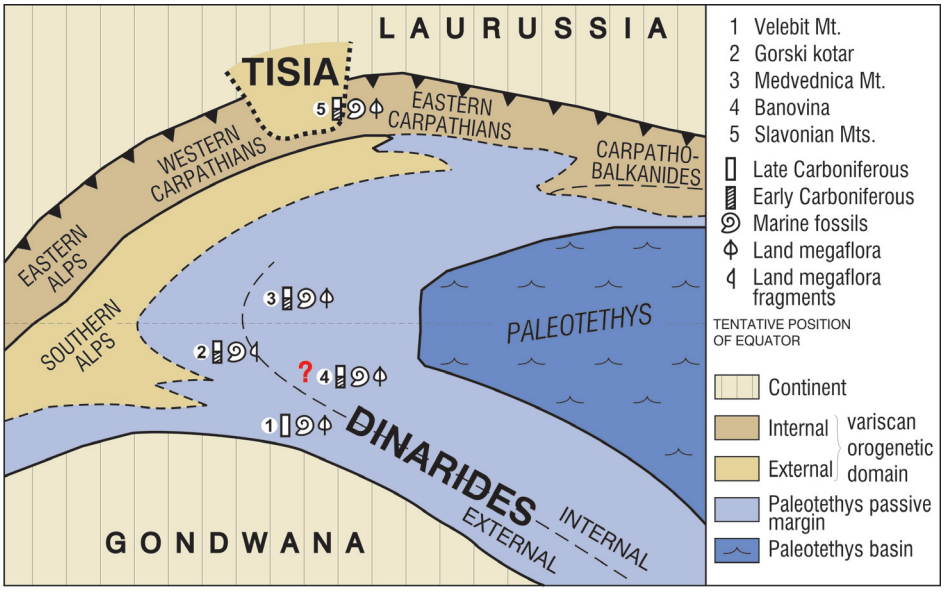


**Figure 3:** Late Variscan palaeogeography of the Circum Pannonian Region (after VOZAROVA et al., 2009) with the presumed position of Croatian Carboniferous terrains.

source of the clastic material is the uplifted Papuk Mt. with granite and metamorphic rocks. Quartz grains are the most common (approximately 50 % grains), followed by plagioclase and micas. Scarce horsetails, ferns and pteridosperms occur within the greywacke (*Asterophyllites equisetiformis* (SCHLOTHEIM) BRONGNIART, *Pecopteris* sp., *Laveineopteris* cf. *tenuifolia* SCHLOTHEIM, *Laveineopteris rarinervis* (BUNBURY) CLEAL et al. (= *Imparipteris attenuata* LINDLEY & HUTTON)), together with *Cordaites principalis* GERMAR, and palynomorpha: *Calamospora, Cordaites* and *Cyrtospora* (BRKIĆ, JAMIČIĆ & PANTIĆ, 1974; JERINIĆ et al., 1994) (Table 1). The freshwater bivalve *Carbonicola* was also observed in these deposits.

Deposition in the Early Permian was influenced by uplift processes (JAMIČIĆ, 1989; JAMIČIĆ & CRNKO, 2009).

## 3. DISCUSSION

During the Devonian and Early Carboniferous, the territory of Croatia was part of a deep ocean. Pelagic fossils (radiolarians, conodonts and/or spores) have been discovered in the Dinarides (Gorski Kotar, Medvednica and Banovina) and Tisia (Slavonian Mts.).

Uplift processes enabled the formation of the Bashkirian-Moscovian carbonate platforms at the western Palaeotethys shelf (MERINO-TOMÉ et al., 2009), including the area of Velebit Mt. and the Lika Region. Intense erosion of the Variscides at the end of the Moscovian enabled massive siliciclastic input into the marine basin. Deposits at all Croatian Dinaride localities exhibit this environmental change. Nutrients derived from land to the shelf areas, together with terrestrial debris, resulted in increased biodiversity of the marine flora and fauna in the Kasimovian and Gzhelian. Uplifted areas were colonised by land flora.

Palaeogeographic reconstructions of the Carboniferous period presume the position of the Dinaride localities along the shelf of Northern Gondwana (DiMICHELLE et al., 2005; VOZAROVA et al., 2009) (Fig. 3).

A diverse megaflora from Velebit Mt. was found in shale, siltite and thin coal intercalations of Late Kasimovian-Gzhelian age (Fig. 2). It consists of scarce lycopsids and horsetails, and common and well preserved ferns, pteridosperms and cordaitales (Table 1). NĚMEJC (1936) suggested a Stephanian age for the described collection, which is in accordance with the age of marine fossils. NĚMEJC also pointed out the lack of conifers in the Velebit flora. Such vegetation might be related to a local precipitation pattern. The prevalence of ferns and pteridosperms over lycopods and horsetails reflects global climate trends in the area (CLEAL et al., 2011). Plant fossils are well preserved, with no traces of perturbations, due to the sheltered environment and lack of transport (TENCHOV, 2011, pers. comm.). Marine foraminifera, bivalves and gastropods from this area are widely spread along Euramerican shelves (KOCHANSKY-DEVIDÉ, 1955; RUKAVINA, 1973; BALAŽ, 1981), whereas the calcareous algae are partly endemic in character (KOCHANSKY-DEVIDÉ, 1970). Distribution of the marine fauna was controlled by the anticlockwise ocean circulation.

Late Palaeozoic deposits in the Gorski Kotar are dominantly clastic and appear as scattered, tectonically outlined patches. Deposition by turbidite currents took place at the shelf slope. The land flora is present only in the form of detritus, and Pennsylvanian marine fossils can be compared to those from Velebit Mt.

The peculiar position of the NW Croatian mountains: Medvednica, Samoborska Gora and Marijagorička Brda has been discussed by many geologists. These mountains are positioned opposite to the Dinaric strike, but they have some characteristics of the Internal Dinarides. PAMIĆ and TOMLJENOVIĆ (1998) proposed the name Zagorje-Mid-Transdanubian Zone for this belt (Fig. 1). The Palaeozoic sedimentary succession of Mt. Medvednica can be interpreted as a low-metamorphic turbidite sequence. Pennsylva-

nian uplift was followed by colonization of the first shelf biota – crinoids, stromatoporids and bryozoans (KOCHANSKY-DEVIDÉ, 1981), comparable with marine faunas from the Euramerican shelf palaeoprovince. The conodont genus *Idiognathoides* (ĐURĐANOVIĆ, 1968, 1973) has also been observed in North America and Northern Europe.

Farther westwards, the terrestrial influence is more pronounced, and sporadic occurrences of land megaflora, *Calamites* cf. *carinatus* and *Sigillaria,* were reported from the Marijagorička Brda Hills and Samoborska Gora Mt. (JENKO, 1944; HERAK, 1956). The predominantly clastic deposits from these two mountains are not metamorphosed and exhibit different characteristics from the SE parts of Medvednica Mt. Lack of marine fossils does not allow precise zonation, but *Calamites carinatus* is known from the Namurian-Westphalian of Euramerica.

The Banovina Region and Trgovska Gora Mt. represent a prolongation of the ore-bearing Sana-Una Unit and are interpreted as the Internal Dinarides. In a regional reconstruction (e.g. VOZAROVA et al., 2009), they are situated near the Gondwana shelf edge, towards the Palaeotethys deep basin (Fig. 3). Turbidite deposition during the Mississippian probably took place on the marginal slope. During the Namurian and Westphalian this area was uplifted. The calcareous alga *Dvinella*, a cosmopolitan genus of the Northern Hemisphere, inhabited shelves surrounding the uplifted islands and produced biogenic bafflestone-type limestone. Emergent areas were colonized by lycopsids (*Stigmaria ficoides*), horsetails (*Calamites suckowi*) and pteridosperms (*Alethopteris aquilina*, *Neurodontopteris auriculata*, *Taeniopteris* cf. *haidingeri*) (Table 1). The same taxa occur in the Pennsylvanian of Northern America and Europe (Czech Republic, France, Hungary) (GULYAS-KIS, CS., 2003; ZODROW et al, 2006). ZODROW et al. (2006) suggest the origin of the marattialen fern *Acitheca* in North America and Western Europe in the middle Pennsylvanian, with later expansion into Eastern Europe, Caucasus, and into the Permian of China. A wide stratigraphic range, from the middle Pennsylvanian into the Permian, is also reported for *Neurodontopteris auriculata* (BOYARINA, 2010). Nevertheless, the presence of lycopods and horsetails would suggest a probable Middle Pennsylvanian (Stephanian A?) age for this flora.

Moslavačka Gora Mt. and Papuk Mt. in Slavonian Mts. belong to the entirely different Tisia Unit (Figs. 1–3). Uplift in the area took place during the Mississippian, and the prominent influence of igneous rocks and metamorphism is typical for the area. Determined plant fossils include *Asterophyllites equisetiformis*, *Laveineopteris rarinervis*, *L.* cf. *tenuifolia* and *Cordaites principalis*. They differ from the described Dinaride floras in age (Westphalian) and composition (BRKIĆ et al., 1974).

## 4. CONCLUSION

Pennsylvanian deposition in Croatia was strongly influenced by terrestrial input in the marine (Western Palaeotethys) basin, due to the Variscan orogeny and intense erosion of the Hercynian Mountains. Some of the uplifted areas were soon colonised with land flora. Remnants of the Pennsylvanian megaflora occur at Croatian localities from different tectonic units: the External Dinarides, Internal Dinarides and Tisia.

Pennsylvanian vegetation in the Dinarides was fern dominated, with an additional cordaite dryland flora in the area of Velebit Mt. and the Lika Region. A precise age is not always clear, due to the lack of index fossils.

Fossil horsetails from the Marijagorička Brda Hills are probably the oldest terrestrial plants in the region, belonging to the Namurian or Westphalian.

Pteridosperms and ferns from Trgovska Gora, together with scarce lycopods and horsetails could be compared with Stephanian A vegetation in Euramerica.

Plant fossils from Velebit Mt. and Lika Region are the most diverse and well preserved, with no traces of transport. Lycopods, horsetails, ferns, pteridosperms and cordaitales were found in this area, while primitive conifers are missing. The age of the Velebit flora is estimated to be Stephanian B or C (Kasimovian-Gzhelian).

Plant remnants in Gorski Kotar are in form of debris, due to the transport by turbidity currents.

The Tisia Megaunit with the Papuk and Moslavačka Gora Mts. was dislocated from the Dinarides. A Westphalian flora from this region is similar to the flora of Eastern America and Central Europe.

It is necessary to continue with the regional study of Croatian Carboniferous localities in order to understand the palaeogeographic relationship between these areas during the Pennsylvanian age.

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