LOWER CARBONIFEROUS (MISSISSIPPIAN) STRATIGRAPHY OF NORTHWESTERN POLAND: CONODONT, MIOSPORE AND OSTRACOD ZONES COMPARED

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Abstract: Detailed stratigraphy of the Tournaisian and Visean in western Pomerania has been established on conodonts, miospores and ostracods recovered from 25 boreholes. Miospore associations from the Tournaisian and Visean are assigned to nine biostratigraphic units (zones and subzones) erected earlier. Three successive benthic ostracod assemblages and two sub-assemblages are distinguished for the Tournaisian. The miospore zones/subzones and the ostracod assemblages/sub-assemblages are correlated with the Tournaisian sandbergi, Lower crenulata, isosticha-X. crenilata, and typicus conodont zones. Stratigraphic gap has been demonstrated at the Devonian/Carboniferous boundary, using the results of both conodont and miospore studies. The Tournaisian/Visean boundary has been established approximately on the first appearance of the miospore species Lycospora pusilla Somers.

Key words: Tournaisian, Visean, biostratigraphy, conodonts, miospores, ostracods, western Pomerania.

INTRODUCTION

Lower Carboniferous strata have been recorded in a number of wells drilled in the coastal part of western Pomerania and in the Koszalin–Chojnice area (Fig. 1). These strata were also encountered, but not pierced through, in several wells located southwest of the latter area (Żelichowski, 1983; Żelichowski & Łoszewska, 1987).

In the study area, the lowermost Tournaisian is developed as the Sąpolno Calcareous Shale Formation, the base of which is Famennian in age (Matyja, 1993). It is likely that sedimentation was continuous across the Devonian–Carboniferous boundary, although a distinct stratigraphic gap has been noted in some sections (Matyja & Stempień-Sałek, 1994). In a few sections, however, different units of the Tournaisian rest unconformably either on the lower Famen- nian (especially in the sections located in the Gozd area), or even on folded lower Palaeozoic rocks (e.g., the Brda 2 borehole). This is due to a local tectonic and erosional episode, which took place at the end of the Devonian and during the Tournaisian. The Tournaisian strata are, in most cases, discordantly overlain by Permian sediments but in several sections near Sarbinowo, Karsina and Gozd, it is the lower Visean which underlies the Permian rocks. Younger strata have been penetrated only in the Sarbinowo 1 section where the middle and upper Visean deposits rest unconformably on the Ordovician (Bednarczyk, 1974), and are discordantly overlain by the Westphalian.

So far, the uppermost Visean and Namurian deposits have not been recorded in western Pomerania. The top of the Lower Carboniferous strata is probably of erosional character and the documented gap spans the topmost
Viséan, Namurian and lower part of Westphalian.

Tournaisian and Viséan deposits in the Kolobrzeg–Chojnice area show a great lithological variability. Incomplete coring coupled with insufficient biostratigraphical data have been the main obstacles in reconstructing the pattern of development of the Devonian–Carboniferous succession. The first attempt to present the arrangement of the Carboniferous lithological bodies and their general depositional environments, was that by Dadlez (1978). Żelichowski (1983, 1995; in Żelichowski & Łoszewska, 1987) revised Dadlez’s lithostratigraphical division and subdivided Lower Carboniferous strata into several informal units called complexes. For prospecting purposes more detailed division into units called “series” has been introduced by Lech (1986). Recently, Lipiec (in Lipiec & Matyja, 1998) modified the division of Żelichowski.

Early biostratigraphic investigations of the Carboniferous deposits in the studied area centered on macro- and microfauna (Błaszyk & Natusiewicz, 1973; Korejwo, 1976, 1979; Matyja, 1976), and spores (Krawczyńska-Grocholska, 1975; Tumau, 1975, 1978, 1979; Górecka & Parka, 1980). A generalized summary of the biostratigraphical division based both on published and unpublished data, was presented by Żelichowski & Łoszewska (1987). Some opinions on age assignments expressed in the earliest papers, were later revised (Matyja & Turnau, 1989; Clayton & Turnau, 1990; Avkhimovitch et al., 1993; Matyja, 1993; Matyja & Stempień-Sałek, 1994), and the miospore zonal scheme proposed by Turnau (1978, 1979) was partly redefined by Avkhimovitch & Turnau (1994) and upgraded by Stempień-Sałek (in Matyja & Stempień-Sałek, 1994).

The details of the conodont and ostracod stratigraphy discussed in this paper are new. On the other hand, the miospore part involves only the sample material interpreted earlier by Turnau (1975, 1978, 1979), and Avkhimovitch & Turnau (1994). Recently, all previously completed palynological logs as well as some old palynological slides have been reexamined. The here presented interpretation uses the upgraded miospore zonal scheme (see Subsection Zonal schemes) and the results of recent miospore studies in Poland and elsewhere.

Because our faunal and palynological samples are derived from the same boreholes, we were able to calibrate the conodont, ostracod and miospore zonation schemes used. In this respect, we also discuss some macrofaunal data published by Korejwo (1993). Our integrated biostratigraphic database permitted to correlate the lithostratigraphic units and to date their boundaries.

The studies have been carried out in the Institute of Geological Sciences of the Polish Academy of Sciences, and in the Department of Regional and Petroleum Geology of the Polish Geological Institute.

LITHOSTRATIGRAPHY

The lithostratigraphical division used in the present paper is that by Lipiec (in Lipiec and Matyja, 1998). Inferred spatial relationships between the lithostratigraphic units are shown in Fig. 2. These relationships reflect a general regressive tendency from an open shelf during the Famennian-middle Tournaisian (Sapolno Calcareous Shale Formation), through very shallow marine in the late Tournaisian (Kurowo Oolite Formation and Grzybowo Shale Member) to terrestrial environment during the latest Tournaisian (Drzewiany Sandstone Formation). The Gozd Arkose Formation reflects the Tournaisian volcanic activity episodes.

Sapolno Calcareous Shale Formation

The uppermost Devonian-lowermost Carboniferous Sapolno Calcareous Shale Formation overlies the Devonian Kojanty and Klanino formations throughout the investi-
gated area (see fig. 8 in Matyja, 1993). It is a succession of open marine carbonate and clayey deposits. The lower, Famennian part of the formation consists of two lithofacies: (1) fossiliferous marly limestones in the shallower part of the basin (northern part of the area), and (2) fossiliferous marls with thin intercalations of organodetrital limestones in the deeper part of the basin (southern part of the area) (see Matyja, 1993; Matyja & Stempień-Salek, 1994).

The younger, Tournaissian part of the formation consists mainly of black, fine-laminated clayey deposits in which faunal remains are rare. The thickness of the formation (excluding the Trzebiechowo marl Member) varies from more than 300 m in the Wierzchowo–Kurowo area to only about 30 m in the Karnino region in the northern part of the area.

**Trzebiechowo Marl Member**

This unit is an upper part of the Sapolno Calcareous Shale Formation. It includes marls, limestones (including oolite limestones), dolostones, and other types of limestones, often dolomitized. Marls and oolite sandstones may be present locally. The oolite-skeletal limestones contain echinoderms, brachiopods, corals, ostracods, and calcareous algae. The formation is up to 200 m thick.

**Gozd Arkose Formation**

It contains arkosic sandstones (volcanoclastic, cf. Muszyński et al., 1996), locally calcareous or dolomitic. Tuffites, claystones, marls and oolite limestones occur subordinately. The thickness of the formation may exceed 400 m.

**Kurowo Oolite Formation**

The formation includes oolite, and oolite-skeletal limestones and, subordinately, other types of limestones, often dolomitized. Marls and oolitic limestones may be present locally. The oolite-skeletal limestones contain echinoderms, brachiopods, lamellibranchs, oocysts, and gastropods. Ostracods and conodonts have also been encountered. In vicinity of Brda, the Trzebiechowo Marl Member is up to 600 m in thickness.

**Grzybowo Calcareous Shale Member**

This member is distinguished within both the Gozd and the Kurowo formations. It contains black shales, calcareous claystones, marls, limestones, and nodules of anhydrite. Fauna is dominated by thin-shelled lamellibranchs, ostracods, brachiopods and gastropods and, locally, brachiopods. The maximum thickness is up to 300 m.

**Drzewian Sandstone Formation**

In the northeastern part of western Pomerania, this is the uppermost unit of the Lower Carboniferous. It contains white and red, fine quartz sandstones, variegated mudstones and claystones, locally calcareous, with anhydrite and palaeosol. Rare fauna is limited to few beds, and is represented by thin-shelled lamellibranchs, ostracods, brachiopods and crinoids. Conodonts were reported from the upper part of the formation in the Sarbinowo 1 section (Korejwo, 1993). The thickness of the Drzewian Sandstone Formation may exceed 400 metres.

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**Fig. 2.** Generalized lithostratigraphic chart of Lower Carboniferous deposits of Kołobrzeg-Chojnice area of western Pomerania (after Lipiec in Lipiec & Matyja, 1998, modified)

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**BIOSTRATIGRAPHY**

In the study area, the main biostratigraphic tool for dating and correlating of the shale-rich, open marine lithofacies comprising lower and middle parts of the Tournaissian are conodonts supported by miospores and ostracods. The upper Tournaissian deposits represent generally very shallow-marine environments, where miospores and ostracods prevail, whereas conodonts are remarkably scarce. The uppermost Tournaissian and Viséan are dominated by terrestrial, mainly siliciclastic deposits, where miospores are the main stratigraphic tool.

**Zonal schemes**

In this section, we have omitted the names of the species creators. The list of complete specific names is given in the Appendix 1.

**Conodonts**

The preliminary "standard" Lower Carboniferous *Siphonodella*-based zonation of Sandberg et al. (1978) is based on the first occurrence of *Siphonodella* species that in most cases are the index species of the zones. The base of the Carboniferous in offshore marine sequences is defined at the base of the *sulcata* Zone. The upper limit of the *isostichia*-Upper *crenulata* Zone is defined by the last occurrence of the genus *Siphonodella*. Fortuitously, this extinction occurred almost simultaneously with the appearance of the new gnathodid species *Gnathodus typicus*, from *Gn. delicatus*. Lane et al. (1980) proposed a preliminary "standard" conodont zonation for the upper Tournaissian–Lower Viséan interval to follow the "standard" *Siphonodella* zonation. As in the case of the *Palmarateopsis*-based standard Upper Devonian conodont zonation, both these "standard" Lower Carboniferous schemes are applicable mainly to open marine, offshore settings. On the other hand, extensive shallow-water environments characterise most of the shelf areas in Belgium and in the British Isles where both "standard" zonations are difficult to apply. Therefore, several local schemes have been proposed in these areas (Groessens, 1974; Conil et al., 1990; Varker & Sevastopulo, 1985; Webster & Groessens, 1990).
Depositional environment within the Pomeranian sedimentary basin underwent evolution from an open shelf during the early and middle Tournaisian to a very shallow-water marine, and, subsequently, a terrestrial environment in the late Tournaisian. Therefore, the Siphonodella-based zonation of Sandberg et al. (1978) and part of the post-Siphonodella zonation of Lane et al. (1980) are applicable in western Pomerania up to the Tournaisian typicus conodont Zone (see Fig. 3). Conodonts younger than the typicus Zone have not been found so far as the uppermost Tournaisian Zone (see Fig. 3). Conodonts younger than the typicus Zone have not been found so far as the uppermost Tournaisian Zone (see Fig. 3).

The oldest documented Tournaisian conodont fauna in the Pomeranian area is that of the sandbergi Zone. The presence of advanced siphonodellids such as Siphonodella quadruplicata, and its co-occurrence with Siphonodella duplicata morphotype 1 (Fig. 4/9) suggest that the lowermost part of the Tournaisian succession in the Rzeczenica 1 section is to be correlated with the upper part of the sandbergi Zone (Sandberg et al., 1978; Clausen et al., 1989). Accompanying forms include representatives of Polygonathus spinulicostatus, Neopolygnathus communis morphotype 1, Polygonathus purus purus, Pandorinellina plumula, Elictognathus bialatus (Fig. 4/13–14) and Elictognathus lacera tus (Fig. 4/15). Bispathodus stabilis morphotype 1, and Polygonathus inornatus.

The succeeding Lower crenulata Zone has been recognized also in the Rzeczenica 1 section (Appendix 2) by the presence of Siphonodella crenulata and its co-occurrence with Polygonathus symmetricus (Sandberg et al., 1978; Belka, 1985), accompanied (see Fig. 3) by Polygonathus radinus (Fig. 5/1) and Polygonathus distortus (Fig. 5/6). Unfortunately, other accompanying fauna consists of long-ranging taxa including Polygonathus triangulus (Fig. 5/4) and Polygonathus inornatus (Fig. 5/2), representatives of Siphonodella obsoleta (Fig. 5/12) and Siphonodella quadruplicata (Fig. 5/3, 13), Neopolygnathus communis morphotype 1, Pseudopolygnathus nodomarginatus (Fig. 5/7–7), Bispathodus spinulicostatus, Elictognathus bialatus and Elictognathus lacera tus (Fig. 5/11) and rare Hindeodus aff. cristatus (Fig. 5/10).

It should be mentioned that due to the extremely rare occurrence of Siphonodella crenulata and the lack of other diagnostic species in most of the investigated sections, it is not possible to separate the sandbergi Zone from the Lower crenulata Zone (comp. Fig. 3 and Appendix 2). The same problem arises with separation of the Lower crenulata Zone from the isosticha–Upper crenulata Zone because of the absence of Gnathodus delicatus. The unseparated interval between the sandbergi and the Lower crenulata zones is characterized by the presence of various polygnathids, pseudopolygnathids and bispathodonts, i.e. Pseudopolygnathus primus (Fig. 4/1), Polygonathus inornatus (Fig. 4/3), Polygonathus flabellus (Fig. 4/7), Neopolygnathus carina morphotype 1 (Fig. 4/4), Neopolygnathus communis morphotype 1 (Fig. 4/5), Bispathodus aculeatus anteposicornis (Fig. 4/8) and Siphonodella quadruplicata (Fig. 4/11).

The presence of Pseudopolygnathus multistriatus morphotype 2 (Fig. 6/8) and Gnathodus cuneiformis (Fig. 6/11–12) well characterize the Lower typicus Zone (Lane et al., 1980) and the equivalent zones (Belka, 1985; Varker & Sevastopulo, 1985; Belka & Groesens, 1986; Sevastopulo & Nudds, 1987; Carman, 1987; Riley, 1993). Other accom-
Fig. 5. Conodonts of the Lower crenulata (Ce1) Zone (1-4, 6-8, 10-12), unseparated Upper duplicata - isosticha - Upper crenulata (Du2-Ce2) Zones (5), and unseparated sandbergi? - Lower crenulata? (Sn? Ce1?) Zones (9). All specimens are from Rzeczenica 1, 2896-2899 m, except when indicated otherwise. All photographs are SEM upper views except 4, 5, 8 (lower views) and 9-11 (side views). 1 - Polygnathus radinus (Cooper), SEM-827, x70; 2 - Polygnathus inornatus Branson, Rzeczenica 1, 2899-2901 m, SEM-657, x70; 3, 13 - Siphonodella quadruplicata (Branson & Mehl); 3: SEM-829, x30, 13: SEM-654, x60; 4-5 - Polygnathus triangulus Voges; 4: SEM-824, x60; 5: Bielica-1, 3516-3517 m, SEM-651, x120; 6 - Polygnathus distortus Branson & Mehl, SEM-658, x90; 7-8 - Pseudopolygnathus nodomarginatus (Branson), 7: SEM-659, x100, 8: SEM-821, x60; 9-10 - Hindeodus aff. cristatus (Youngquist & Miller); 9: Brda-1, 2469-2475 m, SEM-813, x70, 10: SEM-656, x80; 11 - Elictognathus laceratus (Branson & Mehl), SEM-655, x80; 12 - Siphonodella obsoleta Hass, SEM-653, x45
Fig. 6. Conodonts of the Lower typicus (Ty(I)) Zone. Specimens 1-4, 6, 7 are from Drzewiany 1, 2733–2736 m, other specimens as indicated below. All photographs are SEM upper views except 1 and 3 (side views). 1–5 – Clydagnathus unicornis Rhodes, Austin & Druce, 1: SEM-819, ×60, 2: SEM-644, ×100, 3: SEM-820, ×80, 4: SEM-643, ×140, 5: Brda 1, 2192–2198 m, SEM-111, ×95; 6–8 – Pseudopolygnathus multistriatus Mehl & Thomas, 6-7: morphotype 1, 6: SEM-641, ×100, 7: SEM-642, ×150, 8: morphotype 2, Drzewiany 1, 3003–3004 m, SEM-645, ×70; 9 – “Hindeodus” crassidentatus (Branson & Mehl), Chmielno 1, 3588–3599 m, SEM-648, ×50; 10 – Neopolygnathus carina (Hass), morphotype 2, Brda 1, 2325–2326 m, SEM-811, ×80; 11–12 – Gnathodus cuneiformis Mehl & Thomas, early phylogenetic forms, Chmielno-1, 3588–3599 m, 11: SEM-834, ×150; 12: SEM-647, ×150
### Miospore Zone / Subzone

<table>
<thead>
<tr>
<th>Miospore Zone / Subzone</th>
<th>Species defining base of Zone/Subzone (*)</th>
<th>Characteristic assemblage</th>
</tr>
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<tbody>
<tr>
<td>Dictyotriletes pactilis (Pa)</td>
<td>D. plumosus (*)</td>
<td>Lophotriletes tribulosus L. pusilla Schulzospora spp Cingulizonates bialatus</td>
</tr>
<tr>
<td>Schulzospora campyloptera (Ca)</td>
<td>S. campyloptera (*)</td>
<td>Lycospora pusilla Knoxiaspores spp</td>
</tr>
<tr>
<td>Lycospora pusilla (Pu)</td>
<td>L. pusilla (*) W. planiangularata (**)</td>
<td>P. claytonii A. baccatus C. multisetus A. trychera W. planiangularata</td>
</tr>
<tr>
<td>Prolycospora claytonii upper (2)</td>
<td>A. solisorta A. panda G. multiplicabilis S. claviger (*)</td>
<td>P. claytonii A. baccatus C. multisetus U. distinctus R. corynoges V. nitidus P. uncutans D. plumosus</td>
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<td></td>
<td>lower (1)</td>
<td></td>
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<tr>
<td>Convolutispora major middle (3)</td>
<td>S. balteatus (*)</td>
<td>R. corynoges V. nitidus A. macra Tulmispora spp Reticulatisporites carnosus Knoxiaspores spp Dictyotriletes spp</td>
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<tr>
<td></td>
<td>lower (2)</td>
<td></td>
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<tr>
<td>lowermost (1)</td>
<td>R. corynoges L. excisus K. hibernicus (?)</td>
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### Fig. 8. Miospore zones and sub-zones for Lower Carboniferous in western Pomerania and their characteristic species

### Fig. 9. Correlation of the zonal schemes for Lower Carboniferous of British Isles and western Pomerania. Arrows indicate uncertain position of lower boundary of Ma Zone

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<table>
<thead>
<tr>
<th>Series</th>
<th>British Isles</th>
<th>First appearances of index species</th>
<th>Western Pomerania miospore zonation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRIGANTIANT</td>
<td>NC Bellispores nitidus - Reticulatisporites carnosus</td>
<td>R. fracta</td>
<td>Pa Dictyotriletes pactilis</td>
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<tr>
<td></td>
<td>VF Tripartites veluticos - Rotaspora fraca</td>
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<td>Ca Schulzospora campyloptera</td>
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<td></td>
<td>NM Rastriola nigra - Triquatites marginatus</td>
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<td></td>
<td>TC Perotrilites tesselatus - Schulzospora campyloptera</td>
<td>S. campyloptera</td>
<td></td>
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<tr>
<td></td>
<td>TS Knoxiaspores triradiatus - Knoxiaspores stephanophor</td>
<td>W. planiangularata</td>
<td>Pu Lycospora pusilla</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Pa Prolycospora claytonii</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Ca Schulzospora campyloptera</td>
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<tr>
<td>ASBIAN</td>
<td>CM Schopfites claviger - Autrospora macra</td>
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<td></td>
<td>PC Speaenotrites pretiosus - Rastriola clavata</td>
<td>S. pretiosus</td>
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<tr>
<td>HOLKERIAN</td>
<td>BP Speaenotrites balleatus - Rugospora polytycha</td>
<td>S. balleatus</td>
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<tr>
<td></td>
<td>ARUINCIAN</td>
<td>HD Kal.previewitites hibernicus - Umbonatisporites distinctus</td>
<td>U. distinctus</td>
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<td>CHADIAN</td>
<td>VI Valatispores verrucosus - Retusotrites incohatus</td>
<td>K. hibernicus ?</td>
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<tr>
<td>COURCEYAN</td>
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</tbody>
</table>

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**Notes:**
- (*) Indicates species defining the base of Zone/Subzone.
- (**) Indicates other first appearances in the upper part of the Zone.
panying forms (Fig. 3, Appendix 2) include many representatives of Clydognathus uncinoris (Fig. 6/1–5), Pseudopolypogonanthus multistriatus morphotype 1 (Fig. 6/6–7), rare Neopogonanthus carina morphotype 2 (Fig. 6/10), and Hindoedus crassidentatus (Fig. 6/9).

Miospores

Tumau (1978, 1979) erected a local miospore zonal scheme in this region encompassing uppermost Devonian to lower Westphalian strata. The Carboniferous part of the scheme comprises six zones and three subzones, two zones for the Tournaisian, three for the Viséan, and one for the Westphalian. The first two zones have been formally defined, and the succeeding ones are informal. The miospore species characteristic of the zones are shown in Figs 7, 10–11. In the following text, and in some figures, the names of the miospore zones are abbreviated to a two-letter notation. However, their full taxonomic titles are given in Figs 8–9.

The Tournaisian part of the zonation scheme was subsequently modified. Stempien-Salek (in Matyja & Stempien-Salek, 1994) erected four subzones of the Convolutispora major (Ma) Zone. They are designated here the lowermost (Ma1), lower (Ma2), middle (Ma3) and upper (Ma4). The characteristic of the revised and upgraded part of the zonal scheme is shown in Fig. 8.

The Prolycospora claytonii (Cl) Zone was initially divided into three subzones. The base of the upper subzone was based on the first appearance of Rugospora minuta. However, subsequently, it was established that in western Pomerania, the range of this species was much wider. Thus, Avkhimovitch & Tumau (1994) revised the zonal scheme as to recognize only two subzones designated Lower Cl (Cl1) Subzone and Upper Cl (Cl2) Subzone. The new Upper Cl Subzone contains the original middle and upper Cl subzones up to the redefined lower boundary of the Lycospora pusilla (Pu) Zone.

It must be emphasized that the statement by Tumau (1978) concerning the first appearance level of Lycospora pusilla was erroneous. This species does not occur throughout the P. claytonii Zone, i.e. part of the Tournaisian (see discussion in Avkhimovitch & Tumau, 1994).

The local miospore zonation for western Pomerania can be correlated at several stratigraphic levels with the zonal scheme for the type regions of the Lower Carboniferous stages in the British Isles (Fig. 9). This scheme was erected by Neves et al. (1973) and later gradually refined on the basis of new studies (see Clayton, 1985; Higgs et al., 1988a: Higgs et al., 1992). The scheme is keyed to the British Isles Carboniferous stages (Higgs et al., 1988b; Riley, 1993), and at some stratigraphic levels to the Irish and Siphonodella based conodont zonations which is discussed in more detail in the Subsection Results.

The correlation of the Pomeranian and western European schemes for the Tournaisian was discussed in Clayton & Tumau (1990) and Avkhimovitch & Tumau (1994). The present version differs in details from the previous ones due to the results of Stempien-Salek (Matyja & Stempien-Salek, 1994, Stempien-Salek, 1997) who established, that Spelaeotritiletes balteatus and S. pretiosus appeared earlier than Prolycospora claytonii.

The correlation shown in Fig. 9 is based on the first appearances of stratigraphically important species. A further comment is needed only for correlations at some levels.

The base of the Ma Zone cannot be confidently correlated with the base of the HD Zone of northwestern Europe. This is because the presence of Kraeuselisporites hibernicus in the lowermost assemblages of the zone (in the Rzeczenica 1 borehole, see Appendix 2) is not certain. Higgs et al. (1992) considered Cymbosporites acutus as an important species for defining the base of the HD Zone in Belgium. This species has been recorded from the Ma1 assemblages; however, we consider it as an unreliable stratigraphic marker because in Ireland, it ranges downwards into the Famennian (Van der Zwan, 1980), and in the East European Platform, it appears in the Tumulisporites maloevkeensis Zone (Byvsheva, 1985; Avkhimovitch, 1993) very near the Devonian/Carboniferous boundary.

The correlation of upper part of the (Pomerania) Pu Zone with a part of the TS Zone is based on the presence of Waltisporites planiangulata in higher assemblages of the Pu zone. In Rügen, this species first appears in the TS Zone (Carson & Clayton, 1997).

The base of the Pa zone was correlated by Tumau (1979) with the base of the NM Zone on the first appearance of Dictyotritiletes pactilis. However, specimens assigned at that time to D. pactilis represent an older species D. planius (see the Section Systematic comments (miospores). The Pa zone assemblages contain also Potoniespores delicatus. This species appears in the upper part of the TC Zone (Clayton et al., 1977b). Thus, the base of the Pa zone is now considered not older than the upper part of the TC Zone.

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Fig. 7. Miospores of the Convolutispora major (Ma) Zone. Specimens 1, 4-9, 15, 16 are from Biely Bór 1, 2792–2796 m, specimens 2, 10, 11, 13 are from Rzečeczna 1, 1920–1921 m, other specimens as indicated below. All magnifications x500. 1 – Reiusotritiletes circulares Tumau, slide V/67; 2 – Verruciosporites nitidus Playford, slide V/85; 3 – Unbhanatisporites distinctus Clayton, Wierzchowo 10, 3545–3551 m, slide VII/19; 4 – Convolutispora mellita Hoffmeister, Staplin & Malloy, slide V/65; 5 – Knoxisporites irroratus Hoffmeister, Staplin & Malloy, slide V/65; 6 – Knoxisporites hederaeus (Ischenko) Playford, slide V/67; 7 – Convolutispora major (Kedo) Tumau, slide V/64; 8 – Tumulisporites variervaccata (Playford) Staplin & Jansoniou, slide V/65; 9 – Murospora subhohata (Waltz) Playford, slide V/65; 10 – Lophozonotriletes excisus Naumova, slide V/85; 11 – Tumulisporites maloevkeensis (Kedo) Tumau, slide V/86; 12 – Endococcuspora gradinorze Tumau, Rzečeczna 1, depth 2912–2916 m, slide V/83; 13 – Grandisporis upensis (Kedo) Byvsheva, slide V/83; 14–15 – Discernisporites micromaniestus (Haqebaud) Sabry & Neves, slide V/66; 16 – Auroraspora macra Sullivan, slide V/65; 17–18 – Cymbosporites acutus (Kedo) Byvsheva, Nieklonice 2, depth 2877–2891 m, slide VII/36; 19 – Kraeuselisporites hibernicus Higgs, Wierzchowo 10, depth 3513–3517 m, slide VII/51; 20 – Indotriradites explanatus (Luber) Playford, Klaino 1, depth 27812787 m, slide VII/83.
In the description of the assemblages of the Pa zone, Turnau (1979) stated that they lacked Rotaspora. However, further study of samples from Sarbinowo 1 borehole revealed the presence of a single specimen of R. fracta in the highest assemblage representing the Pa zone. Therefore, it is suggested that the base of the western European Tripartites vetustus-Rotaspora fracta (VF) Zone corresponds to a level within the Pa Zone.

**Ostracods**

In the following text, and in some figures, the names of the ostracod assemblages are abbreviated to a two-letter notation. However, their full taxonomic titles are given in Fig. 12.

Only the lowest Carboniferous deposits bear rare entomozaecean ostracods. Specimens occur as internal or external, typically preserved moulds. Only the latior (La) entomozoid Zone has been distinguished based on the presence of single specimens of the index species Richterina latior. This zone corresponds to the lowest Tournaiansulcata to sandbergi conodont zones (Gross-Uffenorde, 1984; Gross-Uffenoorde & Schindler, 1990).

About 80 species of benthic ostracods have been found in the Tournaian strata. Only some have been described (Blaszyk & Natusiewicz, 1973). The majority of ostracods belong to unknown and undescribed taxa, but the preliminary investigation of the fauna has shown that about one third of the species is known from other, sometimes distant areas.

A preliminary, informal Tournaian local zonation that comprises 4 assemblages, based only on small part of the ostracod fauna, is proposed here by Źbicowska. This is the first attempt to show the stratigraphic value of the Tournaian benthic ostracods from Pomerania. Establishing of a formal zonation would be possible only after a detailed analysis of the fauna, which is beyond the scope of this paper.

The characteristics of the assemblages are given in Fig. 12. Lowermost is the Pseudoleperditia venulosa (Vn) assemblage which is divisible into the lower (Vn1) and the upper (Vn2) ones.

The Vn1 assemblage is characterized by the occurrence of Pseudoleperditia venulosa and the short ranging species Namara reticulata. The accompanying known species are listed in Fig. 12 and Appendix 2, and illustrated in Fig. 13. They are characteristic of the lower Tournaian deposits of Belgium, North America and Russian Platform (Green, 1963; Becker & Bless, 1974; Becker et al., 1974; Tschigoya, 1977; Bless et al., 1986; Coen et al., 1988).

The Vn2 assemblage (Fig. 14) is characterized by the co-occurrence of Pseudoleperditia venulosa and the short ranging species Chamishaella obscura. It does not contain stratigraphically important species, and its age can be only approximately established on its relation to miospore samples, which is discussed below.

The succeeding assemblage Cribroconcha postfoveata – Marginia tchigovae (P–T) (Fig. 15) contains species known from the upper Tournaian deposits of Germany and the Russian platform (Blumenstengel, 1975a; Gründel, 1975; Tschigoya, 1977).

The youngest recognized assemblage, Glyptopleura ruegensis–Carbonita fabulina (R–F) (Fig. 16) contains species known from the uppermost Tournaian and Viséan of Germany and Great Britain (Blumenstengel, 1975a, b; Robinson, 1978).

**Results**

**Comparison of conodont, miospore, and benthic ostracod stratigraphic schemes**

Conodonts and, to a lesser extent, entomozoids from the Tournaian succession of the Koszalin–Wierzchowo area provide new biostratigraphic information and control on the age of the miospore zones and benthic ostracod assemblages (Fig. 17). In the following discussion, we will also use information on occurrence of ammonoids, which was provided by Korejwo (1979, 1993). There is little faunal control on the age of informal, local miospore zones for the Viséan.

Correlation of various biostratigraphic schemes has been the concern of Carboniferous biostratigraphers for a long time. In western Europe, miospore assemblages from the Tournaian conodont dated sequences were studied in Ireland (Clayton et al., 1977a, 1978, 1980; Sleeman et al., 1978; Marchant et al., 1984; Higgs et al., 1988a, b), and Belgium (Higgs & Streefl, 1984; Higgs et al., 1992). The palynological boundaries within the Irish Dinantian are also dated by other microfauna (Higgs et al., 1988b). Owing to these contributions, the miospore zonation scheme for the Tournaian proposed by Higgs et al. (1988a) has been correlated with the Irish conodont zonation scheme and the siphonodellid based scheme, which is shown in Fig 17. This chart shows also the correlation of the British Isles and western Pomerania miospore zonation schemes for the Tournaian, based on palynological criteria (see also Fig. 9). The validity of this correlation is controlled at a few stratigraphic levels by conodonts and entomozoids. Conodonts and miospores provide also control on the age of benthic ostracod assemblages. These data are discussed below, and the details of the occurrences are presented in Figs 18, 19, and in the Appendix 2.

In the Rzeczenica 1 section (Fig. 18), the Ma1 assemblages occur just below conodont fauna indicative of the sandbergi Zone, and are bracketed by such fauna (see also Matyja & Stempieri-Salek, 1994). These assemblages were also found below the latior Zone entomozoids and sandbergi-­isosticha–Upper crenulata Zone conodonts (Chmielewski 1 borehole, Fig. 18) and in the same 6 m interval as goniatities Pseudotuamites dorsoplanus dorsoplanus H. Schmidt (Ga α) (Grzybowo 1, 3297–3303 m, and Wierzchowo 10, 3545–3552 m, Fig. 18). The results indicate that the base of the Ma Zone is located either within or slightly below the sandbergi Zone. Palynologically, the equation of the base of the Ma Zone with that of the western European HD Biozone (which is within the sandbergi Zone) is poorly substantiated because the assignment of specimens from the lowermost Ma1 assemblage from the Rzeczenica 1 section to Kraeuselsporites hibernicus is uncertain.

The Ma2 miospore assemblages occur with conodonts of the unseparated sandbergi-­isosticha–Upper crenulata
zones, and entomozoids of the latior Zone (Chmielnko 1), and with the Lower cremlata conodont fauna (Rzeczenica 1). Thus, the base of the Ma₂ subzone is within the sandbergi Zone, and a higher part of the subzone corresponds to a part of the Lower cremlata Zone. This agrees well with the miospore and conodont data from Belgium (Higgs et al., 1992) where Umbonatisporites distinctus first appears at a level within the sandbergi Zone.

In the Gorzyšlaw 9 borehole, a miospore assemblage representing the Ma₃ subzone was found at depth 3141–3142 m by Stempien-Salek (1997). This level is bracketed by conodont faunas of the sandbergi or Lower cremlata zones (Fig. 18). Thus, the base of the Ma₃ subzone is not younger than the Lower cremlata Zone. This is the same stratigraphic position as that of the lower boundary of the balleatus–polypytcha (BP) Zone in Belgium (Higgs et al., 1992).

The Cl₁ miospore assemblages were found below, and/or in association with conodonts of the Lower typicus Zone (Chmielnko 1, Drzewiany 1, and Klanino 1 boreholes, see Figs 18, 19), and the Cl₂ miospore assemblages occur above the Lower typicus faunas (Brda 2 and Drzewiany 1 boreholes, see Fig. 19). In the Biaty Bör 1 borehole, a conodont specimen determined as Polynathus cf. purus purus has been found above the base of the Cl Zone (Matyja, 1976). Polynathus purus purus ranges to the upper boundary of the Lower cremlata Zone (Belka, 1985), but in Belgium P. cf. purus purus was found in the cuneiformis Zone (Belka & Grossens, 1986, table 1) which is equivalent of the Lower typicus Zone.

This, and the conodont data on the Ma Zone discussed above, suggest that the Ma/Cl boundary is within the span Lower cremlata - Lower typicus zones, and the lower boundary of the Cl₂ Subzone is within or above the Lower typicus Zone.

Faunal control on the Viséan miospore zones is very scarce. The ammonoid index species of the Goat Zone - Goniatites crenistria Phill. - has been found in the Sarbinowo 1 borehole at depth 2656–2662 m (Korejwo, 1993), i.e. between the intervals included in the Ca and Pa miospore zones (Fig. 19). This agrees well with the ammonoid data on the equivalents of these zones (see Fig. 9) in the British Isles (Riley, 1993).

In some sections, benthic ostracods were found in association with conodont, entomozoids and miospore assemblages. The ostracod Vn₁ assemblage has been found in association with Ma₃ miospores (Brda 1 borehole), and with the latior entomozoids, sandbergi - cremlata conodonts, and Ma₂ miospores (Chmielnko 1 borehole, see Fig. 18). The Vn₁ assemblage co-occurs with Ma miospores in the Brda 1 borehole. The P-T assemblage occurs below the Lower typicus conodonts (Brda 1 borehole, see Fig. 19) and in association with the Cl₁ miospores (Chmielnko 1 borehole). The R-F assemblage is associated with the Upper typicus(?) conodonts (Biesiekierz 1 borehole) and with the Cl₂ miospores (in the Klanino 1 borehole) (Fig. 19). These data allow to establish approximate correlation between the miospore and benthic ostracod zonations (Fig. 17).

Age of formations

The stratigraphic positions and biozonal assignments of the micropaleontological samples in the boreholes studied are shown in Fig. 18 and Fig. 19, and a generalized chronotratigraphic chart of the Tournaisian deposits is in Fig. 18. Species range charts are in the Appendix 2.

The younger, Carboniferous part of the Sapnolo Calcareous Shale Formation is well dated by means of conodonts, miospores, ostracods, and macrofossils. The oldest conodonts indicate the upper part of the sandbergi Zone, the entomozoid ostracod Richterina (R.) latior indicates the latior Zone (Zbikowska, 1992), and miospore assemblages represent the Ma Zone, the Ma₁ or Ma₂ subzones. Goniatites found in Grzybowo 1 borehole (depth 3297–3303 m), and Wierzchowo 10 (depth 3545–3552 m) give well constrained dates for this part of the Sapnolo Calcareous Shale Formation owing to the occurrence of ammonoids Pseudar­rieties dorsi­plamens dorsiplamens Schmidt and Gat­ten­pleura sp., indicative of the Gatt (Gattendorfia subin­voluta) Zone of the lowermost Carboniferous (Korejwo, 1979, 1993). Benthic ostracods belonging to the Vn₁ subassemblage including species indicative of a lower Tournaisian (Tn₁b) age, are also present.

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Fig. 10. Miospores of the Prolycospora claytonii (CI) Zone and basal part of Lycospora pusilla (Pu) zone. Specimens 1, 12, 13, 17, 22, 23 are from Karsina 1, 2242–2249 m, specimens 3, 8, 20, 24 are from Karsina 1, 2535–2538 m, other specimens as indicated below. All magnifications x500; except when indicated. 1 – Punctatisporites aerarius Butterworth & Williams, slide III/8; 2 – Pustulatisporites unicus tus (Kedo) Byvsheva, Wierzchowo 10, 3332–3339 m, slide VII/25; 3 – Raistrickia clavata Haquebard emend. Playford, slide III/22; 4 – Raistrickia corynogier Sullivan, Gozd 2, depth 2807–2812 m, slide IV/87; 5 – Schopfites delicatus Higgins emend. Higgins, Clayton & Keegan, Bieszterkierz 1, 2907–2913 m, slide IV/93; 6 – Schopfites claviger Sullivan, 6: Drzewiany 1, 2581–2585 m, slide X/35, 7: Wierzchowo 9, 3424–3430 m, slide VII/80; 8 – Crassispora trchera Neves & Ioannides, slide III/22; 9 – Umbonatisporites distinctus Clayton, Brda 1, 2260–2266 m, slide IV/45; 10 – Acanthoprisporites baccatus Hoffmeister, Staplin & Malloy, Karsina 1, 2591–2594 m, slide III/8, 11 – Dicyotrichites membranireticulatus Bertelsen, Drzewiany 1, 3053–3056 m, slide X/82; 12 – Prolycospora claytonii Tow­ nau, slide III/8, 12: x1000; 14: Bascandospora submarginita (Playford) Higgins, Clayton & Keegan, Bieszterkierz 1, 2907–2913 m, slide IV/87; 15 – Acanthotricites socraticus Neves & Ioannides, Wierzchowo 1, 30533056 m, slide X/82; 16 – Dicyotrichites ghunaccus (Byvsheva) Byvsheva, Wierzchowo 9, 3424–3430 m, slide VII/77; 17 – Lycospora pusilla (Ibrahim) Somers, slide III/9; 18 – 19 – Colatisporites multisetus (Luber) Avchimovitch & Turnau, 18. Gozd 2, depth 2807–2812 m, slide IV/87, 19: Wierzchowo 9, depth 3323–3330 m, slide VII/67, x750; 20 – Auroraspore parda Turnau, slide III/22; 21 – Auroraspore macra Sullivan, Wierzchowo 10, 3323–3339 m, slide VII/12; 22 – Rugosaspore mirita Neves & Ioannides, slide III/7; 23 – Gargenospora multiplicative (Kedo) Turnau, slide III/8; 24 – Auroraspore cf. solisorta Hoffmeister, Staplin & Malloy, slide III/22; 25 – Krauseltisporites hibernicus Higgins, Brda 2, 2207–2213 m, slide VI/37; 26 – Spelaeartriletes balleatus (Playford) Higgins, Wierzchowo 10, 3301–3307 m, slide VII/8; 27 – Spelaeartriletes pretiosus (Playford) Neves & Belt, Gozd 3, 2810–2813 m, slide IV/82
The top of the Sapolno Calcareous Shale Formation is dated as the *la tior* entomozoid Zone, and *sandbergi* or *crenulata* conodont Zone (Gorzyslaw 9, Karlino 1, and Chmielno 1 boreholes). The benthic ostracod P-T assemblage occurs in the top part of the formation in the Daszewo R3p borehole.

In the southeasternmost part of the study area, between Biaty Bör and Brda, the upper boundary of the Sapolno Calcareous Shale Formation (i.e., the upper boundary of the Trzebiechowo Marl Member) is erosional, except for the Brda 2 borehole. The stratigraphic position of this boundary is dated as the Lower *crenulata* conodont Zone and *mio­spore* subzone (in the Rzeczyzna 1 borehole), *C1* miospore subzone (in the Biaty Bör 1 borehole) and *C2* miospore subzone (in the Biaty Bör 3 borehole).

Over the entire Kołobrzeg–Chojnice area, except for its southeasternmost part, the limestones and shales of the Sapolno Calcareous Shale Formation are overlain by coarse-grained sediments included in the Gozd Arkose Formation. In the northwestern part of the study area, west of the Kurowo 1 - Wierzchowo 10 line, the boundary between the two formations is within the *Convolutispora major* miospore Zone, *Maz* to *Maz* subzones (Niekłonice 1, Chmielno 1, Gozd 4 boreholes, probably also Klano 1 borehole), but to the east (Kurowo 1, Wierzchowo 10, and Drzewiany 1), it is within a lower part of the *Prolycospora claytoni* (C1) Zone. In the terms of the conodont zonation, this lithostratigraphic boundary is within the Lower *crenulata* Zone in the northwest and in the *isosticha-Upper crenulata* or lower part of the Lower *typicus* Zone in the east.

In upper Tournaian, in the area along the Gozd–Bieszczierz–Grzybowo line, calcareous claystones replaced the coarse grained arkoses. The boundary between the lower part of the Gozd Arkose Formation and the Grzybowo Calcareous Shale Member is dated as lower part of the *Prolycospora claytoni* (C1) Zone. In the Kurowo Oolite Formation, the boundary between the two formations is within or above the Lower *typicus* Zone (Klano 1 1 borehole), and is within a higher part of the *C1* subzone (Niekłonice 1), or within undivided C1 Zone. Benthic ostracod data (Klano 1) are in agreement with this position. Conodonts representing probably the Upper *typicus* Zone have been found in the Grzybowo Calcareous Shale Member in the Biesiekierz 1 borehole, and miospore assemblages representing the *C2* subzone have been recorded from the Rosnowo 1 borehole.

To the west and south from the Gozd–Bieszczierz–Grzybowo line, the Gozd Arkose Formation is overlain by the Kurowo Oolite Formation. The boundary between the two formations is within or above the Lower *typicus* Zone (Drzewiany 1, Chmielno 1 boreholes). Benthic ostracods (Daszewo R3p) indicate a position of the boundary not older than the R-F assemblage, i.e., in upper part of the *C1* Subzone (cf. Fig. 17). In the Brda 2 borehole, a higher part of the formation is dated as the *C2* subzone. Thus, the Kurowo Oolite Formation is roughly a time equivalent of the Grzybowo Calcareous Shale Member.

During the latest Tournaisian, deposition of quartz sandstones of the Drzewiany Sandstone Formation replaced that of clayey and carbonate sediments of the Grzybowo Calcareous Shale Member and Kurowo Oolite Formation. The lower boundary of the Drzewiany Sandstone Formation is within the *C2* Subzone (Rosnowo 1, Gozd 2, probably Wierzchowo 9 and Drzewiany 1 boreholes).

There are considerable differences between the above, miospore based age assignment and that based on macrofauna (Korejwo, 1993). Controversies concern mainly the lower parts of the Drzewiany Sandstone Formation (boreholes Drzewiany 1, Gozd 2, Wierzchowo 9) assigned here, basing on spores, to the Tournaian. In the opinion of Korejwo (1993), the presence in these deposits of brachiopod species *Schizodus arbuliculas* (Mc Coy) and bivalve species *Sanguinolites abdenensis* Ether. indicates the lower Viséan (V1). Although these species are known from the entire Di-nantian, Korejwo (1993) argued that they had been recorded mainly from the Viséan.

The undisputed assignment of the higher parts of the Drzewiany Sandstone Formation in the Karsina 1 section to the Viséan has been confirmed by the occurrence of a miospore assemblage of the lower-middle Viséan *Lycospora pusilla* (Pu) Zone. The formation is relatively well dated in the Sarbinowo 1 section (Fig. 18). Miospores indicate the presence of the Viséan *Lycospora pusilla* (Pu), Schulzospora campyloptera (Ca) and Dictyotriletes pactilis (Pa) zones. The assemblages of the Pu zone in this section include younger elements not found below the *triradiatus-stephaneophorus* (TS) Zone (see Fig. 11) suggesting a middle Viséan age, while miospore species present in the uppermost assemblage point to a late Viséan (Brigantian) age. In

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**Fig. 11.** Miospores of the Dictyotriletes pactilis (Pa) zone. All specimens are from Sarbinowo 1 borehole, specimens 1, 4, 28 are from depth 2559-2562 m, slide IV/16, specimens 2, 3, 6, 7, 9, 10-12, 15 17-19, 21-27, 31 are from depth 2534-2537 m, slide IV/7, specimens 5, 8, 13, 14, 29 are from depth 2534-2537 m, slide IV/9, specimens 16, 20 are from depth 2535-2537 m, slide IV/14, specimen 30 is from depth 2559-2562 m, slide IV/21. All magnifications ×500. 1 – Chetrosphaerites pollenisimilis (Horst) Butterworth & Williams; 2 – Pilosporites venustus Summit & Marshall; 3 – Orchisporis convolutus Butterworth & Spimmer; 4 – Punctatisporites aerarius Butterworth & Williamson; 5 – Anapiculatisporites concinnus Playford; 6 – Lophotriletes trilobatus Sullivan; 7 – Convolutisporites horridus (Ishchenko) Tornav var. trigonalis Jacobowiz, 8 – Waltzispora sp; 9 – Waltzispora planigulata Sullivan; 10 – Foveosporites incultus Playford; 11 – Corbulospora cancellata (Waltz) Bharadwaj & Venkatatasha; 12-13 – Dictyotriletes plumosus (Butterworth & Spimmer) Neville & Williamson; 14 – Diammononoritocnites cervicesaturus (Staplin) Playford; 15 – Diammononoritocnites saestosus (Haquebard & Bross) Hughes & Playford; 16, 20 – Morospora aurita (Waltz) Playford; 17 – Poitoniesspores delicatus Playford; 18 – Cingulizonates bialatus (Waltz) Smith & Butterworth; 19 – Lycospora nocturna Butterworth & Williams; 21 – Knosisporites cf. stephanophorus Loce; 22 – Densosporites sp; 23 – Densosporites variabilis (Waltz) Potonié & Kremp; 24 – Lycospora pusilla (Ibrahim) Somers; 25 – Schizophora plicata Butterworth & Williamson; 26 – Monilotheca culla (Byvscheva) Byvscheva; 27 – Densosporites sp.; 28 – Schulzospora ocellata (Horst) Potonié & Kremp; 29 – Schulzospora campyloptera (Waltz) Hoffmeister, Staplin & Malloy; 30 – Perotrilites tessellatus (Staplin) Neville; 31 – Krauselsisporites echinatus Owens, Mitchell & Marshall.
middle part of this section, the goniatites Goniatites crenistria Phill. and Prolecanites cf. serpentinus (Phill.) have been recorded by Korejwo (1993). They indicate the presence of the late Viséan Gozà ammonoid Zone. The deposits of a higher part of the Drzewiany Sandstone Formation in the Gozd 2 section (depth 2508–2504 m) yielded a macrofaunal assemblage similar to that found in Sarbinowo 1 borehole in the middle Viséan (V2) deposits.

It is concluded that the Drzewiany Sandstone Formation spans the uppermost Tournaissian and much of the Viséan.

Fig. 12. Benthic ostracod assemblages/subassemblages for Tournaissian in western Pomerania and their characteristic species

<table>
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<th>Benthic ostracod assemblage/subassemblage</th>
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<th>Other species present</th>
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Fig. 13. Ostracod assemblage lower Pseudoleperditia venulosa (Vn1). Specimen 1 is from Brda 1, 2676–2682 m, specimens 2-11 are from Chmielno 1, 3952–3962 m. 1 – Namara reticulata Green; 2 – Pseudoleperditia venulosa (Kummerow); 3 – Corvillina triceratina (Posner); 4 – Shishaella olekseeva Tschigova; 5 – Shivaella longa (Tschigova); 6 – Amphissites similis Morey; 7 – Sulcavellina tersiensis Bushmina; 8 – Acutiangulata acutiangulata (Posner); 9 – A. rara Bushmina; 10 – Bairdia lecta Bushmina; 11 – Richterina (Richterina) latior Rabien
LOWER CARBONIFEROUS STRATIGRAPHY

Fig. 14. Ostracod assemblage upper Pseudoleperditia venulosa (V12). All specimens are from Brda 1. 1 – Pseudoleperditia venulosa (Kummerow), 2524.5–2528 m; 2 – Coryellina triceratina (Posner), 2611–2616 m; 3 – Chamishaella obscura Tschigova, 2560–2563 m; 4 – Shishaella longa (Tschigova), 2676–2682 m; 5 – Sulcocavellina tersiensis Bushmina, ibidem; 6 – Acutiangulata acutiangulata (Posner), 2611–2616 m; 7 – Bairdia lecta Bushmina, ibidem

Chronostratigraphic boundaries

Devonian/Carboniferous boundary

The Global Stratotype Section and Point for the Devonian–Carboniferous boundary has been defined at La Serre, southeast Montagne Noir France (see Paproth et al., 1991). The section fulfills the demands of the Group, especially the condition that specimens of Siphonodella praesulcata should be followed by S. praesulcata-sulcata transitional forms.

In western Pomerania, the top of the Upper Devonian sequence yielded abundant and diverse conodont fauna indicative of the Upper expansa and/or Lower praesulcata zones (Matyja, 1993). The base of the Lower Carboniferous sequence is characterised by rare though relatively diverse conodonts characteristic of the sandbergi Zone. In the Rzeceznica 1 section, there are only some metres of a shale devoid of fauna between the documented Devonian Upper expansa - Lower praesulcata zones and the Carboniferous sandbergi Zone. In other investigated sections, in which Devonian/Carboniferous boundary runs within cored intervals, the biostratigraphic gap seems to comprise a similar time interval. There is no conodont data suggesting the presence of conodont zones older than the sandbergi Zone.

A similar range of this stratigraphic gap is also indicated by miospore analysis. Two consecutive, local miospore zones - Tumulispora rariuberculata (Ra), and Convolutispora major (Ma) were distinguished in the Devonian/Carboniferous transition beds (Turnau, 1978). This author suggested (see Turnau, 1978, fig. 3) that a high rate of species disappearances and the first appearances at the Ra/Ma zonal boundary indicates the presence of a stratigraphic gap. Varying opinions on the extent of this gap were discussed in Turnau (1979), Clayton & Turnau (1990), Avkhimovitch et al. (1993), Matyja & Stempien-Salek (1994). The up to-date information on stratigraphical ranges of several critical species in the northwestern Europe (Higgs et al., 1988a) and Belarus (Avkhimovitch, 1993) suggests that in western Pomerania, the counterparts of the northwestern European spore zones lepidophyta-explanatus (LE), lepidophyta-nitidus (LN) and most of, or the entire verrucosus–incohatus (VI) Zone are missing.
Fig. 15. Ostracod assemblage Cribroconcha postfoveata-Marginia tschigovae (P-T). Specimens 1, 2 are from Brda 1, 2319–2326 m, specimens 3, 4, 6, 8 are from Brda 1, 2260–2266 m, specimens 5, 7 are from Chmielno 1, 3794–3796 m. 1 - Amphissites similaris Morey; 2 - Shivaella longa (Tschigova); 3 - Marginia tschigovae (Palant); 4 - Carboprimitia elata Tschigova; 5 - Graphiadactyllis reticulocosta-Grünewald; 6 - Cribroconcha quasicornigera Bushmina; 7 - C. postfoveata Grünewald; 8 - Editia cf. kiselensis (Posner) s. Robinson

The presence in some sections of goniatites of the Gattendorfia subinvoluta (Go) Zone of the lowermost Tournaisian (see Korejwo, 1979, 1993) suggests, however, that the range of the stratigraphic gap could be smaller (in some sections), and limited to the Devonian Middle–Upper prae-sulcata Zones and the Carboniferous sulcata-Lower duplicata Zones.

The nature and possible causes of the gap were discussed in details by Matyja (1993). Apart from the question of the range of the gap, it is clear, however, that the uppermost Famennian–lowermost Tournaisian deposits show extremely reduced thickness, not more than several metres (see Figs 18–19).

Tournaisian–Viséan boundary

The working group of the Subcommission of Carboniferous Stratigraphy of IUGS is currently trying to identify a boundary and to select the boundary stratotype and GSSP that would closely correspond to the base of Viséan as proposed during the 1967 Carboniferous Congress at Sheffield. A lineage within Eoparastaffella has been established in sections in southern China, and sections in Ireland are under investigation (Sevastopulo & Hence, 1999).

It is difficult to establish the position of the Tournaisian–Viséan boundary in the investigated sections of western Pomerania mainly because of the lack of key fauna. The boundary is placed tentatively at the first appearance of Lycospora pusilla. This first appearance, at least in Europe, has been traditionally equated with the discussed boundary (Clayton et al., 1990; Turnau et al., 1997) but, in precise terms, the CM/Pu boundary may be older (Riley, 1993, see also Carson & Clayton, 1997).

**SUMMARY AND CONCLUSIONS**

The detailed conodont, miospore and ostracod analyses permitted to distinguish:

(a) the Tournaisian sandbergi, Lower cremilata, isostitches-Upper cremilata and typicus conodont zones;

(b) nine local Tournaisian and Viséan miospore zones and subzones: major (Maj-Maa), claytonii (C1-C12), pusilla, campyloptera and pactilis;

(c) three Tournaisian, local benthic ostracod assem-
Fig. 16. Ostracod assemblage Glyptopleura ruegensis-Carbonita fabulina (R-F). Specimens 1, 3, 4 are from Klanino 1 (depth indicated below), specimens 2, 5-7 are from Biesiekierz 1, 2590–2894 m. 1 – Shiishella electa Tschigova, 2392.3–2394 m; 2 – Beyrichiopsis foris Jones & Kirkby; 3 – Beyrichiopsis binodosa Blaszynik & Natusiewicz, 2394–2397 m; 4 – Glyptopleura ruegensis Blumenstengel, 2463–2467 m; 5 – Glyptolichwinella annularis (Kummerow); 6 – Acutangulata quadrata Robinson; 7 – Carbonita fabulina (Jones & Kirkby).

blages and two subassemblages: Pseudoleperditia venilosa (Vn1–Vn2), Cribroconcha postfoveata–Marginia tchigovae (P–T) and Glyptopleura ruegensis–Carbonita fabulina (R–F).

Integrated biostratigraphic analysis enabled correlation of local miospore and ostracod schemes with the “standard” conodont zonation. The base of Ma1 subzone is within or below the sandbergi Zone, that of Ma2 subzone is within sandbergi zone, the Ma2/Ma3 subzonal boundary is not younger than the Lower crenulata Zone, and base of Cl Zone is within or below the typicus Zone. The benthic ostracod assemblage Vn corresponds to Ma1 - Ma3 (part) subzones; P–T assemblage encompasses Ma3 (part), Ma4 and Cl1 (part) subzones; R–F assemblage corresponds to Cl1 (part) and Cl2 subzones.

The oldest Carboniferous part of the Sapolno Calcareous Shale Formation corresponds to the sandbergi or Upper duplicata zones. The top of the formation is diachronous, corresponding to the Lower crenulata Zone (in the northwest), isosticha–Upper crenulata or typicus (in the east), and Upper (?) typicus (Trzebiechowo Marl Member in the Brda area). The Kurowo Oolite Formation and Grzybowo Calcareous Shale Member are late Tournaisian in age, and are roughly time equivalents. The Drzewiany Sandstone Formation spans latest Tournaisian and Viséan.

The uppermost Famennian–lowermost Tournaisian unfossiliferous, black clayey deposits rich in pyrite and organic matter are reduced to several metres in thickness. The results of both conodont and miospore studies suggest presence of a stratigraphic gap that comprises the uppermost Famennian (part of the Middle and the Upper praesulcata Zones) and the lowest Tournaisian (the sulcata, duplicata, and the lower part of the sandbergi Zone). A similar range of the gap is also indicated by the miospore data as the equivalents of the western European miospore zones lepidophyta–explanatus, lepidophy–tanidotidus, and most of, or the entire verrucosus–incolatus Zone are missing. The results of earlier studies on macrofauna suggest that the gap could be smaller and limited to the Middle - Upper praesulcata Zones and to the Carboniferous sulcata and Lower duplicata zones.

The Tournaisian–Viséan boundary has been established.
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<table>
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<tr>
<th>Conodont zonation</th>
<th>Entomozoan zonation</th>
<th>British Isles miospore zonation</th>
<th>Western Pomerania</th>
<th>Benthic ostracod assembl.</th>
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Fig. 17. Correlation of biostratigraphic zonations for Tournaisian; * conodont zone of Irish conodont zonation (shallow water facies) dating the PC/CM boundary (Higgs et al., 1988b); relevant range charts are shown in the Appendix 2

approximately on the first appearance of the miospore species Lycospora pusilla Somers. The boundary runs within the lower part of the Drzewiany Sandstone Formation.

The maximum thickness of the most completely preserved Tournaisian deposits exceeds 800 metres (e.g., in the Kurowo 1 and Grzybowo 1 boreholes) and might have been even greater in the Wierzchowo-Brda area where the Tournaisian deposits, devoid of their upper parts (i.e., rocks of Upper typicus and anchoralis-latus conodont Zones), are over 650 m thick.

The penetrated fragments of the lower Viséan are up to 200 m thick (Gozd 2 borehole) and those assigned to the middle and upper parts of the Viséan, are 260 m thick in the Sarbinowo 1 section.

SYSTEMATIC COMMENTS (MIOSPORES)

Most miospore species dealt with in this paper were determined and described more than 20 years ago. Subsequently, the second author worked on miospore taxonomy with such specialists in Carboniferous palynology as T.V. Byvsheva, V.I. Avkhimovich, G. Clayton, and K. Higgs. These studies, and the general progress in taxonomy of Palaeozoic spores resulted in changes in some specific and generic assignments. This topic was discussed in Clayton & Tournau (1990), Avkhimovich & Tournau (1994), and Tournau et al. (1994). The discussion concerned the following taxa: Anaplanisporites baccatus, Colatisporites multisetus, Prolycospora claytonii, Schopfites delicatus, Schopfites claviger and Ferrucosporites nitidus.

In the present paper, some other species are listed under generic or specific names differing from those used in the aërial papers (Tournau, 1975, 1978, 1979). These are Kraeu selisporites hibernicus Higgs (formerly Hymenozonotriletes explanatus (Luber) Kedo morphological type I; Tournau 1978, pp. 12–13, pl. 5, figs. 16, 19, 20), Lophozonotriletes excisus Naumova, 1953 (formerly Tumulispora dentata (Hughes et Playford) n. comb.; Tournau, 1975, p. 516, pl. 5, fig. 1), and Dictyotriletes glumaceus Byvsheva, 1972 (formerly Dictyotriletes margodentatus nov. sp.; Tournau, 1978, p. 8, pl.2, fig. 15). Some other taxonomic problems are discussed below.

Genus Dictyotriletes Naumova emend. Smith et Buttersworth, 1967

Dictyotriletes plumosus (Buttersworth et Spinner) emend Neville et Williams, 1963

Fig. 9 (12–13)

1979 Dictyotriletes pactilis Sullivan; Tournau, pl. 2, figs 6-8.

Description: Trilete spores c. 60 μm in diameter, trilete mark tectate, rays extending almost to spore body margin. Exine 3 μm thick. Distal surface bears a prominent reticulum. Lumina up to 24 μm across, muri narrow, up to 10 μm high, wider at base, tapering to a membranous ridge with a frilled crest. One murus may almost completely encircle the equator.

Remarks: The assignment to D. pactilis was incorrect, the latter species lacks trilete rays.

Genus Pustulatisporites Potonié et Kremp emend. Imgrund, 1964

Pustulatisporites uncatus (Kedo) Byvsheva, 1985

Fig. 8 (2)

1978 Pustulatisporites gibberosus (Haquebard) Playford; Tournau, p. 7, pl. 1, figs 26, 27.

1979 Pustulatisporites gibberosus (Haquebard) Playford; Tournau, pl. 1, fig. 20.

1980 Pustulatisporites uncatus (Kedo) nov. comb.; Byvsheva, p. 58 (combination not valid).

1985 Pustulatisporites uncatus (Kedo) Byvsheva; Byvsheva, pp. 95-96, tab. 18, figs 11-13, cum synonimis.

Dimensions (after Tournau, 1978): 34.5(41.5)49.9 μm (26 specimens).

Remarks: Tournau (1978, p. 7) noted that Pomeranian specimens assigned to P. gibberosus were smaller than those from the type material (see Playford, 1964). It appears that our specimens answer more closely the description of P. uncatus (Byvsheva, 1985, p. 95-96).

Genus Indotriradites Tiwari, 1964

Indotriradites explanatus (Luber) Playford, 1991

Fig. 7 (20)

1941 Zonotriletes explanatus Luber; Luber & Waltz, p. 10, pl. 1, fig. 4.

1978 Hymenozonotriletes explanatus (Luber) Kedo morphologi-
Fig. 18. Biostratigraphic correlation of borehole sections between Gorzystaw and Rzeczenica; all microfossil and goniatite bearing intervals are marked. Carboniferous biostratigraphic zones/assemblages marked by two letter notations: full zonal names are in Figs 3, 10, 12, other notations: L - latior Entomozoid Zone, G - Gattendorfia subinvoluta Zone, Gaa - G. creistria Zone, Famennian zones: Ex - Pri - Upper expansa - Lower praesulcata conodont zones, Ra - rarituberculata Miospore Zone, H - D1 and H - D2 - Lower and Upper hemisphaerico-dichotoma Entomozoid Zone. Insert shows biostratigraphic correlation of Pomerania Carboniferous lithostratigraphic units. Range of Famennian-Tournaisian stratigraphic gap within the Sapolno Calcareous Shale Formation is also shown, arrow indicates an alternative position of the gap upper range (lithostratigraphic units after Lipiec in Lipiec & Matyja, 1998).
## Conodont species range charts

### Appendix 2

**Range charts of conodont, miospore and ostracod species**

<table>
<thead>
<tr>
<th>Formation / Member</th>
<th>Sapino Calc. Sh. Fm.</th>
<th>Trzebnickiow Marl Member</th>
<th>Formation / Member</th>
<th>Sapino Calc. Sh. Fm.</th>
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<td><strong>Lower transgressive sandstone (Bin. - Ca.)</strong></td>
<td><strong>Lower transgressive sandstone (Ca.)</strong></td>
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Ostracode species range charts (selected boreholes)
APPENDIX I – LIST OF CONODONT, MIOSPORE AND OSTRACOD SPECIES

CONODONTS

Bispathodus aculeatus aculeatus (Branson & Mehl, 1934)
Bispathodus aculeatus antepostcornis (Scott, 1961)
Bispathodus spinlicostataes (Branson, 1934)
Bispathodus stabilis (Branson & Mehl, 1934)
Chedagnostus unicornis Rhodes, Austin & Druce, 1969
Elictognathus biculatus (Branson & Mehl, 1934)
Grothagnostus coniformis Mehl & Thomas, 1947
Hindeodus aff. cristatus (Youngquist & Miller, 1949)
“Hindeodus” crassidentatus (Branson & Mehl, 1934)
Neopolygnathus carina (Hass, 1959)
Neopolygnathus commune (Branson & Mehl, 1934)
Planorinellina plumula (Rhodes, Austin & Druce, 1969)
Polygnathus distortus Branson & Mehl, 1934
Polygnathus floribellus (Branson & Mehl, 1934)
Polygnathus incrassatus Branson, 1934
Polygnathus purus purus Voges, 1959
Polygnathus purus subplanus Voges, 1959
Polygnathus radinns (Cooper, 1939)
Polygnathus spicatus Branson, 1934
Polygnathus symmetricus Branson, 1934
Polygnathus triangulus Voges, 1959
Polygnathus vogesi Ziegler, 1962
Pseudopolygnathus deniliquinensis Branson, 1934
Pseudopolygnathus multistratius Branson, 1934
Pseudopolygnathus rodiniformis Branson & Mehl, 1934
Siphonodella cooperi Hass, 1959
Siphonodella crenulata (Cooper, 1939)
Siphonodella duplicata (Branson & Mehl, 1934)
Siphonodella isosticha (Cooper, 1939)
Siphonodella obsolete Hass, 1959
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MIOSPORES

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Amphiculatisporites cominicus Playford, 1962
Anaplanisporites baccatus Hoffmeister, Staplin & Malloy, 1955
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Auroraspora macra Sullivan, 1968
Auroraspora penda Turnau, 1978
Auroraspora solisorp Hoffmeister, Staplin & Malloy, 1955
Baculatisporites fisticulis Sullivan, 1968
Batcandaspora submarginata (Playford) Higgs, Clayton & Keegan, 1988
Cingulizonates biaultas (Waltz) Smith & Butterworth, 1967
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Colatisporites multisetus (Luber) Akkinimovitch & Turnau, 1994
Converrucosporites curvatus (Naumova) Turnau, 1975
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Grandisporsa cornuta Higgs, 1975
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Knoxisporites hederatus (Sullivan) Playford, 1962
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Knoxisporites pristinae Sullivan, 1968
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Knoxisporites trivadiatus Hoffmeister, Staplin & Malloy, 1955
Kraeuselisporites hederatus (Sullivan) Playford, 1962
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Leichtizanisporites sphaerioaregulare (Loose) Potonie & Kremp, 1954
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LOWER CARBONIFEROUS STRATIGRAPHY


Nie we wszystkich zespołach konodontów napotkano gatunki przewodnie, toteż w licznych przypadkach można było określić jedynie przedziały obejmujące dwie lub trzy zony (por. Fig. 3). Typowe zespoły gatunków konodontów zilustrowano na Fig. 4–6.

Zespoły gatunków miospor typowych dla zon lokalnego schematu turneju i wizenu zilustrowano na Fig. 7, 10–11, a charakterystykę zmodyfikowanego schematu dla turneju i wizenu pokazano na Fig. 8. Schemat ten można na podstawie pierwszych появлений gatunków zonalnych korelować ze schematem miosporowym dla rejonów typowych pięter dolnego karbonu Wysp Brytyjskich (Fig. 9).

Wprowadzony w niniejszej pracy podział biostratyfikacyjny dla turneju, oparty na małżoraczkach bentonicznych, obejmuje trzy zespoły, z których najniższy podzielono na dwa podzespoły. Charakterystykę schematu przedstawiono na Fig. 12, a gatunki typowe dla poszczególnych zespołów i podzespołów zilustrowano na Fig. 13–16.

Konodonty, miospory i małżoraczki pozyskano niejednokrotnie z tych samych profilów, z wzajemnie przekładających się poziomów opróbkowania. Pełną dokumentację dotyczącą głębokości pobrania prób i występowania gatunków zamieszczono w dodatku (Appendix 2). Dzięki zintegrowaniu badań można było ustalić wzajemne relacje pomiędzy poszczególnymi podziałami, co przedstawiono na Fig. 17.

Przeprowadzone badania pozwoliły na określenie wieku formacji karbońskich i ich granic (Fig. 18, 19) oraz ustalenie położenia granic chronostratyfikacyjnych – granicy dewon/karbon i turnej/wizenu. W terminologii zon konodontowych, karbońska część formacji ilowców wapnich z Sąpólna zawiera się w przedziale sandbergi - dolna crenulata, tylko na południowym wschodzie (ogniwo margli z Trzebiechowa) utwory te sięgają aż do zony typicus. Granica formacji ilowców wapnich z Sąpólna z nadległą formacją piaskowców arkozowych z Godzu jest diachroniczna; na zachód od linii Kurowo 1 - Wierzchowo 10 przebiega ona w zonie dolna crenulata, a na wschód od tej linii w zonie isosticha–górna crenulata, lub w dolnej części poziomu typicus. Formacja ilowców wapnich z Grzybowska i formacja wapien oolitowych z Kurowa są w przybliżeniu równowiekowe mieszcząc się w zakresie zony typicus. Formacja piaskowców kwarcowych z Drzewian obejmuje najwyższy turnej po górnym wizenu (brygant).