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DEVONIAN/CARBONIFEROUS BOUNDARY AND THE ASSOCIATED PHENOMENA IN WESTERN POMERANIA (NW POLAND) [1]

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(6 figures and 2 plates)

ABSTRACT. The critical interval near the Devonian/Carboniferous boundary displays some features that may be related to the Late Devonian Hangenberg and/or Carboniferous Lower Alum Shale (Becker, 1993) Event(s):

(i) a submarine nondeposition gap connected with strong decrease or even cessation of lime mud "production" for a long time and manifested by a sedimentation of only several dozen cm of black shale during the Devonian Middle and Upper *praesulcata* Chrons, as well as during the Carboniferous *sulcata, duplicata* and part of the *sandbergi* Chrons;

(2) lack of any organic remains within aforementioned black shales, probably due to unfavorable changes in water chemistry and/or water stratification at the end of Devonian, which might have led to a long-term stress and retreat of all faunal groups from the Pomeranian basin.

KEY-WORDS: Devonian/Carboniferous boundary, NW Poland, conodonts, miospores, stratigraphic gap.

RESUME. Limite Dévonien/Carbonifère et phénomènes associés en Poméranie occidentale (NW Pologne). L'interval critique près de la limite Dévonien/Carbonifère permet des observations qui peuvent être reliées aux événements de Hangenberg, au Dévonien tardif et/ou aux shales inférieurs d'Alum (Becker, 1993).

(1) une absence de dépôt sous-marins liées à une forte décroissance ou même un arrêt de la "production" calcaro-argileuse pendant un temps long et qui se traduit par le dépôt de seulement quelques douzaines de cm de shale noir pendant les Chrons dévoniens *praesulcata* moyen et supérieur ainsi que pendant les Chrons carbonifères *sulcata, duplicata* et une partie de *sandbergi.*

(2) l'absence de tout reste organique dans les shales noirs mentionnés ci-dessus, probablement dus à des modifications défavorables dans la chimie de l'eau et/ou la stratification de l'eau à la fin du Dévonien, pouvant conduire à un stress prolongé et au retrait de tous les groupes de faune du Bassin poméranien.

MOTS-CLES: Limite Dévonien/Carbonifère, NW Pologne, conodontes, miospores, lacune stratigraphique.

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1. INTRODUCTION

The Devonian and Lower Carboniferous rocks of Western Pomerania, NW Poland, are covered by younger sediments of a considerable thickness, and have been reached only by exploration drillings. The present-day occurrence of the Devonian and Lower Carboniferous sediments in Western Pomerania is an effect of Late Carboniferous tectonics and subsequent erosion, and their northeastward extent is sharply delineated by a NW-SE striking tectonic line (Fig. 1).

The Devonian and Carboniferous deposits have been recognized in about 90 boreholes grouped mostly in the Koszalin-Chojnice area and along the Baltic coast to the west of Koszalin. We have selected two borehole sections, Gorzys aw-9 and Rzeczenica-1 (see Fig. 1 for location), to demonstrate the nature of the Devonian/Carboniferous contact. Each of the two sections is a representative of slightly different area of the extensive carbonate shelf in northern Poland. In general, Gorzys aw-8 section documents shallow subtidal facies of a carbonate platform foreslope, and Rzeczenica-1 - deeper subtidal facies of an open shelf, during the latest Famennian and the earliest Tournaisian (Matyja 1993).

2. DEVONIAN / CARBONIFEROUS BOUNDARY AND THE ASSOCIATED PHENOMENA

The IUGS Working Group on the Devonian/Carboniferous boundary recommended in 1979 a new operational definition of the boundary. Accordingly, the first appearance of the conodont species *Siphonodella sulcata* within the evolutionary lineage from *S. praesulcata* to *S. sulcata* marks the Devonian/Carboniferous boundary. The Global Stratotype Section and Point for the Devonian/Carboniferous boundary has now been defined at La Serre, southeast Montagne Noir, France (Paproth *et al.*, 1991). La Serre section is far from being an ideal stratotype but, at the time, it was the only known section which showed the "evolutionary lineage of *Siphonodella praesulcata* to *Siphonodella sulcata*" (Flajs & Feist, 1988). The inconveniences of La Serre section, such as the lack of some important stratigraphic guides (for example cephalopods, spores, and ash layers for radiometric dating) and the existence of reworking sediments induced to support La Serre section by the auxiliary stratotype sections of Hasselbachtal in the Rhine Slate Mountains and Nanbiancun in China (Becker & Paproth, 1993; Becker *et al.*, 1993).

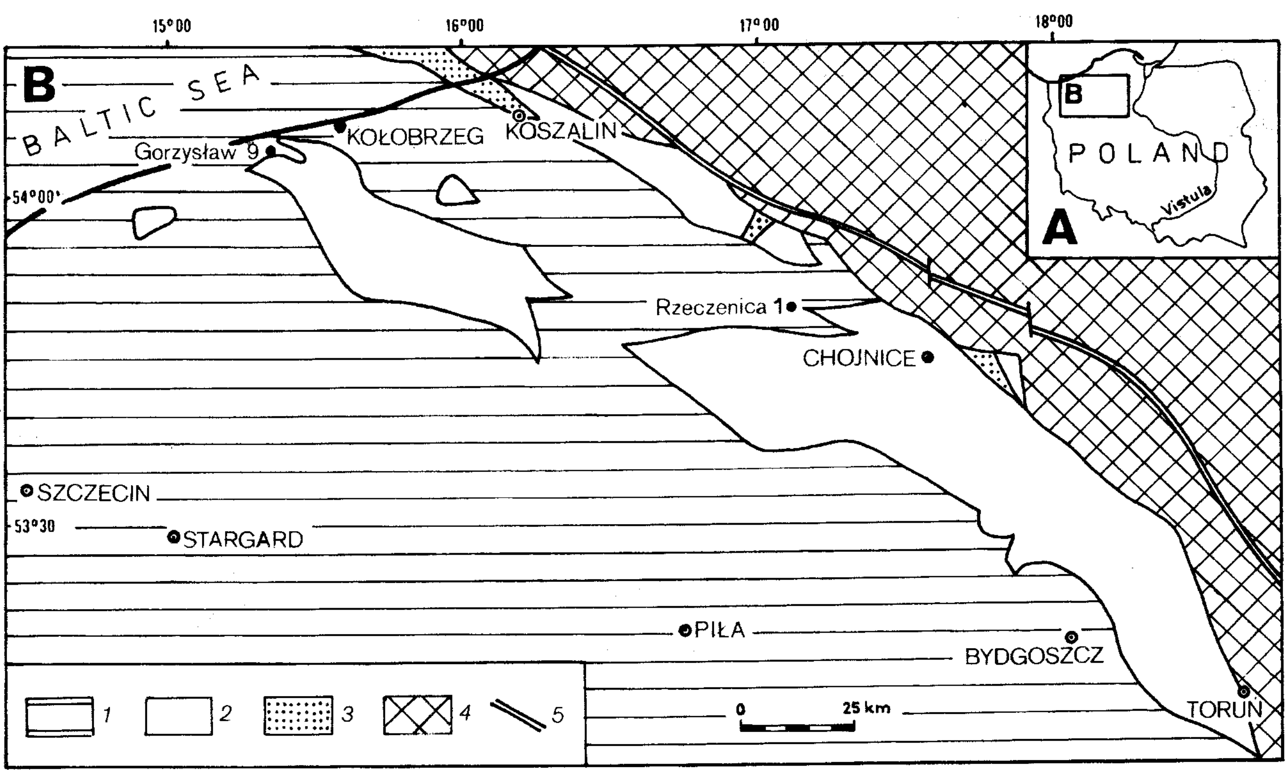


Fig. 1.- Sub-Permian map of Western Pomerania (NW Poland), to show the distribution of Devonian and Carboniferous deposits and the location of studied boreholes [B], after Matyja, 1993; inset [A] shows the position of the area in Poland
1 - Carboniferous, 2 - Upper Devonian, 3 - Middle Devonian, 4 - Silurian and Ordovician, 5 - Teisseyre-Tornquist tectonic line

Unfortunately, there are stratigraphic gaps in the majority of the known sections investigated worldwide, at least in terms of the occurrence of the aforementioned conodonts. Ziegler & Sandberg (1984) argued that a short eustatic fall of sea level just before the end of the Devonian resulted in mass extinction of many Late Devonian organisms, including conodonts, ammonoids, trilobites, ostracodes, corals and some others, in change from pelagic siphonodellid biofacies to more nearshore protognathodid biofacies, as well as in the abrupt lithologic changes at the Devonian/Carboniferous contact which were sometimes accompanied by the absence of some zones. Of the lithologic disturbances observed in the majority of sections the most characteristic are the changes from limestones to mudstones or the presence of regressive or turbiditic sandstones, hardgrounds and unconformities. Therefore, even in the best sections, the boundary itself could be determined only approximately (Ziegler *et al.*, 1988).

In recent years great emphasis has been placed on the Devonian/Carboniferous boundary event, called Hangenberg Event. The relatively vast literature dealing with the Hangenberg Event mass extinction polarises into two broad hypothesis. The first one claims that this phenomenon was due to climatic changes. It is suggested that the Late Devonian southern hemisphere glaciation (Caputo 1985) which was possibly a time equivalent to the Hangenberg Event interval (Streel 1986), may have been a major contributing factor for the return to more "normal" oceanic temperature, salinity and reduction of sea water stratification during the latest Devonian - early Carboniferous. This is in agreement with paleotemperature measurements using oxygen isotope data (Brand, 1989, 1993) and the lack of any gradient in the latest Devonian *lepidophyta* floras distribution (Streel, 1986). The second hypothesis considers paleogeographic changes as the immediate cause of the mass extinction, operating through eustatic changes of sea level and resulting from tectonic effects rather than the other causes (House, 1985; Johnson *et al.*, 1986). A correlation recognized between mass extinction, evolution of organisms and sedimentary perturbation is prefered by House (1989) and Becker (1993).

In the present paper we focus on the stratigraphical problems related to the Devonian/Carboniferous boundary, based on an interpretation of the conodont and miospores succession, as well as on the sedimentary record.

3. DEVONIAN / CARBONIFEROUS BOUNDARY IN THE WESTERN POMERANIA AREA

3.1. GENERAL REMARKS

During the Late Devonian and Early Carboniferous Epochs the Western Pomerania area, the Polish fragment of the relativelly shallow basin, was bordered to the North and to the East by land mass of the East European craton which was a part of the Old Red Sandstone Continent, and sloped southwards into the deeper basin (see Matyja, 1993 Text-fig. 21). The recognized Late Devonian and Early Carboniferous facies pattern within the Pomeranian sedimentary basin depended on the paleogeographical framework which had controlled northward and eastward basin shallowing.

The general late Famennian (from the Late *expansa* up to the Early *praesulcata* Chron) facies pattern in the analysed fragment of the Polish basin was relatively simple, consisting of a carbonate platform in the north and northeast and an open shelf characterized by marly dysaerobic to anaeorobic facies in southward direction (Matyja, 1993; see also Fig. 2). Two lithofacies types were recognized:

(1) fossiliferous marly limestones in a shallower part of the basin (carbonate platform environment in the northern part of the area), and

(2) fossiliferous marls in a deeper part of the basin (open shelf environment in the southern part of the area).

The carbonate-dominated succession is characterised by dark marls with brachiopods and crinoids, interbedded with grey marly limestones mainly composed of allochthonous bioclastic material with dominance of Palaeosiphonocladales algae, encrusting foraminifers, benthic ostracodes, stromatoporoids, crinoids, rare conodonts and miospores. A predominance of marls with rare cephalopods, entomozoacean ostracodes and conodonts as well as with trilobites, pelecypods, gastropods, brachiopods and solitary corals with thin limestone layers composed of allochthonous material characterize the marly dominated succession.

This subtidal sedimentary environment continued into the Carboniferous and was characterized by black marly shales containing relatively rare, in comparison to those of the Devonian age, organic remains. These marly shales are interbedded with fine to coarse sand-size, often graded packstone and

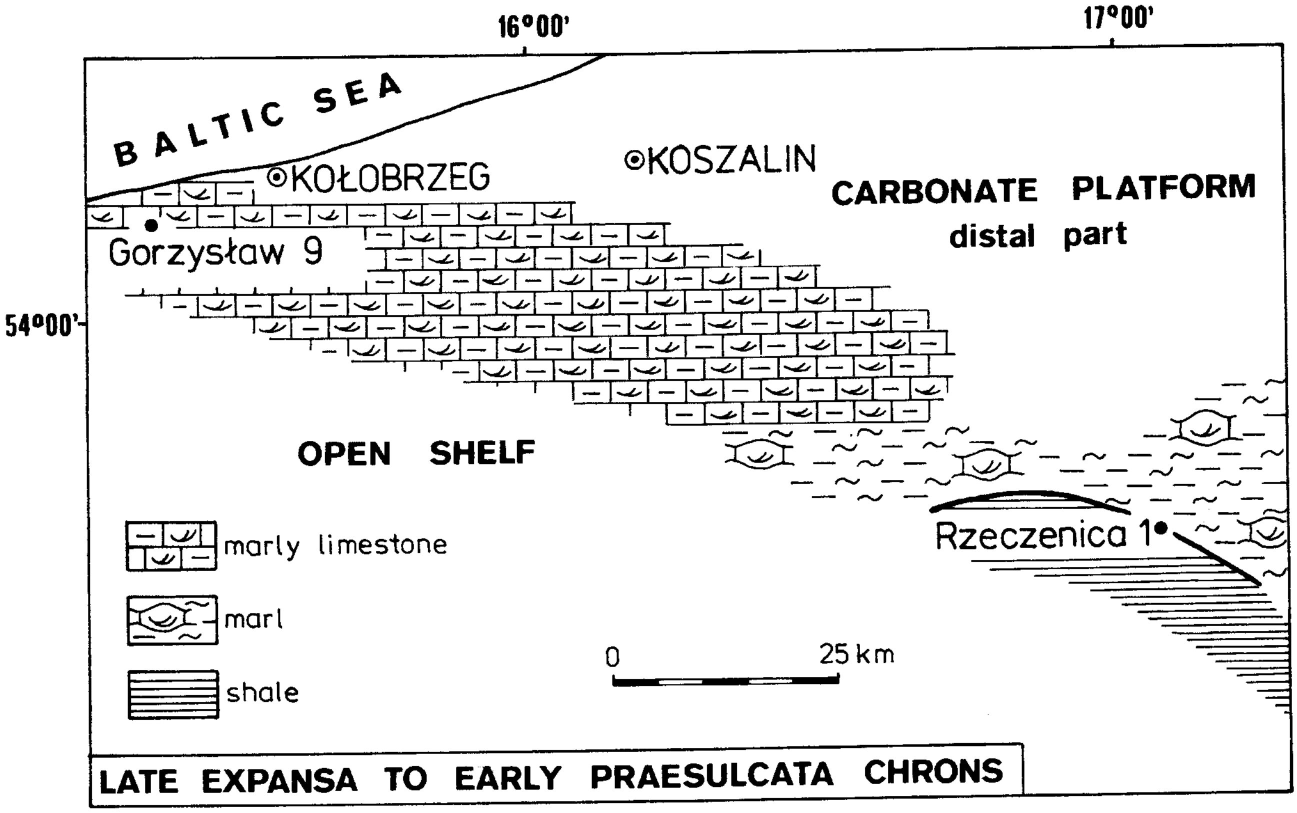


Fig. 2.- Lithofacies pattern in Western Pomerania during the Late *expansa* - Early *praesulcata* Chrons, Famennian (after Matyja, 1993)

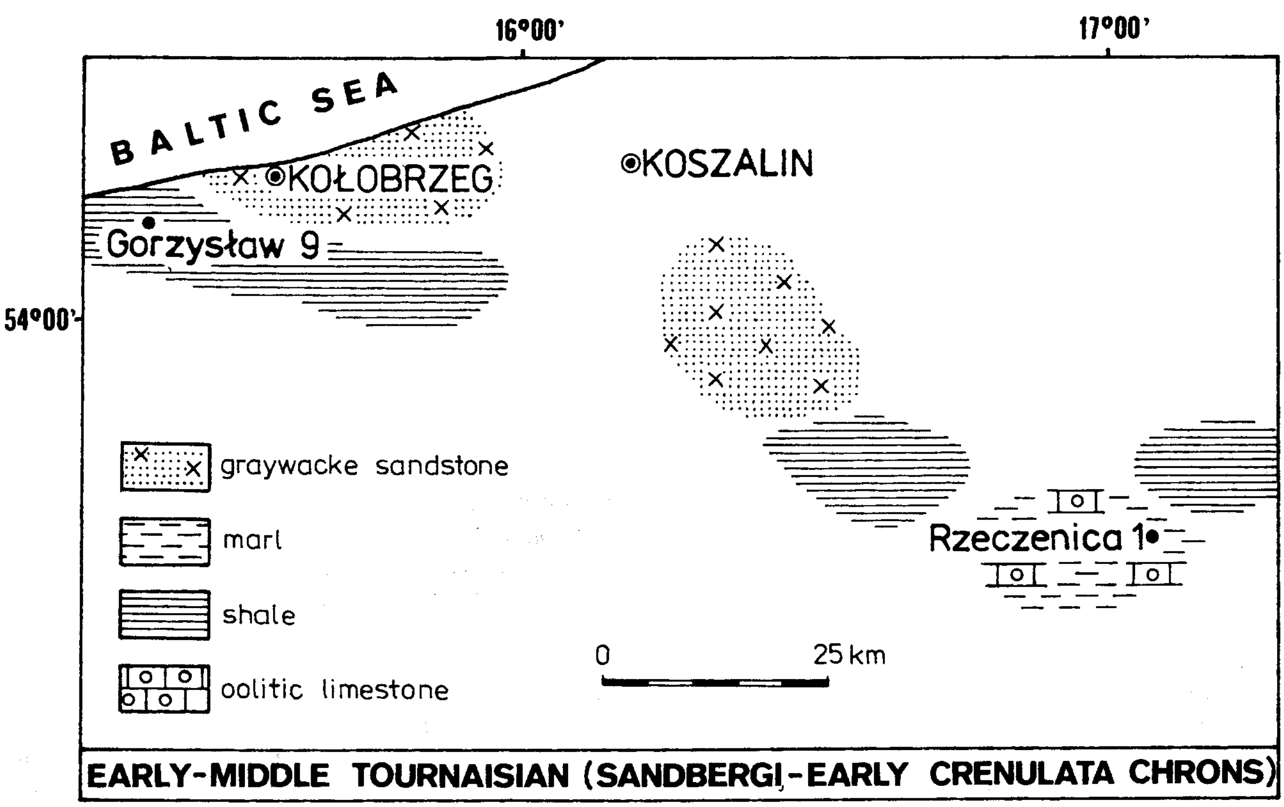


Fig. 3.- Lithofacies pattern in Western Pomerania during the late *sandbergi* - Early *crenulata* Chrons, Early-Middle Tournaisian (after Matyja & Zbikowska, 1994).

grainstone. Allochthonous grains include ooids, intraclasts, and bioclasts of shallow-water fauna. These were probably derived from a foreslope of a carbonate platform situated far to the east. During the same time (*sandbergi* and Early *crenulata* Chrons) clastic turbidites with volcanogenic material were deposited in the northern part of the area, interfingering southwards into the black shale basin sediments (Matyja & bikowska 1994, see also Fig. 3).

3.2. BIOSTRATIGRAPHY

3.2.1. Conodonts

The top of the Upper Devonian sequence yields abundant and diverse conodont fauna indicative of the Upper *expansa* and/or Lower *praesulcata* Zone(s). Unfortunately, the last palmatolepids which are the basis for the Late Devonian standard conodont zonation dissappeared at the end of the *marginifera* Zone owing to ecological reason (Matyja 1993). Therefore, the Upper *expansa* and/or Lower *praesulcata* Zone(s) were recognizable due to the presence of numerous species of *Bispathodus* only, i.e. *Bispathodus costatus, Bi. aculeatus aculeatus, Bi. ultimus, Branmehla suprema* and *Pandorinellina plumula*, and the rare occurrence of *Siphonodella praesulcata* (see Tables 1 and 7 in Matyja, 1993).

The next recognizable conodont zone is Carboniferous *sandbergi* Zone (Matyja, 1993; Matyja & bikowska, 1994). The base of the lower Carboniferous sequence is characterized by rare though relatively diverse conodonts. The presence of *Siphonodella obsoleta* and *Siphonodella quadruplicata* as well as many other species of the genera *Polygnathus (Pol. communis carina, Pol. symmetricus, Pol. inornatus, Pol. triangulus triangulus, Pol. longiposticus, Pol. spicatus, Pol. purus purus, Pol. purus subplanus, Pol. communis communis, Pol. vogesi), Pseudopolygnathus (Ps. nodomarginatus, Ps. dentilineatus), Bispathodus (Bi. stabilis, Bi. aculeatus, Bi. spinulicostatus)* and *Elictognathus (E. laceratus, E.* cf. *bialatus)* below the first occurence of *Siphonodella crenulata* allow the fragments of the sequence to be attributed to the upper part of the *sandbergi* Zone (Sandberg *et al.*, 1978; Varker & Sevastopulo, 1985; Webster & Groessens, 1990).

Conodont zones younger than the Devonian Lower *praesulcata* Zone but older than the Carboniferous upper *sandbergi* have not been found as yet in the whole Western Pomerania area. It should be noted, however, that the questionable presence of the Lower *Gattendorfia* (Gaá) ammonoid Zone has been recorded in two borehole sections (Wierzchowo-10 and Grzybowo-1) located in the northern part of Western Pomerania (Korejwo 1994).

There are only several dozen centimetres of shale deposits, rich in pyrite and organic matter, and devoid of any faunal remains between the documented Devonian Lower (or lowermost Middle) *praesulcata* Zone and the Carboniferous upper *sandbergi* Zone (Figs 4-5). The range of stratigraphic gap, comprising the Devonian Middle and Upper *praesulcata* Zones and Carboniferous *sulcata, duplicata* and probably most of the *sandbergi* Zone has been stated earlier (Matyja 1993).

3.2.2. Miospores

The investigated spores come from dark grey and black shales and shaly intercalation within limestones. Samples have been taken from the depth of about 3000 m (Figs 4-5). Fourty samples (about 150 slides) have been investigated. The preparation of the samples was standard, using hydrochloric and hydrofluoric acid, heavy liquid flotation and fuming nitric acid. The preservation of spores was variable, from very good to very poor.

Two local miospores zones have been distinguished in the uppermost Devonian and Lower Carboniferous: *Tumulispora rarituberculata* (Ra) and *Convolutispora major* (Ma) by Turnau 1978). These two zones have been divided here by M. Stempie -Sa ek into subzones which can be correlated with European standard miospore division of Streel *et al.*, 1987 (Fig. 6; see also Clayton & Turnau, 1990).

Tumulispora rarituberculata (Ra) local Zone is characterized by the occurrence of a rich assemblage of miospores, i.e.: *Ancyrospora sp., Diductites versabilis, Grandispora famenensis, Retispora macroreticulata, R. lepidophyta, Diducites commutatus, Grandispora lupata, Tumulispora malevkensis, T. rarituberculata, T. obscura, Verrucosisporites nitidus* and *Umbonatisporites abstrusus* (numbered from 1 to 12 in Fig 6, see also Pl. 2). Index species for the Ra Zone are: *Tumulispora rarituberculata, Verrucosisporites nitidus* and *Umbonatisporites abstrusus.* First simultaneous appearance of the two last species somewhat above the base of Ra Zone enabled M. Stempie -Sa ek to separate two subzones within *Tumulispora rarituberculata*, lower (Ra1) and upper (Ra2). *Ancyrospora* sp., *Diducites versabilis, Grandispora*

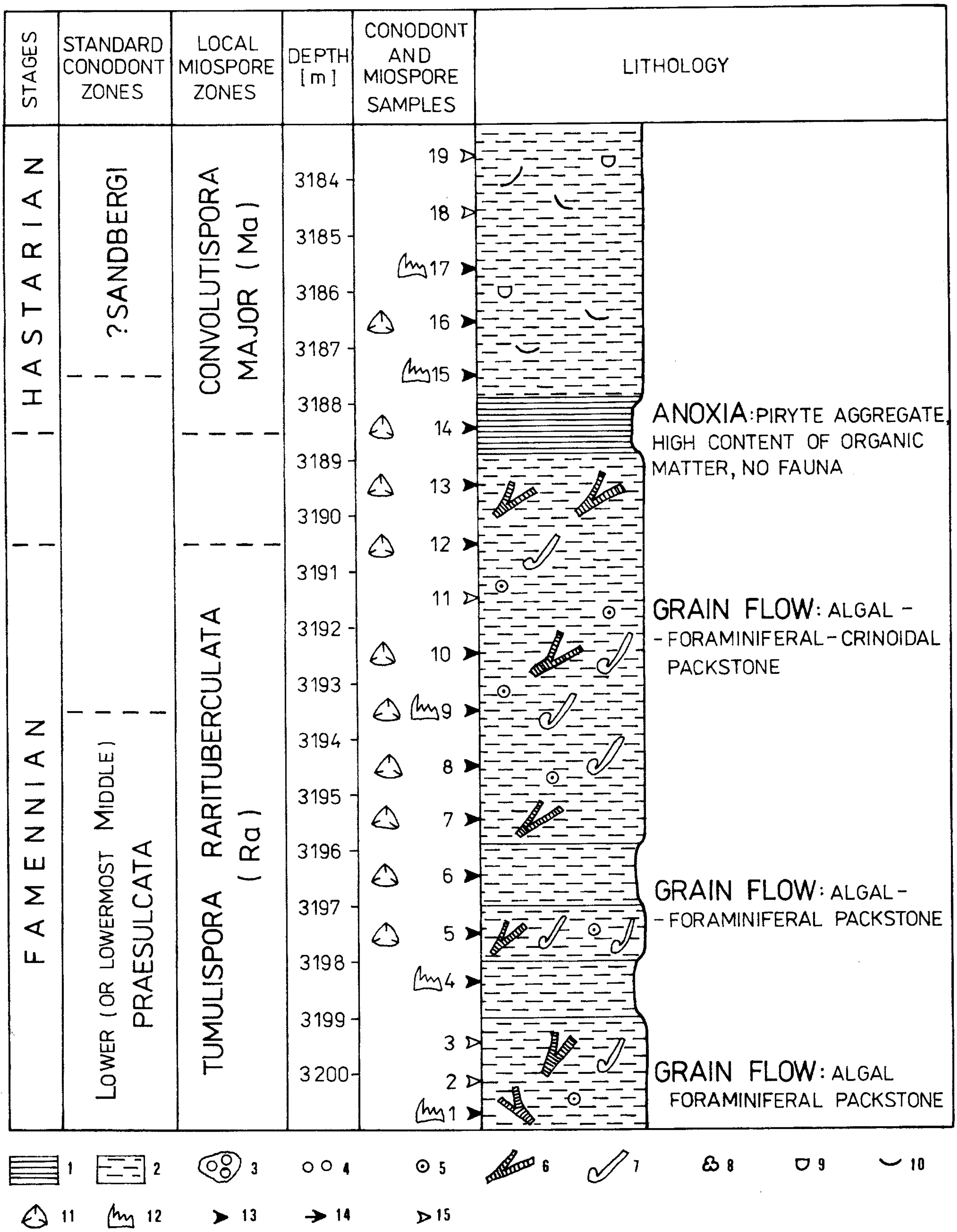


Fig. 4.- Detailed columnar section across the Devonian/Carboniferous boundary in the Gorzys aw-9 borehole section (Western Pomerania) 1.- shale, 2.- marl, 3.- pebble of oolitic grainstone, 4.- ooid, 5.- crinoid, 6.- Palaeosiphonocladales algae, 7.- agglutinated foraminifer, 8.- calcareous foraminifer, 9.- ostracode, 10.- brachiopod, 11.- conodond- and/or miospore-bearing sample, 12.- conodont and miospore data after Matyja & Turnau, 1989, 13.- samples without conodonts and miospores.

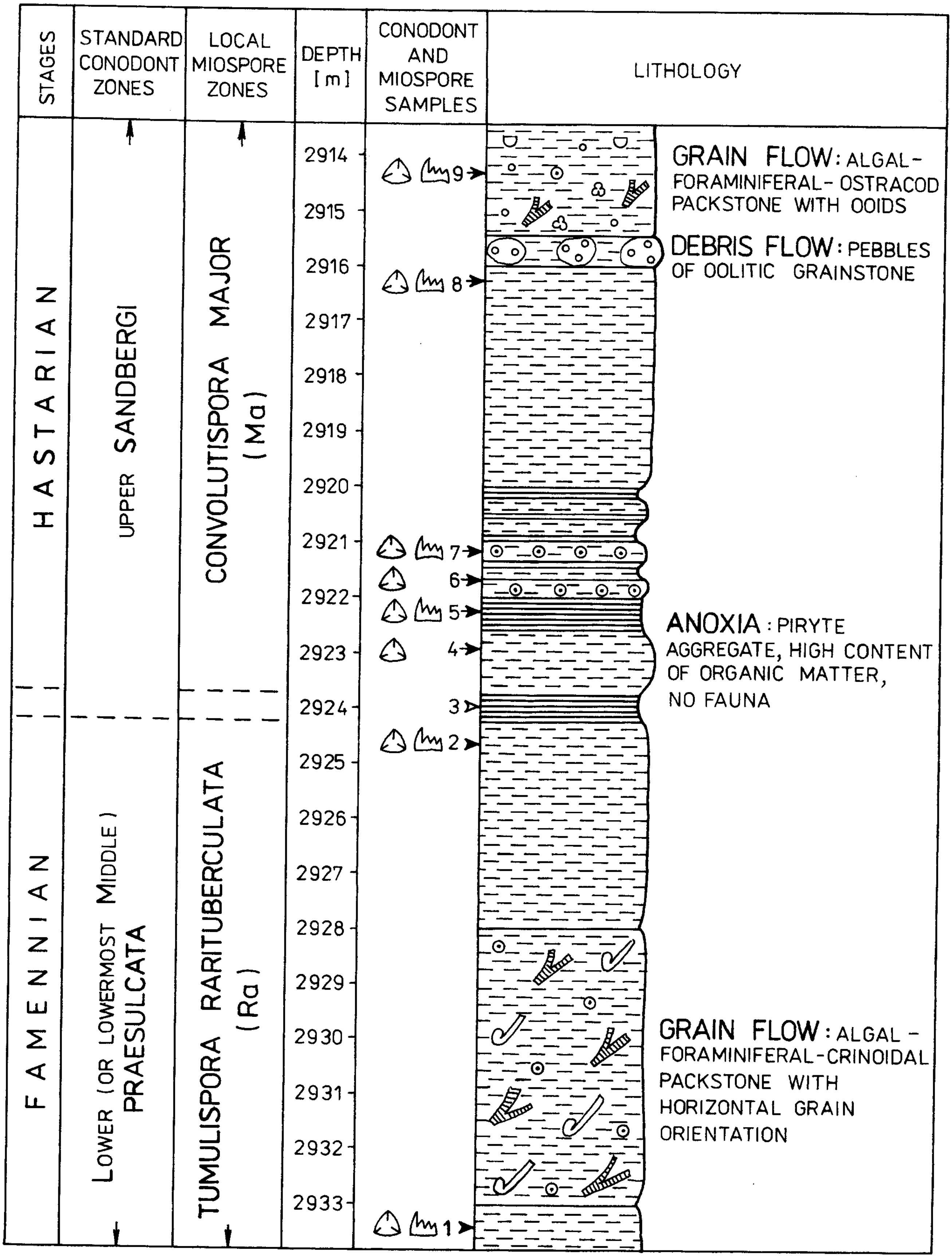


Fig. 5.- Detailed columnar section across the Devonian/Carboniferous boundary in the Rzeczenica-1 borehole section (Western Pomerania). For further explanation see Fig. 4

famenensis, *Retispora macroreticulata* and *R. lepidophyta* have their last occurrence here within the Ra Zone (see Fig. 6).

Convolutispora major (Ma) local miospore Zone is characterized by the occurrence of a rich assemblage of different miospore species, numbered from 6 up to 25 in Fig. 6, among which *Convolutispora major, Cymbosporites acutus*, *Pustulatisporites gibberosus, Raistrickia corynoges*, and *Umbonatisporites distinctus* are the most important. Miospore species numbered from 13 up to 20 have their first appearance within the *Convolutispora major* (Ma) Zone.

Four subzones can be distinguished within the *Convolutispora major* (Ma) Zone, i.e. lowermost (Ma1), middle (Ma2), upper (Ma3) and uppermost (Ma4). Ma1 Subzone is characterized by the lack of species having their last occurrence in Ra Zone (for example *Retispora lepidophyta*), as well as by the lack of species which appear higher up, in the Ma2 Subzone. The base of the Ma2 Subzone has been distinguished on the basis of the appearance of *Crassispora trychera, Schopfites delicatus* and *Umbonatisporites distinctus.* Higgs *et al.* (1992) observed that *U. distinctus* appeared somewhat above the base of the *Kraeuselisporites hibernicus-Umbonatisporites distinctus* (HD) Zone and not at the base of this Zone, as it had been previously considered. Similarly, in Western Pomerania, *U. distinctus* appears only at the base of Ma2 Subzone and not in Ma1 (see Fig. 6). Ma3 Subzone is characterized by the first occurrence of *Spelaeotriletes balteautus*, and the last occurrence of *S. obtusus.* Ma4 subzone has been established on the base of the first occurrence of *Spelaeotriletes pretiosus*.

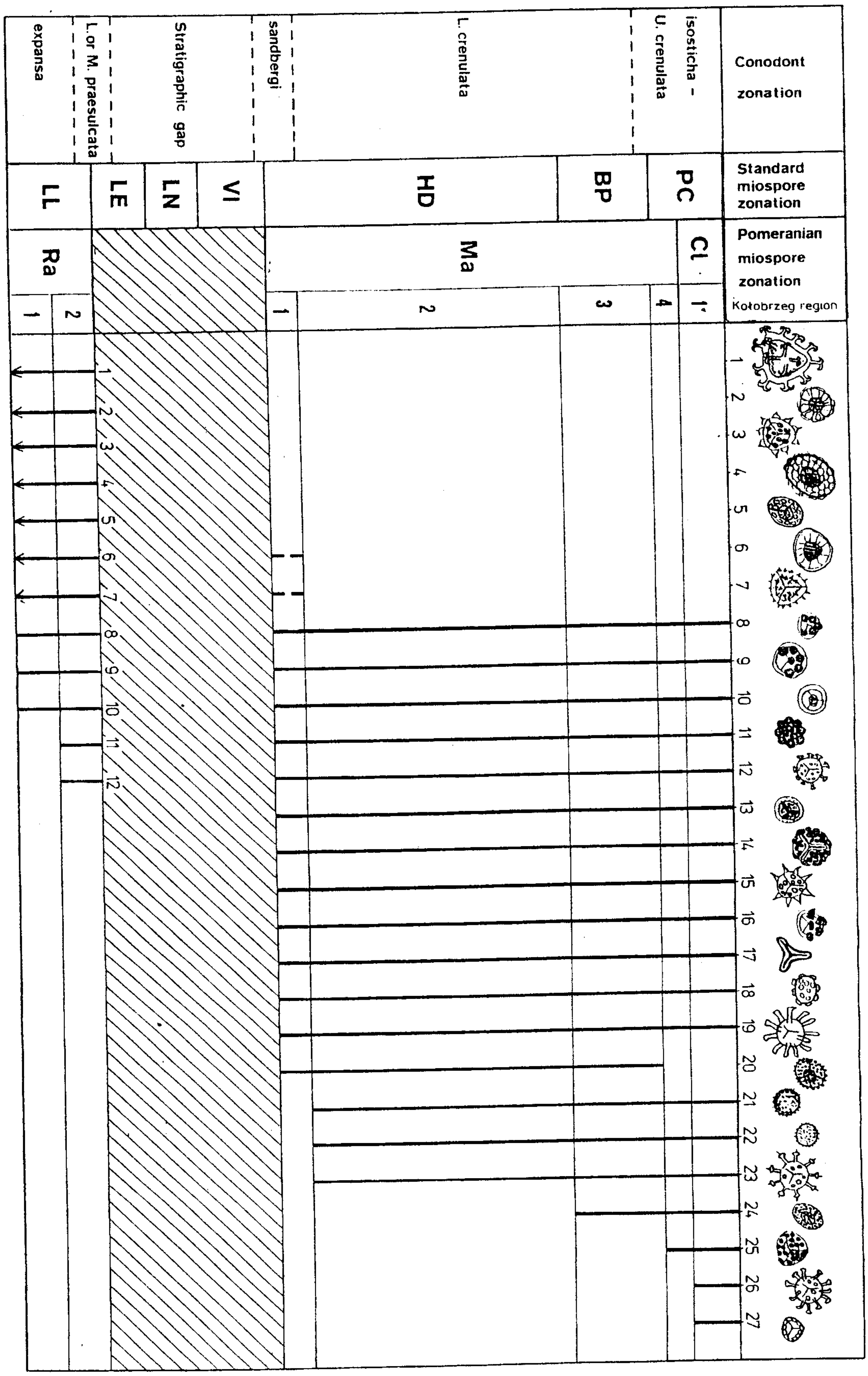
Abundant miospore content makes possible to correlate precisely, the *Tumulispora rarituberculata* (Ra) and *Convolutispora major* (Ma) Zones of Western Pomerania with Western European spore division of Higgs *et al.* (1988). Recently Clayton & Turnau (1990) considered the local Ra Zone to be older than the standard *Retispora lepidophyta-Hymenozonotriletes explanatus* (LE) Zone, because important components of the LE and younger *Retispora lepidophyta-Verrucosisporites nitidus* (LN) floras (i.e. *Vallatisporites vallatus, V. verrucosus, V. pusillites, Hymenozonotriletes explanatus*) are missing in the Pomeranian Ra Zone. Therefore it is suggested that the counterpart of the *Tumulispora rarituberculata* local Zone is the West European *Retispora lepidophyta- Knoxisporites literatus* (LL) Zone (Clayton & Turnau, 1990; see also Fig. 6). The top of the Ra Zone can be correlated with the lowermost part of the Middle *praesulcata* Zone at the earliest, as has been confirmed by ranges of conodonts co-occurring with Ra Zone miospores (Matyja & Turnau, 1989).

In all Pomeranian sections, deposits with *Tumulispora rarituberculata* (Ra) local miospore Zone are overlain by those of the *Convolutispora major* (Ma) local Zone. On the basis of co-existing conodonts the lower limit of the Ma Zone can be correlated with the *sandbergi* conodont Zone (Matyja & Turnau, 1989; Matyja, 1993). Moreover, the presence of the species *Grandispora upensis* in the lowermost part of the *Convolutispora major* (Ma) Zone suggest the possibility of correlation of the Ma Zone with the *upensis* Zone of Byelorussia which is, in turn, correlated with the *sandbergi* conodont Zone (Avchimovitch *et al.*, 1993). Clayton & Turnau (1990) placed the base of the Ma Zone at the top of the West European *verrucosus-incohatus* (VI) Zone.

It seems that the counterparts of the West European miospore Zones *Retispora lepidophyta-Hymenozonotriletes explanatus* (LE), *Retispora lepidophyta-Verrucosisporites nitidus* (LN) and most of the *Vallatisporites verrucosus-Retusotriletes*

Fig. 6.- Range chart of the most important miospores across the Devonian/Carboniferous boundary in Western Pomerania. Standard conodont zonation after Ziegler & Sandberg, 1984 (Famennian part) and Sandberg, Ziegler, Leuteritz & Brill, 1978 (Hastarian part); standard miospore zonation after Streel, Higgs, Loboziak, Riegel & Steemans, 1987; Pomeranian miospore zonation after Turnau, 1978 (zones) and Stempien -Sal ek, this paper (subzones). Numbers of miospore species, as given below:

1. *Ancyrospora* sp.
2. *Diducites versabilis* (Kedo) Van Veen, 1981
3. *Grandispora famenensis* (Naumova) Streel in Becker *et al.*, 1974
4. *Retispora macroreticulata* (Kedo) Byvscheva, 1985
5. *R. lepidophyta* (Kedo) Playford, 1976
6. *Diducites commutatus* (Naumova) Avchimovitch, 1988
7. *Grandispora lupata* Turnau, 1975
8. *Tumulispora malevkensis* (Kedo) Turnau, 1978
9. *T. rarituberculata* (Luber) Turnau, 1978
10. *T. obscura* Staplin & Jansonius, 1964
11. *Verrucosisporites nitidus* Playford, 1974
12. *Umbonatisporites abstrusus* (Playford) Clayton, 1970
13. *Auroraspora asperella* (Kedo) Van der Zwan, 1980
14. *Convolutispora major* (Kedo) Turnau, 1978
15. *Cymbosporites acutus* (Kedo) Byvscheva, 1985
16. *Lophozonotriletes excisus* Naumova, 1953
17. *Murospora dubitata* Higgs, 1975
18. *Pustulatisporites gibberosus* (Hacquebard) Playford, 1964
19. *Raistrickia corynoges* Sullivan, 1968
20. *Spelaeotriletes obtusus* Higgs, 1975
21. *Crassispora trychera* Neves & Joannides, 1974
22. *Schopfites delicatus* (Higgs) Higgs, 1988
23. *Umbonatisporites distinctus* Clayton, 1970
24. *Spelaeotriletes balteatus* (Playford) Higgs, 1975
25. *S. pretiosus* (Playford) Neves & Belt, 1970
26. *Raistrickia condylosa* Higgs, 1975
27. *Prolycospora claytonii* Turnau, 1978


Conodont zonation
Standard miospore zonation
Pomeranian miospore zonation
Kołobrzeg region
isosticha - U. crenulata
L. crenulata
sandbergi
Stratigraphic gap
L. or M. praesulcata
expansa
PC
BP
HD
VI
LN
LE
LL
Cl
Ma
Ra

incohatus (VI) Zone are missing in the Western Pomerania area. Simultaneous appearance of numerous miospore species at the base of the lower *Convolutispora major* (Ma1) Subzone (Fig. 6) is an additional evidence for the gap.

3.3.3. The Devonian / Carboniferous hidden hiatus

It is noteworthy that both conodont and miospore analysis suggest the existence of a gap of almost the same range. The gap can be demonstrated exclusively by biostratigraphy. The only physical manifestation of the sedimentological disturbances within the monotonous shale deposits is the presence of pyrite within the unfossiliferous interval above the Lower (or lowermost Middle) *praesulcata* and below Carboniferous *sandbergi* Zone, as well as the occurrence of rich organic matter. No surfaces with peculiar microrelief, which might be an evidence of corrosion, have been found at the Devonian/Carboniferous boundary. Moreover, there is no evidence of any pre-*sandbergi* abrasion affecting the Famennian and Tournaisian deposits (comp. Szulczewski, 1978; Be ka, 1985). Presumably, this stratigraphic gap resulted from some chemical or hydrodynamic factors rather than from any tectonic uplift which should have been manifested by emersion and abrasion of sediments.

This is probably submarine nondeposition gap which is an effect of a strong decrease or even cessation of lime mud production for a long time. If this is the case, however, the absence of conodonts of two Devonian and nearly three Carboniferous zones is hard to explain. One would expect, rather, an increased abundance of conodonts as a consequence of the low accumulation rate of clay. On the other hand, the assumption that all conodonts might have been destroyed by the corrosion-induced dissolution should be rejected because of the considerable chemical resistance of calcium phosphate. The explanation is that conodonts and other faunal remains could have been mechanically washed out or, which is more probable, unfavorable changes in water chemistry and/or water stratification might have led to a long-term stress and retreat of all faunal groups from the Pomeranian basin.

4. FINAL REMARKS

The Devonian/Carboniferous boundary in the analysed sections is accentuated by a presence of several dozen centimetres of shale deposits, rich in pyrite and organic matter, and devoid of any faunal remains between the documented Devonian Lower (or lowermost Middle) *praesulcata* Zone and Carboniferous upper *sandbergi* Zone.

Detailed analysis of conodont and miospore succession at the Devonian/Carboniferous boundary suggests the existence of stratigraphic gap comprising the Devonian Middle and Upper *praesulcata* conodont Zones and Carboniferous *sulcata, duplicata* and probably most of the *sandbergi* conodont Zones, as well as lack of the counterparts of the West European miospore Zones *Retispora lepidophyta-Hymenozonotriletes explanatus* (LE), *Retispora lepidophyta-Verrucosisporites nitidus* (LN) and most of the *Vallatisporites verrucosus-Retusotriletes incohatus* (VI).

The critical interval near the Devonian/Carboniferous boundary displays some features that may be related to the Late Devonian Hangenberg and/or Carboniferous Lower Alum Shale (see Becker, 1993) Event(s):

(1) a submarine nondeposition gap connected with strong decrease or even cessation of lime mud "production" for a long time and manifested by a sedimentation of only several dozen cm of black shale during the Devonian Middle and Upper *praesulcata* Chrons, as well as during the Carboniferous *sulcata, duplicata* and part of the *sandbergi* Chrons;

(2) lack of any organic remains within aforementioned black shales, probably due to unfavorable changes in water chemistry and/or water stratification at the end of Devonian, which might have led to a long-term stress and retreat of all faunal groups from the Pomeranian basin.

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PLATE 1

Conodonts of the Lower (or lowermost part of Middle) *praesulcata* Zone, Famennian

1 *Bispathodus aculeatus aculeatus* (Branson & Mehl, 1934);
SMF 680 (borehole Rzeczenica-1, depth interval 2924-2925 m), x 100

2 *Branmehla suprema* (Ziegler, 1962); SMF 671 (*ibidem*), x 130

3-4 *Bispathodus ultimus* (Bischoff, 1957), right Pa elements, morphotype 2;
SMF 675-674 (*ibidem*), x 75

Conodonts of the upper *sandbergi* Zone, Hastarian

5 *Elictognathus laceratus* (Branson & Mehl, 1934), lateral view;
SMF 669 (*ibidem*, 2921-2922 m), x 100

6 *Polygnathus* cf. *purus purus* Voges, 1959; SMF 672 (*ibidem*), x 150

7 *Elictognathus* cf. *bialatus* (Branson & Mehl, 1934); SMF 670 (*ibidem*), x 150

8 *Siphonodella* cf. *obsoleta* Hass, 1959; SMF 673 (*ibidem*), x 75

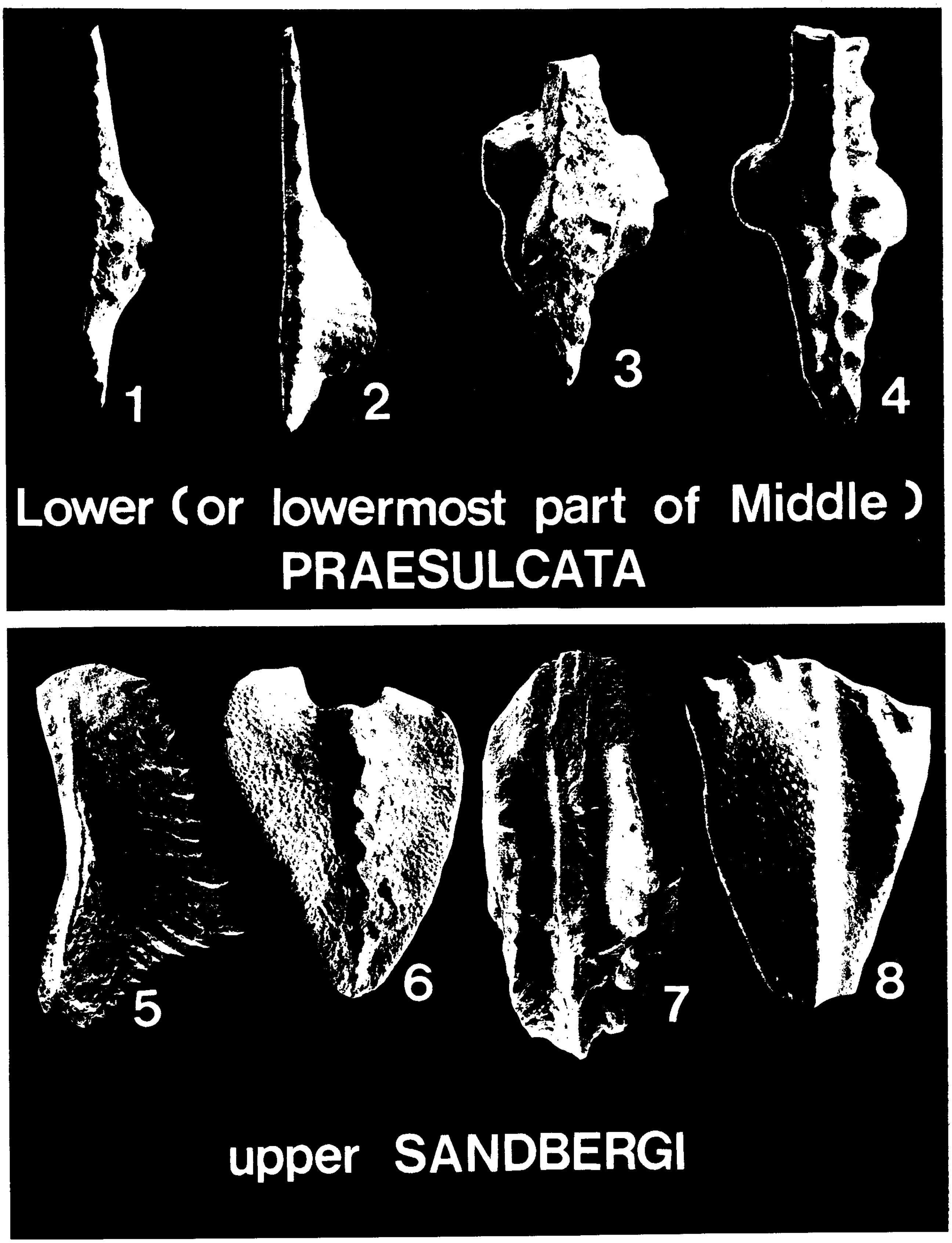

1
2
3
4
Lower (or lowermost part of Middle)
PRAESULCATA
5
6
7
8
upper SANDBERGI

PLATE 2

Miospores of the *Convolutispora major* (Ma) Zone, Hastarian

All miospore photographs x 1000

1 *Raistrickia ramiformis* (Kedo) Avchimovitch & Higgs; (borehole Gorzys aw-9, depth interval 3205-3206 m)

2 *Umbonatisporites distinctus* Clayton; (Gorzys aw-8, 3216-3218 m)

3-4 *Cymbosporites acutus* (Kedo) Byvscheva; (Gorzys aw-9, 3154-3155 m)

5 *Tumulispora malevkensis* (Kedo) Turnau; (*ibidem*, 3198 m)

6 *Lophozonotriletes excisus* Naumova; (*ibidem*, 3208-3209 m)

7 *Raistrickia corynoges* Sullivan; (*ibidem*, 3198 m)

8 *Spelaeotriletes obtusus* Higgs; (*ibidem*, 3154-3155m)

Miospores of the *Tumulispora rarituberculata* (Ra) Zone, Famennian

9 *Diducites versabilis* (Kedo) Van Veen; (Gorzys aw-9, 3207-3208 m)

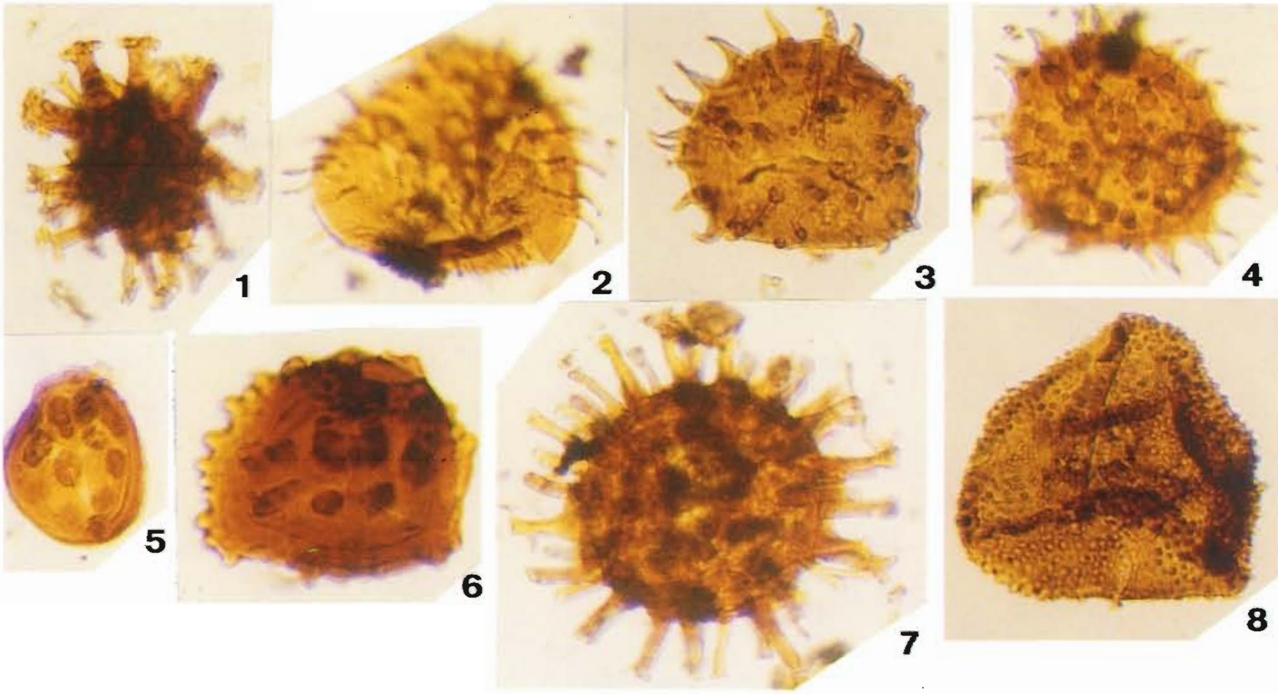
10 *Grandispora lupata* Turnau; (*ibidem*, 3208-3209 m)

11 *Retispora lepidophyta* (Kedo) Playford; (*ibidem*, 3213-3214 m)

12 *Umbonatisporites abstrusus* (Playford) Clayton; (Gorzys aw-8, 3216-3218 m)

13 *Retispora macroreticulata* (Kedo) Byvscheva; (Gorzys aw-9, 3208-3209 m)

14 *Ancyrospora* sp.; (*ibidem*)



Ma Zone

Ra Zone