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Fluvial sedimentology of the Bialy Kamień Formation (Upper Carboniferous, Sudetes, Poland)

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Abstract The Biały Kamień Formation (Namurian B-C) is part of a molasse sequence deposited in the post-Variscan Intra-Sudetic basin. The formation differs from the adjacent deposits by its coarse-grained nature and possession of fining-up cycles, consistent with deposition in a braided gravel-bed river (GII and GIII facies of Miall's 1978 classification). Fine-grained sediments and coal seams are present in the upper part of the formation. The cyclicity mostly seems to reflect autocyclic depositional mechanisms within the tectonically controlled Intra-Sudetic molasse basin.

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INTRODUCTION

The Biały Kamień Formation (Namurian B-C) is a coarse-grained unit within the ca. 12 km thick sequence of molasse deposits of the post-Variscan Intrasudetic basin (Fig. 1 and 2). Its facies development indicates an alluvial origin. The depositional conditions and environmental settings of this formation are described in this paper.

LITHOFACIES

The Biały Kamień formation is up to 400 metres thick. Its dominant lithologies are medium and coarse-grained suboligomitic orthoconglomerates (53%), sandstones, frequently conglomeratic, mostly lithic or sublithic arenites (42%) and interlayers of fine-grained sediments, which locally contain coal seams (5%) (Fig. 3A and B). A number of lithofacies were differentiated within the Biały Kamień Formation on the basis of texture and sedimentary structures (Tab. 1). The facies code proposed by Miall (1978) was used, taking into account Bridge's (1993) comments on this code.

VERTICAL LITHOFACIES SEQUENCE

An analysis of vertical facies transitions using Markow's embedded chain method (Krumbein & Dacey, 1969; Nemec, 1981) was carried out on field logs, core logs and archive material from Lower Silesian mine excavations (Fig. 4).

Facies transitions were analysed using a differences matrix, which reveals transitions occurring with a significant frequency (Radomski & Gradziński, 1978; Nemec, 1981). Only those transitions with the significance level greater than the critical value of $z = 1.64$ (5%) were taken into account for interpretation. Facies transitions showing positive differences matrix values were used to establish modal facies sequence (Radomski & Gradziński, 1978).

It was necessary to simplify the facies classification because of: (1) a limited number of facies transitions noted in the outcrops; (2) significant disproportions in the frequency of the transitions between different facies; (3) an asymmetry in the distribution of facies, favouring medium and coarse-grained sediments; (4) the low frequency of some facies; and (5) the extended classification used. The results are shown in Table 2, column 2 & 3 and Tables 3 and 4, and their graphic interpretation is given in Figures 5 and 6.

Fining-up sequences as observed locally in outcrops (Fig. 5) were demonstrated with an oscillating and asymmetrical character (Fig. 6). These are typical of alluvial cyclic systems (Allen, 1964; Allen, 1965).

The outcrops of the Bialy Kamień Formation beds are found in a narrow belt (Fig. 4), and only give a fragmen-

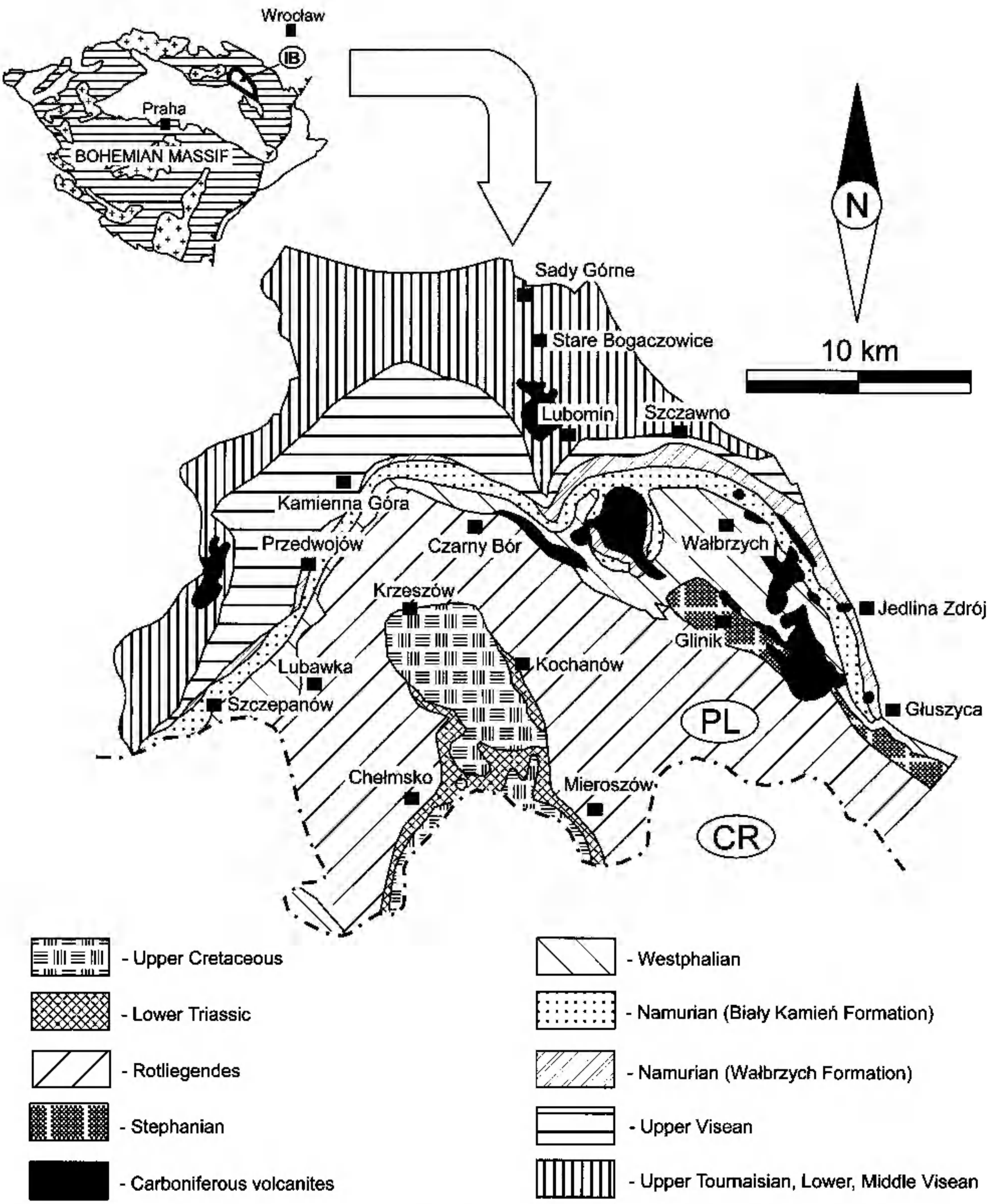


Fig. 1. Simplified geological map of the NW area of the Intra-Sudetic Basin (after Sawicki, 1995) with outline map of the Bohemian Massif (after Franke, 1989) to show its location (IB). Ruled – crystalline domains; crosses – Variscan granites; blank – sedimentary basins; IB – Intra-Sudetic basin

tary picture of the vertical facies transitions present. Because of this, archive underground profiles from mining excavations in the Wałbrzych area (location given in Figure 4) were used. Although the classification system used by geologists working in mines is very simple compared to the standard lithofacies classification (Miall, 1978), it nonetheless could be used after appropriate conversion (Nemec, 1984; Mastalerz, 1985; Mastalerz & Kurowski, 1989). Table 2 shows this simplified facies division classification system and how it relates to the standard system.

Vertical facies transitions obtained from this archive material relative to that obtained from outcrops on the

Table 1

Sedimentary facies of the Biały Kamień Formation

		Facies association	Simplified scheme of the mine facies names	Miall's (1978) facies analogues (modified)		Interpretation
				symbol	name	
1	2	3	4	5	6	7
I	1	conglomerates and sandy conglomerates G	conglomerates Zl	Gm	Massive or crudely bedded gravel	Channel lags, internal parts of the longitudinal bars
	2			Gp	Stratified conglomerate, planar crossbeds	Inner bars, minor channel fills
	3			Gt	Stratified conglomerate, trough crossbeds	Inner bars and dunes (lower flow regime), minor channel fills
	4			Gc	Gravel lenses and horizons in conglomeratic sandstones	Sieve and lag deposits
II	5	sandstones S	sandstones Pc	Sh	Very fine to very coarse grained sandstones, horizontal bedding	Planar bed and top bar deposits (lower and upper flow regime)
	6			Sp	Medium to very coarse grained sandstone, *alpha* or *omikron* planar crossbeds	Inner to transverse bars and dunes, lower flow regime, final stages of channel filling
	7			St	Medium to very coarse grained sandstones, *theta* or *pi* trough crossbeds	Channel deposits at all, bars and dunes, lower flow regime, crevasse-splay
	8			Sr	Very fine to coarse grained sandstones, ripple crossbeds	Final stage of minor channel infilling, top parts of channel bars, crevasse-splays
III	9	fine grained deposits and coals F+C	sandstone shales Łp	Sr/Fl	Very fine sandstones and silty to clayey shales, ripple cross lamination of all types	Abandoned channel fills, levee deposits
	10		clay shales Łi	Fh	Mudstones, horizontal lamination	Abandoned channel fills, levee and flood plain deposits
	11			Fm	Massive mudstones	Flood plain deposits
	12			P	Massive claystones	Soils developed on the flood plain area, marshes and peats
	13			Fr	Mudstones and claystones containing rootlets	*Stigmaria* soils, flood plain
	14		coals C	C	coals	Swamp deposits on the flood plain area

surface are illustrated by differences matrix and "Z" statistics in Tables 5 and 6 and by Figures 7 and 8. The picture obtained reveals a weaker trend towards the formation of asymmetrical fining-up sequences than the earlier example (Fig. 7), but the distinct tendency towards oscillation is upheld. Oscillation-type transitions are also present within the medium and coarse-grained sediments and within the fine-grained sediments but these transitions are not statistically significant (Fig. 8).

An analysis on the archive mining excavation material was also carried out (Tables 7 and 8 and in Figures 9 and 10). The results are unambiguous and comparable to results obtained earlier. They illustrate that the profiles of the Biały Kamień Formation from the outcrop belt are for the most part representative for the whole unit and that grouping the facies, which was necessary for statistical analysis, did not change their modal sequence.

All analyses of the vertical facies transitions in the Biały Kamień Formation confirm the trend towards the generation of asymmetrical cyclic fining-up sequences with a distinct tendency towards oscillation. Two facies groups dominate: conglomerate and sandstone facies represent channel sediments, and the fine-grained facies – silts, shales and coals – represent overbank sediments (Tables 1 and 2) (Allen, 1964; Allen, 1965).

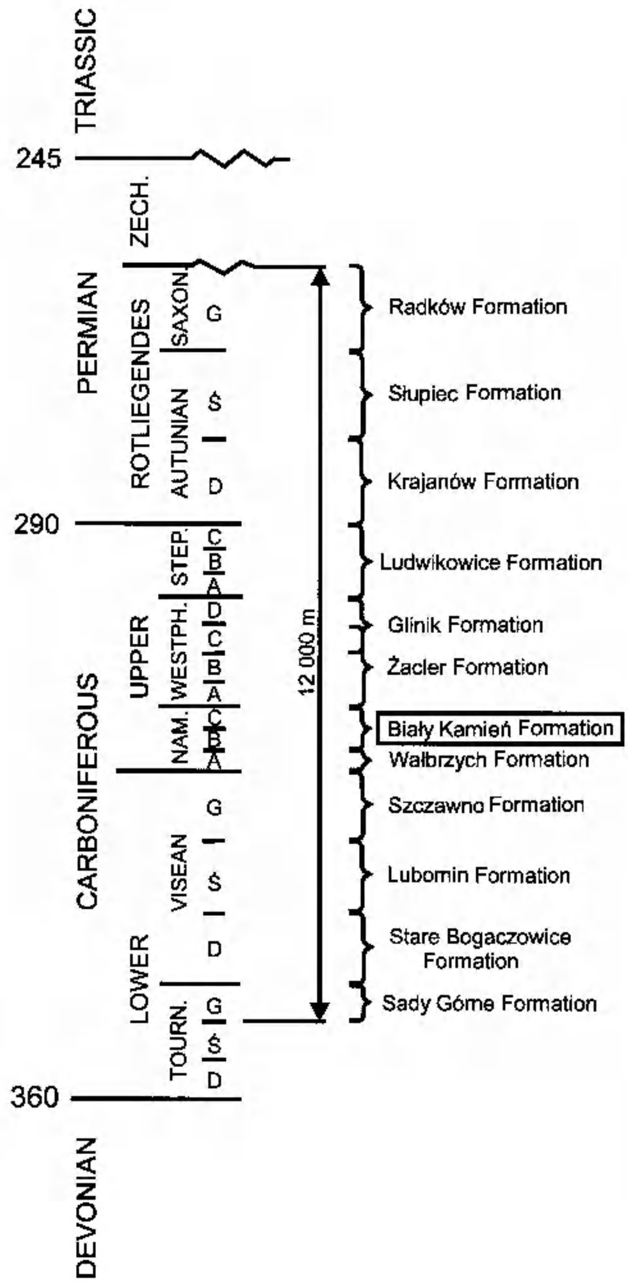


Fig. 2. Stratigraphic scheme for Carboniferous and Permian of the Intra-Sudetic Basin (Nemec *et al.*, 1982; Odin *et al.*, 1982).

FACIES ARCHITECTURE

The dominance of channel sediments in the Biały Kamień Formation (facies assemblages G and S – Table 1) and the rarity of overbank sediments (facies assemblages F and C – Table 1) suggest either a low rate of sediment aggradation outside channels, or erosion due to lateral migration of channel tracts. These relatively simple channel sequence produced with an oscillating type of facies transition is characteristic for a braided river environment. The considerable mobility of the channel tract also meant that the position of the overbank sediments is not as constant as is the case with typical meandering river sediment sequences.

Table 2

Simplified scheme of the facies distinguished (column 2) as well as converted classic (column 4) and mine's (column 5) classifications

N	Facies association	Interpretation	Miall's (1978) facies analogues	Simplified scheme of the mine's name
1	2	3	4	5
1	A	Channel lag	Gm, Gc	Conglomerates and conglomeratic sandstones Zl
2	B	Inner bar deposits and minor channel fills	Gp, Gt	
3	C	Topmost parts of the channel bars and minor channel fills	Sh, Sp, St, Sr (*)	Sandstones Pc
4	D	Levee and adjacent flood plain area deposits	Sr, Sr/Fl, Fh (*)	Sandstone shales Łp
5	E	Flood plain deposits	Fm, P, C (*)	Clay shales and coals Łi+W

(*) – including Stigmaria soils

Table 3

Matrix of the observed minus random transitions for all transitions distinguished in outcrops (simplified facies scheme applied)

	A	B	C	D	E
A		+0.06	+0.15	- 0.15	- 0.06
B	- 0.04		+0.12	- 0.06	- 0.02
C	+0.15	- 0.13		+0.05	- 0.06
D	- 0.26	- 0.04	- 0.03		+0.33
E	+0.07	- 0.05	- 0.37	+0.35	

Table 4

Value of the "Z" statistics based on all transitions distinguished in outcrops (simplified facies scheme applied)

	A	B	C	D	E
A		1.63	3.09		
B			1.39		
C	2.91			1.37	
D					8.32
E	0.48				

River channel subenvironment

Massive conglomerates and conglomeratic sandstones (lithofacies Gm and Gc), make up a considerable part of the channel facies sequence (Table 1, column 7). Their deposition was brought about as a result of stream loading

Table 5

Matrix of the observed minus random transitions for all transitions distinguished in outcrops (mine's facies scheme applied)

	Zl	Pc	Łp	Łi+W
Zl		+0.25	0 0.18	– 0.07
Pc	+0.08		0	– 0.08
Łp	– 0.21	– 0.11		+0.32
Łi+W	+0.12	– 0.45	+0.33	

Table 6

Value of the "Z" statistics based on all transitions distinguished in outcrops (mine's facies scheme applied)

	Zl	Pc	Łp	Łi+W
Zl		5.34		
Pc	1.82			
Łp				7.32
Łi+W	0.75		3.40	

Table 7

Matrix of the observed minus random transitions for mine pits (mine's facies scheme applied)

	Zl	Pc	Łp	Łi+W
Zl		+0.20	– 0.06	– 0.01
Pc	+0.10		– 0.04	– 0.06
Łp	– 0.25	– 0.22		+0.47
Łi+W	– 0.17	+0.07	+0.10	

Table 8

Value of the "Z" statistics based on all transitions distinguished in outcrops (mine's facies scheme applied)

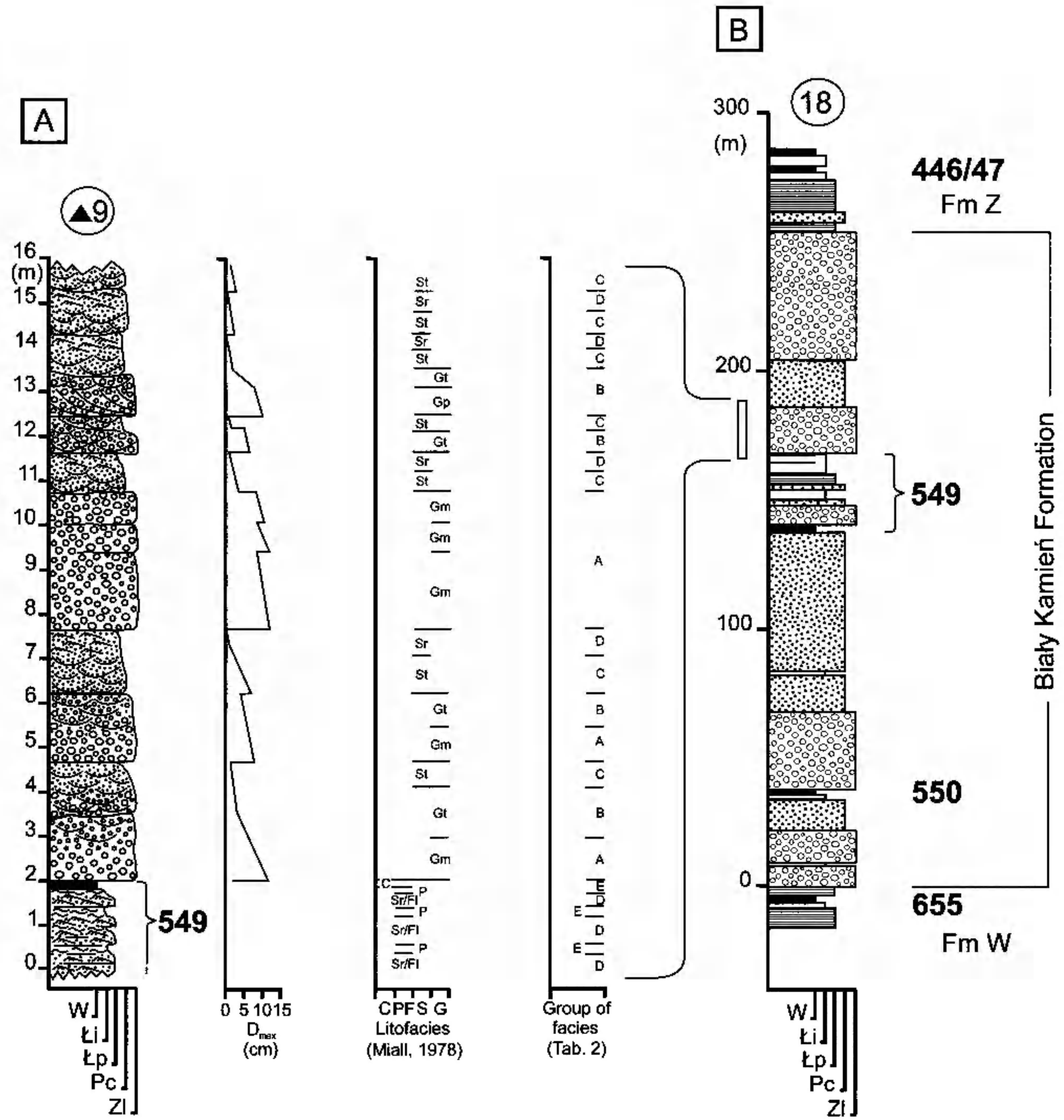
	Zl	Pc	Łp	Łi+W
Zl		14.0		
Pc	6.5			
Łp				16.7
Łi+W		2.4	6.3	

during a period of intensive sediment transport under full stage channel conditions. During "normal" flow, coarse-grained material was transported and deposited in the deeper parts of the channel as dunes. This resulted in the formation of trough cross-bedded conglomerates (lithofacies Gt). Under low stage conditions, the sand and gravel material was deposited under plane beds or dunes (lithofacies Sh and St – Table 1). Large fragments of plant trunks and stems were transported in the deeper parts of channels and locally buried in the sediment to become transformed into large coal phytoclasts (Mastalerz & Mastalerz, 1984).

In-channel gravel bars were also a significant morphological element of the channel subenvironment of the Biały Kamień Formation (cf. Smith, 1970; Rust, 1972; Rust, 1978; Hein & Walker, 1977). These were most often elongated, having developed from aggregations of gravel on the river bed. The initial accumulation of the coarsest material (lithofacies Gm) formed the nuclei of larger bars (Hein & Walker, 1977). They formed under full stage conditions of intensive sediment aggradation, and grew both laterally and parallel to the channel axis. Such gravel bar development gave rise to planar cross-bedded conglomerate sets (lithofacies Gp). In periods of stabilised flow, gravel and then sand was transported over the surface of the bars as dunes and sometimes ripples. Trough cross-bedded conglomerates and sandstones (lithofacies Gt and St, and less commonly Sr – Table 1, column 7) were formed probably as a result of material overload on the slopes of the bars. As the river waters fell, the surfaces of the bars became cut by numerous ephemeral channels which were quickly infilled (lithofacies Gt, Gp, St). In parts of the channel which were cut off for short periods of time, calm conditions promoted the sedimentation of the finest sediment from suspension or from weak currents (lithofacies Sr/Fl, Fh – Table 1). Other channels functioned for longer periods. At their mouths, sand aggraded in the form of microdelta-type bars, with characteristic planar cross-bedding (lithofacies Sp). On the surfaces of the bars there were redeposited peat clasts, later preserved in the form of thin browncoal interlayers. Other larger bars probably became longer-lived alluvial islands, becoming overgrown with plants. Some of the thin coal-mudstone interlayers found among the channel sediments are likely to have had their origin as autochthonous aggregations of plant remains.

Floodplain subenvironment

Thin interlayers of sandstone and mudstone, the character of which fits that of levee sediments of a typical meandering river environment (lithofacies Sr/Fl – Table 1), are the most common overbank sediments present. They separate the in-channel conglomerates and sandstones from the fine-grained and phytogenic sediments of the floodplain. Their heterolithic structure indicates varying hydrodynamic conditions during deposition. They are often cut by crevasse channels. Beyond the levees, horizontally laminated mudstones were deposited by very weak currents. These mudstones fit lithofacies Fh and can be related to the proximal part of a floodplain (Tab. 1). Sequences of these laminated mudstones are commonly divided by sandstone packages, usually showing erosive boundaries rimmed with gravel. They are characterized by sedimentary structures (lithofacies Sh, St, Sr) indicative of falling currents, interpreted as crevasse splay sediments (Tab. 1). In the distal part of the floodplain, the finest grained suspended part of the sediment was deposited in the form of massive mudstones and claystones (lithofacies Fm and P), which were often colonised by plants. The penetrative action of the root systems of these plants erased the primary sedimentary structures, giving rise to palaeosoils (Tab. 1). Plant life was also abundant over crevasse splays, and probably invaded locally channel areas, growing on the surfaces of the larger bars (lithofacies Fr). In this way, the large amount of phytogenic material present led to the development of bogs which were transformed with time into browncoal layers (lithofacies C –



W - coal
Łi - mudstones and shales
Łp - sandy shales
Pc - sandstones
Zl - conglomerates
550 - number of coal-seam
FmW - Wałbrzych Formation
FmZ - Żacler Formation

Fig. 3. Graphic logs of Biały Kamień Formation sediments: a railway cutting near Bialy Kamień (A) and an archival profile from "Thorez" mine, "Jan" pit (B).

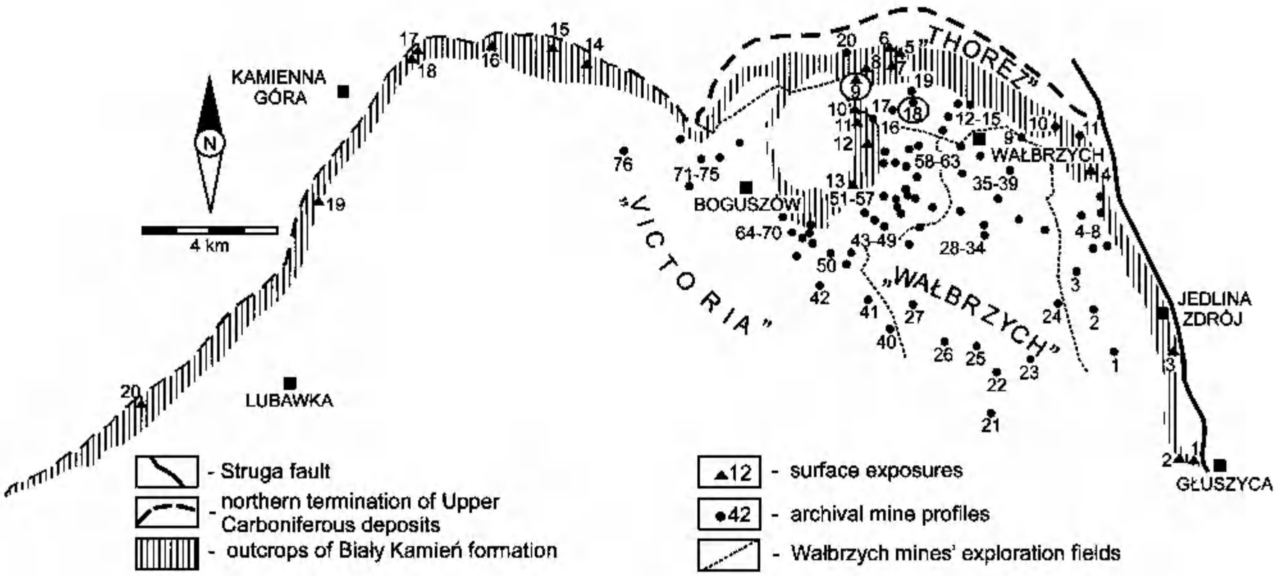


Fig. 4. Location scheme of the Biały Kamień Formation outcrops (Kurowski, 1995) and archival profiles of the Wałbrzych coal mines pits.

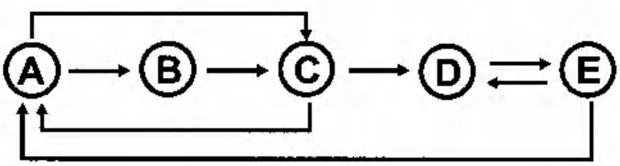


Fig. 5. Preferred facies transitions based on observed minus random transition probabilities (Tab. 3).

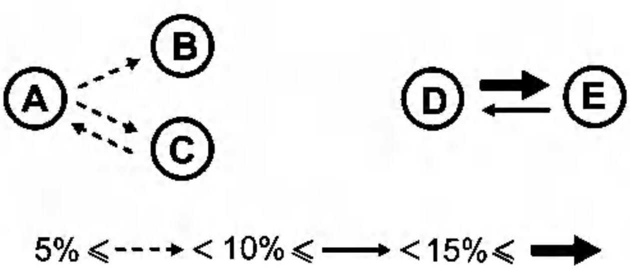


Fig. 6. Preferred facies transitions based on "Z" statistics (Tab. 4).

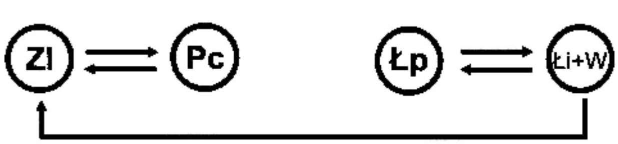


Fig. 7. Preferred facies transitions based on observed minus random transition probabilities (Tab. 5).

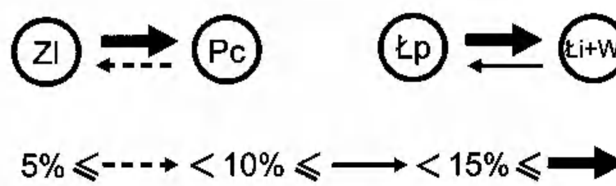


Fig. 8. Preferred facies transitions based on "Z" statistics (Tab. 6).

Fig. 9. Preferred facies transitions based on observed minus random transition probabilities (Tab. 7).

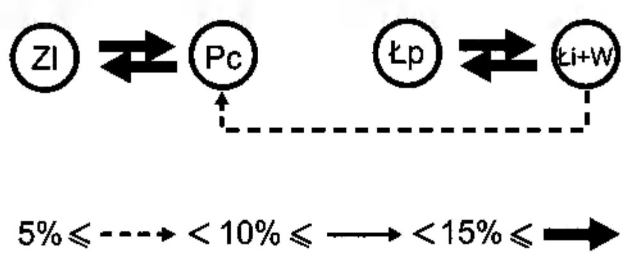


Fig. 10. Preferred facies transitions based on "Z" statistics (Tab. 8).

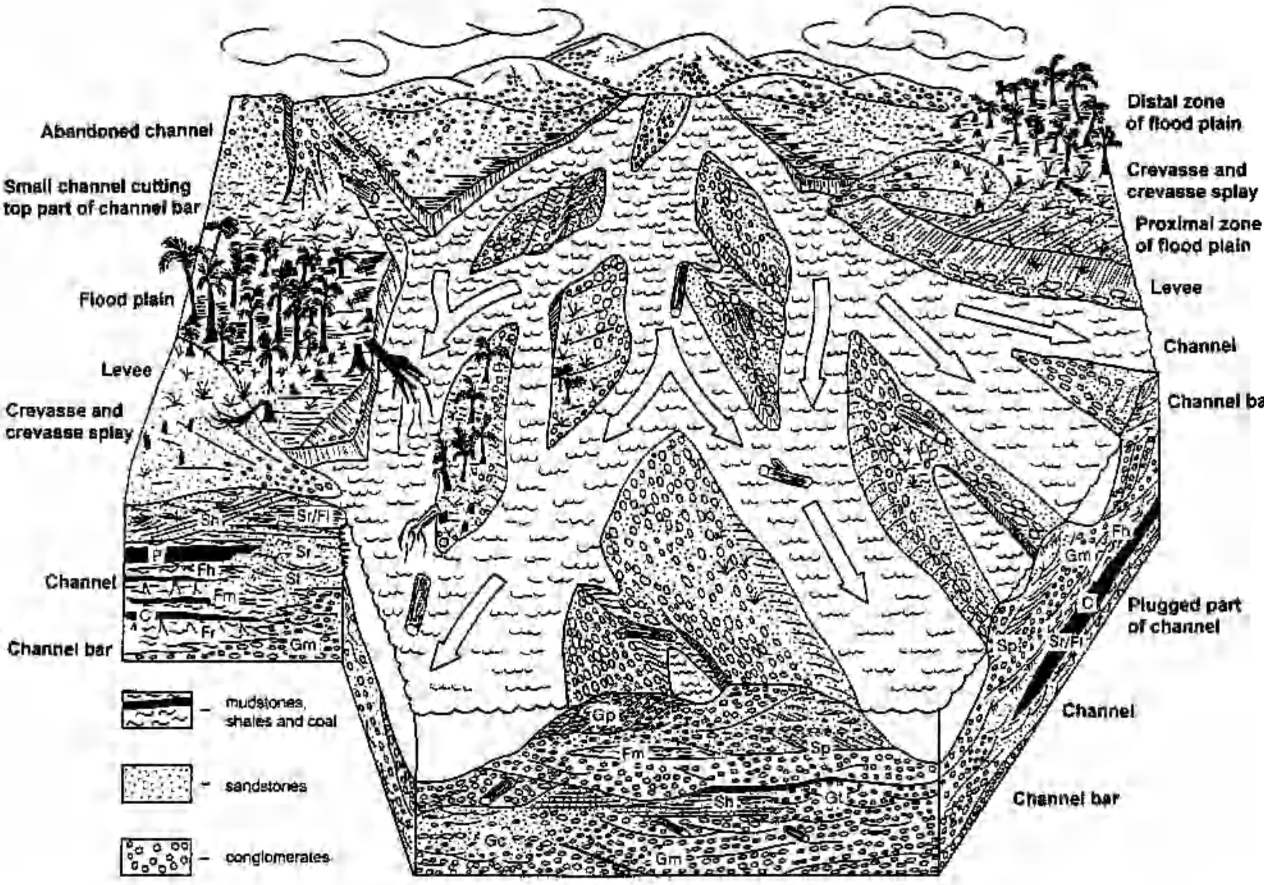


Fig. 11. Sedimentary-environmental model of the Biały Kamień Formation showing dominant facies relationships (for facies symbols see Table 1).

Tab. 1). Figure 11 shows a model illustrating the sedimentary environment (facies architecture) of the Biały Kamień Formation.

SUMMARY AND CONCLUSIONS

The Biały Kamień Formation represents sediments of diversified facies. A Markovian embedded chains analysis of the vertical facies transitions (Krumbein & Dacey, 1969; Nemec, 1981), revealed cyclical fining-up sequences with a tendency toward oscillation within a given sequence. The oscillations are present within the medium and coarse-grained sediments and within the fine-grained sediments, though transitions between these two facies groups are not statistically significant. This leads to a division of the modal sequence into two facies groups, representing sediments from two fluvial sedimentary subenvironments. The conglomerate and sandstone facies represent channel sediments, while the fine-grained facies - silts, shales and coals - represent floodplain sediments (Allen, 1964; Allen, 1965). The asymmetry in the distribution of the facies in favour of in-channel sediments indicates deposition of the Biały Kamień Formation in a braided gravel-bed river environment, possibly conforming to Miall's (1978) braided river GII and GIII type facies.

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