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The Silurian stratigraphy of the Zawiercie–Żarki area (NE margin of the Upper Silesian Coal Basin)

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Structural position, lithological character, major petrographical features and biostratigraphy of Silurian deposits are discussed basing upon data from boreholes drilled between 1970 and 1989. Diagnostic studies of graptolite and conodont fragments have enabled the recognition of Wenlock, lower Ludlow (Gorstian) and presumably locally the lowermost part of upper Ludlow (Ludfordian) deposits within the clastic part of Silurian sequence, whereas within its carbonate part — Llandovery and lowermost Wenlock sediments. The Lower Silurian carbonates pass down into the Ordovician ones probably with sedimentary continuity. This is evidenced by conodont successions in the borehole sections Ż-88 and Ż-89. Achimetamorphic transformations (regional, dynamic and thermal-metasomatic) of Silurian rocks and a high degree of tectonic differentiation between individual sections are common. The lack of stratigraphically complete Silurian sequences results mainly from their intensive tectonism and the pre-Devonian and pre-Triassic erosion.

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INTRODUCTION

Studies of archival core material from the Lower Palaeozoic, including Silurian, of the NE margin of the Upper Silesian Coal Basin were conducted during the period of 1985–1995. They supplied many new data which enabled to extend or verify so far existing views on stratigraphy, lithology and structural position of the system. The stratigraphical-lithological results of these investigations are the subject of this paper.

Cores, thin sections and Silurian fossils were studied from selected boreholes drilled between 1970 and 1985 in the Zawiercie–Żarki–Lubliniec area by the Polish Geological Institute (Upper Silesian Branch in Sosnowiec, former Department of Ore Deposits) and the Geological Enterprise in Kraków. The majority of those boreholes was situated in the following areas of geological exploration: Mrzygłód–Zawiercie (Mz), Koszęcin–Włodowice (KW), Winowno–Będusz (WB), Myszków (Pz), Zawiercie (Rk), Żarki (Ż) and Boronów–Niegowa (BN). Silurian deposits were fully cored in the borehole sections used. In a few sections, the Silurian sequence has not been drilled through (Fig. 2). The material selection followed a good preservation state of core, its recovery, the most complete stratigraphic section (Llandovery, Wenlock, Ludlow), relatively long interval drilled, low degree of tectonism and anchimetamorphic transformations, and possibilities of observing stratigraphical boundaries of the standard division. The location of the investigated borehole sections is shown in Figure 1, and their correlation is depicted in Figure 2.

Overall, cores from more than 50 boreholes were analyzed. For detailed investigations, cores from 35 boreholes were used. The investigations included a detailed lithological description, sedimentological and tectonic (mesostructural) observations, qualitative and quantitative petrographical and microfacies analysis of thin sections as well as identification of fossils (graptolites, bivalves, cephalopods, brachiopods, conodonts). Around 3500 m of cored intervals were analyzed. Total number of 450 samples were collected, including 250

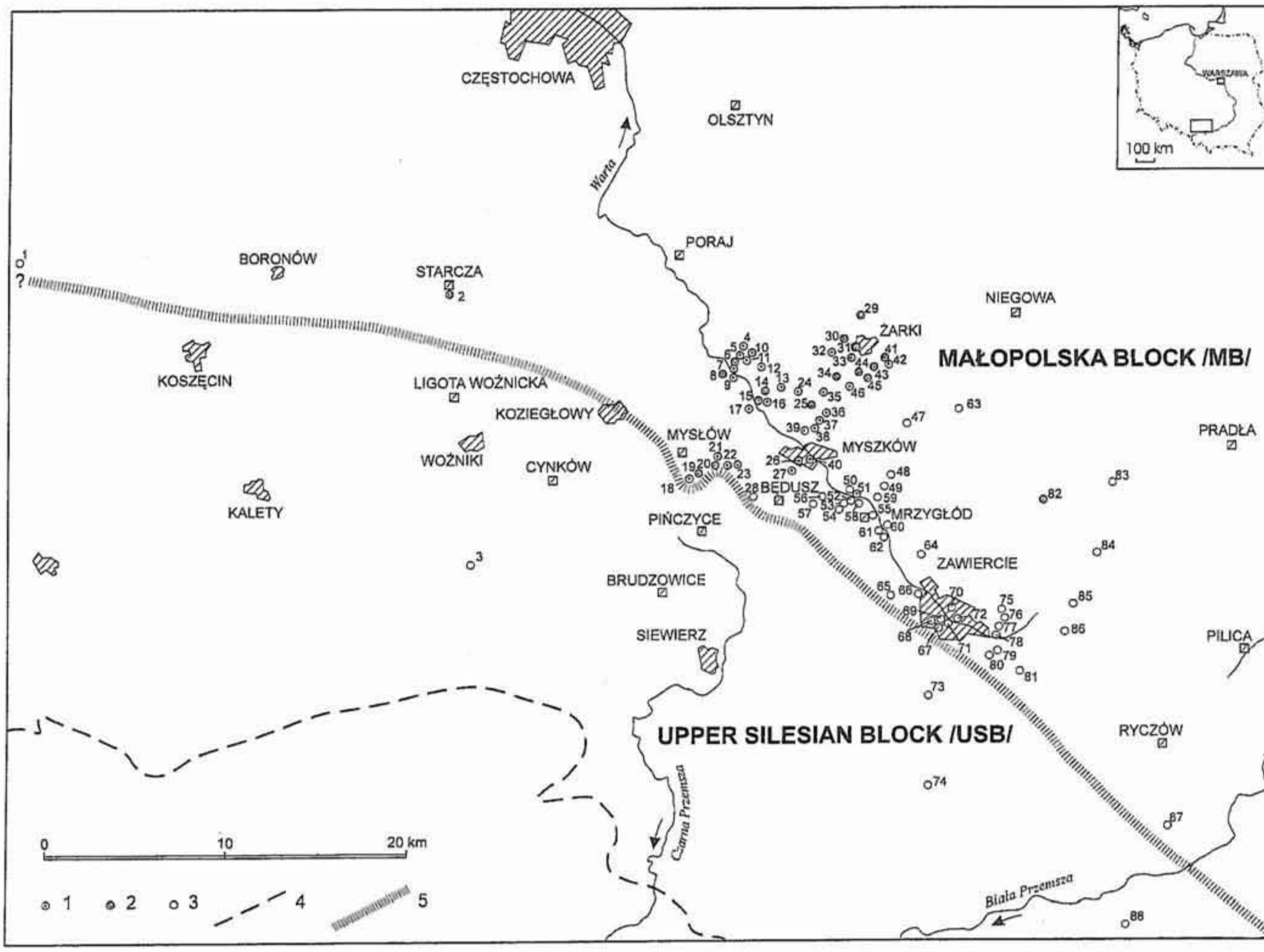


Fig. 1. Location map of boreholes in the Zawiercie–Żarki area (NE margin of the Upper Silesian Coal Basin)

1 — boreholes with Silurian deposits recognized; 2 — boreholes with palaeontologically dated Silurian deposits; 3 — other boreholes mentioned in the text; 4 — boundary of the Upper Silesian Coal Basin (after Z. Buła and A. Kotas, 1994 and J. Jureczka *et al.*, 1995); 5 — presumable extent of the supposed strike-slip fault zone; boreholes: *1* — Lubliniec IG 1, *2* — KW-11, *3* — BM-152, *4* — Ż-14, *5* — Ż-13, *6* — Ż-12, *7* — Ż-11, *8* — Ż-10, *9* — Ż-19, *10* — Ż-21, *11* — Ż-20, *12* — KW-22, *13* — Ż-52, *14* — Ż-42, *15* — Ż-41, *16* — Ż-44, *17* — KW-21, *18* — WB-39, *19* — WB-42, *20* — WB-44, *21* — WB-45, *22* — WB-49, *23* — WB-47, *24* — Ż-54, *25* — Ż-63, *26* — Ż-82, *27* — Ż-81, *28* — Mz-82, *29* — Ż-59, *30* — Ż-58, *31* — Ż-67, *32* — Ż-57, *33* — Ż-66, *34* — Ż-65, *35* — Ż-64, *36* — Ż-75, *37* — Ż-74, *38* — Ż-73, *39* — Ż-71, *40* — Ż-94, *41* — Ż-91, *42* — KW-18, *43* — Ż-89, *44* — Ż-78, *45* — Ż-88, *46* — Ż-77, *47* — Ż-131, *48* — M-1, *49* — A-9, *50* — P-1, *51* — A-4, *52* — M-7, *53* — M-8, *54* — M-9, *55* — M-10, *56* — Pz-6, *57* — Pz-7, *58* — A-3, *59* — A-10, *60* — A-7, *61* — A-6, *62* — A-5bis, *63* — Kotowice 1, *64* — Mz-50, *65* — Mz-4, *66* — TN-261, *67* — Rk-1, *68* — Rk-2, *69* — Rk-3, *70* — Rk-4, *71* — Rk-5, *72* — Rk-6, *73* — TN-100, *74* — Ogrodzieniec 2, *75* — ZMZ-71, *76* — ZMZ-63, *77* — ZMZ-64, *78* — ZMZ-66, *79* — TN-320, *80* — TN-314, *81* — TN-132, *82* — KW-31, *83* — Kz-5, *84* — Kz-3, *85* — Kz-2, *86* — Kz-1, *87* — Kwaśniów, *88* — Klucze 1

Mapa lokalizacji otworów wiertniczych w rejonie Zawiercia–Żarek NE obrzeżenia GZW

1 — otwory wiertnicze, w których stwierdzono osady syluru; 2 — otwory wiertnicze z osadami syluru datowanymi paleontologicznie; 3 — inne otwory wiertnicze wymienione w tekście; 4 — granica Górnośląskiego Zagłębia Węglowego (według Z. Buły i A. Kotasa, 1994 oraz J. Jureczki i in., 1995); 5 — przypuszczalny przebieg strefy domniemanego uskoku przesuwczego; objaśnienia otworów wiertniczych patrz podpis angielski

macro- and microfossil samples and 200 petrographical and microfacies samples. From the latter 140 standard thin sections and 20 polished surfaces were prepared. Some of the thin sections were stained with alizarin-S or Evamy's solution in order to identify carbonate minerals (*cf.* G. M. Friedman, 1959, 1971).

Basic types of carbonate and clastic rocks have been distinguished basing upon their mineral composition, textural features and a character and content of allochemical components. A simplified subdivision has been used for carbonate rocks, describing sparite, clayey sparite and sparse biosparite rocks. The classification by R. L. Folk (1968) for limestones and the classification by R. L. Dott modified by F. J. Pettijohn, *et al.* (1972) for clastic rocks have been applied.

The description of Silurian rocks is supplemented with the results of microscopic analyses. In particular, quantitative and semi-quantitative data on their mineral composition in volume percentage, content and character of bioclasts, structure and texture as well as maximum and most frequent size of quartz grains with their roundness and sphericity have all been taken into account. These have been determined using the method of geometric analysis.

In the course of petrographical investigations, efforts were made to reconstruct — as far as possible — the so-called primary rock type, i.e. a parent character of sediment. It was possible for most of the samples studied, since their microscopic image showed either relics of primary structures or strong analogies to samples collected from non-metamorphosed or poorly metamorphosed rocks. In exceptional cases, comparisons were made with coeval rocks from neighbouring areas, including among others the Precambrian Platform (pre-Vendian) where they have maintained their primary structural and mineralogic features unchanged.

Fundamental data and views on the geological structure of the Zawiercie–Żarki segment and its evolution as well as the occurrence, stratigraphy and lithology of Silurian deposits in this region are given in archival materials and published papers of: S. Z. Różycki (1953), S. Siedlecki (1962), H. Tomczyk (1959, 1960), H. Tomczyk and E. Tomczykowa (1983), F. Ekiert (1971, 1978), S. Bukowy (1972, 1984), C. Harańczyk (1982, 1992), K. Piekarski and A. Siewniak-Witruk (1978), K. Piekarski *et al.* (1980), K. Piekarski and B. Szymański (1982), L. Wielgomas *et al.* (1980, 1986, 1988, 1989), M. Wilczyński (1989), A. Siewniak-Madej (1993), Z. Buła (1994), Z. Buła *et al.* (1995) and M. Jachowicz (1995).

Thin sections and polished surfaces were prepared in the Central Chemical and Technological Laboratory of the Polish Geological Institute. Maceration of micropalaeontological samples were made by J. Serafin and M. Mrowiec, the photos of fossils were taken by J. Modrzejewska and the figures were drawn by M. Bejger and T. Grudzień. All the rock samples, thin sections and fossil specimens have been deposited in the Department of Regional and Petroleum Geology of the Polish Geological Institute in Warsaw.

LITHOLOGY

In the Zawiercie–Żarki segment of the NE margin of the Upper Silesian Coal Basin, Silurian deposits are not exposed on the surface and they are known from boreholes only. They are overlain by Devonian or Triassic deposits, most frequently Lower (Lower Buntsandstein, Röt) and locally Middle Triassic (Ore-Bearing Dolomites). The boundary between the Silurian series and its sedimentary cover is marked by an angular discordance ranging from 10 up to 40°. At the bottom, the Silurian deposits either continuously pass down into the Ashgill carbonates or discordantly overlie Ordovician carbonates of various age and uppermost Precambrian (Vendian)–Lower Cambrian(?) clastics (Fig. 2)[1].

The Silurian sequence is composed of carbonate and clastic deposits complex of small thickness. The lower part of this complex is represented by highly recrystallized carbonate rocks, whereas the upper consists of clastics: claystones, siltstones with subordinary sandstone intercalations and, episodically, interlayers of siliceous (lydites) and pyroclastic rocks (bentonites, tuffites).

The clastics show a variable grade of metamorphism and represent, in their majority, rocks generally defined as phyllites, metapelites, metaaleurites and metapsamites (K. Piekarski *et al.*, 1980, 1982). In this group of rocks, phyllites and metapelites which originated from mudstones, usually show the highest grade of metamorphism.

The Silurian rocks exhibit high degree of tectonism; tectonic breccias, frequent fractures and fissures and oblique sliding planes are all common. Most of the fractures and fissures are secondarily infilled with quartz or carbonates (calcite). Intervals with tectonic deformations are commonly accompanied by obliquely arranged irregular veins which are composed of quartz, carbonates and sulphides — mainly pyrite. The Silurian rocks are variously deformed tectonically: weaker in the Żarki area sections and distinctly stronger in the Mysłów region (*cf.* J. Żaba, 1994).

The borehole section Ż-89 is proposed as a lithostratotype for carbonate-clastic deposits in the Zawiercie–Żarki area of the NE margin of the Upper Silesian Coal Basin (depth 414.1–538.3 m). It shows the most fully developed and palaeontologically well documented (graptolites, conodonts) stratigraphical succession of the system without any significant sedimentary gaps or tectonic breaks. As a hypolithostratotype could serve partial sections of boreholes Ż-78 (depth 375.2–469.5 m) and Ż-63 (depth 270.0–400.0 m) with the most completely preserved and typically developed succession of the Wenlock and lower Ludlow (Gorstian), respectively.

Basing on the data from the partial borehole sections, the reconstructed, incomplete, real thickness of the carbonate-clastic Silurian deposits (Llandovery, Wenlock, lower Ludlow) amounts to about 400.0–450.0 m. The initial stratification surface of the Silurian deposits in particular sections dips variably, ranging from 20 up to 70° and most frequently 20–40° (Fig. 2).

LLANDOVERY

Palaeontologically documented Llandovery deposits have been recognized in borehole sections of Ż-65 (depth 385.5(?)–396.0 m), Ż-78 (depth 453.6–469.5 m), Ż-88 (depth 459.0–468.9 m) and Ż-89 (depth 516.5–538.3 m). Borehole Ż-65 has not pierced through the bottom of the Llandovery deposits. In

[1]Borehole A-4 located near Mrzygłód is the only one in which K. Piekarski noted that the carbonate series and the underlying 500 m thick clastic one, named the skarn limestones with phosphorites (depth 250.2–298.0 m) and shaly-greywacke-conglomeratic formation (depth 298.0–710.0 m), respectively, show similar dip pattern (K. Piekarski *et al.*, 1982). They both were accepted to be Upper Ordovician in age (Ashgill). That author, however, did not take into account a very important fact that in the contact zone between the carbonates and clastics, there is a 6.2 m thick intrusive body (depth 298.0–304.2 m) which is responsible for the above mentioned apparent concordance in dip patterns between the two rock complexes, quite different in their lithology and age. K. Piekarski's interpretation was questioned by Z. Kowalczewski (1990) quoting lithological analogies between the clastic complex deposits (shaly-greywacke-conglomeratic formation *sensu* K. Piekarski *et al.*, 1982) in this borehole section and the clastic series with coarse-grained horizons from other rock sequences recognized by drillings in the middle south of Poland. Z. Kowalczewski (1990) is of the opinion that the clastic complex encountered below the carbonate series in borehole A-4 is Lower Cambrian in age (*Holmia* Zone) and should be distinguished as a separate formation of arkosic sandstones and conglomerates of Myszków.

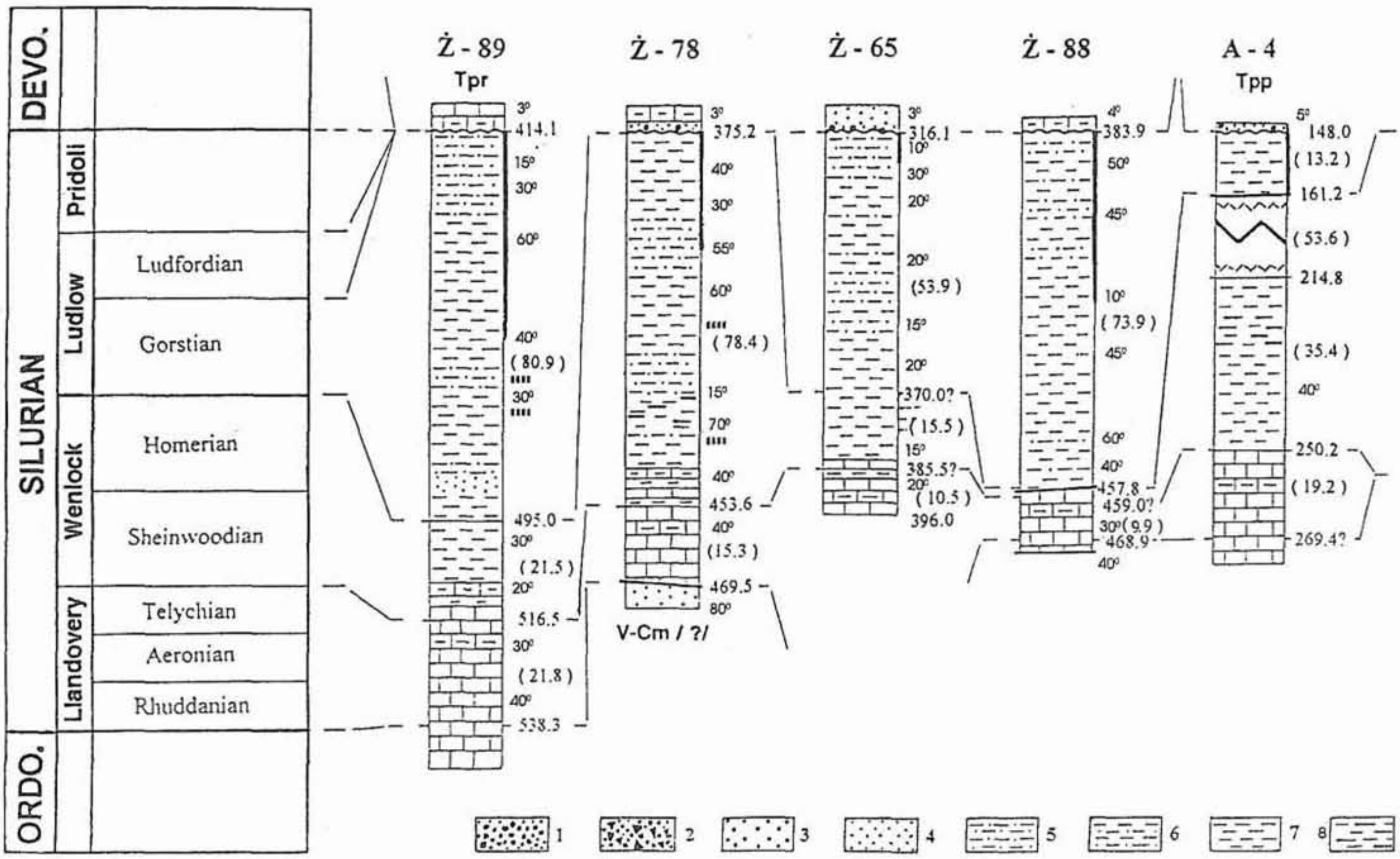
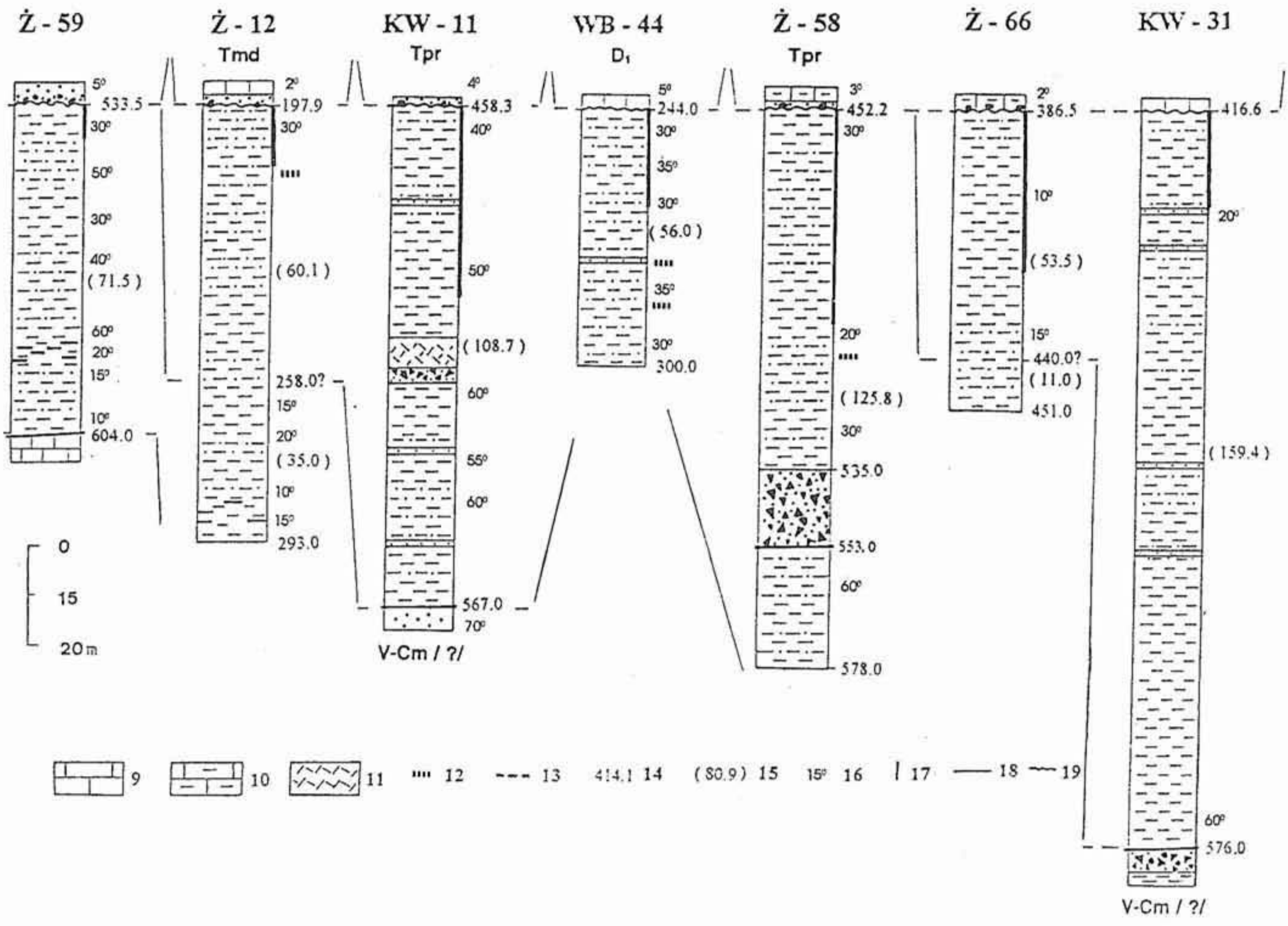


Fig. 2. Correlation of the selected Silurian sections in the Zawiercie–Żarki area (NE margin of the Upper Silesian Coal Basin)
1 — conglomerates; 2 — tectonic breccias; 3 — medium-grained sandstones; 4 — fine-grained sandstones; 5 — siltstones; 6 — mudstones; 7 — claystones; 8 — siliceous rocks, lydites; 9 — limestones; 10 — marly limestones; 11 — magmatic rocks (diabases, porphyries); 12 — pyroclastic rocks (bentonites, tuffites); 13 — pyroclastic material; 14 — depth in metres; 15 — series thickness in metres; 16 — dip of beds; 17 — extent of the zone of secondary epigenetic transformations; 18 — faults; 19 — erosional unconformities; stratigraphical symbols: V-Cm — uppermost Precambrian (Vendian)–Lower Cambrian(?), D_1 — Lower Devonian, Tpr — Lower Triassic (Röt), Tpp — Lower Triassic (lowermost Buntsandstein), Tmd — Middle Triassic (Ore-Bearing Dolomite)

the borehole Ż-78, the Llandovery sequence unconformably overlies the Precambrian (Vendian)–Lower Cambrian(?) complex. In the boreholes Ż-88 and Ż-89 the Llandovery deposits are supposed to be continuously passing downwards into the carbonate Ashgill sediments. The Llandovery deposits are conformably overlain by the Wenlock clastics with subordinary carbonate interlayers at the base (Fig. 2).

The Llandovery is almost solely represented by highly recrystallized carbonate rocks with illegible or poorly preserved primary depositional structures. In each section they show the identical mineral composition and similarity in structural and textural parameters. Limestones, dolomitic limestones and marly limestones are predominant. They are accompanied by organodetrital limestones. Their petrographic features correspond to sparites, clayey sparites and sparse biosparites. Quantitative relations within the three rock types in particular intervals are variable. Clayey sparites and/or sparites are usually predominant (70%). In the lower and middle part of the succession they are interbedded with biosparites (30%). On a macro-scale these rocks are largely massive, compact and hard occasionally more or less secondarily silicified and displaying uneven fracture surfaces. They are light grey and grey, locally — depending on the kind and quantity of clay material admixture — greenish or dark greenish and they usually show a secondary loss of bedding. Characteristic uneven sedimentary discontinuity surfaces with thin clay covers, poorly developed stylolites of various origin as well as small fractures and irregular veins infilled with sulphides, have been noted from limestones. The structure of carbonate rocks is allotriomorphic (granular), and the texture — massive, chaotic.

A qualitative and quantitative mineral composition of carbonate rocks is poorly differentiated. Their groundmass is a compact mosaic of interfingering xenomorphic calcite and/or dolomite grains, 0.3–3.1 mm in diameter. Many of the calcite grains and crystals show polysynthetic twinnings and small fractures. They often exhibit symptoms of having been subjected to dynamometamorphic factors (granuloblastesis).



Zestawienie korelacyjne wybranych profilów osadów syluru w rejonie Zawiercia–Żarek NE obrzeżenia GZW

1 — zlepieńce; 2 — brekcje tektoniczne; 3 — piaskowce średnioziarniste; 4 — piaskowce drobnoziarniste; 5 — mułowce; 6 — skały ilasto-mułowcowe; 7 — iłowce; 8 — skały krzemionkowe, lidyty; 9 — wapienie; 10 — wapienie margliste; 11 — skały magmowe (diabazy, porfiry); 12 — skały piroklastyczne (tufity, bentonity); 13 — materiał piroklastyczny; 14 — głębokość w metrach; 15 — miąższość w metrach; 16 — upad warstw; 17 — zasięg strefy wtórnych przeobrażeń epigenetycznych; 18 — uskoki; 19 — niezgodności erozyjne; indeksy stratygraficzne: V-Cm — najmłodszy prekambr (wend)–kambr dolny(?), D_1 — dewon dolny, Tpr — trias dolny (ret), Tpp — trias dolny (najniższy piaskowiec pstry), Tmd — trias środkowy (dolomit kruszconośny)

Allochemical components are represented by biogenic material, clay minerals (illite, chlorite) and detrital quartz, which — mixed together — occur in different proportions within a particular textural variety. Bioclasts are represented by small fragments of biogenic structures and/or their relics recrystallized to a different degree, and ranging from 0.2 up to 0.6 mm in size. They are chaotically and irregularly distributed: in places they form abundant concentrations in biosparites, whereas in sparites they are locally lacking completely. Bioclasts are mainly represented by fragments of benthic fauna: brachiopods, crinoids, bivalves, gastropods, ostracods, bryozoans(?) and taxonomically non-identified small fragments (varia). The content of biogenic components is small, reaching up to 6.0% per volume in sparites and clayey sparites, and up to 18.0% per volume in biosparites (boreholes Ż-65, depth 389.0–394.0 m and Ż-78, depth 460.0–469.5 m).

Other allogenic components are clay minerals (about 3.0–20.0% per volume) — mainly illite, detrital quartz of aleuritic and psammitic grain-size (0.0–7.5%), chalcedony and neogenic chlorite forming in places aggregate concentrations of fine-flakes. Quartz grains are usually well rounded and poorly sorted. The average size of most frequent grains is 0.07 mm, maximum size 0.22 mm. Sporadically small amounts of minerals representing pyroxene group (epidote), pleochroic fine-aggregate concentrations of biotite, impregnations and patches of ferrum hydroxides and oxides, siderite and sulphides — especially pyrite, have been found.

The above-described set of rocks shows much similarities to the coeval carbonate series recognized earlier in boreholes in the middle south of Poland (e.g. the Lower Silurian limestone complex from the Myszków region — borehole A-4 (depth 250.0–296.4? m) — assumed by K. Piekarski to be Upper Ordovician (Ashgill) (W. Heflik, K. Piekarski, 1978; K. Piekarski *et al.*, 1982) and the Llandovery–lower Wenlock carbonate series encountered in borehole sections Rk-1, Rk-2, Rk-5 and Rk-6 in the Zawiercie region (C. Harańczyk, 1992; M. Nehring-Lefeld *et al.*, 1992).

The recorded incomplete apparent thickness of the Llandovery deposits ranges from about 10.5 m in the borehole Ż-65 to 21.8 m in the borehole Ż-89 (Fig. 2).

WENLOCK

Palaeontologically documented Wenlock deposits have been recognized in borehole sections of Ż-12 (depth 258.0?–293.0 m), Ż-59 (depth 533.5–604.0 m), Ż-65 (depth 370.0–385.5 m), Ż-78 (depth 375.2–453.6 m), Ż-88 (depth 457.8–?459.0 m), Ż-89 (depth 495.0–516.5 m), WB-42 (depth 212.2–300.0 m) and WB-47 (depth 113.5–292.5 m). In boreholes Ż-59, WB-42, Ż-78 and WB-47 they are unconformably overlain by the Triassic transgressive deposits: in boreholes Ż-59, WB-42 and Ż-78 — by the lowermost Buntsandstein and Röt, in borehole WB-47 — by the Middle Triassic (Gogolin Beds) and in the others they continuously pass upwards into the lower Ludlow (Gorstian) mudstones. The Wenlock sequence overlies either the Llandovery deposits (conformably) or the Middle Devonian ones (borehole Ż-59) (with tectonic unconformity). In the boreholes Ż-12, WB-42 and WB-47, the Wenlock deposits have not been pierced through.

The Wenlock age has also been tentatively assumed for the mudstones, basing on their stratigraphic position and lithological features in the following borehole sections: Ż-10 (depth 227.7–251.0 m), Ż-11 (depth 200.1–270.0 m), Ż-13 (depth 197.1–250.0 m), Ż-14 (depth 226.0–300.0 m), Ż-20 (depth 207.1–258.8 m), WB-45 (depth 200.0–300.0 m), A-4 (depth 161.2–250.2 m) and others (Fig. 1). The supposed Wenlock deposits have yielded either no fossils or only non-identified graptolite fragments (sicula, thecal cladia) and poorly preserved brachiopods, bivalves, gastropods and cephalopods.

The deposits are characterized by poorly differentiated lithology and uniform thickness (Fig. 2). Their bipartite succession is composed of carbonates with claystone interbeds being most frequent and thicker upwards — in the lower part, and mudstones with subordinate sandstone interlayers and uncommon siliceous (lydites) and pyroclastic rocks (bentonites, tuffites) — in the middle and upper parts.

Carbonates are chiefly represented by more or less recrystallized marly limestones with subordinate pure limestones, dolomitic limestones and organodetrital limestones. The rocks are light grey and grey, massive, compact and hard, displaying uneven fracture surfaces. They show allotriomorphic structure (granular), and massive, chaotic texture. A qualitative and quantitative mineral composition of most of the limestones corresponds to clayey sparites. The amount of sparites and sparse biosparites is very small.

The mineral composition, structural and textural parameters as well as the content of biogenic material and its type, are matter uniform and do not differ from those of the Llandovery carbonates. The differences are that the Wenlock rocks have a higher average content of terrallochemes — first of all clay material and bioclasts with better preservation state of primary organic structures, as well as that they show a higher frequency of marine discontinuity surfaces and better preserved bedding planes. The recorded thickness of the limestone complex is small and ranges from 5.0 up to 7.5 m (boreholes Ż-78 and Ż-89). The above-described carbonate rocks are lithologically similar to their coeval counterparts from the borehole sections Rk-1, Rk-5 and Rk-6 in the Zawiercie region (C. Harańczyk, 1992; M. Nehring-Lefeld *et al.*, 1992).

The middle and upper parts of the Wenlock succession consist of mainly clastic deposits of various grain sizes. They commonly show a variable grade of secondary transformations (regional, dynamic and thermal-metasomatic anchimetamorphism). These are mostly dark grey and grey claystones, mudstones and siltstones, most frequently horizontally laminated, compact and hard, non-calcareous or occasionally — especially in the lower part — slightly calcareous, and they show intensive steep fissility. They are locally intercalated with thin fine- or, more rarely, medium-grained sandstones of a wacke type. Basically, the interval is distinguishable by a considerable contribution of dark brown bituminous claystones with a negligible content of terrigenous material, representing the so-called dark micro-lithofacies. Sporadically thin intercalations of dark grey siliceous (lydites, borehole Ż-12) and pyroclastic rocks (tuffites and bentonites, boreholes Ż-78 and Ż-65) occur. They compose not more than 1–2% of total thickness of each section. In the lowermost part of the succession within the 4.0–6.0 m interval of claystones and siltstones, an increased content of carbonate micrite has commonly been observed.

The recorded incomplete apparent thickness of the Wenlock deposits in the studied borehole sections ranges from 15.5 m in the Ż-65 to 78.4 m in the Ż-78 (Fig. 2)[2].

LOWER LUDLOW (GORSTIAN)

Lower Ludlow deposits have been distinguished basing upon palaeontological data from several boreholes including Ż-10 (depth 157.4–227.7 m), Ż-12 (depth 197.9–258.0 m), Ż-58 (depth 452.2–578.0 m), Ż-63 (depth 270.0–400.0 m), Ż-65 (depth 316.1–370.0 m), Ż-66 (depth 400.0?–451.0 m), Ż-67 (depth 446.0–466.5 m), Ż-88 (depth 383.9–457.8 m), Ż-89 (depth 414.1–495.0 m) and WB-44 (depth 244.0–300.0 m). The lower Ludlow age has also been assumed for mudstone complexes with non-identified fragments of graptolites from boreholes Ż-44 (depth 238.0–300.0 m), Ż-91 (depth 455.4–525.0 m), KW-11 (depth 458.3–567.0 m), WB-39 (depth 229.0–300.0 m) and WB-49 (depth 180.5–264.5 m), among others.

The lower Ludlow deposits are unconformably overlain by the transgressive Triassic and locally Lower Devonian sediments (Fig. 2). They overlie the Wenlock deposits in sedimentary continuity or show a tectonic contact with Ordo-

[2] It was intended not to refer to the thicknesses of the Wenlock sequences from boreholes WB-47 (179.0 m) and WB-45 (100.0 m), where intrusive rocks have a significant contribution (diabases, porphyres). In the former, the recorded total apparent thickness of these rocks is 101.2 m, and in the latter — 30.0 m, thus the thicknesses of the Wenlock sedimentary rocks are 77.8 and 70.0 m, respectively.

vician carbonates of various age (borehole Ż-67) as well as with Precambrian (Vendian)–Lower Cambrian(?) clastics (borehole KW-11).

The main part of the lower Ludlow sequence is composed of grey and dark grey claystones, mudstones and siltstones occurring in different proportions. They are usually strongly lithified, compact, hard and slightly calcareous in places. They largely show intensive steep fissility and frequently a different degree of silicification. Primary sedimentary structures are either lacking or visible as poorly preserved relics of horizontal and wavy lamination. Fine- and particularly medium-grained sandstones of wacke type are rare (about 10% of total thickness). They usually occur as isolated beds, 0.1–0.5 m locally 0.9 m thick, and only in exceptional cases as thicker sets of beds with indistinct bedding planes. The sandstones are characterized by a loose packing of grains and abundant argillaceous or muddy matrix. In some sections, thin intercalations of bentonites and tuffites, 0.2–0.6 m thick, have been found (Fig. 2).

The uppermost part of the succession below the Triassic overburden is usually altered and decoloured — mottled and variegated — due to secondary weathering processes. The vertical extent of the secondary decolouring changes in a wide range, most frequently from around 10 m (borehole Ż-67) up to 25 m (borehole Ż-89).

The lithology of the lower Ludlow sequences is similar to fragments of the same series recognized earlier in other borehole sections in this region, among others KM-3 (depth 159.7–300.0 m) and KM-29 (depth 103.6–212.0 m) from the Mrzygłód area (M. Ciemniewska, 1978).

The recorded incomplete apparent thickness of the lower Ludlow (Gorstian) deposits ranges from 53.9 m in borehole Ż-65 to 130.0 m in borehole Ż-63 (Fig. 2).

UPPER LUDLOW (LUDFORDIAN)

Upper Ludlow (Ludfordian) deposits have been confirmed by palaeontological data from among others such boreholes as Ż-42 (depth 254.1–300.0 m) and KW-31 (depth 416.6–576.0 m). Their supposed presence, above the palaeontologically documented lower Ludlow (Gorstian) series, has also been tentatively assumed, among others in borehole Ż-66 (depth 386.5–440.0? m). The lower Ludlow age has been also arbitrarily assumed for the unfossiliferous parts of the Silurian series reached immediately below the Lower Triassic or weathered intrusive rocks (porphyry) and breccias, among others in boreholes Ż-44 (depth 235.1–300.0 m), KW-21 (depth 187.5–391.2 m) and Ż-52 (depth 299.1–387.0 m). Their age is indicated by lithological analogies and the position in the borehole sections. The upper Ludlow deposits either pass downwards into the lower Ludlow ones with sedimentary continuity (borehole Ż-66) or they show an unconformable tectonic contact with the underlying uppermost Precambrian (Vendian)–Lower Cambrian(?) clastic complex (borehole KW-31).

The main member of the upper Ludlow succession is composed of grey and dark grey, lithologically uniform claystones, mudstones and siltstones with subordinate thin, 0.2–0.8 m thick, fine- and medium-grained sandstones of quartz wacke and quartz-feldspar wacke types. The majority of the sandstones has a loose packing and contains abundant argillaceous matrix. Such lithology is frequently accompanied by thin, uncommon intercalations of mudstones and siltstones more or less enriched in pyroclastic material petrographically resembling tuffites (borehole KW-31).

The upper Ludlow deposits show many lithological similarities to the earlier described coeval rocks from the Mrzygłód, Zawiercie and Ogrodzieniec regions (E. Ekiert, 1971; K. Piekarski, 1994) and from borehole Lubliniec IG 1 (A. Siewniak-Madej, 1982).

The recorded incomplete apparent thickness of the fragments of the supposed upper Ludlow deposits ranges from 46.1 m in borehole Ż-41 to 159.4 m in borehole KW-31 (Fig. 2).

STRATIGRAPHY

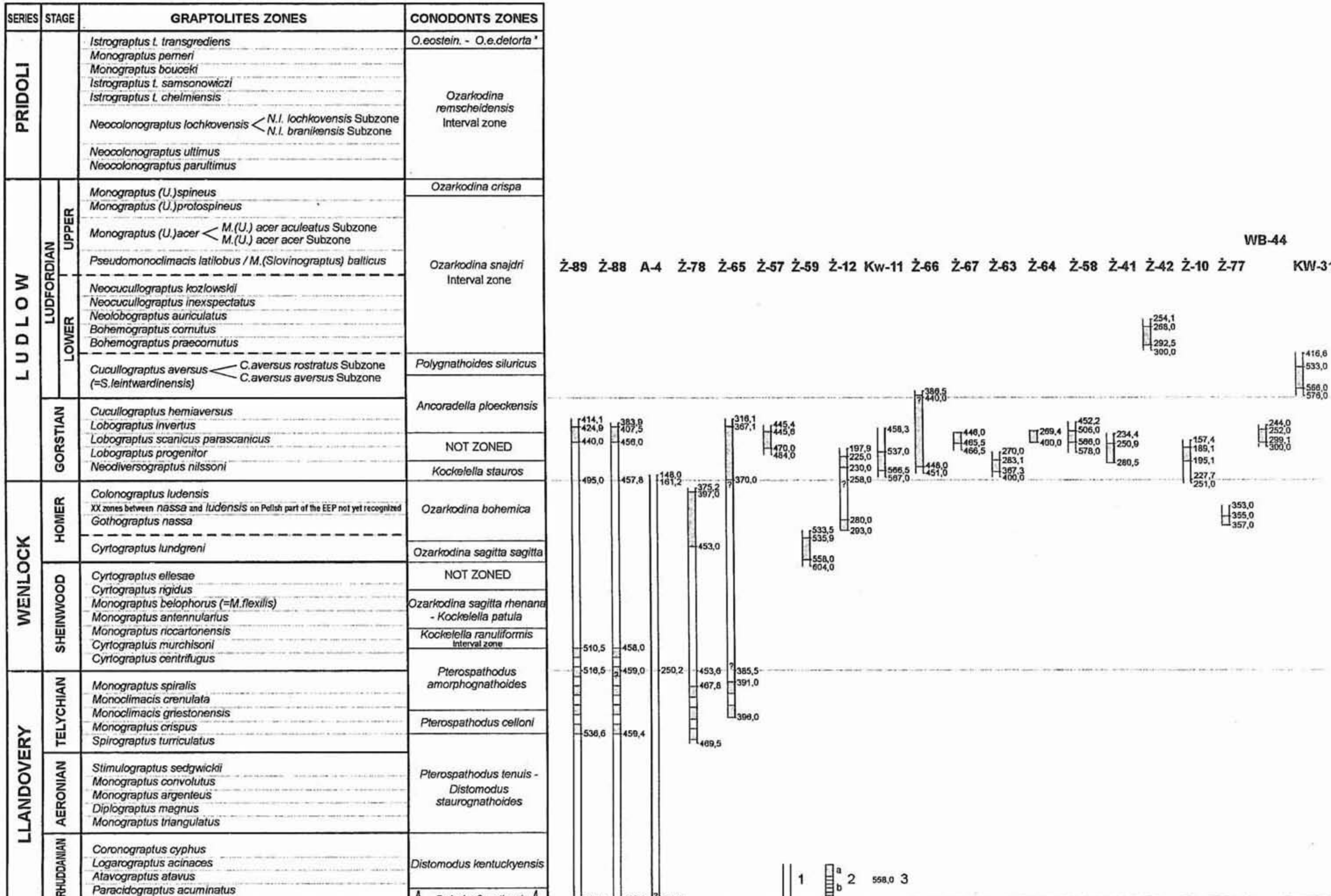
The Silurian sequence in the boreholes studied is represented by three series. The oldest one — Llandovery — is dated basing upon conodonts, whereas the two younger series — Wenlock and Ludlow — upon graptolites (Fig. 3).

LLANDOVERY

Carbonate deposits of this age have yielded either no macrofossils (boreholes Ż-88 and Ż-89) or small numbers of poorly preserved fragments of flattened orthoceratoids, bivalve imprints and small fragments of brachiopods of uncertain taxonomic affinity (boreholes Ż-65, depth 389.0–395.0 m and Ż-78, depth 460.0–469.5 m). The samples collected from these rocks have revealed a wide spectrum of microfossils: conodonts, abundant ostracods, small fragments of inarticulate brachiopods and other organic structures of uncertain taxonomic position (B. Szymański, M. Nehring-Lefeld, 1995).

Conodonts predominating in the residuum are fairly well preserved, so their affiliation to a particular genus can easily be determined. The assemblage includes largely simple forms of a single-cone type belonging to the genera: *Panderodus* Ethington, *Acodus* Pander, *Acantiodus* Pander, *Drepanodus* Pander, *Distacodus* Hinde and *Paltodus* Pander. More complex forms occur sporadically and they are represented by spike-type (genera: *Spathognatodus* Branson et Mehl, *Ozarkodina* Branson et Mehl and *Neoprioniodus* Rhodes et Müller) and branching-type specimens (genera: *Trichonodella* Branson et Mehl, *Boundaya* Hass and *Plectospathodus* Branson et Mehl). The frequency of conodonts in individual borehole sections is variable. The greatest number of specimens has been noted from boreholes Ż-78 (depth 468.0–469.0 m) and Ż-89 (depth 518.0–524.0 m). The taxa recognized by M. Nehring-Lefeld are indicative of the Llandovery age (B. Szymański, M. Nehring-Lefeld, 1995).

The Llandovery age of limestones is evidenced by the following conodont assemblage: *Spathognathodus celloni*



* Ozarkodina eosteinhornensis - Ozarkodina eosteinhornensis detorta

Walliser *s.f.*, *Neoprioniodus subcarnus* Walliser *s.f.*, *Drepanodus aduncus* Nicoll et Rexroad and *Pseudooneothodus becmanni* (Bischoff et Sanneman). *S. celloni* Walliser *s.f.* and *N. subcarnus* Walliser *s.f.* have recently been considered elements of natural species (multielement). The former is defined as a Pa element of the natural species *Pterospathodus celloni* (Walliser), the latter is included into the natural species *Carniodus carnulus* Walliser as a Sc element (J. E. Barrick, G. Klapper, 1976). The stratigraphic ranges of the species comprise the upper Llandovery–lowermost Wenlock. In accordance with the conodont zonal subdivision by O. H. Walliser (1964, 1971) and G. S. Nowlan (1995), the appearance of *Pterospathodus celloni* (Walliser) is related to the *celloni-amorphognathoides* conodont zones, whereas the stratigraphic range of *Carniodus carnulus* Walliser is limited to the *amorphognathoides* Zone only. These zones are established within the conodont level of *Apsidognathus* and correlated with the upper Llandovery–lower Wenlock.

The species *Drepanodus aduncus* Nicoll et Rexroad and *Pseudooneothodus becmanni* (Bischoff et Sanneman) are typical of the Lower Silurian only. Their co-occurrence with the forms of a single-cone type is characteristic of the association described from the Llandovery–lower Wenlock of Wales (R. J. Aldridge, 1972) and the Restevsk and Kitaygorod horizons of the Volhynia and Podolia in Ukraine which are correlated by D. M. Drygant (1974) with the upper Llandovery and Wenlock.

The assemblage of the conodont genera recognized by M. Nehring-Lefeld shows many similarities to the analogous associations described earlier from the Lower Silurian carbonate sequences of boreholes Rk-1, Rk-5 and Rk-6 in the Zawiercie area (M. Nehring-Lefeld *et al.*, 1992) as well as from the lowermost Silurian carbonate complex in the eastern part of the Podlasie Depression (M. Nehring-Lefeld, 1985).

WENLOCK

Upper Wenlock deposits have yielded only few poorly preserved fragments of graptolites, cephalopods, bivalves and small brachiopods. Graptolites are present in borehole Ż-78 at a depth of 397.0–453.0 m (56.0 m). Down to a depth of 440.0 m, appears only *Monograptus* ex gr. *dubius* (Suess), of insignificant stratigraphic importance. It is supposed that these deposits may represent the uppermost Wenlock (*parvus-nassa-ludensis* Zones). This view is also supported by the occurrence of procladia and thecal cladia of *Cyrtograptus lundgreni* Tullberg at a depth of 440.0–453.0 m (Pl. I, Figs. 2, 5), being indicative of the *lundgreni* Zone within this interval. The presence of this zone is also confirmed by the co-occurrence of *Monograptus flemingi* (Salter) (Pl. I, Fig. 3), *Testograptus testis* (Barrande) (Pl. I, Fig. 1) and *Monograptus* ex gr. *dubius* (Suess) (Pl. I, Fig. 4).

The upper Wenlock deposits are also documented in the borehole Ż-59 (depth 533.5–604.0 m). Thecal cladia of *Cyrtograptus lundgreni* Tullberg, recorded at a depth of 535.9–558.0 m (24.5 m), confirm the presence of the *lundgreni* Zone.

The Llandovery/Wenlock boundary in boreholes Ż-65, Ż-78, Ż-88 and Ż-89 has been drawn basing on lithological features at the level where the first, dark coloured bituminous claystones representing a sediment typical of the inner parts of the basin (so-called dark microfacies *sensu* A. Langier-Kuźniarowa, 1967, 1974, 1989), appear amongst carbonate rocks.

LUDLOW

Graptolites are predominant in the biotic assemblage of the Ludlow mudstones. Their state of preservation does not enable the precise recognition of a particular species. However, all the specimens considered together allow to assigne the deposits to the Gorstian and the lower Ludfordian. The following graptolites have been found in the boreholes listed below (Fig. 3):

Borehole Ż-57 — depth 445.6–470.0 m (24.4 m): *Monograptus* ex gr. *dubius* (Suess) and *Lobograptus* ex gr. *scanicus* (Tullberg). This is the *scanicus parascanicus* Zone of the middle Gorstian.

Borehole Ż-58 — depth 506.0–566.0 m (60.0 m): *Lobograptus* ex gr. *scanicus* (Tullberg), *Bohemograptus bohemicus* (Barrande), *B. bohemicus tenuis* (Boucek), *Saetograptus* cf. *chimaera* (Barrande) and *Monograptus* ex gr. *dubius* (Suess). This association is typical of the *scanicus* Zone of the middle Gorstian.

Borehole Ż-63 — depth 283.1–367.3 m (84.2 m): *Bohemograptus bohemicus tenuis* (Boucek), *Neodiversograptus nilssoni* (Barrande) at various depths, *N.* cf. *nilssoni* (Barrande) (Pl. II, Fig. 4), *Monograptus* ex gr. *dubius* (Suess) (Pl. I, Fig. 7) — *nilssoni* Zone of the lower Gorstian.

Borehole Ż-64 — depth 270.0–400.0 m (130.0 m): *Bohemograptus bohemicus* (Barrande), *B. bohemicus tenuis* (Boucek), *Lobograptus* ex gr. *scanicus* (Tullberg), *Saetograptus* sp. and *Monograptus* ex gr. *dubius* (Suess). This

Fig. 3. Stratigraphy of Silurian deposits basing on conodonts and graptolites

1 — recognized intervals of Silurian deposits; 2 — recognized intervals with fossils appearance: a — graptolites, b — conodonts; 3 — depth in metres; Silurian conodont zones after: O. H. Walliser (1971), L. R. M. Cocks and G. S. Nowlan (1993) and G. S. Nowlan (1995); Silurian graptolitic zones and subzones compiled after: O. M. B. Bulman (1970), H. Jaeger (1991), W. G. Kuhne (1955), A. C. Lenz (1982), D. K. Loydell (1993), R. B. Rickards (1976), P. Storch (1988), D. L. Strusz (1995), L. Teller (1969), A. Urbanek and L. Teller (1997) and J. Zalasiewicz (1990)

Stratygrafia osadów syluru na podstawie oznaczeń konodontów i graptolitów

1 — stwierdzone interwały występowania osadów syluru; 2 — stwierdzone interwały występowania: a — graptolitów, b — konodontów; 3 — głębokość w metrach; poziomy konodontowe syluru według O.H. Wallisera (1971), L. R. M. Cocksa i G. S. Nowlana (1993) oraz G. S. Nowlana (1995); poziomy i podpoziomy graptolitowe syluru zestawiono na podstawie O. M. B. Bulmana (1970), H. Jaegera (1991), W. G. Kuhnego (1955), A. C. Lenza (1982), D. K. Loydella (1993), R. B. Rickardsa (1976), P. Storcha (1988), D. L. Strusza (1995), L. Tellera (1969), A. Urbanka i L. Tellera (1997) oraz J. Zalasiewicza (1990)

association is typical of the *scanicus* Zone of the middle Gorstian.

Borehole Ż-65 — depth 367.1–370.0 m (2.9 m): *Monograptus* aff. *uncinatus* Tullberg, *Saetograptus* cf. *chimaera* (Barrande), *Lobograptus* ex gr. *scanicus* (Tullberg), *Cucullograptus* ex gr. *aversus* (Eisenack), *C.* aff. *pazdroi* (Urbanek) — *scanicus parascanicus* Zone of the middle Gorstian.

Borehole Ż-66 — depth 435.8–448.0 m (12.2 m) — only fragments: *Monograptus* ex gr. *dubius* (Suess). This form is common throughout the whole Ludlow, but it seems that in this particular borehole, basing on the analogy to nearby located sections, it indicates Gorstian age.

Borehole Ż-67 — depth 446.0–465.5 m (19.5 m). Abundant specimens are represented by: *Lobograptus* cf. *scanicus scanicus* (Tullberg), *L. scanicus* aff. *parascanicus* (Kuhne), *Bohemograptus bohemicus* (Barrande), *B.* cf. *bohemicus* (Barrande) (Pl. II, Fig. 8), *Cucullograptus* aff. *aversus* (Eisenack), *C.* aff. *pazdroi* (Urbanek) (Pl. II, Fig. 6) and *Monograptus* ex gr. *dubius* (Suess). This assemblage is typical of the *scanicus parascanicus* Zone of the middle Gorstian.

Borehole Ż-88 — depth 407.5–456.0 m (48.5 m): *Lobograptus* ex gr. *scanicus* (Tullberg), *Bohemograptus bohemicus* (Barrande) and *Monograptus* ex gr. *dubius* (Suess). These specimens are typical of the *scanicus* Zone of the middle Gorstian.

Borehole Ż-89 — depth 424.9–440.0 m (15.1 m): *Lobograptus* ex gr. *scanicus* (Tullberg), *Bohemograptus bohemicus* (Barrande), *Monograptus* ex gr. *dubius* (Suess) (Pl. II, Fig. 3) and *Saetograptus* sp. These forms appear in the *scanicus* Zone of the middle Gorstian.

Borehole WB-44 — depth 252.0–299.1 m (47.1 m): *Lobograptus scanicus* cf. *scanicus* (Tullberg), *L.* ex gr. *scanicus* (Tullberg) (Pl. II, Figs. 1, 2, 5), *L. scanicus* aff. *parascanicus* (Kuhne), *Bohemograptus bohemicus* (Barrande), *Saetograptus chimaera* (Barrande) (Pl. I, Fig. 6), *Linograptus* sp. (Pl. II, Fig. 7) and *Monograptus* ex gr. *dubius* (Suess). This assemblage is characteristic of the *scanicus parascanicus* Zone of the middle Gorstian.

The recognized graptolites point to the Gorstian stage of the lower Ludlow. In most of the borehole sections this is usually the *scanicus parascanicus* Zone. It is not unlikely, however, that the lowermost parts of these sections represent the *progenitor* Zone, whereas their uppermost parts — the *invertus* Zone. Two borehole sections (Ż-63 and Ż-66) represent the lowermost zone of the Gorstian — *nilssoni*. Although the graptolites from both of them are poorly preserved and occur in small numbers, the presence of *Neodiversograptus nilssoni* (Barrande) is absolutely certain.

CORRELATION BETWEEN THE SILURIAN DEPOSITS IN THE ZAWIERCIE–ŻARKI ZONE AND THE COEVAL ROCKS FROM NEIGHBOURING AREAS

NIDA TROUGH (MAŁOPOLSKA BLOCK)

A superficial comparison of the Silurian sequence from the Zawiercie–Żarki zone and the Nida Trough reveals strong similarities between both these areas. They show similar stratigraphy, lithology and a degree of tectonism. Significant differences can be seen in facies development, particularly in the lower part of the series (Llandovery, lower Wenlock).

Lower Silurian deposits of the Nida Trough have been recognized so far in four boreholes only: Jaronowice IG 1 (depth 2037.5–2274.9 m), Książ Wielki IG 1 (depth 1185.0–1260.5 m), Strożyska 5 (depth 2824.5–3007.2 m) and Włoszczowa IG 1 (depth 2541.0–2618.6 m). Unfossiliferous claystones, drilled in the Włoszczowa IG 1 (depth 2541.0–2618.6 m) below the Lower Devonian, have been considered to be Silurian basing only on their lithology and position in this section (H. Jurkiewicz, 1975). The Silurian age of the sediments from the remaining borehole sections is confirmed by fossils (K. Jaworowski *et al.*, 1967; H. Jurkiewicz, 1975; W. Bednarczyk *et al.*, 1968).

The Silurian of the Nida Trough is represented by Llandovery (Jaronowice IG 1 and Włoszczowa IG 1), Wenlock (Jaronowice IG 1) and lower Ludlow deposits (Strożyska 5 and Książ Wielki IG 1) documented by graptolites.

Llandovery. K. Jaworowski *et al.* (1967) and H. Jurkiewicz (1975, 1976) are of the opinion that the Llandovery deposits are represented by a clastic series encountered in the boreholes Jaronowice IG 1 (depth 2274.9–2166.4 m) and Włoszczowa IG 1 (depth 2541.0–2618.6 m), 108.5 and 77.6 m thick, respectively. They are composed of dark grey claystones and siltstones intercalated with lydites, limestones and fine-grained sandstones.

Different lithologies from those recognized in the Zawiercie–Żarki region can be generally explained by two factors: (1) overall deepening of the basin from the south-west towards north-east inherited from its earlier evolutional phases, and (2) slow transgression. Lateral changes of the Llandovery deposits between the Zawiercie–Żarki region and Nida Trough also point to a more proximal character of facies, i.e. closer to a hypothetical shoreline, in the south-west, and a more distal character — in the north-east. Such a pattern is confirmed by the increased proportion of sparse biosparite-type limestones towards the south-west, simultaneous decrease in a clay material content as well as the occurrence of marine sedimentary discontinuity surfaces. The small amounts of skeletal benthos (*in situ*), high contribution of dark microfacies claystones and greater amount of sulphides in the Nida region are indicative of probable stronger near-bottom reducing conditions than in more agitated waters of the Zawiercie–Żarki region. Moreover, differences in thicknesses may point to a stronger subsidence in the Nida region.

Wenlock deposits have been recognized so far only in the borehole Jaronowice IG 1 (depth 2068.0–2180.0 m) where the most part of the sequence is well documented palaeontologically (depth 2080.0–2169.0 m). The graptolite assemblage is univocally indicative of the upper part of the lower Wenlock (*belophorus-ellesae* Zones) and upper Wenlock (*lundgreni* Zone). The underlying deposits have yielded no graptolites and they are considered to represent the lower part of the lower Wenlock (H. Jurkiewicz, 1975, 1976).

The correlation between the Nida and Zawiercie–Żarki regions gives a simple picture of facies distribution in the Wenlock: carbonate-clastic in the south-west and clastic in the north-east. These general facies zones correspond to biofacies patterns of the deposits — the lack of graptolites in the lower, i.e. carbonate-argillaceous member of the former, and their presence in the latter.

Basing upon lithological features, the Silurian transgression may be interpreted as gradual or moderately rapid. Intervals of a transitional lithological character are located within the uppermost Llandovery–lower Wenlock part of the Zawiercie–Żarki section. However, it is difficult to determine both the rate of transgression and its possible diachronism over the whole studied area due to poor biostratigraphical data. The transition from a carbonate sedimentation into muddy one in the Zawiercie–Żarki area may be dated at the turn of the Llandovery/Wenlock or at the lowermost Wenlock, whereas in the Nida region that might have occurred before the Llandovery.

Lower Ludlow. In the Nida Trough, the lower Ludlow deposits have been drilled in the boreholes Książ Wielki IG 1 (depth 1185.0–1260.0 m), Strożyska 5 (depth 2824.5–3007.2 m) and most likely Jaronowice IG 1 (depth 2037.5–2068.0 m) (K. Jaworowski *et al.*, 1967; H. Jurkiewicz, 1975; W. Bednarczyk *et al.*, 1968).

In the Książ Wielki IG 1 section, graptolites have been found at a depth of 1202.6–1245.0 m. Their assemblage is indicative of the *nilssoni-scanicus* Zone of the lower Ludlow (K. Jaworowski *et al.*, 1967). The Ludlow deposits in the borehole Strożyska 5 have not been pierced through. Their incomplete apparent thickness amounts to about 182.7 m. They are also palaeontologically well documented by a number of graptolites (depth 2824.5–2981.9 m) representing, in L. Teller's opinion, the lower Ludlow *nilssoni* Zone (W. Bednarczyk *et al.*, 1968). Of other fossils, *Slavia bohemica* Barrande, *Lunulicardium* sp., *Slavia* cf. *bohemica* Barrande and *Cardiola interrupta* Barrande have been found in this section (W. Bednarczyk *et al.*, 1968).

As coeval counterparts of the lower Ludlow clastic series from the Nida Trough, the lithologically similar intervals of mudstones may be considered, recognized in the Zawiercie–Żarki area, among others in the borehole sections Ż-58, Ż-65, Ż-88, Ż-89 and WB-44 (Fig. 1).

The above correlation reveals a pattern of a unified facies development during the lower Ludlow over the areas compared, with a possible lower subsidence rate in the Zawiercie–Żarki zone. Another feature in common for these two areas is a slow but constant development of regressive trend which is manifested in, among others, the lower Ludlow deposition of thick clastic series with intercalations of conglomeratic rocks at the top, resulting from strong erosion of elevated areas (F. Ekiert, 1971; S. Bukowy, 1984; C. Harańczyk, 1992).

KIELCE REGION OF THE HOLY CROSS MTS.

The lithological record and succession of graptolites in the Silurian sections from the Zawiercie–Żarki area are most similar to the coeval clastic sequences known from the Zbrza Anticline in the southern part of the Kielce region. After H. Tomczyk (1962), the so-called Lower and Upper Zbrza Shales have been distinguished there. They are believed to represent the lower Llandovery and Wenlock, respectively (E. Tomczykowa, 1988). Their correlation with the coeval equivalents from the Lower Silurian sections in the Zawiercie–Żarki area may only be very approximate.

The lower Ludlow deposits from the Zawiercie–Żarki area, in turn, can certainly be correlated with the exposed coeval deposits from the southern part of the Holy Cross Mts. (Bardo Trough). In the most complete Prągowiec section, the lower Ludlow is represented by identical facies (with abundant graptolites) as that recognized in the borehole sections Ż-65 (depth 316.1–370.0 m), Ż-88 (depth 407.5–456.0 m) and others (Fig. 3).

CONCLUSIONS

1. The Silurian deposits of the studied sections conformably overlie the Ordovician carbonates (boreholes Ż-88 and Ż-89) or show a tectonic contact with the Ordovician carbonates of various age as well as with the uppermost Precambrian (Vendian)–Lower Cambrian(?) clastics. They are overlain by either transgressive Devonian sediments or Triassic deposits — most frequently Lower Triassic (lowermost Buntsandstein, Röt), locally Middle Triassic (Ore-Bearing Dolomites).

2. Lower part of the Silurian is represented by carbonate rocks (Llandovery–lowermost Wenlock), whereas the upper one consists of mudstones (Wenlock–lower Ludlow) with subordinate sandstones and, uncommonly, thin interlayers of siliceous (lydites) and pyroclastic rocks (tuffites, bentonites).

3. The Silurian clastics show uniform petrographical features and similar qualitative and quantitative composition of both detrital material and matrix.

4. Microscopic data show that the majority of the Silurian claystones belongs to the light-coloured micro-lithofacies, more rarely — especially in the Wenlock — to the dark micro-lithofacies *sensu* A. Langier-Kuźniarowa (1967, 1974,

1989). The content of detrital material in either micro-lithofacies is low and amounts to below 2% and about 1–6% per volume, respectively.

5. It is characteristic that, together with sandstones and siltstones, there occur also loosely packed rocks, rich in matrix, with a moderate degree of mineralogical and textural maturity, which play a significant role in the Silurian section.

6. Three standard stratigraphical units of series rank have been recognized basing upon fossils: the Llandovery (conodonts), Wenlock and lower Ludlow (graptolites).

7. The succession of conodonts in the carbonate borehole sections of Ż-88 and Ż-89 points to a possible sedimentary continuity between the Ordovician and Silurian deposits.

8. A differentiation of the Silurian and Ordovician sections (M. Nehring-Lefeld, B. Szymański, 1998) results from the pre-Devonian and pre-Triassic strong erosion as well as high degree of tectonism in the Caledonian and Variscan times.

9. The Ordovician–Silurian (Llandovery, lower Wenlock) carbonate series can be considered — at least over the area studied — an isochronous correlation marker.

10. The Silurian deposits commonly show initial stages of metamorphism (greenstone facies, chlorite zone, shallower part of biotite zone). This is evidenced by the presence of chlorite-epidote-albite and biotite-albite-actinolite(?). Microscopic data confirm the earlier observations made by K. Łydka (1973), W. Ryka (1973) and W. Heflik *et al.* (1975), who emphasized a regional character of metamorphism to which the Silurian deposits were subjected in this area.

11. The Llandovery carbonate rocks show much similarity in their lithology, mineral content, range and degree of secondary transformations and position in borehole sections, to the coeval carbonate series recognized earlier in boreholes in the middle south of Poland (e.g. the Lower Silurian limestone complex from the Myszków region — borehole A-4 (depth 250.0–296.4? m) — assumed by K. Piekarski *et al.* (1982) to be Ashgill and the Llandovery–lower Wenlock carbonate series encountered in borehole sections Rk-1, Rk-2, Rk-5 and Rk-6 in the Zawiercie region (M. Nehring-Lefeld *et al.*, 1992).

12. The succession of the main Silurian lithological types in the Zawiercie–Żarki area corresponds to three succeeding phases of a distinctly regressive basin evolution. Lithologies in this succession range from carbonates (Llandovery) through carbonate-clayey and dark shales (Wenlock) to mudstones with amount of sandstones increasing upwards (Ludlow). The Wenlock/Ludlow boundary (i.e. the level where intercalations of dark bituminous claystones representing more inner parts of the basin, disappear in borehole sections) may be considered a turning-point from transgressive into regressive stages in the basinal evolution.

13. Strong similarities in lithologies, thicknesses and faunal assemblages of the Silurian deposits between the Zawiercie–Żarki area, Nida Trough and Kielce region may be indicative of their close palaeogeographic connections at that time.

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STRATYGRAFIA SYLURU NA OBSZARZE ZAWIERCIA–ŻAREK (NE OBRZEŻENIE GZW)

Streszczenie

Zaprezentowano rezultaty badań skał syluru z 50 wybranych otworów wiertniczych wykonanych w latach 1970–1989 na obszarze Zawiercia–Żarek przez Państwowy Instytut Geologiczny i Przedsiębiorstwo Geologiczne w Krakowie. Zestawienie wykorzystanych profilów wiertniczych syluru i ich lokalizację przedstawia fig. 1.

Zapis litologiczny syluru tworzy kompleks osadów węglanowo-klastycznych o nieznacznej miąższości. Część dolną kompleksu budują skały węglanowe wykazujące zaawansowany stopień rekrystalizacji, natomiast górną — skały klastyczne: iłowce i mułowce z podrzędnymi wkładkami piaskowców oraz epizodycznie skał krzemionkowych (lidyty) i skał piroklastycznych (bentonity, tufity).

W opracowanych sekwencjach osady syluru ułożone są zgodnie sedymentacyjnie na ordowiku (otwory: Ż-88 i Ż-89) lub kontaktują tektonicznie z różnowiekowymi poziomami bądź węglanów ordowiku, bądź też klastytów najmłodszego prekambru (wend)–kambru dolnego(?). Ich bezpośredni nadkład tworzą albo transgresywnie zalegające osady dewonu, albo triasu — najczęściej dolnego (najniższy piaskowiec pstry, ret), rzadziej środkowego (dolomity kruszconośne). W części profilów sekwencji osadów sylurskich nie przebito (fig. 2).

Na podstawie skamieniałości stwierdzono osady landoweru, wenloku i ludlowu dolnego. Wiek osadów landoweru i wenloku dolnego dokumentują konodonty (B. Szymański, M. Nehring-Lefeld, 1995), natomiast osadów wenloku górnego i ludlowu dolnego — graptolity (fig. 3).

W analizowanym materiale rdzeniowym datowane paleontologicznie osady landoweru napotkano w profilach czterech otworów wiertniczych (fig. 2 i 3). Ich landowerski wiek potwierdza zespół oznaczonych przez M. Nehring-Lefeld konodontów: *Spathognathodus celloni* Walliser *s.f.*, *Neoprioniodus subcarnus* Walliser *s.f.*, *Drepanodus aduncus* Nicoll et Rexroad i *Pseudooneothodus becmanni* (Bischoff et Sanneman).

Wenlok reprezentowany jest przez datowane paleontologicznie osady ilasto-mułowcowe w profilach ośmiu otworów wiertniczych (fig. 2 i 3). Ich wiek dokumentują graptolity: *Cyrtograptus lundgreni* Tullberg (tabl. I, fig. 2 i 5), *Monograptus flemingi* (Salter) (tabl. I, fig. 3), *Testograptus testis* (Barrande) (tabl. I, fig. 1) i *Monograptus* ex gr. *dubius* (Suess) (tabl. I, fig. 4).

Osady ludlowu dolnego wyodrębniono na podstawie datowań graptolitami w profilach dziesięciu otworów wiertniczych (fig. 2 i 3). Za osady sylurskie, należace prawdopodobnie do ludlowu dolnego, uznano ponadto serie skał ilasto-mułowcowych z nieoznaczalnymi fragmentami graptolitów nawiercone m.in. w profilach otworów wiertniczych Ż-44 (głęb. 238,0–300,0 m), Ż-91 (głęb. 455,4–525,0 m), KW-11 (głęb. 458,3–567,0 m), WB-39 (głęb. 229,0–300,0 m) i WB-49 (głęb. 180,5–264,5 m).

Z osadów ludlowu dolnego oznaczono: *Monograptus* ex gr. *dubius* (Suess) (tabl. I, fig. 7; tabl. II, fig. 3), *Monograptus* aff. *uncinatus* Tullberg, *Bohemograptus bohemicus* (Barrande), *B.* cf. *bohemicus* (Barrande) (tabl. II, fig. 8), *B. bohemicus tenuis* (Boucek), *Saetograptus* cf. *chimaera* (Barrande), *Neodiversograptus nilssoni* (Barrande), *N.* cf. *nilssoni* (Barrande) (tabl. II, fig. 4), *Cucullograptus* ex gr. *aversus* (Eisenack), *C.* aff. *aversus* (Eisenack), *C.* aff. *pazdroi* (Urbanek) (tabl. II, fig. 6), *Lobograptus* ex gr. *scanicus* (Tullberg) (tabl. II, fig. 1, 2 i 5), *L.* cf. *scanicus scanicus* (Tullberg), *L. scanicus* aff. *parascanicus* (Kuhne), *Saetograptus chimaera* (Barrande) (tabl. I, fig. 6), *S.* sp. i *Linograptus* sp. (tabl. II, fig. 7).

Występowanie osadów ludlowu górnego (ludfordian) potwierdzono paleontologicznie m.in. w otworch Ż-42 (głęb. 254,1–300,0 m) i KW-31 (głęb. 416,6–576,0 m). Ich prawdopodobną obecność, powyżej udokumentowanej faunistycznie serii ludlowu dolnego (gorstian), przyjęto również warunkowo m.in. w profilu otworu Ż-66 (głęb. 386,5–440,0? m). Za ludlow górny uznano wreszcie arbitralnie nieme faunistycznie fragmenty serii sylurskiej nawiercone bezpośrednio pod triasem dolnym lub zwietrzałymi intruzywami (porfiry) i brekcjami m.in. w profilach wierceń Ż-44 (głęb. 235,1–300,0 m), KW-21 (głęb. 187,5–391,2 m) i Ż-52 (głęb. 299,1–387,0 m).

Za litostratotyp osadów węglanowo-klastycznych syluru dla obszaru zawierciańsko-żareckiego NE obrzeżenia GZW proponuje się uznać profil z otworu Ż-89 (głęb. 414,1–538,3 m), w którym stwierdzono dotychczas najpełniej rozwiniętą i dobrze datowaną paleontologicznie (graptolity, konodonty) sukcesję stratygraficzną systemu pozbawioną znaczniejszych luk sedymentacyjnych i redukcji tektonicznych. Jako hypolitostratotypy można natomiast przyjąć profile cząstkowe z otworów wiertniczych Ż-78 (głęb. 375,2–469,5 m) i Ż-63 (głęb. 270,0–400,0 m), gdzie zachowane są najpełniejsze i typowo wykształcone serie osadów odpowiednio landoweru i wenloku oraz ludlowu dolnego (gorstian).

Zrekonstruowana z profili cząstkowych niepełna miąższość rzeczywista osadów węglanowo-klastycznych syluru (landower, wenlok, ludlow dolny) wynosi przypuszczalnie około 400,0–450,0 m. Stwierdzone kąty upadu warstw są zmienne i wahają się w granicach 20–70°, a najczęściej 20–40° (fig. 2).

Z sukcesji litologicznej syluru wynika, że odpowiada ona trzem kolejnym fazom regresywnej ewolucji zbiornika: od litofacji węglanowej (landower), przez węglanowo-ilastą i ciemnych osadów ilastych (wenlok), po wykształcenie ilasto-mułowcowe ze wzrastającym ku górze profilu udziałem piaskowców (ludlow). Jako punkt zwrotny od transgresywnej do regresywnej fazy rozwoju zbiornika uznać można pogranicze wenloku i ludlowu, tj. moment zaniku w poszczególnych profilach przewarstwień ciemnych bitumicznych iłowców, reprezentujących osady bardziej wewnętrznych, basenowych partii zbiornika.

EXPLANATIONS OF PLATES

PLATE I

Fig. 1. *Testograptus testis* (Barrande)

Borehole Ż-78, depth 453.0 m, x 6

Figs. 2, 5. *Cyrtograptus lundgreni* Tullberg

Borehole Ż-78, x 6; Fig. 2 — fragment of thecal cladium (fragment kladium tekalnego), depth 447.2–448.0 m; Fig. 5 — proximal fragment of procladium (fragment proksymalny prokladium), depth 450.5–450.7 m

Fig. 3. *Monograptus flemingi* (Salter)

Borehole Ż-78, depth 449.1–449.4 m, x 5

Figs. 4, 7. *Monograptus* ex gr. *dubius* (Suess)

Fig. 4 — borehole Ż-78, depth 450.5–450.7 m, x 6; Fig. 7 — borehole Ż-63, depth 283.8 m, x 12

Fig. 6. *Saetograptus chimaera* (Barrande)

Borehole WB-44, depth 261.5–262.5 m, x 9

The photos taken by Mrs J. Modrzejewska

PLATE II

Figs. 1, 2, 5. *Lobograptus* ex gr. *scanicus* (Tullberg)

Borehole WB-44; Fig. 1 — depth 278.0–279.0 m, x 8; Fig. 2 — depth 278.0–279.0 m, x 5; Fig. 5 — depth 269.0–270.0 m, x 9

Fig. 3. *Monograptus* ex gr. *dubius* (Suess)

Borehole Ż-89, depth 424.9 m, x 8

Fig. 4. *Neodiversograptus* cf. *nilssoni* (Barrande)

Borehole Ż-63, depth 298.3 m, x 6

Fig. 6. *Cucullograptus* aff. *pazdroi* (Urbanek)

Borehole Ż-67, depth 457.8 m, x 6

Fig. 7. *Linograptus* sp.

Borehole WB-44, depth 283.8 m, x 7

Fig. 8. *Bohemograptus* cf. *bohemicus* (Barrande)

Borehole Ż-67, depth 451.3–451.5 m, x 4

Fotografie wykonała J. Modrzejewska

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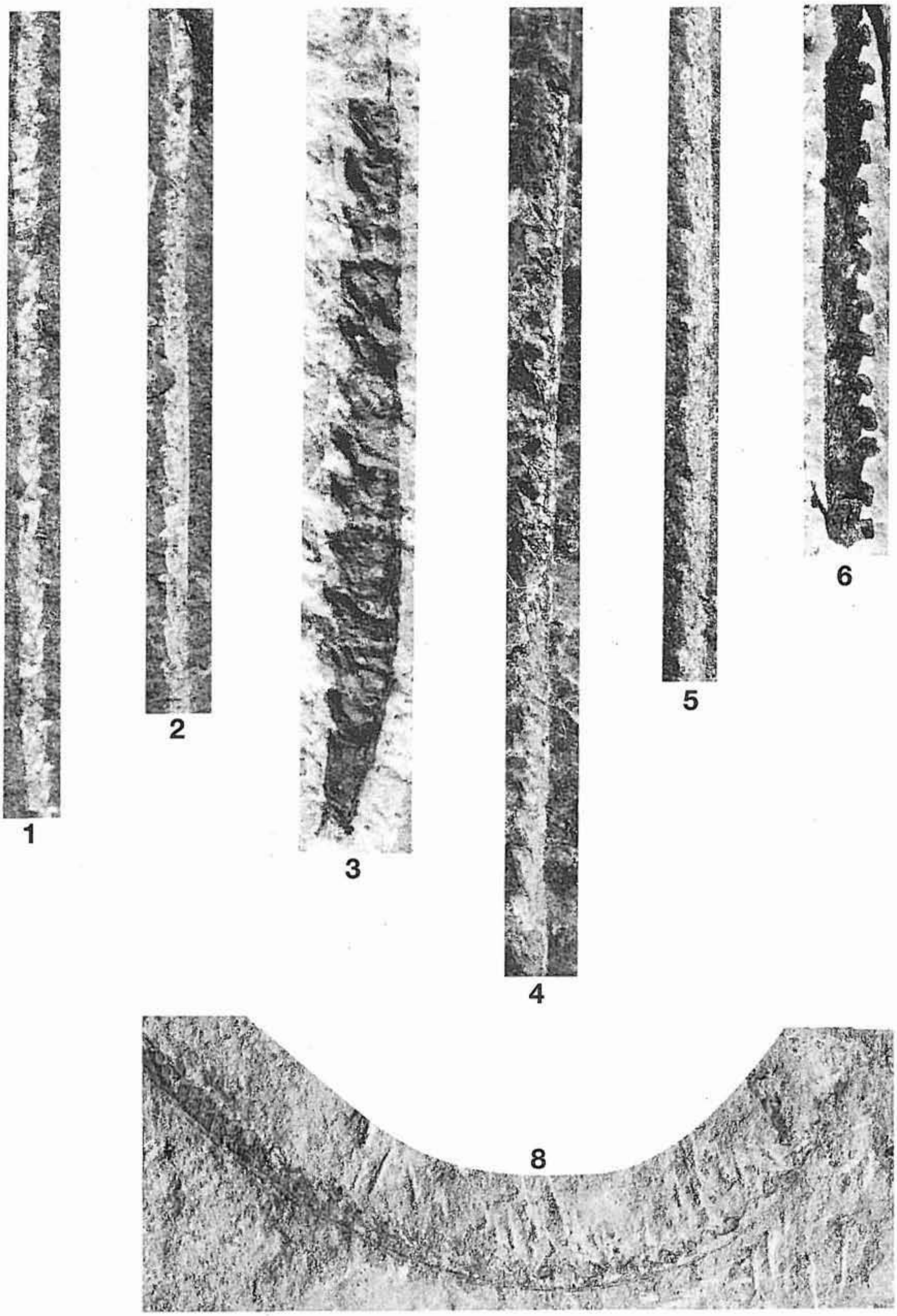
Bronisław SZYMAŃSKI, Lech TELLER — The Silurian stratigraphy of the Zawiercie–Żarki area (NE margin of the Upper Silesian Coal Basin)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