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New palynostratigraphic data from the Namurian Biały Kamień Formation in the northern part of the Intra-Sudetic Basin (SW Poland)

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Palynostratigraphic studies of the Carboniferous strata of the Biały Kamień Formation, outcropping in the northern part of the Intra-Sudetic Basin, are reported. This formation had been earlier assigned to the Upper Namurian and Lower Westphalian A on the basis of macrofloral and palynological data (Gothan and Gropp, 1933; Górecka, 1969) but these results needed checking against the modern international miospore zonation. We described many taxonomically diverse miospore assemblages from these rocks, which allowed to include them into two miospore zones, of *Crassispora kosankei–Grumosisporites varioreticulatus* (KV) and *Raistrickia fulva–Reticulatisporites reticulatus* (FR). These zones are correlated with part of the interval from the upper part of the Namurian A up to the Namurian C. The miospore zone *Cirratriradites saturni–Triquitrites sinani* (SS), identified by Górecka-Nowak (1987, 1995) from the Grzędy IG 1 borehole, extends the age range of the Biały Kamień Formation from Upper Namurian A to Lower Westphalian A. The documentation of these zones together with previous results of palynostratigraphic studies of the underlying Wałbrzych Formation corroborates the record of miospore zones of the Serpukhovian and Bashkirian in the Intra-Sudetic Carboniferous and suggests that there is no stratigraphic gap between the Wałbrzych and the Biały Kamień formations.

Key words: miospores, palynostratigraphy, Serpukhovian, Bashkirian, Namurian, Sudetes.

INTRODUCTION

The palynological studies we describe were undertaken in response to the need to complement the geological exploration of the Biały Kamień Formation in the Intra-Sudetic Basin with the results of modern biostratigraphic studies. This geological unit represents the most complete profile of the Carboniferous rocks in the entire Sudetes, constituting a record of the geological processes taking place at that time. It comprises thick siliciclastic rocks, in some places coal-bearing, mostly of terrestrial origin, within which a number of informal lithostratigraphic units have been distinguished.

These rocks have been previously studied, but with insufficient biostratigraphic documentation (Bossowski et al., 1995). Initial stratigraphic studies were based on observations of lithological changes and thickness as well as on poorly preserved macrofossils (Bossowski et al., 1995). However, palynostratigraphy turned out to be the most precise biostratigraphic tool for the Intra-Sudetic Carboniferous, for rocks of both terrestrial and marine origin.

Studies using this method in the Intra-Sudetic Basin began in the 1960s and have so far concerned rocks of two coal-bearing formations – the Wałbrzych and the Žacler formations, dated by Krawczyńska-Grocholska (1966), Górecka-Nowak (1995), Górecka-Nowak and Majewska (2002, 2003) and Górecka-Nowak et al. (2021). The Glinik and Ludwikowice formations, composed mainly of reddish-brown and variegated rocks, have mostly poor palynological documentation. This comes mainly from grey-coloured mudstones and claystones in the upper part of the Ludwikowice Formation. The conclusions from palynostratigraphic studies conducted by Górecka (1981) and Jerzykiewicz (1987) are different and the palynostratigrahy of the Carboniferous/Permian boundary in Sudetes is still the subject of discussion.

The remaining parts of the Intra-Sudetic Carboniferous profile do not have modern palynological documentation and therefore lack precise dating. These are: the Mississippian Stare Bogaczowice and Lubomin formations as well as the Biały Kamień Formation belonging to the Pennsylvanian. The rocks

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of the latter formation were palynological studied in the 1960s, but not to modern standards. A turning point in Carboniferous palynostratigraphy was introduction of a miospore zonation, initially for western Europe (Clayton et al., 1977), that later, slightly revised, was extended to central Europe (Owens et al., 2004). It remains the standard, and results of prior palynostratigraphic research, such as from the Biały Kamień Formation, are difficult to reinterpret and usually need repeating.

A new phase of palynostratigraphic studies of the Biały Kamień Formation has been carried out at the Department of Stratigraphy of the Institute of Geological Sciences (University of Wrocław). The results of this research and its interpretation are included in the doctoral thesis of the first of the co-authors (Maćko, 2023), the second co-author being the thesis supervisor.

GEOLOGICAL SETTING

The Intra-Sudetic Basin is located on the northern periphery of the Bohemian Massif and most of its area lies in Poland, with only the southwestern wing in the Czech Republic (Fig. 1). The basin is ~70 km long and ~35 km wide with mainly fault boundaries and an axis in the NW–SE direction.

A succession of Carboniferous sedimentary and volcanic rocks, whose thickness is estimated at 12,000 metres, occurs in the Intra-Sudetic Basin (Nemec et al., 1982; Bossowski et al., 1995). It is dominated by coarse-grained clastic terrestrial rocks associated with clastic rocks of marine origin and volcanic rocks.

These rocks represent the Mississippian and Pennsylvanian and placing constraints on their stratigraphic level depends on fossils. The thick Mississippian strata contain numerous marine fossils in the higher part of the profile, i.e. in the Szczawno Formation, which was regarded as Upper Visean on this basis (Żakowa, 1958, 1963). Rocks lying below, also several thousand metres thick, do not contain macrofossils, and were assigned to the Tournaisian and Visean, though older than Upper Visean (Teisseyre, 1958, 1961, 1975; Żakowa, 1963; Nemec et al., 1982; Bossowski et al., 1995). The results of later palynological studies allowed stratigraphic revision of the Mississippian succession in this basin. Palynostratigraphic studies of the oldest Carboniferous rocks showed that the onset of the sedimentation was not earlier than the Middle Visean (Turnau et al., 2002). Górecka-Nowak et al. (2021) palynologically dated rocks of marine origin in the upper part of the Szczawno Formation, previously considered as Upper Visean, which turned out to represent the lowest Serpukhovian. The Pennsylvanian rocks in the Intra-Sudetic Basin comprise thick successions of clastic rocks, usually grey, locally with intercalations and seams of bituminous coal. Its upper part consists of reddish-brown siliciclastic rocks.

THE BIAŁY KAMIEŃ FORMATION IN THE WAŁBRZYCH BASIN

The Biały Kamień Formation is one of the Pennsylvanian Intra-Sudetic formations occurring between two coal-bearing lithostratigraphic units: the Wałbrzych and the Žacler formations. The Biały Kamień Formation is a succession of clastic rocks of varied lithology, dominated by medium- and coarse-grained orthoconglomerates, which constitute over half of this unit. Lithic sandstones and sublithic arenites exceed 40% of its content and are accompanied by fine-grained rocks with thin coal intercalations (Kurowski, 1998). This formation extends across the northern part of the basin, from the vicinity of Głuszyca in the east, through Jedlina Zdrój, Wałbrzych, Kamienna Góra (Ptaszków, Jaczków, Borówno), to the vicinity of Szczepanów in the west. The thickness of the formation varies from 100 m in the northern and western parts to nearly 400 m in the southeastern part. Kurowski (1998) distinguished two lithofacies within it. A coarse-grained lithofacies corresponds to channel sediments. A second lithofacies is represented by mudstones and coaly shales and corresponds to sediments accumulating on a floodplain. There are two thin coal beds in the succession, corresponding to seams number 549 and 550 in the mining nomenclature, but having no industrial significance (Fig. 2).

PREVIOUS WORK ON BIOSTRATIGRAPHY OF THE BIAŁY KAMIEŃ FORMATION

Previous biostratigraphic studies were not able to clearly constrain the age of the Biały Kamień Formation. Macrofloral studies by Gothan and Gropp (1933) indicated that these rocks belong to the Upper Namurian and Lower Westphalian A. Palynological studies carried out in the 1960s, before the Carboniferous miospore zonation scheme for Western Europe was established (Clayton et al., 1977), placed this formation in the interval from the Upper Namurian B to the Lower Westphalian A (Górecka, 1969). Rocks of the uppermost Biały Kamień Formation, penetrated by the deep borehole Grzędy IG 1, were subsequently included in the oldest Westphalian miospore zone, *Cirratriradites saturni–Triquitrites sinani* (SS), representing the Lower Westphalian A (Langsettian) (Górecka-Nowak, 1987, 1995). This result agreed with previous age estimates of the top part of the Biały Kamień Formation by Gothan and Gropp (1933) and Górecka (1968, 1969). In this paper, we describe new palynostratigraphic studies of Biały Kamień Formation.

An additional controversy related to the boundary between the Wałbrzych and the Biały Kamień formations. Early geologists had suggested a stratigraphic gap between these formations, with angular unconformity (Bubnoff, 1924; Berg, 1925; Schober, 1933, *vide*: Górecka, 1968, 1969). The main reason cited for this discordance was a tectonic phase said to cause uplift of the northwestern part of the Intra-Sudetic Basin (Dathe and Petrascheck 1892; Schober 1933; Berg 1938, vide: Górecka, 1969; Grocholski 1960). Later, Grocholski (1960, 1963, 1965, 1974, 1981) and Augustyniak and Grocholski (1968) agreed that an erosional unconformity was present at the boundary between these two formations. Kurowski (1998), though, connected the occurrence of local gaps with the variability of the alluvial environment in which the Biały Kamień Formation was formed. In turn, Dziedzic (1960, 1961, 1971) explained the presence of a small angular unconformity at the boundary between the Wałbrzych and Biały Kamień formations with uneven subsidence of the basin bottom rather than with elevation of this area. Górecka (1962, 1964, 1969) supported the view of continuous deposition and of the absence of a stratigraphic gap. Nemec (1984) considered that the deposition of the Biały Kamień Formation in the vicinity of Wałbrzych was the result of a strong and sudden diastrophic impulse and assumed that this phenomenon could be be related to the development of discordance.

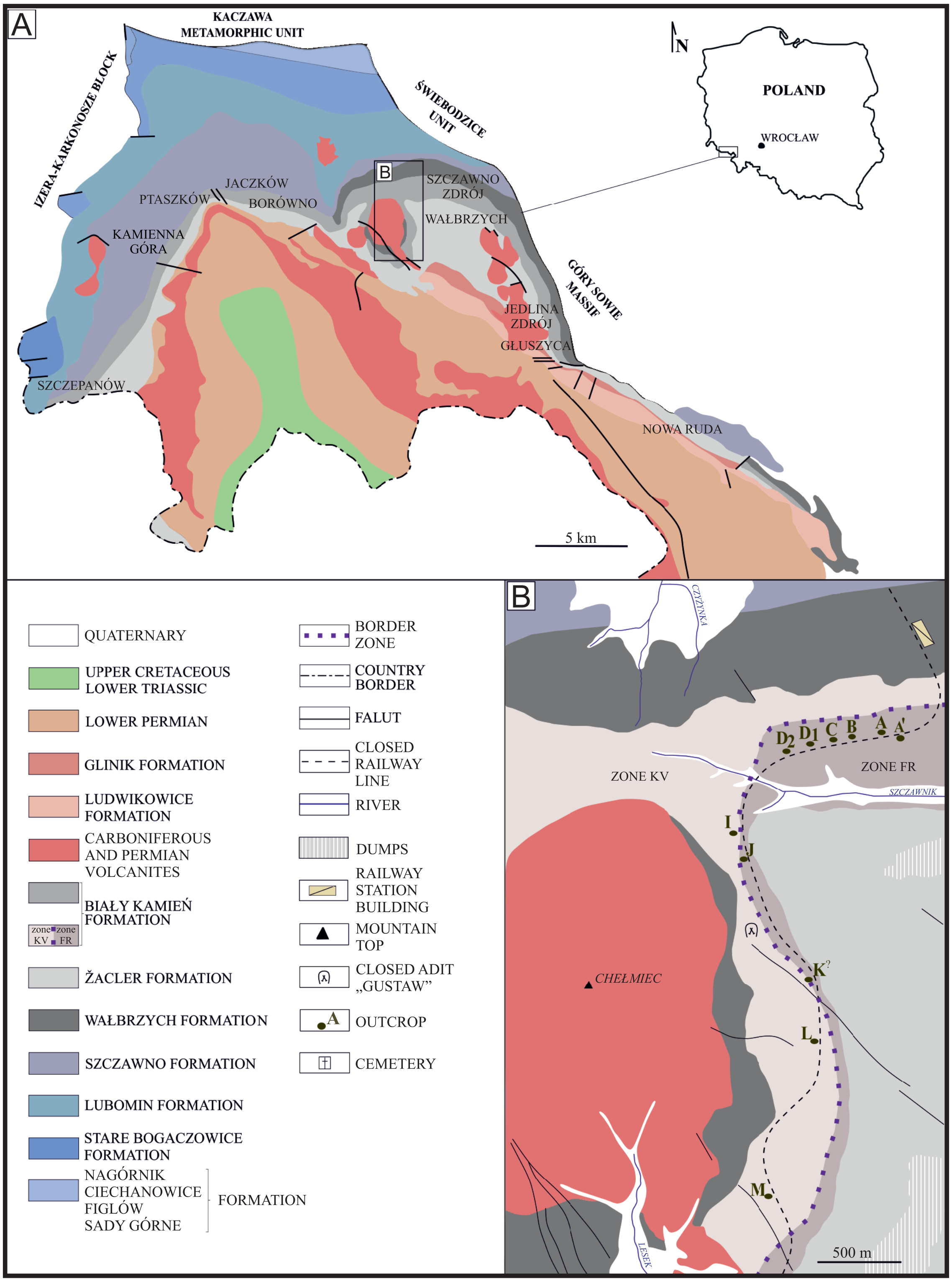

Fig. 1. Simplified geological map of Polish part of the Intra-Sudetic Basin (based on Sawicki, 1967, modified)

MATERIAL AND METHODS

The fieldwork was carried out across the whole outcrop of the Biały Kamień Formation in the northwestern part of the Intra-Sudetic Basin (Fig. 1B) and was focused on sampling rocks at surface exposures. As the fine-grained rocks most useful for palynological studies are relatively rare there, samples for these studies were taken only in the Wałbrzych Sub-Basin, located in the northern part of the Intra-Sudetic Basin, where intercalations of fine-grained rocks and coal occur. Away from the Wałbrzych Sub-Basin, the formation consists of coarse-grained

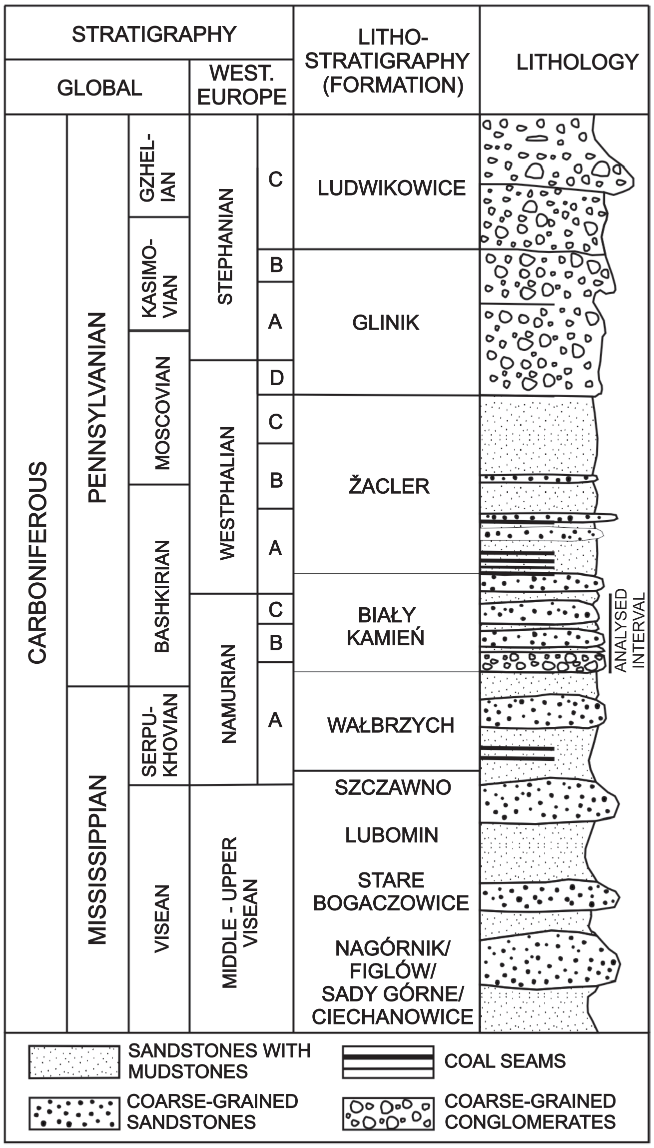

Fig. 2. Lithostratigraphy of Carboniferous rocks in the Intra-Sudetic Basin (*vide*: Bossowski et al., 1995)

rocks. Samples were taken in a profile extending along the disused railway line from the Biały Kamień station southwards, along the eastern border of the Chełmiec massif. Twenty-nine samples were collected from 11 exposures (Fig. 1B: A–M). Depending on the availability of fine-grained rocks:

1 – sample was collected from exposure D_2, L;
2 – samples from exposures A', C, M;
3 – samples from: A, B, D_1, J_3;
4 – samples from I;
5 – samples from exposure K.

All samples except those from site K were productive.

Protocols based on the use of strong acids adapted to the nature of the material collected were applied during sample preparation for the palynological studies (Bercovici and Vellekoop, 2017; Riding, 2021). Approximately 20 grams of rock was used for chemical maceration, and the remaining part of the sample constituted an archival sample. First, the sample was cleaned from surface dirt by scrubbing it under a stream of water and drying in a laboratory dryer. Then, each sample was crushed and ground in a mortar to 0.5–1 mm in size, and then placed in a plastic container. The samples so prepared were flooded with 20% hydrochloric acid to eliminate carbonates, though none of the macerated samples reacted with this acid. Then, the water-rinsed material was subjected to 40% hydrofluoric acid, dissolving silica, silicates, aluminosilicates and sulphides, in a highly exothermic reaction requiring frequent stirring. For mudstone samples, this reaction took several days, and up to a week for carbonaceous shales. The mixture was then diluted with water and washed several times, and then the water was evaporated in a steam bath. The sample was then subjected to the Schulze oxidation process, being flooded with 65% nitric acid while potassium chlorate ($KClO_3$) in dry form was used as a second oxidant. This reaction was strong and lasted up to an hour. Then the sample was sieved in an ultrasonic bath through a 15 µm polyamide mesh. Next, microscope slides in gelatin-glycerin paste were made. In order to determine the miospores, microscopic observations were made in transmitted light using a *Nikon Alphaphot-2 YS2* biological microscope. Microphotographs were taken using a *Canon EOS D200* digital camera. All materials and slides are stored at the Department of Stratigraphic Geology, Institute of Geological Sciences, University of Wrocław.

RESULTS

The palynological studies revealed the presence of abundant palynological matter dominated by phytoclasts with numerous miospores.

The state of miospore preservation was usually good or very good, which allowed their accurate taxonomic identification. Only the 5 samples from site K contained uniformly black palynological matter and miospores occurring there were unrecognizable. This is probably a result of thermal overmaturity, probably related to the location of this site close to the Chełmiec Massif and just near to the fault.

The miospore assemblages found in the samples studied were numerous and taxonomically diverse. 198 miospore taxa, representing 56 genera, were determined. Most of the miospore taxa identified are trilete while monolete miospores and pollen grains were rare. The abundant miospore data enabled both qualitative and quantitative analysis and their comprehensive interpretation. Genera commonly found include *Calamospora, Convolutispora, Crassispora, Cyclogranisporites, Densosporites, Granulatisporites, Lycospora, Punctatisporites, Savitrisporites* and *Verrucosisporites. Lycospora* and *Calamospora* were the taxa with the highest frequency in most of the samples, their content reaching 45%. Three genera, *Crassispora*, *Savitrisporites* and *Punctatisporites*, were also consistently present and quantitatively important components, the content of each of these taxa occasionally exceeding 15%. A group of genera were determined from all or almost all studied samples, but their content was usually low. This group includes *Acanthotriletes, Ahrensisporites, Cirratriradites, Convolutispora, Cyclogranisporites, Densosporites, Verrucosisporites, Bellispores, Grumosisporites, Leiotriletes, Mooreisporites, Raistrickia, Corbulispora, Discernisporites, Knoxisporites, Microreticulatisporites, Neoraistrickia, Orbisporites, Simozonotriletes, Stenozonotriletes, Triquitrites* and *Tripartites*. They occurred as accessories, their content usually did not exceed a few percent and only exceptionally it was higher than 5%.

PALYNOSTRATIGRAPHY

The composition of the miospore assemblages show a typically Carboniferous character (Fig. 3). Among many long-lived taxa, some stratigraphically important species were present. These are mainly species emphasized in the Carboniferous miospore zonation scheme of western Europe (Clayton et al., 1977), later revised and extended to central Europe (Owens et al., 2004). Their stratigraphic ranges are well-known and their occurrence enables precise stratigraphic interpretation (Fig. 4). The following taxa belong to this group: *Apiculatisporis variocorneus, Bellispores nitidus, Cirratriradites saturni, Crassispora kosankei, Dictyotriletes bireticulatus, Dictyotriletes muricatus, Grumosisporites varioreticulatus, Kraeuselisporites echinatus, K. ornatus, Lycospora subtriquetra, Mooreisporites trigallerus, Raistrickia fulva, Punctatisporites sinuatus, Reticulatisporites reticulatus, Stenozonotriletes triangulus* and *Triquitrites bransonii*. The analysis of the taxonomic composition of miospore assemblages from individual sites indicates that they can be divided into two parts, assigned to two miospore zones.

The occurrence of *Raistrickia fulva*, *Crassispora kosankei* and *Grumosisporites varioreticulatus* at sites I, L and M, as well as *Triquitrites bransonii,* which was present in sites I and M, indicate that the rocks studied from these sites should be included in the *Crassispora kosankei–Grumosisporites varioreticulatus* (KV) miospore zone (Owens et al., 2004). Additionally, the occurrence of the species *Mooreisporites trigallerus*, *Lycospora subtriquerta*, *Apiculatisporis variocorneus* and *Cirratriradites saturni* associated with them in the miospore assemblages from these three sites clearly documents the KV zone. This zone is correlated to the upper part of the Alportian and lower part of the Marsdenian in the British division and the uppermost part of the Namurian A and lower to middle parts of the Namurian B in the central European division (Owens et al., 2004). In samples from the remaining sites – A', A, B, C, D1, D2 and J – the presence of the index taxa of the younger miospore zone *Raistrickia fulva–Reticulatisporites reticulatus* (FR) (Owens i in., 2004) was recorded. The boundary between these zones is based on the occurrence of two important taxa that appear for the first time in the lower part of the FR zone, namely *Dictyotriletes muricatus* and *Reticulatisporites reticulatus*. The beginning of their stratigraphic ranges corresponds to the lower part of the FR zone (Owens et al., 2004). The species *Dictyotriletes bireticulatus*, which in the Owens et al. (2004) zonation scheme appears slightly higher within the FR zone, was recorded at three of the sites of this study area. The three taxa noted above are accompanied by other important species: *Apiculatisporis variocorneus*, *Cirratriradites saturni*, *Crassispora kosankei, Gumosisporites varioreticulatus, Kraeuselisporites ornatus, Lycospora subtriquerta, Mooreisporites trigallerus, Raistrickia fulva, Stenozonotriletes triangulus* and *Triquitrites bransonii*. They complement the characteristics of the miospore assemblage of the *Raistrickia fulva–Reticulatisporites reticulatus* (FR) zone, which corroborates that the rocks in

Taxon:	A_1'	A_2'	A_1	$A_{śrd}$	A_2	B_1	B_2	B_3	C_1	C_2	D_1-M_1	D_1-M_2	D_1-W	D_2	J_1	J_2	J_3	I_1	I_2	I_3	I_4	L_1	M_1	M_2
Acanthotriletes echinatus (Loose) Potonié i Kremp		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■			■
Acanthotriletes falcatus (Knox) Potonié i Kremp							■				■	■		■				■	■				■	
Ahrensisporites querickei (Horst) Potonié i Kremp	■		■	■	■	■		■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■
Apiculatisporis variocorneus Sullivan			■			■					■										■		■	
Bellispores nitidus (Horst) Sullivan	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cirratiradites saturni Schopf, Wilson i Bentall		■				■	■		■	■	■	■	■	■	■	■		■	■	■	■	■	■	■
Crassispora kosankei (Potonié i Kremp) Smith i Butterworth	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Crassispora maculosa (Knox) Sullivan																					■			
Cyclogranisporites aureus (Loose) Potonié i Kremp	■	■		■		■	■	■	■	■	■	■		■	■	■	■			■	■	■	■	
Dictyotriletes bireticulatus (Ibrahim) Smith i Butterworth								■	■			■												
Dictyotriletes castaneaeformis (Horst) Sullivan	■	■	■		■	■	■		■	■	■	■			■	■	■			■	■			
Dictyotriletes muricatus (Kosanke) Smith i Butterworth	■	■				■	■			■		■		■		■								
Discernisporites micromanifestus (Hacquebard) Sabry i Neves						■				■														
Grumosisporites varioreticulatus (Neves) Smith i Butterworth	■	■	■	■		■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	
Kraeuselisporites echinatus Owens, Mishel i Marshall																	■							
Kraeuselisporites ornatus (Neves) Owens, Mishel i Marshall						■			■		■	■		■	■	■	■							
Leiotriletes sphaerotriangulus (Loose) Potonié i Kremp														■					■					
Leiotriletes tumidus Butterworth i Williams	■			■		■	■		■		■			■						■			■	
Lycospora pusilla (Ibrahim) Somers	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Lycospora subtriquerta (Luver) Potonié i Kremp	■	■	■	■		■			■		■			■					■		■			■
Microreticulatisporites concavus Butterworth i Williams			■				■	■	■	■														
Mooreisporites trigallerus Neves		■				■	■		■	■	■	■	■		■	■				■	■			
Punctatisporites sinuatus (Artüz) Neves			■		■	■						■						■	■	■	■	■		■
Raistrickia fulva Artüz	■	■				■	■		■			■						■	■	■		■	■	
Reticulatisporites carnosus (Knox) Neves			■	■		■																		
Reticulatisporites reticulatus (Ibrahim) Ibrahim				■					■					■			■							
Rotaspora knoxi Butterworth i Williams			■		■																			
Savitrisporites nux (Butterworth i Williams) Smith i Butterworth	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Spelaeotriletes arenaceous Neves i Owens							■																	
Stenezotriletes triangulus Neves				■		■		■	■															
Tripartites vetustus Schemel									■					■			■							
Triquitrites bransonii Wilson i Hoffmeister		■							■		■			■			■		■				■	
Triquitrites marginatus Hoffmeister, Staplin i Malloy	■		■						■	■	■				■					■			■	
Triquitrites trivalvis (Waltz) Potonié i Kremp																				■				
Verrucosisporites verrucosus (Ibrahim) Ibrahim	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■		■	■

■ present in the sample

Fig. 3. Distribution of stratigraphically important miospore taxa in the rocks studied from the Biały Kamień Formation

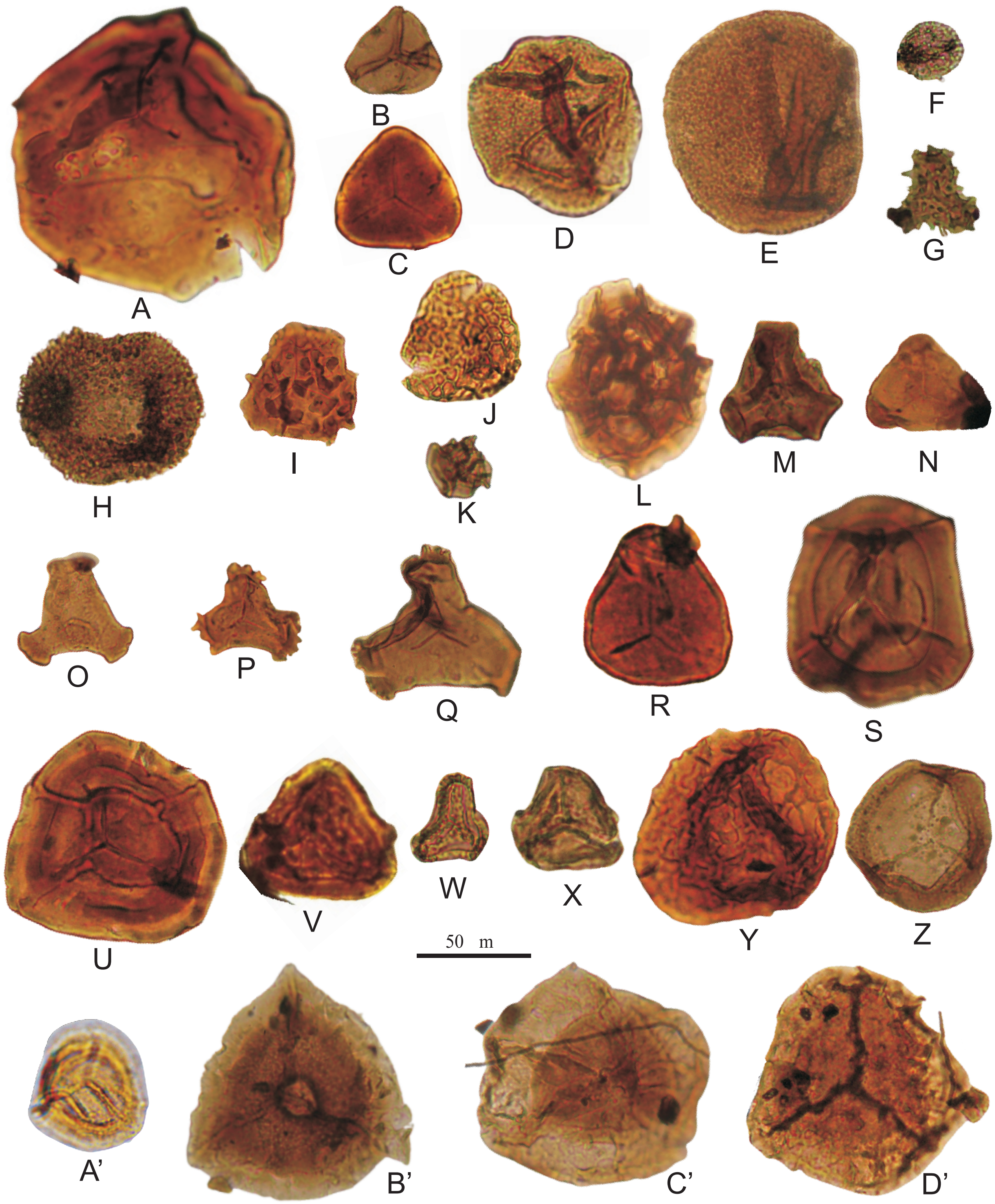

Fig. 4. Microphotographs of selected miospores found in the rocks studied from the Biały Kamień Formation

A – *Punctatisporites* cf. *sinuatus* sample A_1, slide A_1-2, H32-2; **B** – *Leiotriletes tumidus* sample C_1, slide C_1-2, V33-1; **C** – *Leiotriletes sphaerotriangulus* sample D_2, slide D_2-3, W20-1; **D** – *Cyclogranisporites aureus* sample B_1, slide B_1-1, T59-3; **E** – *Verrucosisporites verrucosus* sample A_2, slide A_2-1; S4; **F** – *Acanthotriletes echinatus* sample A_2, slide A_2-2, C50-3; **G** – *Acanthotriletes falcatus* sample D_1, slide D_1-M_1-1, G24-9; **H** – *Apiculatisporis variocorneus* sample D_1-M_1, slide D_1-M_1-1, D12-3; **I** – *Raistrickia fulva* sample I_3, slide I_3-3, W37-2; **J** – *Dictyotriletes bireticulatus* sample D_1-M_2, slide D_1-M_2-2, O18-2; **K** – *Dictyotriletes castaneaformis* sample A_1, slide A_1-1, T27-4; **L** – *Dictyotriletes muricatus* sample A_2’, slide A_2’-4, E50-1; **M** – *Ahrensisporites guerickei* sample A_2, slide A_2-3, G44-2; **N** – *Triquitrites bransonii* sample D_1-M_1, slide D_1-M_1-3, F36-3; **O** – *Triquitrites trivalvis* sample I_3, slide I_3-3, K27-1; **P** – *Tripartites vetustus* sample C_1, slide C_1-3, N29; **Q** – *Mooreisporites trigallerus* sample B_2, slide B_2-3, J54-3; **R** – *Stenozonotriletes triangulus* sample C_1, slide C_1-1, W15; **S** – *Reticulatisporites carnosus* sample $A_{\text{śrd}}$, slide $A_{\text{śrd}}$-3, X22; **U** – *Reticulatisporites polygonalis* sample C_1, slide C1-2, W47; **V** – *Savitrisporites nux* sample A_2, slide A_2-1II, L25-1; **W** – *Bellispores nitidus* sample A_1, slide A_1-2II, W28-4; **X** – *Rotaspora knoxi* sample A_1, slide A_1-2II, W29-3; **Y** – *Grumosisporites varioreticulatus* sample C_2, slide C_2-2, G24; **Z** – *Crassispora kosankei* sample B_1, slide B_1-3, O30-2; **A’** – *Lycospora pusilla* sample C_2, slide C_2-1, J13-2; **B’** – *Cirratriradites saturni* sample D_2, slide D_2-3, P50-4; **C’** – *Discernisporites micromanifestus* sample B_1, slide B_1-2, R50-4; **D’** – *Kraeuselisporites ornatus* sample C_1, slide C_1-2, V55-2 question represent the upper part of the Marsdenian and Yeadonian, corresponding to the upper part of the Namurian B and Namurian C (Owens et al., 2004).

In adopting the palynostratigraphic interpretation above, we need take into account older species in the miospore assemblages, whose stratigraphic ranges are not consistent with the zones identified. For the part of the profile correlated with the KV zone (sites I, L and M), these taxa are *Tripartites marginatus*, *Crassispora maculosa* and *Triquitrites trivalvis*, whose stratigraphic ranges end in the upper part of the *Mooreisporites trigallerus–Rotaspora knoxi* zone (zona TK) (Owens et al., 2004). In the remaining samples, included in the younger FR zone, the presence of *Crassispora maculosa* and other older taxa including *Tripartites vetustus, Rotaspora knoxi, Microreticulatisporites concavus* and *Reticulatisporites carnosus* was also recorded. Their stratigraphic ranges end at the boundary with the TK zone (Owens et al., 2004). Additionally, from sample J3, belonging to the FR zone, *Kraeuselisporites echinatus* was determined, whose stratigraphic range reaches only the central part of the KV zone (Owens et al., 2004). The occurrence of these stratigraphically older taxa in younger rocks indicates that they represent reworked miospores.

The presence of reworked species shows that during the sedimentation of the rocks studied of Late Namurian A to the Namurian C age (i.e. from the end of the Alportian, in the Kinderscoutian, Marsdenian and Yeadonian), erosion of slightly older deposits, from the boundary between the Visean and the Namurian, took place, reworking the rock material and miospores contained within it.

DISCCUSION

The miospore zones of *Crassispora kosankei–Grumosisporites varioreticulatus* (KV) and *Raistrickia fulva–Reticulatisporites reticulatus* (FR) within the Biały Kamień Formation have been identified for the first time (Fig. 1B). This new assignment allows the comparison of the present results with those of previous palynological studies by Górecka (1968, 1969). That author conducted research on fine-grained rocks and coals collected mainly from man-made excavations and trenches from the entire outcrop of the Biały Kamień Formation in the northwestern part of the Intra-Sudetic Basin. Thanks to the excavations the sampling covered the entire profile of the formation. Górecka (1968, 1969) determined an abundant assemblage of miospores consisting of 169 taxa, mainly belonging to Carboniferous long-lived genera as *Apiculatisporites, Calamospora, Cyclogranisporites, Densosporites, Leiotriletes, Lophotriletes, Lycospora* and *Punctatisporites*. This assemblage did not contain the taxa which are now considered as the most stratigraphically important and as applied in the miospore zonation of Clayton et al. (1977) and Owens et al. (2004). Górecka (*ibidem*) divided the profile of the Biały Kamień Formation into three parts. The lower part of the formation contained an assemblage of Visean-Namurian miospore species with a number of species considered to be Westphalian. This part of the profile was interpreted as equivalent to Namurian B. The middle part of the profile according to Górecka (1969) was characterized by the occurrence of taxa characteristic of the Namurian B and C. In turn, in the highest part of the profile, bordering the Žacler Formation, there were no representatives of Visean-Namurian taxa and taxa typical for Westphalian A predominated. The interpretation thus indicated that the age range of the Biały Kamień Formation is from the Namurian B to the Lower Westphalian A. This conclusion, although without reference to the current miospore zonation scheme, which did not then exist, is similar to the conclusion obtained in our recent studies, as regards the division of the profile analysed into three parts. It may be assumed that lower and middle parts of the Biały Kamień Formation profile distinguished by Górecka (1969) probably correspond to the two miospore zones, KV and FR, distinguished in this paper. The upper, Westphalian part of the profile according to Górecka (1969) probably corresponds to the *Triquitrites sinani–Cirratriradites saturni* (SS) zone, documented in the upper part of the Biały Kamień Formation from the Grzędy IG 1 borehole drilled in the 1980s at depth interval of 1672.3–1719.8 m (Górecka-Nowak, 1995). The latter dating indicates that, during recent studies when samples were taken from several surface exposures in the Wałbrzych Sub-Basin, the upper part of the Biały Kamień Formation was not sampled.

The stratigraphic gap between the Wałbrzych and Biały Kamień formations suggested by early researchers (Gothan and Gropp, 1933) was related to discordance and collectively treated as a record of the Namurian tectonic phase in strata of this age in the Intra-Sudetic Basin. This gap seems to have been mainly conceptualized on the sharp lithological change observed between rocks of the upper part of the Wałbrzych Formation and the lower part of the Biały Kamień Formation. This involves the replacement of fine-grained rocks – coal-bearing sandstones and mudstones, belonging to the upper part of the Wałbrzych Formation – by very coarse-grained conglomerates, representing the lower part of the Biały Kamień Formation. To test this hypothesis, the results of palynological studies on the Biały Kamień Formation were compared with current palynostratigraphic data from the Wałbrzych Formation. Górecka-Nowak and Majewska (2002, 2003), based on the miospore assemblages, assigned the lower part of the profile of the Wałbrzych Formation to the *Mooreisporites trigallerus–Rotaspora knoxi* (TK) zone, and its upper part to the *Lycospora subtriquetra*–Apiculatisporis variocorneus (SV) subzone, constituting the lower part SO zone, corresponding to the upper part of the Arsbergian. This conclusion was later corrected and supplemented by the new palynological data published by Górecka-Nowak et al. (2021). They revised the age of the top part of the Wałbrzych Formation based on new finds of the miospore species *Cirratriradites rarus*, allowing rocks of the upper part of the Wałbrzych Formation to be included in the upper part of the SO zone, i.e. to the *Lycospora subtriquetra–Cirratriradites rarus* (SR) subzone. The lower boundary of the SR subzone is correlated with the beginning of the Pennsylvanian and thus with the Mississippian/Pennsylvanian boundary, i.e. with the so-called mid-Carboniferous boundary. In North America, this boundary is very clear and is associated with an unconformity and a gap (Lane et al., 1999). In the Intra-Sudetic Basin it is lithologically elusive because it runs within the profile of the Wałbrzych Formation. The affiliation of the upper part of the Wałbrzych Formation to the SR subzone indicates that the stratigraphic range of the Wałbrzych Formation reaches up to Alportian, but without its highest part and in the central European division it corresponds to the upper part of Namurian A, but also without its highest part. The fact that the lower part of the Biały Kamień Formation belongs to next, *Crassispora kosankei–Grumosisporites varioreticulatus* (KV) zone, which includes the upper Alportian, Kinderscoutian and the lower part of the Marsdenian, does not confirm the existence of a stratigraphic gap between the Wałbrzych and Biały Kamień formations. The boundary between these formations dates to the Uper Namurian A, i.e. the Lower Bashkirian (Fig. 5). Górecka (1969) had a similar opinion as regards the assumed stratigraphical gap, although she located the boundary between these formations higher, i.e. in the Namurian B, considering the

CHRONOSTRATIGRAPHY: GLOBAL			CHRONOSTRATIGRAPHY: WESTERN AND CENTRAL EUROPE			MIOSPORE ZONATION (vide: Clayton et al., 1997; Owens et al., 2004)			FORMATIONS OF INTRA-SUDETIC CARBONIFEROUS
CARBONIFEROUS	PENNSYLVANIAN	MOSCOVIAN	WESTPHALIAN	D	ASTURIAN	*T. securis - T. laevigata*		SL	ŻACLER 3
				C	BOLSOVIAN				
				B	DUCKMANTIAN	*F. junior - M. nobilis*		NJ	
		BASHKIRIAN		A	LANGSETTIAN	*R. aligerens*		RA	
						C. saturni - T. sinani		SS	BIAŁY KAMIEŃ 3
			NAMURIAN	C	YEADONIAN	*R. fulva - R. reticulatus*		FR	BIAŁY KAMIEŃ 1
				B	MARSDENIAN				
					KINDERSCOUTIAN	*C. kosankei - G. varioreticulatus*		KV	
				A	ALPORTIAN	*L. subtriquetra - K. ornatus*	*L. subtriquerta - C. rarus*	SO: SR	WAŁBRZYCH 2
	MISSISSIPPIAN	SERPUKHOVIAN			CHOKIERIAN				
					ARNSBERGIAN		*L. subtriquetra - A. variocorneus*	SO: SV	
						M. trigallerus - R. knoxi		TK	
					PENDLEI	*C. capistratus - B. nitidus*	*V. morulatus*	Vm	SZCZAWNO 2

Fig. 5. Palynostratigraphy of the Biały Kamień Formation (grey colour) and adjacent lithostratigraphic units of the Intra-Sudetic Basin

1 – results of palynostratigraphic analysis within the present research; 2 – results of palynostratigraphic analyses published by Górecka-Nowak et al. (2021); 3 – results of palynostratigraphic analyses published by Górecka-Nowak (1987, 1995)

rocks of the roof part of the Wałbrzych Formation as the equivalent of the Lower Namurian B, and classifying the lower part of the Biały Kamień Formation as the higher Namurian B. Górecka (1969) thus also concluded that these dates preclude the presence of a stratigraphic gap between the Wałbrzych and Biały Kamień formations.

CONCLUSIONS

1. Palynological studies of the Biały Kamień Formation rocks from the Wałbrzych Sub-Basin in the northern part of the Intra-Sudetic Basin proved the existence of two well-documented miospore zones, of *Crassispora kosankei–Grumosisporites varioreticulatus* (KV) and *Raistrickia fulva–Reticulatisporites reticulatus* (FR). These zones correspond to the Bashkirian and upper part of the Alportian, Kindercoutian, Marsdenian and Yeadonianin British divisions and the uppermost Namurian A to Namurian C in the Central European division.

2. This dating complements previous evidence of the miospore zone of *Triquitrites sinani–Cirratriradites saturni* (SS) in rocks of the upper part of the Biały Kamień Formation from the Grzędy IG 1 borehole (Górecka-Nowak, 1995). This extends the age of this formation to an interval from the upper part of the Alportian to the lower part of the Langsettian, corresponding to the Namurian A to Lower Westphalian A.

3. The documentation of these zones in connection with previous results of palynostratigraphic studies of the Wałbrzych Formation (Górecka-Nowak and Majewska, 2002, 2003; Górecka-Nowak et al., 2021) demonstrates a complete record of successive miospore zones of the Serpukhovian and Bashkirian in the Intra-Sudetic Carboniferous.

4. The consistent sequence of these successive miospore zones indicates that palynological data is not consistent with the inference of a significant stratigraphic gap between the Wałbrzych and the Biały Kamień formations.

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