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The palynofacies pattern for the Lower Cretaceous of central Poland

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Sedimentary environments and palynofacies were identified in the Lower Cretaceous of central Poland. The study was based on lithological observations, sedimentological logging and palynological investigations in eleven boreholes. Palynological observations included primarily identification of the proportions, variability and features of individual components of palynological matter. The results were correlated with sedimentological, lithofacies and palaeogeographical data. Sedimentary environments and palynofacies were analysed in the vertical section, and spatially in different areas: in the central basin area, in the carbonate-clastic deposition zone, in the transitional zone (deltaic sedimentation) and in a zone of an active salt pillow. The following sedimentary environments were identified in the Lower Cretaceous: upper shoreface and lower-middle shoreface with transitions to an offshore–open-marine shelf, delta (?delta front) passing up into distributary channel fills on a delta plain, presumed barrier and shallow-marine embayment, lagoon and shallow carbonate-siliciclastic shelf. In case of the absence of diagnostic features for exact determination of sedimentary environments, they were defined as generally marine or transitional (probably deltaic). A maximum flooding surface has been identified in the Poddębice PIG 2 section, represented by a thin dark grey marl bed which is dated approximately at the Berriasian/Lower Valanginian transition. The relationships between sedimentary environments and the characteristics of the palynofacies spectrum were determined, and a palynofacies pattern for the Lower Cretaceous of central Poland has been proposed.

Key words: Lower Cretaceous, central Poland, palynomorphs, organic matter, sedimentary environments, palynofacies pattern.

INTRODUCTION

Examination of palynological matter and palynofacies types (associations), integrated with sedimentological investigations, proved that palynological observations can be used for palaeoenvironmental studies in order to:

– determine the magnitude and location of terrigenous input,
– determine depositional polarity (onshore-offshore direction),
– characterise the depositional environment in terms of sedimentary processes and their dynamics, distance from shoreline, salinity, oxygenation, productivity, water column stability (stratification, mixing), just to mention some applications (e.g., Tyson, 1993; Batten, 1996).

These palynological observations also pointed to the possibility of developing a logical preliminary pattern of distribution of palynofacies and sedimentary environments in the Early Cretaceous basin of the Polish Lowlands. The basin represented a seaway connection between the boreal basins of northwestern Europe and the Tethys Ocean in the south, with predominantly siliciclastic deposition of up to approximately 700 m in thickness (Vejbaek et al., 2010). The Lower Cretaceous deposits are overlain by a thick sequence (locally more than 2000 m) of Upper Cretaceous rocks, mostly carbonates (Leszczyński, 2012). Considering the variability of palynological matter, we must obviously refer to the age of the sediments. The variability is observed in both the spatial and time aspects.

Palynofacies investigations of the Mesozoic successions in Poland and adjacent regions show a relationship between the occurrence of palynomorphs and the type of sedimentary environment. It was well-proved by studies conducted by Leszczyński and Waksmundzka (2008). However, the data are incomplete due to the scarcity of good quality material (long and well-preserved cored intervals) available for sedimentological studies from the Lower Cretaceous.

Our study aimed at developing a preliminary palynofacies pattern of the Lower Cretaceous succession in central Poland, based on the identification of the proportions, variability and features of individual types of palynological matter and on sedimentological investigations. The features of individual types of palynofacies are dependent on the dynamics and variability of the environment, as well as on sedimentary processes.

The definition of palynological matter generally follows that of Batten (1996). Palynological matter comprises the following elements: palynomorphs (pollen grains and spores), dinoflagellate cysts and acritarchs, structured organic matter (STOM) and unstructured (structureless) organic matter (USTOM), which is thoroughly described in Pieńkowski (2004) and Pieńkowski and Waksmundzka (2009).

The analyses were performed on drill cores from described below boreholes (Figs. 1 and 2). Detailed sedimentological logs were produced for most of the boreholes excluding three cases (Człuchów IG 2, Klosnowo IG 1 and Tuchola IG 1), in which

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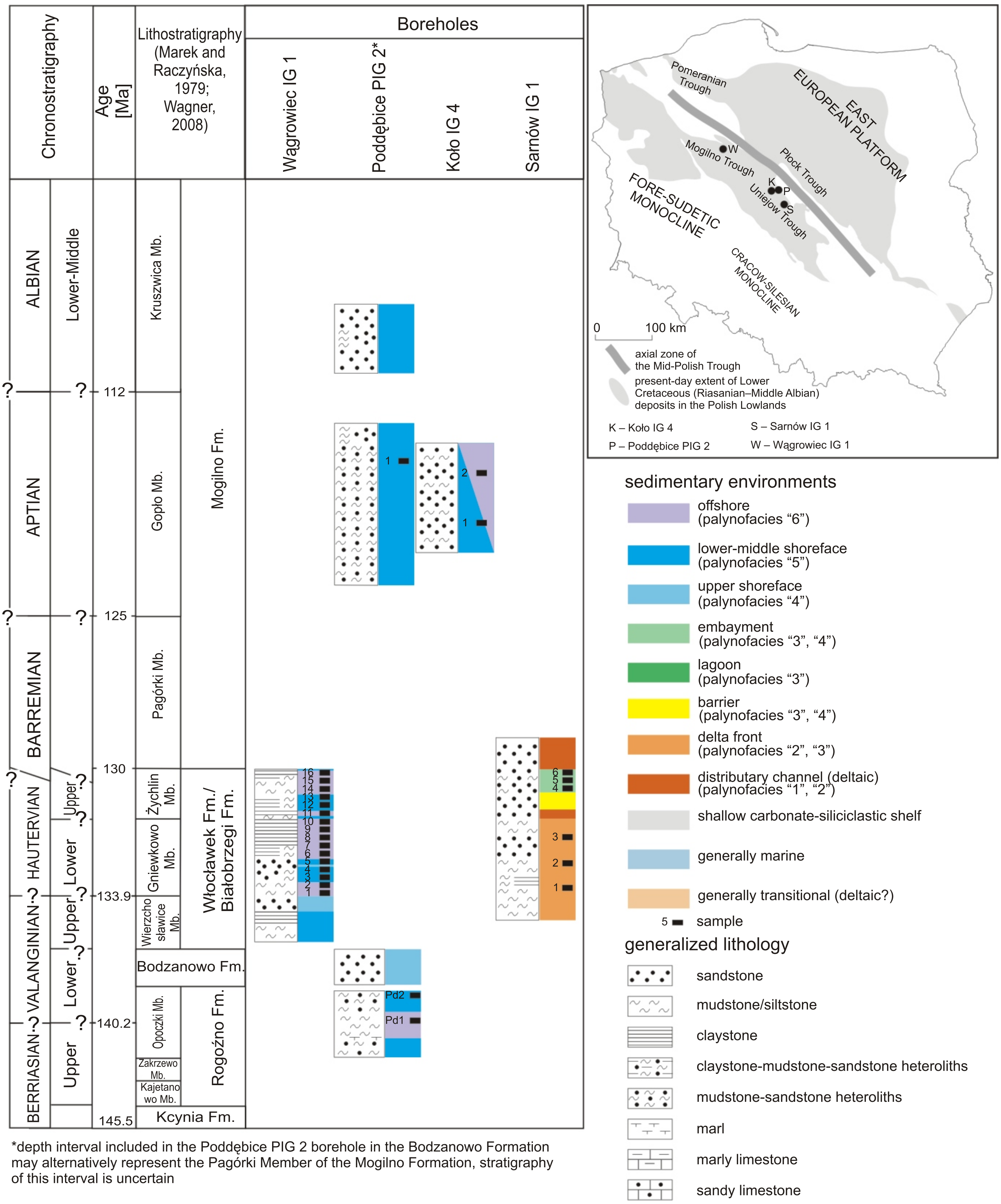
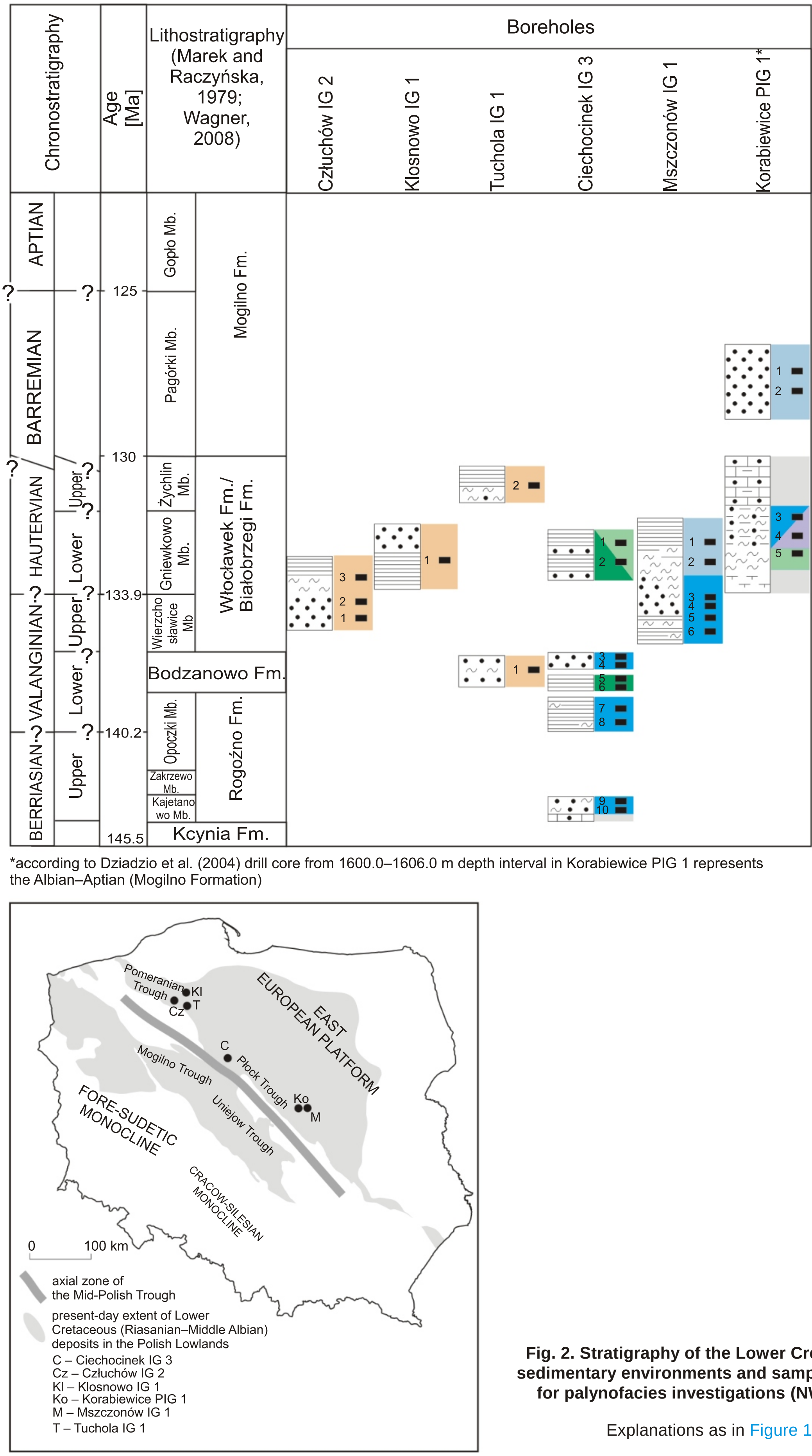


*depth interval included in the Poddębice PIG 2 borehole in the Bodzanowo Formation may alternatively represent the Pagórki Member of the Mogilno Formation, stratigraphy of this interval is uncertain

Fig. 1. Stratigraphy of the Lower Cretaceous, sedimentary environments and sampling points for palynofacies investigations (SW region)



*according to Dziadzio et al. (2004) drill core from 1600.0–1606.0 m depth interval in Korabiewice PIG 1 represents the Albian–Aptian (Mogilno Formation)

Fig. 2. Stratigraphy of the Lower Cretaceous, sedimentary environments and sampling points for palynofacies investigations (NW region)

Explanations as in Figure 1

lithological features of deposits were only analysed. Lithological investigations and sedimentological logging of drill core intervals were then correlated with palynological data because detailed analysis of palynological matter (proportions between spores, pollen grains, algae, wood fragments, black and brown structured organic matter) gives further suggestions about sedimentary environments. For the purpose of the present study, palynofacies is regarded as a type of biofacies containing a certain assemblage of palynoclasts, whose composition is characteristic of a particular sedimentary environment (see Combaz, 1964; Powell et al., 1990; Batten, 1996; Pieńkowski, 2004; Traverse, 2007). For identification of palynofacies types (associations), a scheme proposed by Pieńkowski and Waksmundzka (2009) for Lower Jurassic deposits of the Polish Lowlands was applied. It is most recent and best correlated to detailed sedimentological data. It was developed involving also earlier investigations, e.g., van Bergen and Kerp (1990), van der Zwan (1990) and Dybkjær (1991).

The stratigraphy of the sections studied is based on the lithostratigraphic subdivision of the Lower Cretaceous proposed by Marek and Raczyńska (1979), later modified by Marek (1997), and with formal and informal lithostratigraphic units (formations and members) established for two main regions of the Polish Lowlands – Kujawy and SE Poland (Figs. 1 and 2). Detailed sedimentological logs of the sampled intervals from the Poddębice PIG 2, Wągrowiec IG 1 and Sarnów IG 1 boreholes are presented in Leszczyński and Waksmundzka (2008). Detailed sedimentological logs of the sampled intervals from the Ciechocinek IG 3, Mszczonów IG 1 and Korabiewice PIG 1 boreholes will be published soon in a separate paper.

PREVIOUS STUDIES

There are few papers on modern sedimentological investigations of Lower Cretaceous sections in the Polish Lowlands. Worth mentioning is a thorough study of Neocomian sections from boreholes drilled in the Mogilno and Koło regions (Dadlez and Dadlez, 1987). Analysis of palynological material was performed predominantly for palynostratigraphic purposes. Palynofacies investigations, based on the scheme developed by Tyson (1993), were conducted for the Lower Jurassic (Pieńkowski and Waksmundzka, 2002, 2009; Pieńkowski et al., 2012) and proved that palynological data correlated with sedimentological logging enable more comprehensive analysis of sedimentary environments, showing their effect on playnological spectra. Palynofacies studies for palaeoclimatic and palaeoenvironmental interpretations were also carried out by Fijałkowska (1994, 1995) for the Lower Triassic in the NW margin of the Holy Cross Mts. and for the Zechstein in the North Sudetic Trough.

Work on Lower Cretaceous palynofacies started relatively recently (Leszczyński and Waksmundzka, 2008). The results pointed out to their usefulness for palaeoenvironmental studies, encouraging for further investigations and interpretations in boreholes from various zones of the basin to develop an integrated palynofacies pattern for the Early Cretaceous epicontinental basin in Poland.

Palynofacies and sedimentological investigations of Jurassic epicontinental basins carried out in the Polish Lowlands show that six palynofacies types (labelled from “1” to “6”) can be identified as a general palynofacies pattern, based on the proportions between the number of palynomorphs, and on the presence of organic matter (SOM), plant tissues (phytoclasts) and dinoflagellates (Pieńkowski and Waksmundzka, 2009). These are as follows:

– land (terrestrial environment, alluvial and flood plain, lakes and bogs): abundant palynological material, highly variable with predominance of taxonomically diversified spores; high frequency of plant tissues and tetrads (corroded); phytoclasts both translucent and opaque;
– delta plain passing into alluvial plain: abundant translucent and opaque phytoclasts; predominance of spores and large fragments of organic matter; lower frequency of pollen grains and cuticles (a transitional palynofacies); occasional dinoflagellate cysts and acritarchs;
– lagoons and embayments: characterized by abundant and generally equal amounts of pollen grains and spores; sporadic dark phytoclasts; occasional dinoflagellate cysts and acritarchs; association often similar to “2”;
– shallow-marine shoreface closer to the shore: palynological material abraded, crushed and oxidized; predominance of opaque, black and brown organic matter; low to moderate content of sporomorphs; spores and pollen grains in balance; occasional presence of dinoflagellates and foraminifers; in lower energy environments pollen grains predominate;
– shallow-marine shoreface more distant from the shore (dominated by wave and sea-current action): small amount of translucent organic matter; rare small and rounded opaque phytoclasts; lower frequency of spores and pollen grains and predominance of the latter; dinoflagellates and foraminifers more common than in palynofacies “4” and less frequent than in palynofacies “6”; some palynomorphs show corrosion;
– offshore, open-marine area: presence of translucent organic matter, rare pollen grains, occasional or absent spores and black plant tissues; common dinoflagellates and foraminifers; palynomorphs often show corrosion.

A similar scheme can be used for the Early Cretaceous basin.

MATERIAL AND METHODS

Sedimentological and palynological investigations included the following:

– selecting boreholes for analyses based on existing drilling, lithological and palaeogeographical data;
– lithological and sedimentological logging of drill core intervals, and interpretation of sedimentary environments using the principles of sedimentology;
– collecting samples for palynological and palynofacies analysis;
– maceration of palynological material, followed by preparatory work;
– quantitative analysis of palynomorphs;
– detailed analysis of palynological spectrum: percentage of plankton (relative to the total of palynomorphs), content of phytoclasts in total kerogen and content of organic matter, and proportions between the individual components of the spectrum;
– correlating palynological, sedimentological, lithofacies and palaeogeographical data;
– developing a palynofacies pattern based on the available material.

Different numbers of samples were collected from individual sections, depending on the lithology and drill core condition. The total length of sampled logs was approximately 118 m. The total number of samples analysed was 54. Palynological material was obtained using maceration (7% KOH) and flotation

(CH_3COOH, H_2SO_4) techniques. Three 24 x 24 mm glycerogelatine preparations were produced from each macerated sample.

The boreholes selected for the analysis are located in different areas in terms of palaeogeographic setting. The boreholes Wągrowiec IG 1, Sarnów IG 1, Koło IG 3 and IG 4, and Poddębice PIG 2 are located within the Mid-Polish Trough in its southwestern flank (Fig. 1). The first of them is situated in the Mogilno Trough near the crest of the salt-cored Janowiec Anticline, above a prominent fault zone cutting the whole Mesozoic succession (see Dadlez, 2001: pl. II, cross-section 10). The remaining boreholes are located in the Łódź Trough, within the so-called Mogilno–Ponętów–Pabianice tectonic zone that developed along a prominent fault zone bounding the Mid-Polish Trough to the west (Marek, 1977).

The boreholes Człuchów IG 2, Klosnowo IG 1, Tuchola IG 1, Ciechocinek IG 3, Mszczonów IG 1 and Korabiewice PIG 1 (Fig. 2) are situated to the NE of the basin axis, in the Marginal Trough. The Człuchów IG 2, Klosnowo IG 1 and Tuchola IG 1 boreholes were drilled in the Pomeranian Trough in a close proximity to the Baltic Shield.

A specific palaeogeographic position of the Ciechocinek IG 3 borehole is due to the proximity to the axial zone of the Early Cretaceous basin and close to a large and periodically active salt pillow of Ciechocinek, near the area of maximum subsidence during the Early Cretaceous. The Mszczonów IG 1 and Korabiewice PIG 1 boreholes are located in the south of the Płock Trough in the area where the Białobrzegi Formation is represented mainly by carbonate-siliciclastic facies deposited on a shallow shelf (Marek, 1988, 1997). No ooids are observed in these carbonate intervals.

Sedimentological logging and interpretation of data were based generally on the methods used in the studies of Lower Cretaceous rocks by Dadlez and Dadlez (1987) and of Lower Jurassic deposits by Pieńkowski (1983, 1997, 2004).

Palynofacies analysis was performed in correlation with sedimentary data from drill cores, based on the following elements of the palynological spectrum:

– presence and type of palynomorphs found in preparations;
– spores-to-pollen ratio;
– presence and features of USTOM (unstructured organic matter) – amorphous organic matter formed as a result of bacterial, chemical or other decomposition, including both that of terrestrial derivation (dark and opaque) and aquatic origin (commonly light and translucent);
– presence and features of STOM (structured organic matter) – plant-origin organic matter including all wood remains, cuticles and other detrital particles (excluding palynomorphs) showing "cellular" or zoological features.

RESULTS

KLOSNOWO IG 1, CZŁUCHÓW IG 2 AND TUCHOLA IG 1 BOREHOLES (BODZANOWO AND WŁOCŁAWEK FORMATIONS)

Lower Cretaceous palynological spectrum from these boreholes, studied for megaspores by Waksmundzka (1982, 1992), is dominated by fern spores (low frequency of microspores and very few pollen grains). The identified taxa are listed in Appendix 1*.

Palynological material is commonly oxidized and organic matter elements are large and loosely distributed. Lithological features of the deposits (no sedimentological logs have been made) can indicate a transitional environment of deltaic type (palynofacies type "2"). According to the authors, this palynofacies is strongly associated with an influx of terrestrial material transported by rivers from the Baltic Shield (so-called Kashubian Land – Marek, 1997). The palynological material provides additional evidence for substantial terrestrial influence both in the Bodzanowo and Włocławek formations.

WĄGROWIEC IG 1 BOREHOLE (WŁOCŁAWEK FORMATION)

Palynological spectrum is sparse and infrequent, and all elements are highly corroded, making it difficult to identify properly individual taxa. Sedimentological characteristics of the deposits suggest a generally relatively low-energy marine environment with insignificant influence from the land (offshore, lower-middle shoreface; palynofacies types "5" and "6"; Pieńkowski and Waksmundzka, 2009). Palaeogeographical investigations (Marek, 1988, 1997) indicate that the nearest land extended approximately 50–60 km to the SW (present-day Fore-Sudetic Monocline, south of Poznań). Occasional thin beds, thinly cross-laminated by fine-grained sandstones, can represent storm sediments (cf. Walker and Plint, 1992).

CIECHOCINEK IG 3 BOREHOLE (ROGOŹNO, BODZANOWO AND WŁOCŁAWEK FORMATIONS)

The uniqueness of this palynological spectrum consists in an exceptionally high frequency of spores and pollen grains. The total number of specimens counted in one sample is 2245 spores (67% of the total spectrum) and 1046 pollen grains (33%). The specimens are mostly corroded in some intervals (sedimentary environments interpreted as embayment/lagoon; palynofacies types "3" and "4"; Pieńkowski and Waksmundzka, 2009) and very sparse in the others (interpreted as lower-middle shoreface (?offshore) – palynofacies types "5" and "6") within the Lower Cretaceous section (Fig. 3A–D). However, the taxonomic spectrum is moderately variable and contains dinoflagellates. The identified taxa are listed in Appendix 1 and shown in Figures 4 and 5.

Acritarch and dinoflagellate taxa have not been determined because they are strongly corroded and used for palynofacies, not taxonomic studies.

Some samples contain very abundant spores and pollen grains. There are preparations that contain up to 300 specimens of spores and up to 140 specimens of pollen grains. The pollen grain/spore ratio is variable with the predominance of either pollen grains or spores, however, spores are dominant in most of samples. Such a great number of specimens is unusual and never found so far in Lower Cretaceous deposits of Poland. Furthermore, the palynological analysis indicates the presence of Jurassic material in the spectrum [*Matonisporites equiexinus* Couper, 1958; *Auritulinasporites triclavis* Nilsson, 1958; *Contignisporites problematicus* (Couper, 1958) Döring, 1965]. The palaeogeographic setting of the region is specific due to the occurrence of a large and periodically active salt pillow (salt-cored Ciechocinek Anticline, Dadlez et al., 1998).

* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1071

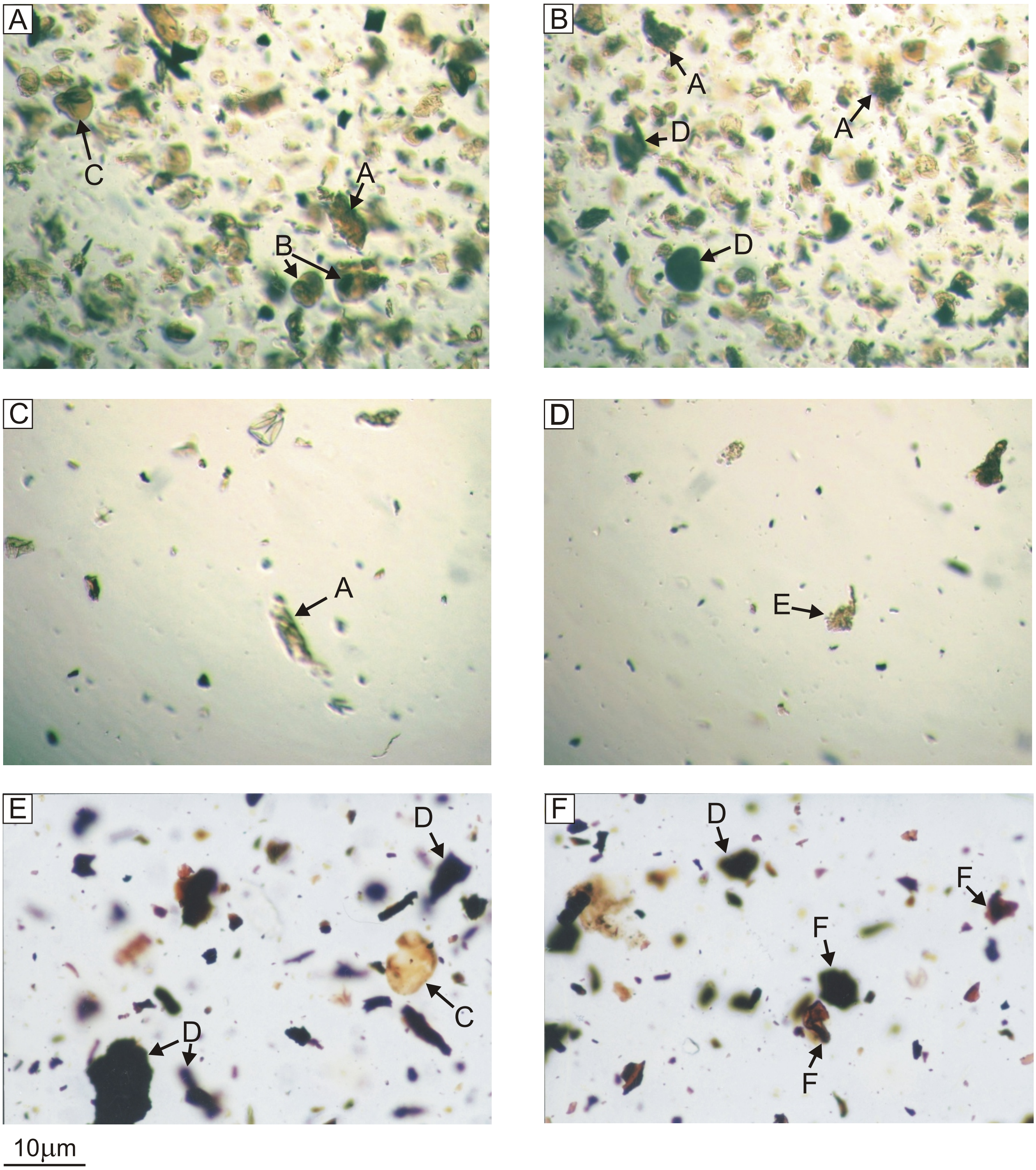


Fig. 3. Example of the difference in the Lower Cretaceous palynofacies associations between some environments

A – Ciechocinek IG 3, depth 383.2 m, extremely abundant association, palynofacies type "3", embayment/lagoon (A – STOM fragment, B – pollen grain, C – microspore); **B** – Ciechocinek IG 3, depth 383.2 m, extremely abundant association, palynofacies type "3", embayment/lagoon (A – STOM fragment, D – USTOM fragment); **C** – Ciechocinek IG 3, depth 332.9 m, very sparse association, palynofacies type "6", lower-middle shoreface (?offshore) (A – STOM fragment); **D** – Ciechocinek IG 3, depth 330.2 m, very sparse association, palynofacies type "6", lower-middle shoreface (?offshore) (E – dinoflagellate fragment); **E** – Sarnów IG 1, depth 1758.0 m, numerous large fragments of unstructured (oxidized) organic matter, palynofacies type "2", deltaic (?delta front) (C – microspore, D – USTOM fragment); **F** – Sarnów IG 1, depth 1745.1 m, numerous small fragments of unstructured organic matter, palynofacies type "2", deltaic/barrier-lagoon (?embayment) transition (D – USTOM fragment, F – strongly oxidized structure of grains)

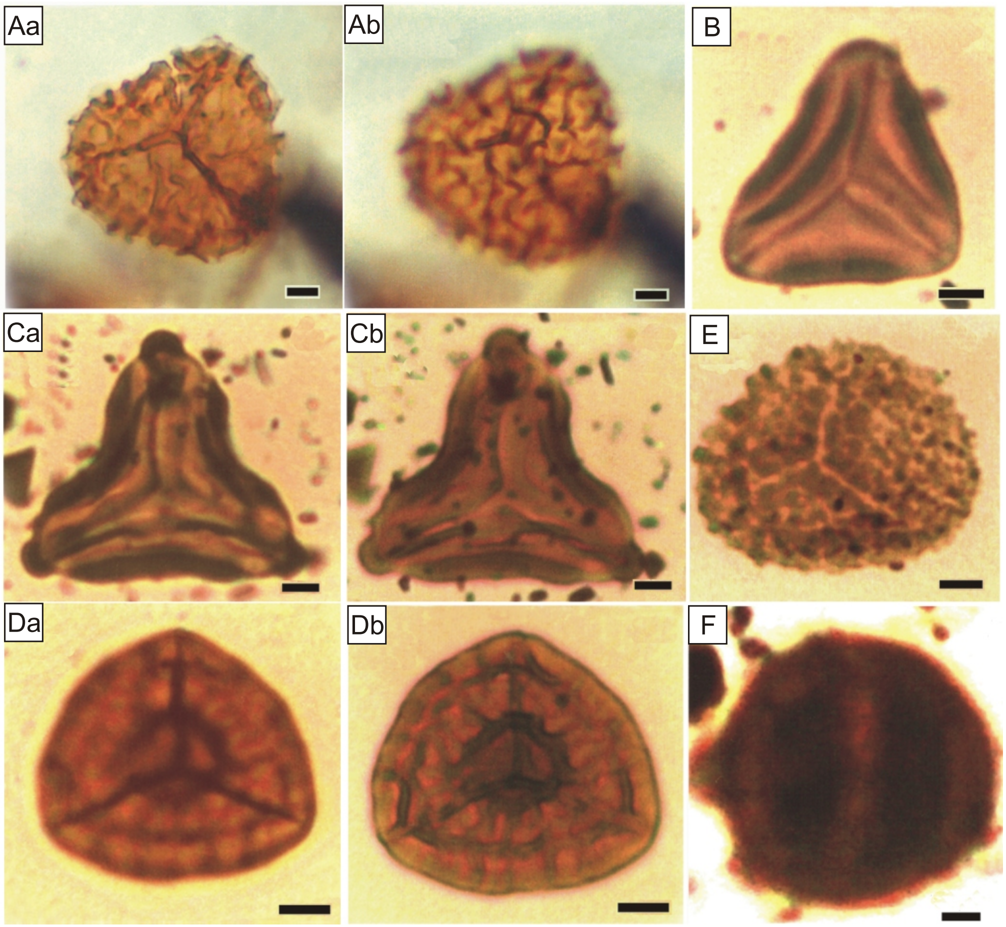


Fig. 4. Some specimens of Lower Cretaceous palynological material from the Ciechocinek IG 3 (A, B, D, E) and Poddębice PIG 2 (C, F) boreholes

Aa, **Ab** – *Lycopodiumsporites semimuris* Danzé-Corsin and Laveine, depth 380.3 m; **B** – *Gleicheniidites senonicus* Ross, depth 380.3 m; **Ca**, **Cb** – *Clavifera triplex* (Bolkhovitina) Bolkhovitina, 2330.8 m; **Da**, **Db** – *Staplinisporites caminus* (Balme) Pocock, depth 380.3 m; **E** – *Baculatisporites comaumensis* (Cookson) Potonié, depth 427.1 m; **F** – *Eucommiidites minor* Groot and Penny, depth 2330.1 m; a – proximal side, b – distal side; scale bar is 10 µm

KOŁO IG 3 AND IG 4 (MOGILNO FORMATION), AND PODDĘBICE PIG 2 BOREHOLES (ROGOŹNO, ?BODZANOWO AND MOGILNO FORMATIONS)

Palynological spectra from these boreholes suggest relatively low-energy marine environments (offshore and lower-middle shoreface, palynofacies types "5" and "6"; Pieńkowski and Waksmundzka, 2009). Dinoflagellates and foraminifers are common. The generally "sparse" palynological spectrum of the Koło IG 4 borehole is conspicuous by the predominance of pollen grains, suggesting offshore areas more distant from land. The identified taxa are listed in Appendix 1 and shown in Figures 4 and 5.

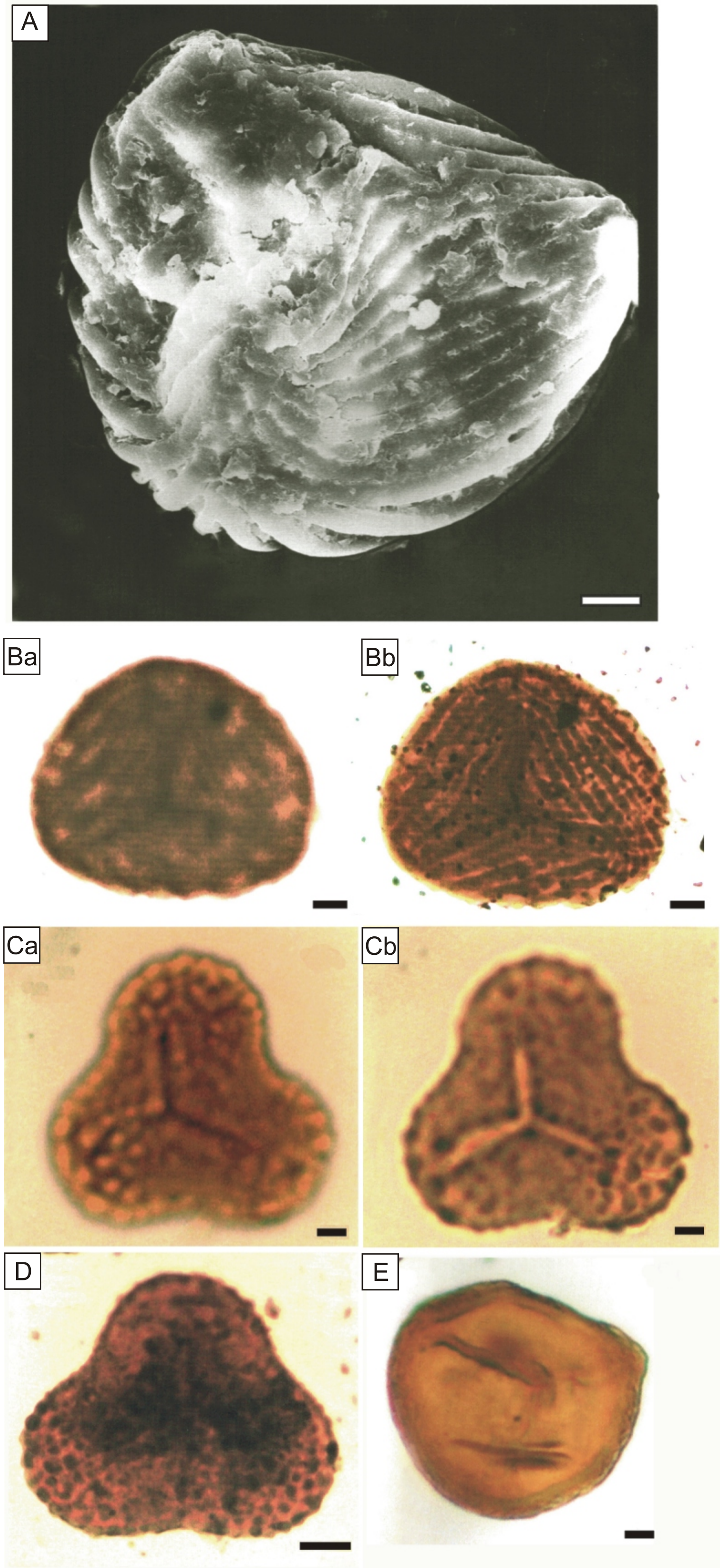
A thin dark grey marl bed within the clastic sequence has been identified in the Poddębice PIG 2 borehole within the Rogoźno Formation (Riasanian–Lower Valanginian).

SARNÓW IG 1 BOREHOLE (WŁOCŁAWEK FORMATION)

This palynological spectrum contains very few strongly corroded microspores and pollen grains of destroyed features, making taxonomic identification impossible. There are also a little bit more small elements of black USTOM (Fig. 3E, F). The grains are commonly oxidized. Neither dinoflagellates nor foraminifers are observed. Regional studies, interpretations of drill core logs (Leszczyński, 2002) and sedimentological analyses showed that this area was probably a zone of deltaic deposition at that time, with delta front, distributary channel and barrier (?embayment) environments (palynofacies types "2" to "4"; Pieńkowski and Waksmundzka, 2009).

MSZCZONÓW IG 1 AND KORABIEWICE PIG 1 BOREHOLES (BIAŁOBRZEGI AND MOGILNO FORMATIONS)

Elements of the spectrum are often mixed and corroded and include *Staplinisporites caminus* (Balme, 1957) Pocock, 1962; *Foveotriletes pseudoalveolatus* (Couper, 1958) Waksmundzka, 1992 and *Callialasporites* sp. (Balme, 1957) Dev, 1964, but more loosely distributed than in the typical case of a transgressive phase, which can indicate strong wave action in a shallow nearshore environment. The features of the palynological material from these deposits suggest palynofacies types "4" to "6" (shallow-marine environment). The presence of dark structureless mudstones with variable spec-



trum of palynological matter (numerous large fragments of structured and unstructured organic matter, corroded foraminifers and rare dinoflagellates) may indicate an embayment environment (palynofacies types "3" and "4"; Pieńkowski and Waksmundzka, 2009).

THE PALYNOFACIES PATTERN

The palynofacies and sedimentological studies of Lower Cretaceous deposits in central Poland enable to come to some general conclusions on sedimentary environments and corresponding palynofacies types (associations). The studies, conducted in different areas of the Early Cretaceous sedimentary basin, have shown considerable variability in the proportions between individual components of the palynological matter in both vertical section of individual boreholes and between different areas of research. The spectra in the individual samples range from very sparse and poorly varied, with loosely distributed palynomacerals (Fig. 3) or even completely lacking of these elements, to very dense and very abundant (Ciechocinek IG 3). There are as well various proportions and amounts of black through brown and light yellow to translucent structured organic matter and unstructured organic matter. The features and appearance of palynomorphs are also variable, including locally strongly corroded.

The distribution of individual sedimentary environments against the Lower Cretaceous stratigraphy in the analysed boreholes (including sampling sites for palynological analysis) is shown in Figure 1. The preliminary palynofacies pattern for the Lower Cretaceous of central Poland is given in Table 1, which presents the relationships between depositional systems (and corresponding sedimentary environments), inferred from the observed lithological and sedimentary features, and the proportions, variability and features of individual components of palynological matter, following the study method developed in Pieńkowski (2004) and

Fig. 5. Some specimens of Lower Cretaceous palynological material from the Ciechocinek IG 3 (C–E) and Poddębice PIG 2 (A–B) boreholes

A – *Cicatricosisporites australiensis* (Cookson, 1953) Potonié, 1956, SEM, depth 2330.8 m; **Ba**, **Bb** – *Cicatricosisporites australiensis* (Cookson, 1953) Potonié, 1956, depth 2330.8 m; **Ca**, **Cb** – *Impardecispora apiverrucata* (Couper, 1958) Venkatachala, Kar and Raza, 1969, depth 380.3 m, note larger ornamentation elements in the radial region; **D** – *Concavissimisporites variverrucatus* (Couper, 1958) Singh, 1964, note exine thickenings in the radial region; **E** – *Densoisporites velatus* Weyland and Krieger, 1953, depth 380.3 m; a – proximal side, b – distal side; scale bar is 10 μm

Table 1

Palynofacies pattern of the Lower Cretaceous in central Poland

<table>
<tr><th>Depositional system</th><th>Depositional subsystem – palynofacies type</th><th>Palynological spectrum</th><th>Sediment features</th></tr>
<tr><td rowspan="2">Deltaic</td><td>distributary channel (delta plain) – 1, 2</td><td rowspan="2">Abundant translucent and opaque phytoclasts. Predominance of large fragments of brown organic matter, plant tissue and spores.
Infrequent pollen grains. Spores dominate over pollen grains.
Organic matter often oxidized.</td><td>Variably grained sandstones, pebbly layer at the base on an erosional surface, trough cross bedding.</td></tr>
<tr><td>delta front – 2, 3</td><td>The characteristic thickening-upward sequence (from mudstones to sandstones), various types of lamination and bedding, occasional bioturbation.</td></tr>
<tr><td rowspan="3">Barrier and lagoon</td><td>lagoon – 3</td><td rowspan="3">Abundant sporomorphs. Generally equal frequencies of pollen grains and spores, but the ration may vary considerably depending on the distance from river mouth.
Variably coloured and sized spectrum.
Organic matter often oxidized.
Occasional dinoflagellates, rare foraminifers.
In lagoons, spectrum dense to very dense and variable.</td><td>Dark grey and brownish claystones/mudstones and siltstones, planar, horizontal and lenticular bedding, less frequent flaser bedding.
Infrequent bioturbation and carbonized plant detritus.</td></tr>
<tr><td>barier – 3, 4</td><td>Structureless sandstones, occasional horizontal and cross lamination</td></tr>
<tr><td>embayment – 3, 4</td><td>Grey to brownish heteroliths and mudstones, wavy and flaser lamination.
Sideritic rocks: laminae, siderite concretions, iron ooids.
Plant detritus, macrofauna (mainly bivalves).
Occasional bioturbation.</td></tr>
<tr><td rowspan="3">Nearshore</td><td>upper shoreface (above fair-weather wave base) – 4</td><td>Moderate amount of sporomorphs. Balance or slight predominance of pollen grains over spores.
Material mixed, often abraded, crushed and oxidized.
Frequent black and brown organic matter.
Occasional dinoflagellates.</td><td>Fine-grained silty sandstones, well-sorted quartz arenites with muscovite and plant detritus, light grey to brownish, structureless or horizontally bedded (sporadic tabular bedding and large-scale trough cross bedding), heavy metals arranged into minute laminae, no bioturbation.
Occasional sandstones with clay flasers and streaks, sporadic bioturbation.
Equivalent to B and B1 facies according to Dadlez and Dadlez (1987).</td></tr>
<tr><td>lower-middle shoreface (between fair-weather and storm wave base) – 4, 5</td><td>Variable and rather sparse spectrum (depending on the distance from land).
Presence of dinoflagellates and occasional foraminifers transported by sea currents.
Frequent spores suggest current activity, absence of spores may indicate strong sea currents. Sparse small fragments of black organic matter. Predominance of pollen grains over spores, or balanced.
Palynological material corroded.</td><td>Grey to brownish variably grained sandstones, poorly sorted; common heteroliths, frequent cross, flaser, wavy and lenticular lamination, rare plant detritus, frequent marine fauna and foraminifers, common bioturbation: trace fossils of ?Asterosoma isp., ?Planolites isp., ?Rhizocorallium isp.; sporadic siderites and iron ooids; muscovite.
Equivalent to A, A1, E and F facies according to Dadlez and Dadlez (1987).</td></tr>
<tr><td>offshore (below storm wave base) – 5, 6</td><td>Generally sparse spectrum. Presence of translucent amorphous organic matter. Remarkable predominance of pollen grains over spores, spectrum mostly light in colour.
Specimens often damaged and corroded, spectrum mixed.
Presence of dinoflagellates and foraminifers.</td><td>Claystone-mudstone-sandstone heteroliths (sandstone components are fine- and very fine-grained), lenticular, flaser and wavy lamination, bioturbation, presence of foraminifers, marine fauna, infrequent plant remains; horizontally laminated mudstones, occasional sphaerosiderites, siderite intergrowths, muscovite.
Equivalent to D, D1, G and H facies according to Dadlez and Dadlez (1987).</td></tr>
<tr><td colspan="2">Open-marine shelf</td><td>Generally very sparse spectrum, low frequency of translucent organic matter of very small size.
Infrequent pollen grains and occasional spores.</td><td>Horizontally laminated dark grey and black mudstones and claystones, sideritic marls, marine fauna, trace fossils Chondrites isp.</td></tr>
</table>

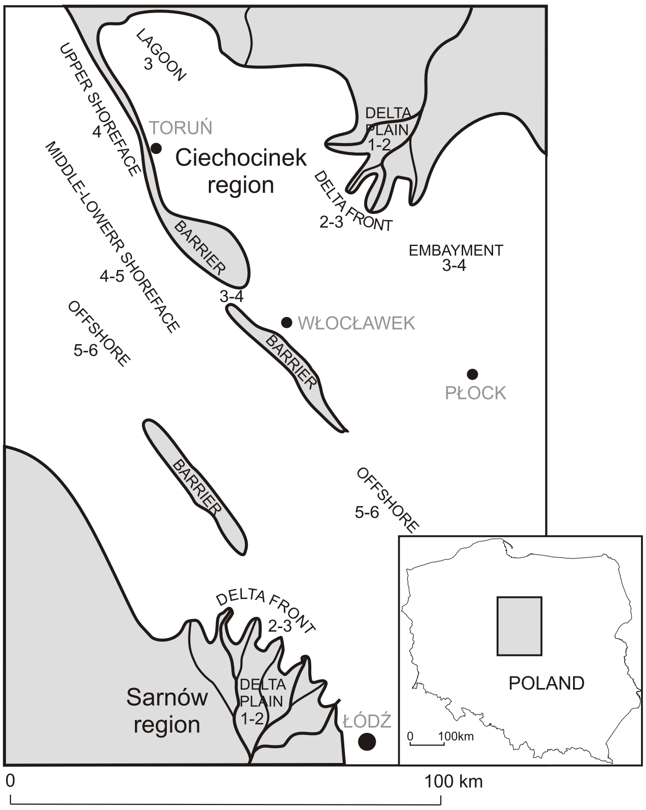
Pieńkowski and Waksmundzka (2009). Figure 6 shows a scheme of distribution of palynofacies associations against a palaeoenvironment background. Overall and detailed description of the relations between palynofacies types and sedimentary environments is presented in Pieńkowski and Waksmundzka (2009).

Based on sedimentological analyses, the following sedimentary environments have been identified (Figs. 1, 2 and Table 1): (1) deltaic (?delta front) probably with overlying distributary channels on a delta plain, (2) a presumed barrier, (3) marine embayment and brackish lagoon, (4) upper shoreface, (5) lower-middle shoreface with a transition to (6) offshore, open marine shelf areas, (7) shallow-shelf carbonate-siliciclastic sediments in the Korabiewice PIG 1 borehole.

In case of the absence of diagnostic features for exact determination of sedimentary environments, the environments were defined as generally marine or generally transitional (?deltaic).

The dark grey marl bed found in the Poddębice PIG 2 borehole, which seems to be placed close to the Berriasian/Lower Valanginian boundary, is interpreted as a maximum flooding surface (Haq et al., 1988). The approximate conventional position of this boundary in central Poland is placed at the top of the so-called lower *sinuata* shales, and defined by the findings of the *Surites* ammonites immediately below the occurrences of the ammonite *Neocomites neocomiensis* d'Orbigny 1841, var. *premolica* Sayn 1907 (Marek, 1969, 1997). Correlation of drill core logs enabled identification of the boundary on a regional scale.

Palynological data and the succession of palynological spectra, considered along with sedimentological features of deposits, can add some important information about the sedimentary environment. Among the most spectacular are suggestions about the dynamics of marine environment. An example may be the succession of palynological matter from the 425–455 m interval of the Ciechocinek IG 3 borehole, in which the structurally varying, abundant and variable palynological spectrum (with clear corrosion of palynomorphs) may suggest an area of the influence of dynamic factors (sea currents) in the marine environment, in a zone located close to a river mouth (prodelta?). Strong corrosion of microspores and pollen grains and predominance of spores over pollen grains also may suggest the activity of dynamic factors in the environment (Pieńkowski and Waksmundzka, 2009).



2-3 palynofacies types (see text for characteristics of palynofacies types)

Fig. 6. A scheme of distribution of palynofacies associations against a palaeoenvironment background

At some intervals, there are abundant small fragments of structured and unstructured organic matter, which suggests shallow nearshore zones close to land.

A regressive trend is suggested in the Wągrowiec IG 1 borehole: deeper marine environments showing a typical offshore palynofacies association is followed by a succession with increasing number of palynomorphs.

Features of palynoclasts can also be indicative of the environment's energy level. At some intervals, intense corrosion of microspores and pollen grains and predominance of spores in the lower-middle nearshore environment may indicate remarkable onshore/offshore water movement in the basin or oxidation of the material (e.g., Ciechocinek IG 3, 425–429 m).

Highly oxidized elements and lack of microspores and pollen grains suggest aerobic condition and a shallow-marine high-energy environment (e.g., Ciechocinek IG 3, sample 510.2 m). Deeper marine high-energy environment can be interpreted if tissue and organic matter fragments are observed, dinoflagellates [*Pterospermella australiensis* (Deflandre and Cookson) Eisenack and Cramer] are present and spores and pollen grains are infrequent and destroyed, making taxonomic identification impossible.

Features of palynoclasts are also sometimes indicative of a zone of sea currents that can transport dinoflagellates into shallow-marine areas.

Especially abundant and varying palynological spectrum was found in the Ciechocinek IG 3 borehole (Fig. 3). As the explanation for this, the present authors suggest that the combination of Zechstein salt activity, tectonic activity along the slope of the East European Platform and relative sea level fluctuations could result in substantial changes in the palaeogeography of this region and, consequently, in shoreline migration. The uplifting salt pillow zone may have either given rise to the formation of barriers (shoals, spits or islands) separating nearshore lagoons from the axial zone of the marine basin, or resulted in the development of marine embayments. At times of relative sea level rise and inactivity of halokinetic movements, normal marine conditions may have existed in the area, including sea-current and wave action. All these events resulted in varying sedimentary environments at those times.

We think that the redeposited Jurassic palynological material, found in the Lower Cretaceous deposits of the Ciechocinek IG 3 borehole, originated from older sediments and was shed from the rising Ciechocinek salt-cored structure. Regional geological interpretations (Niemczycka and Brochwicz-Lewiński, 1988) suggest lack of Kimmeridgian (and maybe uppermost Oxfordian) deposits on the crest of the anticline. It cannot be precluded that erosion in that area could reach the Tithonian or even Kimmeridgian formations already during the Early Cretaceous. The palynological material supplied from these nearby land/island areas was mixed with that transported from the offshore zone. As evidenced from regional stratigraphical and palaeogeographical investigations, salt-cored anticlines formed during the Early Cretaceous mainly at the

Early/Late Berriasian boundary, in the Late Valanginian, at the Valanginian/Hauterivian boundary, in the Barremian and Early Albian (Marek, 1997).

For the Mszczonów IG 1 and Korabiewice PIG 1 boreholes, a higher-energy shallow-marine environment with intervening lower-energy periods is interpreted from the palynological and sedimentological investigations. In this area, part of the section is composed of carbonate and carbonate-siliciclastic sediments deposited in carbonate-siliciclastic/carbonate shelf or carbonate platform environments (see also Dziadzio et al., 2004).

All these trends, observed in the sequence of palynological spectra from the boreholes located in different areas of the basin, helped developing the preliminary palynofacies pattern. However, further studies are necessary to supplement the pattern for other regions and sedimentary environments identified in the Lower Cretaceous succession.

FINAL REMARKS

Due to the scarcity of continuous drill core material from the Lower Cretaceous and usually its poor quality, one should realize that the data on sedimentary environments are fragmentary. However, this fragmentariness reveals a considerable variation in the proportions between individual components of palynological matter and their high vertical variability, indicating their significance for palaeoenvironmental interpretations. Studies of Lower Cretaceous sedimentary environments and palynofacies have shown considerable variation in the proportions between individual components of the palynological matter in both vertical section of individual boreholes and between different areas of research: ranging from very sparse and poorly varied to very "dense" (and even very abundant as in the case of the Ciechocinek IG 3 borehole; Fig. 3) and highly varied. Therefore, the observed regularity and considerable usefulness of palynofacies research for determination of sedimentary environments and processes occurring in the basins of siliciclastic deposition point to the necessity of further investigations and interpretations, and indicate the fields of future research. Such research should be continued to recognise the palynofacies types in the zone of carbonate-siliciclastic deposition in the southern Płock Trough and in the area located further towards the SE. Another region of interest is northwestern Poland (Szczecin Trough, Człopa–Szamotuły tectonic zone, NW part of the Mogilno Trough). Future investigations should be focused mainly on the Mogilno and Rogoźno formations, as well as wetland and lacustrine deposits of the Bodzanowo Formation (NW Poland).

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