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Paleoenvironmental interpretation and palynoflora of Devonian–Carboniferous subsurface sections from the eastern part of the Moesian Platform (Romania)

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ABSTRACT

Palynomorph assemblages and palynofacies analyses have been performed on several core samples from the Devonian–Carboniferous deposits identified in five wells located within the eastern region of the Moesian Platform. The investigated sections include, in ascending stratigraphic order, the Ţăndărei, Smirna, Călăraşi and Vlaşin formations. Based on the stratigraphic distribution of key taxa identified (miospores, chitinozoans, acritarchs), seven biozone intervals (four for the Devonian and three for the Carboniferous) have been recognized. The oldest samples were dated as being part of the *micrornatus–newportense* (MN) – lower part of *breconensis–zavallatus* (BZ) Assemblage Zones (Early Devonian), while the younger ones are assigned to the *kosankei–varioreticulatus* (KV) – *nobilis–junior* (NJ) Assemblage Zones (Pennsylvanian). Palynofacies observations suggest a fairly distal depositional environment during the period between the Lochkovian and Pragian times, followed by some proximal/fluvio-deltaic conditions in Emsian–Early Eifelian (top of the Ţăndărei Formation). The upper Tournaisian to Serpukhovian sedimentary rocks of the Călăraşi Formation and lower part of Vlaşin Formation were deposited in inner neritic environments. Mud-dominated dysoxic/anoxic conditions of the Bashkirian, abruptly transitioned to deltaic deposition and oxidizing environments that persisted to the Moscovian.

The Early Devonian terrestrial palynoflora is dominated by trilete spores which belong to lowland vegetation (vascular plants), the latter preferring areas with open connections via rivers to marine sedimentary basins. Carboniferous samples yielded only terrestrial miospores of various types of arborescent and herbaceous lycopsids and ferns, suggesting different habitats such as non-flooded wetlands or swamps within coastal plain and continental interiors. These assemblages of Carboniferous miospores are an indication of neutral-humid climatic conditions which existed at the time of deposition.

1. Introduction

The Moesian Platform represents a continental block extending 250–300 km north–south and ~600 km east–west, located mainly in the present territories of Romania and Bulgaria (Fig. 1).

Starting with the mid-twentieth century, this unit has been intensively explored for conventional hydrocarbons (Paraschiv, 1979). Dispersed plant spores, as well as marine organisms (chitinozoans, acritarchs), are the primary tools used for biostratigraphic age determination and correlation of subsurface Paleozoic deposits across the Moesian Platform. Only a few papers (i.e., Venkatachala and Beju, 1961, 1962; Beju, 1967, 1971; Venkatachala et al., 1969; Vaida and Verniers, 2005, 2006) are devoted to the palynostratigraphy of the Moesian Platform. Among these, the most detailed palynological study was presented by Beju (1971). Based on the stratigraphic distribution of the palynomorphs (chitinozoans, acritarchs, miospores), the author proposed 6 biozones for the Devonian–Carboniferous interval. During the Early Devonian (Lochkovian–Emsian, D_1 Biozone), the chitinozoans are in continuous decline and become extinct near the end of this period. The palynological assemblage of the D_1 Biozone consists mainly of miospores such as *Anapiculatisporites burtonensis*, *Apiculiretusispora toriensis*, *Emphanisporites rotatus*, *Leiotriletes simplex* and *Retusotriletes rotundus*. The microflora of the mid–Late Devonian (D_2–D_3 Biozones) includes abundant large miospores (e.g. *Calyptosporites* div. sp., *Grandispora* sp., *Hymenozonotriletes* div. sp.) or miospores with "smooth or ornate distal thickening" (*Archaeozonotriletes variabilis*, *Geminospora svalbardiae*, *G. maculata*, *Rhabdosporites parvulus*). The Carboniferous sedimentary succession, assigned to C_1–C_3 Biozones (Beju, 1971), has a diversified

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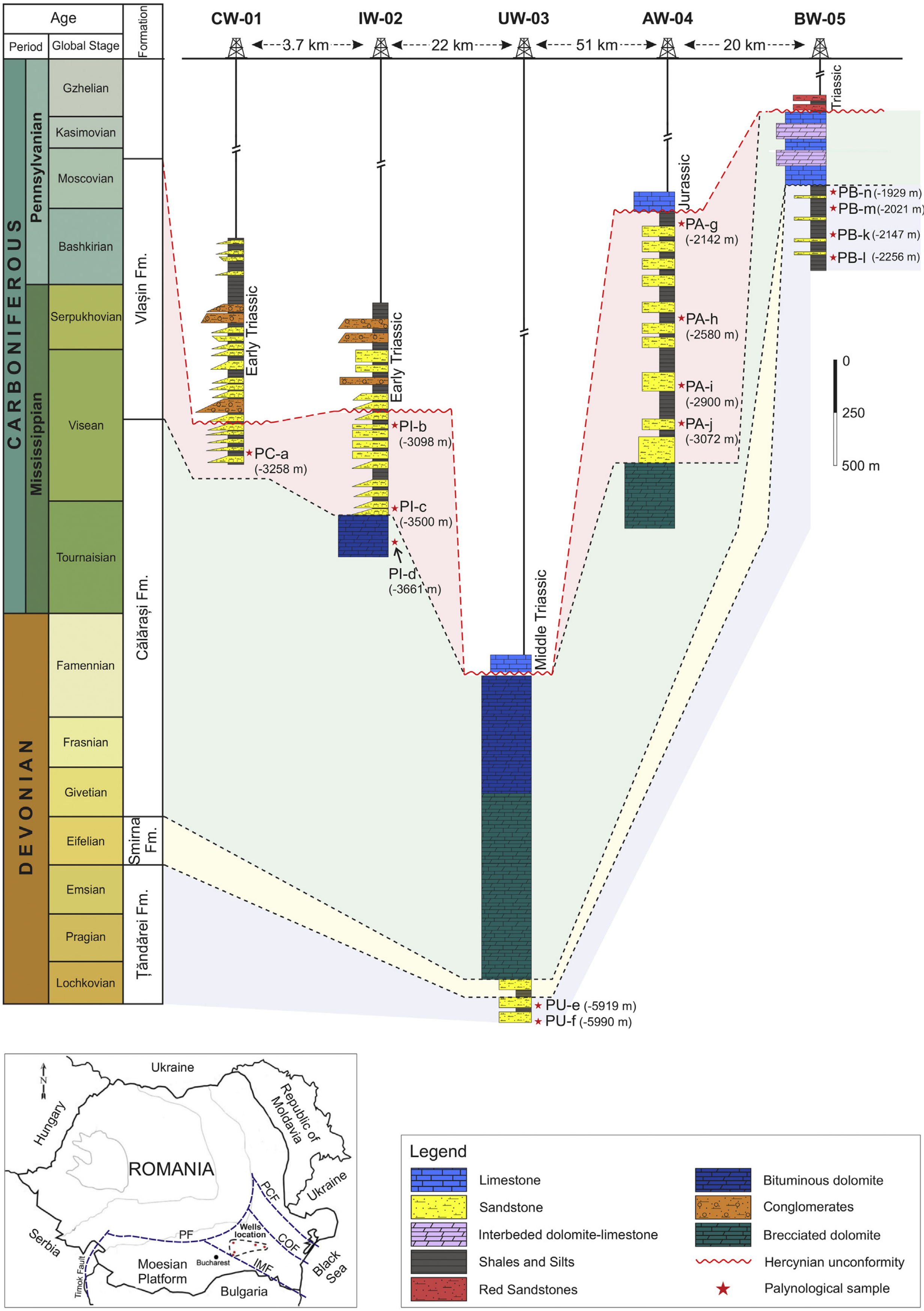

Fig. 1. Lithological logs of the Devonian–Carboniferous deposits in the studied wells, with the location of the analyzed samples. The position of the study area is also shown. Abbreviations: PF – Pericarpathian Fault; IMF – Intra-Moesian Fault; COF – Capidava-Ovidiu Fault; PCF – Peceneaga-Camena Fault.

and well-preserved palynological assemblage. Among the commonly encountered taxa, various species of the *Anulatisporites*, *Cingulizonates*, *Densosporites*, *Granulatisporites*, *Lycospora* genera have been documented (Venkatachala and Beju, 1962; Venkatachala et al., 1969; Beju, 1971).

Other biostratigraphic information was previously obtained based on a diverse macrofossils, the Paleozoic age of the deposits being indicated by the assemblages with graptolites, brachiopods and bivalves (Iordan, 1990, 1999; Seghedi et al., 2005).

Based on Paleozoic palynomorph assemblages (including chitinozoans, acritarchs and miospores; Beju, 1972; Iordan et al., 1985; Vaida et al., 2005), as well as macrofaunas (Iordan, 1972; Iordan et al., 1985), a northern Gondwanan origin for Moesian Platform can be suggested.

In the past, the palynological data (see the works quoted above) have been applied for petroleum exploration to determine a stratigraphic framework of subsurface Paleozoic deposits within the Moesian Platform. In the same context, this palynological study aims to contribute to a better understanding of the Devonian–Carboniferous stratigraphic succession, based on the analysis of 14 core samples from 5 exploration wells located in the eastern part of the Moesian Platform. The palynomorph assemblages were evaluated in terms of their chronostratigraphic significance and their bearing on the understanding of paleoclimatic and paleofloristic evolution across the Devonian–Carboniferous. The biostratigraphic data obtained allowed the correlation of several lithological levels assigned to Ţăndărei, Călăraşi and Vlaşin formations, penetrated by the five exploration wells. This study also aims to interpret the depositional environment during the Devonian–Carboniferous periods based on palynofacies data and palynomorph taxa.

2. Geological setting

The Moesian Platform is an E–W elongated structural unit, bordered to the north and west by the South Carpathians, to the south by the Balkanides, and extends eastwards to the Black Sea (Fig. 1). In Romania, the Moesian platform is separated from the Carpathian belt by the Pericarpathian Fault, oriented E–W and dipping north, with its eastern part being curved northward. Most authors divide the Moesian Platform in two sectors based on crustal thickness, simply named as East and West Moesia (Săndulescu and Visarion, 2000). East and West Moesia are separated by the Intra-Moesian Fault (IMF; Fig. 1) having an implied offset of close to 1000 m (Tărăpoancă et al., 2003).

The basement of the Moesian Platform consists of Precambrian metamorphic rocks and is covered by deposits that can be separated in four sedimentary cycles (Ionesi, 1994), namely: (1) Cambrian–Carboniferous; (2) Permian–Triassic; (3) lower Jurassic (Toarcian)–Eocene; and (4) upper Badenian–Pleistocene.

During the Cambrian–Carboniferous sedimentary cycle, lithological and paleontological data indicate multiple marine depositional environments alternating with periods of continental deposition. The Devonian stratigraphic succession is characterized by lower Devonian marine deposits followed by mid Devonian deposition within brackish and hypersaline lagunal environments (Iordan, 1981; Seghedi et al., 2005). Marine carbonate platform conditions prevailed throughout the Givetian–Visean interval, with various tidal flat environments in the Late Devonian to open marine environments in the Early Carboniferous (Iordan, 1981; Vinogradov and Popescu, 1984). Near the end of the Carboniferous (Pennsylvanian), deltaic/sabkha conditions resulted in the deposition of a terrigenous-paralic succession consisting of claystone and sandstones having plant remains and coal intercalations (Paraschiv and Popescu, 1980). The Cambrian–Carboniferous sedimentary cycle ended with the Variscan Orogeny, an extended period of widespread uplift and erosion across the Meosian Platform (Paraschiv, 1974, 1982).

3. Stratigraphical framework

The Paleozoic deposits of discussion are part of the Cambrian–Carboniferous sedimentary cycle and, within the Meosian Platform, are evaluated based on a limited number of deep wells penetrations. According to Paraschiv (1974, 1982), Ionesi (1994), Seghedi et al. (2005), the main Devonian–Carboniferous lithostratigraphic units of the northern Moesian Platform are represented by the Ţăndărei, Smirna, Călăraşi and Vlaşin formations.

3.1. Ţăndărei Formation

The Ţăndărei Formation has a thickness between 1800 and 3250 m (Ionesi, 1994) and has been identified in several wells located in the eastern and western regions of the Moesian Platform. This geological formation is dated as mid Ordovician–Early Devonian (Iordan, 1981, 1990; Seghedi et al., 2005; Vaida and Verniers, 2006) and includes mainly dark graptolite shales, black argillites (Middle Ordovician–Upper Silurian), a number of argillaceous shales or sandy argillites, and Lower Devonian dark siltstones with gray quartzite intercalations within the uppermost deposits. The Ţăndărei Formation was identified in two wells analyzed by us (i.e. UW-03 and BW-05; Fig. 1) and consists of a sequence of blackish shales with sandstone intercalations.

3.2. Smirna Formation

The Smirna Formation is characteristically sandstone, being comprised of quartzitic sandstones, orthoquartzites, conglomerates and having thin intercalations of limestones and shales. The thickness of these deposits range between 100 and 200 m. The Smirna Formation contains an assemblage of psilophyte plant remains (*Calamophyton primaevum*, *Pseudosporochonus krejcii*), palynomorphs (*Dibolisporites echinaceus*, *D. eifeliensis*, *Emphanisporites annulatus*, *Retusotriletes communis*), placoderm and ostracoderm fishes, brachiopods and corals that support an Eifelian age (Iordan et al., 1985). Of the wells studied by us, the Smirna Formation was identified only in the UW-03 where it has a thickness of approximately 100 m (Fig. 1).

3.3. Călăraşi Formation

From the Givetian stage onwards, multiple tidal and marine environments were developed, resulting in accumulation of a carbonate–evaporite succession consisting of organogenic limestones and bituminous dolomites with evaporite intercalations. Carbonate–evaporite succession persist to the Early Visean and includes deposits up to 2500 m thick (Ionesi, 1994). The Givetian–Early Visean dating for the Călăraşi Formation is based on diversified paleontological content, with assemblages including tentaculites (*Homoctenus krestovnikovi*, *Tentaculites conicus*), brachiopods (*Mucrospirifer bouchardi*), conodonts (*Siphonodella isostycha*), plant remains and palynomorphs (Beju, 1971; Paraschiv, 1974; Iordan, 1981; Iordan et al., 1985).

3.4. Vlaşin Formation

The Vlaşin Formation consists of siltstones and sandstones with coal intercalations and shales, and represents a period of terrigenous sediment input (Paraschiv and Popescu, 1980). This clastic succession included at the Vlaşin Formation does not exceed 700–800 m thick (Ionesi, 1994), and was age dated to Upper Visean–Moscovian based on an assemblage of brachiopods (*Productus carbonarius*), bivalves (*Janeia primaeva*), plant remains (*Calamites cisti*, *Stigmaria ficoides*) and palynomorphs (*Crassispora kosankei*, *Raistrickia fulva*, *Savitrisporites nux*) (Iordan et al., 1987; Paraschiv and Popescu, 1980). Of the five wells studied, the Vlaşin Formation succession was most extensive in the AW-04 well (Fig. 1) where it consisted of alternating sandstones and shales.

4. Material and methods

The study focuses on the palynostratigraphy of five petroleum exploration wells located in the eastern part of the Moesian Platform

(Fig. 1). From these wells, 14 core samples were processed using standard palynological techniques described by Batten (1999). Approximately 50 g of rock from each sample were treated with HCl (37%) to remove carbonates and HF (48%) to remove the silicate minerals. Denser particles were separated from the organic residue using $ZnCl_2$ with a density of 2.0 g/cm^3. The palynological residues were mounted on microscopic slides using glycerine jelly. For this study, a kerogen oxidation procedure was not applied. Palynomorphs and palynofacies constituents (Plates I–V) were photographed using a digital Leica DFC 420 camera mounted on a Leica DM1000 microscope. Appendix A gives a species list of the chitinozoans, acritarchs and miospores encountered. All the microscopic slides are stored in the collection of the Geology Department, "Al. I. Cuza" University of Iaşi.

For the palynofacies analysis, at least 300–400 of unoxidized palynodebris were counted in each sample. Three main groups of kerogen constituents proposed by Tyson (1995), Mendonça Filho et al. (2002), Carvalho et al. (2006) and Ţabără and Slimani (2017) have been recognized in the studied samples, namely: (I) phytoclasts (translucent and opaque organic particles derived from terrestrial plants); (II) palynomorphs (miospores, acritarchs and chitinozoans), and (III) amorphous organic matter (AOM) which includes structureless organic components derived from phytoplankton or degraded higher plant debris.

In the marine environments, the distal–proximal trend is one of the principal controls on kerogen distribution. Two interpretative parameters, based on palynofacies observations and palynomorph assemblages (both ratios are expressed in decimal logarithms; Tyson, 1995), were used for paleoenvironmental analyses, namely:

(i) the continental/marine palynomorphs ratio (C/M). The co-occurrence of terrestrial (miospores) and marine (acritarchs, chlorophytes and chitinozoans) palynomorphs in marine deposits can be used as an indicator of proximal–distal trends (Pellaton and Gorin, 2005). This ratio is calculated as the number of all terrestrial specimens divided by the number of marine palynomorphs. Generally, the C/M ratio decreases offshore.

(ii) the ratio of opaque to translucent phytoclasts (O:Trans). According to Tyson (1995) and Carvalho et al. (2013), opaque particles are derived from the oxidation of translucent phytoclasts transported over a prolonged period of time. In contrast, a high abundance of translucent particles (e.g. woody tissues, cuticles) suggests strong terrestrial influx and deposition within nearshore environments. The ratio tends to increase distally and can be used to interpret proximal–distal trends (Steffen and Gorin, 1993).

An additional indicator of Devonian paleoenvironment is the frequency of the cryptospores versus trilete spores observed in the analyzed samples. Previous studies (Steemans, 1999; Rubinstein and Steemans, 2002; Steemans et al., 2007) have shown that, in general, trilete spores are more abundant than cryptospores in open marine deposits. These authors opine that the cryptospore-producing plants inhabited confined habitats (e.g. swamps or lake margins) and therefore cryptospores would have little chance of being transported by rivers into a marine environment. Conversely, it is believed that trilete spore-producing plants preferred the areas with open connections via rivers to marine sedimentary basins, this interpretation arguing the high frequency of this type of spores in these environments (Steemans et al., 2007).

Carboniferous miospore assemblages were analyzed according to their paleobotanical and paleoecological origins. Based on their paleobotanical affinities, recorded taxa were assigned to three vegetation types (Jäger and McLean, 2008; Orlova et al., 2015), including: forest mire (arborescent and sub-arborescent lycopsid), non-forest mire (all fern-like plants and sphenopsids) and colonizers. These three groups of vegetation are strongly dependent on environment of deposition and show clear proximal–distal trends. Thus, the coastal clastic sections are dominated by forest mire components, while the distal sections are characterized by the predominance of miospores that belong to non-forest mire (Jäger and McLean, 2008). Other climatic indicators (humid to dry conditions) derived from the palynoflora of the Carboniferous samples were interpreted according to the findings by Lindström (2003).

5. Results

5.1. Palynological content

The palynological assemblages are well-preserved, show a low to moderate diversity and include both terrestrial (miospores, phytodebris) and marine elements (chitinozoans, acritarchs and very rarely scolecodonts). A total of 102 taxa (Appendix A), mainly consisting of miospores (83 taxa), acritarchs and chlorophytes (9 taxa) and chitinozoans (8 taxa), were observed. Rare occurrences of scolecodonts and phytodebris are noted.

The following palynomorph assemblages were identified in the studied wells:

5.1.1. BW-05 well

Four core samples of blackish shales were studied from this well. The recovered palynoflora consists of both terrestrial and marine palynomorphs. A higher frequency of marine specimens was observed in PB-k sample (42% of the total palynomorphs), this group being generally dominated by various species of *Ancyrochitina*, *Eisenackitina krizi*, *Sphaerochitina sphaerocephala* (among the chitinozoans) and acritarchs (*Baltisphaeridium pilaris*, *Exochoderma arca*, *Veryhachium trispinosum*). Among the miospores which show a higher frequency in all samples of the BW-05 well can be listed taxa such as *Acanthotriletes inferus*, *Gneudnaspora divellomedia*, *Leiotriletes laevis* and *Retusotriletes maculatus*. Other species such as *Emphanisporites micrornatus* var. *micrornatus*, *E. micrornatus* var. *sinuosus* and *Breconisporites breconensis* were identified only in this well.

5.1.2. UW-03 well

The palynological assemblage identified in two samples from the UW-03 well suggests a high terrestrial input as it is almost exclusively comprised of miospores. The most common spores are *Apiculiretusispora plicata*, *A. brandtii*, *Dibolisporites eifeliensis*, *Gneudnaspora divellomedia* and *Retusotriletes rotundus*, all these taxa being also recorded in BW-05 well. Among the taxa that only occur in this well are *Acinosporites lindlarensis*, *Camarozonotriletes sextantii* and various species of *Grandispora* (high frequency in PU-e sample). Other marine microfossils (e.g. *Leiosphaeridia* sp., *Polyedryxium* sp., *Veryhachium polyaster*) and some specimens of scolecodonts represent a minor component in the assemblage. Chitinozoans are absent.

5.1.3. IW-02 well

Three samples collected from a 563 m thick succession yielded palynological assemblages containing only miospores. The assemblages are generally sparse and of low diversity as shown for the PI-d and PI-c samples. However, palynological content becomes more abundant and diversified for the PI-b sample (Appendix A). The base of the sampled section (3661 m measured depth) is defined by the lowest records of *Anapiculatisporites concinnus*, *Densosporites anulatus*, *Lycospora pusilla* and *Schopfites claviger*, with the top of the interval (3098 m depth) being marked by the predominance of several species of the *Granulatisporites*, *Lycospora*, *Lophotriletes* and *Schulzospora* genera.

5.1.4. AW-04 well

Of the four samples taken from this well, all are devoid of phytoplankton and all contain a very similar palynological assemblage to that identified in the IW-02 well discussed above. The most common species are *Cingulizonates bialatus*, *Granulatisporites granulatus*,

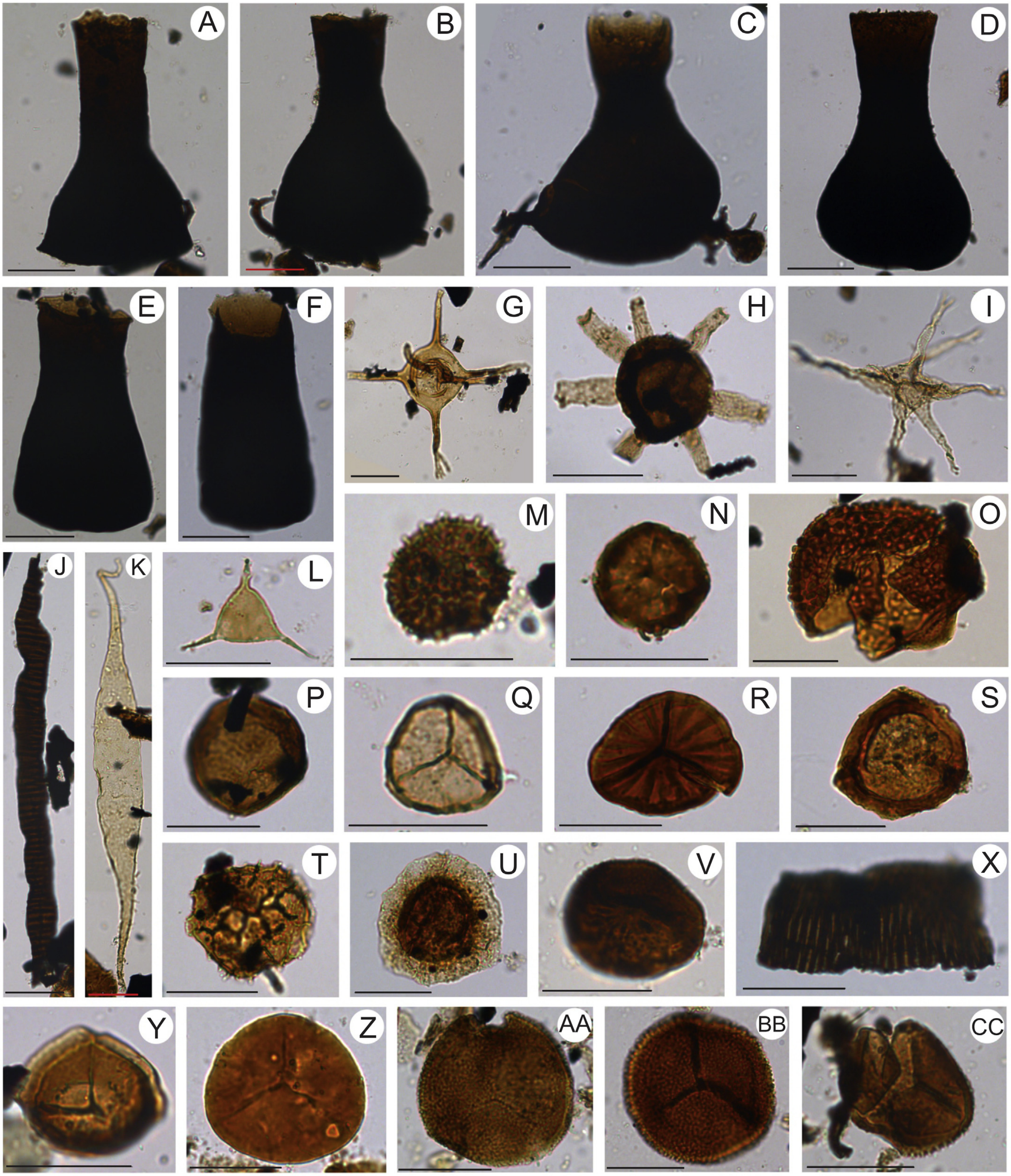

Plate I. The Devonian marine and continental palynomorphs from the Ţăndărei Formation (scale bar: 30 μm). A. *Ancyrochitina aculeata* (sample PB-k). B, C. *Ancyrochitina ancyrea* (PB-k). D. *Sphaerochitina sphaerocephala* (PB-k). E. *Eisenackitina krizi* (PB-k). F. *Conochitina* sp. (PB-k). G. *Exochoderma arca* (PB-k). H. *Baltisphaeridium pilaris* (PB-k). I. *Veryhachium polyaster* (PU-f). J, X. *Porcatitubulus annulatus* (PB-k). K. *Leiofusa litotes* (PB-k). L. *Veryhachium trispinosum* (PB-k). M. *Acanthotriletes inferus* (PB-k). N. *Emphanisporites micrornatus* var. *micrornatus* (PB-k). O. *Verrucosisporites polygonalis* (PU-f). P. *Gneudnaspora divellomedia* (PB-k). Q. *Leiotriletes laevis* (PB-k). R. *Emphanisporites rotatus* (PU-f). S. *Cymbosporites catillus* (PU-f). T. *Dictyotriletes subgranifer* (PU-f). U. *Calyptosporites biornatus* (PU-f). V. *Emphanisporites micrornatus* var. *sinuosus* (PB-m). Y. *Breconisporites breconensis* (PB-n). Z. *Retusotriletes rotundus* (PU-e). AA, BB. *Apiculiretusispora brandtii* (PU-e). CC. *Camarozonotriletes sextantii* (PU-e).

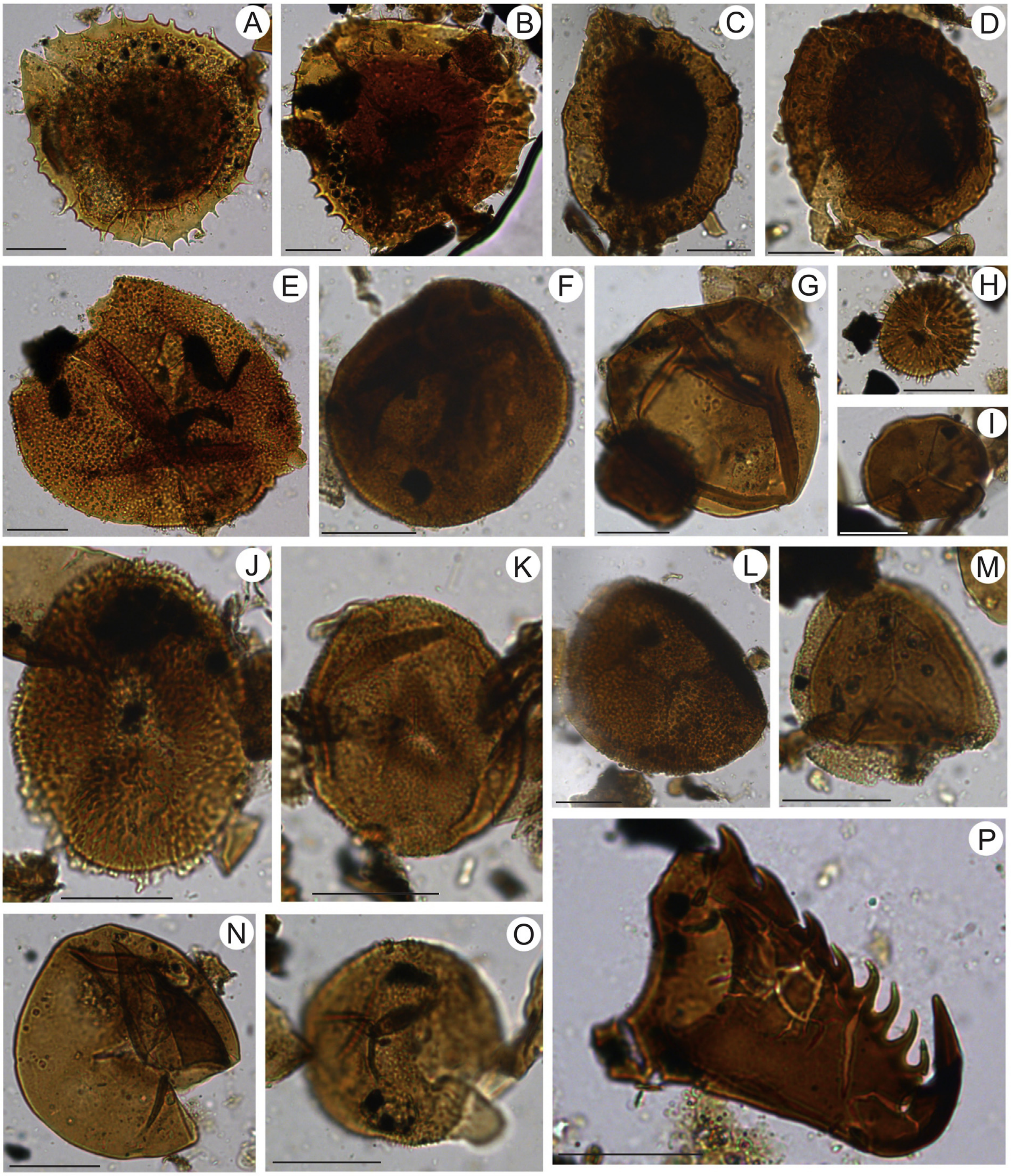

Plate II. Selected Devonian palynomorphs from the top of the Ţăndărei Formation, UW-03 well (scale bar: 30 μm). A, B. *Grandispora douglastownense* (sample PU-e). C, D. *Grandispora protea* (PU-e). E. *Dibolisporites echinaceus* (PU-e). F. *Apiculiretusispora arenorugosa* (PU-e). G. *Leiosphaeridia* sp. (PU-e). H. *Dibolisporites eifeliensis* (PU-e). I. *Ambitisporites avitus* (PU-e). J. *Dibolisporites* sp. (PU-e). K. *Apiculiretusispora plicata* (PU-e). L. *Acinosporites lindlarensis* (PU-e). M. *Grandispora* cf. *permulta* (PU-e). N. *Retusotriletes triangulatus* (PU-e). O. *Apiculiretusispora minor* (PU-e). P. scolecodont (PU-e).

Lycospora pusilla, with taxa such as *Densosporites anulatus*, *Densoisporites truswelliae* and *Lycospora uber* being far less abundant. Biostratigraphic marker taxa such as *Laevigatosporites vulgaris*, *Raistrickia nigra*, *Tripartites vetustus* and *Triquitrites marginatus* are only identified in the samples from the AW-04 well.

5.1.5. CW-01 well

Only one sample (PC-a) from the CW-01 well was analyzed. The palynological assemblage is very similar to the assemblage identified in the PI-b sample of the IW-02 well, and consists of taxa such as *Calamospora* sp., *Cingulizonates bialatus*, *Granulatisporites granulatus*, *Lycospora pusilla* and *Savitrisporites nux*. Two taxa with larger dimensions (i.e. *Spencerisporites radiatus* and *Florinites visendus*; Plate III S, T) were found only in this sample. The interval sampled was previously considered to be Upper Permian in age based on lithology, as micropaleontological analysis failed to provide a definitive age dating due to samples from this interval that were largely sterile.

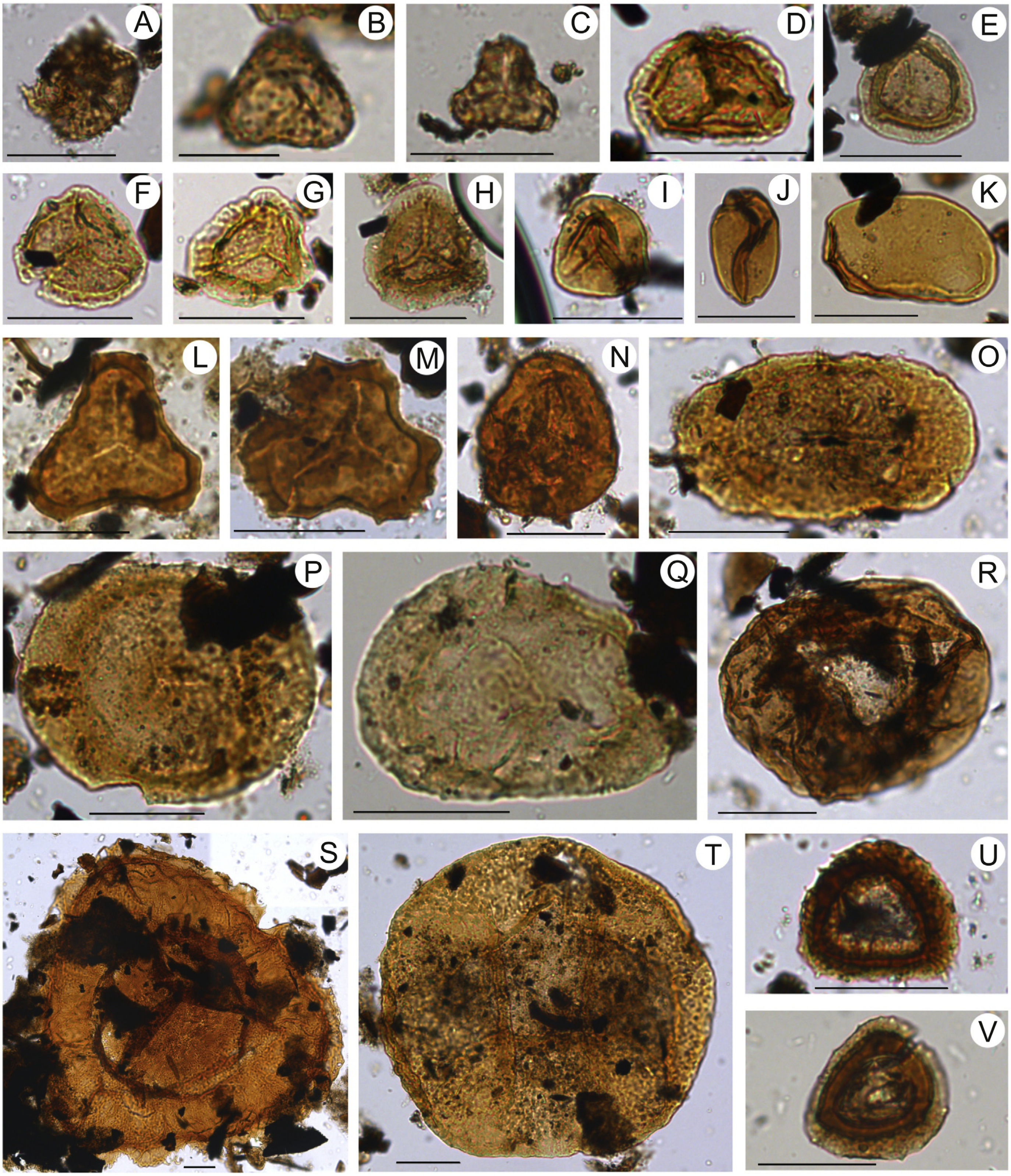

Plate III. The Carboniferous continental palynomorphs from the Călăraşi and Vlaşin formations (scale bar: 30 μm). A. *Schopfites claviger* (sample PI-d). B. *Anapiculatisporites concinnus* (PI-d). C. *Waltzispora* sp. (PI-d). D. *Lycospora pellucida* (PA-j). E. *Lycospora pellucida* (PI-b). F. *Lycospora pusilla* (PA-j). G. *Lycospora uber* (PA-j). H. *Lycospora uber* (PI-b). I. *Leiotriletes gulaferus* (PC-a). J. *Laevigatosporites* sp. (PA-i). K. *Laevigatosporites vulgaris* (PA-g). L. *Triquitrites marginatus* (PA-j). M. *Tripartites vetustus* (PA-j). N. *Densoisporites truswelliae* (PA-j). O. *Schulzospora* sp. (PC-a). P. *Schulzospora rara* (PC-a). Q. *Schulzospora rara* (PI-b). R. *Calamospora* sp. (PC-a). S. *Spencerisporites radiatus* (PC-a). T. *Florinites visendus* (PC-a). U. *Cingulizonates bialatus* (PC-a). V. *Cingulizonates bialatus* (PI-b).

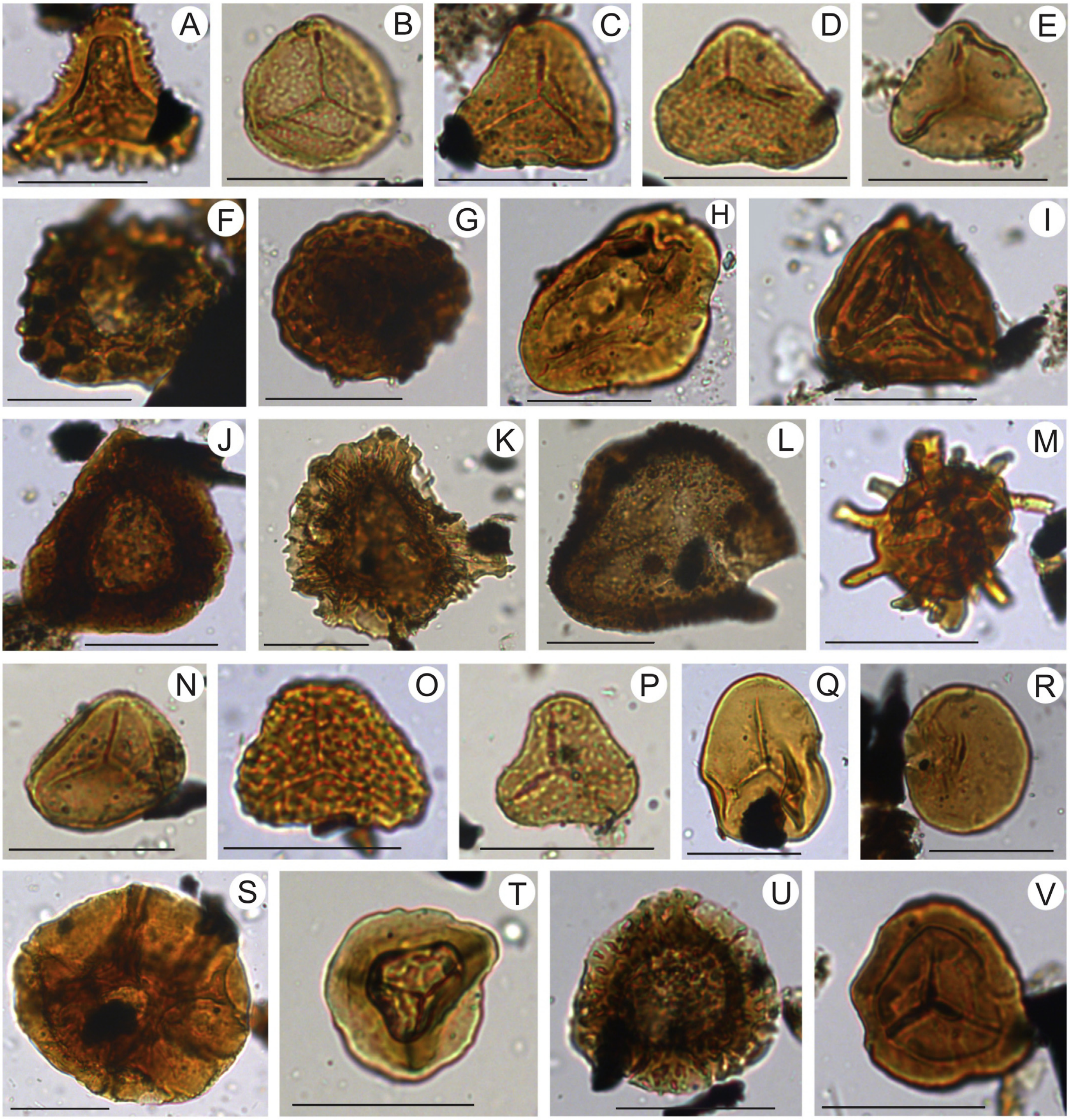

Plate IV. The Carboniferous continental palynomorphs from the Vlaşin Formation (scale bar: 30 μm). A. *Murospora* sp. (sample PI-b). B. *Lycospora granulata* (PI-b). C. *Granulatisporites granulatus* (PC-a). D. *Granulatisporites granulatus* (PI-b). E. *Leiotriletes tumidus* (PI-b). F. *Raistrickia nigra* (PA-j). G. *Convolutispora radiata* (PA-i). H. *Leiotriletes sphaerotriangulus* (PA-h). I. *Savitrisporites nux* (PC-a). J. *Densosporites pseudoannulatus* (PC-a). K. *Cristatisporites* cf. *indignabundus* (PI-b). L. *Crassispora kosankei* (PI-b). M. *Raistrickia* sp. (PI-b). N. *Rotaspora ergonuli* (PI-b). O. *Microreticulatisporites* sp. (PI-b). P. *Lophotriletes mosaicus* (PI-b). Q. *Leiotriletes* sp. (PI-b). R. *Laevigatosporites* sp. (PI-b). S. *Reticulatisporites* sp. (PI-b). T. *Potoniespores delicatus* (reworked, PI-b). U. *Cingulizonates* cf. *capistratus* (reworked, PI-b). V. *Murospora aurita* (reworked, PI-b).

5.2. Palynofacies compositions

For the five wells studied, most of the samples show a clear dominance of particulate organic matter (POM) of terrestrial origin. Four main constituents of POM were recognized, including: opaque phytoclasts (lath-shaped and equidimensional), translucent phytoclasts, AOM (granular form, marine origin) and palynomorphs.

5.2.1. BW-05 well

Samples from the BW-05 well contain a highly variable amount of kerogen. In the 2256–2021 m depth interval (PB-l, PB-k and PB-m samples), the opaque phytoclasts are frequently encountered (90–99% of the total POM; Fig. 2), being commonly small in size (5–40 μm) and are generally rounded. The translucent phytoclasts show low frequencies in this interval (samples PB-l up to PB-m), but have a higher

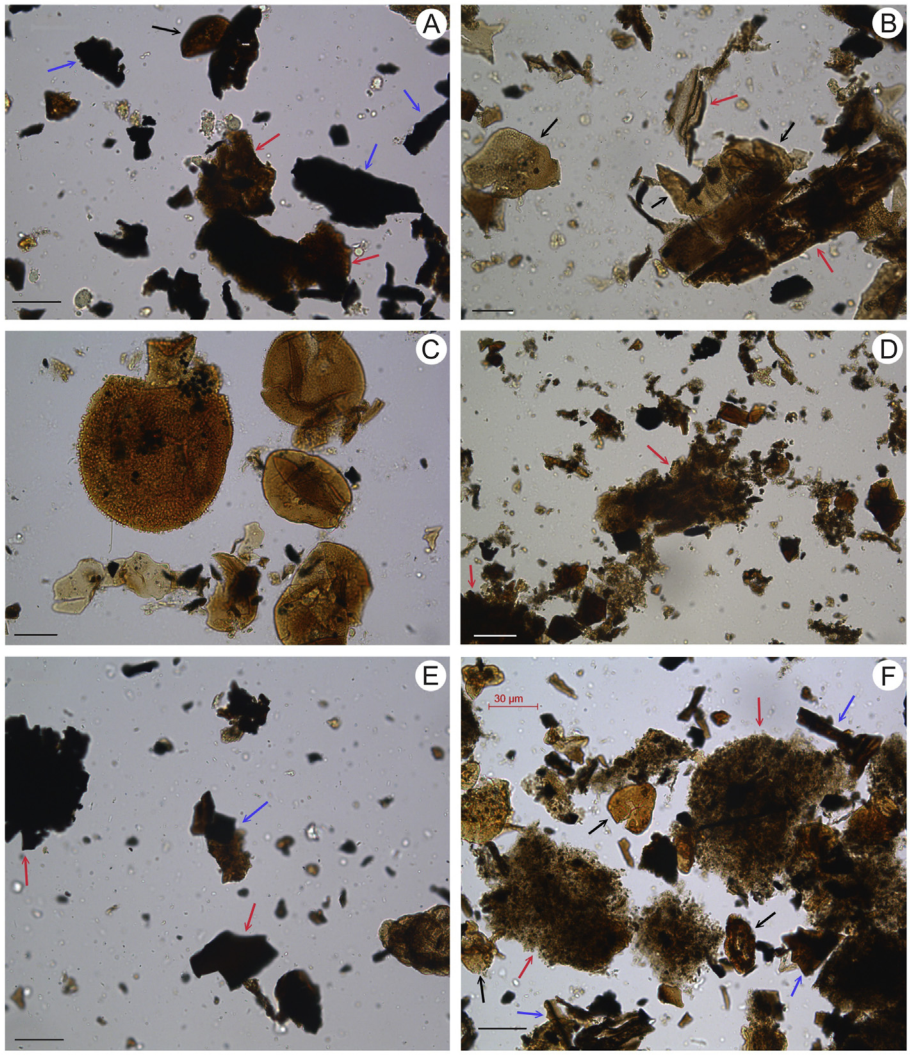

Plate V. The representative palynofacies from the Ţăndărei, Călăraşi and Vlaşin formations (scale bar: 30 μm). A. translucent phytoclasts (red arrows) mixed with opaque phytoclasts (blue arrows) and palynomorphs (black arrow) of terrestrial origin (Ţăndărei Formation, sample PB-n). B. brown woody tissue large in size (red arrows), in association with continental palynomorphs (black arrows) and other terrestrial organic particles (Ţăndărei Formation, PU-e). C. high relative abundance of miospores (Ţăndărei Formation, PU-e). D. partially biodegraded translucent phytoclasts (red arrows) mixed with other continental organic particles (Călăraşi Formation, PI-d). E. a mixed assemblage of angular opaque phytoclasts (red arrows) with translucent organic particles (blue arrow) and palynomorphs (Vlaşin Formation, PI-b). F. a mixed assemblage of amorphous organic matter particles with framboidal pyrite (marine origin, red arrows), palynomorphs (black arrows) and continental phytoclasts (blue arrows) (Vlaşin Formation, PC-a).

abundance (~22%) in the PB-n sample. This type of phytoclasts consist of woody tissues (Plate V A), cuticles (sometimes large in size) and small yellow-brown fragments. The palynological assemblages identified in the PB-k sample contain up to 4% of the total POM. Generally, these assemblages are dominated by miospores, but some high frequencies of the phytoplankton have been observed in PB-l–PB-k sampling interval (25–42% of the total palynomorphs). The palynofacies for these samples also includes rare specimens of phytodebris and scolecodonts.

5.2.2. UW-03 well

Palynofacies assemblages recovered from the samples of this well are dominated by organic matter of continental origin. Translucent phytoclasts are most abundant components in this interval (60–70%; Plate V B), to which are added opaque phytoclasts (up to 35% in PU-f sample) and rare occurrences of AOM. The palynological assemblages are well preserved and diversified, comprising about 1% of the total POM in the PU-f sample, followed by an increase in the relative abundance of up to 15% (consisting mainly of trilete spores; Plate V C) in the younger PU-e sample (Fig. 2). Marine palynomorphs are rare in the PU-f–PU-e sample interval, consisting of a few specimens of acritarchs and scolecodonts.

5.2.3. IW-02 well

The three samples analyzed from the IW-02 well have a moderate to high quantity of organic matter of mostly continental origin. Partially biodegraded translucent phytoclasts (woody tissues, small yellow/brown fragments) are prevalent in the PI-d and PI-c samples (60–75% of the total POM; Plate V D). In contrast, sample PI-b shows an increase in the frequency of angular opaque phytoclasts (Plate V E) that comprise approximately 70% of the POM and are mixed with woody tissues and cuticles. The palynomorph assemblages show a relative abundance ranging between 1 and 4% of the total POM, including numerous specimens of biodegraded spores in the PI-d sample and a predominance of the *Lycospora* genus in the PI-b sample. Rare occurrences of AOM particles (marine origin) were also identified and comprise up to 5% in the PI-d sample. Phytoplankton is absent over this interval.

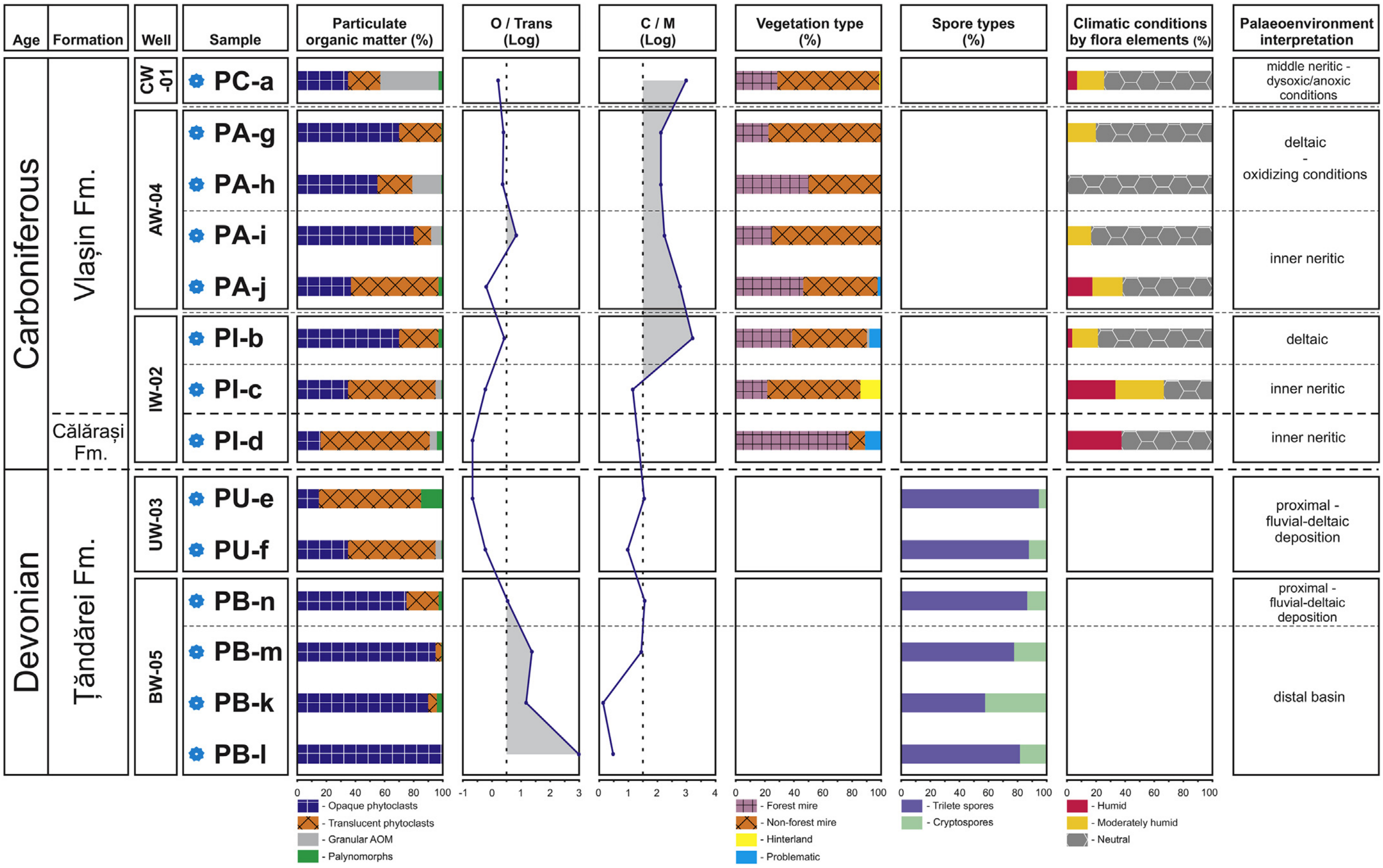

Fig. 2. Relative abundances of particulate organic matter and vegetation type in the Ţăndărei, Călăraşi and Vlaşin formations. The palynofacies parameters (O/Trans, C/M) distribution, climatic conditions and paleoenvironment interpretations are also shown. O/Trans – opaque to translucent phytoclasts ratio; C/M – continental/marine palynomorphs ratio.

5.2.4. AW-04 well

The AW-04 well interval analyzed has an upper and lower section having distinct palynofacies differences. The lower section is characterized by a relatively high proportion of translucent phytoclasts (PA-j sample; Fig. 2) including woody tissues (sometimes large) and tracheids. The upper section (PA-i–PA-g sample interval) has a predominance of opaque phytoclasts that account for 55–80% of the total POM. Some samples within the PA-i and PA-h sample interval also include up to 20% of marine AOM. Terrestrial palynomorphs are generally rare and account for only ~1% of the total POM. A slightly higher relative abundance of terrestrial palynomorphs (~3%) is observed in PA-j sample. Marine palynomorphs are absent.

5.2.5. CW-01 well

For the PC-a sample, the palynofacies assemblage is characterized by a high relative abundance of marine AOM (~40% of the total POM; Plate V F). In addition, various proportions of translucent and opaque phytoclasts are identified (Fig. 2), as well as numerous continental palynomorphs represented only by miospores. A limited number of AOM particles show framboidal pyrite on their surface (Plate V F), indicating an anoxic environment within sediments.

6. Discussion

6.1. Biostratigraphy and correlation with other known biozonations

In this paper, the standard Western European biozonation of the Devonian (Richardson and McGregor, 1986; Streel et al., 1987) and the Carboniferous (Clayton et al., 1977; Owens et al., 2004) is used to establish a biostratigraphic framework for the studied wells. Biostratigraphic age determination is based on the first occurrence (FO) and the last occurrence (LO) of significant marker taxa (mainly miospores). The ranges of the key miospore taxa recorded from the Ţăndărei, Călăraşi and Vlaşin formations are shown in Fig. 3. Seven biozone intervals (four for the Devonian and three for the Carboniferous) are recognized based on the stratigraphic distribution of identified taxa, these indicating the following global stages for the studied sections:

6.1.1. Lochkovian

According to Richardson and McGregor (1986), the *micrornatus–newportense* (MN)–lower part of *breconensis–zavallatus* (BZ) spore Zones corresponds to this age. The Lochkovian age of the PB-l–PB-k sampling interval (BW-05 well, upper part of the Ţăndărei Formation) is supported by two bioevents, namely: FO of *Emphanisporites micrornatus* var. *micrornatus* and LO of *Eisenackitina* aff. *bohemica*. In many areas of Gondwana, *Emphanisporites micrornatus* var. *micrornatus* first appears in the middle part of the *micrornatus–newportense* Zone (Steemans and Lakova, 2004; Breuer et al., 2005; Turnau et al., 2005) while the stratigraphic range of *Eisenackitina bohemica* covers the entire Lochkovian, with its last occurrence reported at the end of this age (Paris and Grahn, 1996; Paris et al., 2000; Vaida and Verniers, 2005). In addition, the PB-l–PB-k sampling interval contains many other long ranging palynomorph taxa typical for Late Silurian–Early Devonian times such as some chitinozoans (*Ancyrochitina aculeata*, *Sphaerochitina sphaerocephala*), acritarchs (*Baltisphaeridium pilaris*, *Multiplicisphaeridium ampliatum*) and miospores (*Acanthotriletes inferus*, *Archaeozonotriletes chulus*). Also, some specimens of phytodebris (i.e. *Porcatitubulus annulatus*) seen in the PB-k sample are frequently identified in Silurian–middle Devonian deposits (Lakova, 2001; Taylor and Wellman, 2009).

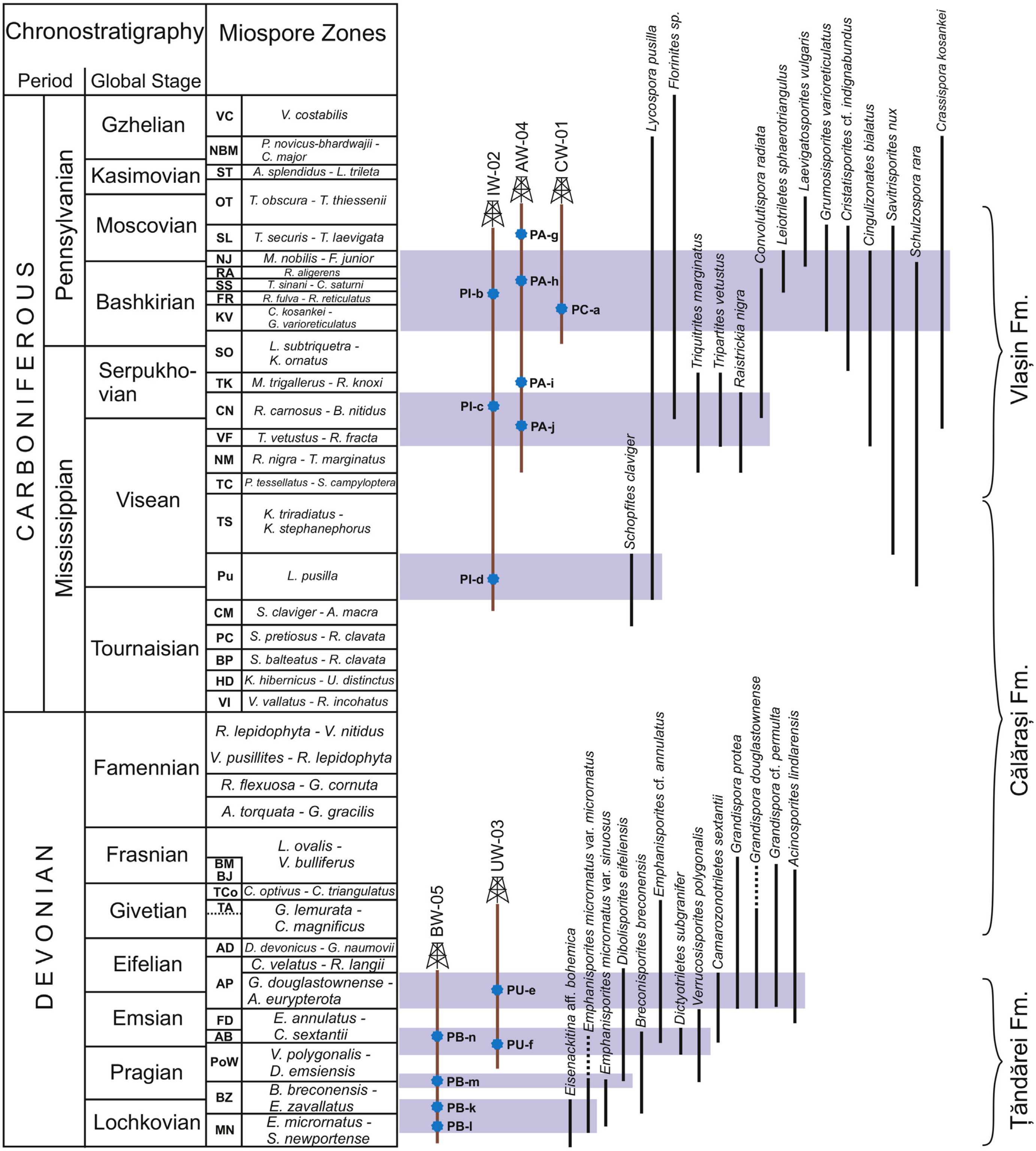

Fig. 3. Zonal schemes and ranges of selected spore taxa recovered in this study. The Devonian zonal scheme after Richardson and McGregor (1986) and Streel et al. (1987), and Carboniferous miospore zonation according to Clayton et al. (1977) and Owens et al. (2004).

6.1.2. Pragian

The boundary between the *breconensis–zavallatus* (BZ)–*polygonalis–emsiensis* (PoW) spore Zones is recognized only in the BW-05 well (PB-m sample; Fig. 3) and is marked by the LO of *Emphanisporites micrornatus* var. *sinuosus* and FO of *Dibolisporites eifeliensis*. According to Turnau and Jakubowska (1989) and Breuer et al. (2005), the latest occurrence of *Emphanisporites micrornatus* var. *sinuosus* was recorded in the middle part of the Pragian, and the same geological age coincides with the earliest occurrence of *Dibolisporites eifeliensis* (Richardson and McGregor, 1986; Turnau et al., 2005; Filipiak, 2011). Therefore, the presence of *Emphanisporites micrornatus* var. *sinuosus* and *Dibolisporites eifeliensis* indicates that the palynological assemblage recorded in the PB-m sample of the BW-05 well (2021 m depth) can be dated mid Pragian.

6.1.3. Uppermost Pragian–Early Emsian

The upper part of *polygonalis–emsiensis* (PoW)–*annulatus–sextantii* (AB) spore Zones chronostratigraphically dated as uppermost Pragian–Early Emsian (Richardson and McGregor, 1986) is recognized in the PU-f sample (UW-03 well) and PB-n sample (BW-05 well). The most important biostratigraphic taxon identified in the PU-f sample is *Dictyotriletes subgranifer*. This species marks the Su interval Zone (upper part of PoW Oppel Zone sensu Streel et al., 1987) in many areas including Poland (Turnau et al., 2005; Filipiak, 2011; Fijałkowska-Mader and Malec, 2011), Saudi Arabia (Breuer et al., 2007) and Algeria (Kermandji et al., 2008). The PoW Oppel Zone is of Pragian–earliest Emsian age, with the Su interval Zone straddling the latest Pragian–earliest Emsian. Consequently, we consider that the assemblage identified in the PU-f sample can be dated as uppermost Pragian, or an age corresponding with the Pragian–Emsian boundary. This finding is also supported by the lack of some characteristic Emsian taxa (e.g. *Camarozonotriletes sextantii*, *Emphanisporites annulatus*) in this sample. The palynological assemblage of the PU-f sample also includes taxa such as *Verrucosisporites polygonalis* and *Dibolisporites eifeliensis*, that are typical for a Late Pragian–Early Eifelian age.

The lower part of *annulatus–sextantii* Zone (Early Emsian) is clearly indicated by the assemblage identified in the PB-n sample (Fig. 3). The base of the *annulatus–sextantii* Zone is marked by FO of *Emphanisporites* cf. *annulatus* (Richardson and McGregor, 1986; Filipiak, 2011) while the top of the AB Oppel Zone (sensu Streel et al., 1987) is revealed by the LOs of the *Breconisporites breconensis* and *Dictyotriletes subgranifer* (Richardson and McGregor, 1986; Fijałkowska-Mader and Malec, 2011).

The biostratigraphic information obtained based on the palynological assemblages of the PU-f and PB-n samples (sampled from different wells) enable a good correlation between the UW-03 well (5990–5998 m depth interval) and BW-05 well (1929–1934 m depth interval).

6.1.4. Late Emsian–Early Eifelian

The assemblage identified in the PU-e sample from the UW-03 well is assigned to the *douglastownense–eurypterota* (AP) Zone of Richardson and McGregor (1986). Among the most important biostratigraphic taxa of this assemblage are *Camarozonotriletes sextantii*, *Grandispora douglastownense* and *G. protea*. According to Richardson and McGregor (1986), Loboziak and Melo (2002) and Filipiak (2011), the FOs of *Grandispora douglastownense* and *G. protea* define the base of *douglastownense–eurypterota* Zone, while the LO of *Camarozonotriletes sextantii* marks the middle part of this biozone (Richardson and McGregor, 1986) or, in Western Gondwana, the top of the *douglastownense–eurypterota* (AP) Zone (Loboziak and Melo, 2002; Fig. 3). This typical upper Emsian–lower Eifelian assemblage also includes taxa with broader stratigraphical ranges (e.g. *Acinosporites lindlarensis*, *Apiculiretusispora arenorugosa*, *Dibolisporites echinaceus*, *Grandispora* cf. *permulta*), both for the younger and higher zones (see Fig. 3).

Sample PU-e of the UW-03 well (5919–5922 m depth interval; Fig. 1) contains the youngest Devonian age palynological assemblage for the studied wells and therefore we consider the age of deposits from the top of the Ţăndărei Formation to be Late Emsian–Early Eifelian.

6.1.5. Late Tournaisian–Early Visean

The *Lycospora pusilla* (Pu) Zone of Clayton et al. (1977) has been identified in the upper part of the Călăraşi Formation (PI-d sample of IW-02 well; Fig. 3). The assemblage identified in the PI-d sample is assigned to the *Lycospora pusilla* Zone based on the FO of zonal index species *Lycospora pusilla* and the LO of the key taxon *Schopfites claviger* that defines the end of the Pu biozone in western Europe (Clayton et al., 1977; Scott et al., 1984; Clayton, 1985). Other characteristic species recorded in this assemblage include *Anapiculatisporites concinnus* and *Densosporites anulatus*, both being frequently quoted in Visean deposits of the northern and southern hemispheres (Beju, 1971; Stempień and Turnau, 1988; Stephenson and Owens, 2006; Playford and Mory, 2017).

6.1.6. Late Visean–Serpukhovian

This geochronologic interval has been recognized based on palynological assemblages identified in three samples (i.e. PA-j, PA-i and PI-c) of the AW-04 and IW-02 wells (Fig. 3). The assemblage of the PA-j sample (3072 m depth, AW-04 well) includes marker taxa such as *Raistrickia nigra*, *Tripartites vetustus* and *Triquitrites marginatus*. The stratigraphic distribution of these species, including their first and last occurrence, allows assignment to the *vetustus–fracta* (VF)–*carnosus–nitidus* (CN) spore Zones (Clayton et al., 1977; Owens et al., 2004; Górecka-Nowak and Muszer, 2011; Orlova et al., 2015). Other species such as *Cingulizonates bialatus*, *Densoisporites truswelliae*, *Schulzospora* cf. *campyloptera,* that are typical for a Visean–Bashkirian interval, also occur in the PA-j sample assemblage. In the AW-04 well, the most important marker taxon identified in the PA-i sample (2900 m depth) is *Convolutispora radiata*, which indicates an Early Namurian age (= Serpukhovian) in China (Zhu, 1993).

The palynological assemblage of the PI-c sample (IW-02 well) includes a small number of taxa, but its age is not older than Serpukhovian, as indicated by the presence of the *Florinites* genus that has its first occurrence at the base of this geochronologic unit (Clayton et al., 1977).

6.1.7. Bashkirian–Early Moscovian

The *kosankei–varioreticulatus* (KV)–*nobilis–junior* (NJ) spore Zones have been recognized in some samples (i.e. PI-b, PC-a, PA-h) from the upper part of the Vlaşin Formation (Fig. 1). The Bashkirian–Early Moscovian interval is well constrained by the taxa of the PC-a and PI-b samples, with the palynological assemblages of these two samples showing several common species (Appendix A). Among the bioevents which mainly reveal the Bashkirian age of these two assemblages, the FO of *Grumosisporites varioreticulatus* in the base of KV Zone (Clayton et al., 1977; Owens et al., 2004) and the LOs of *Cingulizonates bialatus*, *Savitrisporites nux* and *Schulzospora rara* correlating to the Bashkirian–Moscovian boundary (Clayton et al., 1977; Stephenson and Owens, 2006; Fig. 3) can be mentioned. The assemblage of the PI-b sample contains, in addition to the autochthonous palynomorphs typical for Bashkirian, some reworked taxa from upper Mississippian deposits (e.g. *Cingulizonates* cf. *capistratus*, *Murospora aurita*, *Potoniespores delicatus*, *Tripartites vetustus*; Plate IV T–V).

In the AW-04 well, the miospore assemblage of the PA-h sample contains *Leiotriletes sphaerotriangulus* taxon. This species occurs mainly during the Late Bashkirian–Early Moscovian (Pendleton, 2012). For the AW-04 well, a slightly younger age of the PA-g sample is indicated by *Laevigatosporites vulgaris* (Fig. 3), a taxon frequently dated Late Bashkirian–Moscovian (Pendleton, 2012) and associated with upper Pennsylvanian deposits of the Precaspian Depression (Podgainaya et al., 1996).

6.2. Paleoenvironmental reconstruction and paleoclimatic implications

A large proportion of the sedimentary organic matter from the well samples analyzed is of terrestrial origin including opaque and translucent phytoclasts, spores and phytodebris. A small amount of organic matter of marine origin is also present and is comprised of granular AOM, chitinozoans, acritarchs and scolecodonts. Variations in the stratigraphic distributions of the interpretative parameters (i.e. the values of O:Trans ratio, C/M ratio), vegetation type and some climatic conditions revealed by microflora are presented chronologically in the composite profile (Fig. 2).

The upper part of the Ţăndărei Formation defined by samples PB-l up to PU-e (Fig. 2) is dated Late Lochkovian–Early Eifelian in accordance with the biostratigraphic information presented previously. Throughout this lithostratigraphic interval, two types of palynofacies can be recognized, namely: in its lower part (PB-l–PB-m sampling interval, assigned to Late Lochkovian–Pragian age), the POM analyzed is mainly comprised of opaque phytoclasts (small in size and rounded shape) associated with various species of marine phytoplankton, while in its upper part (PU-f, PU-e samples dated Emsian–Early Eifelian) the palynofacies is dominated by translucent phytoclasts (Fig. 2) mixed with terrestrial palynomorphs. The O:Trans ratio in the Ţăndărei Formation (upper Lochkovian–Pragian interval) shows values of 1.18–3, suggesting a more distal depositional environment for this interval. Similar relative environments are also indicated by the C/M ratio, the latter having a lower value in sample PB-k (0.15), and a slightly higher value in sample PB-m. The high frequency of trilete spores and the presence of several specimens of acritarchs and chitinozoans in the PB-l and PB-k samples also supports offshore marine environments for the upper Lochkovian–Pragian section.

In the top of the Ţăndărei Formation (PU-f–PU-e sampling interval, Emsian–lower Eifelian), a modification in the palynofacies composition was observed (Fig. 2) due to some changes of the depositional environment, compared to that of the upper Lochkovian–Pragian. The POM analyzed from the Emsian–lower Eifelian interval is mainly composed of translucent phytoclasts (60–70%), sometimes with large dimensions (Plate V B) indicating a short transport distance. Consequently, a regressive trend or a proximal/fluvio-deltaic environment during the sedimentation of the Emsian–lower Eifelian section is documented by decreasing values of the O:Trans ratio, the increase of the C/M ratio up to 1.54 (PU-e sample) and a high number of the miospore specimens recorded in the same sample.

Only the upper part of the Călăraşi Formation (Givetian–lower Visean) was analyzed, including a section dated upper Tournaisian–lower Visean (PI-d sample; Fig. 1). For the Tournaisian–lower Visean succession, the palynofacies composition exhibits a clear proximal signature, as demonstrated by the predominance of translucent phytoclasts (~75%; Fig. 2) and high frequency of miospores originating from forest mire. Both phytoclasts and miospores show strong bacterial biodegradation. The O:Trans ratio displays a value of −0.67, suggesting an inner neritic environment. The terrestrial palynomorph assemblage identified from the upper Tournaisian–lower Visean deposits is dominated by taxa such as *Lycospora* and *Densosporites* that originate from various types of arborescent and herbaceous lycopsids (Orlova et al., 2015), this assemblage indicating mainly neutral–humid conditions for this period.

For the Vlaşin Formation deposits dated upper Visean–Serpukhovian, the palynofacies content is dominated by translucent phytoclasts (~60% of the total POM) represented by yellow/brown fragments, sometimes large woody tissues and tracheids, to which is added a smaller amount of opaque phytoclasts and a minor fraction (up to 5%) of marine AOM. This palynofacies composition is consistent with deltaic fan input into an inner neritic depositional environment. The interpretation of this paleoenvironment is also greatly supported by the exclusive presence of terrestrial palynomorphs in the palynological assemblage (frequent forest mire-related miospores; e.g. *Lycospora*) and high values of C/M ratio (up to 2.77 in PA-j sample; Fig. 2). Compared to the Late Tournaisian–Early Visean interval, a slight increase in the proportion of flora elements associated with moderately humid to humid conditions was observed for the Serpukhovian deposits.

In the upper part of the Vlaşin Formation (Bashkirian–lower Moscovian deposits), the POM assemblage shows a slightly different composition compared to that described from the lower part of the same formation. The palynological assemblages of the PC-a sample (CW-01 well) and PI-b sample (IW-02 well) both indicate a Bashkirian age, but their palynofacies content is different. In the PC-a sample, the high abundance (~40%) of brown marine AOM associated with framboidal pyrite (Plate V F) and mixed with continental phytoclasts indicates low-energy and dysoxic/anoxic conditions within the basin. In contrast, the POM content identified in the PI-b sample is exclusively of continental origin (angular opaque phytoclasts, woody tissues, cuticles, autochthonous and reworked miospores) suggesting deltaic influences within a proximal area of the basin. The depositional environment consequently interpreted for the Bashkirian Stage is an initial deeper water environment (probably middle neritic zone) that rapidly transitioned to deltaic deposition due to marine regression. This interpretation is in agreement with previous models (Paraschiv and Popescu, 1980; Pană, 1997), which indicate deltaic deposition for this region of the Moesian Platform during the Bashkirian.

The Bashkirian palynological assemblage (PC-a sample) recovered from the sediments deposited in a middle neritic zone is dominated by fern miospores (e.g. *Calamospora*, *Granulatisporites*, *Savitrisporites*, *Schulzospora*) belonging to non-forest mire, the parent plants of these Carboniferous taxa growing mainly as cover plants within non-flooded wetlands (DiMichele and Phillips, 2002). On the other hand, a peak of the arborescent lycopsid (~33% of the total palynomorphs) represented by *Lycospora* genus was observed in Bashkirian sediments (PI-b sample) assigned to a deltaic depositional environment. According to Greb et al. (2006), *Lycospora*-producing plants are significant floral components of the upper Carboniferous swamps and peat mires of the coastal plains and continental interiors. The Bashkirian palynological assemblage recorded from the PC-a, PI-b and PA-h samples indicates mainly neutral–moderately humid climatic conditions for this period (Fig. 2).

Moscovian deposits at the top of the Vlaşin Formation (PA-g sample) contain a POM assemblage dominated by opaque phytoclasts (~70%) and translucent phytoclasts (frequently biodegraded). The opaque phytoclasts of this assemblage are typically equidimensional and angular in shape. Significant amounts of such phytoclasts are often associated with high-energy deltaic deposition and oxidizing conditions (Batten, 1982; Tyson, 1993). This interpretation of the Moscovian paleoenvironment within the studied area is in agreement with pre-existed depositional models (Pană, 1997; Seghedi et al., 2005).

During the Late Carboniferous (probably Kasimovian), most of Moesia was tectonically uplifted and eventually became continental (Seghedi et al., 2005). Sedimentation resumed during the Permian, or even later for some areas of the platform (Ionesi, 1994).

6.3. Paleobiogeography

Large amounts of palynological data from lower Devonian deposits enable some understanding of the world phytogeographic distribution at that time. According to Ziegler et al. (1981) and Raymond (1987), based on global plant distribution, three main realms can be recognized for the Early Devonian, namely: Gondwanan Realm (including the most part of Gondwana), the Angaran Realm (including Kazakhstan and northeastern Gondwana) and the Euramerican Realm (including Euramerica, Siberia and South China).

For the Moesian Platform, paleomagnetic data are completely missing, but a northern Gondwanan origin for Moesia is inferred based on marine palynomorphs. This interpretation is supported by an assemblage of Lochkovian chitinozoans (i.e., *Eisenackitina bohemica*, *Urochitina simplex*) identified in the area of the Moesian Terrane extending Bulgaria to Romania (Iordan et al., 1985; Lakova, 1999; Vaida et al., 2005). *Eisenackitina* aff. *bohemica* was also identified by us in the BW-05 well (PB-k sample), suggesting a dominant northern Gondwanan affinity for Lochkovian marine palynomorphs in East Moesia.

Conversely, for the Early Devonian, Steemans and Lakova (2004) defined the *sinuosus–zavallatus* Phytogeographic Province which is a subprovince of Euramerica and covers the eastern part of the Caledonian Mountains (Avalonia and western part of Baltica). This province is characterized by taxa belonging to the phylogenetic lineage of *Emphanisporites micrornatus* (Breuer et al., 2005) that are restricted to this region. Both taxa occur in the Lower Devonian deposits of northern

Bulgaria and *E. micrornatus sinuosus* was identified by us in the BW-05 well (PB-m sample). These findings indicate that Moesia was close to the southern Euramerican Realm during the Early Devonian. Steemans and Lakova (2004) explained the presence of the chitinozoans which clearly showed a North Gondwanan affinity, joint to *sinuosus–zavallatus* miospore province, by the migration of these palynomorphs allowed by the Rheic Ocean during the Silurian–Devonian transition. Pflug and Prössl (1991) found no support for the existence of a wide Devonian ocean between North Gondwana and Euramerica. Starting with Early Devonian, these two paleocontinents must have been relatively close together to facilitate the active interchange of terrestrial plants that is observed (Galle et al., 1995).

The Upper Carboniferous palynological assemblage recorded in the studied samples includes many taxa belonging to different arborescent or sub-arborescent lycopsids (e.g. *Cingulizonates*, *Densosporites*, *Lycospora*). This palynological content is similar to that described for the Euramerican Phytogeographic Province, being dominated by swamp forest vegetation represented by various lycopsids. However, the palynological assemblage and associated vegetation is slightly different than the Carboniferous vegetation assigned to the Angaran Province that is dominated by cordaites (Oshurkova, 1996).

7. Conclusions

Palynological analysis was carried out for 14 core samples collected from the Devonian–Carboniferous sections of five petroleum exploration wells drilled within the eastern part of the Meosian Platform. Abundant, well-preserved palynomorph assemblages were identified, consisting mainly of miospores and phytoplankton taxa. Based on the assemblages identified and established palynofacies data, interpretations of age, paleoclimate, paleoenvironments and paleobiogeography are made. The main conclusions are the following:

(1) Four Devonian biozone intervals and three Carboniferous biozone intervals were recognized based on the stratigraphic distribution of identified key taxa. The biostratigraphic information obtained suggests that the upper part of the Ţăndărei Formation is Lochkovian to Early Eifelian in age, as indicated by FOs of *Emphanisporites micrornatus* var. *micrornatus* and *Eisenackitina* aff. *bohemica* and LO of *Camarozonotriletes sextantii*. The upper part of the Călăraşi Formation analyzed from the IW-02 well (PI-d sample) is Late Tournaisian–Early Visean, based on occurrences of *Lycospora pusilla* and *Schopfites claviger*. A Late Visean–Early Moscovian age is assigned to the Vlaşin Formation samples as indicated by the FOs of *Tripartites vetustus*, *Triquitrites marginatus* and LOs of *Cingulizonates bialatus*, *Savitrisporites nux* and *Schulzospora rara*.

(2) A relatively high abundance of phytoplankton assemblages (chitinozoans, acritarchs) was observed only in Lochkovian deposits of the Ţăndărei Formation, with the marine assemblage for the PB-k sample of the BW-05 well comprising 42% of the total palynomorphs. Pragian–lower Eifelian deposits at the top of the Ţăndărei Formation have a high diversity of terrestrial palynomorphs (mainly trilete spores), along with subordinated acritarchs and a few chitinozoans. The Carboniferous palynological assemblages identified in the upper part of the Călăraşi Formation and Vlaşin Formation include only species of miospores belonging to arborescent and herbaceous lycopsids, and ferns.

(3) The POM composition, the O:Trans ratio and C/M ratio identified in the Lochkovian–Pragian deposits (Ţăndărei Formation) suggest a more distal depositional environment for the interval. During deposition of the Emsian–lower Eifelian deposits (top of the Ţăndărei Formation), a regressive trend or proximal/fluvio-deltaic environment is interpreted based on palynofacies parameters and the high frequency of miospores. The Carboniferous deposits assigned to the upper part of the Călăraşi Formation (upper Tournaisian–lower Visean) and the lower part of the Vlaşin Formation (upper Visean–Serpukhovian) are typical for inner neritic environments, as indicated by the predominance of translucent phytoclasts (sometimes large in size) and high values of the C/M ratio. The palynofacies composition of the Bashkirian deposits (upper part of the Vlaşin Formation) reflects deposition under mud-dominated dysoxic/anoxic conditions within a middle neritic setting that quickly transitioned to proximal deltaic deposition due to a marine regression. Deltaic facies and oxidizing conditions persisted until the Moscovian, as indicated by the predominance of opaque phytoclasts (having equidimensional and angular shape) mixed with biodegraded translucent phytoclasts observed in the palynofacies composition from the top of the Vlaşin Formation.

(4) The Devonian palynological assemblage includes mainly trilete spores that are associated with lowland vegetation. Based on paleobotanical affinities, these vascular plants grew in open, lowland areas having fluvial connections to marine sedimentary basins. During the Early Carboniferous (Late Tournaisian–Early Visean), the terrestrial palynomorphs are dominated by taxa (e.g. *Densosporites*, *Lycospora*) which belong to various types of arborescent and herbaceous lycopsids, indicating mostly neutral to humid conditions for this period. The parent plants of the Bashkirian palynomorphs suggest different habitats such as non-flooded wetlands or swamps within coastal plains and continental interiors, as well as predominantly neutral climatic conditions.

Author Agreement Statement

We the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author is the sole contact for the Editorial process. He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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