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Palynofacies from Bathonian (Middle Jurassic) ore-bearing clays at Gnaszyn, Kraków-Silesia Homocline, Poland, with special emphasis on sporomorph eco-groups

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ABSTRACT:

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The palynological organic matter of dark clays from Bathonian ore-bearing clays exposed at Gnaszyn (Częstochowa, Kraków-Silesia Homocline, Poland) consists of high proportions of land-derived particles; aquatic elements (mainly dinoflagellate cysts) are comparatively rare. Terrestrial particles include black opaque phytoclasts, dark brown phytoclasts, cuticle remains and subordinate sporomorphs. The latter are represented by eighty-four taxa of spores and pollen grains. They represent various groups of plants, including Bryophyta, Sphenophyta, Lycophyta, Pteridophyta**,** Pteridospermophyta, Cycadophyta or Ginkgophyta and Coniferophyta. The most frequent sporomorphs in almost all samples from Gnaszyn are *Callialasporites* (Araucariaceae), *Cerebropollenites* and *Perinopollenites elatoides* (Taxodiaceae) pollen grains, fern spores with triradiate tetrad mark, bisaccate pollen grains belonging to conifers (Pinaceae or Podocarpaceae) and also to Pteridospermophyta.

Quantitative analysis of the palynofacies shows fluctuations of particular element ratios, which correlate with lithology. Clay intervals that contain siderite concretion levels yielded lower amounts of cuticles in relation to sporomorphs (mainly pollen grains) and dinoflagellate cysts. Intervals of monotonous clays and silts are characterized by a higher ratio of cuticles in relation to other elements, especially dinoflagellate cysts. Also, quantitative analysis of the sporomorphs shows changes in frequency of the representatives of various plant communities, which coexisted during the Jurassic: Upland, Lowland, River, Pioneer, Coastal and Tidally-influenced. These changes might have reflected sea-level fluctuations, which affected vegetation growing on adjacent land. However, the dominance of *Callialasporites* pollen grains, which belong to the Coastal community, indicates that the Gnaszyn assemblage was mainly influenced by the seashore vegetation. The high frequency of Araucariaceae pollen grains and the presence of ferns representing the Osmundaceae, Cyatheaceae, Dicksoniaceae, Schizeaceae, Gleicheniaceae and Matoniaceae indicate a warm climate without large seasonal amplitudes during the deposition of the Gnaszyn succession.

Key words: Palynofacies; Sporomorphs; Ore-bearing clays; Bathonian; Middle Jurassic; Palaeogeography; Epicontinental basin; Poland.

INTRODUCTION

The preliminary results of palynological studies of Middle Jurassic ore-bearing clays from Gnaszyn (Gedl *et al*. 2003) and from other exposures near the town of Częstochowa (Gedl *et al*. 2006a, b, c) showed high proportions of terrestrial material. High amounts of black and dark-brown phytoclasts, cuticles and sporomorphs occur in almost all of the samples analyzed. However, we noted slight fluctuations of the proportions throughout the Gnaszyn succession. Moreover, ratio changes can be correlated with changes in frequencies of sporomorphs representing particular plant communities. Therefore, we combined the results of our studies on land-derived palynological particles, which are supposed to show some environmental changes that took place during deposition of the Gnaszyn succession. The intensity and mode of terrigenous influx into the Bathonian marine basin might prove critical to understanding the sedimentological processes that led to deposition of the ore-bearing clays. Our interpretations constitute part of a multidisciplinary study aimed at a palaeoenvironmental reconstruction of the Gnaszyn succession. We focus on processes directly linked to influx from the neighbouring land into the marine basin. They include the type of organic particles transported into the sea (palynofacies analysis; PG) and reconstruction of the plant communities from the land surrounding Bathonian sea in this area (analysis of sporomorph assemblages; JZ).

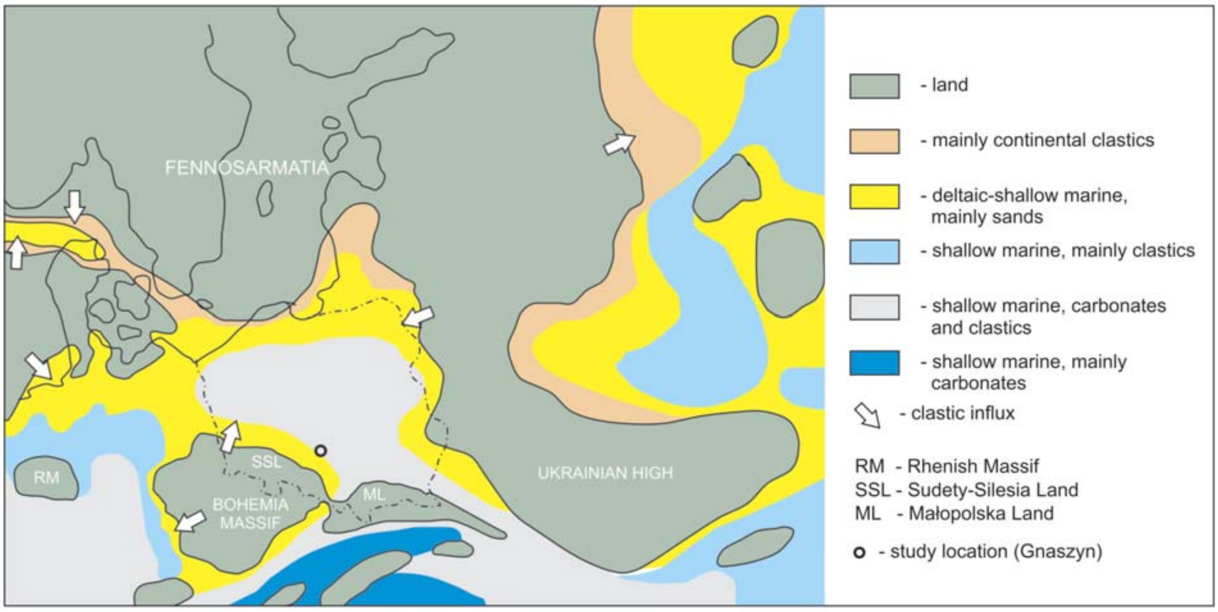
GEOLOGICAL SETTING

The ore-bearing clays represent a characteristic marine facies of the Middle Jurassic of the Polish epicontinental basin. They are mainly dark grey to black clays and silts with minor admixture of a coarser fraction and characterized by horizons of siderite concretions. The ore-bearing clays are of earliest Late Bajocian (Garantiana Ammonite Zone) through early Late Bathonian (Retrocostatum Ammonite Zone; e.g. Różycki 1953; Kopik 1998; Matyja and Wierzbowski 2000, 2003, 2006) age.

The ore-bearing clays are relatively uniform and most complete in the central part of the Polish Basin. In its south-western part (including the Częstochowa area), the succession is less complete and displays a higher facies diversity (e.g. Kontkiewicz 1890; Różycki 1953). This was due to the proximity of land areas; the Bohemian Massif (e.g. Ziegler 1988), surrounded to the north-east by the emergent areas of Silesia and Małopolska (*sensu* Dayczak-Calikowska 1997) (Text-fig. 1). The thickness of the ore-bearing clays in the Kraków-Silesia Homocline varies from 180 m, near Wieluń, to 45 m, in the vicinity of Ogrodzieniec, and to only a few metres in the Olkusz area. They rest upon Lower Jurassic strata in the central part of the Polish Basin, and on lower Middle Jurassic continental or near-shore marine deposits in its south-western part (e. g., Różycki 1953; Dayczak-Calikowska and Kopik 1976). They pass upwards into more sandy deposits succeeded by marls and limestones with ferruginous oolites.

MATERIAL AND METHODS

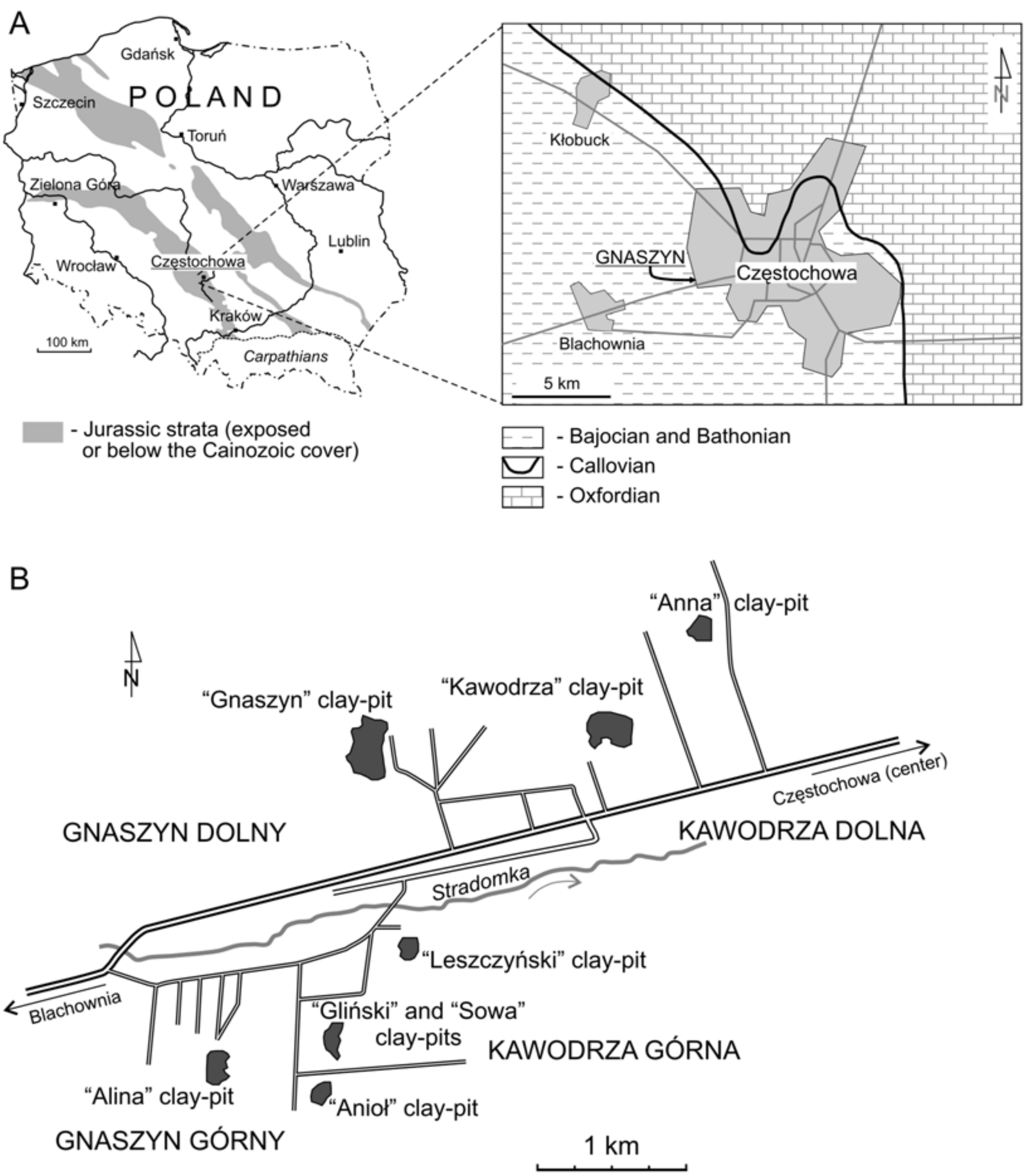
The study is based on forty samples (the main sample set of Gedl and Kaim 2012, this issue) collected from three sections (A, B, and C) in the Gnaszyn clay-pit, in the south-west suburb of Częstochowa (Text-fig. 2). The interval studied represents



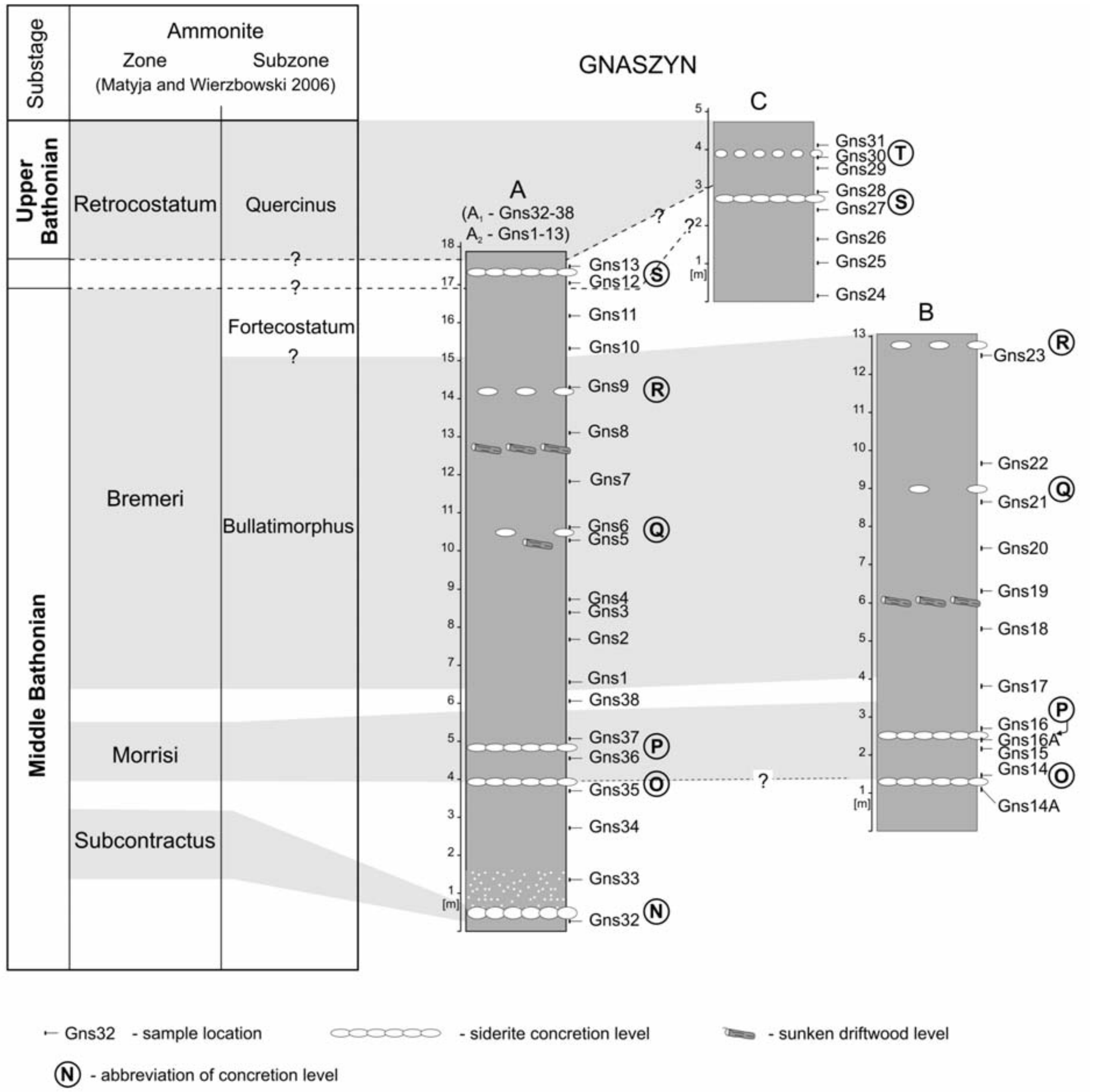
Text-fig. 1. Position of study area at palaeogeographic map of central Europe during Bajocian-Bathonian (from Ziegler 1988) the higher, Middle–lower Upper Bathonian (Subcontractus–Retrocostatum ammonite zones; see Matyja and Wierzbowski 2006, fig. B10.1; Text-fig. 3) part of the ore-bearing clays. The locations of samples are shown in Text-fig. 3.

The samples (20 g of cleaned fresh rock) were processed in the Micropalaeontological Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences in Kraków, following standard palynological processing procedure, including 38% hydrochloric acid (HCl) treatment, 40% hydrofluoric acid (HF) treatment, heavy liquid ($ZnCl_2$+HCl; density 2.0 g/cm^3) separation, ultrasound for 10–15 s and sieving at 15 μm on a nylon mesh. No nitric acid (HNO_3) treatment was applied. Microscope slides were made using glycerine jelly as a mounting medium. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

Counting of organic particles was stopped at 300 counts, whereas all sporomorphs from two slides were determined and counted. Unfortunately, due to poor preservation of the latter, the number of determined sporomorphs hardly ever reached 150 and sporomorphs were determined and counted from additional three slides per sample.



Text-fig. 2. Simplified geological map of the Częstochowa region (A – after Majewski 2000) and location of the Gnaszyn clay-pit (B – after Matyja and Wierzbowski 2003)



Text-fig. 3. Lithological logs of the Gnaszyn sections with sample positions indicated (from Gedl and Kaim 2012)

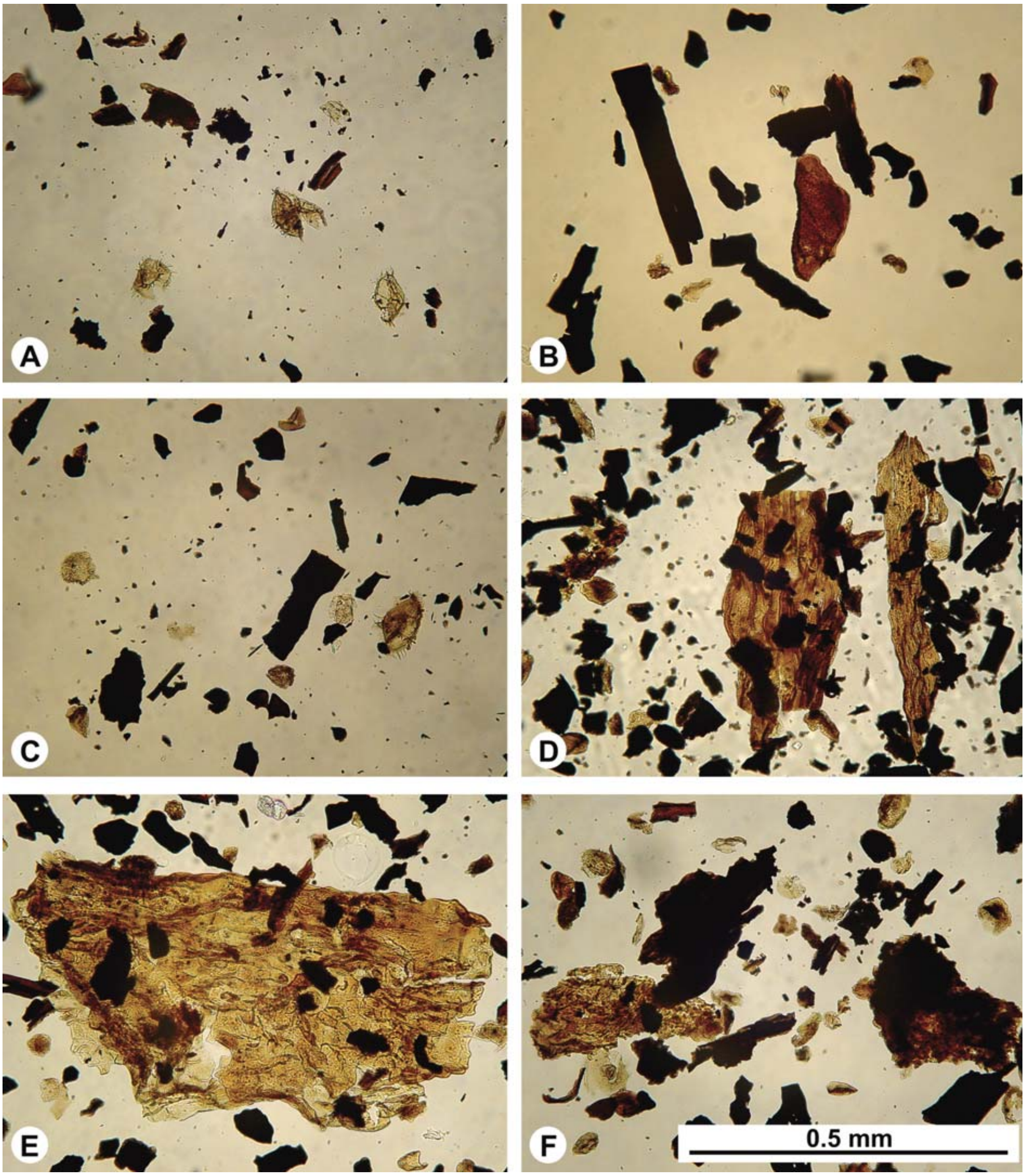
RESULTS

Palynofacies

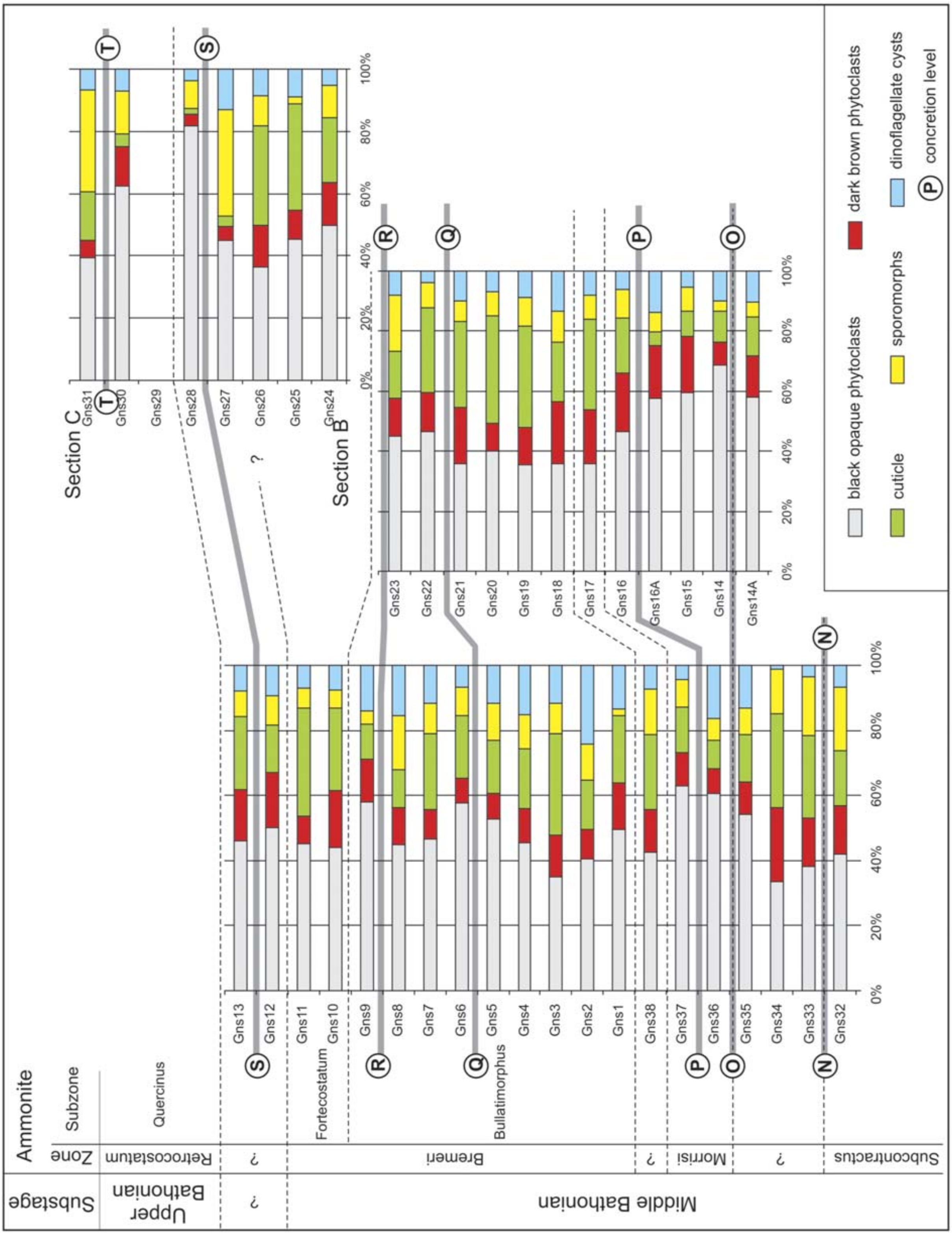
All samples yielded rich palynological material. The palynofacies is characterized by the dominance of terrestrial plant remains – mainly cuticle fragments, black opaque phytoclasts, dark brown phytoclasts and sporomorphs (Text-fig. 4). Aquatic palynomorphs are relatively rare, less than 10% of the palynofacies. The most frequent aquatic elements are dinoflagellate cysts, which occur in all samples. Rare organic linings of foraminifera and very rare acritarchs occur in the majority of samples.

The analysis of palynofacies shows minor fluctuations in the proportions of particular elements (Text-fig. 5). The oldest part of the succession (Subcontractus Zone and the overlying >2-m-thick interval of uncertain position in the ammonite zonal scheme; see Text-fig. 3) is characterized by a relatively high abundance of cuticle remains and sporomorphs (Text-fig. 4D–F). Higher strata, samples Gns35 through Gns37 in section A, and samples Gns14A through Gns16 in section B (see Fig. 3), yielded palynofacies dominated by black opaque phytoclasts (Text-fig. 4A–C). It is noteworthy, that samples Gns37 and Gns16, taken from stratigraphically equivalent horizons, yielded slightly different palynofacies. The palynofacies of sample Gns37 (section A) consists of a higher proportion of black opaque phytoclasts (over 60%) whereas sample Gns16 (section B) contains less than 50% of this element. A similar difference was recognized in the apparently equivalent samples Gns38 from section A and sample Gns17 from section B, representing an interval of uncertain position in the ammonite zonation (see Text-fig. 3): sample Gns38 is much richer in black opaque phytoclasts than sample Gns17 (Text-fig. 5).

The >8-m thick Bullatimorphus Subzone, exposed in sections A and B (see Text-fig. 3), yielded palyno-



Text-fig. 4. Palynofacies types of Bathonian strata exposed at Gnaszyn. A-C – palynofacies dominated by black opaque phytoclasts and relatively frequent dinoflagellate cysts; black phytoclasts, like the cuticles, are rather small-sized (A: Gns9; B and C: Gns14); D-F – palynofacies characterized by high ratio of cuticles including large-sized specimens (D: Gns3; E and F: Gns17) facies characterized by a relatively high proportion of large cuticle remains (over 1 mm in diameter; Text-fig. 5). The exceptions are samples collected from just above the concretion horizons (sample Gns6 above concretion horizon Q, and sample Gns9 above concretion horizon R; see Text-fig. 3); their palynofacies



Text-fig. 5. Palynofacies distribution in the Gnaszyn succession contain higher contents of black opaque phytoclasts, making them similar to the palynofacies of the Morrisi Zone strata

Two samples, Gns10 and Gns11, collected from the Fortecostatum Subzone (section A; see Text-fig. 3) contain palynofacies with a high proportion of cuticle remains (especially Gns10). A similar cuticle content also appears in samples Gns24–26 from the lowermost part of section C, possibly also of Fortecostatum Subzone age (see Text-fig. 3).

The highest samples of the succession are characterized by various palynofacies. Samples from the top of section A (Gns12 and Gns13; uncertain biostratigraphic position; Text-fig. 3) yielded palynofacies dominated by black opaque phytoclasts (approximately 50%) and cuticles ranging from 10 to 20% (Text-fig. 5). Samples Gns27 and Gns28, collected from possibly the same interval (i.e. close to concretionary horizon T), contain a much higher content of sporomorphs (some 30%) and black phytoclasts (over 80% in sample Gns28). Cuticle remains represent a few percent only (Text-fig. 5). A similar low percentage of this element occurs in the topmost samples Gns30 and Gns31, of Upper Bathonian Quercinus Subzone age; black opaque phytoclasts and sporomorphs occur here as important palynofacies elements respectively (Text-fig. 5).

Sporomorphs

Studies on Middle Jurassic sporomorphs from marine strata of Poland are few in number. Rogalska (1976) investigated spores and pollen grains from the Middle Jurassic (Aalenian to Callovian) of the Gutwin borehole (north-east of the Góry Świętokrzyskie Mts.) and from the Bajocian–Callovian of the Międzychód borehole (Fore-Sudetic Homocline). In the Bathonian of the Gutwin borehole the microflora occurs rarely. The most frequent sporomorphs there are pollen grains of Coniferales (Araucariaceae): *Callialasporites* Dev (determined as *Applanopsipollenites* Döring by Rogalska 1976) and fern spores of Filicales. The Bathonian microflora from Międzychód is rich: the dominant sporomorphs are spores of Equisetales, fern spores, and pollen grains of Coniferales (Taxodiaceae, Araucariaceae, Pinaceae, Podocarpaceae).

Terrestrial plant remains from the Częstochowa region have not been investigated in detail yet. Preliminary results of sporomorph studies from the Bathonian succession at Gnaszyn were published by Ziaja (in Gedl *et al*. 2003; *in* Gedl *et al*. 2006c). Moreover, Zatoń *et al*. (2006a) reported a single leaf preserved in a carbonate concretion from the Middle Bathonian (Morrisi Zone) of Gnaszyn: it is a leaflet of a seed fern (Caytoniales), determined as *Sagenopteris* cf. *nilssoniana* (Brongniart) Ward. From the same strata, Marynowski *et al*. (2007) described fossil wood fragments, representing *Prototaxodioxylon* sp., *Agathoxylon* sp., *Xenoxylon phyllocladoides* and *Protopodocarpoxylon* sp. Wood fragments of the latter contains chemical compounds produced only by the conifer families Cupressaceae s. l. (Cupressaceae including Taxodiaceae), Podocarpaceae and Araucariaceae.

Sporomorphs in the Gnaszyn succession (Text-fig. 6) are represented by eighty-four taxa. The spores and pollen grains recognized represent the following groups: Bryophyta, Sphenophyta (Equisetales), Lycophyta, Pteridophyta (Osmundales: Osmundaceae; Filicales: Cyatheaceae, Dicksoniaceae, Gleicheniaceae, Schizeaceae, Matoniaceae, Dipteridaceae, Polypodiaceae?), Pteridospermophyta (Corystospermales, Caytoniales), Cycadophyta (Cycadales, Benettittales) or Ginkgophyta (Ginkgoales), Coniferophyta (Coniferales: Cheirolepidiaceae, Taxodiaceae, Araucariaceae, Podocarpaceae, Pinaceae). Their distribution and numbers of specimens are shown in Text-figs 7–9, and a complete taxonomic list is given in Appendix I.

The most frequent groups of sporomorphs in almost all of the Gnaszyn samples are *Callialasporites* pollen grains belonging to conifer trees of the Araucariaceae. *Cerebropollenites* and *Perinopollenites elatoides* Couper pollen grains belonging to conifers of the Taxodiaceae are abundant in the majority of samples. Various fern spores with triradiate tetrad mark and bisaccate pollen grains from conifers of the Pinaceae or Podocarpaceae and also from seed ferns are very common.

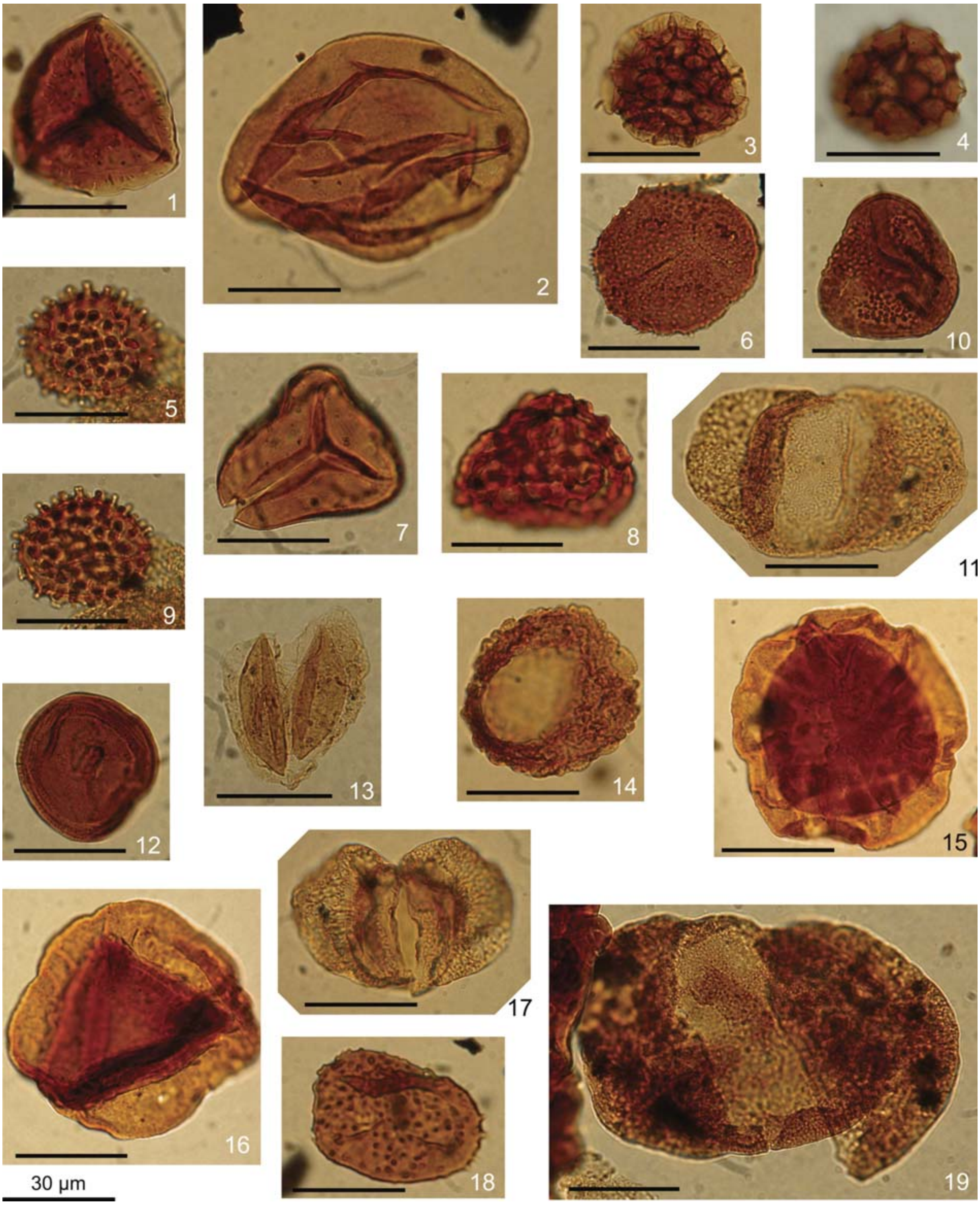
INTERPRETATION

Sporomorph biostratigraphy

Quantitative analysis of the Gnaszyn sporomorph assemblages allows their correlation with the *Callialasporites-Perinopollenites* Zone *sensu* Dybkjær (1991) and Koppelhus and Nielsen (1994), of Aalenian–Bathonian age (see also Koppelhus and Batten 1996). According to Batten and Koppelhus (1996), this zone it is characterized by large numbers of *Callialasporites* pollen grains, abundant *Perinopollenites elatoides* Couper and numerous triradiate spores.

Climatic reconstruction

Abbink (1998) and Abbink *et al*. (2004) proposed quantitative sporomorph analysis for the determination of climate phases, and their criteria are followed herein.



Text-fig. 6. Selected sporomorphs from the Bathonian succession exposed at Gnaszyn. **1** – *Staplinisporites perforatus* (Dettmann 1963) Filatoff 1975; **2** – *Calamospora* sp.; **3** – *Lycopodiumsporites clavatoides* Couper 1958; **4** – *Lycopodiumsporites paniculatoides* Tralau 1968; **5**, **9** – *Neoraistrickia gristhorpensis* (Couper 1958) Tralau 1968 (the same specimen, various foci); **6** – *Baculatisporites comaumensis* (Cookson 1953) Potonie 1956; **7** – *Cyathidites minor* Couper 1953; **8** – *Klukisporites variegatus* Couper 1958; **10** – fern spore; **11** – *Alisporites robustus* Nilsson 1958; **12** – *Classopollis* sp.; **13** – *Perinopollenites elatoides* Couper 1958; **14** – *Cerebropollenites macroverrucosus* (Thiergart 1949) Schulz 1967; **15** – *Callialasporites dampieri* (Balme 1957) Dev 1961; **16** – *Callialasporites trilobatus* (Balme 1957) Dev 1961; **17** – *Pinuspollenites minimus* (Couper 1958) Kemp 1970; **18** – *Apiculatisporis ovalis* (Nilsson 1958) Norris 1965; **19** – bisaccate pollen grain

Araucariaceae pollen grains represent one of the most common groups in Gnaszyn. Their high-frequency occurrence is usually interpreted as indicative of a warm climate without high seasonal amplitudes (Mohr 1989; Abbink 1998). Also indicative of climate are ferns of the Osmundaceae, Cyatheaceae, Dicksoniaceae, Schizeaceae, Gleicheniaceae and Matoniaceae; these plants grew under warm climatic conditions (Abbink 1998, Van Konijnenburg-van Cittert 2002). Thus, a gen-

Number	Chronostratigraphy	Middle Bathonian																		?	
	Ammonite zones	Subcontractus		?		Morrisi		?	Bremeri											?	
	subzones								Bullatimorphis									Fortecostatum			
	Species / Sample	Gns32	Gns33	Gns34	Gns35	Gns36	Gns37	Gns38	Gns1	Gns2	Gns3	Gns4	Gns5	Gns6	Gns7	Gns8	Gns9	Gns10	Gns11	Gns12	Gns13
	Total:	90	156	97	76	78	363	390	57	21	30	42	28	31	44	28	29	13	11	8	28
1	*Staplinisporites* sp.	1																			
2	*Lycopodiacidites* sp..	1										1			1						
3	*Quadreculina analleaeformis*	1	1			1	1	1													
4	Other spores	2						2	4	1		3	1	1	2	2					
5	*Alisporites thomasi*	1		2	1	1	4	3													1
6	*Alisporites* sp.	1		1	1		1	4	1			1			1						
7	*Matonisporites* sp.	2		1								1					1				
8	*Apiculatisporis ovalis*	1	2		1		5	3													1
9	*Cyathidites minor*	3	4		1	1	4	4		1			3							1	1
10	*Pinuspollenites minimus*	1	1	2			2	10	1						1	1				1	3
11	*Araucariacites australis*	4	2	1		2	4	8													
12	*Cerebropollenites macroverrucosus*	18	38	25	16	14	64	92						3	1						
13	*Callialasporites* spp.	3	3	1	2	1	2	4				1				1		2		1	
14	*Cyathidites* sp.	2	1	3				1	1							1			1		1
15	*Callialasporites trilobatus*	1	1	3	2	2	4	4	4		1	2	1	1	2						1
16	*Callialasporites dampieri*	8	15	9	6	4	12	22	11	1	5	4	6	5	2	1	2	2	2	1	2
17	Other bisaccate pollen grains	18	20	13	20	6	40	62	14	6	6	10	4	4	7	6	7	3	1	1	2
18	Other trilete spores of Filicales	6	8	9	2	5	23	23	5	4	1	1	2	1	4	1	1	1	2		1
19	*Auritulinasporites scanicus*		1																		
20	cf. *Conbaculatisporites mesozoicus*		1																		
21	*Foveosporites* sp.		1																		
22	*Lycopodiumsporites paniculoides*		1																		
23	*Varirugosisporites* sp.		1																		
24	*Klukisporites variegatus*		1			1															
25	*Monosulcites subgranulosus*		6				1														
26	*Lycopodiumsporites clavatoides*		5				3	1													
27	*Araucariacites* sp		4	1																	
28	*Leptolepidites* sp.		1	1			1	1							1						
29	*Baculatisporites* sp.		1																1		
30	*Apiculatisporis* sp.		2				1		1						1	1					
31	*Cerebropollenites* sp.		1				4	3	5	2	4	3	1	2	1	3	3	1			2
32	*Lycopodiumsporites* sp.		2			1	1									1			1		1
33	*Perinopollenites elatoides*		4	2	1	2	6	14	1		4	2	3	1	4	3	2	2		1	3
34	*Gleicheniidites senonicus*			1																	
35	*Lycopodiacidites rugulatus*			1																	
36	*Manumia delcourti*			1		2	2	3							1						
37	*Baculatisporites comaumensis*			1			6	3													
38	*Osmundacidites* sp.			1							1	1	1								
39	cf. *Dictyophyllidites crassexinus*				1																
40	cf.*Foveotriletes microreticulatus*				1																
41	*Sestrosporites acutus*				1																
42	*Cerebropollenites mesozoicus*				1		5	4													

Text-fig. 7a. Distribution of sporomorphs in section A of the Gnaszyn succession erally warm climate without distinct seasonal fluctuations is suggested for the Middle–early Late Bathonian of the south-western part of the Polish Basin.

Plant communities

According to, e.g., Chaloner and Muir (1968), Traverse (1988), and Abbink (1998), the composi-

Number	Chronostratigraphy	Middle Bathonian																		?	
	Ammonite zones	Subcontractus			?	Morrisi		?	Bremeri											?	
	subzones								Bullatimorphis									Fortecostatum			
Number	Species / Sample	Gns32	Gns33	Gns34	Gns35	Gns36	Gns37	Gns38	Gns1	Gns2	Gns3	Gns4	Gns5	Gns6	Gns7	Gns8	Gns9	Gns10	Gns11	Gns12	Gns13
43	*Callialasporites minus*				1	1															
44	*Conbaculatisporites* sp.				1	1															
45	*Clasopollis* sp.				2		1	3	1						1						4
46	*Manumia variverrucata*					1															
47	*Tuberositriletes* spp.					1					1										
48	*Alisporites robustus*					3	5	5		1					1	1	1				1
49	Cf.*Calamospora* sp.						1														1
50	*Calamospora tener*						1														
51	*Callialasporites minutus*						1														
52	*Neorastrickia grishorpensis*						1														
53	*Klukisporites* sp.						1														
54	*Lycopodiumsporites australoclavatoides*						1														
55	*Lycopodiumsporites vilhelmi*						1							1	1						
56	*Sestrosporites pseudoalveolatus*						2														
57	*Todisporites* sp.						1														
58	*Callialasporites microvelatus*						4	6													
59	*Lycopodiumsporites reticulumsporites*						1	1													
60	*Osmundacidites wellmanii*						6	6													
61	*Pinuspollenites pinoides*						2	3													
62	*Uvaesporites argentaeformis*						2	2													
63	*Callialasporites turbatus*						4	3		1											
64	*Neorastrickia* sp.						3	3			1					1	1				1
65	cf. *Alisporites radialis*							1													
66	*Brachysaccus microsaccus*							1													
67	*Callialasporites segmentatus*							3													
68	*Chasmatosporites apertus*							1													
69	*Densoisporites* spp							2													
70	*Monosulcites minimus*							1													
71	*Parvisaccites* sp							1													
72	*Platyptera* sp.							2													
73	cf. *Vitreisporites* sp.							1													
74	*Trachysporites* sp.							1						2							
75	*Podocarpiidites* sp.							1	3								1			1	
76	*Contignisporites* sp.								1												
77	*Monosulcites* sp.								1												
78	*Stereisporites* sp.								1												
79	*Varirugosisporites mutabilis*											1				1					
80	*Tuberositriletes montuosus*												1			1					
81	*Trachysporites asper*													2							
82	*Neorastrickia taylori*														1						
83	Trisaccate pollen grains														1						
84	*Converrucosisporites* sp.															1	1				
85	Indet.	16	28	18	15	28	125	71	2	4	6	11	5	8	10	2	9	2	3	1	2

Text-fig. 7b. Distribution of sporomorphs in section A of the Gnaszyn succession tion of fossil terrestrial plant communities is recorded in sporomorph assemblages, and the reconstructions may also be applied to pre-Quaternary settings. According to the Sporomorph Ecogroup Model (SEG) of Abbink (1998), six groups of sporomorphs from the Jurassic and Early Cretaceous of Europe, corresponding to respective plant communities, may be distinguished:

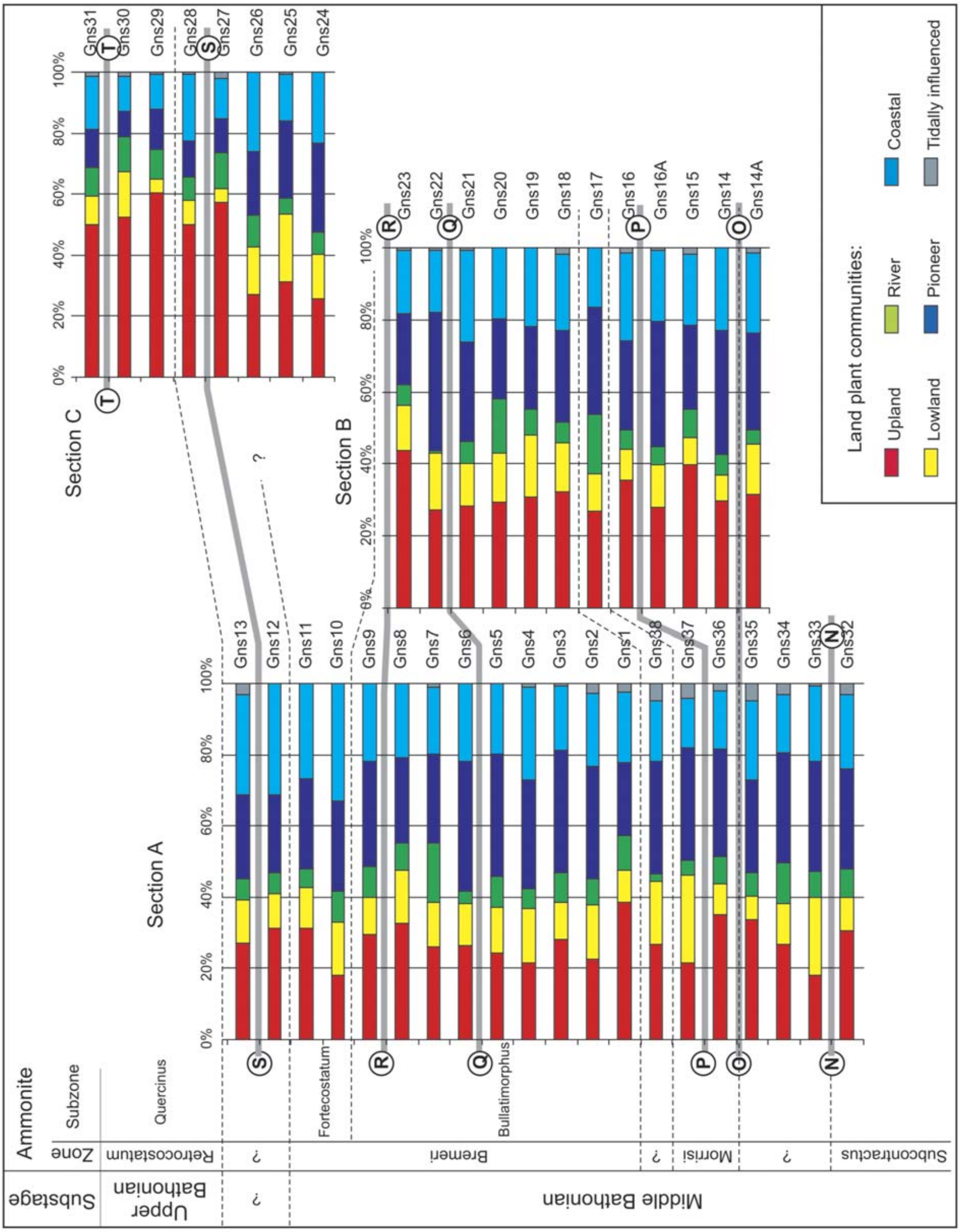
	Chronostratigraphy	Middle Bathonian											
	Ammonite zones	?	Morrisi				?	Bremeri					
	subzones							Bullatimorphis					
Number	Species \ Sample	Gns14A	Gns14	Gns15	Gns16A	Gns16	Gns17	Gns18	Gns19	Gns20	Gns21	Gns22	Gns23
	Total:	71	20	18	61	29	37	28	38	40	36	32	72
1	*Alisporites thomasi*	2											
2	*Manumia delcourti*	1											
3	*Neoraistrickia* sp.	1	1										
4	*Baculatiporites* sp.	3			1								
5	Cf. *Calamospora* sp.	2			2						1	1	1
6	*Callialasporites segmentatus*	1			2				1	1			
7	*Araucariacites australis*	2			1				1				1
8	*Klukisporites* sp.	1			2			1					1
9	*Classopollis* sp.	1			1		1						3
10	*Apiculatisporis ovalis*	3			1	1		1				3	1
11	*Cerebropollenites macroverrucosus*	7			8			1		2	1	6	7
12	*Callialasporites dampieri*	6		1	8	2	1	1	1	3	7	3	5
13	Other spores	4		1		3	1	1	3		1		1
14	*Callialasporites* spp.	2	1		4			3	1	2	2		2
15	*Perinopollenites elatoides*	4	1	2		1	2		3	5	3	1	5
16	*Cerebropollenites* sp.	7	5	3	5		5		1		2	1	1
17	Other trilete spores of Filicales	2	2	3	2	4	2		5	4	1		3
18	Other bisaccate pollen grains	14	4	2	8	3	7	4	6	5	8	9	21
19	*Lycopodiumsporites* sp.		1										
20	*Pinuspollenites minimus*			1		1	1						
21	*Apiculatisporis* sp.			1		1				1			1
22	*Callialasporites turbatus*				3					1	1		
23	*Alisporites* sp.				1	1		2			1	1	1
24	*Lycopodiacidites rugulatus*					1	1						
25	*Alisporites robustus*					1	1			1			
26	*Osmundacidites* sp.					1							1
27	*Brachysaccus microsaccus*						1						
28	*Staplinisporites perforatus.*						1						
29	*Callialasporites trilobatus*						3	1	2	1			1
30	*Cyathidites* sp.						1		1	1		1	1
31	*Quadreculina analleaformis*							1					
32	*Baculatisporites comaumensis*							2	2				
33	*Cyathidites minor*								1	2			
34	*Osmundacidites wellmanii*								1	1	1	1	
35	*Pinuspollenites pinoides*								1				1
36	*Lycopodiacidites* sp.									1			
37	*Tuberositriletes montuosus*									1	1		
38	*Podocarpidites* sp.										1	1	
39	*Platyptera* sp.												1
40	*Podocarpidites ellipticus*												1
41	*Trachysporites asper*												1
42	*Matonisporites* sp.												2
43	Indet.	8	5	4	12	9	9	10	8	8	5	3	9

Text-fig. 8. Distribution of sporomorphs in section B of the Gnaszyn succession

	Chronostratigraphy	Middle Bathonian?			?		Upper Bathonian		
	Ammonite zones	Bremeri?			?		Retrocostat.		
	subzones	Forteco-statum?					Quercinus		
Number	Species / Sample	Gns24	Gns25	Gns26	Gns27	Gns28	Gns29	Gns30	Gns31
	Total:	34	20	34	14	62	17	77	73
1	*Baculatisporites comaumensis*	1							
2	*Platysaccus* sp.	1							
3	*Spheripollenites* sp.	1							
4	*Araucariacites australis*	1	1	1	1				
5	*Cerebropollenites* sp.	1	1			3		1	
6	*Lycopodiumsporites* sp.	1		1				2	
7	*Cyathidites* sp.	1	1	1		1			1
8	*Pinuspollenites minimus*	1			1		1	1	1
9	*Cerebropollenites macroverrucosus*	5	1	1		2			3
10	*Callialasporites dampieri*	5	1	3	2	4			6
11	*Perinopollenites elatoides*	4	1			1		3	2
12	Other trilete spores of Filicales	1	2	2		7	1	6	6
13	Other bisaccate pollen grains	6	2	4	1	16	5	31	24
14	*Baculatisporites* sp.		1						
15	*Leptolepidites* sp.		1						
16	*Osmundacidites wellmanii*		1						
17	*Quadreculina analleaformis*		1						
18	*Cyathidites minor*		1		1	1		1	
19	*Callialasporites trilobatus*		1					1	1
20	*Alisporites* sp.		1			1		1	2
21	Cf. *Calamospora* sp.			1					
22	*Lycopodiacidites* sp.			1	1				
23	*Osmundacidites* sp.			1		1			
24	*Podocarpidites* sp.			1				1	
25	*Neorastrickia* sp.			1			1	2	1
26	*Callialasporites* sp.			2		2	1		4
27	Other spores			1	1	3	1	1	3
28	*Staplinisporites* sp.				1				
29	*Alisporites robustus*				1		1	2	
30	*Matonisporites* sp.				1			1	
31	*Podocarpidites ellipticus*					1			
32	*Tuberositriletes* sp.					1			1
33	*Klukisporites* sp.					1		1	1
34	*Sestrosporites pseudoalveolatus*					1		1	1
35	*Classopollis* sp.					6		5	2
36	*Alisporites thomasi*							1	
37	*Brachysaccus microsaccus*							2	
38	*Cyathidites major*							1	
39	*Gleicheniidites senonicus*							3	
40	*Apiculatisporis* sp.							1	
41	*Calamospora tener*							2	
42	*Lycopodiacidites rugulatus*							1	
43	*Neorastrickia gristhorpensis*							1	
44	*Stereisporites* sp.							1	
45	*Callialasporites minutus*								1
46	Indet.	5	3	13	3	10	6	3	13

Text-fig. 9. Distribution of sporomorphs in section C of the Gnaszyn succession

1. Upland SEG, which consists of plants that grew on higher terrains, well above groundwater level, which were never submerged by water.
2. Lowland SEG, which includes vegetation of plains and/or fresh water swamps. These plains may have been periodically submerged by fresh water, resulting



Text-fig. 10. Sporomorph ecogroups (SEGs) distribution in the Gnaszyn succession

in the possible presence of "wetter" (marsh) and "drier" taxa in this group. There was no influence of (sea) salt, except, perhaps, under extreme circumstances.
3. River SEG, which represents communities consisting of vegetation that grew on river banks, which were periodically submerged and subject to erosion.
4. Pioneer SEG, which includes vegetation of unstable and recently developed ecospace (e.g., vegetation growing at places that had been submerged by the sea for a longer period).
5. Coastal SEG, which includes plants that grew just along the coast, never submerged by the sea but under a constant influence of salt spray.
6. Tidally-influenced SEG, which represents vegetation that was daily influenced by tidal changes (regularly submerged at high tide).

Sporomorphs from the Gnaszyn succession represent all of the above-listed communities. The Upland community is represented by bisacccate pollen grains of seed ferns and conifers (Pinaceae and Podocarpaceae). The Lowland community includes spores of Equisetales, Lycophyta, Pteridophyta, pollen grains of Cycadales, Bennetitales and Ginkgoales, and Coniferales (Taxodiaceae). The River community consists of Bryophyta, Lycophyta, Pteridophyta and seed ferns. The Pioneer community is presumably represented by conifers from the Taxodiaceae, whereas the coastal community consists of conifers from the Araucariaceae and probably the Cheirolepidiaceae. The tidally-influenced community includes Lycophyta (Sellaginellaceae) and seed ferns. The detailed composition of particular SEG (i.e., plant communities) is given in Appendix II.

Usually, it is difficult to attribute a group of plants to just a single type of plant community. Abbink (1998) noted that fern spores of Osmundaceae, Schizeaceae, Cyatheaceae, Dicksoniaceae, Dipteridaceae and Pteridaceae may characterize the Lowland (marsh) or River SEGs. Bryophyte spores may occur in the River SEG or the Lowland (wet) SEG. *Cerebropollenites* is questionably attributed to the Pioneer SEG. *Vitreisporites* pollen grains (Caytoniales) were also included by Abbink (1998) in the River SEG but their parent plant may grow below a canopy of trees and should be attributed to the Coastal SEG, as already suggested by Zatoń *et al*. (2006a).

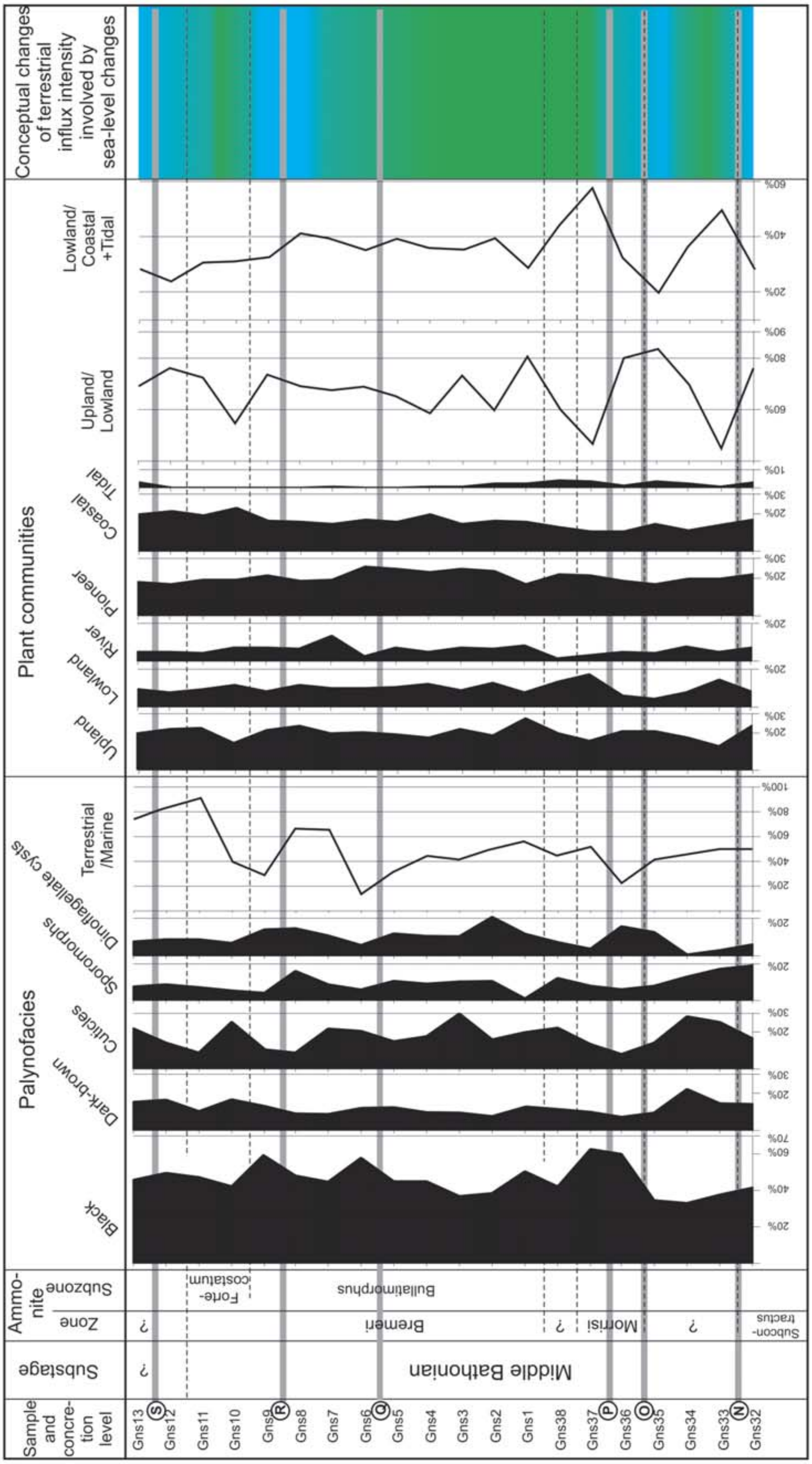
Changes in the proportions or percentages of particular SEGs in Gnaszyn are shown in Text-fig. 10. The lowest percentages are displayed by the Tidally-influenced SEG, usually not exceeding a few percent and sometimes completely absent. The remaining SEGs are more frequent. The most frequent are the Pioneer and Upland SEGs, which range up to over 20%. The Coastal SEG is less than 20%, whereas the Lowland and River SEGs oscillate around 10%. All SEGs show some fluctuations in their vertical distribution (Text-fig. 10), reflecting palaeoenvironmental changes. An explanation of these changes, based on combined SEG and palynofacies changes, is presented below.

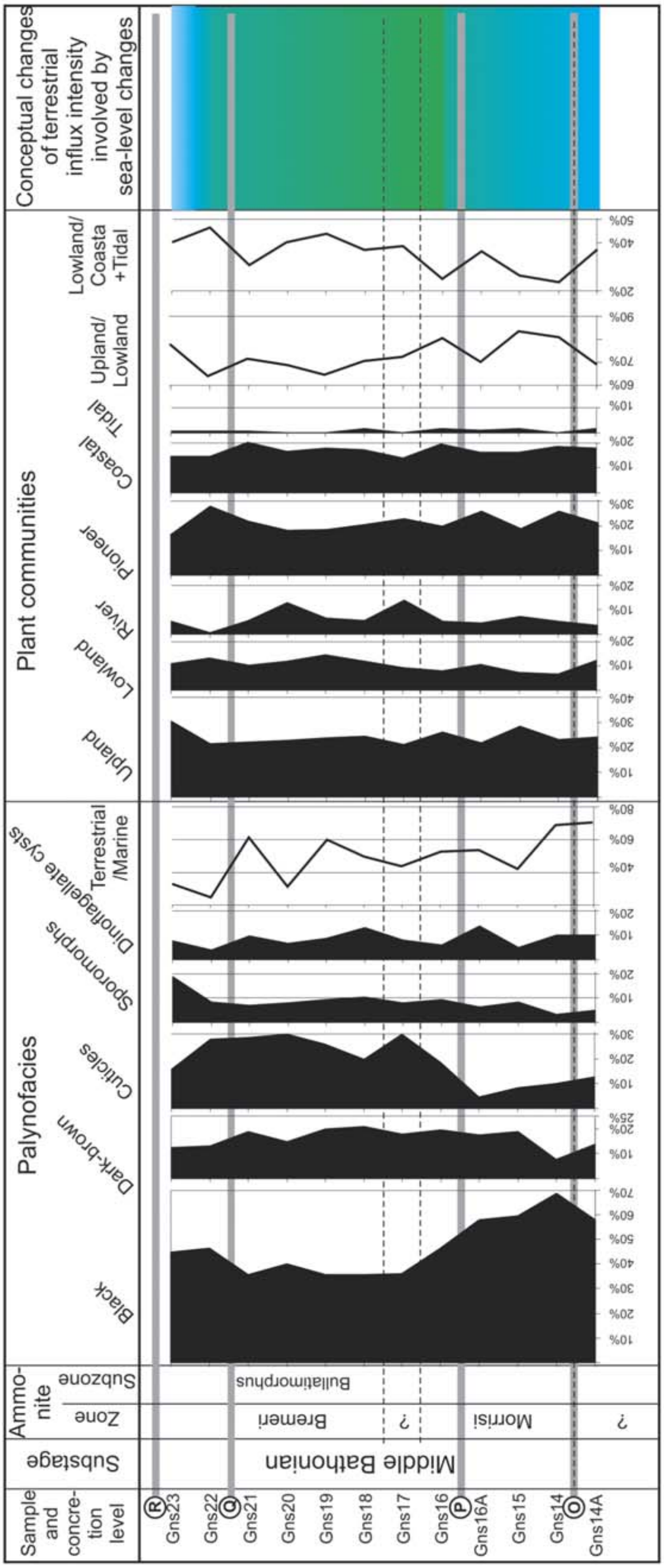
PALAEOENVIRONMENTAL RECONSTRUCTION

The land-derived palynological content of marine sedimentary rocks reflects several factors and processes, including the geomorphology of surrounding land areas (relief of sea-coast area), activity of drainage system (i.e., number and type of rivers), climate (responsible for vegetation type, precipitation/temperature/air-humidity, wind intensity and direction, intensity of rainfall, etc.), hydrodynamic transportation in sea water (surface and bottom currents) and sea-level fluctuations. All of them are strictly related to each other, making a complicated system. Study of the palynological content allows tracing changes within the above-mentioned factors, even on an annual scale. Such precision is not possible in the case of the Gnaszyn material: the rocks are bioturbated and hence the palynological content of particular samples may represent a mixture of various palynological assemblages (palynofacies) reflecting various environmental and sedimentary conditions. Nevertheless, palynofacies analysis from the Gnaszyn succession may be helpful in reconstructing the intensity and mode of the influx of land-derived material into the marine basin during the Middle and earliest Late Bathonian (Text-figs 11–13). Because interpretation of the climate during deposition of the Gnaszyn succession shows rather stable conditions, and assuming that the morphology of the hinterland did not undergo significant modifications, we suppose that it was sea-level changes that influenced the slight changes in the palynological record observed in the succession.

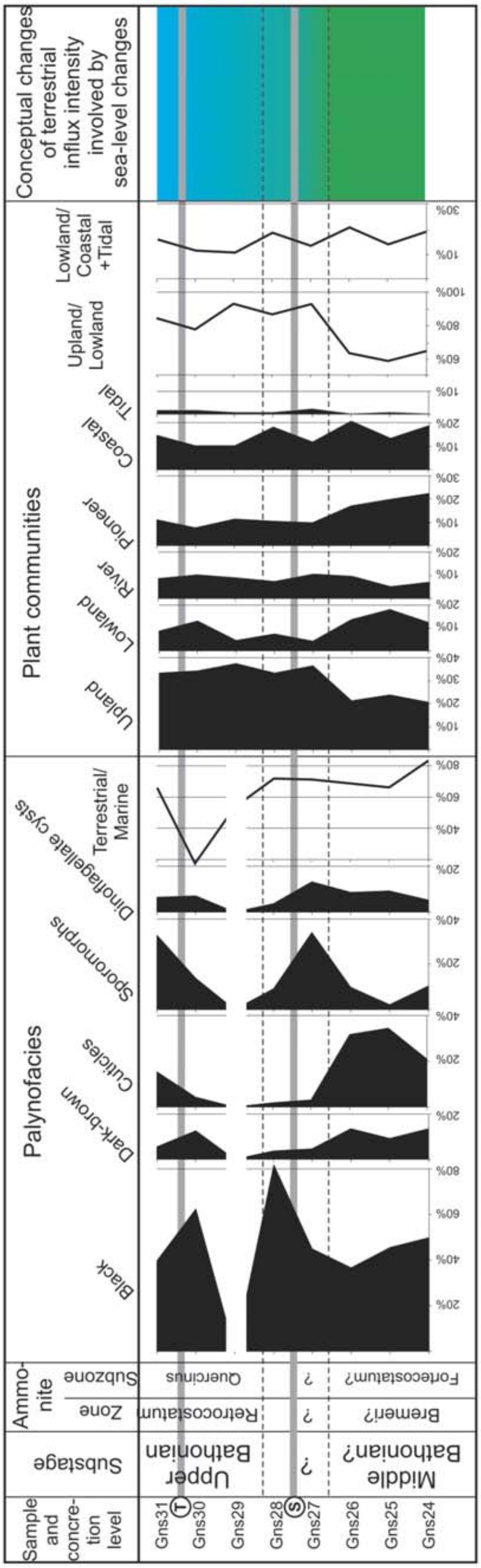
Palynofacies of marine strata consists usually of two main groups: allochthonous particles derived from neighbouring land areas (phytoclasts being land-plant remains in various stages of degradation, sporomorphs, fungi, freshwater algae) and marine (autochthonous) ones including dinoflagellate cysts,

Text-fig. 11. Diversification of terrestrial influx intensity controlled by sea-level fluctuations based on comparison of palynofacies elements and frequencies of particular SEGs, as well as ratios of Marine vs. Terrestrial elements, Upland vs Lowland SEGs and Lowland vs. Coastal+Tidally-influenced SEGs in section A of the Gnaszyn succession. **Green colour** indicates a low sea-level phase and increased influx of terrestrial organic matter; **blue colour** indicates a high sea-level phase and decreased influx of terrestrial organic matter


Sample and concretion level
Substage
Ammonite
Zone
Subzone
Palynofacies
Black
Dark-brown
Cuticles
Sporomorphs
Dinoflagellate cysts
Terrestrial /Marine
Plant communities
Upland
Lowland
River
Pioneer
Coastal
Tidal
Upland/ Lowland
Lowland/ Coastal +Tidal
Conceptual changes of terrestrial influx intensity involved by sea-level changes
Middle Bathonian
Bremeri
Morrisi
Subcontractus
Bullatimorphus
Forte-costatum



Text-fig. 12. Diversification of terrestrial influx intensity controlled by sea-level fluctuations based on comparison of palynofacies elements and frequencies of particular SEGs, as well as ratios of Marine vs. Terrestrial elements, Upland vs Lowland SEGs and Lowland vs. Coastal+Tidally-influenced SEGs in section B of the Gnaszyn succession. **Green colour** indicates a low sea-level phase and increased influx of terrestrial organic matter; **blue colour** indicates a high sea-level phase and decreased influx of terrestrial organic matter



Text-fig. 13. Diversification of terrestrial influx intensity controlled by sea-level fluctuations based on comparison of palynofacies elements and proportions of particular SEGs, as well as ratios of Marine vs. Terrestrial elements, Upland vs Lowland SEGs and Lowland vs. Coastal+Tidally-influenced SEGs in section C of the Gnaszyn succession. **Green colour** indicates a low sea-level phase and increased influx of terrestrial organic matter; **blue colour** indicates a high sea-level phase and decreased influx of terrestrial organic matter

acritarchs, marine algae and linings of foraminifera (see e.g. Whitaker 1984; Boulter and Riddick 1986; Van der Zwan 1990). The proportions of particular groups of allochthonous particles, as well as their ratio versus marine autochthonous particles may serve as a proxy of land influence intensity related to sea-level fluctuations (e.g. Fisher 1980; Sladen and Batten 1984; Whitaker 1984; Steffen and Gorin 1993; Rameil *et al*. 2000; Götz *et al*. 2008). The following proxies are indicative of pelagic/hemipelagic sedimentation, usually associated with high sea-level phases: (i) dominance of phytoplankton (e.g. dinoflagellate cysts) among the palynomorphs; (ii) high diversity of dinoflagellate cyst assemblages (usually increasing basinwards); and (iii) high proportion of black opaque phytoclasts, especially of equidimensional shapes (e.g., Steffen and Gorin 1993; Götz *et al*. 2008). The proxies indicative of deposits originated during low sea-level phases, related to intense influx of terrestrial material, are: (i) high ratio of land plant remains (cuticles, woody particles, degraded debris); (ii) commonly elongated black opaque phytoclasts; and (iii) impoverished dinoflagellate cyst assemblages.

Sea-level fluctuations may also be interpreted based on the variability of Sporomorph Ecogroup (SEG) content. According to Abbink (1998), transgression, or a withdrawal of marine waters from a sea-coast region directly affects the vegetation in this area, leaving a specific sporomorph record. During transgression, a coastal/delta plain area becomes covered by water, thus limiting the proportion of the Lowland SEG. Simultaneously, areas covered by tidally-influenced vegetation (especially when the coastal area is flat) and the Coastal SEG (if steeper) increases. Depending on sea-level rise and the morphology of the coast, an increase in the Upland SEG might also be expected (due to the air-borne nature of the latter, their occurrences may be misleading). In contrast, during sea regression the Lowland SEG increases relative to the Coastal and Tidally-influenced SEGs. Abbink (1998) also noted that the ratio of Lowland vs. Coastal and Tidally-influenced SEGs may be related to sea-level changes. High proportions of the latter SEGs are associated with high sea-level when the sea gradually enters the coast area and limits the extent of the Lowland SEG area.

Sea-level changes in Gnaszyn succession in palynological record

Comparison of SEGs and palynofacies distribution throughout the Gnaszyn succession reveals cyclic changes that are possibly related to sea-level fluctuations. Intervals which might have been deposited during periods of relatively high sea-level phases show a less intense influx of terrestrial organic matter. They are characterized by relative enrichment in black phytoclasts (coincident with a lower proportio of cuticles), and a relative increase in sporomorphs grouped in the Upland, Coastal and Tidally-influenced SEGs (coincident with a decrease in the Lowland SEG; Text-figs 11–13). Black equidimensional phytoclasts, which are frequently treated as a palynofacies element typical of a high sea level (e. g., Traverse, 1988, Götz *et al.* 2008), reach their highest values in the intervals with concretion horizons. This is clearly visible in sections B and C (Text-figs 12 and 13 respectively), where black phytoclast percentages reach the highest values in samples collected close to concretionary horizons (e. g., section B: Gns14, Gns22; section C: Gns28). A clearly visible trend to a decrease in black phytoclasts in section B is already not so pronounced in the coeval part of section A (Text-fig. 11). This suggests a relatively high sea level during the deposition of the interval representing the Morrisi Zone, the upper part of the Bulatimorphis Subzone and the Retrocostatum ammonite Zone. These intervals generally yielded the highest percentages of marine elements (i. e. dinoflagellate cysts), which are also associated with high sea level.

Black phytoclast values correlate inversely with cuticle frequencies: cuticles are most common and represented by the largest particles in the intervals without concretion horizons. High proportions of cuticles reflect intense land influx caused by increased drainage in the hinterland resulting from sea-level fall. Thus, two periods of relatively lower sea level, expressed by more intense terrestrial influx, can be reconstructed during the early Middle Bathonian (above the Subcontractus Zone and below the Morrisi Zone) and the Middle Bathonian (middle part of the Bremeri Zone).

A similar interpretation can be suggested based on the ratio of Upland vs Lowland SEGs. Upland sporomorph assemblages dominate in the lower part of the Gnaszyn succession (samples Gns32–Gns2; Subcontractus–lower part of Bremeri Zone) followed by a gradual increase in Lowland SEGs (up to below concretionary horizon S – samples Gns3 through Gns11 and Gns25) and a repeated increase in the Upland SEG in the highest part of the section (just below concretionary horizon S and upwards). This may be interpreted as a relatively high sea level during the early Middle Bathonian (Subcontractus–lower part of Bremeri Zone) and earliest Late Bathonian (Retrocostatum Zone), separated by a period of sea-level fall. However, frequent occurrence of the Upland SEG, i.e. the element typical of hinterland areas, may be related to the so-called “Neves effect” of Chaloner and Muir (1968), which assumes that the frequency of sporomorphs which are transported from the place of origin to the marine realm is inversely proportional to the distance from source to depositional area. This effect is especially well pronounced in the case of the Upland SEGs, which include “air-borne” bisaccate pollen grains of gymnosperms concentrated in marine sediment by wind transportation.

Another proxy for sea-level fluctuation, the Lowland vs. Coastal and Tidally-influenced SEG ratio, shows the lowest values in the lower part of the Gnaszyn succession (especially in the Morrisi Zone), gradually reaches the highest values in the Bremeri Zone, and lowers again in the topmost Retrocostatum Zone. Again, this may be interpreted as high sea-level during the Morrisi Zone followed by sea-level fall and another sea-level rise in the Retrocostatum Zone.

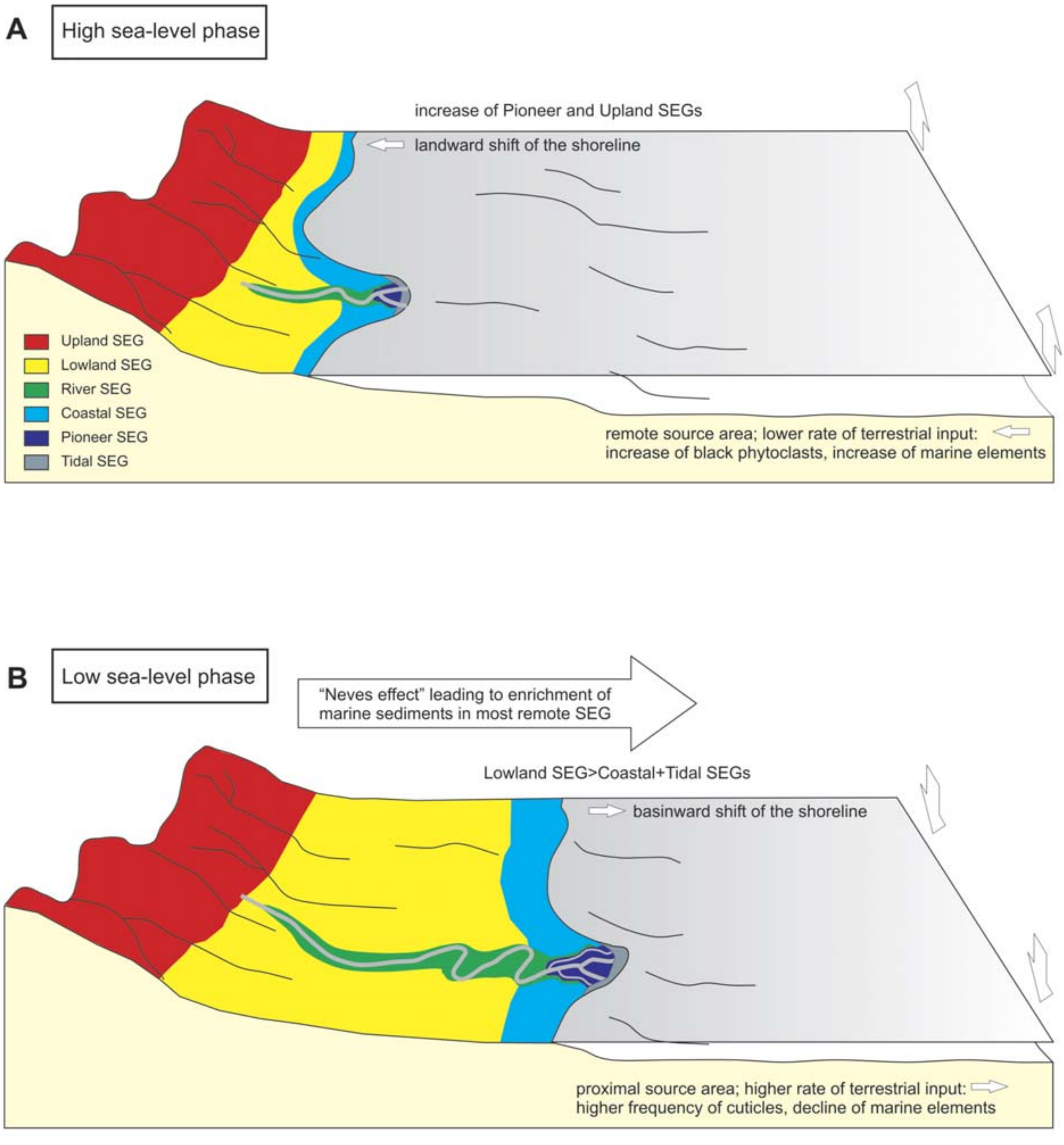
The negative correlation of these two SEG proxies, the Upland vs Lowland and Lowland vs Coastal+ Tidally-influenced ratios, throughout the succession (Text-figs 11–13), gives a similar sea-level trend interpretation: high sea-level conditions during the Subcontractus-Morrisi zones and during the late Retrocostatum Zone, separated by a period of relative lowering of sea level during the middle Middle Bathonian (most of the Bremeri Zone). This interpretation generally coincides with that based on palynofacies distribution. Consequently, the following intervals are interpreted to have been deposited during relatively “high sea-level” (Text-fig. 14A):

(i) basal sample Gns32 (section A) collected directly below concretion level N (Subcontractus Ammonite Zone);
(ii) interval from below concretion horizon O to just above concretion horizon P (Morrisi Zone, and uncertain zone in basal part below concretion horizon O). This interval is exposed in both sections A and B.
(iii) topmost part of the Gnaszyn succession, above sample Gns27, exposed in section C (Retrocostatum Zone, and interval with concretion horizon S).

These intervals are separated by strata deposited during sea-level fall (Text-fig. 14B). These are in particular:

(i) interval above concretion horizon N exposed in section A, up to sample Gns35 (uncertain ammonite zone); it displays a conspicuous shift in Lowland SEG value in sample Gns33;

(ii) interval between concretion horizons P (samples Gns38 and Gns17 in sections A and B respectively) and S (Gns10 and Gns26 in sections A and C respectively), Bremeri Zone; although fluctuating, it displays relatively high values of palynodebris including cuticles. Within this interval, some samples collected above concretion horizons Q and R (Gns6 and Gns9; section A, and Gns22 in section B) show a lower content of cuticles, and a higher content of black phytoclasts; additionally, an increase in dinoflagellate cysts is observed in these samples. Sample Gns9 displays a slight decrease in the Lowland SEG, accompanied by a relative increase in the Upland, Coastal and Tidally-influenced SEGs. These features make them similar to samples from "high sea-level" intervals, which suggest that the deposits that host the Q and R concretion horizons were also deposited during phases of slower sedimentation rate, presumably caused by sea-level rise.



Text-fig. 14. Conceptual reconstruction of the palaeogeography of the Częstochowa area during the Bathonian based on palynofacies and analysis of SEGs. A – high sea-level phase; B – low sea-level phase

DISCUSSION

Dominance of terrestrial organic particles in the Gnaszyn succession, including land-plant debris and sporomorphs, points to the relative proximity of the shore-line and an active river mouth. This observation confirms earlier findings of fossil wood in the same strata by Gedl *et al*. (2003, 2006c), Zatoń *et al*. (2006a), Marynowski *et al*. (2007), Philippe *et al*. (2006), Kaim (2011) or Gedl and Kaim (2012). Sporomorphs representing all conifer families (Cupressaceae s. l., Podocarpaceae and Araucariaceae), macroremains of which were described by Marynowski *et al*. (2007), have been identified in the material studied. Also a pollen grain cf. *Vitreisporites* sp. (Caytoniales; sample Gns38) may represent *Sagenopteris* cf. *nilssoniana* (Brongniart) Ward of the Caytoniales, a plant that left a leaflet of a seed fern found by Zatoń *et al*. (2006a) in the Morrisi Zone.

Subtle changes of palynofacies and particular SEG ratios within the Gnaszyn succession, which in our interpretation reflect sea-level fluctuations during the Middle and earliest Late Bathonian, coincide with the distribution of concretion horizons, which generally occur in intervals with palynofacies indicative of a less intense influx of terrestrial organic matter during a higher sea-level phase. Similar conclusions were drawn by Majewski (2000), who suggested that the concretion horizons must have formed in sediment deposited during phases of a relatively lower sedimentation rate and a reduction in clastic deposition, possibly induced by a higher sea level. Majewski (2000, fig. 4) proposed a model of concretion level formation. According to him, at least some of the concretions underwent partial exhumation (presence of incrusting organisms on concretions; see also Zatoń *et al*. 2006b), and were subsequently covered by sediments during phases of faster sedimentation. Some samples collected just above particular concretion levels contain palynofacies indicative of a more intense influx of terrestrial organic matter then samples from below concretion levels (sample Gns37, section A; sample Gns31, section C).

Deposition of the ore-bearing clays is associated with a major Middle Jurassic transgressive phase, which started after an Early Bajocian regressive event. The deposition of the Gnaszyn succession, representing the Subcontractus–Retrocostatum zones, falls into a major transgressive pulse, which started during the Early Bathonian. The sea covered almost the whole territory of Poland and deposition of the ore-bearing clays ceased during the Late Bathonian (Dayczak-Calikowska 1997). The palynological record suggests that there were some periods with a variable intensity of terrigenous influx during this time. One of the possible reasons for the observed fluctuation is climatic change between arid and humid periods. This model is unacceptable in the case of the Gnaszyn succession. The constant, high proportion of Araucariaceae, points to stable climatic conditions during deposition of the entire succession. Consequently, sea-level fluctuations, as deduced from changes in SEGs, are suggested as the main reason for the observed fluctuations.

Within this general trend, several cyclic fluctuations of lower scale are observed, recorded usually in levels close to the concretion horizons. Samples collected from the levels of concretion horizons yielded SEGs which point to a relatively high sea level. Similarly, palynofacies of the same samples contain peaks of marine element frequencies (except for concretion level Q), also indicating high sea-level conditions.

Our interpretation of a warm climate prevailing during the Middle–early Late Bathonian period seems contradictory to the interpretation of Wierzbowski and Joachimski (2007), who, based on carbon and oxygen stable isotope ratios of calcareous fossils, suggested relatively cool conditions during the Late Bajocian–Late Bathonian. However, their interpretation is based on analysis of marine fossils, and refers to surface-water temperature (below 18.6 ˚C). This difference could be explained by a cold-water current existing during the deposition of the ore-bearing clays. However, the ammonite fauna from this lithostratigraphic unit is typical of the Submediterranean and partly of the Mediterranean provinces (Matyja and Wierzbowski 2000; Zatoń and Marynowski 2004, 2006). Adding the interpretation of Dayczak-Calikowska (1997) that Middle Jurassic transgressions entered the territory of Poland from the Tethyan Ocean, relatively warm-water masses should be expected in the basin studied. Wierzbowski and Joachimski (2007) suggested that the low temperatures inferred from their isotopic studies of marine shells could have been caused by low salinity of the surface waters in which the shells were precipitated (see Gedl *et al*. 2006a, b, c). Palaeotemperatures obtained by Malchus and Steuber (2002) from coeval strata of north-west Poland are much higher (18–27˚C), suggesting warmer conditions, which fit our interpretation much better.

Summarizing, it seems that the terrestrial element content of the sedimentary succession at Gnaszyn reflects mainly subtle changes in sea level (Text-fig. 14). During the early Middle Bathonian a relatively high sea level caused withdrawal of the source area, with limited influx of river-transported remains of vascular plants (e.g., cuticles). Marine ingression covered the coastal plain previously inhabited by lowland plants, causing a reduction in the proportion of the Lowland SEG in the record (Text-fig. 14A). As a result, the effect of lowered sedimentation rate was more pronounced in more off-shore areas where the pelagic signal (dinoflagellate cysts) was stronger.

CONCLUSIONS

(1) All samples contain rich palynological organic matter, dominated, in all cases, by terrestrial elements; aquatic palynomorphs (mainly dinoflagellate cysts) occur subordinately, representing up to a few percent, rarely more than 10%. The most common palynofacies elements are black opaque phytoclasts and cuticle remains. Sporomorphs, represented mainly by bisaccate pollen grains, are up to a few to several percent.

(2) Eighty-four taxa of sporomorphs were recognised. They represent different plant groups, including Bryophyta, Sphenophyta, Lycophyta, Pteridophyta, Pteridospermophyta, Cycadophyta or Ginkgophyta and Coniferophyta (see Table 1). The most frequent groups of sporomorphs, in almost all samples, are: *Callialasporites* pollen grains belonging to conifer trees of the Araucariaceae; *Cerebropollenites* pollen grains and *Perinopollenites elatoides* Couper, belonging to conifers of the Taxodiaceae; fern spores with triradiate tetrad mark; and bisaccate pollen grains from conifers of the Pinaceae or Podocarpaceae and also from seed ferns.

(3) The presence of frequent pollen grains of the Araucariaceae, and the occurrence of ferns from the Osmundaceae, Cyatheaceae, Dicksoniaceae, Schizeaceae, Gleicheniaceae and Matoniaceae, suggest a warm climate, probably without large seasonal amplitudes, during the Bathonian in the Częstochowa region.

(4) High frequency of *Callialasporites* pollen grains, abundant *Perinopollenites elatoides* Couper and numerous triradiate spores indicate that the Gnaszyn succession represents the *Callialasporites-Perinopollenites* Zone *sensu* Dybkjær (1991) and Koppelhus and Nielsen (1994), characteristic of many Aalenian–Bathonian sporomorph assemblages in Europe.

(5) Sporomorph ecogroups (SEGs) from the Gnaszyn succession represent various plant communities which coexisted during the Jurassic: Upland, Lowland, River, Pioneer, Coastal and Tidally-influenced. The dominant *Callialasporites* pollen grains belong to the Coastal community.

(6) Predominance of terrestrial material throughout the Gnaszyn succession points to high terrestrial influx into the Bathonian basin. However, some subtle fluctuations in its intensity could be deduced based on slight changes in the proportions of palynofacies elements, particularly black phytoclasts, cuticles and dinoflagellate cysts. Intervals with a higher proportion of black phytoclasts are treated as having been deposited during periods of relatively lower intensity of terrestrial influx during high sea-level phases, whereas intervals with a higher content of cuticles reflect periods of higher terrestrial influx during lower sea-level phases.

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APPENDIX I

A list of sporomorphs from the Gnaszyn succession arranged according to their botanical affinity *sensu* Balme (1995) and Abbink (1998).

Bryophyta
Staplinisporites perforatus (Dettmann 1963) Filatoff 1975
Staplinisporites spp.
Stereisporites sp.

Sphenophyta
Equisetales
cf. *Calamospora* spp.
Calamospora tener (Leschik 1955) Mädler 1964

Lycophyta
Densoisporites spp. (Sellaginellaceae)
Leptolepidites spp.
Lycopodiacidites spp.
Lycopodiacidites rugulatus (Couper 1958) Schulz 1967
Lycopodiumsporites australoclavatoides (Cookson 1953) Potonié 1956
Lycopodiumsporites clavatoides (Couper 1958) Tralau 1968
Lycopodiumsporites paniculatoides Tralau 1968
Lycopodiumsporites reticulumsporites (Rouse 1959) Dettman 1963
Lycopodiumsporites vilhelmi Guy 1971
Lycopodiumsporites spp.
Neoraistrickia gristhorpensis (Couper 1958) Tralau 1968
Neoraistrickia taylori Playford & Dettmann 1965
Neoraistrickia spp.
Sestrosporites acutus Tralau 1968 (Lycopodiaceae)
Sestrosporites pseudoalveolatus (Couper 1958) Dettmann 1963 (?Lycopodiales)
Uvaesporites argentaeformis (Bolkhovitina 1953) Schulz 1967 (Sellaginellaceae)

Pteridophyta
Osmundales
Osmundaceae
Baculatisporites comaumensis (Cookson 1953) Potonie 1956
Baculatisporites sp.
Osmundacidites wellmanii Couper 1958
Osmundacidites spp.
Todisporites sp.

Filicales
Cyatheaceae, Dicksoniaceae
Converrucosisporites spp.
Cyathidites minor Couper 1953
Cyathidites major Couper 1953
Cyathidites sp.

Gleicheniaceae
Gleicheniidites senonicus Ross 1949

Schizeaceae
Klukisporites sp.
Klukisporites variegatus Couper 1958
Varirugosisporites mutabilis Döring 1965a
Varirugosisporites spp.

Matoniaceae
Matonisporites spp.
cf. *Dictyophyllidites crassexinus* (Nilsson 1958) Tralau 1968 (or Dipteridaceae)

Dipteridaceae
cf. *Conbaculatisporites mesozoicus* Klaus 1960
Conbaculatisporites sp.

Polypodiaceae ?
Contignisporites sp.

Other spores of Filicales

Other spores
Pteridospermophyta
Corystospermales
Alisporites spp.
Alisporites robustus Nilsson 1958
Alisporites thomasi Nilsson 1958
cf. *Alisporites radialis* (Leschik 1955) Lund 1977

Caytoniales
cf. *Vitreisporites* sp.

Cycadophyta
Cycadales, Benettittales or Ginkgophyta
Ginkgoales
Chasmatosporites apertus (Rogalska 1954) Nilsson 1958
Monosulcites minimus Cookson 1947 ex Couper 1953
Monosulcites subgranulosus Couper 1958
Monosulcites sp.

Coniferophyta
Coniferales

Cheirolepidiaceae
Classopollis spp.

Taxodiaceae
Cerebropollenites macroverrucosus (Thiergart 1949) Schulz 1967
Cerebropollenites mesozoicus (Couper 1958) Nilsson 1958
Cerebropollenites spp.
Perinopollenites elatoides Couper 1958

Araucariaceae
Araucariacites australis Cookson 1947 ex Couper 1958
Araucariacites spp.
Callialasporites dampieri (Balme 1957) Dev 1961
Callialasporites microvelatus Schulz 1966
Callialasporites minus (Tralau 1968) Guy 1971
Callialasporites segmentatus (Balme 1957) Srivastava 1963
Callialasporites trilobatus (Balme 1957) Dev 1961
Callialasporites turbatus (Balme 1957) Dev 1961
Callialasporites spp.

Podocarpaceae
Quadreculina analleaformis Maljavkina 1949
Podocarpidites spp.
Podocarpidites ellipticus Cookson 1947
Parvisaccites sp.

Pinaceae
Pinuspollenites minimus (Couper 1958) Kemp 1970
Pinuspollenites pinoides (Nilsson 1958) Lund 1977

Other bisaccate pollen grains
Sporomorphs of unknown affinity
Apiculatisporis spp.
Apiculatisporis ovalis (Nilsson 1958) Norris 1965

Auritulinasporites scanicus Nilsson 1958
Brachysaccus microsaccus (Couper 1958) Mädler 1964

Foveosporites sp.
cf. *Foveosporites microreticulatus* Couper 1958
Manumia delcourti (Pocock 1970) Dybkjær 1991
Manumia variverrucata (Couper 1958) Hoelstad 1985
Platyptera sp.
Platysaccus sp.
Spheripollenites spp.
Trachysporites asper Nilsson 1958
Trachysporites sp.
Tuberositriletes montuosus Döring 1964b
Tuberositriletes spp.
Trisaccate pollen grains
Indeterminateae

APPENDIX II

Classification of the SEGs in the Gnaszyn locality:

Upland
Alisporites robustus Nilsson 1958
cf. *Alisporites radialis* (Leschik 1955) Lund 1977
Quadreculina analleaformis Maljavkina 1949
Podocarpidites spp.
Podocarpidites ellipticus Cookson 1947
Parvisaccites sp.
Pinuspollenites minimus (Couper 1958) Kemp 1970
Pinuspollenites pinoides (Nilsson 1958) Lund 1977
Other bisaccate pollen grains

Lowland
cf. *Calamospora* spp.
Calamospora tener (Leschik 1955) Mädler 1964
Lycopodiumsporites australoclavatoides (Cookson 1953) Potonié 1956
Lycopodiumsporites clavatoides (Couper 1958) Tralau 1968
Lycopodiumsporites paniculatoides Tralau 1968
Lycopodiumsporites reticulumsporites (Rouse 1959) Dettman 1963
Lycopodiumsporites vilhelmi Guy 1971
Lycopodiumsporites spp.
Baculatisporites comaumensis (Cookson 1953) Potonie 1956
Baculatisporites sp.
Osmundacidites wellmanii Couper 1958
Osmundacidites spp.
Todisporites sp.
Converrucosisporites spp.
Cyathidites minor Couper 1953
Cyathidites major Couper 1953
Cyathidites sp.
Gleicheniidites senonicus Ross 1949
Klukisporites sp.
Klukisporites variegatus Couper 1958
Varirugosisporites mutabilis Döring 1965a
Varirugosisporites spp.
Matonisporites spp.
cf. *Dictyophyllidites crassexinus* (Nilsson 1958) Tralau 1968 (or Dipteridaceae)
cf. *Conbaculatisporites mesozoicus* Klaus 1960
Conbaculatisporites sp.
Contignisporites sp.
Chasmatosporites apertus (Rogalska 1954) Nilsson 1958
Monosulcites minimus Cookson 1947 ex Couper 1953
Monosulcites subgranulosus Couper 1958
Monosulcites sp.
Perinopollenites elatoides Couper 1958

River
Staplinisporites perforatus (Dettmann 1963) Filatoff 1975
Staplinisporites spp.
Stereisporites sp.
Leptolepidites spp.
Lycopodiacidites spp.
Lycopodiacidites rugulatus (Couper 1958) Schulz 1967
Neoraistrickia gristhorpensis (Couper 1958) Tralau 1968
Neoraistrickia taylori Playford & Dettmann 1965
Neoraistrickia spp.
Sestrosporites acutus Tralau 1968 (Lycopodiaceae)
Sestrosporites pseudoalveolatus (Couper 1958) Dettmann 1963 (?Lycopodiales)
Uvaesporites argentaeformis (Bolkhovitina 1953) Schulz 1967 (Selaginellaceae)
Other spores of Filicales
cf. *Vitreisporites* sp.

Pioneer
Cerebropollenites macroverrucosus (Thiergart 1949) Schulz 1967
Cerebropollenites mesozoicus (Couper 1958) Nilsson 1958
Cerebropollenites spp.

Coastal
Araucariacites australis Cookson 1947 ex Couper 1958
Araucariacites spp.
Callialasporites dampieri (Balme 1957) Dev 1961
Callialasporites microvelatus Schulz 1966
Callialasporites minus (Tralau 1968) Guy 1971
Callialasporites segmentatus (Balme 1957) Srivastava 1963
Callialasporites trilobatus (Balme 1957) Dev 1961
Callialasporites turbatus (Balme 1957) Dev 1961
Callialasporites spp.
Classopollis spp.

Tidally-influenced
Alisporites spp.
Alisporites thomasi Nilsson 1958
Densoisporites spp. (Sellaginellaceae)

Not attributed
Apiculatisporis spp.
Apiculatisporis ovalis (Nilsson 1958) Norris 1965
Auritulinasporites scanicus Nilsson 1958
Brachysaccus microsaccus (Couper 1958) Mädler 1964
Foveosporites sp.
cf. *Foveosporites microreticulatus* Couper 1958
Manumia delcourti (Pocock 1970) Dybkjær 1991
Manumia variverrucata (Couper 1958) Hoelstad 1985
Platyptera sp.
Platysaccus sp.
Spheripollenites spp.
Trachysporites asper Nilsson 1958
Trachysporites sp.
Tuberositriletes montuosus Döring 1964b
Tuberositriletes spp.
Trisaccate pollen grains
Indeterminateae