Państwowy Instytut Geologiczny
Państwowy Instytut Badawczy

państwowa służba geologiczna
państwowa służba hydrogeologiczna

Załącznik 3b

Summary of Professional Accomplishments

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1. **Name**

Maria I. Waksmundzka

2. **Diplomas, degrees conferred in specific areas of science or arts, including the name of the institution which conferred the degree, year of degree conferment, title of the PhD dissertation**

Geology Technician, Geological Technical College in Warsaw, 1988. Work under the title: *Tasks of geological supervision and supervision on exploration holes of mineral deposits (based on the Suwałki deposit).* Promoter dr hab. Ryszard Sałaciński

M.Sc. in Geology in the field of stratigraphy and exploration geology, graduated with honors, Faculty of Geology Universiti of Warsaw (UW), 1993. Work under the title: *Facies analysis and sedimentation of the Visean and Namurian deposits in the S Lublin Carboniferous Basin.* Promoters Prof. dr hab. Piotr Roniewicz, prof. dr hab. Stanisław Skompski, doc. dr hab. Antoni M. Żelichowski

Doctor of Earth Sciences in the field of geology – sedimentology **(Zał. 1)**, Polish Geological Institut-National Research Institute (PIG-PIB) in Warsaw, 2006. Work under the title: *Facies evolution and sequence analysis of the paralic deposits in the NW and central part of the Lublin Upland.* Promoter Prof. dr hab. Stanisław Skompski

3. **Information on employment in research institutes or faculties/departments or school of arts**

1991-1992 Assistant trainee, UW Institut of Basic Geology Faculty of Geology Department of Dynamic Geology

1993 Technician, UW Institut of Basic Geology Faculty of Geology Department of Dynamic Geology

1993-1996 Assistant, UW Institut of Basic Geology Faculty of Geology Department of Mineral Deposits and Economic Geology

1995-2003 Geologist specialist, PIG-PIB, Department of Regional and Petroleum Geology

2003-2006 Older searching-technical geologist specialist, PIG-PIB, Department of Regional and Petroleum Geology

2006 up to now Adjunct, PIG-PIB Regional Geology Department (before Energy Security Program, Deep Structure Geological Mapping Department, Department of Regional Geology, Mineral Deposit and Geophysics, Department of Regional and Petroleum Geology)

4. Description of the achievements, set out in art. 219 para 1 point 2 of the Act

4.1. Cycle of scientific articles related thematically, pursuant to art. 219 para 1. point 2b of the Act. Title of scientific achievement:

Reconstruction of depositional architecture and palaeogeography of the Carboniferous deposits in the Lublin

4.2. Publications included in the scientific achievement*

* Electronic versions of publications included in the scientific achievement are included in **Zał. 5**, while the statement of the co-author of the publication [A8] is included in **Zał. 6**.

[A1] **Waksmundzka M.I.** 2010. Lithofacies-paleothickness map of Visean. Plate 21. In: Modliński Z. (Ed) *Paleogeological Atlas of the sub-Permian Paleozoic of the East-European Craton in Poland and neighbouring areas 1:2 000 000*: 25-27; 52. PIG-PIB Warsaw

Scoring for the year of publication: 3 points; 2019 Score: 20 points

My contribution to the publication includes the performance of all research, graphic works, as well as writing an explanatory text.

[A2] **Waksmundzka M.I.** 2010. Lithofacies-paleothickness map of Namurian A (Serpukhovian-lowermost Bashkirian). Plate 22. In: Modliński Z. (Ed) *Paleogeological Atlas of the sub-Permian Paleozoic of the East-European Craton in Poland and neighbouring areas 1:2 000 000*: 27-28; 53. PIG-PIB Warsaw

Scoring for the year of publication: 3 points; 2019 Score: 20 points

My contribution to the publication includes the performance of all research, graphic works, as well as writing an explanatory text.

[A3] **Waksmundzka M.I.** 2010. Lithofacies-paleothickness map of Namurian BC (lower

Bashkirian). Plate 23. In: Modliński Z. (Ed) *Paleogeological Atlas of the sub-Permian Paleozoic of the East-European Craton in Poland and neighbouring areas 1:2 000 000*: 28-30; 53-54. PIG-PIB Warsaw

Scoring for the year of publication: 3 points; 2019 Score: 20 points

My contribution to the publication includes the performance of all research, graphic works, as well as writing an explanatory text.

[A4] **Waksmundzka M.I.** 2010. Lithofacies-paleothickness map of Westphalian (upper Bashkirian-Moscovian). Plate 24. In: Modliński Z. (Ed) *Paleogeological Atlas of the sub-Permian Paleozoic of the East-European Craton in Poland and neighbouring areas 1:2 000 000*: 30-31; 54. PIG-PIB Warsaw

Scoring for the year of publication: 3 points; 2019 Score: 20 points

My contribution to the publication includes the performance of all research, graphic works, as well as writing an explanatory text.

[A5] **Waksmundzka M.I.** 2010. Worm's eye map of the sub-Carboniferous unconformity. Plate 33. In: Modliński Z. (Ed) *Paleogeological Atlas of the sub-Permian Paleozoic of the East-European Craton in Poland and neighbouring areas 1:2 000 000*: 37-38; 58. PIG-PIB Warsaw

Scoring for the year of publication: 3 points; 2019 Score: 20 points

My contribution to the publication includes the performance of all research, graphic works, as well as writing an explanatory text.

[A6] **Waksmundzka M.I.** 2012. Braided-river and hyperconcentrated-flow deposits from the Carboniferous of the Lublin Basin (SE Poland) – a sedimentological study of core data. *Geologos* 18, 3: 135-161.

List B MNiSW; Scoring for the year of publication: 9 points; 2019 Score: 40 points

My contribution to the publication includes the performance of all research, preparation of the manuscript in the text and graphic layers, responses to reviews and the final edition of the manuscript.

[A7] **Waksmundzka M.I.** 2013. Carboniferous coarsening-upward and non-gradational cyclothems in the Lublin Basin (SE Poland): palaeoclimatic implications. In: Gąsiewicz A., Słowakiewicz M. (Eds) *Palaeozoic Climate Cycles: Their Evolutionary and Sedimentological Impact. Geological Society, London, Special Publications*, 376: 141-175.

Indexed in the Journal Citation Report

Scoring for the year of publication: 5 points; 2019 Score: 70 points

My contribution to the publication includes the performance of all research, preparation of the manuscript in the text and graphic layers, responses to reviews and the final edition of the manuscript.

[A8] Kozłowska A., **Waksmundzka M.I.** 2020. Diagenesis, sequence stratigraphy and reservoir quality of the Carboniferous deposits of the southeastern Lublin Basin (SE Poland). *Geological Quarterly*, 64: 422–459.

Indexed in the Journal Citation Report

List A MNiSW; Scoring for the year of publication: 70 points;
IF for the year of publication 1.167; 5-year IF 1.188

My contribution to the preparation of the publication included:
(1) development of the concept and methodology of sedimentological studies and sequence stratigraphy, as well as the performance of these studies (2) participation in the development of the criteria of reservoir properties listed in Table 1, (3) analysis of the results of sedimentological studies and sequence stratigraphy in the context of reservoir properties of sandstones, (4) preparation of the manuscript text including the results of sedimentological studies and sequence stratigraphy illustrated in Figures 2-12AB and presented in Tables 2-5, (5) participation in the discussion of results in the context of reservoir properties of sandstones summarized in Table 8, (6) participation in the development of conclusions , (7) co-creating the final version of the manuscript of the article.

4.3. Introduction

The scientific achievement, which is the basis for the application for conferring the degree of habilitated doctor, is composed of 8 thematically related publications. Six of them are monographic chapters (five in the form of maps) [A1]-[A5] and [A7], and the following two are scientific publications in journals included in the list of the Ministry of Science and Higher Education.

The investigations, whose results are presented herein, were conducted in two stages. At first, I performed lithofacies analysis of cores, interpreted the lithology and identified the sequence boundaries in particular boreholes; these results were achieved in the following projects:

- [H5] *Budowa geologiczna i system naftowy rowu lubelskiego a perspektywy poszukiwawcze* [Geology and the petroleum system of the Lublin Graben – prospective potential];
- [P10] *Analiza litofacjalno-paleogeograficzna paleozoiku podpermskiego kratonu wschodnioeuropejskiego w Polsce i na obszarach sąsiednich* [Lithofacies-palaeogeographic analysis of the sub-Permian Palaeozoic of the East European Craton in Poland and neighbouring areas];
- [P16] *Wykształcenie facjalne, stratygrafia sekwencji and diageneza utworów karbonu z południowo-wschodniej Lubelszczyzny* [Facies, sequence stratigraphy and diagenesis of the Carboniferous in the SE Lublin area].

The second step included sedimentological and stratigraphic studies, in each case for the requirements of subsequent publications, whose scope was much beyond the frame of the above projects. I also performed new investigations in selected intervals from 3 continuous cores discussed in my PhD dissertation; the obtained results significantly extended, elaborated and updated its accomplishments.

The scientific scope of my investigations was the reconstruction of sedimentary environments and depositional architecture of the Carboniferous in the Lublin Basin, based on detailed analysis of lithofacies and cyclicity, in a sequence stratigraphic framework related to chronostratigraphy. The studies performed on fully cored boreholes allowed for the reconstruction of palaeoenvironments and palaeogeography, both in the scale of single depositional forms, as well as on a regional scale extending beyond the present-day limits of the Lublin Basin. Regional reconstructions were presented on lithofacies–palaeothickness and palaeogeological maps [A1]-[A5], which were published in the *Paleogeological Atlas of the sub-Permian Paleozoic of the East-European Craton in Poland and neighbouring areas 1:2 000 000* (Modliński 2010 ed.), and in correlation schemes in papers [A6]-[A8]. On them I have presented reconstructions of demonstrative sedimentary environments and sub-environments, as well as their variability within particular chronostratigraphic units of the Carboniferous.

4.4. Methodology of the investigations

The investigations were made based on geological data and geophysical logs from 88 boreholes located in the Lublin Basin. Out of them, 14 are fully cored in the entire Carboniferous succession or in selected intervals. The remaining boreholes are fragmentarily cores with core yield of about 20-40%.

Sedimentological studies included lithofacies analysis through studies of single lithofacies and their associations. In general, I have used the lithofacies code developed by Miall (1978), Rust (1978) and Zieliński (1995), to which I have made some supplementations according to the specific character of the analysed deposits [A6]-[A8]. In the lithofacies code, capital letters refer to textural features and small letters – to structural features [A6 – Tab. 1], e.g. Sp (S = *sandstone*; p = *planar cross-stratification*). Symbols from the genetic code [A6 – Tab. 3], as abbreviations of their name in capital letters, have been used to code bottom forms, processes and sedimentary environments, e.g. FM (*foreset macroform*).

The next stage of the lithofacies analysis was distinguishing and coding lithofacies associations, by selecting lithofacies dominating in thickness – index lithofacies [A6– Tab. 5, 6, 8]; [A8 – Tab. 4]. This was crucial in the reconstruction of various types of fluvial environments by comparison with the model successions of Miall (1996).

One of the elements of sedimentological studies was the analysis of fining-upward cyclothems occurring within fluvial deposits. In this case, I have used the sub-division of such cyclothems into two main types and several sub-types, presented in paper [A6]. I have performed a statistical analysis of cyclothem thicknesses and their components for various fluvial environments with indication of those most predisposed to aggrade sand sediments and to form lithosomes with potential reservoir properties.

Recognition of marine and delta environments required a detailed analysis of coarsening-upward and non-gradational cyclothems [A7]-[A8] with application of an earlier introduced classification (Waksmundzka 2010 [K14]). The analysis was focused on recognizing the lithofacies succession and the completeness of the clay-clastic deposits, comprising genetically-related segments marked 1-3. Based on this, I have distinguished the main cyclothem types. The presence or lack of the remaining segments, i.e. carbonate – 0 and phytogenic – 4, was the base to distinguish subtypes within the main types.

Due to the significantly deep burial of Carboniferous strata, considering the compaction correction was a critical issue in reconstructing the primary thickness of lithofacies and lithofacies associations. This was significant for reconstructing the sedimentary environments and sub-environments, particularly in the case of the analysis of thickness ratios in fining-upward cyclothems, between channel deposits and those formed on the floodplain.

The compaction correction was calculated according to the methodology of Baldwin and Butler (1985), by determining thickness reduction ratios for particular rock types whose values increase with depth [A7]. For a precise interpretation of the fluvial environments and using empirical formulas cited in publication [A6], I have also calculated the height of palaeobottom forms, i.e. transverse bars and megaripples, as well as the depth of river palaeochannels.

For selected coarsening-upward cyclothems I have calculated the primary thicknesses, which allowed for estimating the depth of the marine palaeobasin and the accommodation space of the delta plain. Moreover, I have conducted a statistical analysis for particular depositional systems tracts, which allowed to indicate a genetic link between cyclothem types and the relative sea-level (RSL).

I have characterised the facies development of the Carboniferous deposits and their depositional architecture based on lithological-facies correlation and sequence stratigraphy. Carboniferous lithological logs were correlated based on several isochronous faunal horizons, i.e. *Posidonia corrugata* I, *Posidonia corrugata* II and *Dunbarella papyracea* (Musiał, Tabor 1988) and the corresponding local gamma-ray maxima (Waksmundzka 2010 [K14], [A7]).

In the analysed sections I have distinguished depositional sequences defined after Michum Jr. (1977), as well as their basic elements – parasequences (Van Wagoner 1985), to which cyclothems correspond. Several surfaces have been determined with the sequences: i.e. maximum regression – incipient transgression (T) and maximum flooding surface (MFS), which separate three types of systems tracts: lowstand systems tracts (LST), transgressive systems tracts (TST) and highstand systems tracts (HST) (Posamentier et al. 1988).

In general, I have applied the sequence stratigraphic model for the Lublin Basin, which includes 22 sequences and is related to the global and Western European stratigraphic scheme for the Carboniferous (Waksmundzka 2008 [K11], 2010 [K14]). Following the discovery of the earlier unknown Tournaisian strata in the Lublin area (Pańczyk, Nawrocki 2015), the model was accordingly modified. The change referred to the oldest deposits of the Carboniferous, among which deposits of sequence 1, separated from the Visean by a distinct stratigraphic gap, were attributed to the Tournasisian ([A8]; Waksmundzka et al. in press [K25]).

Regional reconstructions were developed based on lithofacies–palaeothickness [A1]-[A4] and palaeogeological [A5] maps. I have constructed the former ones with application of lithological, facies and thickness data from 88 boreholes, which were elaborated using the coefficient method. Lithofacies–palaeothickness maps are constructed using the classification triangle, with three main lithofacies groups A, B and C, corresponding to the percentage contribution in the succession, in its vertices, as well as the values of coefficients W1 = A/(B+C) and W2 = B/C. The method implies specific averaging of the lithofacies succession. This causes that lithofacies characterised by small thicknesses are not directly reflected in the maps of e.g. the Visean [A1] and Namurian A (Serpukhovian-lowermost Bashkirian) [A2], in favour of lithofacies with dominant thicknesses. Possible sedimentary environments have been reconstructed in the Lublin Basin, where the Carboniferous succession is erosionally reduced, as well as beyond its present-day range.

The palaeothickness of particular Carboniferous stages has been presented on maps using interpolated isopachs. This parameter corresponds to the present-day thickness (without decompaction, which was not included in the concept of the atlas) of units characterized by a complete succession, and a reconstructed thickness in areas secondarily devoid of deposits following mid-Carboniferous and epigenetic erosion. Based on the course and regional position of isopachs with 0 value, I have reconstructed the original depositional range of particular Carboniferous stages and presumed boundaries of the Lublin Basin.

4.5. Results of sedimentological and sequence stratigraphic studies

4.5.1. Lithofacies, cyclicity and sedimentary environments

Interbedding clastic, clay, carbonate and phytogenic rocks, with volcanites, pyroclastics and bauxites in its lowermost part, occur in the Carboniferous succession of the Lublin Basin. Lithofacies analysis of the available cores allowed to distinguish several lithological varieties, i.e. limestone, marl, claystone, mudstone, sandy siltstone, sandstone, conglomeratic sandstone, sandy conglomerate, conglomerate, claystone/mudstone/sandstone stigmaria soil, carbonaceous claystone and coal, among which I have distinguished, coded and characterized lithofacies formed in various environments: fluvial [A6 – Tab. 4; A8 – Tab. 2], delta, shallow clay and carbonate shelf [A7 – Tab. 3; A8 – Tab. 3].

A specific feature of the Carboniferous in the Lublin Basin is its cyclicity; analysis of this cyclicity was the essential part of the sedimentological studies. Three main types of cyclothems with various subtypes have been distinguished in the analysed successions, i.e. fining-upward, coarsening-upward, and non-gradational, with application of earlier introduced classifications (Waksmundzka 2010 [K14]; [A8]).

4.5.1.1. Fluvial environments

Following the lithofacies analysis, I have distinguished, coded and characterized 21-24 lithofacies [A6 – Tab. 4; A8 – Tab. 2] and 23-45 lithofacies associations [A6 – Tab. 5, 6, 8; A8 – Tab. 4], formed in the fluvial environment, as well as in hyperconcentrated flows that occurred in river channels and incised valleys. Below I present the characteristics of these deposits, in an order from the highest to the lowest energy, and fining-upward cyclothems formed in this environment.

Hyperconcentrated flows

An erosional surface occurs in the base of lithofacies associations formed during hyperconcentrated flows. Above occurs high-energy scour-fill sandstone of lithofacies Ss containing various types of clasts, i.e. claystone, mudstone, sideritic concretions and carbonaceous ones. This lithofacies is followed by much thicker massive sandstone Sm, which reaches up to 18 m of present-day thickness. The associations are generally mono-facies, but sporadically occur thin intervals of lower-energy lithofacies Sx, St, Sl and Sh2. The most typical associations formed during hyperconcentrated flows, i.e. for example Sm (Ss) or Sm, as well as fining-upward cyclothems have been illustrated in **Figure 1** based on borehole Łęczna IG 13 in [A6 – Fig. 7]. Other examples are from Łęczna IG 9 [A6 – Fig. 6] and Tyszowce IG 1 [A8 – Fig. 6] boreholes.

The domination of the massive sandstone Sm lithofacies points to rapid deposition in hyperconcentrated flows, which developed in incised valleys (Martinsen 1994; Svendsen et al. 2003). These flows were characterized by high concentration of sediments reaching 20-50% (after Pierson, Costa 1987), which hampered processes of rhythmic bottom transport (**Figure 2**).

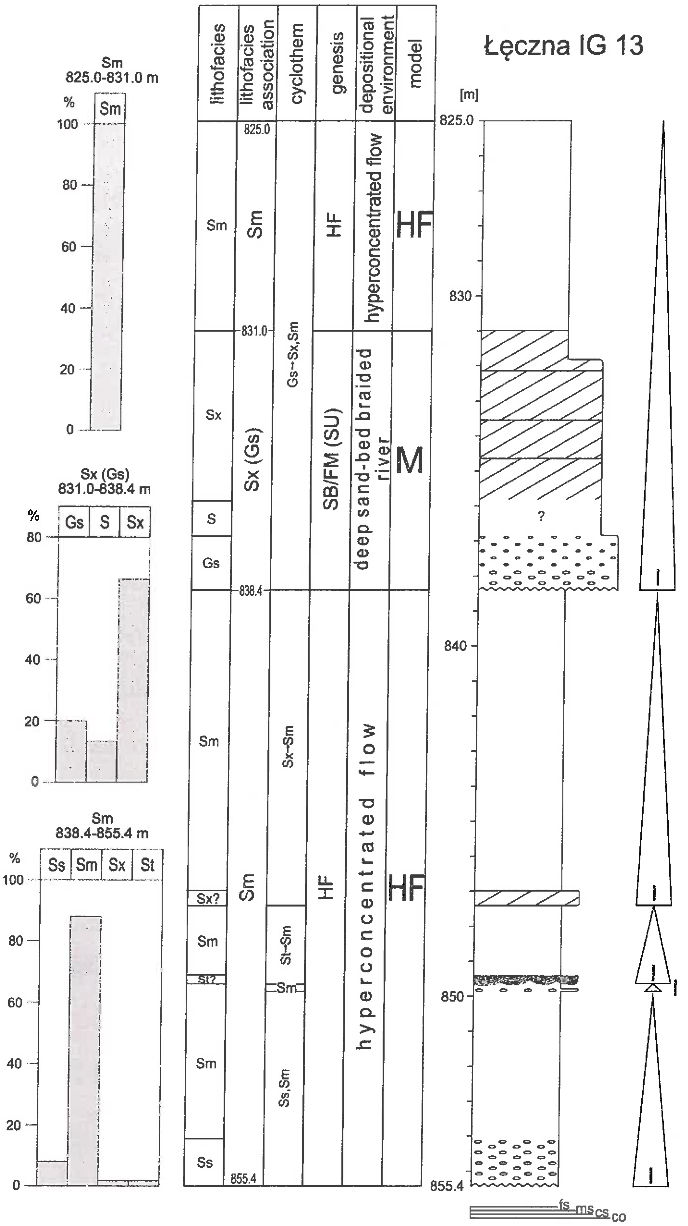

Figure 1. Lithofacies associations and fining-upward cyclothems deposited from hyperconcentrated flows in an incised valley (HF) and in high-energy sand-bed braided-river environment (Model M of Miall 1996).

Within the associations described above, fining upward and transition from coarse sandstone through medium to fine sandstone are common features. In some cases, transition to siltstone is also observed. The most common are fining-upward type I cyclothems– coarse-grained, several metre thick, with lithofacies succession St→Sm or Sx→Sm, in which high-energy lithofacies are accompanied by low-energy lithofacies. Cyclothems composed of two lithofacies associations, high-energy and low-energy ones, are also present. They are characterized by an extremely large thickness reaching 28.5 m and a lithofacies succession Ss, Sm→Sx, St, Sl, Sh and Gs→Sx, Sm. These cyclothems are illustrated in **Figure 1**, and in publication [A6 – Fig. 6, 7; Tab. 7].

Less common are type IIa cyclothems reaching a thickness of about 8 m, in which the lower high-energy member is followed by an upper, low-energy member, composed of horizontal laminated mudstone Fh, described in Tyszowce IG 1 [A8 – Fig. 6; Tab. 5].

The development of fining-upward type I cyclothems and lower members representing type IIa cyclothems, included within one lithofacies association, should be linked with decrease of energy and capacity of the hyperconcentrated flow, as well as its concentration. As a result, beside massive lithofacies appear lithofacies typical of rhythmic bottom transport. In turn, the upper members of type IIa cyclothems were formed during deposition from suspension after the flow ceased. The formation of extremely thick cyclothems composed of two associations is linked with transition of a hyperconcentrated flow after ceasing of its energy and concentration, into rhythmic bottom transport in a braided river. This may be also linked with a reverse process, i.e. disappearance of rhythmic bottom transport in a braided river after increase of flow energy and sediment concentration, and the appearance of a hyperconcentrated flow.

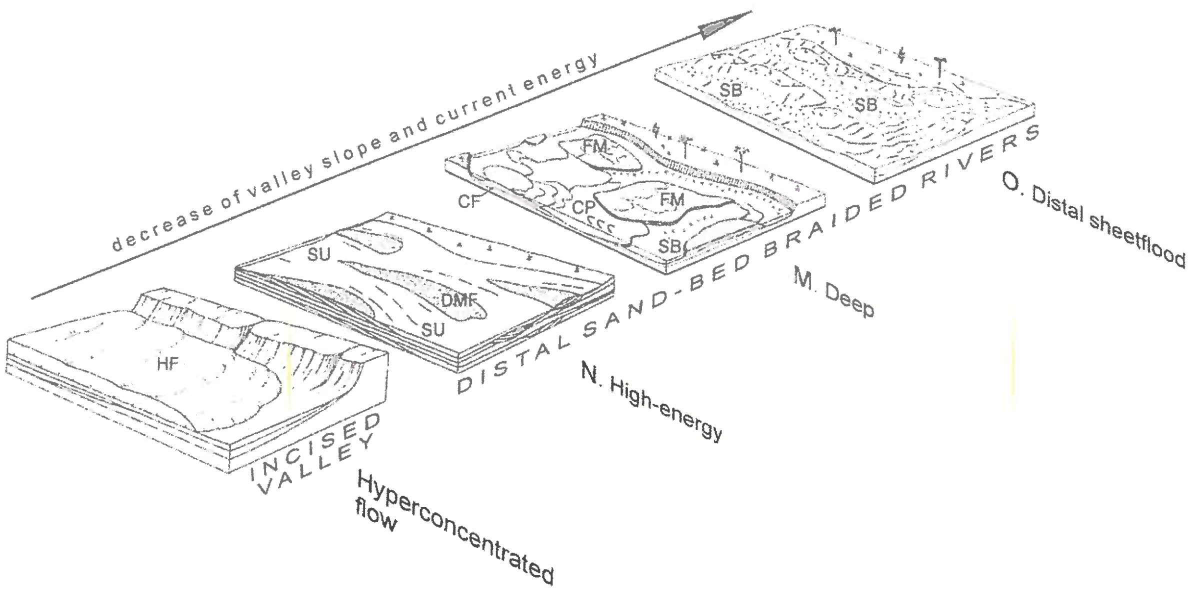

Figure 2. Reconstruction of sedimentation environments of hyperconcentrated flows in an incised valley and three types of braided rivers, that are found in the Carboniferous succession of the Lublin Basin.

Braided rivers

Lithofacies associations dominated by sandstones that formed during rhythmic bottom transport, in which fine and phytogenic lithofacies do not occur or their contribution is very low, at 7–37% (see e.g. Blakey, Gubitosa 1984), are common in the analysed cores. The base of most associations is an erosional surface, emphasized by various types of clasts. These features point to deposition in a **distal sand-bed braided-river** environment, among which I have distinguished 3 types with application of the fluvial classification of Miall (1996), i.e.:

- **High-energy – Model N**

The most typical are lithofacies associations dominated by high-energy horizontal stratified sandstone Sh/Sh2 formed in the upper flow regime and low-angle cross-stratified sandstone Sl, related with energy increase and transition from the lower to the upper flow regime. Rarer is high-energy massive sandstone Sm and scour-fill sandstone Ss, as well as lithofacies from the lower flow regime, i.e. trough cross-stratified sandstone St, large-scale cross-stratified sandstone Sx and ripple cross-laminated sandstone Sr.

These lithofacies are included in particular associations, i.e. Sh (Ss, Sx) and Sl (Sx, St) in Łęczna IG 9 [A6 – Fig. 6, 8; Tab. 5], and Sl (Sm, Sh2) in Tyszowce IG 1 [A8 – Fig. 5], which were formed in a high-energy braided river, resembling **model N** of Miall (1996) and illustrated in **Figure 2**.

- **Deep – Model M**

Relatively common are associations dominated by trough cross-stratified sandstone St, large-scale cross-stratified sandstone Sx or planar cross-stratified sandstone Sp. These lithofacies were formed in a lower flow regime within megaripples or transverse bars. They are rarely accompanied by high-energy massive sandstone Sm, horizontal stratified sandstone Sh/Sh2, low-energy ripple cross-laminated sandstone Sr, fine lithofacies Fh, Fm, Fn deposited from suspension or at ceasing flow, as well as coal of lithofacies C, formed due to carbonization of organic matter accumulated in bogs on the braidplain.

A typical association is St (Sx, Sm) from Łęczna IG 13 [A6 – Fig. 9; Tab. 6], which was formed mainly within 1.8–2.4 m high megaripples, at significant channel depth reaching 3.6–4.8 m. Other associations were usually formed within smaller megaripples, 0.25–0.34 m to 1.47 m high and channel depth from 0.5–0.68 m to 2.94 m.

Transverse bars were formed in some channels with depths up to 2.6 m; they are from 0.95–1.17 m to 2.0–2.6 m high, and the deposited sands form monolithofacies associations

Sp?, illustrated in Łęczna IG 25 [A6 – Fig. 10]. These associations developed in a deep braided river channel, resembling **model M** of Miall (1996) which is illustrated in **Figure 2.**

- **Distal sheetflood – Model O**

Some associations are characterized by large thickness of low-energy, extremely shallow water ripple cross-laminated sandstone Sr and claystone-mudstone lithofacies FSw, Fn, Fh and Fm developed at ceasing flow and/or during deposition from suspension. In some associations occurs coal of lithofacies C, formed in bogs on the braidplain after carbonization of the accumulated organic matter. Sandstones of lithofacies St and Sx indicating short episodes of slightly higher energy are much rarer.

These lithofacies are included in associations, i.e. for example Sr (Sx) in Łęczna IG 9 [A6 – Fig. 8; Tab. 5] or Sr (C, Sx) in Łęczna IG 13 [A6 – Fig. 9], which belong to the lowest-energy ones formed in a shallow low-energy braided river, resembling **model O** of Miall (1996) illustrated in **Figure 2**.

In deposits formed in **distal sand-bed braided rivers** I have distinguished two main types of fining-upward cyclothems: I – coarse-grained; IIa and IIb – fine-grained [A6 – Tab. 7]. Type I is characterized by the presence of one member comprising coarse-grained deposits, i.e. conglomerate and/or sandstone, and the lack of the upper fine-grained member. This type is quite common and may achieve a thickness of 11.7 m [A6 – Fig. 14]. The fining-upward may be related with transition from conglomerate or coarse-grained sandstone to medium- and fine-grained sandstone. Most common is high-energy massive sandstone and conglomeratic sandstone Sm, SGm, horizontal stratified sandstone Sh/Sh2, low-angle cross-stratified sandstone Sl or planar cross-stratified sandstone Sp?, linked with deposition in the lower flow regime. Much less common are lower-energy lithofacies of through cross-stratified conglomerate or sandstone Gt, St, large-scale cross-stratified sandstone Sx and low-energy ripple cross-laminated sandstone Sr.

Examples of lithofacies successions within type I cyclothems, for instance Gt→Sm, Sh, Sp?, St→Sr, have been presented in publication [A6 – Tab. 7] and noted in Łęczna IG 25 [A6 – Fig. 10] and Tyszowce IG 1 [A8 – Fig. 5] boreholes. The origin of fining-upward type I cyclothems may be related with decrease of energy and flow capacity in distal sand-bottom braided rivers.

The most frequent are fining-upward type IIa cyclothems composed of two members [A6 – Fig. 14]. Their thickness may reach 15.6 m. The fining-upward trend is related with the upward transition of coarse-grained sandstone through medium- and fine-grained sandstone to sandy siltstone, mudstone and claystone. The lower members comprise high-energy lithofacies, i.e. Ss, Sh/Sh2, Sl, as well as low-energy lithofacies, i.e. Sx, St, Sr. The upper members are characterized by the presence of massive claystone and mudstone Fm that originated from suspension after the flow ceased. In the top of some cyclothems occurs claystone/siltstone/sandstone stigmaria soil of lithofacies R, formed as a result of floodplain overgrowth by vegetation and development of pedogenic processes.

The rarest are fining-upward type IIb cyclothems, within which dominate low-energy lithofacies and those formed at lack of flow. The lower member includes ripple cross-laminated sandstone Sr formed at extremely low energy, and the upper member comprises lenticular laminated siltstone Fn and wavy laminated sandy siltstone FSw. These lithofacies are accompanied by massive and horizontal laminated claystone and mudstone Fm and Fh, formed during deposition from suspension after the flow ceased. The thickness of type IIb cyclothems may reach 8.6 m, but usually does not exceed 3 m. The typical succession of lithofacies, i.e. Sr→FSw, Fn, Fh, Fm occurs in Rycice 2 borehole [A6 – Tab. 7], and Sr, Sm→Fn – in Łęczna IG 25 borehole [A6 – Fig. 10]. The predominance of extremely low-energy and suspension-related lithofacies indicates that the formation of type IIb cyclothems took place on the floodplain between two main braided river channels at low-energy, ceasing flow, and subsequently during deposition from suspension in lakes.

Meandering rivers

Lithofacies associations characterized by thickness prevalence of 50–70% of fine-grained and phytogenic lithofacies over the sandstone lithofacies have also been described in the analysed succession. An erosional surface occurs in the base of the sandstone associations, emphasized by the occurrence of various types of clasts. A large contribution in these associations have high-energy lithofacies of massive sandstone Sm and horizontal stratified sandstone Sh2 formed in the upper flow regime, as well as low-angle cross-stratified sandstone Sl, related with transition from lower to upper flow regime. Lower-energy lithofacies of through cross-stratified sandstone St and planar cross-stratified sandstone Sp, linked with deposition within megaripples and transverse bars are less frequent. In some cases occur ripple cross-laminated sandstone Sr and flaser laminated sandstone Sf, formed at extremely low energy. Within these associations I have observed a fining-upward trend and transition from coarse- or medium-grained sandstone to fine-grained sandstone.

The features of the associations described above indicate sedimentation in sand-bottom meandering rivers (see Miall 1977; Bridge, Gordon 1985), with intense aggradation as evidenced by the domination of lithofacies Sm, Sh2 and Sl. Typical for this environment is e.g. association Sm (Sl, Sr, St) from Tyszowce IG 1 [A8 – Tab. 4; Fig. 7], which passes upward into a low-energy association comprising massive claystone and mudstone Fm and stigmaria soil R. Such associations are characteristic of the floodplain sub-environment of a sand-bottom meandering river. They were formed during deposition from suspension in lakes, and subsequently under the influence of pedogenic processes after floodplain overgrowth by vegetation.

Within deposits formed in meandering river environments occur fining-upward type IIa cyclothems with two members, in which sandstone lithofacies pass into fine-grained and phytogenic lithofacies. An example of such cyclothem from Tyszowce IG 1 [A8 – Tab. 5] has a succession Sm+Sp+Sl+Sf→Sh1→Sr+St→ Fm→R, comprising both members described above. The thickness of the cyclothems is about 4–10 m. Formation of type IIa cyclothems should be related with autocyclic processes, such as decrease of flow velocity and capacity within meander bars and their lateral migration in channels, as well as allocyclic processes, including decrease of flow energy and channel infilling as a result of base level (RSL) rise.

Fining-upward type IIb cyclothems, dominated by low-energy lithofacies, also occur. An example of such cyclothem is Sr+Sf+Sm+Sh1→Fm+Fh+FSw+Fn from Tyszowce IG 1 [A8 – Tab. 5]. The thickness of type IIb cyclothems varies within 0.3–10 m. The lower member is dominated by low-energy lithofacies of ripple cross-laminated sandstone Sr and flaser laminated sandstone Sf, pointing to ceasing flow within crevasse splays on the floodplain. The upper member includes lithofacies of massive claystone and mudstone Fm and horizontal laminated claystone and mudstone Fh, formed in lakes on the floodplain, where sedimentation took place mainly from suspension at general lack of flow.

Anastomosing fluvial system

Numerous are lithofacies associations dominated by ripple cross-laminated sandstone Sr and flaser laminated sandstone Sf, developed at extremely low flow energy, through cross-stratified sandstone St and large-scale cross-stratified sandstone Sx, linked with lower flow regime and deposition within megaripples and/or transverse bars. A typical association has a succession St, Sx (Sr) as in Tyszowce IG 1 [A8 – Tab. 4].

Common are associations, in which apart from the above mentioned lithofacies occur also high-energy lithofacies of horizontal stratified sandstone Sh2, massive sandstone Sm, scour-fill sandstone Ss, low-angle cross-stratified sandstone Sl, and low-energy horizontal laminated sandstone Sh1. An example of such association is Sh1 (Sm, Sr) from Marynin 1 [A8 – Tab. 4].

The described associations were formed at flow energy varying from high to low and at lack of flow, in strongly aggrading river channels. Such channels occur in the anastomosing fluvial system (see Makaske 2001; Gradziński et al. 2003). This interpretation is also confirmed by the thickness ratios of sandstone associations and low-energy associations formed on the floodplain, which comprise 74–97%. Closer to the channels within crevasse splays were formed sandstone lithofacies Sm and Sf. In turn, lithofacies of massive claystone and mudstone Fm, horizontal laminated claystone and mudstone Fh, as well as stigmaria soil R related with pedogenic processes and coverage of the floodplain by vegetation developed from suspension in lakes on the distal plain. Coal of lithofacies C was formed from carbonization of organic matter accumulated in bogs. A typical association formed in this sub-environment is Fm (R, C) in Tyszowce IG 1 [A8 – Tab. 4].

Within deposits of the anastomosing fluvial system occur fining-upward type IIa cyclothems composed of a lower sandstone member developed in the channel and a fine-grained upper member deposited on the floodplain. An example of such cyclothem is Gs→Ss→Sm+Sr+Sl→ Fh from Tyszowce IG 1 [A8 – Tab. 5; Fig. 5]. The formation of type IIa cyclothems points to processes of infilling and abandonment of channels due to avulsion and RSL rise, and deposition of the submerged floodplain, on which bogs developed and vegetation grew.

Also occur fining-upward type IIb cyclothems, in which the lithofacies were deposited on the floodplain, i.e. sandstone lithofacies Sm, Sf, Sd, Sh1 formed within crevasse splays and mudstone/siltstone lithofacies Fn and FSw – at slow, waning flow on the distal plain. Deposition from suspension of claystone and mudstone lithofacies Fm and Fh took place in lakes, whereas stigmaria soil of lithofacies R formed in areas covered by vegetation. A typical type IIb cyclothem is Sd+Sh1→Fh+FSw+Fd+Fm→R in Tyszowce IG 1 [A8 – Fig. 5, 6; Tab. 5].

4.5.1.2. Delta and shallow-shelf environment

Following lithofacies analysis, I have distinguished, coded and characterized 23-28 delta lithofacies, and clay and carbonate shallow-shelf lithofacies [A7 – Tab. 3; A8 – Tab. 3]. I have also analyzed the succession of lithofacies (members) and degree of completeness of the coarsening-upward and non-gradational cyclothems occurring in these environments [A7 – Tab. 4, 5; Fig. 8-10; A8 – Fig. 8, 9]. As a result, I have distinguished coarsening-upward type Ic, IIc, Id, and IId cyclothems and non-gradational type IIIc and IIId cyclothems. Complete cyclothems include types Ic and Id, incomplete are cyclothems IIc and IId and the genetically linked non-gradational cyclothems IIIc and IIId, in which the coarsening-upward trend does not occur. Typical cyclothems Ic and IIc are illustrated in **Figure 3** from publication [A7].

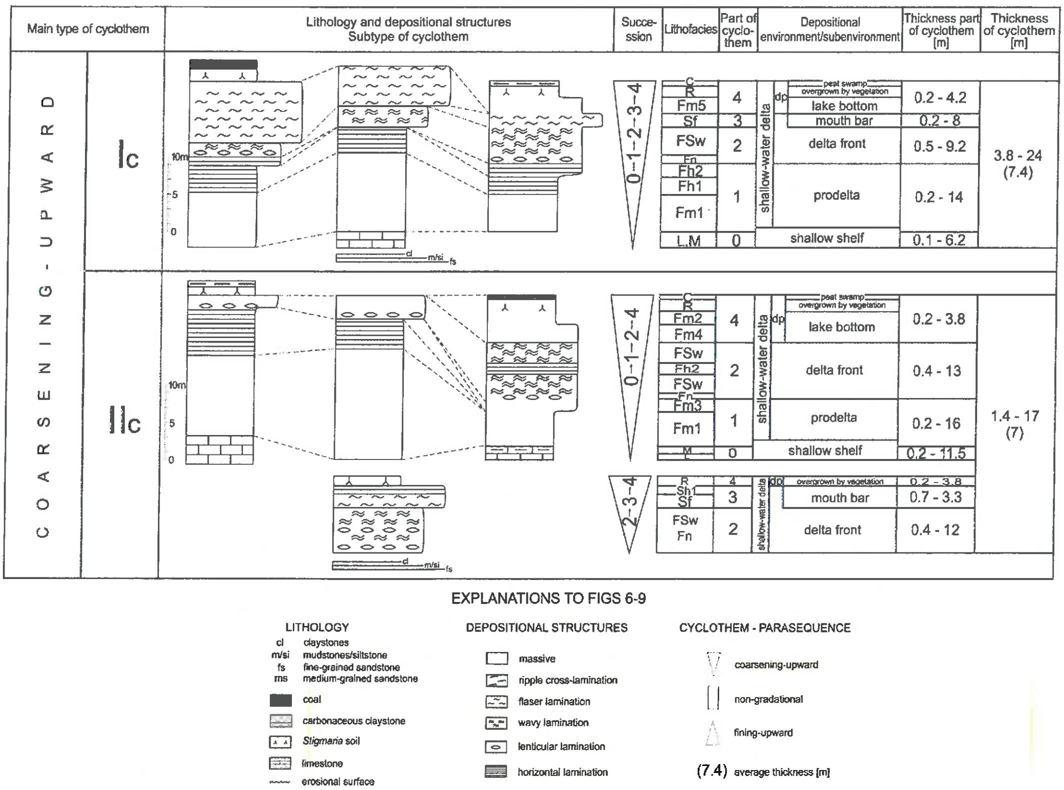

Figure 3. Examples of type Ic and IIc cyclothems along with characteristic lithofacies and their successions (members), thickness and interpretation of the sedimentary environments.

Type Ic cyclothems are composed (from base to top) of the following members comprising particular lithofacies:

- member 0: limestone (L) and marl (M);
- member 1: claystone (Fm1, Fh1), mudstone (Fm3, Fh2);
- member 2: mudstone (Fn, Fh2), sandy siltstone (FSw, FSd);

- member 3: fine-grained sandstone (Sh1, Sf, Sd);
- member 4: stigmaria soil (R), coal (C), claystone (Fm2), mudstone (Fm4, Fm5).

The coarsening-upward trend may be observed in members 1, 2 and 3; it is manifested as transition of claystone to mudstone/siltstone and later to fine-grained sandstone. Such succession characterizes a complete type Ic cyclothem; the incomplete type IIc cyclothem lacks one member, whereas the non-gradational type IIIc cyclothem lacks two members. I have observed 4 subtypes, respectively, within type Ic and IIc cyclothems. The thickness of type Ic cyclothem may reach 34 m, whereas type IIc cyclothem has 47 m.

Type Id cyclothems [A7 – Fig. 10] are composed (from base to top) of the following members comprising particular lithofacies:

- member 1: claystone (Fm2), mudstone (Fm4, Fm5);
- member 2: mudstone (Fh2, Fn), sandy siltstone (FSw);
- member 3: fine-grained sandstone (Sf);
- member 4: stigmaria soil (R), coal (C), claystone (Fm2), mudstone (Fm4, Fm5).

A typical succession is: 1→2→3→4, and the cyclothem thickness may reach 8 m.

Incomplete type IId cyclothems [A7 – Fig. 10] are characterized by succession: 1→2→4 and 1→4, and their thickness may reach about 11 m.

Non-gradational type IIIc cyclothems [A7 – Fig. 9; A8 – Fig. 8] are composed of lithofacies included in members 0, 1 and 4 in type Ic and IIc cyclothems. I have distinguished their two subtypes with a succession: 0→1→4 and 1→4. Their thickness may reach about 20 m.

Non-gradational type IIId cyclothem [A7 – Fig. 10; A8 – Fig. 9] is characterized by succession 1→4, and its thickness may reach about 9 m. The inventory of lithofacies corresponds to lithofacies forming analogous members in the genetically linked type Id and IId cyclothems.

The inventory of lithofacies and analysis of coarsening-upward and non-gradational cyclothems has allowed to reconstruct the environments and sub-environments of delta sedimentation, as well as that characterizing shallow clay and carbonate shelf (**Figure 3**). The subsequent members of a complete type Ic cyclothem correspond to shallow shelf and delta sub-environments, including prodelta, delta slope, mouth bar and delta plain, which I have reconstructed in **Figure 4**. Progradation of delta lobes, during which the deposits of particular sub-environments overlap one another, with successively coarser facies deposited on the prodelta, resulting in a coarsening-upward cyclothem, belongs to autocyclic phenomena (Elliot, 1976b).

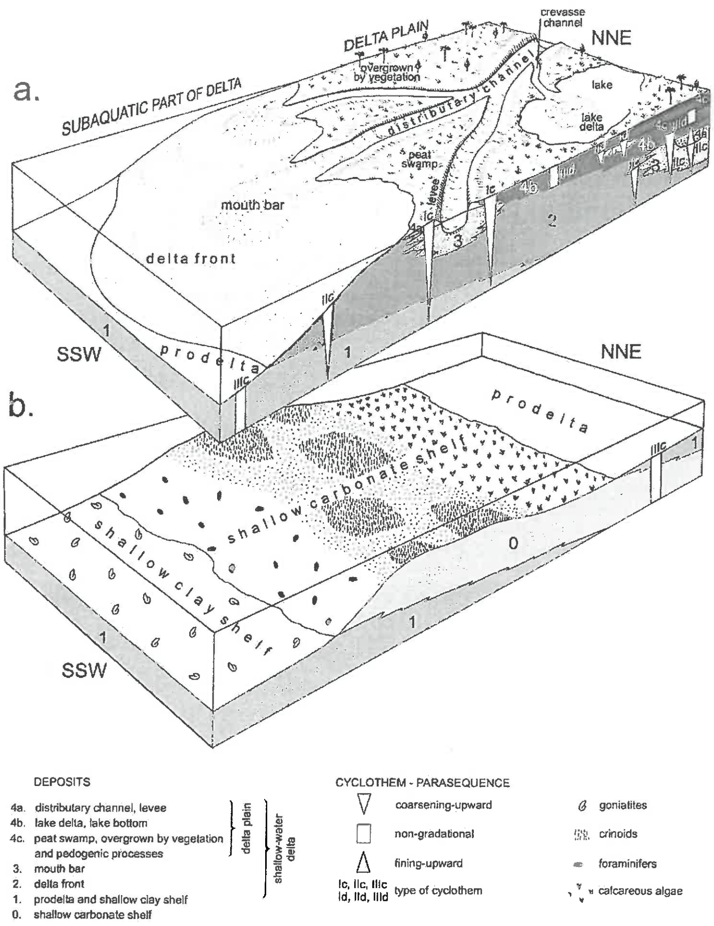

Figure 4. Reconstruction of depositional envinronments and subenvironments of coarsening-upward and non-gradational cyclothems: **(a)** shallow-water delta; **(b)** ramp-type shallow carbonate and clay shelves.

Member 0 comprises limestone (L) and/or marl (M) deposited on a ramp-type shallow carbonate shelf, with three zones differing in wave energy, whose model was introduced by Flügel (2004). This area continued further towards the open sea basin in the delta foreland. In the Carboniferous of the Lublin Basin this environment was characterized in detail by Skompski (1988, 1995) and Waksmundzka (1998 [B1], 2010 [K14]) and [A7].

Claystones (Fm1, Fh1) occurring in **member 1** developed in at least two environments. I have considered those containing goniatite fauna and characterized by very high radiation, manifested as peaks on gamma-ray profiles, as typical for a shallow clay shelf situated in the delta foreland (see Hampson et al., 1999). These lithofacies are most common within faunal horizons *Posidonia corrugata* I, *Posidonia corrugata* II and *Dunbarella papyracea*. The remaining claystones (Fm1, Fh1) without goniatite fauna and with low radiation should be linked with the prodelta, being the most distal part of the delta.

The succeeding **member 2** contains mudstones (Fn, Fh2) and sandy siltstones (FSw, FSd), which were formed in the subaqueous, active zone of delta lobe aggradation on the delta slope (see Wright 1977). The resulting lithologies includes heteroliths comprising clay, mud and very fine sand, often containing large amounts of plant chaff (see Hampson et al. 1999).

The higher **member 3** contains fine-grained sandstones (Sh1, Sf, Sd), which were formed at smallest distance from the mouths of delta distributary channels on the delta mouth bar (see Einesele, 1992). The delta accumulated in an aggradation-progradation regime and sediments of its most active part – slope and mouth bar – intruded onto the prodelta and shallow-shelf deposits. The marine basin infilled with sediment and the upper parts of delta lobes underwent emersion and became the subaerial part of the delta – the delta plain. In the delta plain, sedimentation took place within bogs, where coal and carbonaceous claystone (C) were formed, and in areas overgrown by vegetation, where stigmaria soils (R) developed; these lithofacies comprise the uppermost **member 4**. The delta plain was also the place where coarsening-upward type Id and IId, as well as non-gradational type IIId cyclothems were formed. The characteristic lithofacies succession indicates that they were formed in a lake delta sub-environment (**members 1, 2, 3**), on the lake bottom and after overgrowing of the lake by vegetation under the participation of pedogenic processes (**member 4**). Deposition in distributary channels with fine-grained sandstones of lithofacies Sx, Sm, Sr took place also on the delta plain.

The features of coarsening-upward cyclothems described above indicate that they were formed in a shallow marine delta with dominating influence of fluvial processes, with a type D delta plain (delta system model no. 8) according to the classification of Postma (1995) (**Figure 4**). In reference to the delta classification system of Porębski and Steel (2003), I have assigned the Carboniferous deltas of the Lublin Basin to the inner shelf deltas, within which progradation and aggradation of sediments takes place during RSL highstand (Waksmundzka 2010 [K14], [A7], [A8]).

4.5.2. Depositional architecture, sequence stratigraphy and chronostratigraphy

I have characterized the facies development of the Carboniferous in the Lublin Basin based on correlation of lithofacies and sequence stratigraphy. This allowed to distinguish **sedimentary environments (and sub-environments)**, that is **vast zones in the rank of elements of depositional architecture** (Miall 1988), and determining their variability and evolution within chronostratigraphic units.

The main elements of depositional architecture include the following sedimentary environments and sub-environments, which have been characterized in the previous chapters and presented in **Figure 5** and publications [A6 – Fig. 2], [A7 – Fig. 4, 5] and [A8 – Fig. 10, 11]:

- river channel and incised valley,
- alluvial floodplain with bogs, lakes, overgrown by vegetation, with pedogenic processes, channel bars and crevasse glyphs,
- delta distributary channels,
- delta plain with bogs, lakes, overgrown by vegetation, with pedogenic processes, channel bars and crevasse glyphs,
- mouth bar,
- shallow clay shelf, prodelta and shallow delta front,
- shallow carbonate shelf.

These elements of the depositional architecture have been constrained in a stratigraphic framework with application of sequence stratigraphy, which includes sequences from 1 to 22 (Waksmundzka 2008 [K11], 2010 [K14]). It was correlated with the Western European (Ramsbottom 1977, 1978) and global schemes for the Carboniferous (Davydov et al., 2012), as illustrated in **Figure 6** from publication [A7], modified according to the present-day knowledge on the stratigraphy of the Carboniferous in the Lublin Basin and the presence of the Tournaisian strata in the succession ([A8]; Waksmundzka et al. in press [K25]).

The lithofacies-stratigraphic succession of the Carboniferous presented below is characterized by large variability related to the cyclic appearance of sedimentary environments and the influence of the RSL and local tectonics. These factors are to a variable degree recorded in the basin. They had crucial influence on the development of the succession, creation of sedimentary gaps and erosional reduction of its top.

The Carboniferous lies with an erosional base on Devonian, older Palaeozoic and Ediacaran rocks. The base of the Carboniferous is the lower boundary of sequence 1, which in

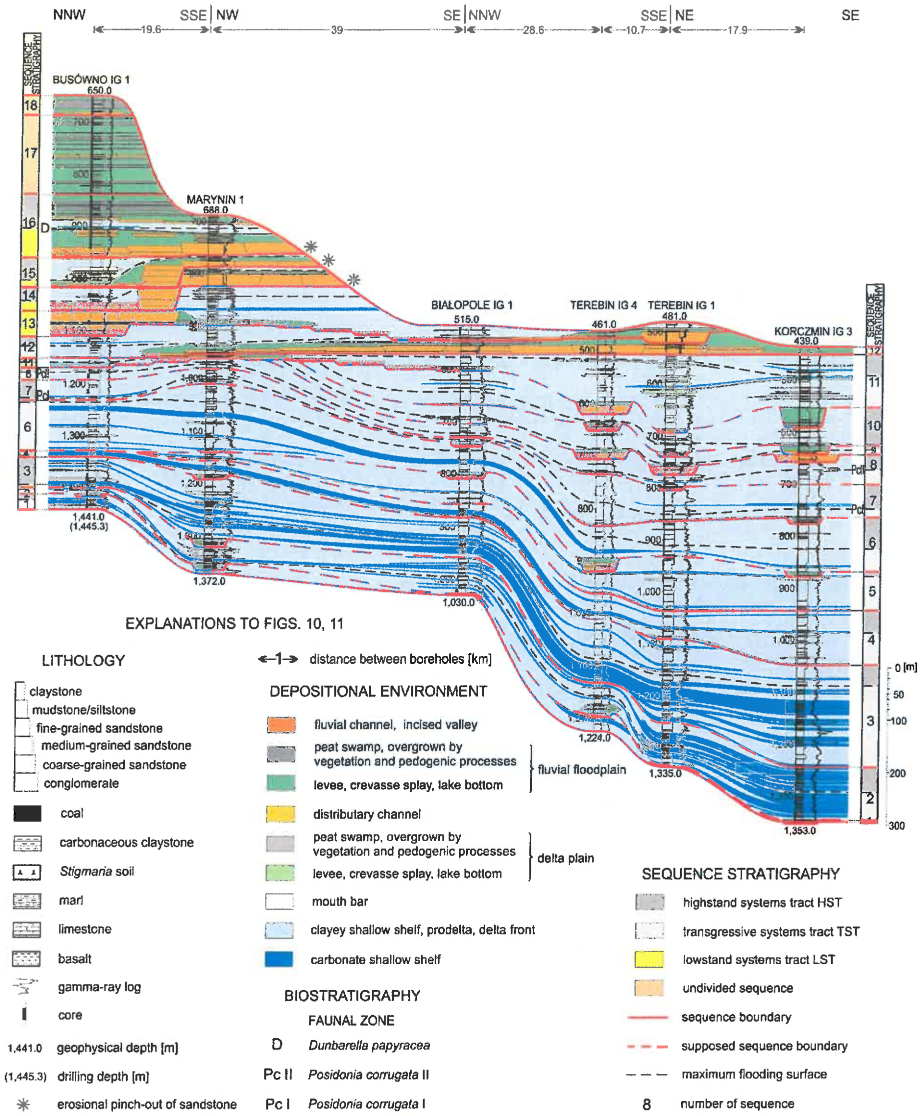

Figure 5. Lithofacies correlation and sequence stratigraphy of the Carboniferous succession of the southeastern Lublin Basin.

the E, SE and in the basin centre corresponds to the base of the Tournaisian. In turn, in the SW it corresponds to the base of sequences 2–4, corresponding to the lower boundary of the Visean.

The oldest deposits in the basin represent the upper Tournaisian, referring to sequence 1, which along with sequences 2–3 do not occur in the NW of the basin. There is a stratigraphic gap between the Tournaisian and Visean, encompassing the lower Visean (Waksmundzka et al. in press [K25]). The Visean comprises an interval from sequence 2 to the lower part of sequence 5 in the central, SW and SE part of the basin.

Namurian A (Serpukhovian–lowermost Bashkirian) encompasses the upper part of sequence 5 and sequences 6-9. Between the Namurian A and Namurian BC occurs a

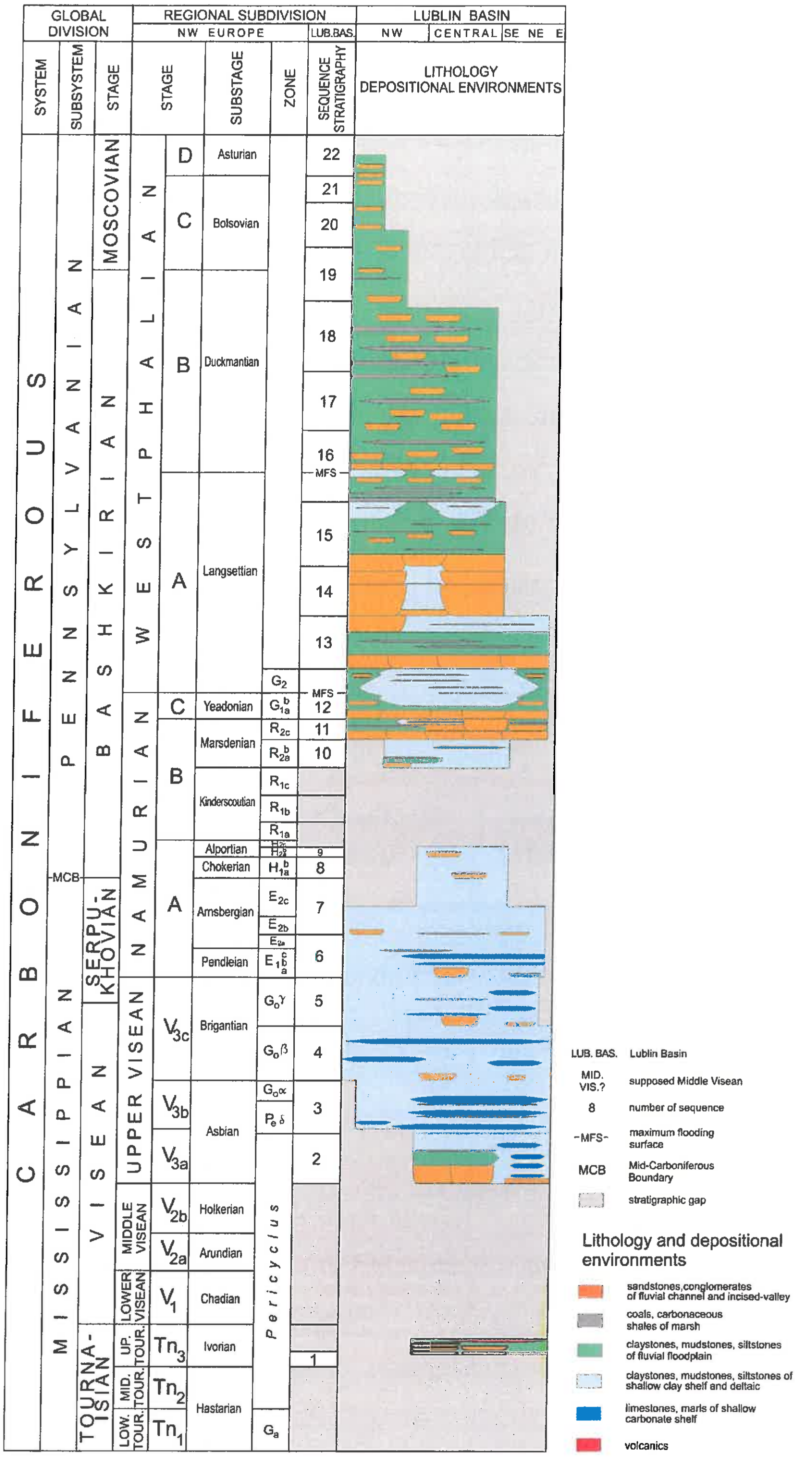

Figure 6. Sequence stratigraphy and chronostratigraphy of the Carboniferous deposits in the Lublin Basin (modified after Waksmundzka 2013 [A7]).

stratigraphic gap, related with erosional removal of the upper part of sequence 7 and sequences 8-10. The largest dimension of this gap occurs in the NW and E of the basin. Namurian BC (lower Bashkirian) encompasses sequences 10 and/or 11 and the lower part of sequence 12. Its most complete succession occurs in the central and SE part of the basin.

The uppermost part of the Carboniferous corresponding to the Westphalian (upper Bashkirian–Moscovian) encompasses the upper part of sequence 12 and sequences 13–22. The most complete succession occurs in the NW of the basin, whereas to the E and SE it becomes gradually more reduced, reaching down to sequences 13–18.

Stephanian (Kasimovian and Gzhelian) deposits have not been noted in the Carboniferous succession of the Lublin Basin.

Despite the large lithofacies variability in the succession, the analysis of thickness proportions of deposits representing the main sedimentary environments within particular stratigraphic intervals has enabled identifying the dominating depositional regime and presenting its temporal evolution. These results are shown in **Table 1**, on lithofacies–palaeothickness maps [A1]-[A4], and in publications [A6 – Fig. 2], [A7 – Fig. 4, 5] and [A8 – Fig. 10, 11].

Chronostratigraphy	**Sequence stratigraphy**	**Depositional regime**	**Thickness share of different environment sediments/lithology [%]**			
			Shallow carbonate shelf/ l	**Shallow delta, shallow clay shelf/ c, m**	**Fluvial floodplain/ c, m, p, cl**	**Fluvial channel, incised valley/s**
Westphalian (upper Bashkirian–Moscovian) [A4]	12^2-22	Fluvial	0	3-30	51-79	15-40
Namurian BC (lower Bashkirian) [A3]	10-12_1	Fluvial-delta	1-2	1 do 85	1-69	7-81
Namurian A (Serpukhovian–lowermost Bashkirian) [A2]	5^2-9	Delta	0-8	66-100	1-9	1-20
Tournaisian*–Visean [A1]	1-5_1	Delta-marine	1-71	29-99	2-20	1-20

Table 1. Thickness share of main sedimentary envinronments of the Carboniferous succession in the Lublin Basin; * after Waksmundzka et al. in press [K25]; $_1$ – lower part of sequence; ^{2} – upper part of sequence; c – claystones; m – mudstones; s – sandstones+conglomerates; p – *Stigmaria* soils; cl – coals; l – limestones+marls

4.5.2.1. Tournaisian–Visean

In the Tournaisian–Visean succession, dominating are claystones and mudstones of transgressive systems tracts (TST) and highstand systems tracts (HST), developed in **shallow delta and shallow clay shelf** environments, which may contribute even up to 99% of the thickness [A1]. They intercalate with numerous limestones formed in a shallow carbonate shelf, whose most numerous and thickest layers occur in sequences 2–4. Deposits representing these environments are most common in the NW of the basin.

TST and HST deposits are characterized by the presence of numerous coarsening-upward type IIc cyclothems, although in the HST the number of these cyclothems is significantly lower [A7 – 18b, 19b]. Rather common are also non-gradational type IIIc cyclothems. The high frequency of these types of cyclothems point to infilling of the sedimentary basin caused by numerous fluctuations of the RSL, mainly at aggradation of sediments of the shallow shelf and the submarine part of the delta lobes. The lowest frequency was observed among type Ic cyclothems, whose presence points to the low contribution of progradation in infilling of the accommodation space in the basin.

Deposits of **fluvial channels and incised valleys** forming lowstand systems tracts (LST) occur in the oldest, Tournaisian part of the succession and near the base of the Visean. They include sandstones (with rarer conglomerates), whose contribution is up to 20%, and occur in the central, SE and SW part of the basin. They form thin, isolated lithosomes with thicknesses reaching over ten metres. Channel deposits are accompanied by claystones, mudstones, stigmaria soils and coals, formed on fluvial floodplains and also included in the LST; their contribution may also reach up to 20%.

Examples of fluvial sedimentary environments, developed in the SE part of the Lublin Basin have been described in publication [A8 – Tab. 4]. In Tournaisian these settings comprised braided rivers (sequence 1), whereas in the Visean – meandering rivers (sequence 3) and most prevalent rivers of the anastomosing system (sequences 2, 4).

The thickness relationship of deposits representing different environments within the Tournaisian–Visean succession indicate that it was formed in a delta–marine depositional regime.

4.5.3.2. Namurian A (Serpukhovian–lowermost Bashkirian)

Deposits of Namurian A (Serpukhovian–lowermost Bashkirian) were formed in similar sedimentary environments as in the Tournaisian–Visean, but with different contributions. The generally larger contributions have TST and HST claystones and mudstones, formed in **shallow deltas and a shallow clay shelf**, which are the largest in the entire Carboniferous and reaches 66–100% [A2]. Numerous are type IIc and IIIc cyclothems, which point to aggradation-type infilling of the accommodation space in the basin by deposits of the shallow shelf and the submarine part of delta lobes [A7 – 18b, 19b]. The significant difference is related with the much lower contribution of limestones of the **shallow limestone shelf** occurring as single, thin horizons within TST and HST. Their frequency in the centre and in the SE of the basin reaches 8%, and they do not occur at all in the NW part of the basin.

Fluvial sandstones filling incised valleys forming the LST have a similar thickness contribution as in the Tournaisian–Visean succession. They are relatively rare, occurring as isolated lithosomes with thicknesses reaching up to 20 m. Fluvial environments developed in the Namurian A (Serpukhovian–lowermost Bashkirian) in the SE part of the basin, from which come examples of a braided river passing into a river of the anastomosing system (sequence 7), meandering river (sequence 7) and hyperconcentrated flows in an incised valley (sequence 9) [A8 – Tab. 4; Fig. 7].

In the Namurian A (Serpukhovian–lowermost Bashkirian) succession there is clear prevalence of deposits formed in a delta depositional system.

4.5.2.2. Namurian BC (lower Bashkirian)

Compared both to older and younger Carboniferous deposits, those representing the Namurian BC (lower Bashkirian) are characterized by a high contribution of sandstones formed in **river channels and incised valleys**, as well as claystones, mudstones, stigmaria soils and coals deposited in various floodplain sub-environments (**Figure 7**; [A3]), which comprise the LST. Sandstone lithosomes reach thicknesses from over 10 to about 40 m, being usually isolated bodies in the Namurian B but characterized by large lateral extension in the Namurian C. Examples of fluvial environments that existed in the Namurian BC (lower Bashkirian) in the SE part of the basin, i.e. braided rivers (sequence 10), meandering rivers (sequence 12), anastomosing rivers (sequences 10–12), as well as hyperconcentrated flows in incised valleys (sequence 11) have been presented in publication [A8 – Tab. 4; Fig. 5, 6]. In turn, examples of various types of braided rivers (sequences 11, 12) from the NW and central part of the basin have been characterized in publication [A6 – Tab. 8; Fig. 8].

In the Namurian BC (lower Bashkirian) succession, beside fluvial deposits occur claystones and mudstones of **delta and shallow clay shelf** environments, composing the TST and HST, whose contribution generally rises to 85% towards the SW and S. However, this contribution is generally lower than in the older part of the succession. The frequency of limestones of the **shallow carbonate shelf**, which occur very rarely as individual layers, is the lowest. Within the TST and HST dominate coarsening-upward type IIc cyclothems, indicating the generally aggrading increment of sediments representing the shallow shelf and submarine

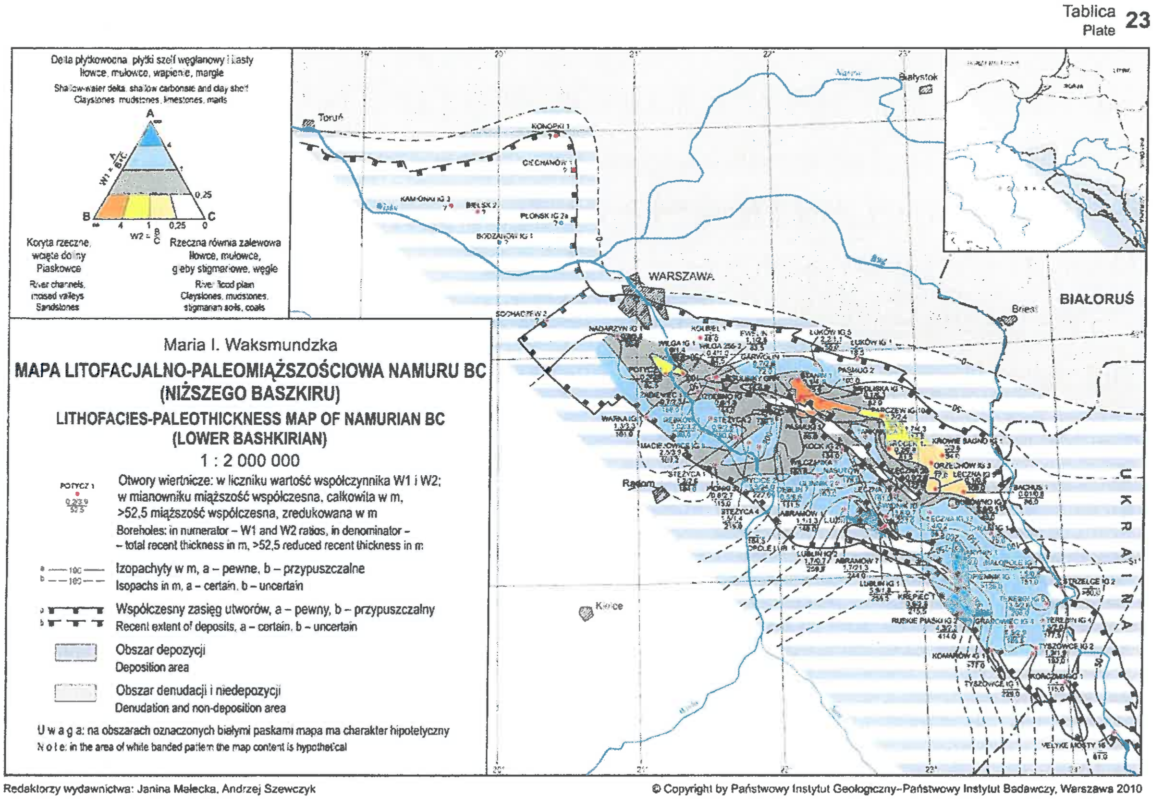

Figure 7. Distribution of sedimentary envinronments in the Lublin Basin during Namurian BC (lower Bashkirian). [A3]

part of delta lobes. A large contribution was observed among coarsening-upward type IId cyclothems and non-gradational type IIId cyclothems, which were formed in floodplain lakes and bogs. The large frequency of these cyclothems points to strong aggradation of sediments of the delta plain, which had a significant contribution in the infilling of the accommodation space in the basin [A7 – Fig. 19a].

The thickness relationships of sediments representing different sedimentary environments suggests that deposits of the Namurian BC (lower Bashkirian) were formed in a fluvial-delta sedimentary regime.

4.5.2.3. Westphalian (upper Bashkirian–Moscovian)

The Westphalian (upper Bashkirian–Moscovian) succession is dominated by fluvial deposits. Within sequences 13–16 they mainly include sandstones of **river channels and incised valleys** contributing up to 40% and forming the LST. Higher sequences 16–22 are dominated by claystones, mudstones, stigmaria soils and coals, reaching up to 79%, formed in various sub-environments of the **floodplain**. In the NW, central and E parts of the basin, various types of braided rivers existed in the early Westphalian (sequences 13–15), as well as hyperconcentrated flows took place in incised valleys [A6 – Tab. 8; Fig. 8, 11]. In fluvial successions there is a clear upward transition from high-energy to low-energy environments. In the SE of the basin they chiefly included rivers of the anastomosing system, rarely meandering and braided rivers [A8 – Tab. 4].

In the Westphalian A, aggradation of deposits of sand-bedded braided rivers within large incised valleys caused the formation of the thickest sandstone lithosome in the Carboniferous, whose thickness reaches about 60–90 m in various parts of the basin. It is also characterized by the largest lateral distribution. In turn, in the upper part of the Westphalian, sandstone lithosomes are numerous but usually isolated and of low thickness reaching merely up to over 10 m.

The relatively lowest contribution have delta and shallow clay shelf deposits, forming the TST and HST, which still occur in sequence 16. Within them I have observed the large contribution of coarsening-upward type Ic and IIc cyclothems in the central part, as indicated by the progradation-aggradation infilling of the accommodation space in the basin. Further to the east, type IIc cyclothems and non-gradational type IIIc cyclothems dominate, which may be linked with large aggradation of marine deposits and the submarine parts of the delta lobes. A large contribution in basin infilling had also aggradation in the delta plain, where numerous coarsening-upward type IId cyclothems and non-gradational type IIId cyclothems developed within lake deltas, lakes and bogs [A7 – Fig. 18a; 19a].

Compared to other parts of the Carboniferous succession, the Westphalian (upper Bashkirian–Moscovian) part may be distinguished by a clearly fluvial sedimentation regime.

4.5.3. Palaeogeography

4.5.3.1. Tournaisian–Visean

Sedimentation in the Lublin Basin was preceded by processes of erosion and non-deposition linked with significant RSL fall in the Late Devonian–early Tournaisian. In the NW of the basin, these processes lasted till the late Visean, resulting in the lack of Tournaisian strata. At least several valleys incised the basin, whose locations are marked on map [A1] as narrow and elongated lithofacies fields with the W1 coefficient reaching 1–4. Due to RSL rise, these valleys became infilled with fluvial deposits which formed the LST. In the SE of the basin, accumulation of sediments in channels of braided rivers took place in the Tournaisian, whereas channels and floodplains of meandering and anastomosing rivers developed in the Visean.

Further RSL rise and oscillations in the Visean caused the domination of shallow shelf carbonate and clay facies, as well as facies formed in the submarine part of delta lobes, mainly the delta slope and prodelta. During high RSL in sequence 3, the marine basin reached a depth of about 80–85 m.

Palaeothickness of the Tournaisian–Visean deposits increases towards the SW and SE [A1]. The presence of maximal thickness values exceeding 400 m in the present-day southern margin of the basin, as well as beyond this boundary indicates the position of the depocentre. The deposition palaeorange and the area of the sedimentary basin in the Visean is recorded by isopach 0, whose course indicates a much wider extent to the SW and NE compared to the present-day range and boundaries of the Lublin Basin. The sedimentary basin was bounded from the N and NE by a vast land area which was subject to denudation and non-deposition.

The wider lateral extent of the Visean strata has been confirmed several years later by the Kraśnik-1 borehole made by Chevron Polska Energy Resources Sp. z o.o. (Hadro et al. 2014), located about 20 km to the SW of the Ursynów–Kazimierz Dolny–Wysokie fault Zone, which is the present-day boundary of the Lublin Basin. In the succession of this borehole, drilled in the Radom-Kraśnik High, palynological studies have confirmed the presence of Visean strata with a thickness exceeding 450 m. This thickness corresponds to the values reconstructed by me on map [A1] in the borehole area.

4.5.3.2 Namurian A (Serpukhovian–lowermost Bashkirian)

During the Namurian A (Serpukhovian–lowermost Bashkirian) the area covered by sedimentation of the submarine parts of delta lobes, mainly delta slope and prodelta, as well as a shallow clay shelf, significantly widened, being related with the rise and high level of the RSL [A2]. Limestones and marly facies of the shallow carbonate shelf appeared relatively rarely and only for short intervals. The marine basin deepened to achieve a maximal depth of about 100 m during transgression in sequence 7, whereas during subsequent transgressions its depth was much smaller and could have reached about 50 m.

Land areas with dominating sedimentation in river channels within incised valleys appeared in the N, centre and SE of the basin during subsequent low levels of the RSL. In the early Namurian A (Serpukhovian), braided, meandering and anastomosing rivers developed in the southernmost part of the basin. Slightly later, in the latest Namurian A (earliest Bashkirian) hyperconcentrated flows appeared also in incised valleys.

The palaeothicknesses increased, similarly as in the Visean, towards the SW, to maximal values exceeding 600 m in the depocentre, located in the basinal margin. The course of isopach 0 towards the N and E of the palaeorange of Visean deposits and overlapping of the Namurian A (Serpukhovian–lowermost Bashkirian) strata point to widening of the margin of the sedimentary basin and shifting of the denudated area to the N and NE by several tens of kilometres [A5].

4.5.3.2. Namurian BC (lower Bashkirian)

Sedimentation of the Namurian BC (lower Bashkirian) was preceded by erosional processes that took place in the Lublin Basin in connection with significant RSL fall. The most significant erosion is recorded in the NW and NE of the basin, and to a smaller degree in its centre and in the SE. This mid-Namurian RSL fall, being of combined eustatic, tectonic and accumulation origin, caused significant reconstruction of the facies zones existing in the Tournaisian–Visean and Namurian A (Serpukhovian).

The dominating shallow shelf and delta environments were largely replaced by land areas with fluvial sedimentation [A3]. RSL fall caused the erosion of incised valleys, which in the NW and E were infilled during RSL rise by deposits of various types of braided rivers. In turn, in the SE they included deposits of hyperconcentrated flows, braided, meandering and anastomosing rivers. The reconstructed probable axis directions of incised valleys from this area ran from the NE to the SW, as well as transversely to this direction [A8 – Fig. 12A].

Further to the SW and S occurred an area with prevailing deposition of shallow deltas and a shallow clay shelf, whereas carbonate facies appeared extremely rarely. The depth of the marine basin was similar to that from the early Namurian. Sedimentation took place within submarine parts of delta lobes, as well as on vast areas of the delta plain, lake deltas, lakes and bogs. In the Visean and Namurian A, delta plain sub-environments appeared rarely, whereas their intense development took place in the Namurian BC.

The palaeothicknesses generally rise to about 400 m towards the SE and SW of the basin, where the depocentre was probably located. In relation to its position in the Visean and Namurian A, it shifted by several tens of kilometres to the SE.

The course of isopach 0 marking the palaeorange of the Namurian BC (lower Bashkirian) deposits indicates that the area of the sedimentary basin expanded laterally by about 100 km to the NW. As a result, it encompassed the Mazovian Zone [A5], in which denudation and non-deposition took place earlier.

4.5.3.3. Westphalian (upper Bashkirian–Moscovian)

During the Westphalian A, in the NW, E and centre of the Lublin Basin dominated sedimentation in various types of braided rivers, as well as hyperconcentrated flows within large incised valleys [A4] during the low level and rise of the RSL. At that time, anastomosing rivers and rarer meandering and braided rivers developed in the SE of the area. The course and depth increase of one of the largest reconstructed valleys from the NE to the SW indicates also the palaeotransport direction of the sedimentary material [A8 – Fig. 13].

Delta and shallow clay shelf environments, related with transgressions and high levels of the RSL existed till the end of the Westphalian A, mainly in the centre and E of the basin, although their contribution was small. The marine basin reached about 50–70 m in depth. Sedimentation took place in the submarine part of the delta lobes – in the prodelta, delta slope and mouth bars, as well as in lake deltas, lakes and bogs on the delta plain.

In the later Westphalian deposition took place in a continental-fluvial environment, mainly in the fully developed floodplain sub-environment with lateral bars, crevasse glyphs, lakes, lake deltas and bogs, and within river channels.

The reconstructed smallest palaothicknesses occur in the NW, NE and E of the basin, in an area located beyond the present day range of Westphalian (upper Bashkirian–Moscovian) deposits. Increase of palaeothicknesses took place generally towards the S and SW of the basin. Maximal values exceeding 1300–1400 m occur in the NW, E and SE part of the Lublin Basin. Although the direction of palaeothickness increase is similar for the entire Carboniferous, the development of several local depocentres did not take place in previous intervals. Only the depocentre in the SE of the basin was situated in a generally similar position as earlier. In turn, the development of two subsequent depocentres points to new areas with large accommodation space, developed along with the reconstruction of the paralic basin into a continental basin.

The palaeorange of Westphalian (upper Bashkirian–Moscovian) deposits corresponding to isopach 0 is larger than the present-day range and points to a lateral extension of the sedimentary basin by about 50 km to the NE [A5], in which denudation and non-deposition took place earlier.

4.6. Summary of the obtained results

Based on lithofacies, cyclicity and sequence stratigraphy analysis, I have reconstructed the depositional architecture and palaeogeography of the Carboniferous in the Lublin Basin. Elements of the depositional architecture have been characterized – sedimentary environments, i.e. shallow clay and carbonate shelf, delta, fluvial environments and hyperconcentrated flows.

The Carboniferous lithofacies-stratigraphic succession is characterized by large variability, related with cyclic appearance of particular sedimentary environments, as well as the modifying influence of RSL oscillations and local tectonics. These factor were decisive for the infilling of the accommodation space in the basin, as well as the mid- and post-Carboniferous erosion. The LST are characterized by deposits of braided, meandering and anastomosing rivers, which flew in incised valleys, where hyperconcentrated flows also took place. The TST and HST are dominated by delta, and shallow clay and carbonate shelf facies.

The thickness relationships of deposits representing various environments within the Tournaisian–Visean indicate a delta-marine depositional regime, and within the Namurian A (Serpukhovian–earliest Bashkirian) – a delta regime. The marine basin attained the maximal depth of about 100 m during the transgression of sequence 7. Reconstruction of facies zones took place at the Namurian A/Namurian BC boundary. In the Namurian BC (early Bashkirian), the shallow shelf and delta environments were largely replaced by continental areas with fluvial sedimentation. The marine basin existed till the end of Westphalian A, whereas later in the Westphalian deposition took place solely in a continental–fluvial environment.

Palaeothickness analysis indicates that beginning from the Tournaisian–Visean to the Namurian BC (early Bashkirian), a depocentre developed close to the southern margin of the Lublin Basin; it gradually shifted to the SE of the basin. In the Westphalian (late Bashkirian–Moscovian) following the reconstruction of the paralic basin into a continental basin, two new depocentres were formed in the NW and E of the basin.

During the Carboniferous, the area of the Lublin sedimentary basin most probably had a much wider extent than that deduced from its present-day boundaries and the present-day ranges of particular Carboniferous stages. Successfully younger palaeoranges onlap the extent of older strata, which indicates widening of the sedimentary basin framework and shifting of the denuded continental area to the N and NE. Deposition in the Lublin Basin was ceased by tectonic inversion, which formed its present-day boundaries, as well as erosionally reduced the top of the Carboniferous succession.

4.7. Literature cited

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5. Presentation of significant scientific or artistic activity carried out at more than one university, scientific or cultural institution, especially at foreign institutions

5.1. Foreign institutions

My first possibility of research in a foreign institution was in 1994 at the **Eberchard Karls Universität Tübingen,** in **Tübingen (Germany),** where I performed petrographic analyses of dispersed organic matter coupled with measurements of vitrinite reflectivity on samples of borehole cores of Carboniferous rocks from the Lublin Basin. The laboratory and microscopic analyses were made in the **Laboratory of Organic Matter Petrology** supervised by **Dr. Bertrand Ligouis**. Following his invitation I also took part in field sedimentological studies of the Carboniferous coal basins Montceau and Decazeville, as well as in the Permian Autun basin in France, being courses for students of geology of that university. This trip was a perfect opportunity to compare Polish and French coal-bearing successions, observe the Carboniferous/Permian boundary in the Autun basin and exchange experience.

During my next trip in 1995 to the **University of Sheffield, Department of Earth Sciences,** in **Sheffield (United Kingdom)** in the frame of the TEMPUS program [G1], I did further petrographic analyses of dispersed organic matter in Carboniferous samples from the Lublin Basin, as well as measurements of vitrinite reflectivity in the laboratory supervised by **Prof. David A. Spears**. My stay at the **Department of Earth Sciences** was also the occasion to exchange experience with its staff, of which most specialized in the studies of coal-bearing Carboniferous deposits in the United Kingdom.

In 2005–2009 I was part of an over 120-member team, which participated in the research project *Petroleum Geological Atlas of Southern Permian Basin Area* [P9]. This project was coordinated by the **Geological Survey of the Netherlands TNO (project manager Dr Hans Doornenbal)** and accomplished in an international team by European geological surveys, i.e. the Belgian GSB, British BGS, Danish and Greenland GEUS, German BGR, Polish PIG-PIB (all are research institutes), as well as universities and hydrocarbon prospecting companies. The project activities focused on the sedimentology, stratigraphy and geology of Carboniferous coal and hydrocarbon deposits in European basins were conducted during project meetings in the headquarters of geological surveys **TNO in Hoofddorp (2006, the Netherlands), BGR in Hannover (2006, Germany) and BGS in Edinburgh (2007, United Kingdom)**. During these meetings intensive cooperation and exchange of experience with the 11-member research team working on the Carboniferous took place, particularly with **Dr Henk Kombrink** from the **Geological Survey of the Netherlands**. The effect of this project was co-authorship of the paper Kombrink et al. (2008) [K12], and co-authorship of the *Chapter 6 Carboniferous* [J2] and *Chapter 15 Reserves and production history* [J3] in the *Petroleum Geological Atlas of Southern Permian Basin Area* (2010).

Exchange of scientific experience with **Prof. Stanislav Opluštil from the Faculty of Science, Charles University in Prague (Czechia)** began in 2004 during the 10th Coal Geology Conference organized by him, where I presented a talk [E1] and co-authored a poster [E2]. During that conference I also began cooperation with **Dr hab. Artur Kędzior from the Institute of Geological Sciences, Polish Academy of Sciences.** A continuation of this cooperation was an invitation to the scientific program *International Geological Correlation Programme # 469: Late Westphalian terrestrial biotas and paleoenvironments of the Variscan foreland and adjacent intramontane basins* [O1] in 2006–2009, coordinated by **Prof. Christopher J. Cleal from the Department of Biodiversity & Systematic Biology National Museum Wales (United Kingdom), Prof. Stanislav Opluštil and Dr. hab. Artur Kędzior**. I was part of a 25-member international team, which worked on this program. The project activities focused on coal sedimentology, stratigraphy and petrology in the Carboniferous of European basins were achieved during a project meeting in the headquarters of the Institute of Geological Sciences, Polish Academy of Sciences in Kraków in 2006, organized in an international conference formula [Ł1], during which I presented a co-authored talk. The effect of this program is co-authorship of the research paper Cleal et al. (2009) [K13].

5.2. National institutions

University of Warsaw

During my employment in 1993–1996 at the Faculty of Geology, University of Warsaw, at first in the Department of Dynamic Geology and later in the Department of Mineral Deposit and Economic Geology, I conducted sedimentological, stratigraphic and petrographic studies of organic matter from coal-bearing Carboniferous deposits in the Lublin Basin based on borehole geological data and geophysical logs. The studies were conducted in the frame of a GRANT financed by KBN entitled *Diageneza materii organicznej z utworów namuru Lubelskiego Zagłębia Węglowego przy zastosowaniu metod: sedymentologicznych, organogeochemicznych i petrologii węgla. Część I – sedymentologiczna* [F1], which I was supervisor and main contractor. Part of the results achieved during this GRANT were presented in publication [B1].

Petrobaltic

In 1996–1997 I was a contractor of a project commissioned to PIG-PIB and financed by **Petrobaltic**, entitled: *Ocena perspektyw poszukiwawczych złóż ropy i gazu ziemnego w basenach sedymentacyjnych młodszego paleozoiku na obszarze zachodniej części polskiego sektora Bałtyku – bloki H, K, L – Etap I, II, III* [R1]. In the frame of this project, in 1996 in the headquarters of Petrobaltic in Gdańsk, I did sedimentological and petrographic studies on the cores of Carboniferous deposits from boreholes in the Polish Baltic Sea sector. I also collected samples for palynological studies from these cores.

Polskie Górnictwo Naftowe i Gazownictwo S.A.

My first sedimentological-stratigraphic studies conducted on borehole material owned by Polskie Górnictwo Naftowe i Gazownictwo S.A. took place in the headquarters of the Wołomin Branch in 1995 in the frame of a GRANT financed by KBN [F1].

Later, in 1997, also in the Wołomin Branch, I did lithofacies and stratigraphic analysis of cores of Carboniferous deposits in the hydrocarbon deposits Stężyca and Rycice area in the Lublin Basin, as well as collected samples for palynological analysis and biostratigraphic studies based on conodonts. These activities were conducted in the frame of projects [R2]-[R3], on commission and financial support of Polskie Górnictwo Naftowe i Gazownictwo, in which I was supervisor and main contractor. During these projects I cooperated with the Director of the Wołomin Branch, Dr. Jan Kaczyński, as well as its staff. I presented the obtained results during 3 national conferences [D1], [D2], [L3], and in publications [J2], [K11], [K12] and [K14].

Further studies of core data owned by Polskie Górnictwo Naftowe i Gazownictwo S.A. were performed in 2007 in the headquarters of the Piła Branch, in the frame of the research project *Petrologia, sedymentologia i nowa litostratygrafia utworów czerwonego spągowca dolnego z wybranych profili platformy waryscyjskiej* [P6] financed by MNiSW, in which I was contractor. In this project I was responsible for lithofacies analysis of cores of Carboniferous deposits comprising the Permian basement in south-western Poland.

I conducted sedimentological-stratigraphic studies coupled with sampling for palynological and petrographic analyses in 2018 and 2019 on Carboniferous cores owned by Polskie Górnictwo Naftowe i Gazownictwo S.A. in the Central Core Storage of PGNiG "Chmielnik" in Chmielnik. The studies were conducted in the frame of a project which I supervised and was the main contractor, entitled *Geneza wulkanitów i skał towarzyszących karbonu basenu lubelskiego w kontekście perspektyw boksytowych i węglowodorowych*, financed by the MNiSW.

6. Presentation of teaching and organizational achievements as well as achievements in popularization of science or art

6.1. Didactic achievements

My didactic achievements conducted in 1991–1996 were related with my employment in the Faculty of Geology, University of Warsaw, in the Department of Dynamic Geology and later in the Department of Mineral Deposit and Economic Geology. These activities included courses in dynamic geology, deposit geology and drilling, and field courses in the Holy Cross Mountains and the Kraków area in dynamic geology, deposit geology, drilling and mining.

After change of my workplace to Państwowy Instytut Geologiczny, I only occasionally had teaching activities. In 2000 I co-organized and co-lead a course for the PGiNG staff in Kraków on the *Identyfikacja i prognozowanie środowisk sedymentacyjnych i litologii osadów na podstawie danych sejsmicznych i otworowych* on the invitation from this company. I also took part in the teaching process at the Faculty of Geology, University of Warsaw in co-operation with Prof. dr. hab. Stanisław Skompski. Subsequently in 2005, 2006, 2009, and

2011 on his invitation I gave 4 lectures on sequence stratigraphy based on the Carboniferous of the Lublin Basin in the frame of the course *Metodologia Stratygrafii*. I was also co-supervisor of a MSc project *Stratygrafia sekwencji i sedymentacja utworów karbonu rejonu Niedrzwicy (płd.-zach. Lubelszczyzna)* finalized in 2010.

As the director of the Energetic Safety Program in 2012–2016 in PIG-PIB, I was the scientific tutor of two interns from the Mining Academy in Kraków and introduced four new employees to work at PIG-PIB, which was linked with scientific support and evaluation of their activities in the conducted projects.

6.2. Organizational achievements

6.2.1. Project supervision

During my entire employment I supervised 19 projects. My activities included elaborating the range of the planned works in form of an application or offer, coupled with preparation of a detailed financial schedule (9 in cooperation), and later coordinating the performed analyses and other activities related with research, technical issues, field studies, editorial works, reporting, negotiating work and cooperation contracts, financial accounting with NFOŚiGW and preparing of final reports. The teams in the scientific-research and commercial projects comprised from 2 to 10 members, whereas in projects conducted in the frame of PSG – from over 10 to about 60 members. The projects were accomplished by PIG-PIB staff in cooperation with specialists and experts from other research units, i.e. University of Warsaw, Jagiellonian University, Adam Mickiewicz University, Mining Academy in Kraków, and Oil and Gas Institute.

The first project which I supervised during my employment at the Faculty of Geology, University of Warsaw, was GRANT [F1] financed by KBN and realized in 1995. As an employee of PIG-PIB, subsequently in 1998–2004, 2008–2010, 2015–2017 and 2017–2020, I supervised 4 research projects [H2], [H4], [P27], [P37] financed by MNiSW.

Additionally, in 2006–2019, I supervised 5 subsequent projects [P2], [P3], [P11], [P20], [P31] conducted in the frame of assignments of the Polish Geological Survey (PSG), focused on elaborating and publishing 42 issues in the series *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*. The published issues from the series were updated to modern publishing standards, by introducing a new graphic layout, good quality of print and paper, elements translated into English, and a wider range of the presented research.

In the PSG in 2008–2016 I have supervised 3 projects related to the potential methaneyield of coal layers in the Lower Silesia Coal Basin [P7], supporting the activities of the Minister of the Environment [P25], and state activities performed by the PSG for elaborating the assessment of geological perspective treatment of hydrocarbon deposits and preparation of tender material for the concession organs [P26].

In 1997–2013 I have also supervised 5 commercial projects, commissioned by PGNiG [R2]-[R3], FX Energy [S2], Gora Energy [S4], and the Ustka Local Government Council [T1].

Regional Geology Department (before Energy Security Program, Deep Structure Geological Mapping Department, Department of Regional Geology, Mineral Deposit and Geophysics, Department of Regional and Petroleum Geology)

6.2.2. Functions fulfilled in PIG-PIB

During my employment in PIG-PIB I have occupied various chairman functions in 2006–2016:

- **2006-2011 director of the laboratory** of Regional Geology and Basic Geology of Deep-Seated Structures;
- **2007-2008 vice director** of the Department of Regional Geology, Mineral Deposit and Geophysics;
- **2008-2011 vice director** of the Deep Structure Geological Mapping Department;
- **2011-2012 vice director** of the Energetic Safety Program;
- **2012-2016 director** of the Energy Security Program.

I consider the supervision in 2012–2016 of the Energy Security Program as the largest organizational challenge in my career. The most significant achievement from this supervision was the employment and accomplishment of about 25 new tasks of the PSG in subsequent plans for 2013, 2014 and 2015, focused on the energetic safety of Poland, out of which several are still continued as enduring tasks of the PSG.

6.2.3. Participation in competition teams

As the director of the Energy Security Program and the secretary of 6 competition commissions, in **2013–2015** I have conducted competition procedures for research and non-research positions in PIG-PIB.

6.2.4. Participation in the PIG-PIB Scientific Council

In 2015–2017 I was an elected member of the PIG-PIB Scientific Council and the vice president of the Organizational–Economic Commission in this Council. The main tasks of the commission included evaluating candidates for directorial functions, including the vice directors, as well as PIG-PIB financial plans and reports. The commission evaluated over 30 persons based on the presented assessment of their activities, qualifications, management achievements and in course of interviews.

6.3. Achievements in popularizing science

As the graduate of the Geological Technical College in Warsaw, I maintain contact with the staff and students of this school by participating in the celebration of the Miner's and Geologist's Day and Geological Competitions for college students. I support the teaching process in this and several other colleges in Poland that educate geology technics, by passing on, personally or by distribution lists, numerous teaching aids and books in geology.

I have also endowed in 2017 two prizes for the finalists of the XVIII edition of the Polish and the XI edition of the Polish-Lithuanian *Konkurs Geologiczno-Środowiskowy Nasza Ziemia – środowisko przyrodnicze wczoraj, dziś i jutro. Geologiczne barwy Ziemi* organized by the Geological Museum of the PIG-PIB for primary school students.

7. Apart from information set out in 1-6 above, the applicant may include other information about his/her professional career, which he/she deems important.

7.1. Discussion of the remaining scientific-research achievements

PRIOR TO OBTAINING THE PH.D. DEGREE

My first individual project, realized in 1995 was a GRANT financed by KBN [F1]. Based on lithofacies, microfacies and cyclicity analysis in cores from 5 boreholes, I have interpreted the sedimentary environments in the Carboniferous deposits from the central part of the Lublin Basin and prepared their lithological-stratigraphic correlation. I have also assessed the thermal maturity of these deposits based on archival results of Rock-Eval pyrolitic analyses.

The main results of this project, as well as the results of my MSc research have been published as a monograph chapter [B1], which for the first time characterized depositional systems and transgressive-regressive cycles in the Carboniferous of the Lublin Basin in reference to litho- and chronostratigraphic units.

After change of my employment to PIG-PIB, in 1996–1997 I was contractor of a commercial project on the commission of Petrobaltic [R1] (supervisor doc. dr. hab. A.M. Żelichowski). In the frame of this project I prepared an original lithofacies analysis and interpretation of depositional environments in the upper Carboniferous from 4 cores, which constituted part of an assessment of the oil and gas prospective potential in the western part of the Polish Baltic Sea sector.

In 1997–1998 as supervisor and main contractor, I accomplished two commercial projects commissioned by PGNiG [R2]-[R3], in which for the first time I performed lithofacies analysis, interpretation of depositional environments and correlation of the Carboniferous in the hydrocarbon deposit Stężyca and Rycice area in the Lublin Basin, based on 4 cores. In 1998, I was contractor of a commercial project commissioned by PGNiG [R4] (supervisor dr. hab. P. Krzywiec), in which I prepared an original sedimentological-stratigraphic analysis of Carboniferous correlation horizons K, I, and H, which was part of a seismic analysis near Stężyca and Rycice. The lithofacies columns prepared during these projects became the basis for further studies and publications, which were published after obtaining the PhD degree, i.e. [J2], [J3], [K11], [K12], and [K14]. They were also presented in two national conferences [D1]-[D2].

In 1998–2000 I was contractor in a scientific-research project [H1] (supervisor dr. hab. J. Grabowski), during which I selected representative lithofacies from the Carboniferous succession in the Lublin Basin, which were next analysed by other project contractors with application of palaeomagnetic methods in order to assess their feasibility to orient borehole cores. The result of this cooperation is co-authorship of a paper (Grabowski et al. 2002) [C1].

The first large, interdisciplinary project, which I conducted in 1998–2000 was the scientific-research project [H2]. In the frame of this project I have made an original lithofacies analysis, interpretation of sedimentary environments and correlation of Carboniferous deposits in 7 cores, which were next integrated with the results of petrographic, petrophysical and geochemical data, coordinated by Dr. A. Kozłowska. The main results of this research were presented in the 10th Coal Geology Conference (2004 Prague, Czechia) [E1]-[E2], and in publications after conferring the doctoral degree [K11], [K14].

In 2002–2004, as supervisor and main contractor of the scientific-research project *Ewolucja facjalna i analiza sekwencji w paralicznych utworach karbonu z płn. – zach. i* *centralnej Lubelszczyzny* [H4], I conducted original sedimentological and sequence stratigraphic analyses based on 17 cores. For the first time the facies evolution of the sedimentary environments was reconstructed in the frame of a sequence stratigraphic scheme (encompassing sequences 1–16). The project was finalized in my PhD dissertation bearing the same title, resulting in conferring a PhD degree in Earth Sciences, in geology – sedimentology. The main results of my PhD dissertation were published in two subsequent papers [K11] and [K14].

Simultaneously with the preparation of the PhD dissertation, in 2003–2005 I was contractor of a large, interdisciplinary scientific-research project (supervisor Prof. dr. hab. M. Narkiewicz) [H5], in the frame of which I prepared an original lithofacies analysis, interpretation of depositional systems, correlation, sequence stratigraphy and distinguishing stratigraphic-resource complexes for 27 (including 10 new in relation to the range of the PhD dissertation) Carboniferous successions from boreholes located along 4 regional cross-sections, as well as analysis of archival data and well logs for about 50 other boreholes from beyond the correlation lines. These studies have enabled to construct a facies and stratigraphic framework for the remaining petrographic, tectonic, seismic, petrophysical, hydrodynamic analyses, and 1D modelling performed by the project contractors. During this project, I have successfully tested on subsequent c. 40 boreholes the sequence stratigraphic model elaborated in my PhD dissertation, which was next extended to encompass the higher, limnic part of the Carboniferous succession that included 6 sequences 17–22. This allowed me to falsify the sequence stratigraphic model worked out in the PhD dissertation based on studies of an almost three-fold number of boreholes compared to the original number of boreholes.

The effect of this project [H5] was co-authorship of a paper (Narkiewicz et al. 2007 [K2]), co-authorship of a talk at an international conference (Krzywiec, Waksmundzka 2010 [M1]), and authorship of paper [K11], which appeared after conferring the PhD degree.

AFTER CONFERRING THE PH.D. DEGREE

Apart from the topics described under my main scientific achievement, my activities after conferring the Ph.D. degree were focused on the following issues.

7.1.1. Carboniferous studies in SW Poland and the national resources potential

In 2006–2008 I participated in elaborating a research topic focused on the Rotliegend deposits from selected successions in SW Poland (supervisor Prof. dr. hab. A. Maliszewska)

[P6]. I performed original lithofacies studies of the Carboniferous deposits occurring in the Permian basement coupled with characteristics of the sedimentary environments based on data from 5 boreholes.

In 2009–2011, I was contractor in a project on commission of AGH (supervisor Prof. dr. hab. T. Peryt) [P15], whose main aim was the assessment of the degree of knowledge on Polish oil reservoirs coupled with indicating the direction of further research and prospecting works, which I have prepared for the Carboniferous of the Lublin Basin after analysis of 68 archival projects and atlas publications.

In 2013–2015 [P21] and 2017–2019 [P30], I was contractor of the first PSG project and its continuation, which was focused on recognizing potential zones of unconventional hydrocarbons in Poland (supervisor dr. hab. T. Podhalańska), e.g. within the Carboniferous of SW Poland. In cooperation with Dr. A. Becker I have elaborated 10 lithofacies-stratigraphic sections of boreholes, along with selecting and characterizing potential reservoir lithological complexes, i.e. sandstone, shale and hybrid, which were the basis of further petrographic, petrophysical, geophysical, organic matter maturity analyses and models for generation of petroleum expulsion, prepared by other project contractors. The most important results of project [P21] were presented in two papers, of which I am co-author (Podhalańska et al. 2016 [K23]; Podhalańska et al. 2016 [K24]), as well as a poster on an international conference (Podhalańska et al. 2017 [M2]).

In 2013–2015 and 2017–2020 I took part in two PSG projects *Szacowanie zasobów złóż węglowodorów – zadanie ciągłe PSG* (supervisor Dr. A. Wójcicki) [P24], [P34], in the frame of which, in cooperation with Dr. A. Becker, I have elaborated the assumptions and indispensable lithofacies-stratigraphic and regional data for assessing the prospective potential of Carboniferous strata in the basement of SW Poland. These results, coupled with data referring to other chronostratigraphic systems were the basis of the assessment of *tight gas* resources by Dr. A. Wójcicki and included in the PSG report *Prognostyczne zasoby gazu ziemnego w wybranych zwięzłych skałach zbiornikowych Polski* (Wójcicki et al. 2014 https://www.pgi.gov.pl/docman-tree-all/prasa/2995-raport-prognostyczne-zasoby-gazu-ziemnego-w-wybranych-zwiezlych-skalach-zbiornikowych-polski/file.html).

In 2015–2018 I was contractor of the first PSG project focused on the analysis of geological and geophysical data prior to access to the State Geological Archive (NAG) from areas subject to concessions for petroleum prospecting and recognition or uptake (supervisor Dr. M. Jasionowski) [P26]. In 2015–2017 I was contractor in the first PSG project aimed at integrating geological-resource data on the petroleum systems of Poland (supervisor Dr. A. Becker) [P29]. In the frame of this project I have prepared lithofacies-stratigraphic columns for 39 boreholes from Western Pomerania, along with distinguishing potentially collector and sealing horizons. These results allowed to prepare a framework for analyses performed by other project contractors; in consequence a series of maps was prepared: structural, thickness, lithofacies, hydrogeological, porosity and permeability distribution, as well as petroleum potential.

In 2020 as contractor of a PSG project encompassing the revaluation of the condition of geological reconnaissance in Poland for petroleum and metal ores prospecting and uptake (supervisor Dr. A. Feldman-Olszewska) [P33], I have prepared a characteristics of the geological structure and Carboniferous succession in the Lublin Basin, Mazovian zone and Pomeranian Basin, as well as the perspectives of petroleum occurrence, along with indicating the directions of further studies in form of a new PSG project.

7.1.2. Studies of the Carboniferous in the Lublin Basin

In 2015–2017 I was contractor and supervisor of the scientific-research project [P27], in the frame of which I prepared an original lithofacies and sequence stratigraphic analysis of the oldest Carboniferous strata in the Lublin basin belonging to the Kłodnica Member, based on 11 boreholes. The remaining petrographic analyses were made by Dr. A. Kozłowska and Dr. M. Pańczyk. The most important data from the obtained results related to the distinguishing of Tournaisian strata in the succession and its characteristics have been presented in a paper (Waksmundzka et al. in press [K25]).

I have continued studies on the Tournasisian in the Lublin basin in 2017–2020 in a subsequent scientific-research project [P37], on a larger number of boreholes and with application of a wider spectrum of research methods, which included also SHRIMP detrital zircon analysis, palynologic and biostratigraphic studies.

7.1.3. The *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego* series

In 2006–2019 I was contractor and supervisor of 5 subsequent projects in the frame of PSG tasks [P2], [P3], [P11], [P20], [P31], during which I prepared the lithological-stratigraphic and sedimentological characteristics of 10 Carboniferous successions from the Lublin Basin, Mazovian zone and basement of the Mid-Polish Swell. The result of these projects is authorship or co-authorship of 11 monograph chapters* [J1], [J7]-[J10], [J18]-[J20], and 16 papers* [K1], [K3]-[K5], [K7]-[K10], [K15]-[K22] in the series *Profile*

Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego (https://www.pgi.gov.pl/oferta-inst/wydawnictwa/serie-wydawnicze/profile-otworow-pig.html). I was also scientific editor of 2 issues containing the description of boreholes Lublin IG 1 [K6] and Komarów IG 1 [H1], as well as co-editor of the issue with borehole Wilga IG 1 [H2].

* Due to the non-cyclic character of this series, in 2008, 2014, 2018, 2019 it was categorized as a monograph, and in 2007, 2011, 2012 – as a journal.

7.1.4. Atlas editions

***Petroleum Geological Atlas of Southern Permian Basin Area* 2010 (J.C. Doornenbal, A.G. Stevenson Eds.)**

In 2005–2009 I was contractor of 2 scientific-research projects [P4], [P5] (supervisor Prof. Dr. hab. T. Peryt) realized in PIG-PIB, as well as the international project [P9] (project manager Dr. H. Doornenbal **TNO**); these projects have been characterized in chapter 5. The *Petroleum Geological Atlas of Southern Permian Basin Area* as well as a publication [K12] were prepared in the frame of these projects; in the atlas I have co-authored 2 chapters [J2] [J3].

***Atlas paleogeologiczny podpermskiego paleozoiku kratonu wschodnioeuropejskiego w Polsce i na obszarach sąsiednich 1:2 000 000* 2010 (Z. Modliński Ed.)**

In 2008–2010 I was contractor of a scientific-research project (supervisor Dr. hab. Z. Modliński) [P10] focused on constructing lithofacies–palaeothickness and palaeogeological maps for the systems of the sub-Permian Palaeozoic in the East European Craton in Poland and neighbouring areas, and their publishing in an atlas. In the frame of this project I have prepared 9 original lithofacies–palaeothickness and palaeogeological maps with an explanatory text, among which 5 [A1]-[A5] are part of the scientific achievement and have been characterized in chapter 4.

In maps that are not included in the scientific achievement, I have illustrated the palaeogeography of the Lublin Basin after the Namurian A (Serpukhovian–lowermost Bashkirian) [J4] and the palaeoranges of sediments formed in the Namurian BC (lower Bashkirian) and Westphalian (upper Bashkirian–Moscovian) [J5]. The third map, i.e. *Mapa paleogeologiczna dolnej strony przedpermomezozoicznej powierzchni niezgodności* [J6] was constructed based on the compilation of 4 geological maps of Poland of the authors cited in the Atlas, which is an updated contemporary exposed geological map without

Permian–Mesozoic strata in NE Poland, with introduction of formal Carboniferous chronostratigraphic units.

***Atlas geologiczny Polski* 2017 *Geological Atlas of Poland* 2020 (J. Nawrocki, A. Becker Eds.)**

In 2013–2015 I participated in a scientific-research project, whose aim was elaborating and publishing the first *Atlas geologiczny Polski* (supervisor Prof. Dr. hab. J. Nawrocki) [P23]. In its frame I have co-worked on preparing an exposed geological map under the Permian–Mesozoic [J11A], Carboniferous thickness map [J12A], location of deep boreholes [J13A], and stratigraphic charts [J14A]-[J15A]. In 2020 the English version of the atlas, *Geological Atlas of Poland* was published. In this version I am co-author of the maps and charts presented above [J11B]-[J15B].

7.1.5. *Stratigraphic chart of Poland*

In 2004–2006 I was contractor of a PSG project *Stratygraficzna tablica Polski* (supervisor Prof. Dr. hab. R. Wagner) [P1], aimed at preparing a published updated Polish version of the stratigraphic chart. In the frame of this project I prepared the stratigraphic column and elaborated the sedimentary environments for the Carboniferous in the Lublin Basin. The stratigraphic chart was published in 2008.*

* I have not indicated this position in my list of achievements, because the dimension of the figure I have authored was too small to be classified as a monograph chapter.

7.1.6. 3D models

In 2013–2015 and 2018–2020 I was contractor of two PSG projects, focused on constructing 3D digital geological models. In the first project (supervisor Eng. J. Chełmiński) [P22], I prepared the model assumptions, as well as lithofacies-stratigraphic columns for 85 boreholes, which were the basis for the first 3D model of the Carboniferous in the Lublin Basin prepared by project contractor Dr. Z. Małolepszy.

In the second project I worked on the model assumptions for Carboniferous strata in the vicinity of the Gorzów Block (NW Poland) (supervisor Dr. E. Szynkaruk) [P32], and interpreted lithological columns for 37 boreholes in Petrel, based on which the 3D model was prepared by project contractor Dr. Z. Małolepszy.

7.1.7. Central Geological Data Base (CBDG)

In 2006–2010 I took part in 2 subsequent PSG projects aiming at the verification and supplementation of data in the subsystem OTWORY in the Central Geological Data Base

(CBDG) (supervisors Prof. Dr. hab. R. Wagner and Dr. M. Słowakiewicz) [P8], [P14], which are available on-line on the PIG-PIB webpage. During these projects I introduced an original stratigraphic scheme for the Carboniferous using formal units for about 100 boreholes from the Lublin Basin and the Mazovian Zone.

In a following PSG project in 2009–2012 I took part in supplementing the CBDG (supervisor M.Sc. E. Machalska) [P18], by preparing the characteristics of about 45 chronostratigraphic and about 70 lithostratigraphic units from the upper Carboniferous. These activities continued in 2020 in the frame of a subsequent PSG task (supervisor M.Sc. M. Sołowczuk) [P36], in the frame of which I updated and characterized selected formal chronostratigraphic units of the Carboniferous in the application *Słowniki stratygraficzne CBDG.*

7.1.8. Elaboration and protection of stratotype sections of borehole cores

In 2008–2010 and 2015–2017 I took part in two subsequent PSG projects (supervisor Dr. K. Leszczyński) [P12], [P28], focused on elaborating and protection of selected stratotype sections of borehole cores stored in NAG. In co-operation with Dr. A. Kozłowska, I selected two unique, fully cored intervals of Carboniferous strata from the Lublin Basin, of which the first one has already been studied and protected, and the second one will be studied in the continuation of this task in 2021–2023 [P40].

7.1.9. Safe CO_2 geological storage

In 2008–2010 and 2010–*2012 I was involved in the first PSG projects aimed at recognizing formations and structures for safe CO_2 geological storage along with their monitoring program* (supervisor Dr. Eng. A. Wójcicki) [P13], [P17]. My activities included analysis of lithofacies-stratigraphic data of Carboniferous deposits in the Lublin Basin, Mazovian Zone and Western Pomerania based on about 130 boreholes, in which I selected sandstone horizons fulfilling the criteria of reservoir rocks with sealing horizons.

7.1.10. Assessment of environmental hazards

In 2011–2013 I took part in a PSG project (supervisor Dr. M. Konieczyńska) [P19] dealing with rendering an assessment of natural environment hazards linked with conducting prospective and exploitation boreholes for unconventional hydrocarbons. In the project I was responsible for preparing a characteristics of Carboniferous and Devonian complexes as potentially sealing media for the Ordovician and Silurian gas-bearing formations in the Wierzbica study area located in the Lublin Basin.

7.1.11. Commercial projects

In 2006 I conducted and coordinated elaboration of geological and geophysical data in the frame of a project commissioned by EOG Resources (supervisor Dr. hab. P. Krzywiec) [S1] for about 40 boreholes from the Lublin Basin, as well as their correlation along 7 regional cross-sections.

In 2007, on the commission of FX Energy Poland [S2], I prepared the facies development, sequence stratigraphy and characteristics of reservoir sandstones in the Carboniferous from the vicinity of Wilga–Żabieniec in the Lublin Basin based on 13 boreholes and their correlation, as well constructed thickness maps for the area.

My participation in the next project in 2007 on the commission of Orlen Upstream (supervisor Dr. hab. P. Krzywiec) [S3] included co-preparation of a report containing e.g. the results of sedimentological-stratigraphic studies in the Carboniferous of the Lublin Basin.

In 2013 with Dr. A. Becker I worked in a project commissioned by Gora Energy [S4], in which I prepared a lithological-facies and stratigraphic column of Carboniferous strata in borehole Marcinki IG 1 based on measuring core sections coupled with distinguishing lithological-facies complexes.

7.1.12. Presently active projects

At present, I am working on Carboniferous deposits in two PSG projects, which are a continuation of my earlier cooperation with the team preparing 3D models. The first project covers the area of the Szczecin Basin (supervisor M.Sc. Ł. Nowacki) [P38], and the second covers the entire area of Poland (supervisor Dr. E. Szynkaruk) [P39].

In 2022–2023 I will be contractor of a PSG project (supervisor M.Sc. J. Iwańczuk) [P41] with regard to Carboniferous deposits, as well as the scientific co-editor, together with Dr. A. Becker, of the Maciejowice IG 1 borehole for publication in the series *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*.

7.1.13. Courses and workshops

In 2000–2016 I participated in 12 courses and workshops, which contributed to widen my knowledge with regard to sequence stratigraphy [H1'], unconventional hydrocarbons [P11'] and nuclear atomic science [P3'], as well as methods of project management [P1']- [P2'], human resources management [P7'], [P9'], [P10'], public finance management [P4'], protection of classified information [P5']- [P6'], and negotiations [P8'].

7.2. Summary of the scientific and research achievements (including the items included in point 4)

SCIENTIFIC AND RESEARCH ACHIEVEMENT	Before the Ph.D. degree	After the Ph.D. degree	SUM
Total number of points MNiSW: Before 2019: for release year/for 2019 Years 2019-2021	 b.d./60 -	 340/1140 240	 340/1200 240
Total IF	-	3.398	3.398
Total 5-year IF	-	3.116	3.116
h-index according to the base WoS*	-	3	3
h-index according to the base Scopus*	2	8	8
Total number of citations by WoS*/ Including no self citations	0	93/90	93/90
Total number of citations by Scopus*/ Including no self citations	16/16	179/156	195/172
Total number of publications with chapters in monographs	2	58	60
Publications in the journals from the list JCR	0	5	5
Publications in the journals from the base WoS/Scopus	0/2	4/9	4/11
Conference materials posted in the base Scopus	0	3	3
Publications from the list A MNiSW	0	4	4
Publications from the list B MNiSW	0	22	22
Publications from 2019-2021 from the list MNiSW	0	2	2
Published scientific monographs	0	0	0
Editing/co-editing of monographs and journals	0	3	3
Published chapters in monographs	1	31	32
Membership in the editorial boards of monographs	0	1	1
Published articles in scientific journals	1	27	28
International programs	-	1	1
Speeches and co-authorship (lecture/poster) at national conferences	2	3	5
Speeches and co-authorship (lecture/poster) at international conferences	2	4	6
Article reviews	0	4	4

Co-promotion of the MSc thesis	0	1	1
Internships in foreign scientific institutions	1	0	1
Project supervision	2	17	19
Implementation/co-implementation of scientific and research projects, as well as PSG	6	37	43
Commercial projects commissioned by oil companies	5	4	9
Presently active projects	-	3	3
Courses and workshops	1	11	12
Awards for scientific work and decorations	-	5	5

Table 2. List of scientific and research achievements before and after obtaining the Ph.D. degree; WoS – Web of Science; JCR – Journal Citation Report; * as of March 8, 2021

Maria Waksmundzka

(Applicant's signature)