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Sedimentary history of a Mississippian to Pennsylvanian coal-bearing succession: an example from the Upper Silesia Coal Basin, Poland

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Abstract – The coal-bearing succession of the Upper Silesia Coal Basin consists of deposits filling a flexural foredeep basin. Accumulation initially compensated for regional and differentiated subsidence, after which the general depositional surface remained nearly flat. The deposition of the coal-bearing succession started at the end of Mississippian times (Pendleian Subage) and continued with hiatuses through almost the whole of Pennsylvanian times, and stopped in the Westphalian D Subage. The up to 8500 m thick coal-bearing succession traditionally has been divided into four main units called 'Series', and all of them are subdivided into subsidiary units known as 'Beds'. The occurrence of the intervals containing marine faunas within the lower 'Paralic' part of the coal-bearing succession resulted from eustatic ingressions. The higher 'Limnic' part of the succession was laid down in fluvial systems, while the lower part was formed mostly in a fluvial and, to a lesser extent, complex coastal system. Sedimentation of the coal-bearing succession was controlled by both autogenic and allogenic factors.

Keywords: Carboniferous, Upper Silesia, sedimentology, coal petrography.

1. Introduction

The Upper Silesia Coal Basin, located in southwestern Poland and the northeastern Czech Republic (Fig. 1), is the largest coal basin in Europe, with a total area of about 7400 km^2. The basin has a triangular shape, being bounded on its western side by overthrust Devonian to Mississippian sediments of the Moravo-Silesian fold-zone, and to the north by the Lubliniec–Kraków tectonic zone. Its southern limits have been identified based on records from deep boreholes of the Carboniferous coal-bearing strata below Miocene deposits and nappes of the Outer Carpathians. The Upper Silesia Coal Basin was part of a larger sedimentary basin located in a foreland position in front of the Moravo-Silesian orogen during Late Palaeozoic times. Some typical features for flexural foredeep basins have been observed (Gradziński, 1982): (1) a general decrease in the rate of subsidence and a gradual eastwards shift of the zone of maximum subsidence (the opposite direction to the overthrusted Moravo-Silesian sediments), (2) a general transport direction parallel to the front of the orogen, (3) stronger tectonic deformation adjacent to the orogen, and (4) cannibalism of parts of the previously deposited sediments.

The coal-bearing succession of the Upper Silesia Coal Basin has a very long and complicated sedimentary history. It started at the end of Mississippian times (Pendleian Subage) and continued with sedimentary breaks through almost the whole of Pennsylvanian times, ultimately stopping in the Westphalian D Subage. The stratigraphy has been established mostly using macro- and microfloras. Faunas are relatively rare and comprise mostly pelecypods and subsidiary foraminifers, gastropods and cephalopods (Bojkowski, 1972). These sets of data allow the recognition of several stages and stratigraphical gaps between them.

The Upper Silesia Coal Basin appears to have been an integral part of the Variscan Foreland paralic basin-complex, which also includes the coal basins of northern Germany, the Lowlands, northern France and Britain. Unlike these other coal basins to the west, there is no evidence of marine deposits in the Westphalian part of the Upper Silesia succession, but this probably reflects the more marginal position of the basin. Understanding the geological evolution of the Upper Silesia Coal Basin is thus critical to evaluating the overall history of the Variscan Foreland as a major terrestrial habitat in Late Carboniferous times. Although there has been considerable research on the coalfield over the last half-century, the results have been largely published in Polish. The present paper will summarize the most recent work and present a synthesis of the sedimentary history of the Upper Silesia Coal Basin, allowing it to be viewed in its wider palaeogeographical context.

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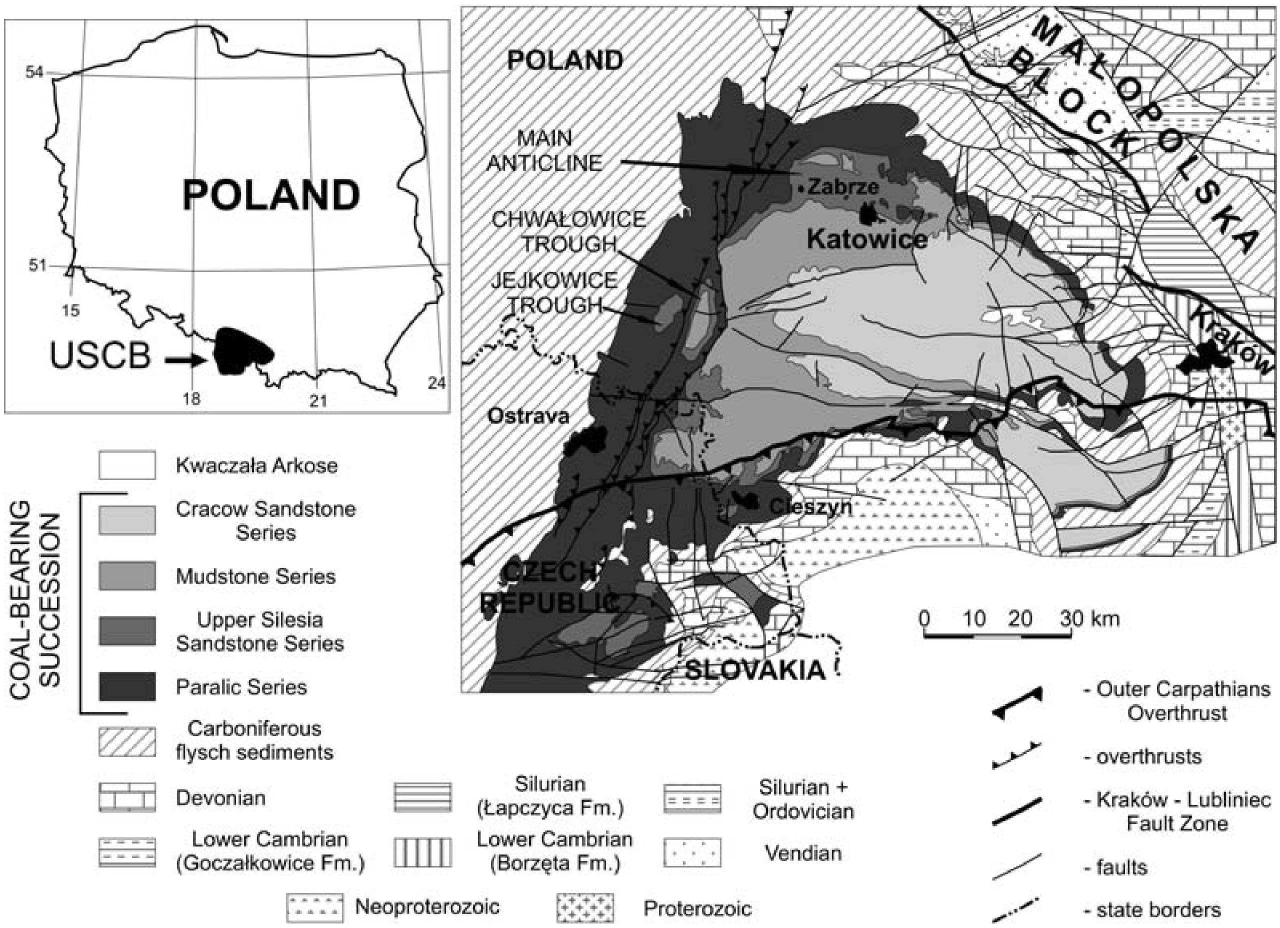

Figure 1. Simplified geological sketch map, after Buła & Żaba (2005). Inset map shows the general geographical location of the basin in southern Poland. USCB – Upper Silesia Coal Basin.

2. Lithostratigraphy

The up to 8500 m thick coal-bearing succession, characterized by repeating lithosomes of sandstone, mudstone and coal seams, and with a virtual lack of limestones, has been subdivided into two parts (Dembowski, 1972*a*). The older one, called 'Paralic', contains interbeds with marine and brackish faunas. The occurrence of intervals with marine faunas resulted from repeating eustatic marine ingressions and regressions (Doktor & Gradziński, 1999). The younger 'Limnic' part lacks these marine intervals and has been deposited in a continental setting. Traditionally, this succession has been divided into four main informal lithostratigraphical units called 'Series', and all of them are subdivided into subsidiary units known as 'Beds' (Fig. 2).

In the western part of the Upper Silesia Coal Basin, the Paralic Series is subdivided into four units: (1) Petřkovice Beds, (2) Hrušov Beds, (3) Jaklovec Beds and (4) Poruba Beds. The lithostratigraphy of the eastern part is slightly different due to the reduced number of intervals with marine faunas. The Sarnów Beds and Flora Beds are approximately the equivalent of the Petřkovice Beds and Hrušov Beds, respectively. The Grodziec Beds correspond with the next two units of the Paralic Series, that is, the Jaklovec and Poruba beds (Kotas & Malczyk, 1972*a*). The upper part of the coal-bearing succession is subdivided into three series: (1) the Upper Silesia Sandstone Series consisting of the Jejkowice Beds, Zabrze Beds and Ruda Beds, (2) the Mudstone Series consisting of the Załęże Beds and Orzesze Beds, and (3) the Cracow Sandstone Series, which comprises the Łaziska Beds and Libiąż Beds. The coal-bearing succession is overlain by Kwaczała Arkose, which lacks coal seams (Siedlecki, 1951). A characteristic feature of this upper part of the coal-bearing succession is an onlap arrangement of the elements of the Upper Silesia Coal Basin.

The distinct tripartite division of the succession's continental stage was caused mainly by allogenic factors. Development of the intervals dominated by coarse-grained deposits (the Upper Silesia Sandstone and Cracow Sandstone series) was the result of increasing supply of the clastic material due to tectonic movement in the source areas. Significant lateral and vertical variability on both regional and local scales of the clastic and phytogenic sediments was controlled mainly by autogenic phenomena (Doktor & Gradziński, 2000).

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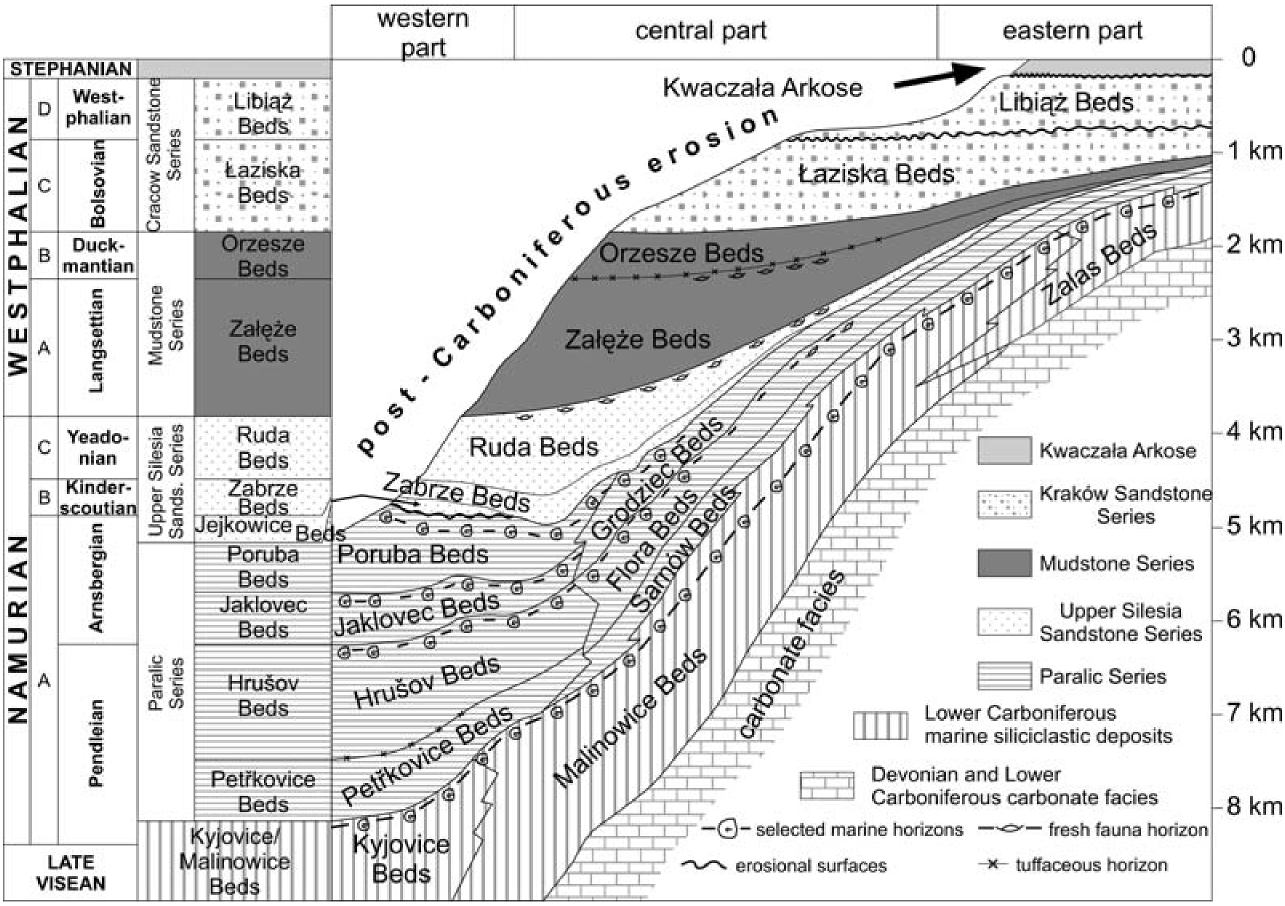

Figure 2. Stratigraphical cross-section through Upper Silesia Coal Basin infill, showing the age, reconstructed distribution and thickness of the main lithostratigraphical units, modified after Kotas (1994).

3. Sedimentary history

3.a. Paralic Series

Deposits of the Paralic Series represent two of the youngest substages of the Mississippian. The Petřkovice Beds and Hrušov Beds (and their counterparts from the eastern part of the basin) belong to the Pendleian Substage, while the Jaklovec Beds and Poruba Beds (Grodziec Beds) are Arnsbergian in age. The frequent occurrence of faunas within the fine-grained sediments has allowed correlative horizons to be identified, which can be traced across almost the entire Upper Silesia Coal Basin. These faunal horizons help divide the Paralic Series into beds. The deposits of the Paralic Series were deposited in fluvial and complex coastal systems (Fig. 3). Within this depositional system, numerous subenvironments have been recognized, linked with deltas and ‘open sea’ (Doktor & Gradziński, 1999). The top of the Štur Marine Band marks the lower boundary of the Paralic Series. The upper boundary of this series is situated at the bottom of the 510 coal seam. The total thickness of the Paralic Series reaches nearly 3800 m and decreases eastward to about 200 m.

The Paralic Series consists mainly of fine-grained sediments (up to 70 % in the Petřkovice Beds), sandstones and coal seams (Kotas & Malczyk, 1972*a*).

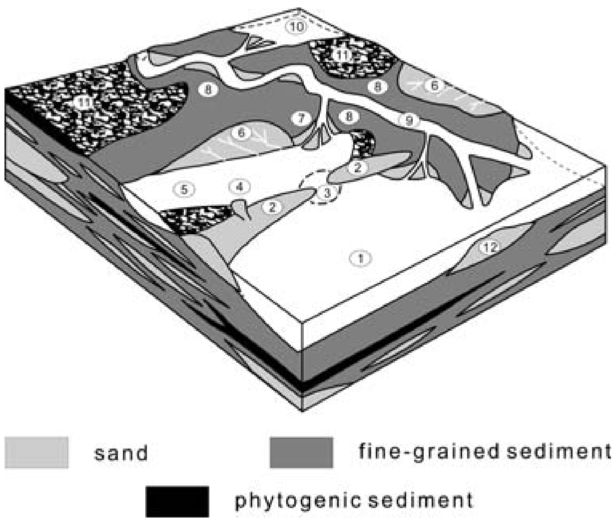

Figure 3. Synthetic facies model of the Paralic Series, showing depositional environments and their deposits (from Gradziński, Doktor & Kędzior, 2005). The block-diagram is not drawn to scale. 1 – sea, 2 – barrier, 3 – tidal delta, 4 – washover fan, 5 – lagoon, 6 – tidal flat, 7 – crevasse delta, 8 – natural levee, 9 – main distributary channel, 10 – bay, 11 – peat bog, 12 – delta mouth bar.

Sandstones usually consist of packages a few metres thick, but in some cases can make prominent stacks (up to 30 m) genetically linked with barriers, delta

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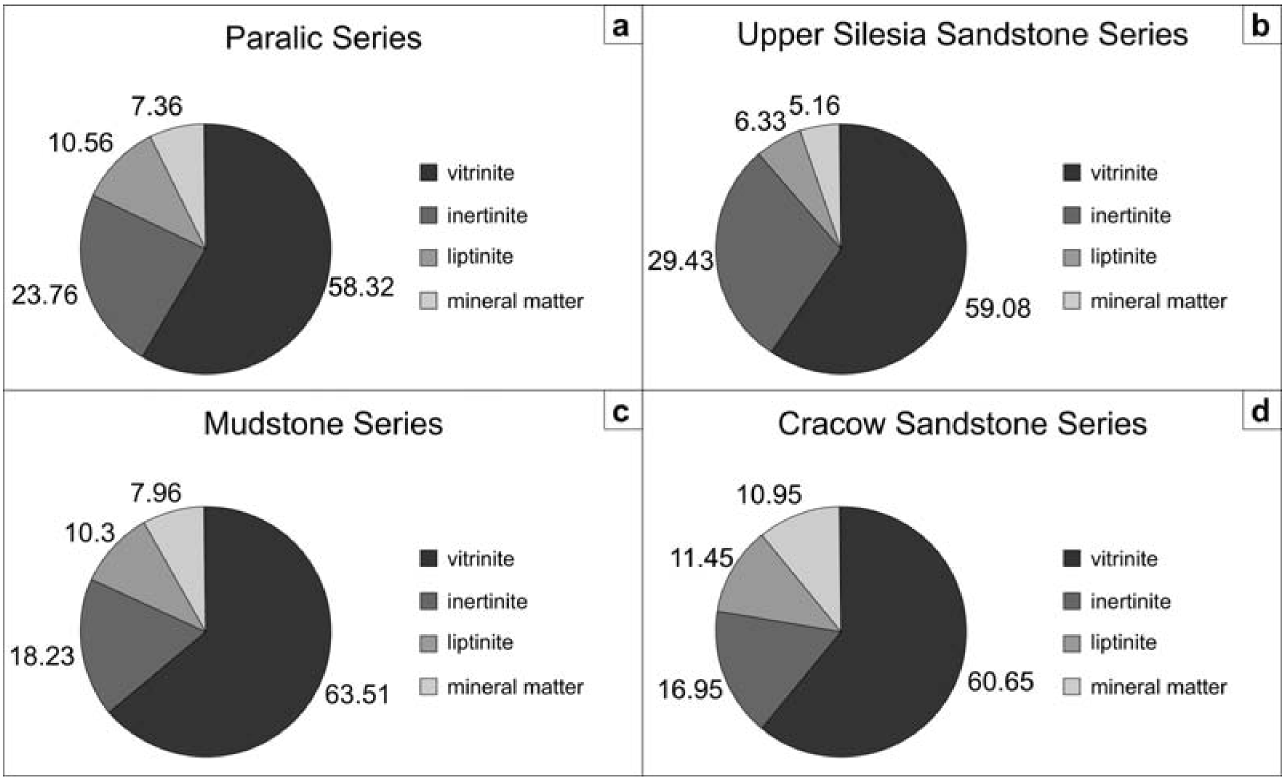

Figure 4. Mean maceral-groups content (in %) for the four main lithostratigraphical units of the Upper Silesia Coal Basin (according to Jurczak-Drabek, 2000).

mouth bars or fluvial channels (Doktor & Gradziński, 1999). Conglomerates and tufogenic sediments only appear subordinately. Coal seams within the Paralic Series are usually thin, only sporadically reaching more than 1.5 m. Macroscopically, they are dominated by bright mixed lithotypes (vitrino-clarine, durino-clarine, clarino-vitrine). In the microscopic composition of the coals, the vitrinite group prevails (58 %); with inertinite 24 % and liptinite 11 % (Jurczak-Drabek, 1996, 2000). Mineral matter does not exceed 7 % (Fig. 4a).

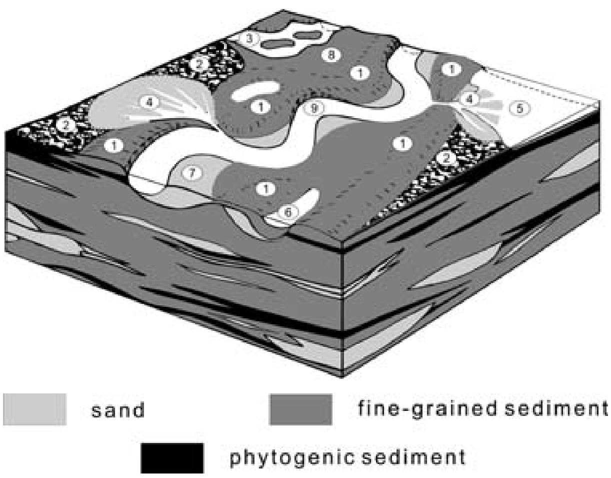

Figure 5. Synthetic facies model of the Mudstone Series, showing depositional environments and their deposits (Gradziński, Doktor & Kędzior, 2005). The block-diagram is not drawn to scale. 1 – natural levee, 2 – peat bog, 3 – anastomosing river, 4 – crevasse splay, 5 – flood basin, 6 – oxbow, 7 – point bar, 8 – floodplain, 9 – meandering river.

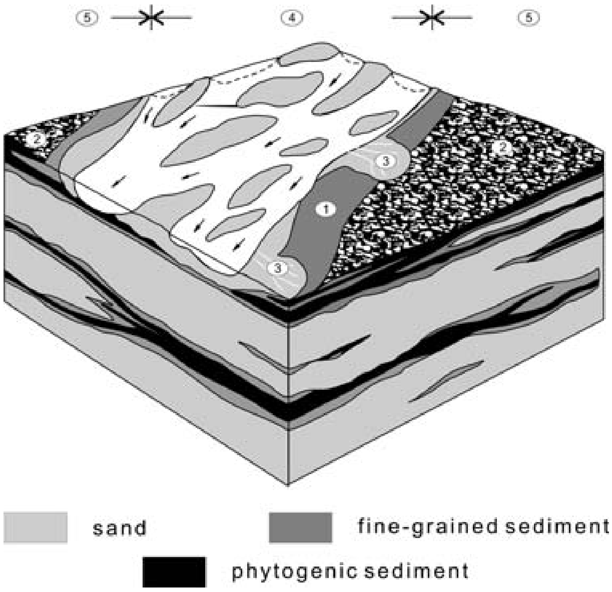

Figure 6. Synthetic facies model of the Cracow Sandstone Series, showing depositional environments and their deposits (Gradziński, Doktor & Kędzior, 2005). The block-diagram is not drawn to scale. 1 – natural levee, 2 – peat bog, 3 – crevasse splay, 4 – braided channel belt, 5 – overbank area.

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Sub-system	Stage	Sub-stage	Regional units			Lithologies	Important horizons	Thickness		Sedimentary environments	Coal petrography	
MISSISSIPPIAN	NAMURIAN	Arnsbergian	Poruba Beds	Grodziec Beds	PARALIC SERIES	Mainly claystones and siltstones, in some parts of the basin occur up to 40 m thick packages of sandstone and conglomerates (Zamek Conglomerates). More than 80 coal seams (0.1-3.7 m thick) and 45 mineable	Roemer (Ib) marine band (top) Barbara marine band (bottom)	1.1 km	400 m	Coastal plain, fluvial and deltaic system	*Main lithotypes: vitrino-clarine durino-clarine clarino-vitrine clarino-durine. Remaining constitute less than 3%*[a] Vitrinite group: 58.3% colinite[b]: 97.9% telinite[b]: 2.1% Inertinite group: 23.8% sporinite[b]: 88.7% cutinite[b]: 80.1% resinite[b]: 3.2% Liptinite group: 10.6% fusinite[b]: 24.2% semifusinite[b]: 36.1% micrinite[b]: 9.2% macrinite[b]: 3.5% sclerotinite[b]: 2.3% inertodetrinite[b]: 24.7% Mineral matter: 7.3%	*clarino-vitrine vitrino-clarine dominating in the lowermost and uppermost part of the section; durino-clarine clarino-durine in the middle part*[a]
			Jaklovec Beds			Mainly siltstone and claystone, relatively high content of sandstones (up to 42%). In eastern part of USCB occur thick packages of sandstone (30-60 m) More than 30 coal seams (0.1-3.7 m thick)		380 m		Coastal plain, fluvial and deltaic system		*vitrino-clarine; clarino-vitrine* Vitrinite group: 68% Liptinite group: 16% Inertinite group: 16%[a]
		Pendleian	Hrušov Beds	Flora Beds		Mainly siltstone and claystone, relatively high content of sandstones (up to 48%). About 100 coal seams (mineable only few)	Enna marine band (top) Whetstone horizon (at the bottom of the Hrušov Beds)	1.3 km	400 m	Coastal plain, fluvial and deltaic system		
			Petřkovice Beds	Sarnów Beds		Mainly claystones and siltstones, in some parts of the basin occur up to 80 m thick packages of sandstone. 8-10 thin (~0.3 m) coal seams	Nannette marine band (top)	800 m	200 m	Coastal plain, fluvial and deltaic system		
			Kyjovice Beds (upper part)	Malinowice Beds (upper part)		Mainly clayey shales with subordinate amount of sandstones, rare stigmarian soils and dispersed thin coal seams	Štur marine band (at the top of the Kyjovice Beds)	1.5 - 1.2 km (whole unit)	1.1 - 0.9 km (whole unit)	Flysch (pseudomolasse)	*Main lithotypes: vitrino-clarine, durino-clarine, clarino-vitrine, durine. Remaining constitute less than 3%*[a] Vitrinite group: 48.7% Inertinite group: 26.5% Liptinite group: 10.5% Mineral matter: 14.3%	

Figure 7. The main features of the Paralic Series. Coal petrography data based on (a) Knafel (1983) and (b) Jurczak-Drabek (A. Jurczak-Drabek, unpub. Ph.D. thesis, Polish Geological Inst., 1997).

3.b. Upper Silesia Sandstone Series

The continental stage of the basin infill begins with the accumulation of the Upper Silesia Sandstone Series. Deposition was preceded by regional erosion. This stratigraphical gap spans two of the oldest substages of the Pennsylvanian Subsystem and is documented by a floristic break. The Upper Silesia Sandstone Series is composed of the Jejkowice Beds (only in the southwestern part of the basin), Zabrze Beds and Ruda Beds (Kotas & Malczyk, 1972*b*; Kotas, 1995). The Jejkowice Beds constitute the uppermost part of the Arnsbergian Substage, while the Zabrze Beds belong to the Kinderscoutian Substage. The next stratigraphical gap, spanning the whole of the Marsdenian Substage, separates the Zabrze and Ruda beds, which represent the Yeadonian Substage. The Upper Silesia Sandstone Series, like the other continental series of the Upper Silesia Coal Basin, is characterized by a scarcity of widespread correlative horizons; only three can be distinguished: the No. 510 and No. 501 coal seams, and the fresh-water fauna horizon at the top of the Ruda Beds. The base of the Upper Silesia Sandstone Series is placed at the bottom of the widespread No. 510 coal seam. The upper boundary is situated at the top of the aforementioned fresh-water fauna horizon.

The deposits of the Upper Silesia Sandstone Series were accumulated on a wide alluvial plain constructed by a braided and meandering fluvial system (Kędzior *et al.* 2004). The maximum thickness of this unit reaches 1200 m and wedges out eastward. The series mainly consist of sandstones (up to 95 % in the Jejkowice Beds), fine-grained sediments (mudstone and siltstone) and coal seams. The Jejkowice Beds and Zabrze Beds in the southwestern part of the basin contain packages of coarse-grained deposits up to 100 m thick. Similar stacks are present at the bottom of the Ruda Beds in the Main Anticline area. Generally, sandstone content decreases upward, and close to the upper boundary of the series, coarse-grained sediments

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Sub-system	Stage	Sub-stage	Regional units		Lithologies	Important horizons	Thickness	Sedimentary environments	Coal petrography	
PENNSYLVANIAN	NAMURIAN	Yeadonian	Ruda Beds	UPPER SILESIA SANDSTONE SERIES	Lower part of this unit contains thick sandstone packages (up to 80 m), gradually passing into more and more fine-grained deposits. Numerous thick coal seams (up to 8 m), but laterally unstable	Hubert fresh-water fauna horizon (top)	800 m in western part and wedge out in the eastern part of the basin	Braided to meandering fluvial system	*Main lithotypes: vitrino-clarine clarino-vitrine durino-clarine clarino-durine. Remaining constitute less than 4%*[a] Vitrinite group: 59.1% colinite[b]: 98.7% telinite[b]: 1.3% Inertinite group: 29.4% sporinite[b]: 93.3% cutinite[b]: 3% resinite[b]: 3.7% Liptinite group: 7.9% fusinite[b]: 12.1% semifusinite[b]: 40.1% micrinite[b]: 20.2% macrinite[b]: 4.6% sclerotinite[b]: 2.7% inertodetrinite[b]: 20.2% Mineral matter: 5.5%	*clarino-vitrine vitrino-clarine decreasing of durino-clarine clarino-durine*[a]. Increasing number of the clastic intercalations (coal shales, claystones)
		Mars-denian	GAP?		STRATIGRAPHICAL GAP?					GAP?
		Kinderscoutian	Zabrze Beds		Mainly fine- to medium-grained sandstones. In SW part of the basin thick (up to 100 m) packages of coarse-grained sandstones and conglomerates. In northern part occurs greater amount of fines (mainly siltstones and mudstones). Thick (up to 24 m) coal seams, almost all are economically important	Coal seam N° 501 (top) Coal seam N° 510 (bottom)	250 m in western part and wedge out in the eastern part of the basin	Braided to meandering fluvial system		*Main lithotypes: vitrino-clarine durino-clarine clarino-vitrine clarino-durine.* Domination of the vitrinite group. The highest content of inertinite in comparison with other units[a]
		Alportian/ Chokerian	STRATIGRAPHICAL GAP?		STRATIGRAPHICAL GAP					GAP
MISSISSIPPIAN		Arnsbergian	Jejkowice Beds (only in SW part of the basin)		Mainly medium- to coarse-grained sandstones with conglomerates. Rare and relatively thin intercalations of siltstones and mudstones. Lack of widespread and thick coal seams	Erosional surface (bottom)	150 m	Braided rivers (alluvial fan?)		Lack of the coal seams

Figure 8. The main features of the Upper Silesia Sandstone Series. Coal petrography data based on (a) Knafel (1983) and (b) Jurczak-Drabek (unpub. Ph.D. thesis, Polish Geological Inst., 1997).

constitute less than 15%. Phytogenic material constitutes up to 10% of the total thickness of the whole series and includes very thick coal seams (usually several metres thick, up to 24 m). Macroscopically, the coals are dominated by bright mixed lithotypes (vitrino-clarine and clarino-vitrine). Under the microscope, macerals of the vitrinite group prevail (58%), with inertinite 28% and liptinite 8% (Jurczak-Drabek, 1996, 2000). Mineral-matter content does not exceed 6% (Fig. 4b).

3.c. Mudstone Series

The Mudstone Series is in sedimentary continuity with the upper part of the Upper Silesia Sandstone Series. The lower boundary of the Mudstone Series is arbitrarily placed at the top of the fresh-water fauna horizon. In the eastern part of the basin, where the Upper Silesia Sandstone Series is absent and the Mudstone Series overlaps different units of the Paralic Series (see Fig. 2), this boundary is marked by a stratigraphical unconformity (Porzycki, 1972). The top of the Mudstone Series is marked by a sharp lithological change and is placed at the bottom of the thick sandstone packages. The Mudstone Series consists of two units: the Załęże Beds (ascribed to the Langsettian Substage) and the Orzesze Beds (which represent the Duckmantian Substage). This subdivision was possible due to presence of a key tuffite horizon. The Mudstone Series also includes a correlative fresh-water fauna horizon. Both of these horizons are not present everywhere, thus distinguishing the Załęże and Orzesze beds is not always obvious. The maximum thickness of the Mudstone Series reaches 2000 m, decreasing eastward to 150 m. The Mudstone Series occupies the largest area compared with all the other continental coal-bearing units of the Upper Silesia Coal Basin.

The deposits of the Mudstone Series were accumulated on a wide alluvial plain of meandering and anastomosing river systems (Doktor & Gradziński, 1985) (Fig. 5). The characteristic feature of the Mudstone

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Sub-system	Stage	Sub-stage	Regional units		Lithologies	Important horizons	Thickness	Sedimentary environments	Coal petrography	
PENNSYLVANIAN	WESTPHALIAN	Duckmantian	Orzesze Beds	MUDSTONE SERIES	Mainly claystones and mudstones with abundant syderitic nodules. Subordinate amount of fine- to medium-grained sandstones. Rare conglomeratic layers (purely intraformational). Relatively high sandstone content close to lower boundary and decreasing upward. Numerous coal seams, usually thin and laterally unstable		~ 400 m in western part close to eastern margin - wedged up	Fluvial, meandering (probably anastomosing too). Ephemeral, shallow lakes	*Main lithotypes: vitrino-clarine clarino-vitrine durino-clarine clarino-durine. Remaining are insignificant*[a]. Vitrinite group: 63.5% colinite[b]: 97% telinite[b]: 3% Liptinite group: 10.3% sporinite[b]: 86% kutinite[b]: 8% resinite[b]: 6% Inertinite group: 18.2% fusinite[b]: 24% semifusinite[b]: 40% micrinite[b]: 10% macrinite[b]: 5% sclerotinite[b]: 3% inertodetrinite[b]: 18% Mineral matter: 8%	
		Langsettian	Załęże Beds		Mainly claystones and mudstones with abundant syderitic nodules. Subordinate amount of fine- to medium-grained sandstones. Rare conglomeratic layers (purely intraformational). Close to the upper boundary sandstone content increases, making thick (up to 40 m) packages. Numerous coal seams, usually thin and laterally unstable	Andrzej fresh-water horizon (Langsettian/ Duckmantian boundary) Tuffite horizon (top of this unit)	~ 1300 m in western part close to eastern margin - wedged up	Fluvial, meandering (probably anastomosing also). Ephemeral, shallow lakes		Main lithotypes: vitrino-clarine clarino-vitrine durino-clarine. Remaining are insignificant. The highest content of the vitrinite group in the coal-bearing succession. Intercalation of the sapropelic coals[a]

Figure 9. The main features of the Mudstone Series. Coal petrography data based on (a) Knafel (1983) and (b) Jurczak-Drabek (unpub. Ph.D. thesis, Polish Geological Inst., 1997).

Series is the prevalence of fine-grained deposits (up to 80 %) in lithological composition. Coarse-grained sediments (mainly fine- to medium-grained sandstones) constitute 20–30 %, and phytogenic material 3–5 %. Tufogenic sediments and conglomerates (purely intraformational) occur sporadically. The Mudstone Series contains 158 coal seams, 71 of which have an economic importance (Jureczka & Kotas, 1995). Macroscopically, the coals are dominated by bright mixed lithotypes (vitrino-clarine, clarino-vitrine and durino-clarine). In the microscopic composition of the coals, the vitrinite group prevails (64 %); the others (inertinite and liptinite) constitute 18 % and 10 %, respectively (Jurczak-Drabek, 1996; 2000). Mineral matter does not exceed 8 % (Fig. 4c).

3.d. Cracow Sandstone Series

The Cracow Sandstone Series terminates the coal-bearing succession of the Upper Silesia Coal Basin (Dembowski, 1972*b*). This unit is distinguishable by the prevalence of sandstone-forming thick lithosomes. The lower boundary of the Cracow Sandstone Series is placed at the bottom of the first, thick coarse-grained sandstone body. Regionally, this is a disconformity, which appears to be onlapped eastwards by younger strata. The upper boundary is hard to define due to the similarity of the upper part of the Cracow Sandstone Series with the overlying Kwaczała Arkose. This boundary is placed 180 m above the No. 110 coal seam (see Kotas, 1995). The Cracow Sandstone Series consists of two subunits: (1) the Łaziska Beds and (2) the Libiąż Beds. Lithologically, they are very similar to each other and the division between them is based on palaeobotanical grounds. The Cracow Sandstone Series spans the latest Duckmantian through to the Westphalian D. However, on the basis of the macrofloral evidence it is assumed that a stratigraphical gap separates the Łaziska and Libiąż beds, comprising most of the Bolsovian Substage and the lower Westphalian D Substage (Kotasowa & Migier, 1995; Kmiecik, 1995; Kotas, 1995). The maximum thickness of the Łaziska Beds reaches 1080 m (in the western part of the basin), whereas that of the Libiąż Beds is 560 m. Nowhere does the observed thickness of the Cracow Sandstone Series exceed 1100 m (Gradziński, Doktor & Słomka, 1995).

The sediments of the Cracow Sandstone Series were deposited within a braided fluvial system comprised of laterally coexisting channel tracts and floodplains. The latter were the sites of accumulation of both clastics and phytogenic material (Fig. 6). The Cracow Sandstone Series is dominated by coarse-grained deposits, which constitute 80–90 % of the unit's total thickness. The total content of the fine-grained deposits reaches up to 12 %, whereas that of the coal is 2.5–6.5 % (Gradziński, Doktor & Słomka, 1995). The Cracow Sandstone Series contains 38 coal seams, among which 26 have an economic importance (Jureczka & Kotas, 1995). Macroscopically, the petrographical composition of the

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<table>
<tr><th>Sub-system</th><th>Stage</th><th>Sub-stage</th><th colspan="2">Regional units</th><th>Lithologies</th><th>Important horizons</th><th>Thickness</th><th>Sedimentary environments</th><th>Coal petrography</th></tr>
<tr><td rowspan="7">PENNSYLVANIAN</td><td rowspan="3">STEPHANIAN</td><td>Stephanian B</td><td colspan="2">Kwaczała Arkose</td><td>Mainly poor consolidated coarse-grained arkosic sandstones and gravels with silicified tree trunks. Subordinate red and variegated mudstone interbeds depleted of plants remains. Lack of coal seams</td><td>Lack of the traceable horizons. Lower boundary appointed on the basis of occurrence red and variegated sediments</td><td>~ 400 m</td><td>Fluvial, distal sandy braided rivers</td><td>Lack of
coal seams</td></tr>
<tr><td>Barruelian</td><td colspan="2" rowspan="2">STRATIGRAPHICAL GAP?</td><td colspan="5" rowspan="2">STRATIGRAPHICAL GAP?</td></tr>
<tr><td>Cantabrian</td></tr>
<tr><td rowspan="4">WESTPHALIAN</td><td rowspan="2">Westphalian D</td><td>Libiąż Beds</td><td rowspan="4">CRACOW SANDSTONE SERIES</td><td>Mainly medium- and coarse-grained sandstones, subordinate conglomerates. Relatively thin packages of siltstones and mudstones usually contained up to 12 coal seams. Coal seams are thinner and distance between them becomes greater</td><td></td><td>~ 560 m</td><td>Fluvial, distal sandy braided rivers</td><td rowspan="4">Main lithotypes: vitrino-clarine; clarino-durine durino-clarine; clarino-vitrine vitrine.
Remaining are insignificant[a].

Vitrinite group: 60.7%
colinite[b]: 95%
telinite[b]: 5%

Liptinite group: 11.4%
sporinite[b]: 89%
kutinite[b]: 7%
resinite[b]: 4%

Inertinite group: 17%
fusinite[b]: 18%
semifusinite[b]: 48%
micrinite[b]: 14%
macrinite[b]: 5%
sclerotinite[b]: 1%
inertodetrinite[b]: 15%

Mineral matter: 10.9%</td></tr>
<tr><td rowspan="2">STRATIGRAPHICAL GAP?</td><td colspan="4" rowspan="2">STRATIGRAPHICAL GAP?</td></tr>
<tr><td>Bolsovian</td></tr>
<tr><td>Duckmantian</td><td>Łaziska Beds</td><td>Mainly medium- to coarse-grained sandstones and subordinate conglomerates. Relatively thin packages of siltstones and mudstones usually contained up to 24 coal seams. Thickness range of the coal seams is variable (0.1-7 m)</td><td>Tuffogenic horizon in the middle part of Łaziska Beds. Lower boundary-abrupt change in lithology, but diachronous</td><td>~ 1100 m</td><td>Fluvial, distal sandy braided rivers</td></tr>
</table>

Figure 10. The main features of the Cracow Sandstone Series and the Kwaczała Arkose. Coal petrography data based on (a) Knafel (1983) and (b) Jurczak-Drabek (unpub. Ph.D. thesis, Polish Geological Inst., 1997).

coals is dominated by mixed lithotypes (vitrino-clarine, clarino-durine, durino-clarine and clarino-vitrine). In the microscopic composition, macerals of the vitrinite group (61 %) prevail; the remaining groups (inertinite and liptinite) constitute 17 % and 11 %, respectively (Jurczak-Drabek, 1996, 2000). Mineral-matter content does not exceed 11 % (Fig. 4d).

4. Kwaczała Arkose

The Kwaczała Arkose represents the youngest unit in the foredeep succession and overlies the coal-bearing succession of the Upper Silesia Coal Basin. This unit lacks coal seams and other plant remains, thus both the age and its exact relationship to the substratum remain unclear. This unit contains silicified Dadoxylon tree trunks and, on the basis of analogies with other similar deposits from the basins of the Czech Republic, it is thought to be Stephanian B in age (Siedlecki, 1951; Rutkowski, 1972). Poorly lithified arkosic coarse-grained sandstones and conglomerates with interbeds of variegated mudstones dominate the Kwaczała Arkose. Lithologically, the Kwaczała Arkose is very similar to the underlying deposits of the Libiąż Beds. The Libiąż Beds and Kwaczała Arkose are probably separated by a stratigraphical gap spanning the Cantabrian and Barruelian substages (Kotas, 1995). The maximum thickness of the Kwaczała Arkose reaches 400 m. The sediments of the Kwaczała Arkose, similarly to those of the Cracow Sandstone Series, were deposited within a braided fluvial system.

5. Synthesis

Sedimentation of the coal-bearing succession of the Upper Silesia Coal Basin was controlled by combined autogenic and allogenic factors. Differentiated flexural tectonic subsidence has been successively compensated by accumulation of the sediments within the basin. Owing to this, the general depositional surface in the

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successive stages of the basin development was nearly flat, and was mostly (with the exception of the marine ingressions) an extensive accumulation plain.

The upper 'Limnic' part of the coal-bearing succession is represented by depositional fluvial systems, while the lower 'Paralic' part subordinately contains complex coastal systems. Within fluvial systems, channel belts and floodplains (sites of deposition of both clastic and phytogenic material) environments coexisted. Migration and sudden shifts of sedimentary environments have been caused mainly by autogenic factors.

Westward of the depocentre, coal seam splitting is a characteristic feature for the coal-bearing succession of the Upper Silesia Coal Basin. Particular coal seams have different lateral extents, but only a few can be traced for more than a dozen kilometres distance.

Macrofloral evidence has been used to place particular lithostratigraphical boundaries, and has allowed the recognition of several stratigraphical gaps. Some of these gaps span whole substages, but such hiatuses cannot be confirmed by lithological changes of the basin infill.

Increasing supply of coarse-grained sediment into the basin (during deposition of the Upper Silesia Sandstone Series and the Cracow Sandstone Series) has been mainly responsible for differences in the style of the fluvial systems. It should be linked with allogenic factors like tectonic movement in the source areas and probably with long-term climatic changes. The appearance of the Kwaczała Arkose, which is lithologically very similar to the underlying deposits of the Libiąż Beds but devoid of coal seams, could also be related to such changes.

The most important features of the coal-bearing succession of the Upper Silesia Coal Basin are summarized in Figures 7 through 10.

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