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Palynology of the upper Visean Paprotnia Beds (Bardo Unit, Polish Sudetes)

Anna GÓRECKA-NOWAK and Jolanta MUSZER

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The siliciclastic rocks of the Paprotnia Beds from the Bardo Unit (Polish Sudetes) provide abundant and diverse palynological material. The miospore assemblages recovered allow distinction of two miospore biozones. The *Tripartites vetustus–Rotaspora fracta* (VF) Biozone was recognized in the lower and the middle parts of the section. In its upper part the *Cingulizonates capistratus* (Cc) Subbiozone, the lower part of the *Cingulizonates capistratus–Bellispores nitidus* (CN) Biozone was distinguished. These results indicate that the rocks of the Paprotnia section, considered earlier on the basis of biostratigraphic and radiometric data as upper Asbian, should be assigned to the upper Asbian and Brigantian. The location of the Asbian/Brigantian boundary and the possible occurrence of a gap in the Brigantian part of the section are discussed. Palynofacies observations of miospore preservation and frequency provided additional information, which confirm the gradual shallowing of the environment of deposition from offshore to onshore. Thermal maturity assessment of organic matter, based on miospore colour, indicates early mature and mature stages of organic matter thermal alteration.

Anna Górecka-Nowak and Jolanta Muszer, Institute of Geological Sciences, Wrocław University, Cybulskiego 30, PL-50-205 Wrocław, Poland, e-mails: anna.gorecka-nowak@ing.uni.wroc.pl, jolanta.muszer@ing.uni.wroc.pl *(received: January 13, 2011; accepted: June 8, 2011).*

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INTRODUCTION

The Bardo Structural Unit, a separate tectonic unit in the Western Sudetes (Lugicum; Fig. 1), has a complicated geological setting. It consists mainly of Mississippian sedimentary rocks, but also contains some deposits from at least the Upper Ordovician to the Upper Devonian (Haydukiewicz, 1990). According to the tectonostratigraphic model two main successions are distinguished: autochthonous/parautochthonous and allochthonous (Wajsprych, 1986, 1995). The autochthonous/parautochthonous succession is composed of a Famennian to Mississippian succession, deposited in different habitats from platform to foreland. The lithostratigraphic succession is outlined by Kryza *et al.* (2008). The allochthonous succession occurs as exotic large olistoliths of deep marine strata in the uppermost part of the autochthonous/parautochthonous sequence and is assigned to the Upper Ordovician–Upper Devonian (Haydukiewicz, 1990).

The stratigraphic succession in the Bardo Structural Unit is still difficult to understand in detail because of sparse palaeontological evidence and lithofacies variability, as well as its complicated tectonic history. Therefore the lithostratigraphic scheme proposed by Wajsprych (1995) is informal. Palynological analysis appears promising, which until now has been applied only sporadically (Majewska-Bill, 2006) and the results are not published.

The goal of the present palynological studies of the Paprotnia Beds, one of the stratigraphic marker in the Mississippian rocks of the Bardo Unit, was the stratigraphic interpretation and comparison to previous faunistic zonations. Additionally the assessment of the thermal maturity of the organic matter and the observations on the palynofacies were carried out.

STRATIGRAPHY

The Paprotnia Beds, being an informal lithostratigraphic unit, belong to the upper part of the autochthonous/parautochtonous succession. They are included in the lower part of the Winna Góra sequence (Fig. 2), which consists of several facially differentiated sedimentary rocks (Wajsprych, 1995). The stratigraphic position of this unit is difficult to determine be-

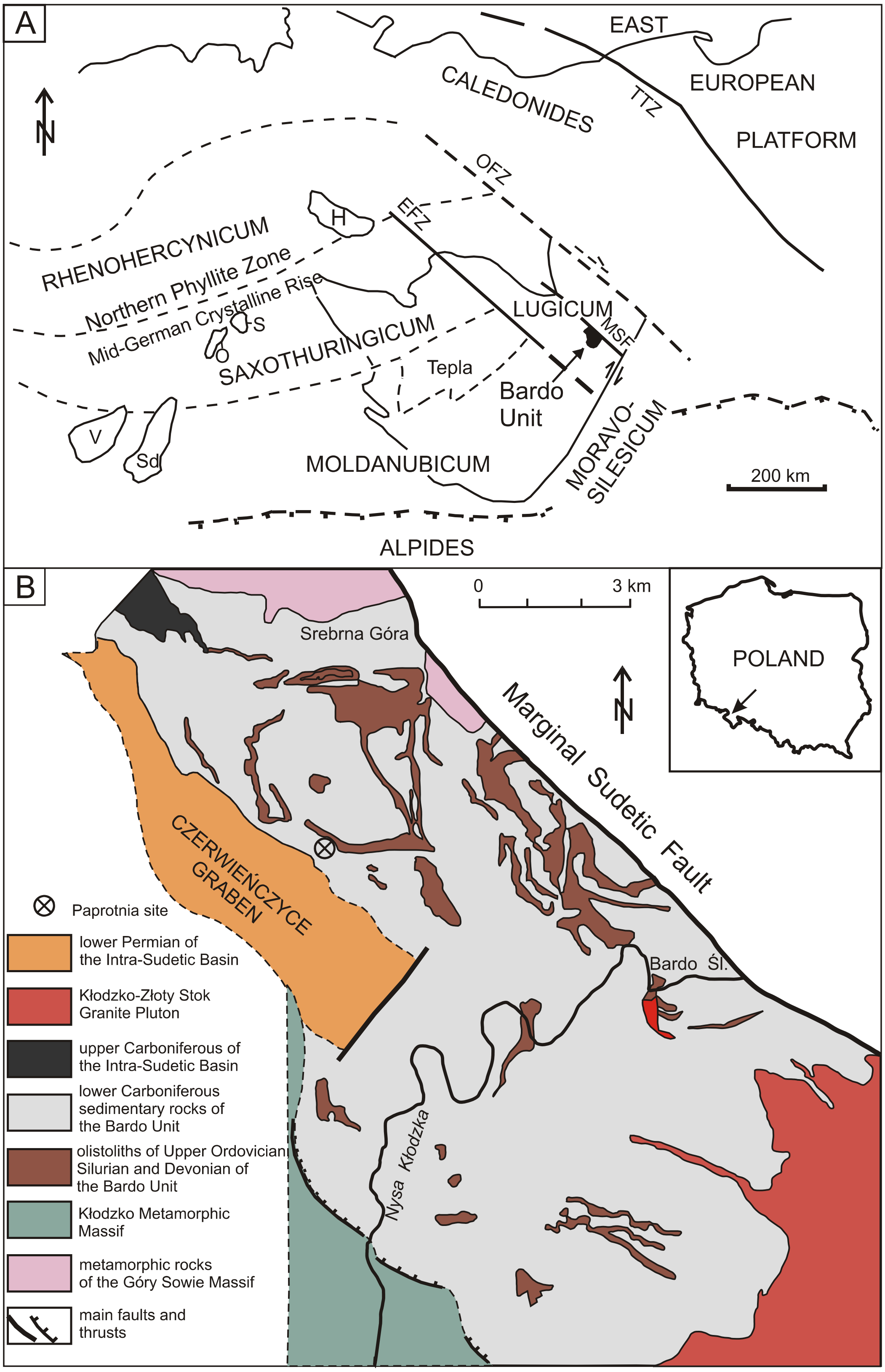


Fig. 1A – location of the Bardo Unit in the Mid-European Variscides (after Żelaźniewicz, 1995, modified); B – location of the Paprotnia site on the generalized geological map of the Bardo Unit (after Oberc, 1957 and Haydukiewicz, 2002, modified)

EFZ – Elbe Fault Zone, H – Harz, MSF – Marginal Sudetic Fault, O – Odenwald, OFZ – Odra Fault Zone, S – Spessart, Sd – Schwarzwald, TTZ – Teisseyre-Tornquist Zone, V – Vosges

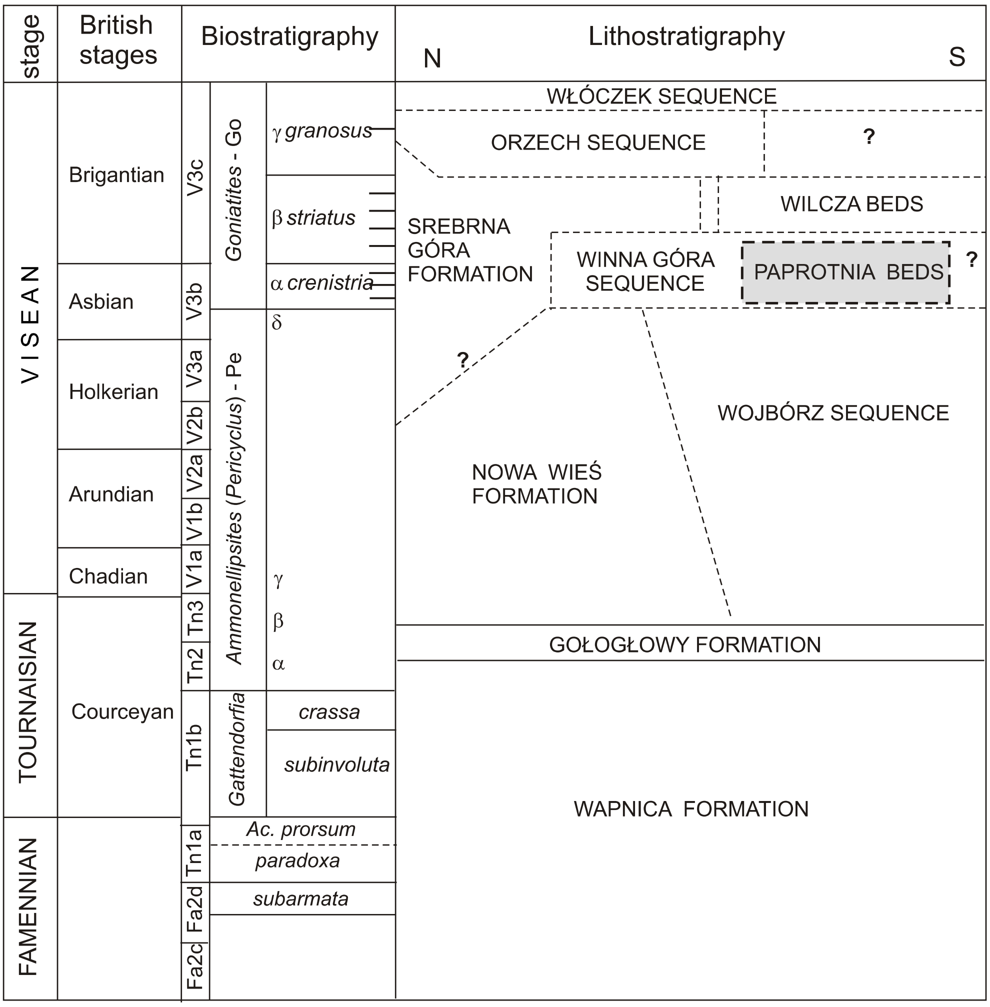


Fig. 2. Generalized stratigraphic scheme of the autochthonous/parautochthonous succession of the Bardo Unit (according to Wajsprych, 1995, modified) correlated with the British Isles stratigraphy based on Harland *et al.* (1989)

cause of the complicated tectonic framework and unexposed contact with neighbouring units. The Wojbórz sequence and the Nowa Wieś Formation probably underlie the Winna Góra sequence and the Srebrna Góra Formation, which consists of flysch deposits, occur above them (Fig. 2).

The Paprotnia Beds occur only in the western part of the Bardo Unit (Fig. 1) and are exposed on the southern slope of Paprotnia Hill, between villages of Czerwieńczyce and Wojbórz, about 1.5 km east of the village of Czerwieńczyce, in the roadside section (E 16°37’29.247”, N 50°31’56.865”). The exposed section is about 13.7 m-thick, but the entire thickness of the Paprotnia Beds is determined at about 20–25 metres (Haydukiewicz and Muszer, 2002). Unfortunately, the contact with the underlying rocks is not exposed. The strata are composed mainly of claystones and mudstones, greywackes and subordinate carbonates. They dip at 50–60° to the north and in the topmost part of the section pass gradually into polymictic conglomerates named the Wilcza Beds (Wajsprych, 1995).

In the Paprotnia section some stratal successions can be distinguished (Fig. 3). The lowermost part is composed of greenish-grey and grey claystones and mudstones with a few thin intercalations of dark grey micritic limestones (up to 3 cm thick). These deposits are overlain by dark grey and dark olive mudstones with intercalations of sandy-mudstones and greywackes as well as six layers (A–F) of bentonite. Irregularly distributed mudstone nodules also occur in this succession. The middle part of the section comprises greywackes and sandymudstones with lenses and nodules of dark grey organodetrital limestones (up to 40 cm thick). The abundance of limestones sharply decreases upwards. The upper part of the section is represented by greywackes with sandymudstones. They terminate the Paprotnia Beds and pass gradually into the Wilcza conglomerates that contain rare intercalations of greywack and mudstones.

The Paprotnia Beds have been studied by geologists and palaeontologists since 1839 (von Buch, 1839 – *vide* Schmidt, 1925). These rocks were described as the “shalegreystone series” (Finckh *et al*., 1942), “upper horizon of Carboniferous Limestone” (Oberc, 1957), “Czerwieńczyce beds” (Żakowa, 1963) and recently as “the Paprotnia series” (Wajsprych, 1995; Haydukiewicz and Muszer, 2002). They are considered as rich in macro- and microfossils and biostratigraphically well-dated. Their late Visean age was determined on the basis of goniatites, brachiopods, corals and foraminifers (Schmidt, 1925;

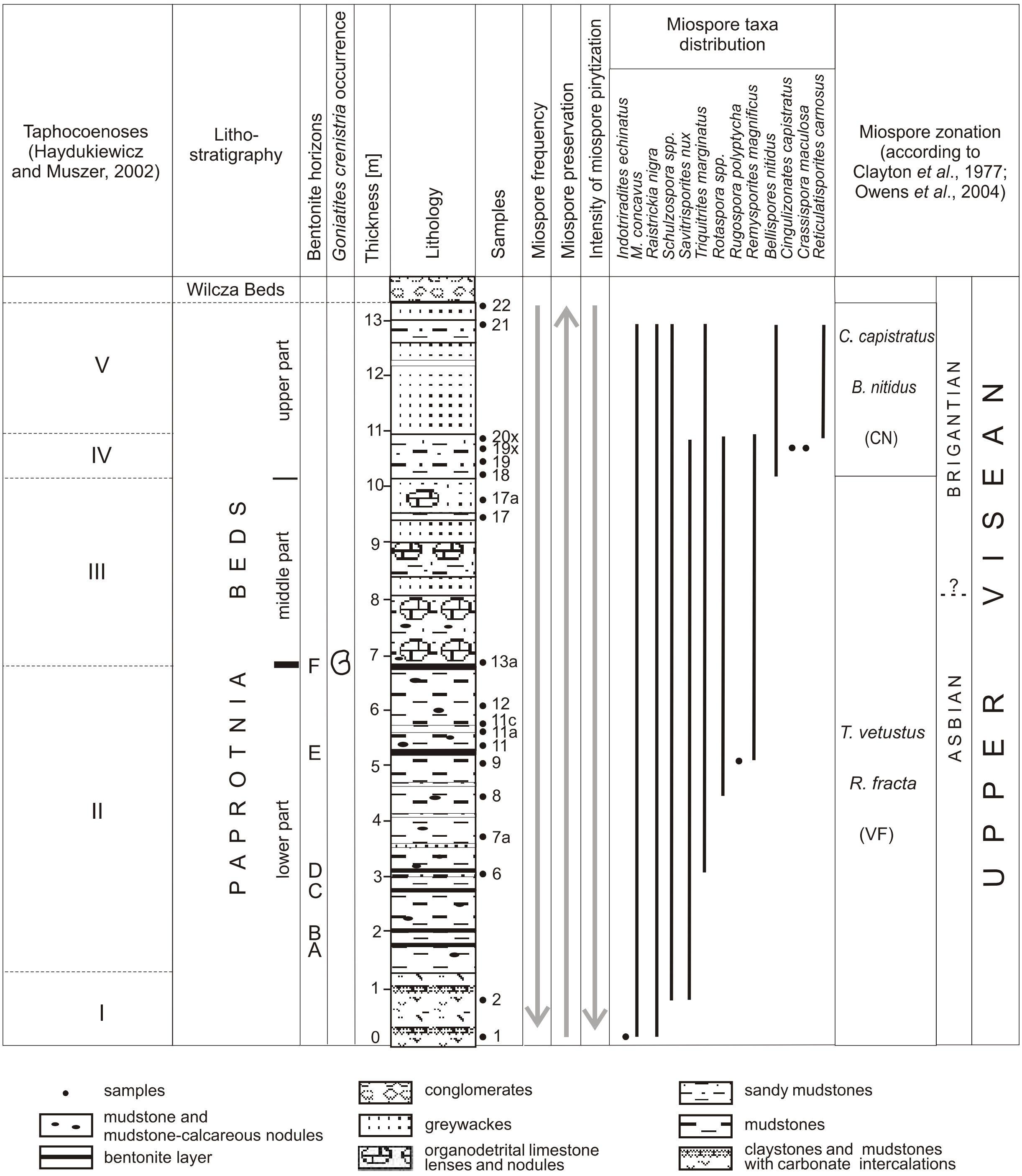


Fig. 3. Simplified lithological column of the Paprotnia section, distribution of taphocoenoses (I–V based on Haydukiewicz and Muszer, 2002), stratigraphically important ammonoid and miospore taxa as well as palynofacies data

Paeckelmann, 1930, 1931; Górecka and Mamet, 1970; Fedorowski, 1971; Haydukiewicz and Muszer, 2002) and partly on miospores (Majewska-Bill, 2006). The occurrence of *Goniatites crenistria* indicates that these rocks belong to the Asbian (Kryza *et al*., 2010). A late Asbian age was supported also by the latest radiometric dating of the bentonite A from the lower part of the section (Fig. 3) at 334 ±3 Ma (Kryza *et al*., 2007, 2008, 2010). Recently, numerous specimens of the trace fossil *Zoophycos* have been found in the top portion of the lower part of the section, just below the horizon of organodetrital limestone nodules (Muszer and Haydukiewicz, 2010*a*, *b*). These sediments are interpreted as having been formed between storm and fair-weather wave base, probably within oxygenated water.

Unfortunately the upper part of the profile has a drastically reduced faunal assemblage and no index fossils have been cited from it (Haydukiewicz and Muszer, 2002). Its uppermost part contains only macrofloral fossils and floral detritus (Górecka, 1958). Rocks from this part of the section has not provided miospore data in previous palynological studies (Majewska-Bill, 2006).

Analysis of the stratigraphic distribution of the fossils, their state of preservation, taxonomic composition and the character of the biotic accumulation, were used by Haydukiewicz and Muszer (2002) to reconstruct the environmental conditions. Five taphocoenoses (I–V) were recognized in the vertical sequence of the Paprotnia section. Both lithological and palaeontological features of the Paprotnia Beds indicate a gradual environmental change from offshore to onshore conditions. Haydukiewicz and Muszer (2002) interpreted these strata as the shallower-water facies equivalent of the pelagic *crenistria* Limestone (cd III α) widespread in the Kulm facies of Variscan Europe.

MATERIAL AND METHODS

The mudstone and claystone samples for the palynological studies, totalling 25, were taken from across the Paprotnia Beds. Each rock sample was divided into two parts: one for palynostratigraphic studies, and another for palynofacies observations and the assessment of the organic matter thermal maturity. Both parts of the samples were processed in concentrated hydrofluoric acid. Samples for the palynostratigraphic studies were later oxidized using Schulze's method and next sieved though an 18 μm sieve in an ultra-wave bath. The microscopic slides were studied using a *Optiphot Nikon* microscope and the microphotographs were taken using a *Canon Powershot A640* digital camera. All microscopic slides are stored in the Institute of Geological Sciences, Wrocław University.

The palynological studies comprised the determination of miospores and the stratigraphic interpretation of their assemblages. The miospore studies were complemented by palynofacies observations, consisting of determination of the composition of palynological particles. The frequency of miospores and the state of their preservation were also taken into account. The thermal maturity of the organic matter was assessed basing on the colour of *Lycospora* specimens using Batten's scale (1984).

RESULTS

The microscopic studies revealed the occurrence of rich miospore assemblages in 19 of the samples. Miospores appeared to be the only palynomorph group found. They are very abundant in rocks from the lower part of the section (samples 1–12), although in samples from its middle and upper parts they are less numerous. Their frequency in rocks from the uppermost part of the section (sample 22) was extremely low (Fig. 3).

The miospores are generally poorly preserved, but the state of their preservation varies. The main destructive factor is pyritization. Scars after the pyrite crystals on the miospore exines are common and in many cases they have destroyed the structure of the exine, so the identification of many specimens is impossible. Numerous poorly preserved miospores were determined to genus level only. A decrease in pyritization intensity up the section was observed (Fig. 3). The mechanical destruction of miospores was also an important factor influencing their state of preservation. A gradual decrease in the number of mechanically destroyed miospores was also noticed up the section (Fig. 3). Another, less significant destruction factor, is the thermal overmaturity of a few miospores, which are very dark and barely recognizable. These specimens occur among much lighter miospores and they were found in assemblages from the whole section. All these factors influence the improving state of miospore preservation up the section. The best preserved miospores were found in the sample 21 from its uppermost part.

The miospore assemblages from the studied samples are diverse. Nearly two hundred miospore taxa were determined and most are listed in Appendix. Some of the more important and better preserved miospores are shown in Figures 4 and 5.

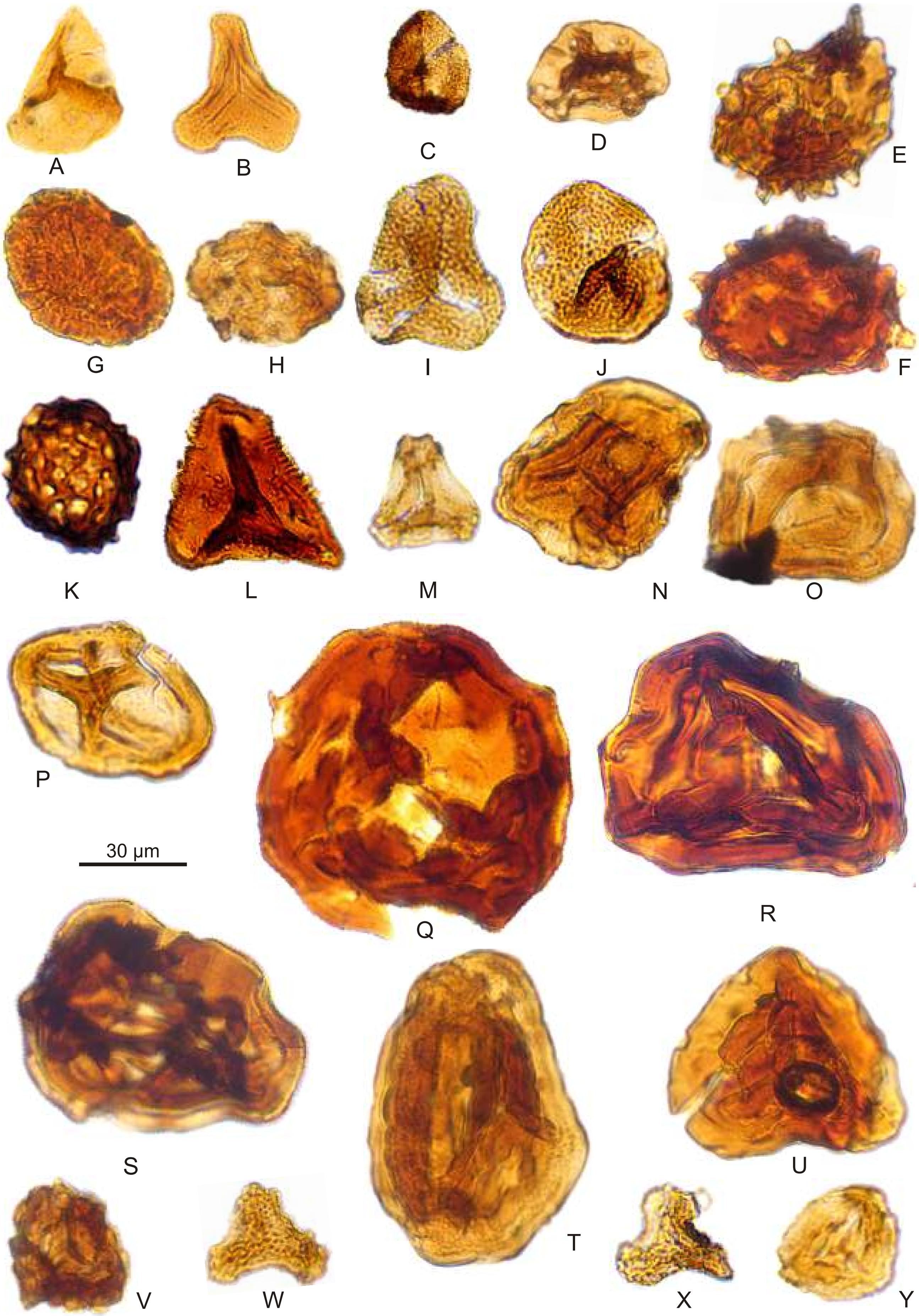
The miospores occurred among abundant phytoclasts, consisting of brown and black rectangular particles as well as phytoclasts of oval or irregular outline and of similar colour. Very abundant black phytoclasts occurred in sample 22 from the top part of the Paprotnia Beds. In some samples, mainly from the lower and middle parts of the section, a small amount of brown amorphous organic matter was observed.

The miospores show a wide range of colours – from orange to dark brown or even black. The colours of the *Lycospora* specimens varied from orange to orange-brown and their thermal maturation index amounts to 3–4. Darker *Lycospora* specimens were not observed in the samples studied samples.

PALYNOSTRATIGRAPHIC INTERPRETATION AND PALYNOFACIES

Many late Visean miospore taxa were found throughout the section. *Waltzispora planiangulata, Triquitrites marginatus, Rugospora polyptycha, Schulzospora campyloptera, S. elongata, S. ocellata, S. plicata, S. rara, Remysporites magnificus, Rotaspora ergonulii, Raistrickia nigra, Microreticulatisporites concavus, Crassispora maculosa, Indotriradites echinatus, Grandispora echinata, Dictyotriletes pactilis* and *Colatisporites decorus* are among them. *Savitrisporites nux* and *Rotaspora knoxi,* the miospore taxa which appeared at the base of the miospore Biozone *Tripartites vetustus–Rotaspora fracta* (VF; Clayton *et al.*, 1977, 1978) were also determined from each part of the section. This indicates that all studied rocks are not older than this miospore biozone.

The biozonal index species *R. fracta* was not recognized but there were some poorly preserved specimens, determined as *Rotaspora* sp. They occur rather systematically in and above sample 11. It is worth noting the relatively low frequency of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Triquitrites and lack of *Tripartites*, which are usually abundant in upper Visean rocks. This was probably controlled by the ecology of the environment or by transport way of miospores to the sea.

Some stratigraphically important miospore taxa, such as *Reticulatisporites carnosus, Bellispores nitidus* and very rare specimens of *Cingulizonates capistratus* were found only in the upper part of the section (samples 18–21). Their presence indicates that these rocks should be assigned to the younger miospore Biozone *Cingulizonates capistratus–Bellispores nitidus* (CN; Clayton *et al*., 1978; Owens *et al*., 2004). The base of this zone is marked by the first occurrence of *Cingulizonates capistratus*, which is considered as a common component in miospore assemblages of Western Europe (Clayton *et al*., 1978; Owens *et al*., 2004) but the range base of *Bellispores nitidus* seems to be coincident with that level (Owens *et al*., 2004). Considering the extremely rare occurrence of *C. capistratus* in the rocks studied, the lower limit of this zone in the Paprotnia section is established just below sample 18, where *B. nitidus* appeared.

The lack of any the stratigraphically important miospore taxa typical of the upper part of the CN Biozone, such as *Ahrensisporites guerickei*, *Verrucosisporites morulatus*, *Potoniespores elegans* and *Crassispora kosankei*, indicate that the rocks studied belong to the *Cingulizonates capistratus* Subbiozone, established in the lower part of the CN Biozone by Owens *et al*. (2004).

The miospore assemblages contain also a few older miospores, typical of the Tournaisian and lower Visean. The following taxa were included in this group: *Retusotriletes communis*, *Verrucosisporites baccatus*, *Knoxisporites triradiatus*, *Potoniespores delicatus*, *Rugospora minuta*, *Perotrilites tesselatus* and *Indotriradites hibernicus*. All these taxa are considered as reworked. The occurrence of *Stenozonotriletes coronatus* in rocks of the CN miospore Zone should be also considered to reflect reworking.

The observations of the frequency of miospores, their preservation, including the intensity of pyritization, provide important data on the interpretation of sedimentary environment. The decreasing miospore frequency up the section should be interpreted as a result of increasing sediment input during accumulation. The extremely poor frequency of miospores and the presence of very numerous black phytoclasts in the uppermost part of the section indicates an intense reworking processes. The decrease of the pyritization intensity observed in the same direction may be explained by increasing oxygen levels in the water and the gradual decrease of the number of mechanically destroyed miospores is probably connected with the shorter distance of their transportation (Tyson, 1987, 1995). All these changes may be considered as indicators of a gradual shallowing of the environment of sedimentation. At the end of the Paprotnia Beds sedimentation an episode of intense reworking happened.

The orange to orange-brown colours of *Lycospora* specimens indicate the early mature and mature stages of organic matter alteration. According to Batten (1996) this corresponds to a vitrinite reflectance ranging from 0.5 to 0.75%. A few relatively dark specimens occurring across the section are considered as reworked. The undeterminable, overmatured miospores, which were found in some samples, probably also belong to this group.

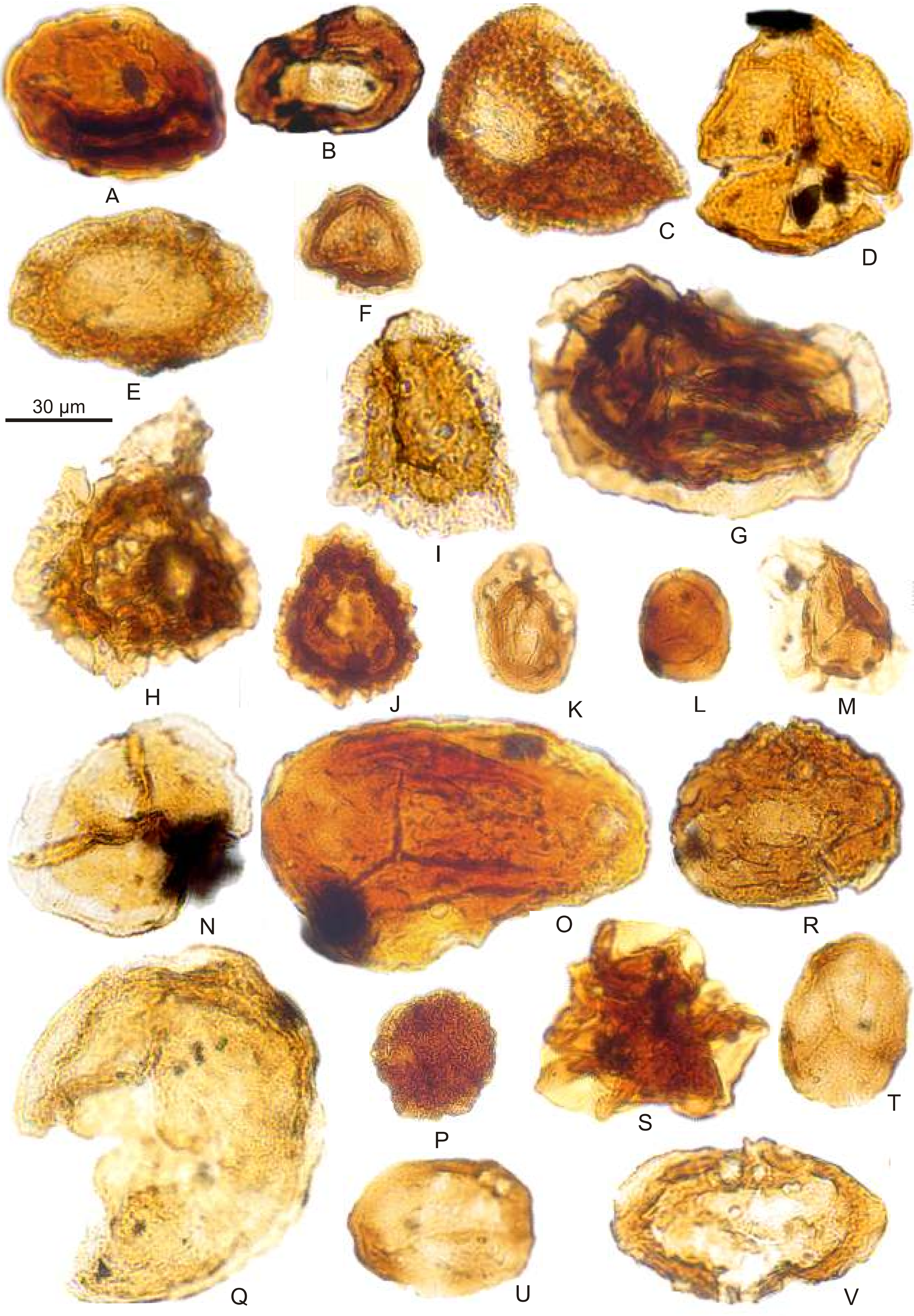
DISCUSSION

The stratigraphic interpretation of the miospore data obtained from rocks of the Paprotnia Beds, presented above, in connection with the previous macro- and microfaunal data, provide a good opportunity to precisely constrain the age of the studied rocks. The stages, recognized in the British Isles on the basis of both eustatically controlled sedimentary cycles and the fossil content (Ramsbottom, 1973; George *et al*., 1976), are used, although their correlation with the biostratigraphic divisions based on different fossil groups is in places difficult and still not established in detail.

Previous biostratigraphic studies of the Paprotnia Beds have been based on the macro- and microfaunal data and goniatites, which are the most important group of fossils occurring there. The occurrence of the index taxon *Goniatites crenistria* Phill. in the middle part of the Paprotnia section, close to its base (Fig. 3), is evidence of the upper Visean (V3b) ammonoid *Goniatites crenistria* (Go IIIα) Biozone (Haydukiewicz and Muszer, 2002). *Nomismoceras vittiger*, which was also found in these rocks, has a broader stratigraphical range and is known also from the *striatus* (Go IIIα) Biozone (Żakowa, 1958, 1995). The *Goniatites crenistria* Biozone is usually assigned to the upper Asbian, so Kryza *et al*. (2010) used this in dating the Paprotnia Beds. Later Korn and Kaufmann (2009) and Korn and Titus (2011) pointed out that in the British Isles this zone corresponds to the uppermost Asbian, but in the Rhenish Mountains it does not reach the top of this stage.

Fig. 4. Miospores from the Paprotnia Beds

A – *Leiotriletes tumidus*, sample 19, slide kr, A 10, 4; **B** – *Waltzispora planiangulata*, sample 11, slide 1, J15, 2; **C** – *Anaplanisporites baccatus*, sample 9, slide 1, Z 54, 1; **D** – *Adelisporites multiplicatus*, sample 11a, slide 1, A 25, 4; **E** – *Raistrickia nigra*, sample 19x, slide 2, J 28, 2; **F** – *Raistrickia nigra*, sample 11, slide 5, F 12, 4; **G** – *Convolutispora cerebra*, sample 11, slide 7, P 61, 1; **H** – *Convolutispora florida*, sample 19x, slide 1, M43, 1; **I** – *Microreticulatisporites concavus*, sample 21, slide 1, O 26, 1; **J** – *Microreticulatisporites punctatus*, sample 21, slide 1, X 42, 3; **K** – *Bascaudaspora* sp., sample 11, slide 2, U 44; **L** – *Diatomozonotriletes trilinearis*, sample 11, slide 1, X 36, 4; **M** – *Ahrensisporites duplicatus*, sample 21, slide 2, P 43, 2; **N** – *Knoxisporites literatus*, sample 9, slide 5, M 12, 2; **O** – *Knoxisporites stephanophorus*, sample 11, slide 4, S 35, 1; **P** – *Knoxisporites triradiatus*, sample 20x, slide 1, J 38, 2; **Q** – *Reticulatisporites carnosus*, sample 21, slide 1, S 41, 1; **R** – *Reticulatisporites carnosus*, sample 21, slide 1, X 17, 2; **S** – *Reticulatisporites carnosus*, sample 20x, slide 1, F 21, 3; **T** – *Orbisporis* sp., sample 9, slide 5, Y 12, 1; **U** – *Savitrisporites nux*, sample 11a, slide 1, I 14,1; **V** – *Secarisporites remotus*, sample 11a, slide 1, T 20, 1/3; **W** – *Bellispores nitidus*, sample 19, slide dl, E 46, 3; **X** – *Bellispores nitidus*, sample 18, slide 2, R 44, 2; **Y** – *Rotaspora knoxi*, sample 20x, slide 1, N 52, 4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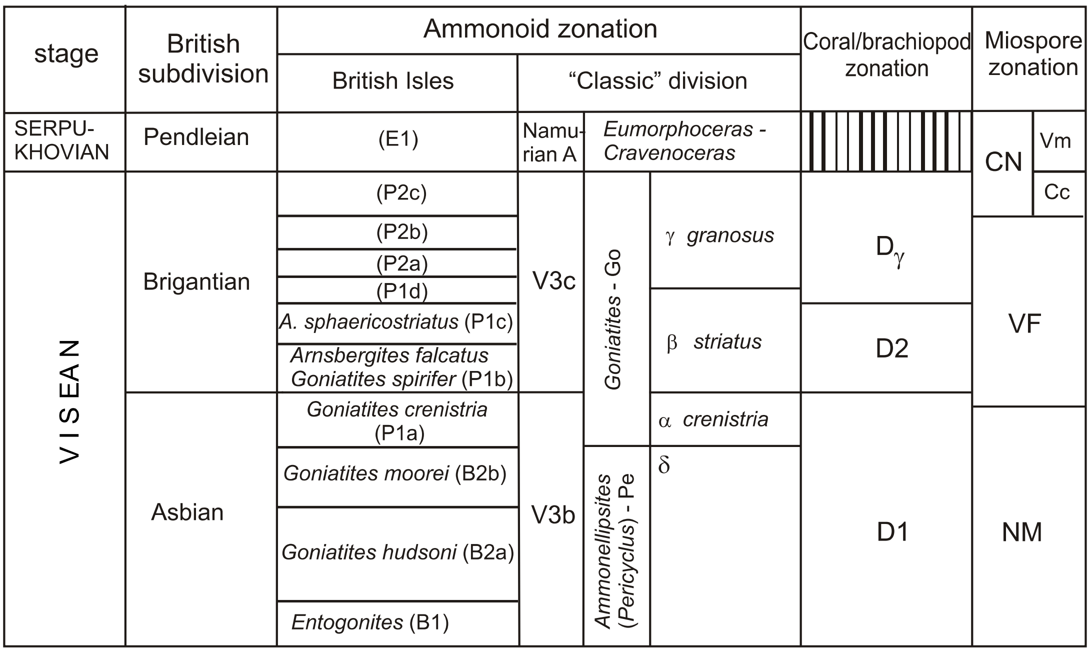

Fig. 6. Biostratigraphic correlation of upper Visean based on Clayton *et al*. (1977), Harland *et al*. (1989), Ebdon *et al*. (1990), Riley (1993), Cossey and Adams (2004), Owens *et al*. (2004), Weyer and Menning (2006), Korn and Titus (2011)

In the middle part of the Paprotnia section Górecka and Mamet (1970) distinguished the *Archaediscus karreri–Howchinia gibba–Valvulinella youngi* foraminiferal Zone, also coinciding with the *crenistria* IIIα Zone. The rugose coral assemblages recognized from the same rocks were considered by Fedorowski (1971) as typical of the D_2 coral Zone of the British nomenclature, which seems to be slightly younger and now is correlated with the Brigantian (Riley, 1993; Cossey and Adams, 2004; Fig. 6). Some index brachiopods were also found from the rocks discussed, but they are not stratigraphically important as they are characteristic of longer time intervals – the Visean and late Visean–Serpukhovian (Kryza *et al*., 2010).

The miospore data derived from the lower and middle parts of the Paprotnia section indicate that these rocks should be assigned to the miospore zone *Tripartites vetustus–Rotaspora fracta* (VF). The same result was obtained during the previous palynostratigraphical studies of Majewska-Bill (2006), who assigned rocks from entire section studied to this biozone. According to Clayton *et al*. (1977) the base of the VF miospore Zone coincides with the base of the Brigantian and the zone extends through the major part of this stage. The lower limit of the VF Biozone was correlated with the base of the D2 rugose coral Zone and was located slightly above the base of the P1 ammonoid Zone. Clayton *et al*. (1978) and Clayton (1985) were of the same opinion on the location of the base of this zone. Later, Ebdon *et al*. (1990) reported that palynological studies on the type section had revealed that the key VF zonal miospore taxa had been found in the upper Asbian. In recent papers the base of the VF miospore Zone is located in the upper part of the Asbian, so the VF Biozone is correlated with the upper Asbian and lower Brigantian (Owens *et al*., 2005; Jäger and McLean, 2008). This opinion is also applied in the current stratigraphical interpretation (Fig. 6).

The occurrence of *Goniatites crenistria* and miospore assemblages typical of the VF Biozone in the same rocks indicate that they should be assigned to the upper Asbian. This concerns the lower part of the Paprotnia Beds and the lowermost portion of their middle part, where *G. crenistria* has been found. The radiometric data of 334 ±3 Ma obtained from the bentonite A fits very well with a late Asbian age (Kryza *et al*., 2007, 2008, 2010).

Fig. 5. Miospores from the Paprotnia Beds

A – *Grumosisporites rufus*, sample 11a, slide 3, E 22; **B** – *Densosporites spinifer*, sample 9, slide 6, O 60, 2; **C** – *Cristatisporites echinatus*, sample 2, slide 1, B 18, 4; **D** – *Crassispora maculosa*, sample 19, slide dl, T 54, 4; **E** – *Cingulizonates capistratus*, sample 19x, slide 1, M 24, 3; **F** – *Lycospora pusilla*, sample 11a, slide 1, P 44, 1; **G** – *Camarozonotriletes cyrenaicus*, sample 21, slide 1, Q 41, 3; **H** – *Indotriradites echinatus*, sample 1, slide 1, F 37, 1; **I** – *Indotriradites* cf. *ornatus*, sample 7a, slide, 1, M 18, 2; **J** – *Vallatisporites galearis*, sample 11, slide 1, M 26, 4; **K** – *Auroraspora panda*, sample 11a, slide 1, D 9, 4; **L** – *Auroraspora macra*, sample 11a, slide 3, Q 23, 3; **M** – *Auroraspora velata*, sample 11, slide 5, B 51, 2; **N** – *Discernisporites micromanifestus*, sample 21, slide 2, Q 52, 3; **O** – *Remysporites magnificus*, sample 20x, slide 1, K 54, 1; **P** – *Rugospora minuta*, sample 11a, slide 3, E 22; **Q** – *Perotrilites magnus*, sample 11c, slide 4, J 56; **R** – *Perotrilites perinatus*, sample 2, slide 1, X 10, 2; **S** – *Perotriletes tesselatus*, sample 11a, slide 2, T 47, 1; **T** – *Colatisporites decorus*, sample 11a, slide 1, Q 19, 2; **U** – *Schulzospora rara*, sample 11c, slide 4, E 16, 1; **V** – *Schulzospora ocellata*, sample 7a, slide 1, R 20, 2

Our new miospore data indicates that the upper part of the section certainly belongs to the miospore biozone *Cingulizonates capistratus–Bellispores nitidus* (CN). This biozone is correlated with the Visean-Serpukhovian transition and its base is located at the P2b–P2c boundary (Fig. 6). The CN miospore Zone is subdivided into two subzones: the *Cingulizonates capistratus* (Cc) Subbiozone, assigned to the upper Brigantian and the *Verrucosisporites morulatus* (Vm) Subbiozone, belonging to the Pendleian (Owens *et al*., 2004). The rocks studied from the upper part of the Paprotnia Beds should be included in the first of these subbiozones, correlated with the upper Brigantian. The lower boundary of the CN miospore Biozone has been located in the base of the upper part of this lithostratigraphic unit. This corresponds with the base of taphocoenoseis IV (Fig. 3), in the vertical succession of taphocoenoses recognized by Haydukiewicz and Muszer (2002), and coincides with changes of lithology.

The miospore assemblages recently found in the upper part of the Paprotnia Beds allowed the palynostratigraphic dating of rocks which earlier had not provided any stratigraphically significant fossils. According to previous opinions these rocks had been considered as the same in age as rocks from the lower and middle parts of the section (Haydukiewicz and Muszer, 2002; Majewska-Bill, 2006).

The Asbian/Brigantian boundary in the Paprotnia section should be located between the levels where *G. crenistria* has been found and where miospore taxa typical of the CN Biozone appear. This means that this boundary is certainly located in the middle part of the section, above its lowermost portion (Fig. 3).

The age of this part of the section is determined as Brigantian, based of the coral assemblages of the D2 coral Zone recognized by Fedorowski (1971). The greywacke intercalations occurring there are probably the record of the European Brigantian third-order regression (Herbig *et al*., 1999), so the Asbian/Brigantian boundary is supposed to be located in the middle part of the studied section, below the greywacke intercalations (Fig. 3). The consequence of this interpretation is the possibility of the occurrence of a gap between the middle and upper parts of the section discussed. This gap would correspond to the P1d, P2a and P2b ammonoid zones and its existence is concluded from the correlation of the biostratigraphic divisions based on different fossil groups (Fig. 6). The rocks occurring below and above this possible gap are generally similar although a disappearance of the calcareous nodules is noted (Fig. 3).

The palynological data also provided new information on the environment of sedimentation. A lack of evidence of marine phytoplankton among palynomorphs the found supports the conclusion of Haydukiewicz and Muszer (2002), who considered that the sedimentation of the Paprotnia Beds took place in a shallow marine environment. The palynofacies data, including observations of the miospore frequency and the state of their preservation, indicates a gradual shallowing of the habitat. This conclusion supports the earlier interpretation of Haydukiewicz and Muszer (2002), who considered the rocks discussed as a record of the transition from the offshore to onshore environment.

Observations of the miospore pyritization may be used as additional information on the characteristics of the taphocoenoses, particularly considering the level of water oxygenation. The intensive pyritization of the majority of miospores from the taphocoenoses I and II indicate limited oxygen access. In the middle and upper parts of the section (taphocoenoses III and IV) scars after pyrite crystals are also present, although they gradually became more scarce and in the uppermost part (taphocoenose V) they disappear. These observations indicate increasing water oxygenation levels during sedimentation, as inferred by Haydukiewicz and Muszer (2002).

The thermal maturity of the organic matter has been assessed on the basis of miospore colour as of early mature to mature stages. This result corresponds to the conclusion of Haydukiewicz (2002), who studied conodont colours in the Bardo Structural Unit and distinguished five zones of different thermal alteration. The Paprotnia section is located in zone II of relatively low thermal maturity, which is distant from the SE part of the Bardo Unit, where the influence of the thermal alteration caused by the Kłodzko–Złoty Stok intrusion is most significant (Haydukiewicz, 2002).

CONCLUSIONS

1. Two miospore biozones have been recognized in the Paprotnia Beds. The lower and middle parts of the section has been assigned to the *Tripartites vetustus–Rotaspora fracta* (VF) Biozone, corresponding to the upper Asbian and lower Brigantian. The upper part of the section belongs to the *Cingulizonates capistratus–Bellispores nitidus* (CN) Biozone (more precisely to the *Cingulizonates capistratus* Subbiozone), correlated with the upper part of the Brigantian.

2. Both palynological and macrofaunal data as well as the results of recent radiometric dating indicate that:

- the lower part and at least lower portion of the middle part of the Paprotnia section should be assigned to the upper Asbian;
- the rocks of the middle part of the section, occurring above these, should be considered as the upper Asbian, belong to the Brigantian;
- the upper part of the section should certainly be included in the upper Brigantian.

3. The upper part of the section is younger than was considered earlier.

4. The Asbian/Brigantian boundary should be probably located in the middle part of the section, below the greywacke intercalations, which are possibly connected with the European Brigantian third-order regression.

5. If is possible that a gap, corresponding to the P1d, P2a and P2b ammonoid zones, occurs between the middle and upper parts of the Paprotnia section.

6. The palynofacies data provide additional arguments to support the opinion of Haydukiewicz and Muszer (2002) that sedimentation of the rocks studied took place in a shallow marine environment, probably during an offshore to onshore transition.

7. The early mature to mature stages of thermal alteration of organic matter, assessed on the basis of miospore colours, support previous palaeothermal inferences of Haydukiewicz (2002), based on conodont colours.

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APPENDIX

The composition of the miospore assemblages from the Paprotnia Beds

Taxa	1	2	6	7a	8	9	11	11a	11c	12	13a	17	17a	18	19	19x	20x	21	22
Acanthotriletes castanea Butterworth and Williams, 1958					+		+	+		+	+						+		
Acanthotriletes baculatus Neves, 1961								+											
Acanthotriletes echinatus (Knox) Potonié and Kremp, 1955	+	+	+				+							+				+	
Acanthotriletes mirus Ishchenko, 1956															+				
Acanthotriletes multisetus Playford, 1963															+				
Acanthotriletes triquetrus Smith and Butterworth, 1967					+					+									
Adelisporites multiplicatus Ravn, 1986								+											
Ahrensisporites duplicatus Neville, 1973														+	+		+	+	
Ahrensisporites sp.	+		+							+									
Anapiculatisporites hispidus Butterworth and Williams, 1958							+												
Anapiculatisporites tersus Playford, 1963								+											
Anaplanisporites baccatus (Hoffmeister, Staplin and Malloy) Smith and Butterworth, 1967		+				+	+	+	+	+	+				+	+		+	
Anaplanisporites denticulatus Sullivan, 1964															+				
Anaplanisporites globulus (Butterworth and Williams) Smith and Butterworth, 1967										+									
Auroraspora macra Sullivan, 1964								+											
Auroraspora panda Turnau, 1978								+											
Auroraspora velata (Felix and Burbridge) Ravn, 1991							+												
Bascaudaspora canipa Owens, 1983						+	+			+									+
Bascaudaspora variabilis Owens, 1983	+								+						+				
Bascaudaspora sp.							+												
Bellispores nitidus (Horst) Sullivan, 1964														+	+	+	+	+	
Calamospora pallida (Loose) Schopf, Wilson and Bentall, 1944					+		+								+				
Calamospora microrugosa (Ibrahim) Schopf, Wilson and Bentall, 1944			+					+			+				+		+		
Calamospora minuta Bharadwaj, 1957					+													+	
Calamospora mutabilis (Loose) Schopf, Wilson and Bentall, 1944				+	+					+			+		+				
Calamospora pedata (Loose) Schopf, Wilson and Bentall, 1944															+			+	

App. cont.

Taxa	1	2	6	7a	8	9	11	11a	11c	12	13a	17	17a	18	19	19x	20x	21	22
Camarozonotriletes cyrenaicus Loboziak and Clayton, 1988		+		+	+	+	+	+			+	+		+			+	+	
Cingulizonates bialatus (Waltz) Smith and Butterworth, 1967	+			+		+	+	+			+				+	+	+		
Cingulizonates capistratus (Hoffmeister, Staplin and Malloy) Staplin and Jansonius, 1964																+			
Cirratriradites elegans (Waltz) Playford, 1963				+	+		+												
Colatisporites decorus (Bharadwaj and Venkatachala) Williams, 1972								+											
Convolutispora ampla Hoffmeister, Staplin and Malloy, 1955												+							
Convolutispora cerebra Butterworth and Williams, 1958				+			+			+		+							
Convolutispora cerina Ravn, 1979							+		+										
Convolutispora florida Hoffmeister, Staplin and Malloy, 1955					+			+								+	+		
Convolutispora harlandii Playford, 1963	+																		
Convolutispora jugosa Smith and Butterworth, 1967					+														
Convolutispora punctatimura Staplin, 1960						+													
Convolutispora varicosa Butterworth and Williams, 1958														+	+	+			
Convolutispora vermiformis Hughes and Playford, 1961																	+	+	
Corrugatisporites borrealis Ravn, 1991							+	+											
Crassispora maculosa (Knox) Sullivan, 1964															+				
Cristatisporites bellis Bharadwaj and Venkatachala, 1961																+			
Cristatisporites echinatus Playford, 1963		+		+															
Cristatisporites hibernicus (Higgs) Higgs, 1996												•							
Cyclogranisporites minutes Bharadwaj, 1957		+					+	+			+				+				
Densosporites anulatus (Loose) Smith and Butterworth, 1967						+			+		+			+	+		+		
Densosporites intermedius Butterworth and Williams, 1958					+														
Densosporites pseudoannulatus Butterworth and Williams, 1958							+		+										
Densosporites sphaerotriangularis Kosanke, 1950															+				
Densosporites spinifer Hoffmeister, Staplin and Malloy, 1955		+			+	+	+	+			+	+		+	+	+		+	
Densosporites triangularis Kosanke, 1950								+									+		
Densosporites variomarginatus Playford, 1963									+										
Diatomozonotriletes trilinearis Playford, 1963							+												
Dictyosporites clatriformis (Artüz) Sullivan, 1964								+							+				
Dictyosporites fragmentimurus Neville, 1973						+													
Dictyotriletes pactilis Sullivan and Marshall, 1966				+															
Dictyotriletes sp.			+		+	+	+		+		+	+							
Discernisporites micromanifestus (Hacquebard) Sabry and Neves, 1971							+		+									+	
Foveosporites sp.						+	+												
Gorgonispora convoluta (Butterworth and Spinner) Playford, 1976							+												
Grandispora cf. *echinata* Hacquebard, 1957						+													
Grandispora echinata Hacquebard, 1957							+	+	+						+	+			
Granomurospora sp.	+																		
Granulatisporites granulatus Ibrahim, 1933			+		+	+	+	+		+	+	+	+	+	+		+	+	
Granulatisporites microgranifer Ibrahim, 1933						+			+						+	+			
Granulatisporites minutus Potonié and Kremp, 1955	+																		
Grumosisporites inaequalis (Butterworth and Williams) Smith and Butterworth, 1967					+			+							+				
Grumosisporites rufus (Butterworth and Williams) Smith and Butterworth, 1967		+					+	+			+					+	+		
Indotriradites echinatus (Owens *et al.*) Higgs, 1996	+																		
Indotriradites cf. *ornatus* (Neves) Owens, Mishell and Marshall, 1976; Higgs, 1996				+															

App. cont.

Taxa	1	2	6	7a	8	9	11	11a	11c	12	13a	17	17a	18	19	19x	20x	21	22
Knoxisporites dissidus Neves, 1961							+												
Knoxisporites literatus (Waltz) Playford, 1963					+	+		+	+										
Knoxisporites stephanophorus Love, 1960						+	+	+											
Knoxisporites triradiatus Hoffmeister, Staplin and Malloy, 1955		•		•		•	•				•						•		
Laevigatosporites vulgaris (Ibrahim) Alpern and Doubinger, 1973		+	+				+		+						+				
Leiotriletes inermis (Waltz) Ishchenko, 1952		+					+	+	+				+	+	+			+	
Leiotriletes parvivermiculatus Playford, 1963		+																	
Leiotriletes parvus Guennel, 1958						+													
Leiotriletes subintortus (Waltz) Ishchenko, 1952								+	+										
Leiotriletes sphaerotriangularis (Loose) Potonié and Kremp, 1955											+								
Leiotriletes tumidus Butterworth and Williams, 1958	+	+	+		+		+			+				+	+	+	+		
Lophotriletes commisuralis (Kosanke) Potonié and Kremp, 1955		+					+	+							+				
Lophotriletes labiatus Sullivan, 1964							+												
Lophotriletes microsaetosus (Loose) Potonié and Kremp, 1955					+														
Lophotriletes tribulosus Sullivan, 1964							+												
Lophozonotriletes dentatus Hughs and Playford, 1961		+	+				+	+								+			
Lophozonotriletes varioverrucatus Playford, 1963															+				
Lophozonotriletes triangulatus Hughs and Playford, 1961						+	+												
Lycospora pusilla (Ibrahim) Somers, 1972	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+
Lycospora orbicula (Potonié and Kremp) Smith and Butterworth, 1967			+						+										
Lycospora noctuina Butterworth and Williams, 1958			+						+			+							
Microreticulatisporites concavus Butterworth and Williams, 1958	+	+		+	+		+	+									+	+	
Microreticulatisporites microreticulatus Butterworth and Williams, 1958	+		+				+	+	+										
Microreticulatisporites punctatus Knox, 1950	+	+	+				+	+				+		+			+	+	
Monilospora moniliformis Hacquebard and Barss, 1957																	+		
Monilospora dignata Playford, 1963														+					
Murospora intorta (Waltz) Playford, 1962	+					+													
Murospora tripulvinata Staplin, 1960					+														
Orbisporis orbiculus Bharadway and Venkatachala, 1961			+				+	+											
Orbisporis sp.						+	+	+								+			
Perotrilites perinatus Hughes and Playford, 1961		+					+	+	+										
Perotrilites magnus Hughes and Playford, 1961									+										
Perotrilites tesselatus (Staplin) Neville, 1973		•				•		•											
Potoniespores delicatus Playford, 1963								•		•									
Punctatisporites aerarius Butterworth and Williams, 1958		+			+						+				+			+	
Punctatisporites fissus Hofmeister, Staplin and Malloy, 1955							+								+				
Punctatisporites glaber (Naumova) Playford, 1962	+	+	+				+	+		+	+		+				+		
Punctatisporites minutus Kosanke, 1950		+			+					+	+	+						+	
Punctatisporites nitidus Hoffmeister, Staplin and Malloy, 1955						+	+	+			+				+				
Punctatisporites obliquus Kosanke, 1950								+											+
Punctatisporites parvivermiculatus Playford, 1962											+								
Pustulatisporites papillosus (Knox) Potonié and Kremp, 1955							+	+											
Raistrickia nigra Love, 1960	+	+	+	+	+	+	+	+		+	+			+	+	+		+	
Remysporites magnificus (Horst) Butterworth and Williams, 1958						+											+		
Reticulatisporites carnosus (Knox) Neves, 1964																	+	+	
Retusotriletes communis Naumova, 1953																		•	
Rotaspora ergonulii (Agrali) Sullivan and Marshall, 1966															+				
Rotaspora knoxi Butterworth and Williams, 1958					+					+							+		
Rotaspora sp.							+			+	+				+	+	+		
Rugospora minuta Neves and Ioannides, 1974							•	•			•						+		
Rugospora polyptycha Neves and Ioannides, 1974						+													

App. cont.

	1	2	6	7a	8	9	11	11a	11c	12	13a	17	17a	18	19	19x	20x	21	22
Savitrisporites nux (Butterworth and Williams) Smith and Butterworth, 1967		+	+	+				+		+						+	+		
Schulzospora campyloptera (Waltz) Hoffmeister, Staplin and Malloy, 1955		+		+	+	+	+	+	+		+			+		+	+		
Schulzospora elongata Hoffmeister, Staplin and Malloy, 1955					+				+						+				
Schulzospora ocellata (Horst) Potonié and Kremp, 1955			+	+	+				+		+			+	+		+	+	
Schulzospora plicata Butterworth and Williams, 1958									+										
Schulzospora rara Kosanke, 1950				+				+	+						+		+		
Secarisporites remotus Neves, 1961				+			+	+		+	+	+			+		+		
Simozonotriletes sp.						+													
Spelaeotriletes arenaceous Neves and Owens, 1966		+																	
Spinozonotriletes balteatus Playford, 1963		+																	
Stenozonotriletes clarus Ishchenko, 1958								+											
Stenozonotriletes coronatus Sullivan and Marshall, 1966								+							•		•		
Stenozonotriletes minutus Ishchenko, 1956							+												
Stenozonotriletes bracteolus (Butterworth and Williams) Smith and Butterworth, 1967							+								+	+			
Stenozonotriletes denticulatus Ischenko, 1956						+													
Stenozonotriletes lycosporoides (Butterworth and Williams) Smith and Butterworth, 1967							+	+											
Stenozonotriletes stenozonalis (Waltz) Ishchenko, 1958						+	+	+			+					+			
Stenozonotriletes sp.	+	+		+	+	+			+	+	+					+			
Tholisporites scoticus Butterworth and Williams, 1958		+		+	+	+													
Tricidarisporites arcuatus Neville, 1973						+													
Tricidarisporites balteolus Sullivan and Marshall, 1966							+												
Tricidarisporites rarus (Playford) Ravn, 1991								+											
Triquitrites marginatus Hoffmeister, Staplin and Malloy, 1955			+														+	+	
Vallatisporites ciliaris (Luber) Sullivan, 1964															+				
Vallatisporites galearis Sullivan, 1964							+												
Velamisporites irrugatus Playford, 1978			+												+				
Verrucosisporites baccatus Staplin, 1960							•	•	•					•					
Verrucosisporites cerosus (Hoffmeister, Staplin and Malloy) Butterworth and Williams, 1958								+											
Verrucosisporites eximius Playford, 1963																+			
Verrucosisporites gobbetti Playford, 1963														+					
Verrucosisporites sp.				+			+							+	+				+
Waltzispora polita (Hoffmeister, Staplin and Malloy) Smith and Butterworth, 1967							+												
Waltzispora planiangulata Sullivan, 1964		+	+				+	+		+	+	+		+	+		+		

• – reworked miospore